

Current and Future Developments in Artificial Intelligence

(Volume 1)

*(Intelligent Computational Systems:
A Multi-Disciplinary Perspective)*

Edited by:

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Current and Future Developments in Artificial Intelligence

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PREFACE

Any knowledge is as old as its date reveals. The idea of editing a book as a planet in the galaxy of AI will make you as old as AI and as young as what has been and is being published today.

What is of concern in this contemporary life, at the intellectual level, where machine -the digital in specific- governs the manner by which the different aspects of human perceptions are applied in a given field is to enhance human's comprehension. On one to one basis, not even a temporary success will be registered in this realm, unless the problem is analyzed in a multi-dimensional and multi aspect sense. Books like this provide the interested readers in academic world different access channels, found so far, in having a broader perspective on the subjects of the matter(s) in AI. Many literary packages, each one better than the previous ones, are published in order to quench this never ending quest.

The objective of research on the constituent theme here is to promote their advances made towards accomplishments. In this multi-disciplinary package, the authors seek to present their innovative views on their themes of interest in this realm; consequently, pronouncing a general statement would be wrong, and for not committing this wrong I would suffice by bulleting the content of each one of the chapters presented to provide a panorama of what is defined and expected in Simulation, Interaction with humans, and Application categories:

1. Simulation of intelligent behavior
2. An individualized view on schools of artificial intelligence
3. The vast span of dealing with incomplete information in automated negotiation
4. Reverse perception effect on cognition leading to stimulated behavior
5. Lack of lexicon-based sentiment analysis in Persian language
6. Regressive retrospect counter-intuitive view of ethics, autonomy and cooperation of agents
7. Minimizing estimation error through polynomial utility function
8. Prediction in the world of finance
9. The role of stochastic geometry in multi-object filters
10. Multi-agent architecture applied in parallel process Holonic systems
11. Robot-assisted language learning alternate to CALL and MALL

The authors here challenge the theoretical meta-problems that manipulate the existing practical problems.

It is a pride to have the Foreword of this eBook written by Dr. Michael N. Huhns, Distinguished Professor Emeritus of Computer Science and Engineering.

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FOREWORD

After more than six decades of research, artificial intelligence is now being used for many endeavors, helping people manage their lives, secure their homes and information, perform routine tasks in homes, hospitals, and offices, and automate their travel. The applications are widespread and so are the technologies needed to create them. This book provides a comprehensive treatment of intelligent systems and includes contributions from leading researchers and developers in a range of disciplines.

The need for the book appears obvious: computational systems are fast becoming ubiquitous and pervasive and we would like them to be effective and friendly. They are *ubiquitous* because computing power and access to the Internet are being made available everywhere; they are *pervasive* because computing is being embedded in the very fabric of our environment. For example, our houses, our furniture, and our clothes will contain computers that will enable our surroundings to adapt to our preferences and needs. This leads also to unprecedented complexity in our envisioned systems, because commercial, educational, and industrial enterprises will be linked, and human spheres previously untouched by computing and information technology, such as our personal, recreational, and community life, will be affected.

In the midst of the complexity, we need the computational systems with which we interact to behave intelligently, i.e., rationally, and there are many facets to intelligent behavior. These facets do not exist in isolation, although they can be investigated individually. This has been the primary investigative approach so far in computer science research. However, the next major advances will come from more comprehensive approaches, where combinations of the facets will produce intelligent behaviors needed for complex and realistic domains. Creating effective combinations will require that researchers understand the various facets, and this book provides some of the required understanding.

Dr. Faria Nassiri Mofakham has assembled papers that span the *fundamental areas* of interactions among intelligent software agents, robot languages, ethical behavior of agents, and human language, and the *application areas* of manufacturing, finance, and education. She leads with a paper by Ghasem-Aghaee, Ören, and Yilmaz that covers both areas, in that it surveys the use of simulation to investigate agent-based behaviors and to control agent-based behaviors in applications. The paper is exceptionally thorough and provides a basis for considering the papers that follow, notably the paper by Coelho that considers simulated worlds of intelligent systems, the paper by Aydogan et al. that considers simulated negotiations, and the paper by Magessi and Antunes that simulates human attitudes using agents.

For computational systems to be considered intelligent, they must be able to interact with humans in ways that seem natural, i.e., as other humans would. This requires the systems to understand human emotions, as Basiri et al. investigate, and to behave ethically, as Ören and Yilmaz analyze. They must also operate efficiently and yield plausible results when processing large amounts of information, as Esmaelian, Shahmoradi, and Nemati show in their paper on classification.

Finally, the fundamental advances must be applied to important problems to demonstrate their utility and capabilities. The paper by Nazemi and Heidenreich uses advances in machine learning to improve the understanding of bond rates in financial markets. The paper by Gostar, Hoseinnezhad, and Bab-Hadiashar addresses sensor management from the perspective of intelligent sequential decision-making in the presence of stochastic uncertainty. Their results have broad applicability, including to the Internet of Things. Basiri and Ghasem-Aghaee consider how complexity can be reduced in large-scale systems using an AI approach based on multi-agent holonic systems that self-organize and behave autonomously. Modern manufacturing can benefit from this approach. The paper by Tafazoli and Parra describes how robots and artificial intelligence can improve education, specifically the learning of natural languages.

In summary, I am excited by the possibilities for new computational systems that are engendered by this book, as well as by the challenges that remain. This book provides a solid foundation for advances in the intelligent behavior of computational systems.

Dr. Michael N. Huhns

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SIMULATION

CHAPTER 1**Simulation, Intelligence and Agents: Exploring the Synergy****Nasser Ghasem-Aghaee^{1,2,*}, Tuncer Ören³ and Levent Yilmaz⁴**¹ *Computer Eng. Dept. of Sheikh Bahaei Univ., Baharestan, Iran*² *Univ. of Isfahan, Isfahan, Iran*³ *School of Electrical Eng. and Computer Science, Univ. of Ottawa, Ottawa, ON, Canada.*⁴ *Computer Science and Software Engineering, Samuel Ginn College of Engineering, Auburn University, Auburn, AL, U.S.A.*

Abstract: Simulation is applied to exhibit the extent of how the offered valuable functionalities of given issues are appreciated. A systematic glossary of about twenty types of intelligence provides a synoptic background for intelligent behavior that can be represented by agents. The three categories of the synergy of simulation and software agents are discussed in the following three sections: agent simulation, agent-supported simulation, and agent-monitored simulation. Extensive bibliographic analysis which is based on about 440 references supports each category of the synergy of simulation and software agents. Discussion of some desirable research directions and a conclusion section terminate the article.

Keywords: Agent-directed simulation, Agent-monitored simulation, Agent simulation, Intelligence, Software agent, Supported simulation.

INTRODUCTION

The synergy of simulation and intelligent software agents is explored here. Many possible applications of simulation are highlighted in Sec. 2 to appreciate the research patterns it offers. A review of intelligence and intelligent entities and the agents is reviewed in Sec. 3. A systematic glossary of about twenty types of intelligence provides a synoptic background for intelligent behavior that can be represented in agents. The possibilities of the synergy of simulation and agents are reviewed in Sec. 4. Three categories of the synergy of simulation and software agents of: agent simulation, agent-supported simulation, and agent-monitored simulation, are discussed in the following three sections. Each of these three

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sections is supported by a bibliographic analysis of about 440 references. Discussion on some desirable research directions and drawing a conclusion constitutes the last section.

1. SIMULATION: HIGHLIGHTS

To be able to grasp the full potential of the synergy of simulation and software agents, acquiring knowledge on different types of simulation is essential. Modeling and simulation can be perceived from the following perspectives: (1) Purpose of use, (2) Problem to be solved, (3) Connectivity of operations, (4) Types of knowledge processing, and (5) Philosophy of science. The three purposes of simulation are: (1) Perform experiments, (2) Provide experience and (3) Imitation, pretense [1]. In this article, the focus is on the experimental aspect of simulation. In this context, simulation is a goal-directed experimentation with dynamic models, (*i.e.*, models with time-dependent behavior). One way to distinguish different types of simulations is to consider whether a simulation program runs independent from the real system, two categories of simulation became possible: stand-alone simulation and embedded simulation [2].

1.1. Stand-alone Simulation

Here, the simulation program runs independent of the system of interest; almost all types of conventional simulations are stand-alone simulation. As listed in Table 1, there exist six types of applications of stand-alone simulation: decision making, training to enhance decision skills, training to enhance motor and related decision skills, training to enhance operational skills, understanding and education, and entertainment.

Table 1. Applications of stand-alone simulation.

Decision making for: - <i>Prediction</i> of behavior and/or performance of the system of interest - <i>Evaluation</i> of alternative models, parameters, experimental or operating conditions on model behavior and/or performance - Sensitivity analysis - Planning - Acquisition - Design - Prototyping - Proof of concept
Training to enhance <i>decision skills</i> (gaming simulation) (also called constructive simulation)
Training to enhance <i>motor skills</i> and related decision skills (simulators) (also called virtual simulation)

(Table 1) contd.....

Training to enhance <i>operational skills</i>
Understanding and education
Entertainment (simulation games, animation of dynamic systems)

Simulation for decision making is run for prediction, evaluation, sensitivity analysis, planning, acquisition, design, prototyping, and proof of concept. *Gaming simulation* is run for training to enhance decision skills. In defense applications, this type of simulation is named *constructive simulation* and includes *war gaming*, while, it is applicable for operations other than defense like, conflict management and peace assurance. In business applications, gaming simulations include *business games* which can be run in zero-sum environments to enhance decision making skills subject to competition or in non-zero-sum environments to enhance decision making skills subject to cooperation [3]. *Simulators* are often *human-i-the-loop simulations* where operators use virtual equipment to develop motor skills and the associated decision skills. In defense applications they are named *virtual simulation*. In complex systems like scientific and social systems, simulation provides the possibility to test the given hypotheses on the nature and behavior of a system and makes them easy to *understand*. Simulation is an enabling technology applicable in enhancing *learning/teaching* many topics. In *entertainment*, simulation is run for simulating games and for the animation of dynamic systems.

1.2. Embedded Simulation

In *embedded simulation*, simulation program runs together with the system of interest. The embedded simulation is of the two purposes of: enrichment and support of real system operations, (Table 2).

Table 2. Embedded simulation application.

<i>Enrichment</i> of real system operation (The system of interest and the simulation program operate <i>concurrently</i>) Goals: - simulation-based augmented/enhanced reality operation (for training to enhance motor skills and related decision skills) - on-line diagnostics
<i>Support</i> of real system operation (The system of interest and the simulation program operate <i>alternately</i> to provide predictive displays) - parallel experiments while real system is running

In *enrichment of real system operation*, the system of interest and simulation program runs *concurrently*. Depending on the objectives, there exist different possibilities like: simulation-based augmented/enhanced reality and on-line

diagnosis. The *Simulation-based augmented/enhanced reality* is an accepted form of advanced training environments where real operators can operate real equipment at augmented reality mode. The embedded simulation systems are well known especially in training associated with equipment operation [4]; and are applicable in decision systems [5]. In the *on-line diagnosis*, the output of the simulation program and the real system is compared on-line, where, any deviation in the real system's behavior from the simulated behavior may indicate a malfunction.

In the second type of embedded simulation application, the objective is to support the real system operation. Here, the system of interest and the simulation program operate *alternately* to provide predictive displays where, real system data can be applied: 1) to calibrate the simulation model and its parameters and 2) as input to the simulation system in order to evaluate the effects of decisions regarding the real system's behavior before feeding them to the real system.

1.3. Other Perspectives

In another context, there exists the possibility to discriminate different types of simulation, based on where the computations are carried out. The computation can be run on a single computer or on different computers in a network¹. The last possibility leads to *distributed simulation* [6, 7] and possibly to *Web-based simulation* (which could rely on *agent-directed simulation* and can apply mobile agents in simulation.) The advantages of distributed simulation [8] (p.261) are:

- Partitioning the simulation problem between machines with high potential of interest
- Interoperability and sharing of resources
- Exploiting graphics, ability provided by special machine

Distributed-interactive simulation is run mostly in military applications, where simulators from different types of forces are connected to form a full battle situation [9, 10]. In *parallel simulation*, simulation program operates on multi-processor machines something true in real world where systems naturally operate in parallel. The advantages are increased speed and/or increased size of the model [8] (p.261). *Federated simulation* [11] is an example of interoperability of several simulation studies; each named a federate. This simulation is based on the military requirements of the Department of Defense (DoD) of the USA and joint forces of NATO (NATO MP). Current realization relies on High Level Architecture (HLA). For HLA education, refer to Morse (2000). The HLA is applied a methodology-based simulation approach [12]. For other aspects of simulation, there exist some taxonomies available on the following topics: simulation [13], simulation languages [14, 15], simulation models [16], simulation model behavior

[17], simulation model processing [18, 19], simulation quality assurance [20], and artificial intelligence (AI) in simulation [21].

2. INTELLIGENCE, INTELLIGENT ENTITIES, AND AGENTS

Intelligence is an important characteristic and is being studied since the ancient times [22]. The same researches state: “Working meaningfully in the field of intelligence requires a broader background than might be the case in another field. Work in this field cross-cuts cognitive psychology, biological psychology, developmental psychology, differential psychology, educational psychology, personality psychology, cultural psychology, industrial-organizational psychology, and possibly other areas of psychology. To keep up with this field and advance it, one must be able to understand and to integrate the contributions from these various aspects of the field.” Intelligence exists in natural systems like in humans, animals, and in engineered systems like robots, in some AI software systems, and agents. In cyberspace, they are named info-habitants [23].

Most of the authors in AI adopted Minsky’s definition: “Artificial intelligence is the science of making machines to perform things that would require intelligence if done by humans” [24]. However, there exist counter examples on this, for example, taking the cubic root of a number on the human part would require, knowledge (of the algorithm) and mental ability (intelligence); while, done by a calculator, this ability is not sufficient to allow the calculator be labeled as intelligent. Some taxonomies of intelligence are given by Schmutter [25] and Sternberg [22]. In an early study where a classification of about 500 types of knowledge and knowledge processing knowledge was presented, Ören [26] wrote:

The advances in studies of the brain and cognitive sciences are very important and would have implications on artificial intelligence. However, it would be very useful to demystify intelligence and to identify its components in terms of knowledge for knowledge representation and knowledge processing (or knowledge-processing knowledge) in order to embed them in different machines having knowledge-processing abilities.

It may take long while, if not ever, before the use of the term ‘intelligence’ would mean ‘artificial intelligence’, ‘machine intelligence’, ‘computational intelligence’, or ‘synthetic intelligence’. Currently, when we use the term ‘satellite’ we no longer think of the moon, the natural satellite of the earth, whereas, in the 1960s, one had to use the term ‘artificial satellite’ to denote any man-made satellite. The objective of building man-made satellites was obviously not to replace the natural one(s) but to create new modalities of them. Similarly, the objective of AI is not to replace natural intelligence but to create new modalities of intelligence or advanced knowledge processing. Davis and Hersh who quoted from Good state

that Good (1964, 1965) “observes first of all that there is no point in building a machine with the intelligence of a man since it is easier to construct human brains by the usual method.” One should build an ultra-intelligent machine which may “be defined as a machine that can far surpass all the intellectual activities of any man however clever” [27].

Once the elements of advanced knowledge representation and knowledge-processing knowledge are well defined, they can be expressed in terms of different programming paradigms such as distributed, parallel, real-time, procedural, and functional programming; and data-flow, object, rule-oriented, and agent-based paradigms.

In the *Handbook of Human Intelligence*, an all-embracing definition of intelligence is offered as follows: “we shall try to define intelligence, as have others before us, as a goal-directed adaptive behavior”. At the end of the chapter, we will argue: that this definition does indeed fit the body of ideas is agreed upon [26, 28].

2.1. Types of Intelligence

The objective here is to realize the engineered systems with advanced cognitive knowledge processing abilities. As a generic definition, the following definition is accepted: “intelligence (human, animal, or machine) is an adaptive and goal-directed knowledge processing ability” [29]. Intelligence has several aspects and types worthy of being discriminated. Taxonomy of intelligence types is illustrated in Fig. (1), where rectangles with continuous lines are the types of intelligence and rectangles with dashed lines being the criteria to distinguish the types of intelligence. In the later sections, a reference to intelligence may point out to any one of these types of intelligence. Intelligence is enhanceable. Any type of intelligence can best be represented in a continuum as the level or the value of the intelligence (wherever metrics and measurement processes are defined), rather than by a binary choice.

With respect to knowledge processing abilities, there exist two types of machines or systems: Systems for knowledge processing and systems with additional knowledge processing abilities. Knowledge processing machines are the computers. For a historic view of knowledge processing machines other than computers, refer to [26]. Machines or systems with additional knowledge processing abilities have knowledge processing abilities to satisfy their main purpose of existence better [26]. Such machines or systems can, perform optimization (like a tracking missile or a vehicle-sensing road). In engineering applications, systems or machines with knowledge processing abilities to support/optimize their functionality are named the smart systems (such as smart

bridges); however, intelligence of these types of applications is rather low. In machine intelligence, some of the metrics applicable to humans, such as intelligence quotient (IQ) would be meaningless, since machine intelligence is independent of the machines' age.

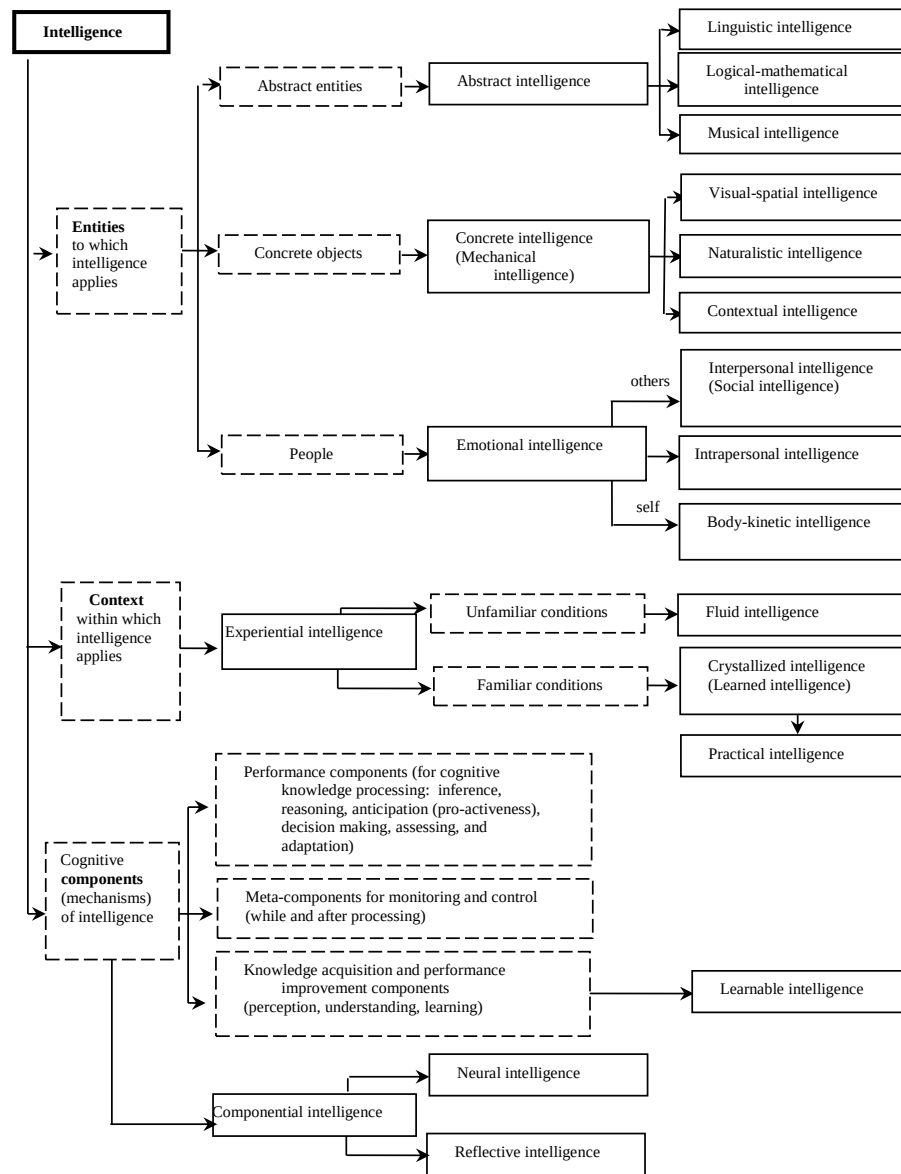


Fig. (1). Types of intelligence.

A systematic glossary² of the types of intelligence is presented in Table 3. The taxonomy refers to three aspects of intelligence: the *entities* where intelligence is applied, the *context* within which intelligence applied and the *components* (mechanisms – structures and processes) of intelligence.

Table 3. Types of intelligence (a systematic glossary).

Aspects		Types	Definitions
generic			Intelligence is an adaptive and goal-directed knowledge processing ability [29].
	abstract		Abstract intelligence is the ability to understand and manipulate with verbal and mathematical symbols [30].
	entities	- linguistic	Linguistic intelligence is the capacity to use words effectively orally or in writing [31].
		- logical-mathematical	Logical-mathematical intelligence is the capacity to use numbers effectively and to reason well [31].
		- musical	Musical intelligence is the capacity to perceive, discriminate, transform and express musical forms and sensitivity to rhythm, pitch and melody [31].
entities	concrete		Concrete intelligence (mechanistic intelligence) is the ability to understand and manipulate with objects [30].
	objects	- visual-spatial	Visual-spatial intelligence is the ability to perceive the visual-spatial world accurately and sensitivity to color, line, shape, form, and space [31].
		- naturalistic	Naturalistic intelligence is the ability to recognize and classify plants, animals, or minerals and cultural artifacts [31].
		- contextual	Contextual intelligence is the ability to adapt to, select, and shape the environment [32].
	people (emotions)		Emotional intelligence (EI) involves the ability to monitor one's own and others' emotions, to discriminate among them, and to use the information to guide one's thinking and actions (modified from Mayer and Salovey, 1993; in the original: "EI is a type of social intelligence".) [33]
		- others	Interpersonal intelligence is the ability to perceive and make distinctions in the moods, intentions, motivations, and feelings of other people for managing emotions [31]. Social intelligence is interpersonal intelligence.
		- self	Intrapersonal intelligence is self-knowledge and the ability to act adaptively on the basis of that knowledge [31].
			Body-kinesthetic intelligence is the ability to use one's whole body to express ideas and feelings or to use one's hands to produce or transfer things [31].

(Table 3) contd.....

Aspects		Types	Definitions
context			Experiential intelligence is the ability to deal with new tasks or situations and the ability to use mental processes automatically [32].
	unfamiliar	- fluid	Fluid intelligence is one's ability to reason and solve problems in novel or unfamiliar situations [34].
	familiar	- crystallized	Crystallized intelligence is the extent to which an individual has attained the knowledge of a culture. (Also called learned intelligence) [34].
		- practical	Practical intelligence is the ability to do well in informal and formal educational settings; adapting to and shaping one's environment [35].
components			Componential intelligence refers to the cognitive components of intelligence. It includes performance components, meta-components for monitoring and control, and knowledge acquisition and performance improvement components [35].
		- neural	Neural intelligence is rooted in a biological system and determined by neural efficiency –the brain's physical processes [36].
		- reflexive	Reflexive intelligence refers to one's broad-based strategies for attacking problems, for learning, and for approaching intellectually challenging tasks. It includes attitudes that support persistence, systemization, and imagination. It includes self-monitoring and self-management [36].
		- learnable	Learnable intelligence is the combination of both experiential and reflective intelligence [36].

The objective of studying intelligence in this chapter is to distinguish its types in a sense that they would be useful in representing software agents; hence, some modifications to the definitions are made. To give full credit to the authors from whom the definitions are borrowed, their names are expressed and to clarify that they are not the original definitions, modified definitions are indicated.

2.1.1. Entities

The *entities* to which intelligence is applied are of three groups: abstract entities, concrete objects, and people. *Abstract intelligence* is intelligence applied to abstract entities such as ideas, and has the three main sub-types of: linguistic intelligence, logical-mathematical intelligence, and musical intelligence. *Concrete intelligence*, (named *mechanistic intelligence* as well) applies to concrete objects and has the three sub-types of: *visual-spatial intelligence*, *naturalistic intelligence*, and *contextual intelligence*.

Emotional intelligence is applied to self (intrapersonal) or to others (interpersonal). Emotional intelligence has an aspect which concerns only others, (*i.e.*, empathy). *Empathy* is “sensitivity to others’ feelings and concerns and taking

their perspective; appreciating the differences in how people feel about things” [37]. Three other aspects of emotional intelligence are: self-awareness, managing emotions, and motivation are applicable to one's self and others as well. *Self-awareness* of emotions is observing oneself and recognizing feelings as they happen. *Emotional awareness* is observing others to recognize feelings as they happen. *Managing emotions* is “handling feelings so that they are appropriate and realizing what is behind a feeling, and finding manners to handle fears and anxieties, anger, and sadness” [37].

Motivation is channeling emotions in the service of an objective; emotional control; delaying gratification and stifling impulses. Hence, *emotional intelligence* is the ability to monitor one's own and others' emotions, to discriminate among them, and to use the information to guide one's thinking and actions. *Social intelligence* is emotional intelligence applied to others.

The relations between the emotional intelligence with intrapersonal and interpersonal (social) intelligence are expressed in Fig. (2). In the literature emotional intelligence is defined as to be a type of social intelligence, while, here the view is explicitly different, (Fig. 2).

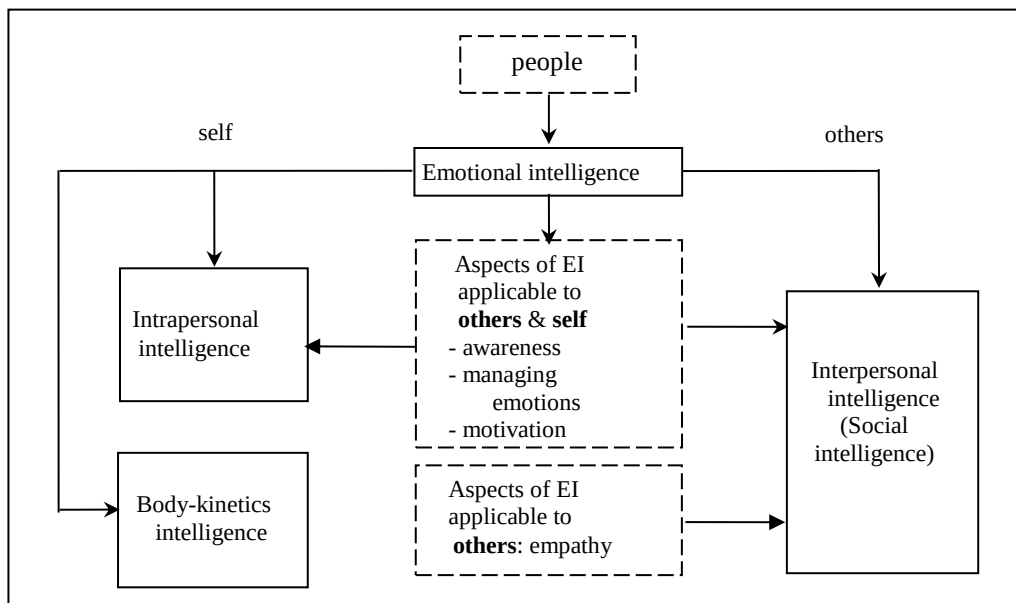


Fig. (2). Relation of emotional intelligence with intrapersonal and interpersonal (social) intelligences.

There exists a strong relation between intelligence (especially social intelligence) and personality traits and facets [38]. The basis for fuzzy agents with personality is elaborated in [39, 40].

2.2.2. Context

The *context* within which intelligence operates can be unfamiliar or familiar. *Experiential intelligence* is the ability to deal with new tasks or situations and the ability to use mental processes in an automated manner. *Fluid intelligence* is an intelligence type operating in unfamiliar situations. The intelligence is *crystallized intelligence* with *practical intelligence* as a subtype.

2.3. Components

The components of an intelligent knowledge processing entity consist of: performance, monitoring and control, and knowledge acquisition and improvement components. *Performance components* realize several types of cognitive knowledge processing such as inference, reasoning, anticipation (pro-activeness), decision making, and assessing [26]. *Monitoring and control components* monitor self and others during knowledge processing (introspection for self, perception for others) or after knowledge processing activities (postmortem analysis). *Knowledge acquisition and improvement components* are for perception, understanding [41] and learning. The last type leads to learnable intelligence, equally important for natural intelligence and for machine intelligence and software agents' intelligence. Identification of the components or mechanisms –structures and processes of intelligence– leads to componential intelligence [35]. The two types of componential intelligence are the *neural intelligence* and *reflexive intelligence*.

2.4. Agents

Agents are autonomous software modules with perception and social ability to perform goal-directed knowledge processing, over time, on behalf of humans or other agents in software and physical environments. The last part of the definition begins with *on behalf of* is a truism and if omitted would be implied.

The *core* knowledge processing abilities of agents include: reasoning, motivation, planning, and decision making. Additional abilities of agents are needed to increase their intelligence and trustworthiness. Abilities to make agents *intelligent* include anticipation (pro-activeness), understanding, learning, and communication in natural and body language. Abilities to make agents *trustworthy* and assuring the sustainability of agent societies include being rational, responsible, and

accountable, which lead to rationality, skillfulness and morality (*e.g.*, ethical agent, moral agent).

Software agents may have most of the aspects of intelligence as outlined in Table 3. The type and level of needed intelligence depend on the knowledge processing requirement of the task. In the next section, regarding synergies of simulation and agents, it will become apparent how drastically does the intelligence represented by software agents contribute to simulation. There exists a strong relation among intelligence (especially emotional intelligence), personality traits and facets [38]. The basis for fuzzy agents with personality is elaborated in [39, 40].

2.5. Software for Agents

Java Agent DEvelopment framework (JADE) is implemented in Java language and used in developing agent applications [42, 43]. JADE is probably the most widespread agent-oriented middleware applied today. JADE is a completely distributed middleware system with a flexible infrastructure allowing easy extension with add-on modules. JADE offers a rich set of programming abstractions allowing developers to construct JADE multi-agent systems with relatively minimal expertise in agent theory. The JADEX agent framework is presented by [44], which supports reasoning by exploiting the BDI model and is considered as an extension to the widely applied JADE middleware platform.

NetLogo [45, 46] is a multi-agent programming language and modeling environment for simulating complex natural and social phenomena.

The Recursive Porous Agent Simulation Toolkit (Repast) is one of the several agent modeling available toolkits. Repast borrows many concepts from the Swarm agent-based modeling toolkit [47]. The three implementation of the Repast agent modeling toolkit is presented by North, *et al.* [48].

The evaluation of free Java-libraries for social scientific agent-based simulation is presented by Tobias and Hofmann [49]. A survey of various agent-based modeling platforms is presented by Nikolai and Madey [50]. Railsback *et al.* apply five software platforms in agent based simulation [51].

3. SYNERGIES OF SIMULATION AND AGENTS

Agent-directed Simulation refers to the synergy of software agents and simulation. As observed in Fig. (3), there are three possibilities that can be considered under two groups: 1) simulation for agents: which consists of agent simulation and, 2) agents for simulation which consists of agent-supported simulation and agent-monitored simulation [11]:

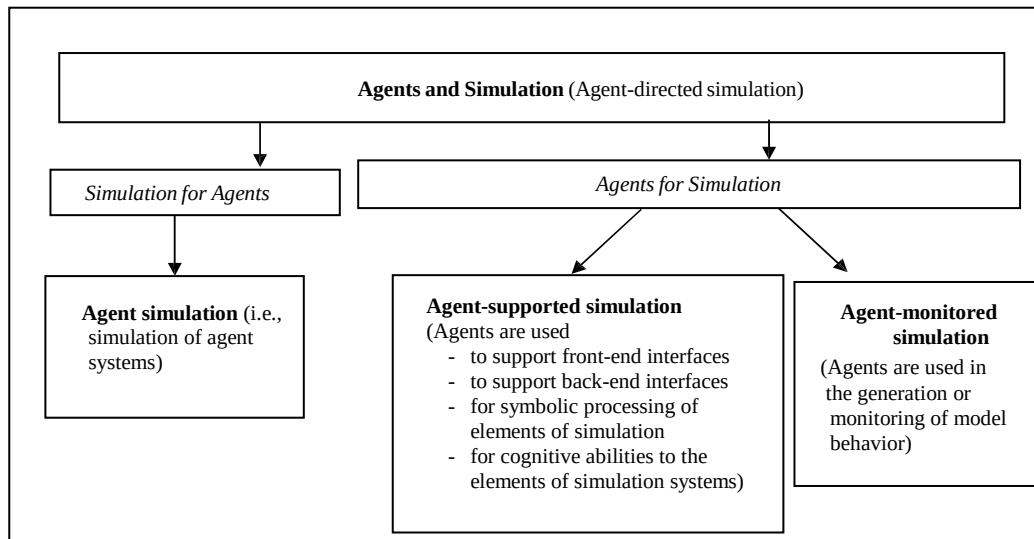


Fig. (3). Types of agent-directed simulations.

- *Agent simulation* is simulation of agent systems. It is also named agent-based simulation.
- *Agent-supported simulation* is the use of agents for at least one of the following purposes:
 1. To provide computer assistance for front-end interface functions in a computer-aided simulation study;
 2. To provide computer assistance for back-end interface functions in a computer-aided simulation study;
 3. To process elements of a simulation study symbolically for example, consistency checks; and
 4. To provide cognitive abilities to the elements of a simulation study like learning, understanding and/or hypothesis formulation.
- *Agent-monitored simulation* is the use of agents for generation and/or monitoring of agent behavior. (This is similar to the use of AI techniques –like qualitative simulation– in generating model behavior).

The simulation synergy symmetry and artificial intelligence in general [21, 29] and the simulation synergy and agents are tabulated in Table 4.

4. AGENT SIMULATION

Agents provide a natural pattern to represent intelligent entities. *Agent simulation* is involved in natural or engineered entities with cognitive abilities represented by

agents. Here the three constituent parts of this simulation, the: applications, methodology, and software for agent simulation are presented.

Table 4. Types of simulation, based on the synergy of simulation with ai and with agents.

Synergy of Simulation and:		Synergy is in the:
<i>agents</i> (Agent-directed simulation)	<i>AI</i> (AI-directed simulation)	
(Agent simulation) Simulation of agents which represent natural or engineered systems which have cognitive abilities (such as infohabitants)	(Cognitive simulation) Simulation of natural or engineered systems, which have cognitive abilities	Model (and associated machine intelligence)
Agent-supported simulation)	(AI-supported simulation)	Support functions (and associated machine intelligence)
Agents are used to support user interface functions: • Front-end interface functions • Back-end interface functions	AI is used to support user interface functions: • Front-end interface functions • Back-end interface functions	
Agents are used to support processing of any specification (for purposes other than model behavior generation or monitoring), <i>e.g.</i> : • Agent supported simulation quality assurance	AI is used to support processing of any specification (for purposes other than model behavior generation or monitoring), <i>e.g.</i> : • AI supported simulation quality assurance	
Agent-supported simulation program processing • Agent-supported simulation program generation • Agent-supported simulation program processing, <i>e.g.</i> : • Agent-supported simulation program comprehension	AI-supported simulation program processing • AI-supported simulation program generation • AI-supported simulation program processing, <i>e.g.</i> : • AI-supported simulation program comprehension	Generation and/or monitoring of model behavior (and associated machine intelligence)
(Agent-monitored simulation) Agents are used for the generation and/or monitoring of model behavior	(AI-based simulation) AI is used for the generation and/or monitoring of model behavior: Knowledge-based simulation Qualitative simulation	

4.1. Applications

A synopsis of the application areas of agent simulation is presented in Tables 5a-e. Almost all references are dated after year 2000. The engineering applications of agent simulation used in electrical engineering, irrigation systems, manufacturing systems, mechatronics, network, robotics, software, and

transportation / logistics are tabulated in bold in Table 5a. The economy and management applications of agent simulation, references on economy, e-commerce, and management are presented in Table 5b. The agent simulation of social systems and human behavior applications and references that cover social systems, psychology/human behavior, and physiology are presented in Table 5c. The agent simulation of environmental issues is presented in Table 5d. Table 5e is on military applications.

Table 5a. Agent simulation – engineering applications.

Reference	Year	Author(s)	Application Areas
[52]	2000	Dewi <i>et al.</i>	Electrical engineering
[53]	2000	Weinhardt <i>et al.</i>	
[54]	2000	North	Electric power
[55]	2002	Brucks & Mosler	Solar power plant
[56]	2004	Rabiee & Ghasem-Aghaee	Soccer
[57]	2003	Abrami <i>et al.</i>	Irrigation system
[58]	2001	Barreteau <i>et al.</i>	
[59]	2000	Bertelle <i>et al.</i>	
[60]	2000	Brennan & William	Manufacturing system
[61]	2010	Jahangirian <i>et al.</i>	
[62]	2004	Giret & Botti	
[63]	2009	Leitao	
[64]	2000	Macedo	
[65]	2002	Mönch & Stehli	
[66]	2005	Valckenaers & Brussel	
[67]	2002	Oberschelp <i>et al.</i>	Mechatronics
[68]	2000	De Franceschi <i>et al.</i>	Network
[69]	2003	Eymann <i>et al.</i>	
[70]	1998	Kim, G.J. & Kim, Y.S.	
[71]	2003	Kotenko & Maňkov	
[72]	2000	Barchanski & Veci	Robotics
[73]	2001	Bernhardt <i>et al.</i>	
[74]	2008	Ghasem-Aghaee <i>et al.</i>	
[75]	1997	Kitano <i>et al.</i>	
[76]	2002	Klančar <i>et al.</i>	
[73]	2001	Rolf <i>et al.</i>	
[77]	2015	Shafii <i>et al.</i>	
[78]	2002	David <i>et al.</i>	Software
[79]	2000	Kindler	
[80]	1996	Minar <i>et al.</i>	
[81]	2000	Osman & Bargiela	
[82]	2000	Rarau <i>et al.</i>	
[83]	2000	Uhrmacher & Kullick	

(Table 5a) *contd....*

Reference	Year	Author(s)	Application Areas
[84] [85] [86] [87]	2002 2002 2003 2007	Briegel Franke <i>et al.</i> Nagel Weyns <i>et al.</i>	Transportation /Logistic
[88]	1998	Parunak <i>et al.</i>	Industrial supply network
[89]	2002	Silva <i>et al.</i>	Scheduling of logistic processes
[90] [91] [92] [93] [94] [95] [96] [97] [98] [99] [100] [101]	2003 2005 1997 2009 2003 2003 2003 2000 2002 2006 2002 2013	Bernocco <i>et al.</i> Bazzan <i>et al.</i> Burmeister <i>et al.</i> Chen Champion <i>et al.</i> Fujioka & Ishibashi Hallé <i>et al.</i> Hertkorn & Wagner Hofmann <i>et al.</i> Huard <i>et al.</i> Pritchett Zhang, <i>et al.</i>	Traffic

Table 5b. Agent Simulation Management/Economy Applications.

Reference	Year	Author(s)	Application Areas
[102] [103] [104] [105] [106] [107] [108] [109] [110] [111] [112] [113] [114] [115] [116] [117] [118] [119] [120]	2002 2002 1999 2001 2000 2001 2003 2001 2001 2002 2001b 2003 2003 2003 2014 2003 2002a 2002b 2001	Bauer <i>et al.</i> Brouwers & Verhagen Chaturvedi & Mehta Deguchi <i>et al.</i> Fougères <i>et al.</i> Fukuta <i>et al.</i> Holanda <i>et al.</i> Iba <i>et al.</i> Kurahashi & Terano Macal & North Mizuta & Yamagata Pajot Phan Sinha-Ray <i>et al.</i> Sornette, D. Soulié & Théband Winoto Winoto Winoto & Tang	Economy
[121] [122] [123] [122]	2016 2002 2001 2002	Alrifai <i>et al.</i> Chiarella <i>et al.</i> Fukumoto & Kita Gallegati <i>et al.</i>	E-commerce

(Table 5b) contd....

Reference	Year	Author(s)	Application Areas	
[124]	2010	Honarvar & Ghasem-Aghae	E-commerce	
[125]	2000	Janssen & Verbraeck		
[126]	2000	Kalisz & Florea		
[127]	2001	Kawamura <i>et al.</i>		
[128]	2009	LI-xia		
[129]	2000	Marti		
[130]	2000	Mizuta & Steiglitz		
[131]	2001a	Mizuta & Yamagata		
[132]	2003	Moyaux <i>et al.</i>		
[133]	2006	Nassiri-Mofakham <i>et al.</i>		
[134]	2007	Nassiri-Mofakham <i>et al.</i>		
[135]	2008	Nassiri-Mofakham <i>et al.</i>		
[136]	2009a	Nassiri-Mofakham <i>et al.</i>		
[137]	2009b	Nassiri-Mofakham <i>et al.</i>		
[138]	2015	Nassiri-Mofakham <i>et al.</i>		
[139]	2001	Praça <i>et al.</i>		
[140]	2011	Roosmand <i>et al.</i>		
[141]	2002	Sallans <i>et al.</i>		
[142]	2014	Shahmoradi <i>et al.</i>		
[143]	2000	Wiedemann		
[144]	1998	Yoo <i>et al.</i>		
[145]	2002	Antona <i>et al.</i>	General planning	Management
[146]	2001b	Bousquet <i>et al.</i>		
[147]	2004	Bousquet & Le Page		
[148]	2003	Bruzzzone & Revetria		
[149]	2002	Carlson <i>et al.</i>		
[150]	2001	Dorokhov		
[151]	2002	Farolfi <i>et al.</i>		
[152]	2000	Fu <i>et al.</i>		
[153]	2005	Garcia		
[154]	2002	Gilbert <i>et al.</i>		
[155]	2001	Henoch & Ulrich		
[156]	2011	Khouj <i>et al.</i>		
[157]	2002	Lynam <i>et al.</i>		
[158]	2001	Martin & LePage		
[159]	2001	Pahl-Wostl		
[160]	2003	Szymanski <i>et al.</i>		
[161]	2002a	Tiffany <i>et al.</i>		
[162]	2002b	Tiffany <i>et al.</i>		
[163]	2000	Urban & Sibbel		
[164]	2003	Walsh & Sawhney		
[165]	2001	Zimmermann <i>et al.</i>		
[166]	1997	Anderson	Real time planning	
[167]	1999	Edala <i>et al.</i>	Supervisory Control systems	

Table 5c. Agent simulation social systems and human behavior applications.

Application Areas		Author(s)	Year	Reference
Social systems	Social approaches	Axtell	1998	[168]
		Azad-Manjiri & Ghasem-Aghaee	2010	[169]
		Boisot <i>et al.</i>	2003	[170]
		Bourjot & Chevrier	2001	[171]
		Carley	2002	[172]
		Conte <i>et al.</i>	1998	[173]
		David <i>et al.</i>	2000	[174]
		Davidsson	2002a	[175]
		Davidsson	2000b	[176]
		Davidsson	2000c	[177]
		Downing <i>et al.</i>	2001	[178]
		Gilbert	2002	[179]
		Ghasem-Aghaee <i>et al.</i>	2009	[180]
		Grimm & Railsback	2005	[181]
		Hofmann	2002	[98]
		Honarvar & Ghasem-Aghaee	2009a	[182]
		Joseph, <i>et al.</i>	2014	[183]
		Kazemifard, <i>et al.</i>	2006	[184]
		Kazemifard <i>et al.</i>	2009	[185]
Social systems	Social approaches	Kazemifard <i>et al.</i>	2011a	[186]
		Kazemifard <i>et al.</i>	2014	[187]
		Klinger	2000	[188]
		Kottonau & Pahl-Wostle	2002	[189]
		Martinez-Miranda <i>et al.</i>	2002	[190]
		Martinez-Miranda & Aldea	2004	[191]
		Martinez-Miranda & Pavón	2008	[192]
		Moss	2000	[193]
		PoorMohamadBagher <i>et al.</i>	2009	[194]
		Ören <i>et al.</i>	2009	[195]
		Ray <i>et al.</i>	2000	[196]
		Remondino	2003	[197]
		Reynolds, <i>et al.</i>	2002	[198]
		Rossetti <i>et al.</i>	2000	[199]
		Saam	2000	[200]
		Sansonnet & Valencia	2003	[201]
		Servat <i>et al.</i>	1998	[202]
		Simão & Pereira	2003	[203]
		Sun	2006	[204]
		Thébaud & Locatelli	2001	[205]
		Verhagen	2000	[206]
	Population dynamics	Bousquet <i>et al.</i>	2001a	[207]
	Simulator for harbor	Jarjoui <i>et al.</i>	2001	[208]

(Table 5c) contd....

Application Areas	Author(s)	Year	Reference
Psychology / human behavior	Adamatti & Bazzan	2003	[209]
	Baillie & Toleman	2001	[210]
	Baillie	2002	[211]
	Brucks	2001	[212]
	Ghasem-Aghaee & Ören	2003	[40]
	Ghasem-Aghaee & Ören	2007	[213]
	Ghasem-Aghaee <i>et al.</i>	2006	[214]
	Ghasem-Aghaee <i>et al.</i>	2007	[215]
	Ghasem-Aghaee <i>et al.</i>	2008	[74]
	Kazemifard <i>et al.</i>	2006	[184]
	Kazemifard <i>et al.</i>	2011b	[216]
	Kazemifard <i>et al.</i>	2012	[217]
	Mazadi <i>et al.</i>	2008	[218]
	Mosler	2002	[219]
	Mosler & Tobias	2001	[220]
	Nassiri-Mofakham <i>et al.</i>	2006	[133]
	Nassiri-Mofakham <i>et al.</i>	2007	[134]
	Nassiri-Mofakham <i>et al.</i>	2008	[135]
	Nassiri-Mofakham <i>et al.</i>	2009a	[136]
	Nassiri-Mofakham <i>et al.</i>	2009b	[137]
	Nassiri-Mofakham <i>et al.</i>	2014	[221]
	Nassiri-Mofakham <i>et al.</i>	2015	[138]
	Roosmand <i>et al.</i>	2011	[140]
	Schmidt	2002	[222]
	Shahmoradi <i>et al.</i>	2014	[142]
	Zafari <i>et al.</i>	2015	[223]
	Zafari <i>et al.</i>	2016	[224]
	Zafari <i>et al.</i>	2016	[224]
Negotiation	Alrifai <i>et al.</i>	2016	[121]
	Lopes <i>et al.</i>	2000	[225]
	Lopes <i>et al.</i>	2001	[226]
	Nassiri-Mofakham <i>et al.</i>	2006	[133]
	Nassiri-Mofakham <i>et al.</i>	2008	[135]
	Nassiri-Mofakham <i>et al.</i>	2009	[136]
	Nassiri-Mofakham <i>et al.</i>	2015	[138]
	Praca & Ramos	2001	[139]
	Ramezani <i>et al.</i>	2011	[227]
	Schmelz	2001	[228]
	Shahmoradi <i>et al.</i>	2014	[142]
	Zafari <i>et al.</i>	2015	[223]
	Zafari <i>et al.</i>	2016	[224]
	Zafari <i>et al.</i>	2016	[224]

(Table 5c) *contd....*

Application Areas		Author(s)	Year	Reference
Physiology	Immune systems	Reilly <i>et al.</i> Meshkin <i>et al.</i> Shafaei & Ghasem-Aghaee	2001a 2010 2008	[229] [230] [231]
	Malaria epidemiology	de Vries	2001	[232]
	Micro-biology	Jonker <i>et al.</i>	2002	[233]

Table 5d. Agent simulation - environmental applications.

Application Areas		Author(s)	Year	Reference
Environment	Ecosystem	Campos & Hill Castle & Crooks Franchesquin & Espinasse Franchesquin <i>et al.</i>	1998b 2006 2000 2003	[234] [235] [236] [237]
	Land use	Gotts Ligtenberg <i>et al.</i> Rand <i>et al.</i>	2001 2002 2003	[238] [239] [240]
	Sand piles	Breton <i>et al.</i> Rand <i>et al.</i>	2001 2002	[241] [242]

Table 5e. Agent simulation – military applications.

Application Areas	Author(s)	Year	Reference
Military	(AOS)	2016	[243]
	Baxter & Hepplewhite	1999	[244]
	Bullock <i>et al.</i>	2000	[245]
	(CHSSI)	2002	[246]
	Cil, & Mala	2010	[247]
	Gaston	2000	[248]
	Gaupp & Hill	1999	[249]
	Hill <i>et al.</i>	2003	[250]
	Janssen & De Vries	1998	[251]
Military	Lucas <i>et al.</i>	1992	[252]
	Lucas & Goss	1999	[253]
	Maamar	2001	[254]
	Ören <i>et al.</i>	2000b	[255]
	Rao <i>et al.</i>	1993	[256]
	Schwarz <i>et al.</i>	2002	[257]
	Tolk	2005	[258]
	Yilmaz & Paspuletti	2005	[259]

Table 6a. Agent simulation methodology in general.

Author(s)	Year	Reference
Artikis <i>et al.</i>	2001	[260]
Campero <i>et al.</i>	2000	[261]
Cohen	2001	[262]
Dugdale <i>et al.</i>	2000	[263]
Epstein	2006	[264]
Ferber <i>et al.</i>	2003	[265]
Ghasem-Aghaee & Ören	2003	[40]
Greensbey	2001	[266]
Hare <i>et al.</i>	2002	[267]
Ivashkin	2001	[268]
Jávor	1990	[269]
Jávor	1992	[270]
Kazemifard <i>et al.</i>	2011b	[216]
Lepperhoff	2001	[271]
Marietto <i>et al.</i>	2002	[272]
Miller & Page	2007	[273]
Nagendra & Chartier	1999	[274]
Nassiri-Mofakham <i>et al.</i>	2008	[135]
Nassiri-Mofakham <i>et al.</i>	2015	[138]
Nesterenko & Parinov	2000	[275]
Ören <i>et al.</i>	2000b	[255]
Ören	2001b	[11]
Ören	2001c	[276]
Ören & Yilmaz	2004	[277]
Ören & Yilmaz	2011	[278]
Ören & Yilmaz	2015	[279]
Ören <i>et al.</i>	2015	[280]
Ören & Yilmaz	2017	[281]
Ören <i>et al.</i>	2016	[282]
Obaidat <i>et al.</i>	2016	[283]
Pitts & Chiu	1999	[284]
Ramanath & Gilbert	2003	[285]
Reilly <i>et al.</i>	2001b	[286]
Saval <i>et al.</i>	2001	[287]
Schlunbawn	2000	[288]
Surdu <i>et al.</i>	1998	[289]
v & Shimohara	2001	[290]
Tandayya & Zobel	2000	[291]
Terán	2001	[292]
Tokumoto et al	2001	[293]
Uhrmacher	1997	[294]
Uhrmacher & Schattenberg	1998	[295]
Voinea	2001	[296]
Yilmaz & Ören	2009	[297]
Zafari <i>et al.</i>	2016	[298]

4.2. Methodology

The list of references a synopsis of the methodology of agent simulation is presented in Tables **6a-6c**. The references on agent simulation methodology, in general, are tabulated in Table **6a**.

In some of the early references especially the ones by Jávör the adopted concepts are similar to that of the agents but are referred to accepted terminology of demons or daemons. The special aspects of agent simulation methodology like architecture of agent simulation systems, mobile agents; adaptive, parallel, and Web-based simulation; and chaotic, complex, and distributed systems are tabulated in Table **6b**.

Table 6b. Agent simulation methodology special aspects.

Methodology	Author(s)	Year	Reference
Architectures	Bakam <i>et al.</i>	2001	[299]
	Boutekkouk	2015	[300]
	Coma <i>et al.</i>	2003	[301]
	Dangelmaier <i>et al.</i>	2002	[85]
	Das & Reyes	2001	[302]
	Fianyo <i>et al.</i>	1998	[303]
	Garrido & Brena	1998	[304]
	Henoch & Heinz	2000	[305]
	Honarvar & Ghasem-Aghaee	2009b	[306]
	Milde	2000	[307]
	Muhlenbein <i>et al.</i>	2000	[308]
	Nassiri-Mofakham <i>et al.</i>	2015	[138]
	Sarjoughian <i>et al.</i>	2001	[309]
	Schultmann <i>et al.</i>	2000	[310]
	Sun	2006	[204]
	Uhrmacher	1999	[311]
	Uhrmacher <i>et al.</i>	2001	[312]
	Zhao <i>et al.</i>	2003	[313]
	Zafari <i>et al.</i>	2016	[298]
Mobile agents	Jávör & Mészáros-Komáromy	2003	[314]
	J. H. & Kim, T. G.	2001	[315]
	Nassiri-Mofakham <i>et al.</i>	2006	[133]
	Uhrmacher <i>et al.</i>	1998	[316]
	Uhrmacher <i>et al.</i>	2000	[317]

(Table 6b) contd....

Methodology		Author(s)	Year	Reference
Simulation	Adaptive	Ghasem-Aghaee <i>et al.</i>	2005	[318]
		Miller & Page	2007	[273]
		Moshe	1998	[319]
		Ören <i>et al.</i>	2016	[282]
		Theodoropoulos <i>et al.</i>	2008	[320]
		Yilmaz <i>et al.</i>	2006	[321]
	Parallel	Anderson	2002	[322]
	Web-based	Akoulchina & Ganascia	1998	[323]
		Campos & Hill	1998a	[324]
Systems	Chaotic	Terna	1998	[325]
		Yilmaz & Phillips	2007	[326]
	Complex	Servat	2002	[327]
		Nassiri-Mofakham <i>et al.</i>	2015	[138]
	Distributed	Adnan <i>et al.</i>	1998	[328]
		Biswas & Merchawi	2000	[329]
		Ramaswamy <i>et al.</i>	2001	[330]
		Shoham & Leyton-Brown	2009	[331]
		Theodoropoulo & Logan	1999	[332]
		Uhrmacher & Gugler	2000	[333]
		Vincent <i>et al.</i>	1998	[334]
		Weiss	1999	[335]
		Wilson <i>et al.</i>	2000	[336]
		Wooldridge	2009	[337]
		Yilmaz	2006	[338]

The methodology of emerging holonic agent simulation –for the simulation of cooperative behavior is tabulated in Table 6c.

Table 6c. Agent simulation methodology: cooperation & holonic agents.

Methodology	Author(s)	Year	Reference
Cooperation	Barbat	2000	[339]
	Calabrese, <i>et al.</i>	2010	[340]
	Dania & Salaheddine	2001	[341]
	Gerber <i>et al.</i>	2011	[342]
	Gerber <i>et al.</i>	1999a	[343]
	Gerber <i>et al.</i>	1999b	[344]
	Gerber <i>et al.</i>	2001	[345]
	Ghasem-Aghaee & Basiry	2015	[346]
	Hilaire <i>et al.</i>	2008	[347]
	Mařík & Pěchouček	2000	[348]
	Mařík <i>et al.</i>	2001	[349]

(Table 6c) *contd....*

Methodology	Author(s)	Year	Reference
Cooperation	Nassiri-Mofakham <i>et al.</i>	2006	[133]
	Nassiri-Mofakham <i>et al.</i>	2008	[135]
	Nassiri-Mofakham <i>et al.</i>	2015	[138]
	Ören	2001a	[350]
	Rodriguez <i>et al.</i>	2006	[351]
	Russ & Gerber	2001	[352]
	Schillo <i>et al.</i>	2001	[353]
	Schillo <i>et al.</i>	2002	[354]
	Ulieru <i>et al.</i>	2001	[355]

4.3. Software for Agent Simulation

The software for agent simulation is introduced in Table 7, which are clustered into three categories of: language, software and environment. In each category some recent software are presented.

5. AGENT-SUPPORTED SIMULATION

A simulation environment can have two types of, front-end and back-end interfaces. The *Front-end interfaces* are applied to specify, edit, or generate elements of a simulation problem; the *Back-end interfaces* are applied in systems to communicate with the users, the primary and auxiliary outputs of the system.

Table 7. Software for agent simulation.

		Author(s)	Year	Reference
Language	- Agent-0: Agent-oriented programming	Shoham	2002	[356]
	- Agent Builder	(AgentBuilder)	2000	[357]
	- Java Agent Development Environment	Bellifemine <i>et al.</i>	2000	[42]
	-Multi-Agent Programming	Bordini, <i>et al.</i>	2006	[358]
	- Java Agent Template	(JAT)	2000	[359]
	- XML: Extensible Markup Language	(XML)	2016	[360]
Software	- JADE: developing multi-agent systems	Bellifemine, <i>et al.</i>	2007	[43]
	-JADEX: implanting a BDI-infrastructure for JADE agents	Braubach, <i>et al.</i>	2003	[44]
	- JATLite: A Java agent infrastructure with message routing.	Jeon <i>et al.</i>	2000	[361]
	Java- libraries	Tobias & Hofmann	2004	[49]
	- KQML specification language	(KQML)	1993	[362]
	- Building cognitively rich agents using the SIMAGENT toolkit.	Sloman & Logan	1999	[363]
	- Repast Organization for Architecture and Development	(Repast)	2003	[364]
	- Swarm: The Swarm simulation system – a toolkit for building multi-agent simulations	Minar <i>et al.</i>	1996	[80]

(Table 7) contd.....

		Author(s)	Year	Reference
Environment	- Agent UML: A formalism for specifying multiagent software systems.	Bauer <i>et al.</i>	2001	[365]
	- CABLE: Co-operative agent building environment	Martin, P. <i>et al.</i>	1999	[366]
	- Specification and simulation of multi-agent systems in CaseLP.	Martelli <i>et al.</i>	1999	[367]
	- DARPA: Knowledge sharing initiative	(DARPA)	1993	[362]
	- JAMES: A Java-based agent modeling environment for simulation	Uhrmacher <i>et al.</i>	2001	[312]
	- Netlogo: design and implementation of a multi-agent modeling environment	Tisue & Wilensky	2004	[46]
	- RoboCup: Rescue simulation agent communication language	Morita, S.	2009	[50]
	- Agent based modeling platforms	Nikolai & Madey	2009	[368]
	- Repast – Toolkit	Wang <i>et al.</i>		

Agent-supported simulation is applied in agent technology to support simulation activities in modeling and simulation environments and simulation-based problem solving environments. This support is comprised of: front-end and back-end interface activities, agent-supported symbolic processing like agent-supported validation and verification, and agent-supported cognitive abilities with respect to the elements of simulation systems like agent-supported program generation, program integration (as it would be the case in the formation of federations using HLA) and program understanding for documentation and/or maintenance purposes. For each one of the categories of knowledge and knowledge processing knowledge, an important category of knowledge processing activity is required to ensure the reliability of the associated elements. The possibilities for agent support in modeling and simulation environments are outlined in Table 8, for the following elements of simulation studies: objective of the study, parametric models, model parameters, design of experiments, experimental conditions, simulation program, and the behavior and recommendations. For each one of the elements, this support can contribute to its generation, specification/editing, and processing.

Table 8. Possibilities for agent support in modeling and simulation environments.

For elements of simulation studies	For generation	For specification / editing	For processing
Goal	- goal generation - hypothesis formulation	- goal specification / Editing	- goal processing - goal seeking - goal evaluation, ...

(Table 8) *contd.....*

For elements of simulation studies	For generation	For specification / editing	For processing
<i>Parametric Model</i>	- modeling - model formulation - model synthesis	- model editing - knowledge-based model editing	- model-base management - model analysis - model characterization - model evaluation - model transformation
<i>Model Parameters</i>	- parameter estimation - calibration	- knowledge-based editing - parameters - auxiliary parameters	- symbolic processing of: - parameters - auxiliary parameters
<i>Design of Experiments</i>	- knowledge-based design of experiments	- specification / editing of design of experiments	- processing (evaluation, selection, ...) of design of experiments
<i>For every experiment: Experimental Conditions</i>	- knowledge-based generation of experimental conditions (represented as: - dynamic templates or - semantic nets)	- specification/editing of experimental conditions - initial conditions of state variables - behavior generator - behavior generation parameters - ...	- automatic selection of: - behavior generator - behavior generation parameters - reliability - ...
<i>Simulation Program</i>	- transformation of problem specifications into a simulation program - automatic compiling / link editing necessary modules	- automated editing of simulation programs	- processing simulation programs: (legacy programs, new programs) - program understanding - program reliability
<i>Behavior and Recommendations</i>	- monitoring behavior generation conditions - comparing real-system behavior and simulated behavior to detect anomalies in a real system	- automatic editing of experimental conditions	- behavior monitoring - behavior analysis - evaluation of: - behavior - performance measure - decision variables

The front-end and back-end functionalities of the elements of modeling and simulation environment are outlined in Fig. (4). The front-end interface functionalities include: anticipation of user's needs and help [369], just-in-time-learning and considering emotion [370], explanation, assistance, guidance, (unsolicited) advice, advanced types of inputs like perception, speech input, body language, deictic input, facial expression of emotions, and multimodal interaction such as haptic input [371].

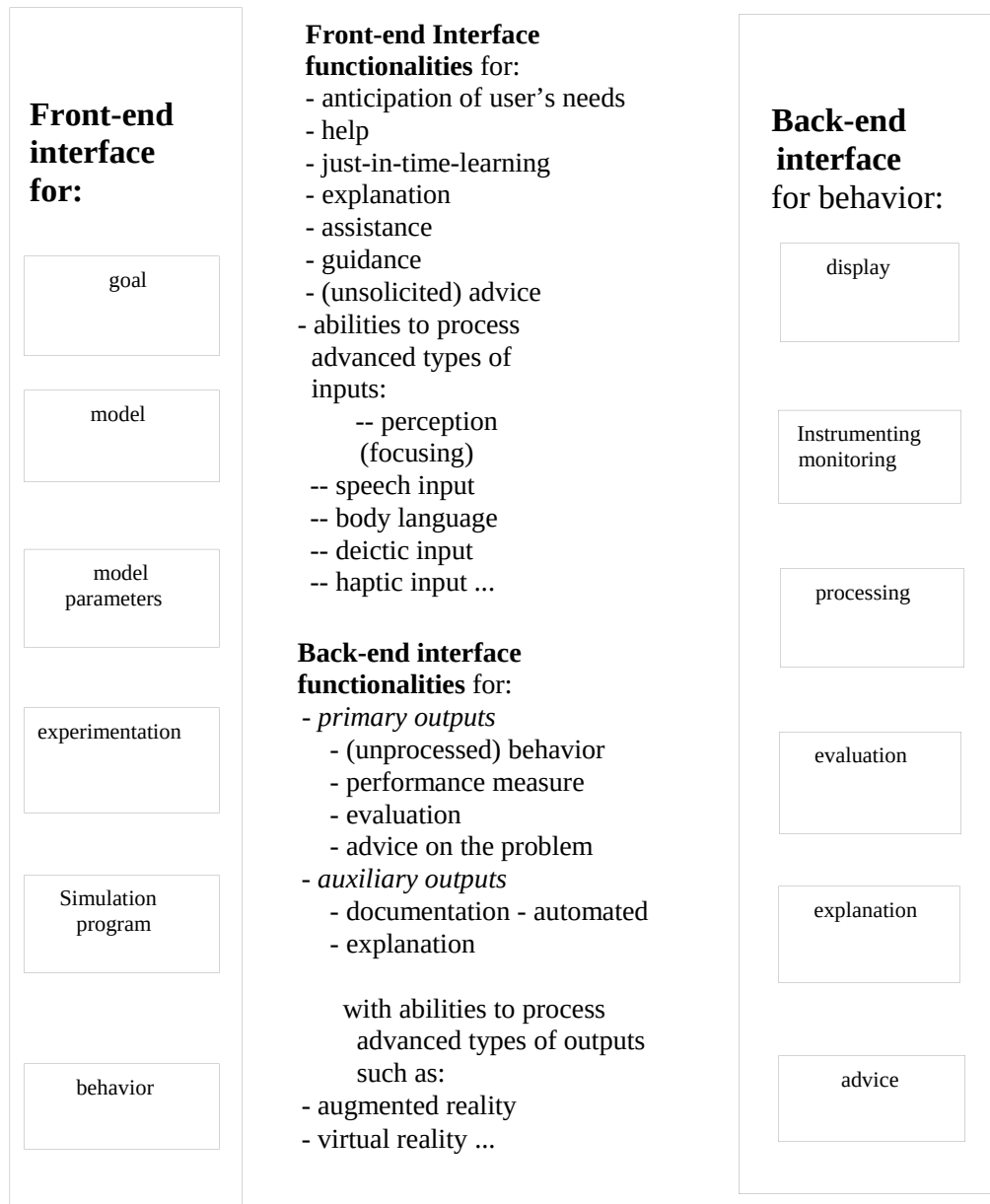


Fig. (4). Functionalities for front-end and back-end interfaces of simulation environments.

The back-end interface functionalities provide support for behavior display, instrumenting / monitoring, processing, evaluation, and advice. Advanced types of outputs like augmented / enhanced reality and virtual reality are the parts of the

functionalities of back-end interfaces. The works on agent-supported simulation are shown in Table 9.

6. AGENT-MONITORED SIMULATION

Agent-monitored simulation is applied in agent technology during run time, to generate model behavior or to monitor generation of model behavior. This simulation is similar to applying the AI techniques in generating model behavior, (e.g., qualitative simulation). The perception and understanding feature of agents makes them pertinent for monitoring tasks. Agent-monitored simulation is applicable in complex experiments and deliberative knowledge processing tasks like planning, deciding and reasoning.

Table 9. Agent-supported simulation.

To support		Author(s)	Year	Reference
Front-end Interface	- airline ticket assistance	Groves & Gini	2013	[372]
	- animated pedagogical agents	Johnson <i>et al.</i>	2003	[373]
	- animated user interface agents	Rist <i>et al.</i>	1997	[374]
	- behavior-based control	Alexander <i>et al.</i>	2010	[375]
	- collaborative interface agent	Eisenstein & Rich	2002	[376]
	- evolution of user interaction	Johnson <i>et al.</i>	2003	[373]
	- intelligent user interface	Davis <i>et al.</i>	2003	[377]
	- intelligent interface agent	Pitts & Ping Hwang	1999	[378]
	- intelligent user interface	Bikovska <i>et al.</i>	2006	[379]
	- intelligent user interface	Tuchinda & knoblock	2004	[380]
	-intelligent user interface	Cheyre & Julia	1999	[381]
	- natural language interfaces	Moran <i>et al.</i>	1997	[382]
	- user/machine systems	Rich & Sidner	1997	[383]
	- sensor/emitter model	Presser <i>et al.</i>	1999	[384]
	- sensor/emitter model	Dryer	1997	[385]
	- visualization environment	Wasfy <i>et al.</i>	2004	[386]
Back – end interface	- end-user individual-based modeling	Ginot <i>et al.</i>	2002	[387]
	- user interfaces and mobile agents	da Silva <i>et al.</i>	2000	[388]
	- distributed control of simulation	Jávor	1996	[389]
	- explanation	Haynes <i>et al.</i>	2009	[390]
	- explanation	Vasconcelos <i>et al.</i>	2004	[391]
	- natural language advice	Kuhlmann <i>et al.</i>	2004	[392]
	- natural language advice	Nassiri-Mofakham <i>et al.</i>	2014	[221]
Symbolic Processing	-distributed symbolic computation	Schimkat <i>et al.</i>	2000	[393]
	- emergence of inquiry conversation	Omori & Nishizaki	1999	[394]
	- graphical rule-building and maintenance interfaces.	Grimes	1998	[395]
	- ILOG rules agent	Haren <i>et al.</i>	1987	[396]
	- simulation-based systems engineering	Yilmaz & Ören	2010	[397]
		Chella <i>et al.</i>	1997	[398]

(Table 9) contd.....

To support		Author(s)	Year	Reference
Symbolic Processing	- symbolic and the behavioral processing of data - symbolic performance and learning in continuous valued environment - test and refine models - verification and validation	Rogers	1997	[399]
		Kennedy & Theodoropoulos	2006	[400]
		Balci	2004	[401]
Cognitive abilities to the elements of simulation systems	- adaptive mesh generation - agent decision making model - agent intelligence to support human org. - automated evaluation of internet business - cognitive abilities - cognitive emergence - complex dynamic environment - cooperation tools for supply chain management - decision support - design of experiments - dynamic reasoning agent - efficiently locating resource on the world wide web - experimental design - human bidding behavior - information warfare - integrated assessment model - integrating agents into HLA-based dist. virtual environment. - integration of databases using the mobile code - intelligent matchmaking for information agents - interoperation - language parsing and understanding - multi-sensor planning - negotiation - negotiation - office automation - processes controlled by agents - scheduling in a realistic environment - social models - the assistant as a multiagent system - training, help, and documentation - traffic intersection control - understanding the design requirements	Hilaire <i>et al.</i>	2000	[402]
		Brouwers & Verhagen	2003	[403]
		Knoblock <i>et al.</i>	2008	[404]
		Chong & Cho	2001	[405]
		Ören <i>et al.</i>	2014	[1]
		Castelfranchi	1998	[406]
		Garay, <i>et al.</i>	1999	[407]
		Klingebliel <i>et al.</i>	2001	[408]
		Yilmaz & Tolk	2008	[409]
		Crain	1999	[410]
		Kazar <i>et al.</i>	2000	[411]
		Grey <i>et al.</i>	2000	[412]
		Ören	2001d	[276]
		Nassiri-Mofakham <i>et al.</i>	2015	[138]
		Mack & Alzone	1997	[413]
		Krywkow <i>et al.</i>	2002	[414]
		Wang <i>et al.</i>	2003	[415]
		Claro & Sobral	2000	[416]
		Lu & Sterling	2000	[417]
		Yilmaz & Paspuleti	2005	[259]
		Pandit & Kalbag	1997	[418]
		Hodge & Kamel	2001	[419]
		Novais <i>et al.</i>	2000	[420]
		Nassiri-Mofakham <i>et al.</i>	2009	[136]
		Thomas & Fischer	1997	[421]
		Kruzel & Vondrak	2000	[422]
		Pesenti <i>et al.</i>	2001	[423]
		Moss	1998	[424]
		Itmi <i>et al.</i>	2002	[425]
		Fujishima	1997	[426]
		Dresner & Stone	2005	[427]
		Cohen <i>et al.</i>	1989	[428]

Agent-monitored simulation provides benefits like:

- generating model behavior
- running deliberative knowledge processing like planning, deciding and reasoning
- monitoring the generation of model behavior
- increasing the efficiency of performing dynamic simulation
- understanding of nonlinear dynamics of system
- better understanding of social (and economic, political, cultural) processes
- sensitive dependency on initial conditions
- handling complex experiments
- helping to construct adaptive model (*e.g.* cognitive psychology model, mental model, social model ...).
- helping to construct qualitative simulation models

Highlights of some agent-monitored simulation studies are as follows:

Jávor is a leader in applying demons to control complex systems' simulation [429, 430]; Jávor and Szűcs [431, 432]. In the early 1980s, when he was contributing to the field, the term 'software agent' was even not known. Abdullah and Ören [433] described an agent-monitored virtual instrumentation feature for simulation environments. Benyamina *et al.* [434] applied agents to study the behavior of system evolution. Hocaoglu *et al.* [435] described "an agent that monitors simulation environment and accepts the simulation model as its own environment. The main advantage of doing so is to be able to construct and execute (intelligent and conventional) systems requiring sophisticated knowledge, cognition, and decision-making traits in a convenient setting". Tan and Xu [436] applied intelligent agents to perform data filtering in High Level Architecture (HLA). They described the design and architecture of an agent-monitored Run-Time Infrastructure (RTI), an RTI where an agent-monitored Data Distribution Management (DDM) filtering mechanism is applied. Tan *et al.* [437] described an agent-monitored DDM for HLA. Wagealla *et al.* [438] presented "an algorithm for the transparent detection of faults that might affect agent execution, migration, and communication." Iwu and Zobel [439] described "a mechanism for profiling network attacks based on evidence gathered by agents from the crime-scene." Mikat *et al.* [440] presented a simulation study on traffic light optimization with agent-monitored behavior of the traffic signals. A synopsis of the Agent-monitored simulation studies is presented in Table 10.

7. SOME PROMISING RESEARCH AND DEVELOPMENT AREAS

Challenges in simulation, in general, are covered in [2, 136, 138, 298, 448 - 450]. Some of the appropriate research directions are defined as: *agents with personality, fuzzy holonic agents with personality, trustworthy agents, ethics for*

agents, moral agents, agents with advanced cognitive abilities, neural fuzzy agents, multi-agent learning, soft computing and software agents. Some promising research and development areas for the synergy of simulation and agents are tabulated in Tables 11a and b.

Table 10. Abilities of agent-monitored simulation.

Abilities of Agent-Monitored Simulation	Author(s)	year	Reference
A model for organization interaction	Dignum	2004	[441]
An ontology-based dictionary of understanding	Ören <i>et al.</i>	2007	[442]
Coordination, organization	Dignum <i>et al.</i>	2006	[443]
Agent-monitored analysis of organization	Dignum & Tick	2007	[444]
Cognitive complexity	Ghasem-Aghaee & Ören	2004	[445]
Data filtering	Tan & Xu	2001	[436]
Decision support system	Jávor	1997	[430]
Detection of Faults	Wagealla <i>et al.</i>	2001	[438]
DEVS/RAP	Hocaoğlu <i>et al.</i>	2001	[435]
Discrete-event multi-models	Yilmaz & Ören	2005	[446]
Experiment control	Jávor	1994	[429]
Methodology - DDM for HLA	Tan <i>et al.</i>	2001	[437]
Methodology for the reconstruction of models	Jávor & Szűcs	2000	[432]
Network attack profiling	Iwu & Zobel	2002	[439]
Optimization	Jávor & Szűcs	1998	[431]
Simulation study on traffic light optimization	Mikat <i>et al.</i>	2003	[440]
Specifying, detecting and analyzing emergent behaviors	Chen <i>et al.</i>	2007	[447]
Study behavior of system	Benyamina <i>et al.</i>	2000	[434]
Virtual Instrumentation	Abdullah & Ören	1997	[433]

Table 11a. Some promising research and development areas to fully benefit from the synergy of simulation and agents – agent simulation.

Agent-directed simulation		Promising research and development areas
Agent simulation	to make agents more intelligent	Features to make agents more intelligent, such as motivation, reasoning, anticipating, understanding, assessing, learning, and communication in natural language. Soft computing and agents Agents with several types of intelligence (Table 3) such as: - agents with emotional intelligence - introspective agents (for self-evaluation) Simulation of biological, ecological and social systems with cognitive abilities
	to make agents more trustworthy	Features to make agents trustworthy Responsibility and reliability issues in agent simulation Role of ethics for agents (moral agents) [23]

(Table 11a) contd.....

Agent-directed simulation		Promising research and development areas
Agent simulation	additional abilities for agents	Agents with cultural filters Anticipatory agents in simulation Fuzzy holonic agent simulation (with personality) (and with intelligence) Fuzzy knowledge processing Holons and holonic agent simulation (for cooperative systems) Simulation of agents with personalities (based on personality theories and not on haphazard inclusion of some emotions)

Table 11b. Some promising research and development areas to fully benefit from the synergy of simulation and agents – agent supported- and agent-monitored simulations.

Agent-directed simulation		Promising research and development areas
Agent supported simulation for:	front-end interface	Intelligent interface agents Natural language interfaces Body language interface
	back-end interface	Holographic avatars in simulation
	symbolic processing of elements of simulation	Reliability of simulation studies and agents - agent-based built-in reliability - agent-based verification and validation Program generation Program integration
	cognitive abilities to the elements of simulation systems	Cognitive abilities to the elements of simulation, such as learning, understanding and/or hypothesis formulation Program understanding for documentation and/or maintenance purposes Agents in simulation-based problem solving environments
Agent-monitored simulation		Use of agents for the generation or monitoring of model behavior Agents for virtual instrumentation in simulation

CONCLUSION

A systematic glossary of about twenty types of intelligence provides a synoptic background for intelligent behavior that can be represented by agents. Software agents represent a powerful computational pattern and a modeling pattern for intelligent entities. In this article, a comprehensive view on the synergy of simulation and software agents is presented based on an analysis of about 45 documents. This study covers the state-of-the-art concept of: agent simulation or simulation of systems modeled by agents, agent-supported simulation, and agent-monitored simulation. An overview of some studies and the development areas to fully benefit from the synergy of simulation and agents conclude this work with a great applicable functional outlook. It appears that synergy of simulation and

agents, has a very promising future from research as well as application points of view.

NOTES

¹ A *network* consists of two or more computers connected together so that they can share resources. Two or more national and/or international networks connected together form an *internet*.

An *intranet* is a private network inside an organization or a company. An intranet may be a simple network or an internet.

The *Internet* is the international collection of interconnected networks that all use the TCP/IP (Transmission Control Protocol/Internet Protocol).

² A *glossary* lists the terms in alphabetical order. In a *systematic glossary*, the terms and definitions are grouped in a logical order with a classification scheme.

CONFLICT OF INTEREST

The authors confirm that this chapter content has no conflict of interest.

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CHAPTER 2

Living with Digital Worlds: A Personal View of Artificial Intelligence

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Abstract: In recent years, Artificial Intelligence (AI) has been in the news again due to advances in machine learning, speech processing, natural language generation, robotics and agent technology, not to mention due to big investments. Examples, such as Google Translate, Microsoft's Skype Translator, Google's RankBrain, IBM's Watson, Apple's Siri, Honda's ASIMO and new startups mix with movies, healthcare, social and political simulation and energy management. AI achieved some success in education, medicine, cognitive and complexity sciences due to better interfaces, algorithms and mechanisms, and due to interdisciplinary research in techniques that mirror biological behaviour. A closer look at animal and human behaviour (mimicking nature) and to how brains store/process information may help AI continue innovating to further develop. Today, there is a different stance in schools of AI and a cooperative way of viewing different technologies working together in an integrative way, including understanding limitations and dangers (*e.g.* Facebook emotion study). Furthermore, this is a strong signal of more democracy and respect for approaches to consider intelligence at large, thus also indicating a more mature field. In this chapter, I give an overview of the field of Artificial Intelligence to explain why recent breakthroughs and better algorithms have tackled big data.

Keywords: Algorithms, Areas and territories, Digital worlds, Mechanisms, Models, Paradigm shifts techniques,.

1. INTRODUCTION

'Invariance hypothesis is a powerful approach to bridge the large gap between contemporary machine learning, with its emphasis on millions of labeled examples, and the primate visual system that in many instances can learn from a single example.'

Cristof Koch, Allen Institute for Brain Science, 2015.

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When I arrive in a town that I have been to before, my brain senses where I am again and recreates the mental map of my environment. It uses the same brain regions where I store new memories. I do not require any GPS as I am sure I found my place and I use my skills for pathfinding, two key components for survival. I can also answer two navigating questions: Where am I? Where am I going?

In order to look at Artificial Intelligence (AI) as one of the ideas that will play a role in our future [1 - 3], we need to picture a map of new sciences, moving from this discipline to Artificial General Intelligence (AGI), to gain versatility and adaptability of human intelligence, influenced by the knowledge of the human brain and again by all of AI's schools. But this pedestrian walk to a generalised type of intelligence is not enough, because there is a network of other disciplines with which AI interacts often. In fact, some disciplines, namely mathematics, philosophy and psychology, were incorporated into the foundation of AI from the start at the Dartmouth Conference of 1956.

Children learn everything based on experiences, always finding general patterns, and in this way, they create a large number of other patterns in linguistics, logic, and even mathematics. They build new knowledge based on previous knowledge, and they can explore their own overall knowledge to draw new conclusions. A group formed by Professor Claes Strannegard from the University of Gothenburg made an AI program that can learn how to solve problems, imitating how children develop intelligence [4].

During the 1980s, AI had its golden years with more than 5,000 people attending IJCAI-85 at UCLA, including a large amount of startups involved in high level programming languages and expert systems, yet some disasters (or false promises) put into question the value of its creativity and innovation. Nevertheless, ingenuity and a desire for mysteries were still strong. Toffler published *The Third Wave* [5] and called our attention to a shift from the analogue to the digital. Steve Jobs (remember his mantra 'focus and simplicity'?) discovered that the consumer switch to PCs was difficult to overcome that year, left Apple and founded Next, General Magic and Pixar, and the AI scientific community came back to the trenches to think more in depth. It was too early to sing victory and the signs of huge breakthroughs were not yet visible. Crick and Koch proposed a new theory about consciousness based upon vision, yet the neurosciences were starting their march towards new explorations. The decade of the brain was the 1990s and the one of the mind was during the following decade.

A disruption occurred when informatics moved from a centralised to a distributed computing power, from closed to open problems, and AI from individual to social

systems. The area of Agents was consolidated with the emergence (scale-freeness) of agency and connectionism became stronger, opening the way to evolutionary computation and to bonds with human sciences. Also, with the disaster of expert systems (rules were not the solution for everything) toy examples were wrapped up on the shelf and complex problems started to be solved, but with difficulties.

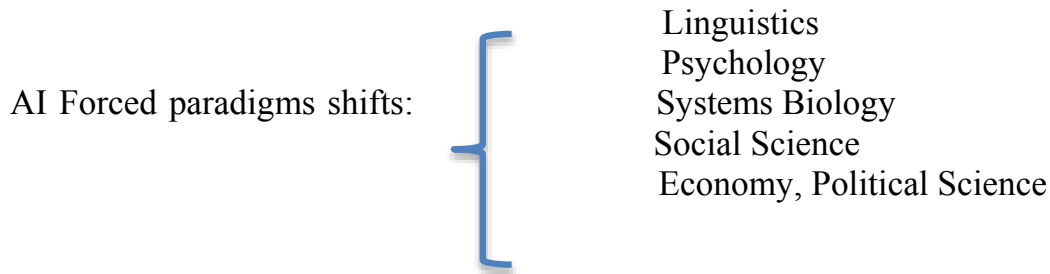


Fig. (1). Impacts of Artificial Intelligence.

Over the years, AI was not well structured, and we thought we could design new powerful artefacts with only models, algorithms and systems [6]. Rules were strong with knowledge-based and expert systems, but insufficient to guarantee a solution for hard and complicated problems. To arrive at general intelligence, *i.e.* to be inspired by human beings, it was necessary much more and not only environments with digital worlds [7, 8]. AI influenced a lot of disciplines (see Fig. 1) and several schools of thought (see Fig 2), helping the creation of cognitive psychology, computational linguistics and social simulation. Also, mathematics influenced AI, namely logic aided knowledge representation and reasoning, statistics was crucial to natural language understanding (machine translation and speech recognition), optimisation gained with Monte Carlo techniques influenced games (computer Go), and probability was decisive for dealing with uncertainty in language processing.

Symbolic	Pattern Recognition	Logic Programming
Neural Networks	Fuzzy Systems	Genetic Algorithms
Evolutionary Programming	Artificial Life	Agents
Social Simulation	Deep Learning	

Fig. (2). Schools of Artificial Intelligence.

The Santa Fe Institute opened in 1984 with a group of scientists from mathematics, physics, biology, and computer science, but only a few noticed that movement. Cognitive science [9] was already alive when complexity science was in its infancy [8]. A talk by Demetri Terzopoulos in Montreal [10] presented an aquarium with reactive artificial fish and made a big impression upon the audience, but no one was expecting the importance of the topic for movies (animation, special effects for stuntmen, and productions with thousands of figurants). Three years later, Terzopoulos' work was more widely implemented by a student [11].

Due to advances in computer technologies, the film industry experienced great progress, making possible the picture *Avatar* by James Cameron (2009) [12], which discussed and/or utilised the following innovations:

- Artificial life/agents ('rendering', 'blending', 'morphing'), including a mental link between a human operator and an avatar, and the creation of a new interactive world (Pandora).
- Special effects, computation and 3D graphics animation (movement capture) by Weta Digital.
- Affective computation: facial expressions (subtle movements of the eyes, mouth and ears) and the role that skin plays in these expressions.
- Illumination of massive environmental areas in the interactive world.
- Automation of many repeated processes: final battle, including a film sequence with 800 characters generated by computer (Tesla S1070 GPU server).

Apart from complexity and cognition, AI needed to face big data and to understand learning processes, integration of techniques, cooperation among schools, globalisation, ubiquity, and digital industry (industry 4.0 is starting now in Portugal).

The book *Being Digital* by Negroponte [13] was announced as the road map for survival on the information superhighway and proclaimed that the future was digital. Music, telephones, books, magazines, newspapers, radio, television, movies, photos, education, healthcare, banking, transportation, and almost everything were dominated by this new technology [14]. AI was young being only 40 years under its belt and was often compared with science fiction by the media, yet the change from atoms to bits was already in the mind of Steve Jobs when he placed software above hardware and firmware as the essential element of informatics. The internet was a reality and everyone decided to be wired and creative.

Will the future be digital, where everything made by atoms will be replaced by a digital copy made up with bits? Interfaces that previously required interacting *via*

a mouse are turning into touchscreen (Apple's iPad and various smartphones) and voice recognition software (Apple's Siri). These artificial assistants are now using speech to aid consumers in finding the way to a good restaurant nearby.

Recently, magazines (*Wired*, *New Scientist*), newspapers (*The Guardian*, *Le Monde*, *The New York Times*) and journals (*Nature*, *Science*, *Communications of the ACM* and *Scientific American*) praised AI for profound breakthroughs and great ideas. However, AI was attacked by Jaron Lanier, Elon Musk, Noam Chomsky, Bill Gates and Stephen Hawking for dangers and wars due to the possible bad use of this technology. The whole AI community reacted with an open letter, on research priorities and ethics, signed by more than 25,000 scientists [15 - 18].

AI is recognised as 'the study and design of intelligent agents' and 'the study of intelligence as computation' [19], or 'the science and engineering of making intelligent machines' [19]. It is a part of computer science that is now involved greatly in problem solving, machine learning, speech recognition, natural language processing, vision, knowledge representation, reasoning, planning, searching and agents, namely the areas that have been more active in 2016. It is an open discipline, interacting with philosophy, linguistics, psychology, neurosciences, anthropology, engineering, mathematics and physics. AI often interacts *via* agents with complexity science and social simulation [20], eager for interdisciplinarity and the union of human, animal, natural and artificial systems to face changes and define policymaking [21].

Social simulation (SS) is a third area of AI, differing from both the deductive and inductive approaches, generating data that can be analysed inductively, but coming from a rigorously specified set of rules rather than from direct measurements of the real world. Simulating a phenomenon is akin to generating it – constructing artificial societies. SS has been active over the last few decades [22] and journals like *Nature* and *Science* are attentive to its value and relevance for several disciplines, namely sociology, economics and political science.

Negroponte wrote 'Computing is not about computers any more', but AI is still about intelligence (the brain and the mind, but also the body), a Greek word that was and still is difficult to define accurately because humans may have different intelligences yet be good in only a few. Up until now, a piece of technology could not understand most of what we say to translate it to other languages, however this is no longer the case and is an example of a recent breakthrough. Computers (iPhones from Apple and Android Wear watches from Google) can translate spoken and written conversations, recognise photos, identify faces and be personal assistants that can visit museums with us, explaining paintings and other

objects. Computing appliances, although far from the complex thinking machines that are humans, are able to deal with common sense [23] and translate poetry, nevertheless with great difficulty. With the growth of the web, new advances have collected, stored and shared large amounts of data, and, by using probabilistic modelling, suggest and propose the best solutions for diagnostics (health), books, movies, restaurants, or the fastest routes home.

AI became necessary for systems that deal with images the way people do by answering questions about them. People help enterprises and institutions to stay vigilant, competitive, proactive, and make decisions using AI innovations (*e.g.* IBM's cancer diagnostics, Apple's Siri mixing search and speech, Amazon's recommendations, Google's search of information). Today, airplanes and cars require computers to be autonomous, and they avoid faults and human errors with great success. In addition, Galileo systems predict what could happen in disaster scenarios by considering how physical objects could collide and interact using deep learning tools. The core ways in which AI has evolved and has actually begun shaping human behaviour are as follows:

- AI improves as people use it.
- When we focus AI, we do not see one single program, but an aggregation of diverse software, engines and multiple agents.
- AI is founded on helping human beings to think and live smarter (however, because anything we learn can be immediately transferred to others, are we actually becoming smarter?).

The latest breakthroughs are the results of core advances and competition (IBM *versus* Google and Apple, Facebook *versus* Google, Twitter *versus* Amazon), including developments in machine learning, reasoning and perception, on a stage set by advances in multiple other areas of computer science and influenced by many disciplines (*e.g.* data analytics) engaged in interdisciplinary dialogues. What makes Apple, Facebook, Google, Apple, Amazon, Twitter, Microsoft or IBM look eagerly towards AI? They are buying new startups (like DeepMind by Google or Whetlab by Twitter), and creating laboratories and institutions to foster the future. By looking at the last AI conferences (*e.g.* IJCAI, AAMAS, AAAI, ECAI, EUMAS, CCS), we discover a lot of new ideas, realities, advancements, brands, products and services.

2. ROAD MAP: TERRITORIES

'The best teacher is experience.'
Jack Kerouac, 1922-1969.

For a long time, the path of AI was dominated by psychology [1]. Mathematics,

neurophysiology, engineering and philosophy were also able to influence scientists to approach other cognitive abilities apart from problem solving (reasoning and memory), namely planning, pattern/speech recognition and understanding natural language. Biology, genetics, social sciences and neurosciences were the last disciplines to constrain the making of artefacts and real systems. Yet, the progress of our comprehension of the brain and consciousness [24] over the last two decades has been enormous, in particular the fusion of mind and body, the role of self (sensory integration plus control of information processing and action) and interactions with self-awareness, reflection, deliberation and knowledge.

During a talk in Lisbon, Damasio [25] recognised the relevance of criticism from philosophy [26] and the weakness of some of his theories about consciousness published in *Self Comes to Mind* [24]. In fact, we are always being informed about the state of our body (forgotten by philosophy and cognitive science) and that the mind we have is connected to life. Consciousness is necessary to govern our feelings because of the emotional states we may be driven to. Our 'self' is nothing more than the representation of the body in the mind: the organism, as the foundation of subjectivity, is represented in the mind.

What really AI and machine intelligence is? The search for a good definition was the holy grail for a while. Several directions were tried, 'AI is the computation dedicated to solving those problems where human beings are very good', or 'AI is the study of intelligence as computation', and the whole field was designed by adding areas that could be considered the right pieces of a complicated puzzle. The boundaries of the direction of thought were always fuzzy and, from the start, problem solving was chosen as a good direction to take. It was almost an obvious bet, yet resourcefulness was behind the thin red line marking frontiers. Knowledge representation and search (including heuristics) were immediately associated, and everybody was in hurry to offer solutions for all problems. There was friction between reality and fiction, where artificial and virtual worlds lie. Beyond the limits, the space was uninhabited, but it was expected that these empty areas needed further attention and exploration.

The map of AI is not yet compacted and complete. Gaps are everywhere. However, there are many critics worried about the coming dangers of superintelligence that AI could potentially bring into being, and the media is heavily concerned with AI that is already pushing the boundaries of human comfort: war exists in every continent, communications are not secure, and real privacy is over. The rise of machines was not a surprise: for some time, language translation has been popular in business, speech understanding was in progress, machine vision appeared on streets and squares for fun and for security purposes,

and search algorithms were required since the start of the internet. Progress has been high, as investment, but we know that formal and profound work is still weak since computational complexity puts severe limitations on learning and reasoning algorithms. Bugs and faults are within us, and despite high progress, surprisingly little has been gained until now.

Over the last four decades and following IJCAI conferences, we have identified the rough sketch of a road map having a theoretical core (knowledge representation, reasoning, heuristic search, logic programming and problem solving) and a circular layer of applications (natural language processing, expert systems, robotics, vision, speech recognition, automatic theorem proving, games). That map was further transformed into a plane with small continents and big oceans, and like earth over the history of time, some regions were attracted and others split in the years ahead. The interdisciplinarity dialogues [27] among sub-areas provoked some change in boundaries and the emergence of unions (knowledge representation, reasoning and logic; perception and vision; natural language processing, information systems and data mining; constraints, satisfiability and search; planning and scheduling; distributed and multi-agent systems; search and heuristics). The need for the integration of techniques, technologies and methods has been a common trend for several difficult problems [23], such as common sense (with several types of reasoning), language translation (with statistics) or even machine learning mixed with neural networks to face big data.

There has been some stability in the hot topics of AI, where research has been more supported by funds, such as knowledge representation, reasoning, machine learning, agents, search, natural language processing, planning, and vision (the role and the preferences of DARPA). Recently, most of the papers selected for IJCAI (with a rate of acceptance of around 18%) are related to machine learning, agents, knowledge representation, reasoning and agents, but game theory has become a hot field. At IJCAI-2015 in Buenos Aires, the most active areas were, in order, machine learning, knowledge representation and reasoning, and game theory. Thereafter, the most active areas were applications, agents and planning. Natural language processing, knowledge based systems, robotics and vision, and constraints received less attention.

Comparing the editions of IJCAI-2011 (Barcelona) and IJCAI-2013 (Beijing), we can conclude that agents and constraints decreased in importance, but that seems unstable. Changes have been conditioned by good applications, and today, big data and the autonomy of a driverless car (associated with more than 10 technologies; among them, laser range finder, front camera for near vision, bumper mounted radar, aerial that reads precise geolocation, ultrasonic sensors on

rear wheels, devices within the car, synergistic combining of sensors programmed to interpret common road signs, mapping in advance, and programming real life road behaviours) seem to dominate in the news.

3. MODELS

‘So if you want to be out there helping to change the world in useful ways, it is really helpful to have some understanding of models.’

Scott E. Page in Model Thinking MOOC, 2013.

Before ‘algorithms’ became the buzz word for AI, models were recognised as the most important concept to discuss around the design of any artefact. First, they were linked with the idealised understanding of a physical system (representation of the mathematical structure of components) or an object (relationships between its facets). Through rules (productions), equations and logics, a construction of a theory was set up, covering certain features and making them attractive for the experimentation of a collection of phenomena, see Fig. (3). A model must always be sound and strong enough to support observations in the near future [28, 29].

Models improve our ability to make accurate forecasts [30]. They help us make better decisions and adopt more effective strategies, and they can even improve our ability to design institutions (organisations) and procedures (policies). Models support our thinking through time (duration, ‘elan vital’, intuition, the concepts

introduced by Bergson [31]). Also, they help disentangle temporality from spatiality, observing and interpreting phenomena [31].

1950s to 1980s

Models
Algorithms
Systems

1990s to now

Rules
Architectures
Mechanisms

Fig. (3). Key elements of Artificial Intelligence.

We are living in a changing world, full of intricacies and complexities, with plenty of interactions among citizens, enterprises, institutions and governments whose behaviours aggregate to generate more unexpected events. Riots, civil protests, terrorist attacks, market disruptions, and migrations are common and invade the news. How can we make sense of them? Models make us better

thinkers because they help us to organise data and information, to explore the internet for suggestions about knowledge and to advance predictions with the analysis of decisions and alternatives. This exercise helps us to think about strategies and policies before social events occur [32].

It is common that professionals involved with models outperform those who do not utilise them, but this depends on the soundness of the models and the care taken in the making of these tools. In particular, the choice of the proper models is essential for final success, yet the design of organisations and procedures depends heavily on the efficacy of models mixed with the understanding of patterns in data and the identification of the relationships of problems to be faced. The whole spectrum of problems, including derivation (theorem proving and evaluation of language correction) to formation (program synthesis), including planning (enterprise organisation), interpretation (medical diagnosis), combinatorial (scheduling) and solution generation (architectural design) shows a diversified palette of issues.

George Box contends that, ‘essentially, all models are wrong, but some are useful’, and he was right. Segregation [33], riots [34], standing ovation, equation-based, agent-based, linear or non-linear, the choice always depends on the data, and in the end, it is important to look to the assumptions, the results and the nature of the applications to assert the rightness of the chosen model.

We know aggregation or simple addition hold unexpected surprises, and due to this, we can be attentive to the fact that synergy or the behaviours of whole systems cannot be predicted by the behaviours of their individual parts. That is, which model contains just the right amount of detail to reproduce the interesting parts of a certain phenomenon, while leaving out the extraneous parts that would just waste processing time and add confusion? It is by exploring many models, critiquing them, finding each model’s limits, strengths and weaknesses, that we build and deepen our comprehension. The reason is simple: we are exploring a subject from many perspectives and along many levels of abstraction.

Suppose we need to develop an installation of civil protest, violence and fighting [35 - 40] within crowds with a platform (NetLogo) and a workbench (ProtestLab). We need to take into account measures (properties, parameters, variables), complexity (states, behaviours, interaction modes), cognition (agency, potency, desire, mimicry), social intelligence (power, legitimacy, grievance), and the simulation (a realist film or a novel with photographs of reality). But, we need to be careful when evaluating emergent properties to properly grasp realism, taking into account the results of surveys and interviews with protesters, the observation of video clips of those protests and what is said within social networks. Of course,

we are forced to be aware of public data on the internet (for example, the Social Conflicts Analysis Database and FSI repositories).

Beyond necessary techniques, such as agent-based modelling (ABM) and game theory, to deal with emergent behaviour through the interaction of simple agents by crowd and opinion dynamics, we also need autonomous agents (complex agent architectures with sophisticated reasoning and decision processes), multi-agent systems (coordination), social simulation (with ABM), complexity science, cognitive science, and social networks (social theory, social learning). There are now several applications along a wide spectrum: segregation (multiple contexts), diffusion over social networks, consensus, auto-organisation and cooperation, cooperation and social tolerance, opinion formation, reputation/trust, opinion dynamics in social structures, multiple relations, roles and contexts (permeability and switching), disease spreading, culture, personality, and human nature. For example, the last call for MABS2016 prioritised, submissions in the domain of governance and policymaking.

Eventually, we need to consider alternatives, such as the use of abstract models for civil and ethnic violence, for revolution and insurgence, and to explain large scale emergent phenomena in terms of a small number of simple rules by the adoption of middle-range model for phenomena at definite space and time scales with context-specific information, and/or a facsimile model for crowd dynamics and land combat. Thereafter, we can consider intelligence trait features within agent models to observe the options available, from simple/reactive to cognitive (for example, BDI, PECS, or Agent_Zero). Meanwhile, it is important to fully understand rationality, decision-making and learning capabilities, and delving deeper still, it is important to try to discover whether social and moral sensitivity is needed, and the relevance of emotional capability (affective computation) for approaching realism. So, the need of bridges between neuro and social sciences (ABM for engineering installations) must be evaluated, and we need to maintain our attention to behaviour imitation and dispositional contagion (important not only for conflicts, but for the spread of diseases and news).

The question of realism is interesting to consider, namely the fidelity of representation, the truth to 'nature', and the sensitivity analysis of agents' attributes. A better comprehension of a system's behaviour is necessary with more precise simulations and by maintaining behaviours adaptive to context rules. Also, we need to include features observed in real events, such as the clustering of active and violent protesters, the formation of moving confrontations, the occasional fights and arrests, policemen with defensive and offensive behaviours, and media agents wiggling around the hot spots. Sentiment analysis (zig-zag

changes) is also relevant to confirm the validity of opinion polls about social issues.

People protest because of grievances created by feelings of relative deprivation (discrepancy between individual expectations and capabilities, which is related to the potential for conflict), illegitimate inequality, moral indignation or a suddenly imposed grievance that induces a cleavage within society. This is a complex path-dependent process with multiple levels and players, which requires care to handle, and this has prompted Lemos, Coelho and Lopes to develop a workbench called ProtestLab to invest in experimentation [39, 40]. ProtestLab considers two model entities, agents and scenario, and a variety of interactions. All concept designs were done with the NetLogo tool, which made the process of overviewing and scheduling easier, including the quantitative measures of crowd patterns and protests intensity, and also parameterisation and validation issues.

In what concerns a particular environment, three levels are considered by ProtestLab: 1) the macroscopic (for world, country, media), 2) the mesoscopic (for the protest), and 3) the microscopic (for individuals). The workbench also considers scenario features (attraction points, obstacles, empty, flags, exits, entrances), quantitative measures (emergent crowd patterns, protest intensity), police *versus* protesters effectiveness, and potential media coverage. Regarding the agents, three main types are considered: 1) protesters, 2) police (plus command), and 3) media reporters. Furthermore, various subtypes are also addressed, such as protester subtypes (behaviours/personalities: ‘hardcore’, ‘hanger-on’, ‘passer-by’) and police subtypes (command, offensive, defensive, multi-role). The architecture of all players is reactive and the agents have multiple states (quiet, active, violent, fighting) with four types of interaction: 1) aggressive infection (contagion), 2) avoid/approach, 3) engage/fight, and 4) run away.

4. HUMAN INGENUITY

*‘You don’t understand anything until you learn it more than one way.’
Marvin Minsky, 1927-2016.*

The discovery of neural and biological mechanisms (relationships between causes and effects in a system, in terms of the system’s entities and their activities) has been a pivotal improvement in AI. There are two recent examples, one regarding how the brain navigates [41] and another about the language AI-2 of bacteria for achieving quorum sensing [42]. The Nobel Prize in Chemistry for 2015 recognised the cellular toolbox, which describes three DNA repairing mechanisms. Although AI is still far from exploring this toolbox in artificial agents, other advances have been made, such as the work of a startup, MintLabs,

which provides a platform that allows researchers to see the neural connections of a living brain. This new technology helps us to observe the differences between the brain of a patient and that of a healthy human being [43].

We know that deep learning computer networks act like a human brain to foster a sort of intelligence, which is not fixed but rather can be developed and augmented through effort. This is reminiscent of Leonardo da Vinci's proclamation that 'experiment is never default, only our judgement'. Also, a model which can learn from data to make predictions can identify human features, and software can translate eye movements into commands to control devices. Through neuroengineering, we can insert implants into a brain (motor cortex), such as an electrode laden chip, to connect with a computer *via* an interface.

A 58-year-old tetraplegic woman was the first to use her mind *via* a mind-body link to control a robot arm to lift and drink from a soda can in the BrainGate2 study. The experiment was conducted by professor [44], and it was a triumph of mind over mechanics (brain-computer interfaces, neuroengineering), where electronic implants in the brain turn a person's thoughts into commands for a robot.

Later, a quadriplegic man, used his thoughts to direct a robot arm to put a beer up to his lips, a direct link that was achieved between the brain's electrical activity (neurons) and machines. Aldo Faisal from the Centre for Neurotechnology at Imperial College London used eye movements and a software table that translated the data into machine commands to control wheelchairs, computers and video games [45]. Other big projects, such as Human Brain (EEC), Connectome and BRAIN initiative (USA), are in progress. Neuroengineering is now well established, and the number of variations along the brain-computer connection are trivial.

Due to recent developments in eye-tracking technology, we can determine where in a visual scene people are directing their gaze to reveal people's objectives, such as where they want to go, what they want to do, and who they want to interact with. In the neuroscience of eye movements, algorithms turn a glance into a command for a wheelchair, a wink into a mouse click or the dart of a pupil into the swing of a game paddle. To predict intention, algorithms now depend on training from real-world data, such as data acquired by recording volunteer's eyes as they drive a wheelchair with a joystick or operate a robotic arm. Gradually, the software learned to tell the difference between the way people look at a cup when they are evaluating its contents and when they want to pick it up and take a drink.

Machines that teach themselves are today another direction of neurosciences. Deep learning networks consist of layer upon layer of connected computer

processing units called artificial neurons, each of which performs a different operation on the input at hand, such as an image to be classified. The deeper the networks (the more layers), the higher the level of abstraction. Google DeepMind also used deep learning [46] to teach itself to play a dozen Atari video games in order to create a program to beat the best European Go player, mimicking what IBM did with Deep Blue in May 1997 for Chess when grand master and world champion Garry Kasparov was defeated.

Do we have free will? Our choices seem to be freer than previously thought as the brain-computer duels show. Brain studies assert that, to a certain point in time, we can suspend a decision, making a different choice or change of behaviour.

The purpose of such work is to explore ideas by scaling up from simple organisms to account for the more nuanced behaviours of humans. How do our brains process competing motivations? The answer is simple: stimuli can trigger different responses that depend on the dynamics within a network of neurons. As a matter of fact, important functions must be viewed in terms of collective activity states in the brain.

5. MECHANISMS

'The present contains nothing more than the past, and what is found in the effect was already in the cause!'
Henri Bergson 1859-1941.

Increasing realism in the dialectic relationships among agents (individuals, personalities, feelings, actions), social features (types, groups, exchanges), collectives (multitudes, mobilisations, rebellions), and institutions (organisations, governments) is creating an urgency to take into account the social phenomena made up of actions, interactions, and states of mind of constituted individual actors [47]. Proto-narratives are temporal sequences of events constituting a story which emerges out of a cascade of local interactions between nodes in a social network. Picking up the behaviour of an agent in a narrative, we find a process of bringing about some state or of preventing some change of state.

An example of civil conflicts (protests) includes a collision of (individual) drives, fear barrier lowering (situational), and imprisonment (contextual, within a timeframe imposed by a jail term). In fact, we have two possible models of violence, one based on fear and the other based on anger. In the first case, fear relates to the mechanism of jailing [48] or memory. Here, we can cover conflict and violence along two tracks: 1) the cognitive (social, ethical) and 2) at the intersection of social physics and machine learning. In the second case, anger, the

bonds among agents (friendship and social order) and trust (reputation) play the key role.

Mechanisms (processes that are set up to accomplish a goal) are today necessary for tackling complicated applications and describing particular details. When we choose to cover the case of civil protests, violence and fighting within crowds, we consider two main features, namely mobilisation (social networks) and influence (interactions and relations), which further have multiple levels, such as violence, struggles, scales (expand/blow-up, shrink), links, modes of interaction, and formation of action patterns. Mechanisms are diversified, from general to particular, from mental to behavioural, or even centred on interaction, learning, or decision-making around choices and preferences.

There is a chain of steps, from the big problems of society to models and social simulation, and again to the identification of optimal paths for society. Policy options can be derived, in light of personal needs and goals, and even the White House can later promote recommendations for other situations. The case study of smart cities, conducted at the Santa Fe Institute is a good example [49]. Austerity, inequality and corruption may provoke a legitimacy feedback situation (legality, justification, acts of consent) prior to opening a window of opportunity for a conflict/crisis, and even the credibility of a government is open for debate.

There are other mechanisms we can discuss, such as power [50, 51] and desire. Power relates to the social structure and social processes [52] that govern the relations between individuals and groups (power of, power over, power of influence) and causal relations (dependence, political governance). Desire is linked to social influence and sensemaking, and its geometry is made of triads and triangles (subject, object, mediator). Imitation, infection, competition, envy, friendship or enemy ties, rivalry, passion, vanity, reputation, resentment, power, love, deceit, and anguish are several aspects that deserve further study [53].

The positions of the characters in a novel that are in a triangular situation are the self (subject) and the other (mediator, rival) facing a target (object), thus uncovering a model for desires and human relations. Behind this, there is the structural thinking of two competitors [54]. The role of copying and imitating the object, and the variable distance in the triangle, separates the mediator/rival from the desiring subject.

In fact, protests are also narratives, like complex adaptive systems (manifestations act as streams of protesters) where an individual character is a trigger for action and for switching events. Global patterns (clusters) emerge from local interactions, and passer-by protesters may turn into violent ones. Protests and violent confrontations change fast into social movements. Police agents attach

goals, and their reactive architecture (scan-plan-behave) is augmented to detect unprotected points, threatening clusters, and available police. Also, they identify unnecessary orders and those available are sent to points to be guarded. Government legitimacy is a variable to measure in Epstein's formula: the disposition, G-N, connects the grievance and the risk [55]. Mechanism design deals with the details, such as parts and devices (algorithms), embedding, fitting together the pieces of jigsaws, chains of causal reasoning, explanations and justifications, propositions, laws, principles, and conventions.

6. MACHINE LEARNING VARIETY

'The point of all this is to be able to spend more time at the beach!'
Nils Nilsson.

When reviewing any area of AI (reasoning, knowledge representation, problem solving or learning), we discover the diversity of AI schools, such as symbolic (logic, cognitive psychology, mathematics), connectionism (neurosciences), robotics (engineering, control theory), ALife, evolutionism (biology, genetics), Bayesian networks (statistics, probability theory) and socially inspired simulation (social sciences, agents).

The diversity of techniques is everywhere, such as in learning through rules (productions), backpropagation algorithm, dot-product algorithm, genetic algorithm, neural networks or analogy algorithm. When facing problem solving, we also find several heuristics to explore and the potential to make an analogy, generalisation and induction, or to validate a problem and to use auxiliary problems (*e.g.* in geometry theorem-proving) as constructions to open shortcuts.

Recently, apart from looking to diversity, we are used to integrating, mixing, or blending techniques to handle greater complexity because we have many parts with lots of interactions among them, social coexistence, and a multitude of points of view. A good example is common sense, where we need several reasoning techniques (taxonomic, geographic, temporal) that come together to understand the origin of the complication of understanding a current conversation with anyone based upon fragments of learned patterns relating to speech.

Algorithms and models are determinants for extracting information from large volumes of data and inferring knowledge based on this data. Two AI techniques are used to work on data: 1) machine learning and 2) data mining. An example is the predictive maintenance of air planes in the aeronautics industry in conjunction with the optimisation of airline routes. Then there is Google's DeepMind, which is the control of an environment (observation, action, reward) by deep reinforcement learning involving an algorithm (Deep-Q-network) that is able to

develop a wide range of competencies in a diversified range of tasks [46]. A neural network with many layers of nodes (deep convolutional network architecture) can learn concepts (object categories) directly from raw sensory data, exploiting the local spatial correlations in images. Such an algorithm is robust enough to support transformations, like changes of viewpoint or scale, and make predictions from data.

The exploitation of reinforcement learning in problems of real-world complexity is based upon two competencies found in human and animal behaviour: 1) the ability to derive efficient representations of the environment from sensory inputs, and 2) the ability to generalise past experience to new situations, requiring recognition of complex patterns (long-term planning around improving climate-change models, decision-making applied to health-care, exploring medical images to make diagnoses or treatment plans) [21]. Deep learning finds multiple higher level representations and more abstract features defined in terms of lower levels, and this capability means the architecture is dealing with more details thus replicating more fidelity.

The DeepMind general-purpose algorithm was tested with 49 different arcade games, such as Pong, Breakout, and Space Invaders, to interpret the games' patterns, and this skill was recognised as similar to one necessary to play Go. New software replicating this skill with Go was named AlphaGo and was able to beat the European Champion, Fan Hui (8-dan, and 5 in 5 games). The program was able to beat the best silicon-based rivals with a 99.8% success rate and made the front cover of *Nature* [56].

The board game Go (19x19) has greater complexity than Chess (8x8): a turn in Go offers 250 moves against the 35 possible moves in Chess, and the average 150-moves of Go contain 10^{170} more board configurations. Both are two player, deterministic perfect information games. Rules-based games are better arenas for computers than non-rules-governed games. Go cannot be solved by algorithms that search exhaustively for the best move. Chess has too many possible configurations to be solved by brute force alone, thus a tree search (the potential paths the game can evolve into and the selection of the best candidate moves looking as far ahead as possible) was adopted with a supercomputer. There is a need to cut down searches by looking a few turns ahead and judging which player has the upper hand (IBM's Deep Blue beat Kasparov in 1997). Chess programs search about 14 moves ahead, and start beating grand masters at this point. This tree grows quickly, and even quicker for Go because there are less constraints on each move.

In Go, recognizing winning and losing positions is much harder. To interpret Go boards and to learn the best possible moves, AlphaGo applies deep learning in neural networks (brain inspired software in which connections between layers of simulated neurons are strengthened through examples and experience). AlphaGo studied 30 million positions from expert games, capturing abstract information on the state of play from board data (strategy) and categorising images from pixels. It played against itself across 50 computers, improving with each iteration – a technique known as reinforcement learning. AlphaGo has two main strategies: 1) the capability to select the best move by scanning a sample of simulated future games, and 2) the ability to pick moves and interpret boards. Two networks are necessary, one for values to evaluate positions on the boards, and another for tactics to select the moves of the two-coloured pieces (policy network).

Let us observe the history of Go to understand how AI advanced. Twenty years ago, the prediction was that, to get a human pro-level in any Go program, we would first have to solve AI. Yet, ten years later, everything changed. Go software started incorporating Monte Carlo tree search (MCTS), and by 2008, the first Go program beat a professional (8-dan). The leap from pre-MCTS to MCTS was greater than from MCTS to AlphaGo.

Applying deep learning separately to the issues of tree search, branching factor and position evaluation provoked a shift. MCTS had already solved the position problem. There was now insight for not playing games out to the end, rather cutting them off at 20 moves or so, and then using a deep learning based evaluator (value network) in AlphaGo. There was no need to play out as many games as traditional MCTS. To address the branching factor, there was an independent deep learning network that suggested the best moves to search from each position (policy network). Both deep learning networks seemed to grasp more subtle issues of Go knowledge and understanding what MCTS could not – they work more like brains do, although brains have a complex interplay between perception and planning that does not exist yet in deep learning systems. Humans are able to conceptualise whereas deep learning plus MCTS cannot.

With deep learning, it is possible to design artefacts with hierarchy sensory processing that teach themselves and have the general ability to learn on their own. The deeper the network – the more layers of connected computer processing units called artificial neurons – the higher the level of abstraction at which it can operate. For example, Google's Photo app runs a photo through each successive layer of the network, and it identifies elements within the image at an increasing level of abstraction until it achieves, by detection, the whole face within the picture.

We can now teach machines to see or to learn because we have identified algorithms that are able to capture those abilities. This power to develop better algorithms was achieved by reverse engineering through considering how people think about a problem. Another example is SegNet, a new smartphone-based system that can accelerate the development of driverless cars. SegNet is better than sensors, using a mixture of radar and LIDAR, because it learns by example. It is also highly capable in accurately recognising things in an image. The tackling of data sets by deep learning is now extended to other commercial players, such as Facebook's facial recognition, Microsoft's Skype language translation tool, and Twitter's porn identification. In summary, an advantage of AI is precisely the design of better algorithms that have been used for recognising faces, understanding spoken language and playing games, and this advantage has been obtained by machine learning.

7. AGENT SHAPES

'Never abandon a theory that explains something until you have a theory that explains more.'

John McCarthy 1927-2011.

The world is unpredictable and politics have always been uncertain [52]. Humans are forced to make choices and decisions throughout life to survive, and the same happens with artificial agents. Their behaviours are always a big surprise. As with people, agents also need to be attuned to their environments and the precise context of an application.

Agents' behaviours can be studied looking to human/animal individuals in isolation or with heavy interactions in society [21]. In either situation, nature is revealed and the character is shown like the colours of the rainbow. That is why affective computing is needed for more complicated manners and interactions with the help of complexity sciences. The diversity of architectures, from reactive to cognitive architectures, covers forms such as perception-memory-action, scan-plan-behave, sense-think-choose-decide-intervene, or feel-reason-act.

With the renaissance of the neurosciences and some examples of the deep inspection of brains, it would be interesting to critically review the theme of mental models for intelligent agents [22, 55], starting with BDI – a contribution of philosophy [57] – and carefully observing the PECS modelling of human behaviour [58] as well as updating [48] with the help of neurocognition [22].

In Epstein's latest book [22], we are driven back to mimetic desire [59] and to the question of who observes whom [54]. Agents are based on equations or on models (from reactive to cognitive ones), depending on what they are supposed to do.

There is more apart from their mind to design, and often the body is important to specify. Unfortunately, there has been less research on a theory of bodies for artificial agents.

The film industry is requesting more involvement of agents in big productions to decrease overall budgets. Also, social simulation applications [60, 61] around policy design (state governance) have been eager of better shapes for agents that are more in tune with the complexities of social interactions [47].

8. PREDICTING THE FUTURE

'Touch consists of knowing till where we can reach.'
Jean Cocteau, 1889-1963.

Thinking smarter is the future, according to Kevin Kelly [62]. Three recent breakthroughs have unleashed the long-awaited arrival of AI: cheap parallel computation, big data, and better algorithms. Speed and power were quite important for the film and game industries (more reality and authenticity). Big data with machine learning is the key ingredient that is now pushing enterprises forward (Google, Microsoft, Facebook, Yahoo) with the offer of quality services and recommendations. Algorithms are already helping people to decide what to watch, to listen to or to read. NSA algorithms operate upon huge volumes of data and the Google search algorithm (RankBrain) is always busy. Algorithms perform calculations, help data processing (for generating scenes in movies) and automate reasoning. The finance industry is also eager for algorithms and not for data websites. City trading floors are occupied with currency, bank approvals, automatic investment, dealing with pensions, shareholdings, or savings. Other industries are entangled with store cards, online retail, job matches, governance, or predicting the future. Maintaining privacy seems to be far from desired.

Amplifying AI is now possible, and an example is network intelligence, which is infinitely scalable. Watson (IBM's cognitive service) was able to defeat the previous human champions of the Jeopardy game quickly with multiple answers and a probability of success. Its logic-deduction engine (the language-parsing components) operates on different codes, on different chips, and in different locations, but all are cleverly integrated into a unified stream of intelligence (Deep QA). Another example is Scanadu, a startup devoted to promoting a diagnostic device for cancer, inspired by the Star Trek medical tricorder and powered by cloud AI. Sentient Technologies is exploring AI to create a system that, through continuous monitoring, can predict the onset of sepsis 30 minutes ahead of time and with 91% accuracy.

There is an example of clever medicine that shows how AI can help problem solving in pharmacology. Todd Zion, a chemical engineer from MIT, discovered a different way of making drugs while doing his PhD. He started by doing experiments, and later, he decided to open a startup called SmartCells. The aim was to create a smart insulin by trial-and-error rather than by a goal-driven approach. This clever drug was bought by the giant Merck and will soon be available on the commercial market.

A case study about how to attack cancer and to augment the probability of saving patients by collective action was devised by Jay Tenenbaum [63], an AI scientist. It is known as Cancer Commons, and it was organised around the building of a huge database. Behind it, there is a model of personalised medicine inspired by the particular features of this disease group. It started with two beliefs: every cancer is unique and the patients hold the answers, which implied the re-evaluation of the entire standard-of-care treatment model that dominated healthcare for a while.

The database included genomic data, medical records (patients' diagnoses, treatment histories, results, side-effects) and diaries of patient experiences. Cancer Commons has learned from its growing database to match each person to the best treatment by identifying individual patient traits and linking to previous ones. Crowdsourcing was inspired by how the internet started, by taking networks of information and collaboration, and then connecting them to each other. The lesson was simple: go where the patients are and use their information to create a feedback loop to Cancer Commons and for the doctors treating those patients, adopting the principle 'learn, improve and optimise service'. The result was staggering: cancer deaths were reduced by 50% within 10 years.

The case of complex diseases, like cancer, exemplifies how AI can be used to explore shortcuts to solve difficult and complex situations. Smart research robots were adopted for accelerating searches on cancer treatments and finding optimal treatment combinations, and we can isolate the abilities, the expertise and the advancements obtained. Also, in 2016, computer vision has been used to detect skin cancer. Overall, the use of AI in the healthcare industry has been beneficial in the following ways:

- Abilities: planning and conducting experiments with many substances; drawing conclusions from the results.
- Expertise: finding optimal treatment combinations (new drug compounds) for killing cancer cells.
- Advancement: focusing on the same cancer types by returning multiple times until the disease is switched off.

There are other good examples that can be isolated to discover how AI has been able to solve some medical deadlocks. One such example is a prosthetic hand that can feel physical sensations. Again, we may isolate the novelty, the ability and the advancement obtained as follows:

- Novelty: artificial hand is directly connected to a brain with 100% accuracy; mechanical finger gently touched.
- Ability: prosthetic limb controlled by thoughts has feedback from signals travelling back to the brain.
- Advancement: neural technologies explore sensing and the motor cortex; biotechnological restoration of near-natural function; potential restoring active memory (RAM) by developing brain interfaces; treat memory loss from a traumatic brain injury or complex neuropsychiatric illness [44]; with biomechatronics, links to nerfs and muscles support smarter artificial legs and arms.

Outside of the healthcare field, machines can be trained to predict the photos and illustrations people will remember and find memorable with astonishing accuracy. Before, predicting human visual memory was out of reach. However, Aditya Khosla *et al.* [64] found that images that evoke disgust, anger and fear tend to be more memorable than those that evoke awe or contentment.

Is it possible to humanise device (smartphone) interactions with some AI within the environment of the Internet of Things [65]? says yes, and with his app, Snips, transforms the phone to adapt to a few situations. The app's natural language processing and machine learning software identifies an address, guesses what you are going to do and provides a pre-configured solution. In brief, Snips aggregates the data and the links that are relevant so that it learns about the owner of the phone – activities, habits and preferences – by applying twenty algorithms to the messages, calendar, contact list and background location to anticipate commands. Is Snips smart or trying to comprehend how people use the facility? Unfortunately, we are still far from the buildings of Pritzker's 2016 winner, Alejandro Aravena, characterised by 'the ability to connect social responsibility, economic demands, design of the artefact, thoughtful and appropriate use of materials, and commitment to creating public spaces to benefit the larger community'.

But Hindi is not alone. Viv, a three-year-old AI startup founded by Dag Kittlaus, is also developing voice-controlled personal assistants, trying to find a new way to interact with mobile devices and competing with Apple's Siri, Google Now, Microsoft's Cortana, Amazon's Alexa, and Facebook's M, which all turn speech and text into actionable data. Viv is a program that writes its own program in

order to scale thousands of services working together that know nothing about one another, and it will also include modules of learning to adapt discovered user preferences and be ubiquitous.

A general theory of complexity that is a concise and parsimonious mathematical framework is being researched at the Santa Fe Institute (SFI) to understand complex adaptive systems, such as biological and social systems. The aim is to predict behaviours *via* modelling and to simulate dynamic non-linear and complex systems. The project on cities and urbanisation, led by Luis Bettencourt, stresses the creation of a new interdisciplinary synthesis to describe cities in a quantitative and predictive way, and it is also a step towards the modelling of innovation and sustainability in developing human societies.

9. CHALLENGES

‘AI will help us solve big problems in genomics, energy, and climate science.’

Eric Schmidt, Google Chairman, September 14, 2015.

There are still many topics in AI that need to be further discussed, and we must take steps others fear by shifting paradigms. An exploration of subjectivity is one of them as the theory of mind is far from being completely understood, even regarding animals. Sustainability is another topic where an answer implies a list of fields, such as energy, climate change, transportation, food, urban planning or even information technologies. Cities are eager for solutions for environmental and socioeconomic challenges associated with urban areas and involving innovative policies, data and technology. However, utopia is also a part of the answer, as are ethics and politics. The recent criticism over AI regarding technological dominance forgets ecology and morality [66], along with the battle between the artificial and the natural. The common good of humanity requires the presence of philosophy and agents with moral dispositions [67].

Humans know that all encounters are key to our lives and change us in infinite ways. The past is remembered and remains important to us, and we use drivers, such as the songs we used to listen to, to help retrieve those memories. But what about artificial agents? They have no persona, no memory of experiences, and it is not possible to inspect the ‘and, what if...’ rule. Identity is a facet we need to improve upon to get quality for these agents. How do they feel? How can they explore emotions at large?

There are still territories full of worst-case scenarios, such as calamity (crisis, revolutions, epidemics, fires, tsunamis, earthquakes, airplane crashes), tropical ecosystems (weather alerts), city traffic jams (smart cities), economic market

regulation, civil conflicts (with or without riots and violent clashes with police), and social landscapes (with diverse cultures, institutions, movements, groups, collectives, communities), and only with agent based models and social simulation can we start to understand how to view possible solutions [68, 69] or to imagine ways out with more creativity.

Neuroscientific research has made a sound contribution to the understanding of how the mechanism of aggression works in the brain. Aggression causes new nerve cells to be generated in the hippocampus, and this process plays a key role in learning at the behavioural level. The basic building blocks that make up complex behaviours are similar in different organisms, and they combine with other blocks to create an enormous variety of behavioural reactions in animals and humans [21].

Our behaviours, and the behaviours of animals, have an influence on the function of the brain and may provoke long-term changes even at the cellular level. Brain research requires knowledge in unexpected fields, such as optics, game theory, economics or sociology, (see Fig. 4).

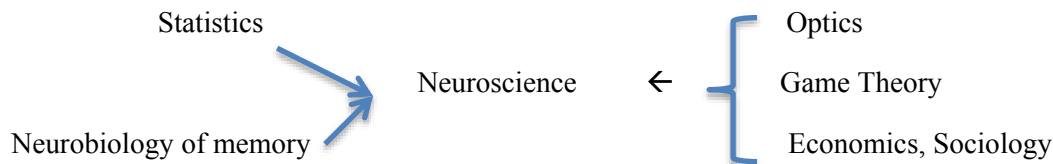


Fig. (4). Frontiers in Neuroscience.

Looking to the structures of the brain, the amygdala is associated with emotional memory, including memories of unpleasant stimuli, such as aggression, fear, and anxiety, meanwhile the hippocampus is associated with spatial and short/long-term memory (cages, mazes). Going back to the mechanism of aggression as an example, the brain starts to function in a different way. The number of new cells of the hippocampus increase, and if fighting goes on, the activity of existing cells also changes. New cells seem to be among the key contributors to an increase in aggression and are perhaps also responsible for anxiety [70].

Mapping the pattern of individual neural connections can provide insights into the computational processes (complex behaviour) that underlie the workings of the human brain. Such a conclusion is based upon a study of the fruit fly's (*Drosophila melanogaster*) sensory systems, where it was possible to focus the active conversations between neurons during a behaviour or the sensory experience of smelling a banana. The researchers used fluorescent molecules of

different colours to tag neurons in the brain to discover which connections were active [71].

Different synapses are active during various behaviours, and we can see those in the same animal and with our three distinct labels (this R&D was done in the context of the BRAIN Initiative project).

Other neuroscientific studies based upon models and simulation have recently opened new alleys for AI, bringing new knowledge. The behaviours of the human mind and the observation of neurons, in detail, can be done with physics equations. A mathematical model of the mind can be explored for understanding psychiatric disorders (obsessive-compulsive, bipolar, attention deficit, schizophrenia, and autism) because these are represented in sequential memory. All human behaviours and our processes of thinking are sequential in time, and the mind processes a sequence of numbers, events, or ideas that underpin how people think, perceive and interact as social beings.

Revisiting my previous research, I find a list of interesting themes which require further thoughts and quests: agent development methodology (extending KISS, KIDS, Spiral), interdisciplinary practices with a precise aim, new theoretical understanding of complex systems, understanding human behaviour through mathematical analysis of social networks, making sense of big (socio economic) data, interplay of duration with life (change and becoming), intelligence expansion toward instinct and intuition abilities, smart mobility, contactless services, smart cities and transportation in more sustainable regions, and the association of cyber security and identity to defend privacy.

The interaction of bioinformatics (visualisation of medical images) with neurosciences is growing with new possibilities. CloudNeuroimaging (CloudN), software from MintLabs that is inspired by 3D Google Maps, can generate maps of brain connections by merging the MRI brain images of a patient with a 3D coloured map. This facility allows the identification of illness, *i.e.* the properties and precise localisation (similar to GPS) of brain lesions, quantifying the true state of tissues and guiding clinical trials forward. Before, the evaluation and diagnosis of brain diseases was based upon clinical scales of symptoms and subjective observation. With CloudN, neuroconnections are visible and predictions become easier; diagnoses become objective with rigorous damage calculation of the brain by quantifying variables. Advanced therapies will be possible due to access to an extensive database of brain images. There is a shortcut between image and insight because we can start analysing our data instantly and there is no need to install and maintain any software.

AI and machine learning make it possible to deal with huge amounts of data, and the next step after big data is big image. Such ways forward can foster the discovery of causes and mechanisms of some deadly diseases. The work of MintLabs is precisely associated with those mechanisms of neurotransmission and synaptic communication in neuropsychiatric diseases (connectomics). In future research, AI also envisages exploring the mechanisms of social order, agent leadership and power, agent self-awareness (anticipate the impact of other individual/collective actions), collective bonds (friendship), emotional profile (love, hate, fear, anger), instinct capability, thinking over time and rewinding the passage of time (forward, back) to measure realism.

CONCLUSION

'How does it feel to be own your own, with no direction home, like a complete unknown, like a rolling stone?'
Bob Dylan, 1965-66.

Artificial Intelligence has often been cutting edge and has always been able to move, sometimes backward, to go deeper in search of more knowledge, or forward to generate leaps ahead. Today, for those like Andy Rubin, the creator of Android, and Larry Page of Google, AI is the next great platform and all will be connected to a networked intelligence. In my own perspective, AI is linked to soft and hard intelligence, and it needs to have attentive observers able to look to the past and to the future in order to create images of new artefacts needed for better living (accessibility, usability and aesthetics).

There is an inertia of asking for change towards a better life and for a change of attitudes regarding the architecture of the artificial in equilibrium with the natural world (animals and nature). Machine collaboration is already available with Watson. It is called intelligence amplification (IA), and rather than depending on his or her finite body of knowledge, a doctor can use a supercomputer capable of surveying vast amounts of information (from earlier to up-to-date research papers) to quickly present or suggest decisions that might not have been thought of or known about. IA puts humans in control and leverages computing power to amplify our capabilities. The feedback loop created by exposing intelligence to humans through application programming interfaces enables Watson to learn and improve from users' decisions. Like much of IA, Watson becomes smarter by amplifying our own intelligence.

Looking to the innovation history of Rubin, from social networking (Spies in the Wire, 1981), mobile computing (General Magic, 1992), smartphone design (Danger, 2001), mobile platform (Android, 2003), self-driving cars (Google, 2004), artificially intelligent hardware (Playground, 2015), we discover a vision

of the future along a timeline of creative impulses and a hive of ideas. Also, there is the research direction of informatics from crude hardware to software, and back to smart hardware, and we may deduce AI is now more capable of huge leaps.

Can we say that much of AI focuses on mapping out massive neural networks, gathering amounts of data and having lots of multi-agent systems around? The answer is no. And, we may stand in social simulation (with agent based modelling), around the internet and searching for what was done in the last decade. Some will argue that is specific, in narrowly defined tasks, and we approximate the web of neurons in the human brain. Yet, today AI is already hundreds of layers of mathematical operations (algorithms), a large design space. Are we requiring urgently new artificial intelligence tools, open source software based on deep learning, like TensorFlow (Google), CNTK (Microsoft) and Torch (Facebook, Google)?

The social simulation community [72] believes in new possibilities of facing big problems, such as understanding levels and directions of interaction or modelling culture with a great impact on science, technology, and society (competitiveness). However, they question how much complexity is needed in agents to get a good picture and what kind of model is necessary to understand and predict (qualitative analysis, integrate heterogeneous models).

Looking around us, we find a rather uncontrolled and unpredictable world, an out-of-equilibrium economy and features of social complexity, multiple ontological levels with volumes of connections in many directions from micro to macroscopic planes, and an interdependence of behaviours and cultural facets where technology-driven innovation emerges full of energy.

The experiments around Chitchats (XiaoIce, Watson included), on regular conversations (and small talks) about ways to creatively solve problems in a wide-variety of themes and professions, proved to be analogue to a Google search (too heavy for the one eager to get to the point), yet without getting multiple, potentially-related connections. With Watson, discussions are more focused, and perhaps this can create a genuine alternative (GT-Watson plus technique) to the search engine itself in what may be the human-computer interaction model. Before, it was human tendency to guide (everybody has a bunch of heuristics), but now the artificial agent is in charge to conduct and to discover the meaning and purpose of an entire inquiry.

IBM's Watson was trained by Georgia Institute of Technology students in the areas of engineering, architecture, biology, systems and computing, and was directed to check whether professionals were aided in problem solving and to retrieve natural language information. No personality was associated to the chat

(the messaging system, Slack, has this facility) and there was no intention of transforming it into a social awareness chat (*e.g.* for messaging or recommending systems). Such a research direction is more general and opens other interesting questions for the exploration of applications in gaming, education and healthcare, or even in aiding pedestrians (tourists) around a town (Microsoft's Cortana, Apple's Siri).

AI is now everywhere, in personal photo archives (facial recognition), self-driving cars (Toyota, Cadillac, Ford or Tesla are near), universal translators (Google Translate), body trackers (Microsoft Xbox Kinect deployed a new machine learning technique, a method called decision forest, where AI guesses the body's most likely next position), or even smarter news feeds (social networks' speech and image-recognition software to more efficiently identify viral videos). And, for each problem, we need intelligence (the criteria that enable us to distinguish between true and false problems and it has affinity with space) and intuition (the faculty for finding solutions, it leads us to go beyond the state of experience toward the conditions of experience, and it has affinity with time [31], or thinking fast and slow, according to Kahneman [73]).

It is nice to be faced with critical thinking in order to take note of facets often forgotten by those always in rush. The space of possibilities is huge, and experimentation opens surprising alleyways that must be studied with great care. AI has a role to play in a global world of increasing complexity and will make a difference by facing not only scientific challenges, but also social and economic ones, namely those linked to education, healthcare and environment of lower-income communities.

A paradigm shift in how we think, live and interact with AI is underway (a new renaissance) after the strong criticism made by Chomsky and others (as discussed in the introduction of this chapter), and the quick reply by the community. Also, the role of AI matters in society. The consideration of ethics [66] is a nice move to centre the whole discussion and to push a new way of holistic thinking about the dangers of technologies [74]. As a matter of fact, we need to develop better tools to predict trends and to communicate evidence about choices and decisions [75]. Fei-Fei Li was right when she said, 'We need to inject humanism into our AI education and research by injecting all walks of life into the process' [76].

Scientific breakthroughs will be powered not only by advanced computing capabilities that help researchers manipulate and explore massive datasets, but also by the ways that scientists collaborate with one another and with technologies. It is necessary to build global cooperation with social networks that

can help the movement from personal archives into a common scientific repository (the science of commons).

Today, research is being done on multiple continents, and emergent countries have a word in how science is made. One possibility is with networks of research collaboration. Obviously, there is a need for strategic thinking and long-term planning because our world is changing and we need to interact deeply with politics and society [52]. Finally, we must request that our governance be based upon best-available evidence and balanced by responsibility for action [77, 78]. Good practices are always a good principle to have in mind, namely:

- Simplicity as an aim.
- Multitude of modelling approaches to attain realism.
- Replication and re-implementation (repeatability) mandatory for explanatory purposes or for attaining realism.
- Model calibration and validation to get perfection.

A general theory of complexity is present in several research agendas because we need a concise, parsimonious, and potentially mathematisable framework for understanding complex adaptive systems. The aim is to understand and predict behaviours *via* modelling and simulation of dynamic, non-linear and complex systems. Insights about complex biological and social systems hold promise as foundations for such a theory.

Leslie Valiant [79], a scientist of computational complexity theory, made efforts to dissolve the distinctions between biology, computation, evolution and learning. He assumed there is an equivalence between the capabilities of brains and computers. In 1984, he got the Turing Award with the probably approximately correct model (PAC), and he defined the conditions under which a mechanistic system could be said to ‘learn’ information. In an interview, Valiant advanced the question, ‘Which aspects of artificial intelligence could be made into quantitative theory?’ and he gave ‘learning’ as the answer [79]. He explained that he needed some theory which combined both computation and statistics to describe what the phenomenon was. ‘Learning is calculation, but the goal of learning is to perform well in a world that is not precisely modelled ahead of time’. He went on to state, ‘the knowledge an individual has must have been acquired either through learning or through the evolutionary process’ and ‘some of the biggest challenges that remain for machines are those computations which concern behaviours that we acquired through evolution’ [80].

The idea of narratives as complex adaptive systems is also challenging because temporal sequences of events (stories) are popular not only in literary criticism, but also in crisis management (*e.g.* street protests and violence) and video game

design. With the help of simulation, we can advance and open new alleyways to comprehend fully how government legitimacy relates to grievance.

How much sensitivity analysis should we have? Contagion and imitation: which one is best when making simulations? Is neural deepening a good direction to increase modelling resolution? Empathy and awareness are far from being completely understood, but are they required? There are still several battles that need to be won and many frontiers that we must explore to have a beautiful world [66].

CONFLICT OF INTEREST

The authors confirm that this chapter content has no conflict of interest.

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A Baseline for Nonlinear Bilateral Negotiations: The full results of the agents competing in ANAC 2014

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Abstract: In the past few years, there is a growing interest in automated negotiation in which software agents facilitate negotiation on behalf of their users and try to reach joint agreements. The potential value of developing such mechanisms becomes enormous when negotiation domain is too complex for humans to find agreements (e.g. e-commerce) and when software components need to reach agreements to work together (e.g. web-service composition). Here, one of the major challenges is to design agents that are able to deal with incomplete information about their opponents in negotiation as well as to effectively negotiate on their users' behalves. To facilitate the research in this field, an automated negotiating agent competition has been organized yearly. This paper introduces the research challenges in Automated Negotiating Agent Competition (ANAC) 2014 and explains the competition set up and results. Furthermore, a detailed analysis of the best performing five agent has been examined.

Keywords: Automated Negotiation, Nonlinear Utility Functions, Agent Competition.

1. INTRODUCTION

Conflict is an omnipresent phenomenon in human society [1 - 3]. It spans from daily situations like discussing a holiday plan with friends and arranging a meeting between colleagues to complex scenarios like politics and business. Automated negotiation tools provide an important mechanism for decision makers

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to resolve their conflicts and to reach mutually acceptable agreements. There is a growing interest and need for automated negotiation mechanisms [3, 4]. To facilitate the research in automated negotiation, an international competition namely Automated Negotiating Agent Competition (ANAC)¹ [5] is yearly organized. This competition challenges researchers to design and develop fully-automated negotiating agents that can negotiate under certain protocols and conditions. To compete, one has to develop a negotiating agent that can negotiate across a variety of negotiation scenarios. In all variants of the competition, the agents have to negotiate with incomplete knowledge - agents do not know neither their opponents preferences nor their negotiation strategy.

From May 2010 to May 2013 four instances of the ANAC competition [6 - 9] have been held in conjunction with the International Conference on Autonomous Agents and Multiagent Systems (AAMAS). This competition follows in the footsteps of a series of successful competitions that aim to advance the state-of-the-art in artificial intelligence (other examples include the Annual Computer Poker Competition and the various Trading Agent Competitions (TAC) [10]). ANAC focuses specifically on the design of practical negotiation strategies. In particular, the overall aim of the competition is to advance the state-of-the-art in the area of bilateral, multi-issue negotiation, with an emphasis on the development of successful automated negotiators in realistic environments with incomplete information (where negotiators do not know their opponent's strategy, nor their preferences) and continuous time (where the negotiation speed and number of negotiation exchanges depends on the computational requirements of the strategy). One of the successes of ANAC lies in the development of state-of-the-art negotiation strategies that co-evolve every year; some notable examples include [11, 22]. The previous four incarnations of ANAC already yielded more than 60 new strategies and scenarios [6] which can be used as benchmarks to test the efficacy of subsequent work in this area. This is in line with the goal of ANAC to build a community in which work on such negotiating agents can be compared by standardized negotiation benchmarks and performance metrics.

Each year, the organizers bring up a new challenge for the participants. This year, ANAC 2014's focus is on negotiating with nonlinear utility functions as well as dealing with large-scale outcome spaces [23]. In ANAC 2014, negotiating agents were not allowed to access the structure of the nonlinear utility functions directly; therefore, they needed to explore the outcome space smartly to generate their bids. The main challenge in ANAC 2014 is to explore a large-scale outcome space effectively. In this paper, we explain the competition setup and results of the qualification and final rounds. Furthermore, we analyze the performance of the best performing five agents in an additional experimental set up. Following the competition, we systematically generated 108 different negotiation scenarios and

tested the performance of the best performing five agents elaborately. We studied the effect of the domain size, the number of constraints and issue-constraint distribution on the performance of the agents.

Our experimental results show that the agent applying a Genetic Algorithm namely *Gangster* outperforms the other agents in terms of the individual utility gained by the agents. The performance of the agents using Simulated Annealing in their strategy, namely *Agent M* and *Whale Agent* is closed to the performance of *Gangster* agent. On average, the performance of *Agent M* with respect to the distance to Pareto optimal outcome and Nash outcome is slightly better than *Gangster* agent. Their overall performance regarding to the utilitarian social welfare metrics is almost the same. Moreover, our evaluation results also show that the performance of the agents highly depends on their opponents and the negotiation scenarios played. For example, *DoNA* agent, which was ranked at second place in ANAC 2014, was outperformed by all agents in the second experiment. In the second experiment DoNA had less opponents and in the second experiment a greater variety of scenarios was used.

The rest of this paper is organized as follows: Section 2 gives an introduction on ANAC 2014 rules and competition setup. Section 3 provides an overview of agents participated in ANAC 2014. Section 4 explains ANAC 2014 qualification and final round results while Section 5 provides a detailed analysis of best performing five ANAC 2014 agents. Finally, Section 6 concludes the paper with directions to future work.

2. ANAC 2014

Each year, the ANAC organizers bring a new challenge to the participants (e.g. discount factors in ANAC 2011 [7, 24], private reservation value for each agent in ANAC 2012 [9], learning from past negotiation sessions in ANAC 2013 [25]). The 2.1 ANAC 2014 Rules focus of ANAC 2014 is on bilateral multi-issue negotiation, in which each agent's preferences are represented in the form of nonlinear utility functions as well as dealing with large-scale negotiation domains. In such complex domains, exploring the outcome space is not as straightforward as it was in the former competition, in which linear additive utility functions were used on relatively small-size domains. To sum up, the main challenge in ANAC 2014 is to find efficient exploration strategies for interdependent preferences, particularly on large-size domains.

As in previous years, the General Environment for Negotiation with Intelligent multi-purpose Usage Simulation (GENIUS)² [26] has been used in ANAC 2014. GENIUS is a research tool for automated multi-issue negotiation that enables ANAC participants to develop and to test their negotiating agents. It also provides

an easily accessible framework to develop negotiating agents via a public API. Each participating team has to design and build a negotiating agent using the GENIUS. For ANAC 2014, we extended the GENIUS framework with nonlinear utility functions in the form of weighted hypercubes [27, 2].

2.1. ANAC 2014 Rules

The aim for the entrants to the competition is to develop an autonomous negotiating agent. Performance of the agents is evaluated in a tournament setting, where each agent is matched with all other submitted agents, and each pair of agents will negotiate in a number of negotiation scenarios. There is an initial qualifying round, and the top 8 performing agents will continue to the finals, which is held at the AAMAS 2014 conference. All teams that make it through to the finals have a representative attending the AAMAS 2014 conference, who has the opportunity to give a brief presentation describing their agent.

In the previous years, additive utility functions were used to represent negotiating agents' preferences in ANAC. Since realistic negotiation scenarios involve bundles of interdependent issues under one or more specific constraints, as a main update with respect to the previous year, ANAC 2014 extends the agents' utility model to *nonlinear utility functions* (see Section 2.2). When generating scenarios, we should not restrict the interdependencies to low-order constraints but allow multidimensional interdependencies to be parametrically defined. One way of doing it is to generate a utility spaces as an hypergraph with connectivities defined as hyperedges connecting a number of issues [28]. Such approach allows a quantitative assessment of the complexity of any nonlinear utility space using information entropy [29]. Moreover, using a graph-theoretic analysis of the complexity gives a good estimate of the performance of any optimization algorithm. Therefore, we use weighted hypercubes to represent agents' preferences.

In these scenarios, the agents no longer have linear utility functions; instead, they can only sample their utility of a bid through a `getUtility()` method. In terms of the agent design, this means that the agents do not have access to methods pertaining to scenarios, such as functionality specifying the weights of the negotiation issues. The participants were not allowed to exploit the structure of the nonlinear preferences, so that it becomes a challenge to explore the outcome space efficiently. The agents have to search the utility space bid-by-bid, using the `getUtility()` method for any bid they are interested in. Another challenge is to deal with largesize domains, with outcome spaces as big as 10^{50} outcomes.

Negotiations are bilateral and based on the alternating-offers protocol. Offers are exchanged in real time with a deadline after 3 minutes. In addition, half of the domains contain a discount factor, which causes the value of an agreement to decrease over time. The challenge for an agent is to negotiate without any prior knowledge of the opponent's preferences and strategy. Negotiations are repeated several times to obtain statistically significant results. Agents can be disqualified for violating the spirit of fair play. The competition rules allow multiple entries from a single institution, but require each agent to be developed independently.

2.2. Negotiation Scenarios

In all ANAC competitions the scenarios form the setting in which the participating agents compete with each other. The agents play against each other over a number of scenarios. In ANAC 2014 setting, a negotiation scenario consists of domain description and two conflicting nonlinear preference profiles. There exists a number of preference representation used in automated negotiation [26, 30 - 32]. For convenience, only integer issues are considered for domain specification and each agent's preferences are represented in the form of weighted hypercubes [27, 33]. According to this representation, a utility function consists of a set of hypercube regions in the outcome space. Each hypercube represents a single constraint c_k . A numeric *weight* or *utility value* $u(c_k)$ is associated to each constraint. The utility of a given bid, o is calculated as sum of the utility values for the hypercubes including this bid, as follows:

$$u(o) = \sum_{c_k \in C | Satisfy(o, c_k)} u(c_k). \quad (1)$$

Fig. (1) shows a sample utility function for a two-issue negotiation problem. This utility function consists of a unary constraint $C1$ and two binary constraints $C2$ and $C3$. The corresponding utility values associated to these constraints are 5, 10 and 12 respectively. According to this example, the contract x ($issue_1=2$; $issue_2=3$) would yield a utility value $u(x) = 15$ for the agent, since it satisfies both $C1$ and $C2$ (that is, constraints $C1$ and $C2$ overlap, creating a region of higher utility). The contract y ($issue_1=4$; $issue_2=2$), on the other hand, would yield a utility value $u(y) = 5$, because it only satisfies $C1$.

It is worth noting that we extend this representation to support negated *constraints*, which are satisfied when the given bid remains outside of the given hypervolume. This richer expressiveness allows us to approximate any desired function, by a finite number of constraints [2].

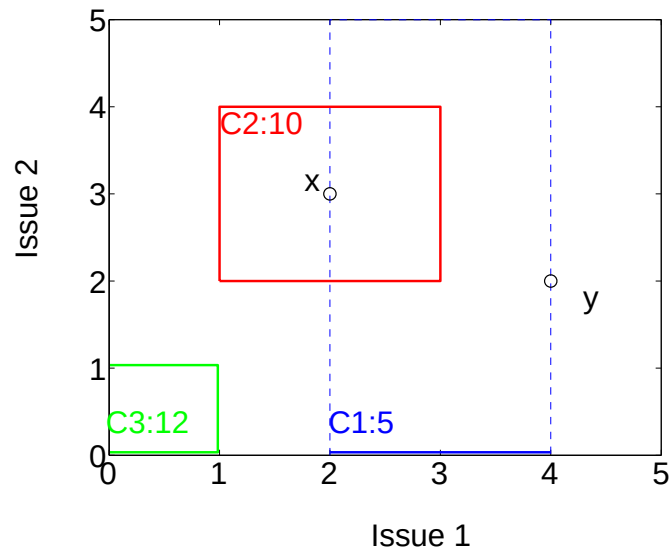


Fig. (1). Example of a utility space with two issues and three constraints.

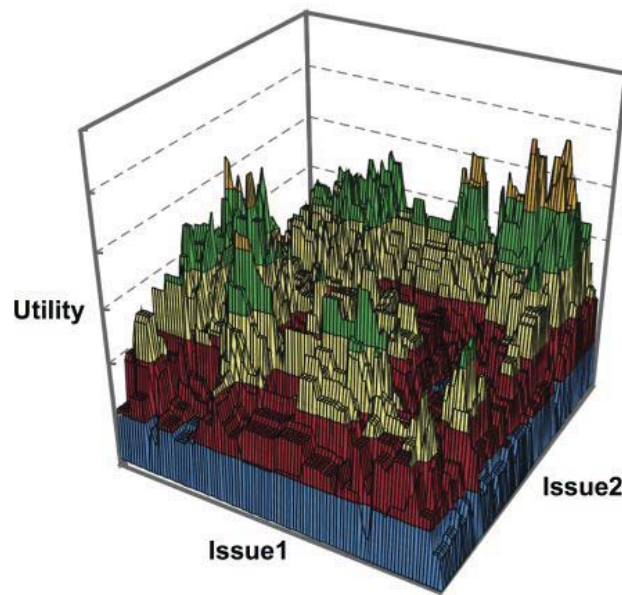


Fig. (2). Utility Space for a Single Agent.

Fig. (2) shows an example of a nonlinear utility space. There are two issues, *i.e.*, two dimensions, with domains $[0, 99]$. There are 50 unary constraints (*i.e.*, that

relate to 1 issue) as well as 100 binary constraints (*i.e.*, that inter-relate 2 issues). The utility space is, as we can see, highly nonlinear, with many hills and valleys. It will generally be the case, in fact, that agents do not fully know their desirable contracts in advance because each own utility functions are simply too large and complex. If we have 10 issues with 10 possible values per issue, for example, this produces a space of 10^{10} (10 billion) possible contracts, too many to evaluate exhaustively. Agents must thus operate efficiently in a highly uncertain environment.

In addition, one of the key points in achieving automated negotiation in real life has been nonlinearity and size of the domains. Some real-world negotiation problems involve nonlinear and large domains. The agent strategies working effectively with linear preferences, may not work well when we have nonlinear preferences [34]. Therefore, the constraint-based nonlinear utility function with integer issues has been seen as one of the important topics in automated negotiations [27, 33]. The existing work analyzes and defines some measures for the constraint-based nonlinear utility function [35], and other existing works try to improve the effectiveness of finding contracts in the bumpy nonlinear utility function [36 - 39].

Typically, the characteristics of a negotiation scenario such as size, number of issues, opposition, discount factor and reservation value can greatly influence the negotiation outcome [40]. Therefore, also in the ANAC 2014 competition, we systematically varied some of these factors. Given our focus on the scale of the domains and the nonlinearity, we generated scenarios to differ in terms of number of issues, number of possible proposals, opposition of preference profiles and mean distance of all points in the outcome space to the Pareto Frontier. We decided to use 12 negotiation scenarios for ANAC 2014 as described in Table 1.

In more detail, three types of negotiation domains with varying size (*e.g.*, moderate, large and very large) were defined. For each domain category, different discount factors and reservation values have been allocated (See Table 1). For each integer issue, 10 possible integer values are possible. If the number of issues is equal to 50, this domain has 10^{50} possible outcomes. In the rest of the paper, we will use the following domain categories:

- Moderate Domain: consists of 10 issues - 10^{10} outcomes
- Large Domain: consists of 30 issues - 10^{30} outcomes
- Very Large Domain: consists of 50 issues - 10^{50} outcomes

The utility spaces of three different scenarios are graphically represented in Fig. (3).

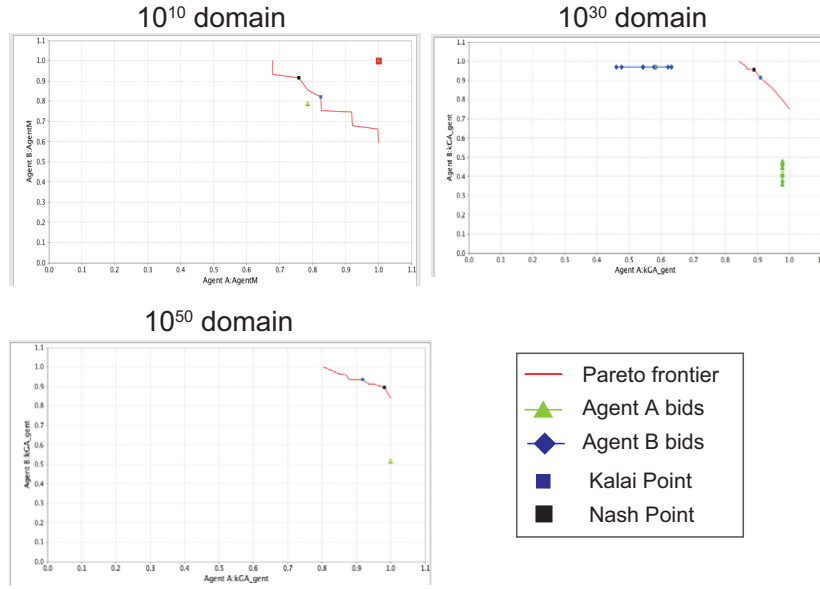


Fig. (3). Utility Spaces of Three ANAC 2014 Negotiation Scenarios.

2.3. Competition Setup

We used GENIUS [36] as the tournament platform for running and analyzing a variety of negotiations in ANAC 2014. Some sample negotiation scenarios were provided to the participants. However, the negotiation scenarios used in the competition were not known by the participants in advance. The success of each negotiating agent is measured by considering the results of all negotiations within the underlying tournament.

Table 1. Negotiation Domains in ANAC 2014.

ID	Number of Issues	Size of Outcome Space	Discount Factor	Reservation Value
1	10	10^{10}	None	None
2	10	10^{10}	0.50	None
3	10	10^{10}	None	0.75
4	10	10^{10}	0.50	0.75
5	30	10^{30}	None	None
6	30	10^{30}	0.50	None
7	30	10^{30}	None	0.75
8	30	10^{30}	0.50	0.75
9	50	10^{50}	None	None

(Table 1) contd.....

ID	Number of Issues	Size of Outcome Space	Discount Factor	Reservation Value
10	50	10^{50}	0.50	None
11	50	10^{50}	None	0.75
12	50	10^{50}	0.50	0.75

Given the complexity of the negotiation domains, within the given time (from submission to having the final results available at the AAMAS 2014 conference that hosted our competition), and the availability of computers to run the tournaments, it was infeasible to set up a single tournament for the expected number of agents. The expected number of agents was around 18 based on the emails we received that expressed an interest to participate. Running a full tournament for 19 agents, where each agent negotiates against 18 other agents in all negotiation scenarios, requires at least 1026 hours (19×18 different combinations $\times$ 3 minutes per negotiation $\times$ 12 scenarios $\times$ 5 repetitions = 1026 hours). Therefore, ANAC 2014 consisted of two phases: a qualifying round and a final round. The aim of the qualifying round is to determine the top 10 agents that will compete in the final round. In total 21 agents were submitted from 13 different institutions in 8 different countries. Before starting the qualifying round, all submitted agents were tested and two of them were disqualified as their code did not run correctly. Therefore, 19 agents were considered in the qualifying round. These agents were distributed to three groups (pools) randomly for the qualifying round. It took two weeks to complete three tournaments in which approximately 6 or 7 agents negotiated with each other. From each pool, the best three agents with respect to social welfare and individual utility were qualified for the final round. From one pool, we picked the best four agents; that makes 10 in total. It is worth mentioning that in ANAC 2014, the participants were not allowed to update their agents after the qualifying round.

In order to complete such an extensive set of tournaments within a limited time frame, we used five high-spec computers, made available by Nagoya Institute of Technology and Tokyo University of Agriculture and Technology, Japan. Specifically, each of these machines contained an *Intel Core i7* CPU, at least 16GB of DDR3 memory, and a hard drive with at least 2TB of capacity.

In the final round, we ran a single tournament for the qualified 10 agents. We considered the utilitarian social welfare criterion, the sum of each agent's individual utility. The same negotiation scenarios were used in both qualifying and final rounds. The single tournament consisted of $10 \times 9 \times 12 = 1080$ negotiation sessions. Each agent pair negotiated twice (*i.e.*, switching their roles) since the role of the negotiators might change the negotiation outcome. Each negotiation session was repeated five times.

Table 2. Finalists of ANAC 2014

Agent Name	Affiliation	Team Members
<i>AgentM</i>	Nagoya Institute of Technology	Makoto Niimi
<i>AgentYK</i>	Shizuoka University	Yoshiaki Kadono
<i>BraveCat</i>	University of Isfahan	Farhad Zafari Faria Nassiri-Mofakham
<i>DoNA</i>	Bar Ilan University Ariel University	Eden Shalom Erez Inon Zuckerman
<i>E2Agent</i>	Nagoya Institute of Technology	Yuichi Enoki
<i>Gangster</i>	IIIA-CSIC Barcelona	Dave de Jonge
<i>Group2Agent</i>	Delft University of Technology	Balint Szollosi-Nagy Marta Skarzynska David Festen
<i>kGAgent</i>	Tokyo University of Agriculture and Technology	Shinji Kakimoto Katsuhide Fujita
<i>Sobut</i>	University of Electro-Communications	Satoshi Takahashi
<i>WhaleAgent</i>	Nagoya Institute of Technology	Motoki Sato

3. ANAC 2014 AGENTS

In total 21 agents were submitted from 13 different institutions in 8 different countries. Two of them were disqualified as their code does not run correctly. Among 19 agents, the best 10 agents with respect to social welfare and individual utility were qualified for the final. Table 2 lists the ANAC 2014 finalists. To prevent the manipulation, the participants were not allowed to submit more than one agent. Multiple submissions from a single institution were allowed if only each agent would be developed independently by different team members.

In the rest of this section, we provide, in alphabetical order, a brief description of the individual strategies of the finalists based on the provided descriptions by the teams.

AgentM [41]

AgentM has a cooperative and compromising strategy considering the negotiation time and the difference between the best and worst bid offered by the opponent. The bidding strategy is aim to improve the social welfare using Simulated Annealing (SA) considering the frequency of the opponent's bids for each issue. While generating its bid, this agent considers its own best bid, the best bid offered by its opponent and the most frequently asked bid by its opponent so far. The acceptance of the opponent's bid is decided whether or not the utility of the opponent's bid is higher than the lowest utility asked by the agent itself during the negotiation.

AgentYK [42]

AgentYK aims to generate bids increasing the social welfare by using *BidElement* and *PairBidElement*, so that they are more likely to be accepted by the opponent. According to its bidding strategy, this agent evaluates to what extent the given bid would be preferred by the opponent as well as considering its own past compromises. Typically, it evaluates the similarity of a given bid with the opponent's previous bids. This agent tries to make bids that are more likely to be accepted by the opponent by considering the co-occurrences in the history of the negotiation. It is also inclined to make more compromised proposals at most three times through the end of the negotiation session.

BraveCat [43]

BraveCat employs a hybrid bidding strategy called RBT strategy (R: Random, B: Behavioral, T: Time dependent), which is a mixture of a random strategy, a time dependent strategy, and a behavioral strategy. *BraveCat* uses a new distance based opponent model to estimate the utility of a candidate bid to be sent to the opponent in each round of the negotiation. Moreover, by using iterative deepening search, *BraveCat* overcomes the limitations imposed by the huge amount of memory needed in the large domains.

DoNA [44]

DoNA employs a domain-based approach using behavioral strategies based on solely two domain parameters: reservation value and discount factor. These two parameters are used to divide the class of all possible domains into different regions, in each of which employs a predefined strategy relying on a behavioral intuition. It considers the state space of domains divided into a 3-by-3 grid of combination of values. DoNA agent applies a cognitive model based on the analysis regarding the time allocated to the negotiations and the concession stance for the given reservation value and discount factor. It computes the minimum acceptable utility value by random sampling of offers where the distribution of opponent's bids is estimated by a normal distribution as follows: $argmin = 1.2 * \mu + 2.4 * \sigma$ (where σ is the standard deviation, and μ is the average).

E2Agent [45]

E2Agent is an extension of *Agent K* [33], winner of the ANAC 2010 competition. When creating a counter offer *Agent K* calculates a target utility U_t based on the previous offers made by the opponent and the remaining negotiation time. *Agent K* then makes random bids above the target utility. If there is no bid with the

target utility, the target utility is lowered slightly. The target utility U_t at time t is calculated using the following formula:

$$U_t = 1 - (1 - E_{\max}(t)) \cdot t^\alpha, \quad (2)$$

where $E_{\max}(t)$ is the estimated maximum value the opponent will present in the future based on the average and variance of previous bids, and α is a parameter which controls the concession speed. *E2Agent* uses a sophisticated acceptance mechanism, where it will use the average and variations of the previous bid utilities presented by the opponent in order to determine the best possible bid it can expect in the future. It will either accept or reject the offer based on the probability that the opponent will present a better offer in the future. If it has already received an offer from the opponent with the same utility or higher, it will

offer that bid instead. In addition, it searches for bids with Simulated Annealing to find the bids effectively since it difficult for *AgentK* in the nonlinear domains.

Gangster [46]

Gangster applies a Genetic Algorithm (GA) to explore a large-scale bid space associated with nonlinear utilities. It calculates a target utility for the agent. It decides whether to accept its opponent's bid by comparing it with the target utility. It applies a global GA to get the samples of the agreement space and stores 10 of the bids with the highest utilities and it also applies a local GA similarly. It proposes the best proposal in the current round or any of the previous rounds. *Gangster* gets some advantages of employing a GA with Manhattan distance and the combination of local and global GAs.

Group2Agent [47]

Group2Agent tries to find bids with the high social welfare in the complex domains. It uses the Greedy Coordinate Descent (GCD) algorithm [48], which can scale linearly with the number of issues and is shown to be effective, locating meaningful middle ground between negotiating parties. It can gain the high average social welfare of 1.79, being only 0.03 below the optimal social welfare solution and found the optimal solution itself 3 out of 25 times. Furthermore, GCD scales better than algorithms such as SA used in other agents.

k-GAgent [49]

k-GAgent applies the *SPEA2* [50], a method based on GA for multiple objective optimization, to explore the Pareto Frontier effectively. To estimate the

opponent's utility function, the opponent's bid is divided into small parts considering the combinations of issues, and it considers how many times of these parts occurs in opponent's past bids.

Sobut

Sobut employs a simple martingale bidding method used in the casino. If it wins the previous game, it tries to choose the minimum bid utility using the probability of winning (P) in next game. If it loses, it tries to choose the default value in the next game. In other words, the P and the utility of the minimum bid are decided according to the following equations.

$$P = \max(\text{previous outcome}, \text{reserve value})$$

$$\text{Utility of minimum bid} = \max(P, r)$$

WhaleAgent [51]

WhaleAgent has two bidding strategies: Hard headed and Conceder. According to the hardheaded strategy, it offers a bid whose utility is greater than 0.9 at the beginning of negotiations. Through the end of the negotiation, it decreases the threshold of accepting its opponent's bids. If the utility of the opponent's offer is greater than this threshold, it accepts that bid. The threshold is equivalent to the value used in Hardheaded strategy and Conceder strategy. The agent is inclined to accept any offer in the end of the negotiation in order avoid to fail the negotiations. To search the bid space with nonlinear utility values, the agent employs a search strategy that combines Simulated Annealing and Hill Climbing. First, it explores bids whose utility is greater than the threshold by using the Hill Climbing strategy. When it cannot find such a bid, it uses the Simulated Annealing using a random starting point.

4. RESULTS OF ANAC 2014 COMPETITION

Qualifying Round

First, the *qualifying round* was played in order to select the finalists from the 19 agents that were submitted by the participating teams (2 agents were disqualified from the trial tests). 19 agents were divided into three groups (pools) randomly, and the best three agents according to utilitarian social welfare and individual utility in each pool proceeded to the final round. Each tournament was not repeated to prohibit the learning from the previous tournaments.

Agent Name	Mean (Individual)	Rank (Individual)	Mean (Social welfare)	Rank (Social)
E2Agent	0.60449771	1	1.467013776	1
GROUP2Agent	0.569022057	2	1.309827507	2
kGA_gent	0.567855409	3	1.253293459	4
Sobut	0.514388859	4	1.25826658	3
ArisawaYaki	0.502270746	5	1.216825393	6
Simple ANAC2013	0.498502294	6	1.219932496	5

Fig. (4). Average scores of each agent in the qualifying round (pool1).

Fig. (4-6) show the results of each agent in the qualifying round (pool1, pool2, and pool3). The finalists are selected from all pools by considering the individual utilities and social welfare. The individual utility means the average of utility of the individual agent in the tournaments. The social welfare means the average of the sum of utilities of two agents in the tournaments. As figures showing, the best three or four agents are selected by considering the individual utility and social welfare. As a results, *kGAgent*, *E2Agent*, *GROUP2Agent*, *Sobut* are selected as finalists from the pool1; *Gangster*, *WhaleAgent*, *AgentYK* are selected as finalists from pool2; *DoNA*, *AgentM*, *BraveCat* are selected as finalists from pool3. They are the best three in each pool considering the individual utility or the social welfare.

Agent Name	Mean (Individual)	Rank (Individual)	Mean (Social welfare)	Rank (Social)
Gangster	0.694014347	1	1.596774909	2
WhaleAgent	0.682003332	2	1.606191324	1
AgentYK	0.659956126	3	1.59018266	3
Flinch	0.649326182	4	1.573767682	4
AgentQuest	0.639303883	5	1.472990004	6
Simpaico	0.595949075	6	1.509024094	5

Fig. (5). Average scores of each agent in the qualifying round (pool2).

Agent Name	Mean (Individual)	Rank (Individual)	Mean (Social welfare)	Rank (Social)
DoNA	0.668464329	1	1.285703724	2
AgentM	0.542950221	2	1.28268408	3
BraveCat v0.3	0.518940747	3	1.422961239	1
AgentTRP	0.484535552	4	1.119857699	5
Aster	0.479403688	5	1.112286696	6
AgentTD	0.464952079	6	1.168321409	4
Atlas	0.410946126	7	0.947732281	7

Fig. (6). Average scores of each agent in the qualifying round (pool3).

Final Round

The final round consisted of 10 agents that were selected from the qualifying round. For each pair of agents, under each preference profile, we ran a total of some negotiations. By averaging over all the scores (individual utility and social welfare) achieved by each agent (against all opponents and using all preference profiles), the final ranking were decided. Formally, the average score $U_{\Omega}(p)$ of agent p in scenario Ω is given by:

$$U_{\Omega}(p) = \frac{\sum_{p' \in P, p \neq p'} U_{\Omega}(p, p') + U_{\Omega}(p', p)}{2 \cdot (|P| - 1)} \quad (3)$$

where P is the set of players and $U_{\Omega}(p, p')$ is the utility achieved by player p against player p' when player p is playing side A of Ω and player p' is under the

side B of Ω . For the final round, we matched each pair of finalist agents, under each preference profile, for a total of 5 times.

It is notable that *AgentM* was the clear winner of both categories (see Table 3 and 4). However, the differences in utilities between many of the ranked strategies are small, so the ranking of several of the agents was decided by a small margin. Finally, the first places in the individual utility and social welfare categories were awarded to *AgentM*; The second place in the individual category was awarded to *DoNA*; The second place in the social welfare was awarded to *Gangster*.

Table 3. Tournament results in the final round (Individual Utility).

Rank	Agent	Score	Variance
1	<i>Agent M</i>	0.754618239	3.12×10^{-5}
2	<i>DoNA</i>	0.742245035	9.31×10^{-6}
3	<i>Gangster</i>	0.740674889	3.49×10^{-6}
4	<i>WhaleAgent</i>	0.710740252	3.90×10^{-5}
5	<i>GROUP2Agent</i>	0.708401404	6.38×10^{-5}
6	<i>E2Agent</i>	0.703955008	2.85×10^{-5}
7	<i>kGAgent</i>	0.676595111	5.02×10^{-5}
8	<i>AgentYK</i>	0.666450943	2.38×10^{-5}
9	<i>BraveCat</i>	0.661940343	2.84×10^{-5}
10	<i>Sobut</i>	0.627684701	1.71×10^{-5}

Table 4. Tournament results in the final round (Social Welfare).

Rank	Agent	Score	Variance
1	<i>Agent M</i>	1.645412137	4.12×10^{-5}
2	<i>Gangster</i>	1.627451908	1.21×10^{-5}
3	<i>E2Agent</i>	1.608936143	1.39×10^{-5}
4	<i>WhaleAgent</i>	1.603199277	3.55×10^{-5}
5	<i>AgentYK</i>	1.569877186	1.16×10^{-4}
6	<i>GROUP2Agent</i>	1.56154598	8.46×10^{-5}
7	<i>BraveCat</i>	1.545384774	3.11×10^{-5}
8	<i>DoNA</i>	1.473686528	3.89×10^{-5}
9	<i>Sobut</i>	1.469972333	1.12×10^{-4}
10	<i>kGAgent</i>	1.463168543	4.32×10^{-4}

In more detail, we can discuss the relationships between the social welfare and other measures. As Fig. (7 and 8) show, the percentage of agreements and the pareto distance are important features of obtaining the high social welfare. Especially, the correlation coefficient of the percentage of agreements is about 1.0 and the average of pareto distance is about -1.0. In other words, the effective strategy of obtaining the social welfare is that finding the pareto frontiers with the high percentage of agreements.

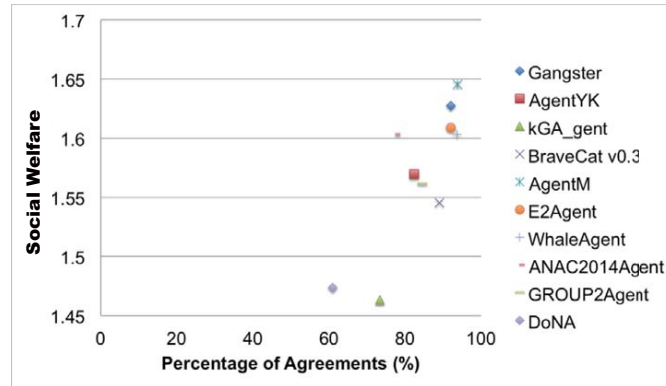


Fig. (7). Plotting graph between the percentage of agreements and the social welfare (A correlation coefficient = 0.8735).

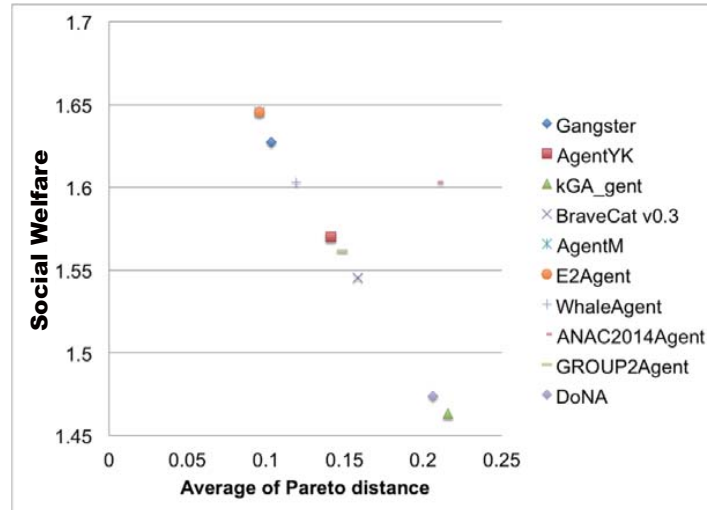


Fig. (8). Plotting graph between the average of pareto distance and the social welfare (A correlation coefficient = -0.9994).

5. IN DEPTH EVALUATION OF ANAC 2014 AGENTS

After the competition, a detailed analysis of best performing five ANAC 2014 agents, namely *Agent M*, *DoNA*, *Gangster*, *WhaleAgent*, and *E2Agent*, has been carried out. We first explain our experimental setup, then present the results, after which we analyze the negotiation results with respect to several characteristics of the negotiation scenarios.

5.1. Experimental Setup

For the in depth evaluation of ANAC 2014 agents, a variety of negotiation

scenarios were generated. For the generation of these negotiation scenarios, we consider the following factors:

- The number of issues (n).
- The number of constraints (m).
- The constraint-issue distribution (π).

Each distribution π assigns a predefined number of issues $[1, n]$ to each constraint. For example, $\pi(c_k)$ denotes the number of issues involved in constraint c_k , where $k \in [1, m]$. Our scenario generator supports three types of distributions:

1. Uniform distribution: $\pi(c_k) = p, \forall k, p \in [1, n]$. All constraints have the same cardinality.
2. Power-law distribution: $\pi(c_k)$ is scale-free in terms of $k, k \in [1, m]$. In other words, few constraints are dense (involve most of the issues) while most of the other constraints have only fewer issues.
3. Random distribution: $\pi(c_k)$ is randomly chosen from $[1, n]$, for all k .

In our experiments, an agent i 's preference profile is therefore generated randomly based on a tuple (n, m, π_i) . The idea behind the constraint-issue distribution is to have a generative model allowing us to specify the complexity of each profile. For instance, two negotiating agents 1 and 2 will respectively have two utility spaces (n, m_1, π_1) and (n, m_2, π_2) . The complexities of π_1 and π_2 are reflected through their entropies $H(\pi_1)$ and $H(\pi_2)$ [52].

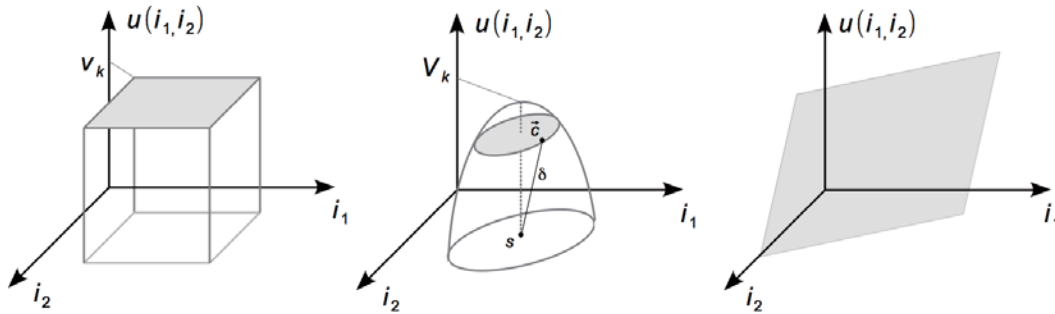


Fig. (9). Cubic, bell and linear constraints.

When generating the scenarios, we attempted to diversify the agent profiles along the following lines. First, we assume that an agent's utility space is built using three types of basic parametric constraints. As shown in Fig. (9), we distinguish linear (hyperplane), bell-shaped and conic-shaped utility functions [52]. Secondly, it is possible to adjust the complexity of any given utility space by specifying the

constraint-issue connectivity using the π distribution. Such connectivity affects the computational complexity required to optimise over any given utility space [29]. Utility spaces with randomised sets in particular, render the search for optimal bids more difficult.

It is important to note that the used scenarios do not account for the level of competitiveness or collaboration between two agents. In particular, we did not differentiate between the cases where the constraints are disjoint sets, and thus giving rise to a zero-sum game, and the cases where the constraints are nested, which yields a collaborative behaviour. Instead, we used generic randomised sets, which reinforces complexity and is useful for any temporal (not utilitarian) assessment of the agents performances.

For our experiments, 108 different negotiation scenarios were generated by taking the number of issues n to be in $\{2, 10, 50\}$, the number of constraints m in $\{1, 10, 50, 100\}$, and the constraint-issue distributions are drawn from $\{Random, Uniform, Power - law\}$. Note that 9 different combinations exist for constraintissue distribution in bilateral negotiations (e.g. Random vs. Random, Random vs. Uniform and so forth). As a result, 3 different number of issues * 4 different number of constraints * 9 different combinations of constraint-issue distributions in bilateral negotiation makes 108 different negotiation scenarios. The deadline for each negotiation was set to 3 minutes, as it was in the competition. We picked the five best agents from ANAC 2014, each agent negotiates with the other agents and plays in both sides ($5 \times 4 \times 2 = 40$ negotiations). Each negotiation is repeated 5 times and we have 108 negotiation scenarios, which makes 21600 negotiation runs in total.

5.2. Experiment Results

We evaluated the performance of the agents according to the following criteria:

- The average utility gained by the agent (*i.e.*, individual utility).
- The average distance to the closest Pareto outcome.
- The average distance to Nash outcome.
- The average utilitarian social welfare (*i.e.*, sum of all agents' utilities).

Table 5 shows the performance of each agent with respect to each aforementioned criterion over 21600 negotiations. According to these results, *Gangster* outperforms other agents in terms of the individual utility gained by the agents on average. The performance of *Agent M* is close to *Gangster* (0.511 vs 0.543). As far as optimality of a negotiation outcome is concerned, it is desired to reach agreements on the Pareto Frontier and/or to reach a Nash solution. Therefore, it is desired to find agreements whose distance to Pareto outcome and/or Nash

outcome is as small as possible. Table 5 shows that *Agent M* performs best according to these criteria followed by *WhaleAgent* and *Gangster*. With respect to the average utilitarian social welfare, the performance of *Agent M* and *Ganster* is almost the same and they outperform other agents.

Table 5. Overall Performance of Best Five ANAC 2014 Agents over 21600 Negotiations.

Criterion	E2Agent	DoNA	AgentM	Gangster	Whale
Avg. Utility:	0.478	0.353	0.511	0.543	0.490
Avg. Pareto Distance:	0.180	0.349	0.112	0.117	0.117
Avg. Nash Distance:	0.252	0.434	0.163	0.180	0.182
Avg. Social Welfare:	0.936	0.652	1.056	1.057	1.046

It is worth mentioning that *DoNA*, that was ranked in second place in ANAC 2014 (see Section 4), is outperformed by all agents in this experimental setup. This inconsistency can be explained by the fact that the performance of an agent highly depends on its opponents. In the final round of ANAC 2014, *DoNA* negotiates against nine different agents while it negotiates against the best four agents among those agents in this analysis. Furthermore, the negotiation scenarios used in this section are different than the scenarios used in the final round of ANAC 2014. This clearly influences the performance of the agents.

In the following sections, we investigate the effect of domain size, constraint size and constraint-issue distribution on the performance of these agents.

5.3. Effect of Domain Size

Table 6 shows the negotiation results by grouping the negotiations according to their domain size (number of issues). Considering the average individual utility gained by the agents, it can be seen that *Gangster* agent is the best performer. According to this performance criterion, the performance of *WhaleAgent* and *Agent M* is similar to each other and they perform better than *E2Agent* and *DoNA*. It can be seen that the performance of *DoNA* drops drastically when the outcome space becomes increases to 10^{50} , based on 50 issues with 10 possible values. In general, the performance of all agents reduces when we increase the domain size to 10^{50} . In the table, domain size is indicated by the number of issues, as the number of possible values per issue is always 10. So domain size indication 2 actually means 10^2 , and indication 10 stands for 10^{10} .

In terms of utilitarian social welfare, *Gangster* is the winner in the negotiations where the domain size is 2 or 10; however, when the domain size is 50, *WhaleAgent* gains higher social welfare on average. According to the results

showing the average distance to Nash outcome, we can say that *Agent M* and *WhaleAgent* perform better than *Gangster* agent. That is, *Gangster* agent achieves higher utility for himself while *Agent M* and *WhaleAgent* consider other agents' utility and act more collaboratively in their negotiation so that that negotiation outcomes seems to be more fair. As far as the results regarding to the average Pareto distance are considered, the performance of *Gangster* agent drops when the outcome space becomes huge. *WhaleAgent* performs better than *Gangster* agent when the domain size is 50.

5.4. Effect of Constraint Size

In this section, we study whether the number of constraints in a given negotiation scenario has any effect on the performance of the agents. Table 7 shows the negotiation results by grouping them according to the number of constraints in the underlying negotiation scenarios. According to the average individual utility gained by the agents, the winner is *Gangster* agent, irrespective of the constraint size.

When the number of constraints is extremely low or high, using *Gangster* agent seems a promising approach in terms of the average distance Pareto outcome. However, when the number of constraints is 10 or 50, then *Agent M* and *WhaleAgent* perform better. This is also valid for utilitarian social welfare. If we investigate the performance of the agents with respect to the average distance to the Nash solution, *Agent M* is the best choice except for the extreme case in which a negotiation scenario consists of only a single constraint.

Table 6. Overall performance of best five ANAC 2014 agents wrt varying domain size.

Performance Criterion	Domain Size	E2Agent	DoNA	AgentM	Gangster	Whale Agent
Average	2	0.492	0.366	0.557	0.572	0.492
Utility:	10	0.503	0.431	0.512	0.582	0.509
	50	0.439	0.261	0.463	0.475	0.469
Average	2	0.214	0.384	0.091	0.084	0.117
Pareto Distance:	10	0.127	0.217	0.087	0.088	0.088
	50	0.198	0.445	0.158	0.177	0.145
Average	2	0.329	0.516	0.171	0.188	0.228
Nash Distance:	10	0.210	0.322	0.147	0.163	0.158
	50	0.217	0.465	0.172	0.190	0.159
Average	2	0.938	0.652	1.136	1.142	1.088
Social Welfare:	10	0.993	0.803	1.093	1.104	1.083

(Table 6) contd.....

Performance Criterion	Domain Size	E2Agent	DoNA	AgentM	Gangster	Whale Agent
	50	0.879	0.501	0.941	0.926	0.968

Table 7. Overall performance of best five ANAC 2014 agents w.r.t. varying constraint size.

Performance Criterion	Constraint Size	E2Agent	DoNA	AgentM	Gangster	Whale Agent
Average	1	0.474	0.188	0.466	0.537	0.459
Individual	10	0.496	0.397	0.553	0.556	0.521
Utility:	50	0.480	0.417	0.531	0.558	0.510
	100	0.462	0.409	0.493	0.522	0.469
Average	1	0.199	0.513	0.144	0.120	0.151
Pareto	10	0.196	0.370	0.125	0.166	0.124
Distance:	50	0.173	0.275	0.089	0.092	0.088
	100	0.150	0.237	0.091	0.089	0.103
Average	1	0.307	0.673	0.213	0.210	0.244
Nash	10	0.285	0.454	0.189	0.240	0.198
Distance:	50	0.225	0.331	0.132	0.140	0.141
	100	0.191	0.278	0.120	0.130	0.143
Average	1	0.875	0.330	1.006	1.052	0.986
Social	10	1.001	0.728	1.125	1.072	1.121
Welfare:	50	0.955	0.779	1.088	1.087	1.083
	100	0.915	0.771	1.007	1.018	0.995

5.5. Effect of Constraint-Issue Distribution

In this section, we study the effect of the complexity of negotiation scenarios on the performance of the agents. Complexity is defined in terms of the entropy of each constraint-issue distribution. The higher the entropy, the more complex the distribution is. The complexity of the negotiation scenarios are as follows:

$$H(\pi_{uniform}) > H(\pi_{random}) > H(\pi_{pl})$$

This presupposes that entropy correlates with the bumpiness of the utility space and the computational time needed to explore it [29]. Table 8 shows the negotiation results grouped by their constraint-issue distribution. Based on these results, we can say that *Agent M* is good at complex domains. According to all evaluation criteria, *Agent M* is the winner when the scenarios are generated with normal distribution. For relatively less complex negotiation scenarios generated by random distribution, *Gangster* agent is the best choice.

We note that having more constraints implies more marginal utility ($\sum_{k=1}^m w(c_k)$) but not necessary better agreement zones. In this sense, one constraint provides low utility when it is isolated in the overall utility space. Moreover, having many large constraints give better utility for the agents since such large constraints give more acceptable agreements.

DoNA agent gets the lowest average individual utility and utilitarian social welfare. Similarly, its performance is dropping as the complexity of the negotiation domain in terms of distributions type is increasing from power-law towards uniform. *DoNA* gets better utility on average for power-law, but less for random and lesser for uniform.

This decreasing performance is due to the increasing complexity and the usage of a behavioral strategy that only focuses on satisfiability (instead of optimality) with respect to the discount factor and the reservation value. The increasing complexity reduces the marginal utility and renders any satisfactory parameter value as performing well enough for the agent.

Agents adopt different metaheuristics when sampling their utility spaces (Simulated Annealing, Genetic Algorithms, Heuristic Search, *etc.*). To understand the effect of domain complexity on the agents, we should understand the nature of the used metaheuristics and how they perform given different distributions (π). Depending on the domain, such metaheuristics can be for instance randomized or not, global or local, use the opponent bids or not, *etc.* When comparing the agents' performances, it is important to classify the agents based on their metaheuristics. For instance, metaheuristics that rely on randomization (Simulated Annealing, Genetic Algorithms) work well when there is no prior knowledge of the constraints shapes and connectivity.

Table 8. Overall performance of best five ANAC 2014 agents wrt constraint-issue distribution.

Performance Criterion	Constraint-Issue Distribution	E2Agent	DoNA	AgentM	Gangster	Whale Agent
Average	Uniform	0.509	0.264	0.570	0.565	0.531
Individual	Power-Law	0.602	0.488	0.654	0.727	0.633
Utility:	Random	0.372	0.330	0.403	0.436	0.376
Average	Uniform	0.229	0.561	0.137	0.159	0.181
Pareto	Power-Law	0.205	0.336	0.123	0.139	0.137
Distance:	Random	0.123	0.190	0.082	0.068	0.080
Average	Uniform	0.260	0.606	0.159	0.186	0.208
Nash	Power-Law	0.255	0.407	0.164	0.185	0.189

(Table 8) contd.....

Performance Criterion	Constraint-Issue Distribution	E2Agent	DoNA	AgentM	Gangster	Whale Agent
Distance:	Random	0.187	0.255	0.121	0.115	0.131
Average	Uniform	1.014	0.510	1.152	1.119	1.083
Utilitarian	Power-Law	1.188	0.927	1.368	1.379	1.345
Social Welfare:	Random	0.738	0.614	0.817	0.845	0.817

The complexity of the utility spaces affects the exploration time. For example, if the agent is sampling a power-law distribution, he can find the optimal bids quicker than if the utility space was distributed according to a uniform distribution. An agent with a power-law distribution and a sampling metaheuristic that works well with power-law topologies will quickly know what his best bids are. He can consequently focus more on his acceptance/concession strategies. An agent with a complete distribution will have to search the utility space and propose at the same time.

CONCLUSION

In this paper, we describe the fifth international automated negotiating agents competition. The main challenge in ANAC 2014 is to design intelligent negotiating agents that can explore a large-scale outcome space effectively under time constraints. In this competition, we used negotiation scenarios using nonlinear utility functions and agents were not allowed to access the structure of their utility function. Therefore, they need to use advance search techniques such as Simulated Annealer, Hill-Climber, Genetic Algorithms and so on.

Following the competition, we conducted additional experiments in order to analyze the performance of the best performing five agents elaborately. To achieve this, we generated 108 different nonlinear negotiation scenarios systematically and ran 21600 negotiations to evaluate the agents with respect to a number of performance criteria. We consider the average individual utility gained by the agents, the utilitarian social welfare, the average distance to Pareto and Nash solution. Our results showed that *Gangster* agent outperforms other agents regarding to the individual utility and social welfare while *Agent M* is better off regarding to other metrics. Furthermore, we studied the effect of domain size, constraint size and issue-constraint distribution on the performance of the agents. An interesting result is that *Agent M* gains higher individual utility than *Gangster* agent in complex negotiation scenarios generated with uniform distribution while *Gangster* agent is better off for other type of scenarios.

In conclusion, we believe that ANAC facilitates the research in automated negotiation. The joint discussions with the participating teams gave us great

insights for the future competitions. There is a great interests in multilateral negotiation and human-agent negotiation. As a future work, we are going to organize a multiparty negotiation competition in which the negotiating agents have more than one opponents. In addition, it is also interesting to investigate human-agent negotiation although its experimental set up might be costly (*i.e.* we need human negotiators to test the performance of the agents).

NOTES

¹<http://ii.tudelft.nl/anac>

²<http://ii.tudelft.nl/genius>

CONFLICT OF INTEREST

The authors confirm that this chapter content has no conflict of interest.

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CHAPTER 4

A Multi Agent Model for Reverse Perception Effect

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Abstract: One of the most intriguing and challenging problems in cognitive science is the difference between the individuals' perception about reality and the reality itself. Until the last decade, the main focus has been on the behaviour of individuals and the evidences of their biases, according to some stimulus. Now, researchers have centred their focus on the main reasons why these biases occur. Consequently, it is important to analyse deeply what are the consequences of these biases to society. For that purpose, we tackle the problem by using the case study of Acquired Immune Deficiency Syndrome (AIDS) and how people perceive it. In this article, we built a multi agent model to understand the consequences to the society when individuals do not perceive correctly, the reality. The obtained results reveal that the agents who perceive more correctly the danger of HIV are the ones who have more propensities to be infected and contaminate the rest of population. This is the opposite of what is expected from perception demonstrating the existence of a reverse effect.

1. INTRODUCTION

According to the United Nations, the number of individuals infected by Human Immunodeficiency Virus (HIV) in 2014 is estimated to be around 36,900,000 varying between 34,300,000 and 41,400,000 persons all over the world [1]. People infected with this virus, have been increasing constantly over the last decades. Adults with more than 15 years old are the group with more prevalence of this disease. Fundamentally, the sub-group comprehends between 25 and 49 years old. On the other hand, children under 15 years old have less prevalence of HIV virus as the young adults between 15 to 24 years old [1]. The results reveal the importance of sexuality on the dissemination of virus.

The prevention is small because of the knowledge about HIV prevention among young people (15-24) [2 {Prevention, 2016 #42}]. The percentage of young people between 15–24 of >age who correctly identify various ways for the prevention of the >sexual transmission of HIV and reject major misconceptions about HIV transmission is in average 30,48% for females and 34,73% for males.

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The condoms work and are cornerstone of safer sex practices and a greater responsible for the reduction of HIV transmissions worldwide. If condoms guarantee safety, why only 65% of men use condoms on a consistent basis? And how is it possible that more than 20% of HIV-negative men are willing to put themselves at risk by engaging condom free sex? In the case of women, a mere 11% report ever using a condom. Worse yet, women are far less likely overall to use condoms than their heterosexual male counterparts even if they are aware of consequences.

Regarding these numbers, we claimed to analyse the reasons and raise questions about why people who have awareness about the dangers of HIV are the ones that have less cautions in protecting themselves. What are the implications to the evolution of society? Should Governments supply condoms for free?

In order to explore this problem, we built a multi-agent based model under the theoretical approach of perception, where sometimes exists a cognitive bias to reality. The model took as baseline the AIDS model developed by Longenecker [3]. However, we did substantive changes in order to pursuit our experiments.

Our changes are related with the inclusion of perception in the model. For that, we divided the agents in three groups. The first one is composed by agents who perceive the real problem of AIDS and their consequences in life. The second one has individuals who perceive the problem partially. And the third one is the group where each member does not perceive the danger of AIDS, at all.

The article is organised as follows. Next section explains how the perception works. Section 3 is a travel around the existent theories of perception and their significance. Section 4 explores and explains the differences between perception and reality. In section 5, we analysed the relation between stimuli and perceptibles with repercussions in all chain process of perception. After that, in section 6, we characterise the role of cultural matrix as a filter of perception. In section 7, we do incursions inside the perception of reality. In section 8, we explain the choice of AIDS as a case study to explore.

In section 9, we present our model with subsequent changes done to the Steve Longenecker work. Section 10 explores the obtained results and in section 11, we discuss them under the theoretical approach of perception. Finally, in section 12, we conclude our article with the principally achieved ideas and inducing future steps in our research.

2. EXPLAINING PERCEPTION

Perception involves the organization, identification, and interpretation of

information given by senses in order to represent and understand the environment [4]. All perception processes are made of signals from the nervous system, with repercussions on the sense organs through physical and chemical stimulation [5]. For example, smell is influenced by odor molecules, vision involves light striking the retina of the eye and hearing as a percussion of sound waves. Perception is not only a receptor of these signals but an active agent of the brain. Learning and consequent knowledge mediates the way that people perceive things. Perception is also modulated by memory, expectations and attention [6, 7].

Some authors argued that perception can be composed by two processes [7] that work in a constant and dynamically interactive way. Perception starts with processing sensory input. This process has the incumbency of transforming this low-level information to higher-level information. For example, when an individual wants to recognize an object, the first process is to assimilate the shape of the object in order to compare with the shape that he has on his mind. After this, we have the process where the connection is established with what was conceptualized in the people's mind and according to their expectations. Then, this process in conjunction with the concepts, knowledge and the selective mechanisms of attention influences perception. In the past, senses were typically understood as passive receptors. However, when scientific community started to study illusions and ambiguous images, it was found that the brain's perceptual systems, instead of acting passively are in fact active. Besides that, it was demonstrated that perception is a pre-conscious attempt to make sense of their input [6]. There is still dynamic scientific discussion about the degree to which perception is an active process with a dynamic hypothesis subject to be tested. Comparing it with science, or whether practical tangible information brought by senses is sufficiently rich to make this procedure pointless [6]

In this sense, the perceptual systems of the brain allow people to view the environment around them as stable. Even considering that, the information brought by senses is normally considered as incomplete and constantly mutable. Human brains are structured as puzzles or by modules, where different areas process distinct types of information. Most of these brain parts follow a logic of sensory maps. Maps with the incumbency of situating and guiding some features of the surrounding environment make them part of the brain's surface. These distinct pieces or modules are interconnected and influence each other. A good example to understand this, is for instance, that taste is strongly influenced by smell, like vision is strongly influenced by noise.

Perception is dependent on complex functions inherent to the nervous system. As being subjectively, it may appear to be generally easy, because this processing happens mostly outside conscious awareness [5].

3. GOING AROUND THEORIES

There are some theories on literature. Most of them are associated to a sense like the visual perception theory. Meanwhile, there are some theories usually referenced in the literature that we should analyse carefully in order to give guidelines to our model.

3.1. Direct Perception

Cognitive theories about perception argue using the assumption that there is a lack of stimuli. These theories marginalised the relevance of stimuli in all the brain processes that belong to the chain of perception. This perspective of perception claims out that sensations and stimuli are in their essence and by themselves without capacity to give an interesting depiction of the world [8]. Sensations require enhancing, which is the scope of the mental model beyond perception. An alternative theory, different from the cognitive theory, is the perceptual ecology approach presented by James J. Gibson [9]. Gibson dismisses the assumption of the so called “poverty of stimulus” by refusing the idea that perception is sustainable on upon sensations. Rather, he examined what information is really displayed to the perceptual frameworks. Gibson’s theory presupposes an expected presence of steady, unbounded, continuous and dynamical stimulus and information in the “ambient optic array”. He also addresses that the visual system can identify this information. Following this logic, this theory is considered as information based theory instead of sensation based [9]. Gibson and other psychologic researchers who work within this paradigm have established step by step how the world could be specified to a determined object. These researchers explore the object using “the lawful of projection” of information about the world in energy arrays. “Specification” would be the most detailed mapping of some world characteristics into a perceptual array. Given such mapping, no improvement is required and perception is traditionally referenced as direct perception [10].

3.2. Perception in Action

An ecological comprehension of perception was obtained from Gibson's initial work. In “Perception of Action”, the key idea is that perception is an essential property of quicken activity. Without perception, the activity would be unguided, and without activity, perception would fill no need. Enliven activities require perception where both can be depicted as “two sides of the same coin, the coin is activity”. Gibson works are based on the assumptions that particular entities, which he called “invariants”, already exist in real world. It is part of the present reality that all perception process builds its foundations upon these “invariants”. A perspective known as constructivism held and defended by logicians regards the

continual adjustment of perception. It means a nonstop modification of perception and activity to the outer input which correctly constitutes the “entity”. The entity is an element which is subsequently distinct from being invariant [11].

Glaserfeld considers an “invariant” as an objective to be integrated with a pragmatic need to permit an underlying measure of comprehension. In the sense of being set up, before the redesigning, an announcement aims to accomplish. The “invariant” does not require that it represents the actuality. Glaserfeld describes “invariant” as extremely impossible, that what is wanted or dreaded by an organism form will never endure change over the long haul. This social constructionist theory thus allows for a needful evolutionary adjustment [12].

A numerical theory of “perception-in-action” has been idealized and examined in numerous types of controlled development. The theory has also been portrayed in a wide range of types of life species of organism by using the General Tau Theory. For this theory, Tau information, or “time-to-goal” information is the crucial “percept” in perception.

3.3. Evolutionary Psychological And Perception

Some researchers from philosophy stated that the goal of perception is the obtainment of knowledge. Instead, for evolutionary psychologists, the main purpose of perception is to guide action [13]. For instance, they argued that deep perception appears to interact, not to help us in knowing the distances to other objects but instead, help us move around in space [13]. Evolutionary psychologists say that animals and people use vision to avoid impact proposing that vision is essentially to guide activity, not providing knowledge [13].

Constructing and keeping up sense organs is metabolically costly. So these organs are only evolved when they enhance an organism’s aptitude suitability and capability [13]. More than a half portion of the brain is given to process sensory information and prepare tangible data. In this process, the brain itself expends around one-fourth of one's metabolic resources. So, the faculties must give extraordinary advantages to capacities [13]. Perception accurately reflects the world. All animals rational and not rational get valuable and exact data through their senses [13].

Researchers, who study perception and sensation, fast comprehend the human senses and faculties as adaptations [13]. Depth perception comprises of handling over about six visual signals, each of which depends on the regularity of the physical world [13]. Vision was developed to react to the limited scope of electromagnetic energy vitality that is abundant and that does not go through objects [13]. For example, sound waves give valuable data about the wellsprings

and the distances to objects, when bigger animals are making and listening to lower-frequency sounds and little animals are making and listening to higher-frequency sounds [13]. The same idea could be transposed to taste and smell that react to chemicals in the environment that are critical for adaptation in the environment of evolutionary adaptation [13]. The feeling of touch has numerous faculties where pain, while unpleasant, is adaptive [13]. An essential adaptation for senses is range shifting, by which the organism becomes temporarily more or less sensitive to sensation [13]. Sensory capacities of various life forms regularly coevolve, similar to the case with the knowing about using eco location bats and the moths that have advanced to react to the sounds that the bats make [13]

Evolutionary psychologists claim that perception demonstrates the principle of modularity, with specialized mechanisms handling particular perception tasks [13]. For instance, individuals with damage to a specific part of the brain experience the illness effects with a particular deformity of not having the capacity to perceive faces [13]. Evolutionary psychologists propose that this demonstrates a purported face-perusing module [13].

3.4. Structural Information Theory

Structural information theory is a theory about human perception and in particular about visual perceptual organization which is the neuro-cognitive process that empowers us to see scenes as structured wholes comprising objects orchestrated in space [14].

Structural Information Theory started as a quantitative model of visual pattern classification. Structural Information Theory incorporates quantitative models of symmetry perception and a modal completion. It is a theory supported by a perceptually adequate formalization of visual regularity, a quantitative record of perspective conditions and a capable type of neuro computation [15]. Structural Information Theory has been contended to be the best characterized and best expansion of Gestalt ideas [16]. It is the main Gestalt approach which provides a formal math that produces conceivable perceptual interpretations [16].

While visual stimuli are based essentially on multi-interpretable, the human visual system normally has a primordial preference for one interpretation. To clarify this inclination, Structural Information Theory presented a formal coding model beginning with the assumption that the perceptually favoured interpretation of a stimulus is the one with the least complex code. A least difficult code is a code with least data stack, that is, a code that empowers a recreation of the stimulus utilizing a base number of expressive parameters. Such a code is obtained by catching the most extreme measure of visual consistency and yields a multiple levelled association of stimulus.

The suspicion that the visual system learns a least complex interpretation is known as the simplicity principle [17]. Historically, the simplicity principle is data of the hypothetical interpretation of the Gestalt law of Prägnanz which is propelled by the regular propensity of physical systems to subside into generally stable states defined by at least free-energy [18]. In addition, it goes far beyond the old proposal of “minimum description length principle” in Algorithmic Information Theory. It is like the theory of Kolmogorov complexity or it could be seen as a formalization of Occam's Razor. This is considered as the easiest and the best interpretation to data.

Since the 60s, Structural Information Theory for brain research and Algorithmic Information Theory for computer science have advanced autonomously as practical choices for Shannon's established data theory which had been produced in communication theory [19]. In Shannon's methodology, things are appointed codes with lengths with respect to the frequencies of event (*e.g.*, in the Morse code). Be that as it may, in numerous areas, including perception, such probabilities are not really quantifiable. Both Structural Information Theory and Algorithmic Information Theory bypass this issue by swinging to illustrative complexities of individual things.

Despite the fact, there are some pertinent differences between Structural Information Theory and Algorithmic Information Theory. For example, Structural Information Theory makes the perceptually applicable qualification in the middle of auxiliary and metrical data, though Algorithmic Information Theory does not. Structural Information Theory encodes for a confined arrangement of perceptually in significant sorts of regularities, while Algorithmic Information Theory encodes for any imaginable regularity. In Structural Information Theory, the applicable result of an encoding is a multiple hierarchical association, while in Algorithmic Information Theory, it is just a complexity value.

3.5. Interface Theory

The interface theory of perception developed by Donald Hoffman establishes that “natural selection drives true perception to swift extinction” [20]. Natural selection has preference for perceptions that are more useful. According to this theory, the role of perception is to rebuild part of the properties and categories of the objective and real world. For Hoffman, our perception is nothing more than a useful fiction [20]. The main objective of perception is to forecast the correct and effective properties and characteristics of the world. “A goal of categorization is to classify its structure”. Hoffman argues under evolutionary bases, that our perceptions exist to guide our behaviour in a niche like a user interface, exclusive to each type of species. He compared our perception to a personal computer which

hides its complexity through icons. In this sense, perceptions hide the complexity of the world for our own safety. The interface theory spins around evolution to indicate the path in object categorization. Transposing this framework of perception to a risk perception, we must say that, in the case of risk, the situation is different. Risk is a mind concept build in our brains. So we must need to perceive the world and construct the risk firstly and then perceive the risk itself by reconstructing it, in our brains [20].

3.6. Empirical Perception Theory

An empirical theory of perception is a theory which has the main function of explaining the emergence of perceptions and how do they arise. This theory sustains that sensory systems integrate information relative to the statistical properties of real world. An integration is carried out into their design and associated incoming stimuli to this information, while analysing sensory stimulation separately into its components or features [21].

Empirical theory of perception begins regarding the evaluation that stimulation of the retina is in the major part of occasions which is considered as ambiguous. Empirically, the most suggested mechanism commonly taken into account for avoiding this ambiguity is “unconscious inference” [21].

Empirical theory was the principal theory, which suggests under some circumstances that judgements, a kind of higher-level cognitive process, could suppress the perception of senses leading to a true perception of distance in space. It also establishes a bridge between these “judgments” and syllogisms, which are considered as equivalent ones. Researchers who defended this theory had built fervently the new idea that sensory systems, instead of performing logical operations on stimuli, have reached truly and strong conclusions. It means, that this light focuses on the rising of certain orientations between them, so its origin has some distance between them. The judgements are considered to make associations, so that for example if sensory attributes occur simultaneously, they are usually present when an object is at a given distance. A distance allows conditions for an observer to see an object with those attributes. This allows associations form the premises for inductive “judgements” which augment the reasoning with detailed knowledge of the anatomy of sensory mechanisms. These mechanisms improve sense impressions with acquired knowledge through application of heuristics. Recently, contemporary empirical theory of perception seeks to explain the physiological foundations of this “unconscious inference”. More precisely, in terms of how sensory systems acquire information about general statistical features of their environments. After that, it applies this information to sensory data in order to shape perception. A rectification of

stimulus ambiguity by a priori knowledge about the real world is commonly adopted by this theory.

The empirical theory of perception departs from the foundation of empirical theory, in terms of considering the importance of the optical inverse problem. Solutions to this problem are rarely possible. Although, it can sometimes be approximated through the imposition assumption-based constraints, on the “solution space”. If we go around the world under the basis of sensory stimulation, it represents alone the inverse problem in the essence of biology [21].

The inverse problem introduces us a dilemma for traditional approaches to perception. For instance, it argues that a neuronal filtering exists where resources are detected in computational and logical calculus on retinal inputs to validate the high-level features of a perceptual scene, like normal percepts as for example contrast. Meanwhile, it is hard to imagine how these computations are done for inverse problem. If these computations are actually performed, it would be interesting to analyse and understand them since they would have little or nothing to do with the properties of the real world. In summary, the approaches behind Empirical Theory of perception are based on different forms, arguing that there is only one path for organisms to successfully overcome the inverse problem, which is exploiting their long and varied past experience with the real world.

4. THE GAP BETWEEN PERCEPTION AND REALITY

It is not a new subject, the difference existent between perception and reality among the scientific community [22]. The issue emerges under the aware experience context of conscious experience founded on the theoretical archetypes of perception [22 - 24]. In literature, the epistemological dualism remains [25] that fits in the problem of propagation of HIV. Do people perceive the effective danger current in the real world or do they merely construct an internal perceptual copy about that danger through neuronal processes inside their brains? Essentially, the dispute is between two philosophical and even physical approaches: Are we living in a world of direct realism or representative realism? Simply, the fact is that some individuals don't perceive effectively the danger of HIV and for that reason, avoid prevention that could come from representative realism. The perceived reality is an internal representation and not the real world itself. This is explained by the Tunnel theory which states that we have a group of mental filters acting on our subconscious based on our beliefs and our experiences. Consequently, and following the logic of this theory, each individual could perceive differently, the same world.

Modern science suggests that reality seems radically opposed to the world as we perceive it through our senses. Indeed, it is becoming normal to listen to the

scientific community and other agents claim that much of our perceptual experience is a kind of pervasive illusion rather than a faithful presentation of various aspects of reality [26]. Following this view, the object properties such as colour and forms do not belong to external objects. Scientists assume that fictions are generated by the brain that we mistakenly ascribe to the world around us. The world itself is empty of properties created by us for the quantum perturbations of matter/ energy that are studied by physicists. However, is this a case where science and common sense are genuinely at odds, or can the dilemma be solved?

The logical reason to think and assume a perceptual experience as a kind of illusion arises in part from our susceptibility to illusions in general. Many scientists accept the empirical evidences of these mistakes and assume what they call collectively, the perceptual experiences, as existing only within our own minds [26].

Given that, our senses can be easily hoodwinked; it is a small step to fortify the conclusion that all perceptual experiences must be illusory, or that object characteristics don't exist externally, but only in the minds of the perceivers. Meanwhile, we should consider such conclusion to be too heedless. An important appointment to stand out is that perceptual system could be hoodwinked in many cases, it doesn't mean that this happens all the times and for all the cases. Most of perceptual failures come from the operation of our visual system. People visual system calibrates the balances of light in such a way that enables them to correctly judge all the architecture of objects, which is needed to create the appearance of the object.

It means that visual system has evolved to take into account lighting and other effects in order to reveal the underlying properties of physical objects under a wide range of possible circumstances. Until now, there is no reason to suppose that these properties shouldn't include all the characteristics of objects. Only when we have multiple properties subjects to multiple constraints. This happens because our visual cortex is only sensitive to a small fraction of the electromagnetic spectrum, of which visible light forms just a part. The objects also reflect and absorb light from the infrared and ultraviolet ends of this spectrum. All the way up to radio waves and gamma ray and all the colours that we are capable of seeing, can be created by combining varying proportions of primary colours. This means that some reflectance profiles that yield different combinations of light waves nevertheless appear wholly indistinguishable to us.

The problem, then, is not that reality contains no colours, but rather that it contains too many, both within and beyond the range of electromagnetic radiation

to which our eyes are sensitive. Many of these exotic colours look identical or are completely invisible to us, making our perceptual abilities limited at best.

Another perspective of analysing the gap between perception and reality is the case when people perceive any familiar object. What is given immediately by our subjectivity comes from our past experiences. For example, when we want to represent an object that is real and we saw it, so we do it by sensation and not by perception [27]. It means that the visual shape of the object is built through the sensation of touching the object.

The main goal is to understand what we really perceive from the world around us. In other words, the goal is to understand the relation among reality like real things, ideas and objects, the sensation that we have captured from them and understanding that we generate in our minds. This remarks the relation made by Locke, where understanding is nothing more than ideas caused by our sensations [28]. But if there exists a gap between perception and reality, should it be considered reality as something not integrated to our sensation? Perhaps this is the difference between thought and sensations. These are interesting points that continue to instigate the scientific community for effective answers, since it generates challenges on the fundamentals of human epistemologies and ontologies. Nowadays, we can put the intuition of philosophers behind. Neuroscience has been contributing a lot to the construction of a clear and sustainable understanding of perception. At this time, we are in conditions to put away the philosophical perspectives of perception and their repercussions on thought, reasoning and reality. In terms of psychology, neuroscience has helped to go a step forward from the adaptation of narrowest and opaque stimulus-response conception [29] and behaviourism [30]. Perception has become a core concept and it has a central role in our intentions.

Another proposed theory as is mentioned before is the Interface Theory of Perception [20]. This is a theory which defends that the perception has the goal to reconstruct some of the properties and categories existent in the real world. According to this theory, perception appears associated to a subjacent fiction mechanism. In other words, the interface theory presupposes perception as a process to predict properties and characteristics of the real world. It monitors the behaviour of individuals. In AIDS, individuals' perception leads to a reconstruction of the real danger of being infected and the possibility of dying. And based on that, those individuals take in consideration various mechanisms of prevention. So it is supposed that people avoid HIV, since perception should be driven to swift extinction. People perceive according to what is more useful for them.

5. STIMULI AND PERCEPTIBLES

“Perception is a dynamic conflict between the attempts of an outer world to impose an actuality on us and our efforts to transform this actuality into a self-centred perspective” [31]. For this author, there is a constant and dynamic friction between the external reality and our physiological, cultural psychological characteristics. External reality tries to influence ourselves by our perceptions and shaping our awareness. When the influence vectors into clash forming equilibrium is when our perception triggers. So perception is a result of confrontation of ourselves with reality. RJ Rummel treats perception as the end of a sequence of psychophysical processes, invested with meaning and orientation by a cultural matrix. The whole process could appear to us as common sense. To better understand perception is to find out an equilibrium of power between inner and outer directed powers.

By exploring a little bit more, in the author work, we discovered that he assumes that reality exists outside our minds and bodies. In fact, reality contains potentials and dispositions. This is quite true because reality exists independently of us, if it doesn't catch our attention and match our interest. All the consequences have intuit of power on individuals' senses, in order to stimulate them.

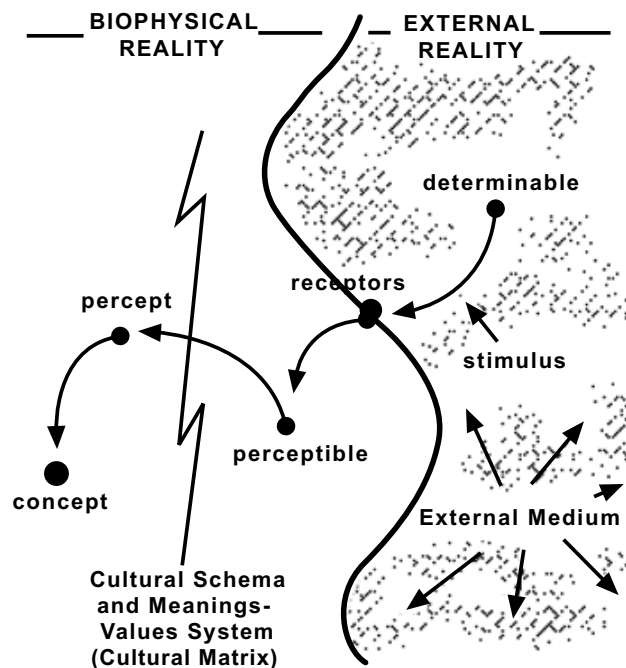


Fig. (1). The interaction between external reality and biophysical reality. A figure retrieved from RJ Rummel book [31].

Basically, Fig. (1) tells us that people become determinable towards the existing reality, where they must receive external stimuli from the environment affecting their sensory receptors. Such as a vehicle lights at night avoiding the danger or even the simple look of a person who is attentive to what we do. A stimulus is a conductor of energy ranging from feeling to feeling. Stimulus can be exchanged between us from time to time or in an instant. These can form a sequence of stimulus up to energy limit channelled for the proper effect. The speed of the process depends on the focus of perception.

Once a stimulus is carried from the determinable to our sensory receptors, it is then transformed and interpreted electrically by the body's neurological system. Complex neural paths transmit the result from the receptors to the respective cortex in the brain. RJ Rummel has called perceptibles the resulting deposits in the brain. He also called physiological medium the neurological transmission system between receptors and perceptible.

Unmistakably what is coordinated toward us as a stimulus might vary from what is obtained as perceptible. The external medium could adjust the stimulus, or there might be no medium present to pass it on. For example, voices can't be heard through a vacuum. In addition, what is transferred to our sensory receptors can't be conveyed with rigour to the brain. We can only receive a restricted scope of inputs. Moreover, what we receive is constrained to some specific areas which are physically modified through the transmission process to our brains. In this manner and for instance, the conveyed passed on from the basilar layer of the cochlea in the internal ear has not the same frequency as that of the receipt sound. This is a good example of how our sensory structure could affect the way we perceive reality and the biases that could be generated. Biases that in fact generate distortions about what we conceive as reality influence consequently our decisions.

Different type of animals, obviously vary in their restrictions for physiologically transmitting stimuli conveyed to their receptors [32]. Each species translates outside reality within its own physiologically inner sensory structure. There is a different sensory for each type of animals. The way that we have created devices for augmenting our receptors and in this manner our physiological sensory structure, does not change the biological evidence about our outside world. At this moment, we know that the daily external world is in a continuous modification of stimuli of outer reality through our perceptible one.

The two distinct paths which convey stimuli from the determinable to the brain are shown in Fig. (1). The sequential transition from the determinable, where the stimulus resides, to the receptors, passing through the medium is where the

neuronal transmission occurs and becomes a perceptible. It is a chain where each step is necessary but not sufficient to achieve the final output. The characteristics of this chain of metamorphoses and the presence of various sensory structures for every species contend against numerous assortments of reality. This puts us in front of some kind of dualism or perspectives [31]. Different types of direct realism, for example guileless realism, where the perspective is to build on the thing that we sense, are unsustainable. What arrives into our brains is not specifically what is out there on its plenitude, in spite of the fact that the perceptible might be pretty much designed after external reality involving viewpoints or aspects of realities.

6. THE FILTER OF CULTURE IN PERCEIVING REALITY

Perceptible is what the brain gets. However, they are not what might be perceived. Or maybe, perceptibles achieve instinctive mindfulness or intuitive awareness through the cultural structure and system of meanings and values. It is a kind of social arrangement of implications, characteristics and attributes. The structure comprises the essential categories given by culture for making the perceptibles clear and the cultural instruments for their interpretation. The categories include cause and effect situations, connection, space and time. The structure gives guidance toward the perceptibles. The cultural structure of meaning and values brings to the perceptibles their hugeness. It provides perceptibles significance for us, informs them with design, relegates them reason and gives them worth. The perceptibles are given their interpretative significance through the meaning-values framework and arrange the structure for our judgements and behaviours. Fig. (1) demonstrates a perceptible going through this entire chain of mental orientation where it is subject to continuous investiture of this cultural matrix to end up as a percept. It is the perception we acquire, to which we are aware, that we are conscious of.

A few illustrations of perceptibles and perceptions may help understand their distinctions. Perceptibles are nerve impulses which arrive into the brain as it transmits a complex formless accumulation of stimuli. A perception might be a specific sound or shape of an object.

While our perceptual awareness begins with the percepts, where a well-designed structure is found, which actually strengthens us so that we are more cognitively related to the percepts. This structure makes percepts more clairvoyant. This conceptual stage of perception includes our fitting percepts and language both together in interactivity. This is the nomenclature level, where percepts are transformed into concepts meaning particular invariant properties. For example, the generation of attitudes. Something or someone whose or who is perceived

receives an associated connotation. Plainly, perception transforms itself into a concept through the cultural matrix. Our cultural learning strongly defines if we are intentionally mindful or consciously aware and how we conceptually structure awareness. So, there is a reverse effect of perception on the Cultural Structure Matrix and on the Meanings and Values System which continuously refines the knowledge of reality. (see Fig. 2).

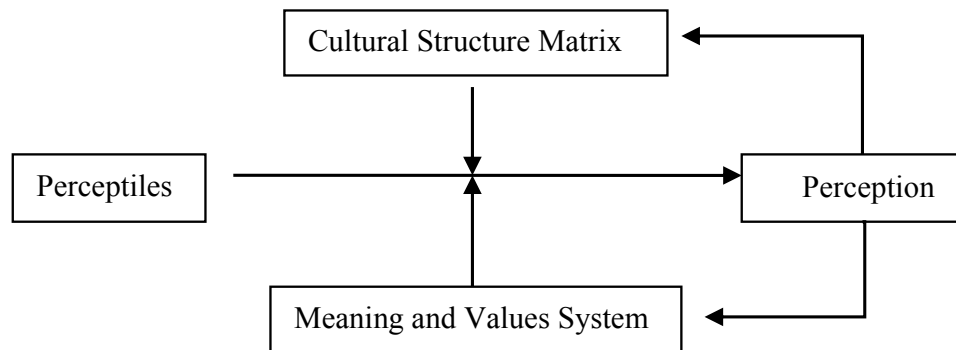


Fig. (2). The relation between perceptibles and perception.

7. INSIDE THE PERCEPTION PROCESS OF REALITY

This record of perception is uncongenial with the perspectives of different rationalists who likened sensations with perceptibles and they argued that we are aware or specifically mindful of external reality, through these sensations. Most of these rationalists trusted that our perception or concepts are directly based on or directly reflect on our sensations. They conceived that ideas are straightforward in light of or specifically mirror our sensations.

They didn't get consensus on the relation of judgment and thought to sensations. Meanwhile, rationalists argued that perceptibles or sensations were concerned correctly since they permitted little space for cultural influences to intercede in the middle of them and perceptions or thoughts. They didn't value the degree or the extent to which cultural learning and substance changes in our perception and the degree to which conscious sensations culturally intervene view about perceptions of external reality.

It was already noticed that the course from determinables as stimuli to our receptors and from receptors to perceptibles is at best case a transmission with defects. Presently, it could be seen that the mental adjustment of perceptibles into perception is a modification or a kind of metamorphosis and not a basic

transmission. It is a dynamic process of continuous transformation. In this way, literature has found out that the faith, in direct realism, has been specifically perceived deliberately and is conscious about what is “out there”. Or the argument that we perceive a representation, like a guide about what is there. An untenable representation is despite the fact generally believed today among social researchers and particularly a supposition hiding different perspectives on social conflict.

However, it should be important to include and comment that psychology would consider the above perspective of perception horribly lacking. Probably it is considered a biocultural perceptual determinism built on just a fractional perspective of perception [31]. And perhaps, they would be right, RJ Rummel defended. Under this perspective, we consider that this approach is lacking the relevance of our psychological dimension with the associated neuroses, abilities, motivations and intentions, like it is referenced by RJ Rummel. Besides, it misses the role of memory and temperance. It will be acceptable, but normally it is what really happens. The social psychologist would accurately add taking roles and expectations on, which was missed by RJ Rummel. Social psychologists will take into account the interactive connection between behaviour and perception.

In order to comprehend why it has been incorporated recently into psychological dimensions, we should consider the glaring omission of perceptual illusions or hallucinations that sometimes happen in people’s brains. We sometimes perceive that what does not exist in external reality, or what we do perceive is grossly distorted beyond any cultural influences. For example, to see pink elephants when someone has a fever or having apparitions are statements frequently described by people. If we enter into the field of ideology by investing perceptibles with perceptually integrated themes, like the exploitation of people committed by capitalism or communist conspiracies, are other very common distortions of reality.

Consequently, while stimuli are important and not sufficient to the ignition of our receptors, perceptibles are neither adequate nor essential for perception. To start with, the cultural matrix and values framework give a point of view inside of some perceptibles which are given interpretation and some are overlooked. In this way, the huge number of formless and differed perceptibles, that the brain gets as result of a look, will be lessened to the perception of an object or an event. Foreground and background might be precluded and unessential perceptibles other than the central definable will be overlooked. The fact that the brain gets perceptibles doesn’t provide guarantee that they will be transformed into perceptions.

After all, we may perceive without any associated perceptible. We may simply project into external reality. For instance, the vision of an individual when no comparing perceptible has been gotten by the brain. Along these lines is patent that perceptibles are not necessary the origin to trigger perceptions.

Until this point we should ask ourselves, how do we shape perceptions? What role in perception do perceptibles act, as they are neither essential nor adequate? To respond to these questions, we must reinterpret the psychological reality designed in Fig. (1). We should now consider perceptibles as entering a field of mental powers equipped for executing them or pounding them until, when distorted and wear, they achieve awareness. A field that fits for making inside of itself, and completely out of its neighbourhood strengths, perspectives and perceptions. We subsequently would find that as we progressively see perception as being inside of a psychological field, a causal chain theory of perception, even if it has been changed, turns out to be more untenable. External objects, what RJ Rummel called determinables, may produce stimuli, which get to change and selected through our physiological medium and transformed by our cultural matrix into perceptibles. Instead, what we know or are aware of, that which we perceive, may just remotely relate to the subsequent perceptibles or might be only mental creations. That is, there is a dynamic, mental engagement in perception, a conflict of external reality with a psychological reality, a kind of friction of two worlds whose fight lines involve our perception. Therefore, while helpful as an underlying temporary draw, the basic perspective of perception as a unidirectional process running from external object to stimuli to receptors and after them to perceptibles ends up in perception. In this order, the concept must be changed for a rationalistic and dialectical field theory of perception.

8. AIDS AS A CASE STUDY

AIDS is one of the worst diseases in the world, originating the death of thousands of individuals. We chose this disease and respective virus to investigate the role of perception in society, since according to empirical data retrieved from surveys, people don't perceive the danger of being infected as it is in reality [33]. And most surprisingly, people who have the knowledge of the disease dangers and have more experience, form the group who less care about prevention measures take [33].

Human immunodeficiency virus (HIV) infection and acquired immune deficiency syndrome (AIDS) is a conjunct of conditions caused by infection with the HIV virus [33], [34], [35]. Following initial infection, an individual doesn't perceive any symptoms or may feel a short period of sickness [36], [37], [38], but normally, the individuals have a long period of absence of symptoms [33]. As the

infection evolves, it affects more the immune system, causing problems to it and increasing the danger of proliferation of infections or cancers which normally do not affect people immune systems [20]. These late symptoms of infection are referred as AIDS [36], [37], [38]. But what should instigate us is the propagation of this infection, constantly growing, in a world where people have more knowledge about it, considering the propaganda made by media all over these years.

The transmission of HIV is done by three main paths: sexual contact, significant exposure to infected body fluids or tissues and from mother to child during pregnancy, delivery or breastfeeding [39]. There is no danger of acquiring HIV if exposed to other type of fluids of infected person, only by blood [40]. Meanwhile, the most frequent way of transmission of HIV is through sexual contact with an infected person [33]. The majority of all transmissions worldwide occur through heterosexual contacts however, the pattern of transmission varies significantly among the countries. For example, in the United States, as of 2009, most HIV sexual transmission occurred in men who had sex with men [39] accounting for 64% of all new cases.

In terms of unprotected heterosexual contacts, the danger of HIV transmission is estimated per sexual act appears to be four to ten times higher in low-income countries than in high-income countries [33]. So, income is a determinant factor for propagation of HIV, because poor people don't have sufficient money to protect themselves with condoms. However, campaigns carried out by United Nations and also other Governments distribute condoms free of cost.

Commercial sex workers including the pornography industry have an increased rate of HIV [33]. Rough sex has a high potential of transmission. Sexual assault is also believed to carry an increased danger of HIV transmission as condoms are rarely worn. Taking in consideration these facts, we must ask if people perceive effectively the danger of HIV and what is the role of awareness? It is quite strange that a disease who claims a person's life, those people adopt behaviours which can lead them to death.

9. AIDS PERCEPTION SIMULATOR MODEL

This model simulates the perception of danger and contributes to the spread of the human immunodeficiency virus (HIV), *via* sexual transmission, through a small isolated human population. It therefore illustrates the perception of people about the real danger and consequential effects of certain sexual practices across a population. The model follows the assumptions of Interface Theory.

The model examines the impact of perception of danger reflected on four aspects of sexual behaviour. The agents were grouped according to their perception of danger associated to HIV. We defined three groups. The first group perceives correctly the dangers of HIV. It means this group take special cares about its own sexual protection and perceives the use of condoms as a minimizer of HIV danger. Furthermore, this group is assumed to make consciousness decisions which minimize the danger of proliferation of the virus into the society. This type of decisions include the continuing use of condoms and the tendency to practice abstinence in the first dates looking for a better knowledge about the sexual partner. The amount of time in which couples stay together on durable relationship is high adopting preventive behaviour and does tests with regular frequency. The practice of abstinence in the first date and durable commitment between sexual partners give us an idea that changes in the sexual customs of a society, based on the government propaganda, could be successful or not in the prevalence of sexually transmitted disease. While the use of the condom and regular HIV tests could provide us solutions for the problem depending of agents' decision of using them.

The second group is composed by agents who perceive part of the danger: They have a partial perception of being contaminated. It means they have partial knowledge and awareness about the danger of HIV. In this sense, they probably perceive that the use of condoms is not as safe as it is recommended. Or they do not perceive that alternating couples is a danger to be infected with HIV virus as it is the fact of having sex at first date. Or they do not perceive the usefulness of doing tests with some regularity.

The third and last group is composed by agents who do not perceive any of the dangers that are cited above. Agents who have multiple sexual partners or commonly have sex in the first date are part of the members of this group. Agents who refuse the need for the use of condoms, because they think they can trust in their sexual partner. Or agents who refuse the idea of doing tests to control if they have HIV (see Fig. 3).

Each agent of these groups has its own perception. We add perception to the agents in our multi-agent model where they perceive the dangers according to the eminent evolutions in society. For that, we used Weber-Fechner Law [41]. In psychophysics, the Weber–Fechner law combines two different laws of human perception, which both describe ways to the resolution of perception which diminishes for stimuli with greater magnitude. The differential of perception (dp) is given by (1).

When the pumping beam is passing through droplet, its intensity is decreasing according to Beer-Lambert law:

$$dp = \beta dSS / SS \quad (1)$$

The parameter “ dSS ” gives the differential increase in sexual stimulus and “ SS ” is the instantaneous stimulus, which varies between 0 and 1. The parameter “ β ” (from 0 to 1) is normally estimated using real data of agents’ behavior and gives strength power of sexual stimulus. For this multi-agent model, β is a slide parameter controlled by us to do the experiments.

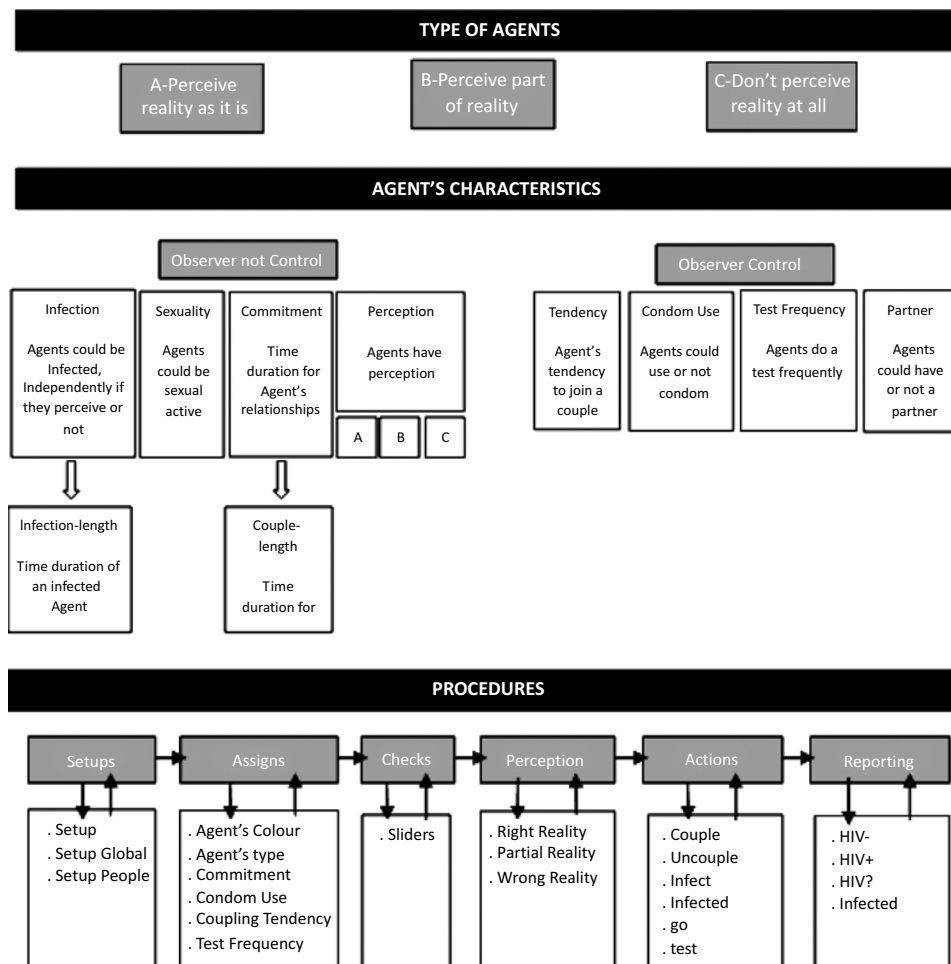


Fig. (3). Perception multi-agent model.

The next step, we carried out the integration of equation (1) in our model and obtained equation (2) as intermediate result. (2)

$$p = \beta \ln SS + k \quad (2)$$

Where, k is the constant of integration and $\ln$ is the natural logarithm. Then we solve k and rearranging the equation, we get the formula (3) for perception.

$$p = \beta \ln SS / SS_T \quad (3)$$

SS_T (0-1) is the threshold of sexual stimulus below the danger which is not perceived at all. The model reflects a logarithmic relation between the sexual stimulus and perception. The meaning of this relationship has the foundation on the assumption that if sexual stimulus varies as a geometric progression, the corresponding perception of danger is greater than its original value.

If the perception p is low, it means that the instantaneous sexual stimulus exceeds slightly the level, where the danger is not perceived by agents. And the respective strength of the stimulus is also lower. Consequently, this type of agents only perceive the danger, partially. If the gap between both types of stimulus is high and the respective strength is also higher, the perception is high. This perception is associated to agents who perceive the danger correctly. Finally, when a gap does not exist between both stimuli, it means that the instantaneous sexual stimulus is equal to the limit where agents do not perceive the danger, so the perception is equal to 0. That perception is associated to the group of agents who doesn't perceive danger as it really is. For this multi-agent model, β is a slide parameter controlled by us to do the experiments as it is SS_t . Instead, SS is generated randomly for each agent.

The parameters from multi-agent model established in [1] like the average of condoms use, the average of coupling tendency, the average commitment and the average of test frequency taken become dependent from the perceptions value. All these variables remain in the model but instead of being sliders controlled by the researcher, the variables are built through code with the same limits. The difference is in the rules established inside the models depending on the value of perception.

Consequently, if perception is equal to 0, then the average use of condom is zero, the agents have an average coupling tendency close to 10, the average commitment is below 4 weeks and there is no test of HIV during a year. These are the characteristics from the group who doesn't perceive risk as it is.

On the other hand, if the perception tends to 1, we have the opposite situation. It is the case where agents are careful and have lower coupling tendency, the relationships are more stable rounding approximately 200 weeks, the use of condom is very common and agents do more tests often, 2 times in one year. Clearly, it is the case where agents assimilate the danger in a correct way. In the cases where perception varies between 0 and 1, it means that these variables assume average values between the limits.

By allowing the user to control strength of the stimuli and threshold of sexual stimulus, the user can explore indirectly an important dimension of HIV's threat to public health. Because the virus does not make itself immediately known in its host, agents are often infected for some time before a test or immune deficiency symptom identifies them as such. Regular identification of individuals infected by the virus could have significant public health impacts if knowledge of the infection positively affects sexual behaviours. This model explores this possibility by making all individuals, who know of their positive HIV status always practice safe sex.

In order to make the model work, "couples" was used to represent two people engaged in sexual relations. Individuals wander around the world when they are not in couples. Upon coming into contact with a suitable partner, there is a chance that the two agents will "couple" together, depending on their stimulus and consequent perception. When this happens, the two agents stand next to each other holding hands as a representation of two people in a sexual relationship. The presence of the virus in the population is represented by the colours of individuals. Three colours are used: green individuals are uninfected, blue individuals are infected but their infection is unknown and with the colour red are the individuals infected and their infection is known.

To finalise the description of our model, we need to explain that an agent after perceiving the danger that exists in real word transforms the danger in risk. And the risk has associated to it a risk perception. In this model, we use an architecture which was developed some years ago by Magessi and Antunes [42]. It is an architecture that represents the process of risk perception of agents. In each run cycle, agents are constantly doing the mismatch between the perception of the danger that comes out from real world and the concept of risk that they have inside of their minds. In this way, agents are continuously improving their perception of risk. In this sense, a transformation of the danger exists in a risk which increases the extension of perception chain identified on literature and described earlier in this document. Consequently, agents who do not perceive the danger at the beginning, can adjust continuously their perception, having the conditions to get a better knowledge about the problematic nature of HIV.

The danger exists outside in the world and risk is conceived directly in the agent's minds. When an agent does not perceive correctly, it means that the risk is also not right and does not reflect the reality as it is. We assume, on this model, a strict relation between both the concepts. (See Fig. 4).

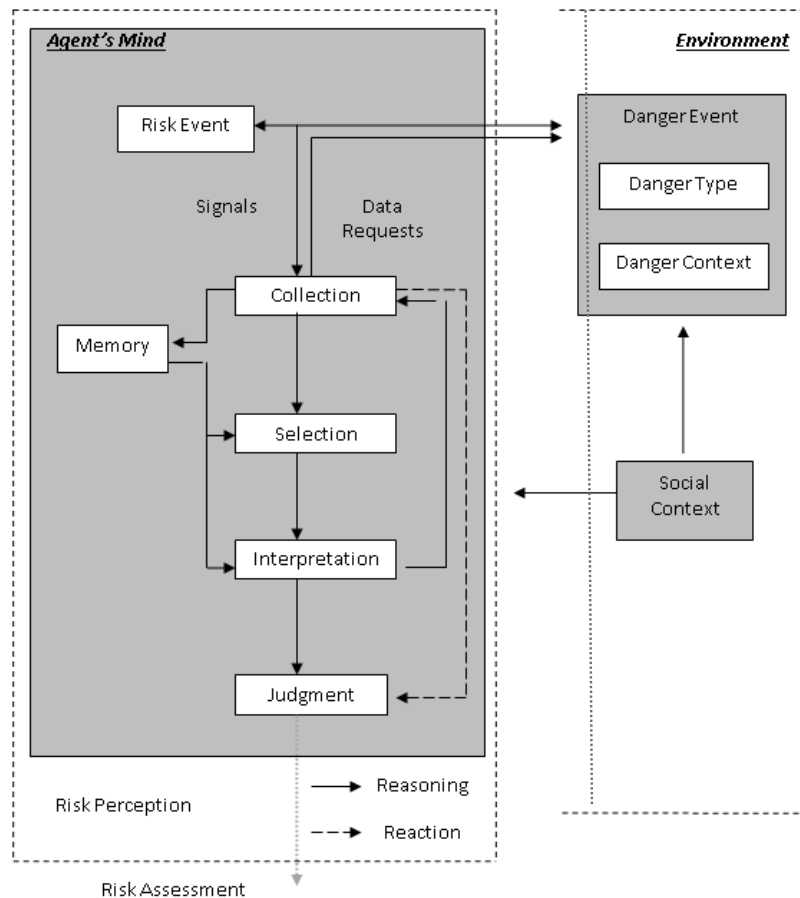


Fig. (4). Risk perception architecture (adapted from [42]).

10. EXPLORING OUTPUT RESULTS

The results reported in this section were obtained conducting the described experiments using version 5.1.0 of the NetLogo framework [1]. NetLogo is a programmable modelling environment for simulating natural and social phenomena. It is particularly well suited for modelling complex systems developing over time.

At this stage of research, we are still doing more experiences and getting in-sights on how the several parameters impact the system dynamics. So, in this section, we will only hint at the kind of results we obtained and present our analysis.

First of all, we analyse the case where the gap among stimuli is equal, which means that instantaneous and thoughtless stimuli having the same level of the threshold (SS_i) where agent cannot perceive correctly the danger ($p=0$) that occurs if s/he decides to have sex.

In such a case, the average condom use is about 8 in 10, the average coupling tendency is 2 revealing that agents are more reticent to have sex and the commitment of agents is high where relationships have an average duration rounding 186 weeks. Furthermore, agents do tests with a frequency of 1,78 times a year. This situation results in 2,8% of agents infected (See Fig. 5).

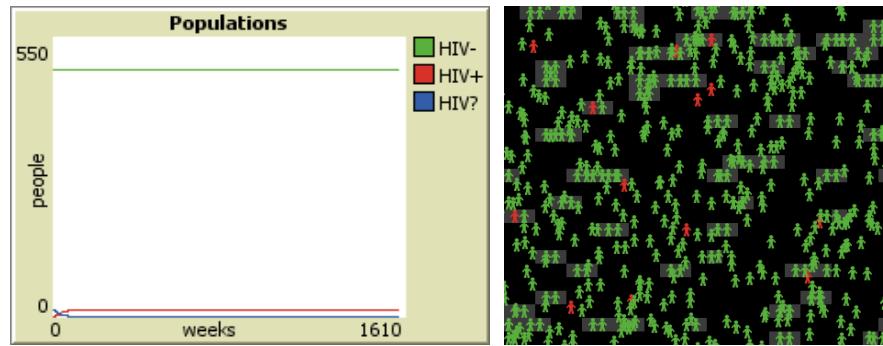


Fig. (5). Percentage of infected population when danger is not perceived correctly ($p = 0$).

As we can see from Fig. (2), most of the individuals are not infected with HIV, there is not an oscillated level of infection and just a few are infected and aware of that. This figure demonstrates that when people don't perceive the danger as it is and subsequently the reality, they have the tendency to assume a conservative approach in terms of sexual behaviour. Clearly, there is a practice to adopt protective measures to avoid contagion. And people behave in an inflexible way in the presence of the unknown.

Second, we analyse the case where the gap among stimulus is unequal, which means that instantaneous and thoughtless stimulus is higher than the threshold (SS_i) where an agent perceives partially the danger ($0 < p \leq 0.25$) that occur if s/he decides to have sex.

In such a case, the average condom users are about 7 in 10, the average coupling tendency is 3 in 10 revealing that the agents are continuously reticent to have sex

and the commitment of agents is high, where relationships have an average duration rounding 156 weeks in 200. Furthermore, agents do tests with a frequency of 1,55 times a year in 2,00 possible. This situation results in a 53,7% of agents infected (see Fig. 6).

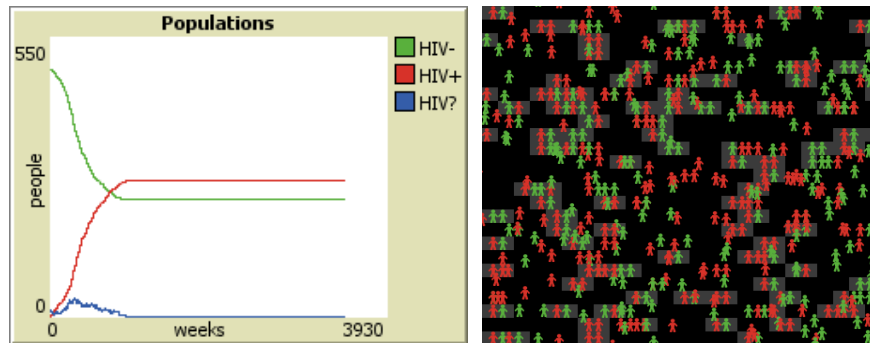


Fig. (6). Percentage of infected population when danger is perceived partially ($0 < p \leq 0,25$).

As we can see from this figure, when people perceive partially the dangers of HIV, they tend at the beginning to be careful and adopt protection measures to avoid HIV. However, as the time passes by, people tend to have more unsafe sexual interactions and the number of uninfected individuals start to fall, after a couple of weeks. Instead, as the number of uninfected people decreases, the number of infected people starts to increase exponentially until it crosses the number of uninfected individuals and reaches a kind of limit. On the contrary of the other situation, the number of infected individuals who are aware of their situation is higher than the number of the individuals without HIV. Another difference from the case before, where people perceive correctly the danger of being infected, is the appearance of a small group of individuals who are infected, but they are not aware of that.

Third, we analyse the case where the gap among stimulus is also unequal, which means that instantaneous and thoughtless stimulus ($0,5$) is higher than the threshold ($SSt=0,25$), but the strength of stimulus ($0,5$) is higher than the other case ($0,25$), where an agent perceives also partially the danger ($0,25 < p \leq 0,75$) that occurs if s/he decides to have sex.

In such a case, the average condom used is about 4 in 10, the average coupling tendency is 6 in 10 revealing that agents have more propensity in having sex and the commitment of agents decreases, where relationships have an average duration rounding the 54 weeks in 200. Furthermore, agents do tests with a

frequency of 1,02 times a year in 2,00 possible. This situation results in 89,7% of agents infected (see Fig. 7).

This figure shows that after a few weeks, most of the people tend to become infected until reaching a certain limit. The growth is exponential and the level of contagious is considerably higher, if we compare with the situation where people perceive partially the danger of HIV virus and AIDS. It is important to highlight that in this situation where people perceive correctly the danger of HIV virus, a substantial group of individuals emerges at the beginning who are infected but are not aware of their condition. It is a group in which level becomes even higher than the group of uninfected people. However, over time, more or less 5 years, the people who aren't aware become conscious about their situation and they move to the group of people who are aware of having the disease. The figure shows that in some short period of time, the individuals who aren't aware of their condition are more than the individuals who are aware of that. This points out that it takes some time to become aware of the disease, even if the danger is partially perceived.

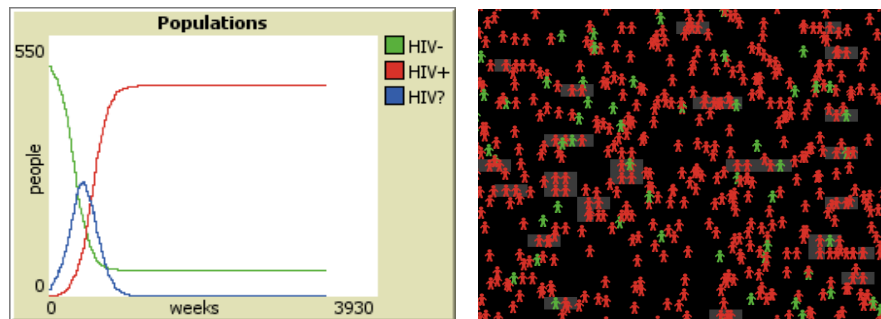


Fig. (7). Percentage of infected population when danger is perceived partially ($0,25 < p \leq 0,75$).

Finally, in the fourth case, we analyse the situation where the gap among stimulus is high, which means that instantaneous and thoughtless stimulus ($0,99$) is higher than the threshold ($SSt=0,25$), remaining the strength of stimulus in $0,5$, where an agent perceives almost correctly the danger ($0,75 < p \leq 1$) that occurs if s/he decides to have sex.

In such a case, the average condom use is about 2 in 10, the average coupling tendency is 8 in 10 revealing that agents have more propensity in having sex and the commitment of agents decreases where relationships have an average duration rounding the 5 weeks in 200. Furthermore, agents do tests with a frequency of 0,30 times a year in 2,00 possible. This situation results in 100% of agents infected (see Fig. 8).

On behalf of figure number 5, we can denote that most of the people become infected, even if they perceive correctly the danger and reality of being contaminated by HIV virus. The individuals who are not infected decrease deeply in about one year becoming all contaminated. All the people move from a situation of uninfected to a situation of infected with the curiosity of not being aware that they are infected, staying in ignorance for a long time, more than five years. Only after those years, they start to become aware that they are infected. Everything happens with people perceiving correctly the danger and the reality of HIV virus and AIDS.

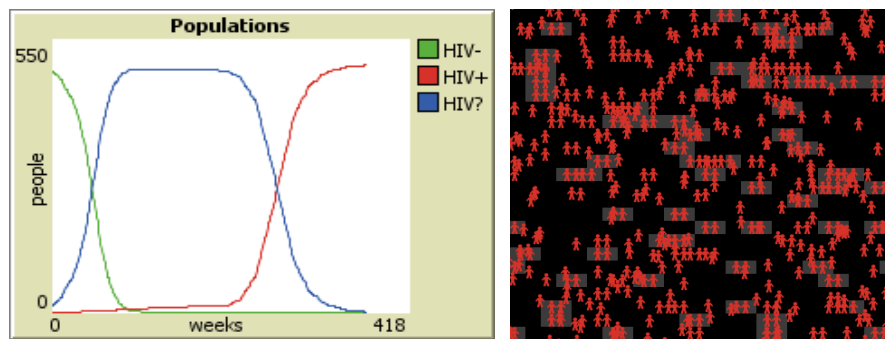


Fig. (8). Percentage of infected population when danger is perceived almost correct ($0,75 < p \leq 1$).

11. DISCUSSING RESULTS

As we can see from the obtained results, as far as are the instantaneous sexual stimuli from the threshold (the limit where agents don't perceive correctly the danger), the higher is the perception of agents about the danger of contagion. However, the higher is the perception of HIV danger, the more individuals become infected.

Another interesting result was verified that the higher is the perception, the more are the agents who are seropositive but they don't know that. It is quite interesting to understand that, the better the individuals' perception, it doesn't mean that they become aware of the real danger and reality. It takes some time to be aware about it and in an inverse proportional relation. The output results are consistent with the inexistent guarantee referred before, about the direct cause effect relationship of determinables, perceptibles, perceptions and awareness (see Fig. 9).

These achievements make us understand why HIV is continuously growing up, instead of decreasing. This makes us question, on one hand what are the roles of perception and awareness? Because the expected result would be, the better a danger like HIV is perceived, the higher should be the awareness of individuals. A

sequence that should result, from agents, in the adoption of more careful measures and protected behaviours or, at least, it is expected to. But in fact, what happened was the inverse logical sequence. The better or the higher was the perception of the danger of HIV, the higher was the propensity of agents in taking risky decisions and unprotected behaviours.

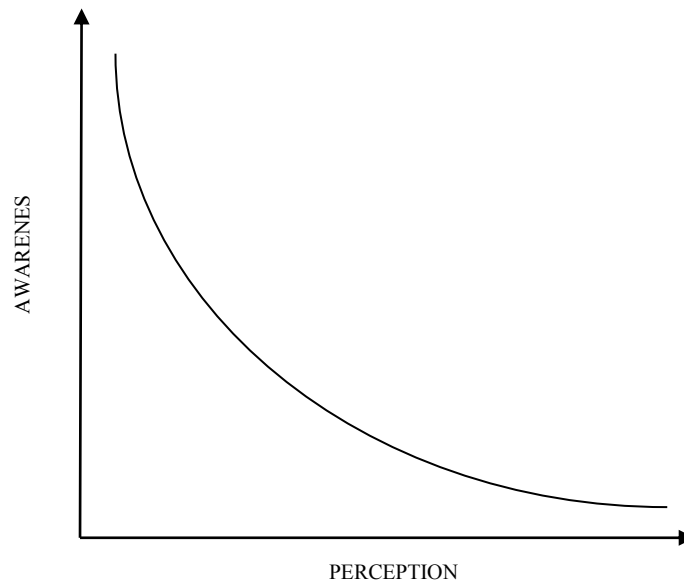


Fig. (9). Relation between perception and awareness – reverse effect.

On the other hand, another important aspect is the impact of health policies that have been developed with huge propaganda associated to solve the contamination problem of HIV. A problem for governments that needs reflection considering the imprudent behaviour of agents, is what concerns their sexual activity. For example, agents could follow the line of thought that if the condom is free, perhaps the disease is not so dangerous. Because if it was as dangerous as they say, the condoms would have to be paid. And in fact, the reality proves that poor countries where condoms and HIV tests are distributed for free with a lot of propaganda are the ones, where the infection rate of HIV is increasing and AIDS is an evil disease. On contrary, in the countries, where the condoms and HIV tests are paid attention the numbers of individuals have been decreasing during the last years.

The relation between time and awareness reveals that when agents' perception is high, the continuous stimuli is strong enough to "blind" their perception for a long period of time which induces us to assume that it is, on this time schedule, the critical point for agents to confirm the reality as it really is. The question that we

should consider is about the main reason why the agents take so long to become aware of the reality. It puts them in a situation of acting first and think later, when they take decisions. This situation is important, since it is evident that decision and perception are quite different. An agent could perceive a danger in one way and decide in another, differently from what was perceived. This instigates us to real life and asks why people many times do not decide according to what they perceive? In fact, perception transforms itself as the process that influences decision, which could not be true. As we can see, they could be mutually exclusive and independent. (see Fig. 10)

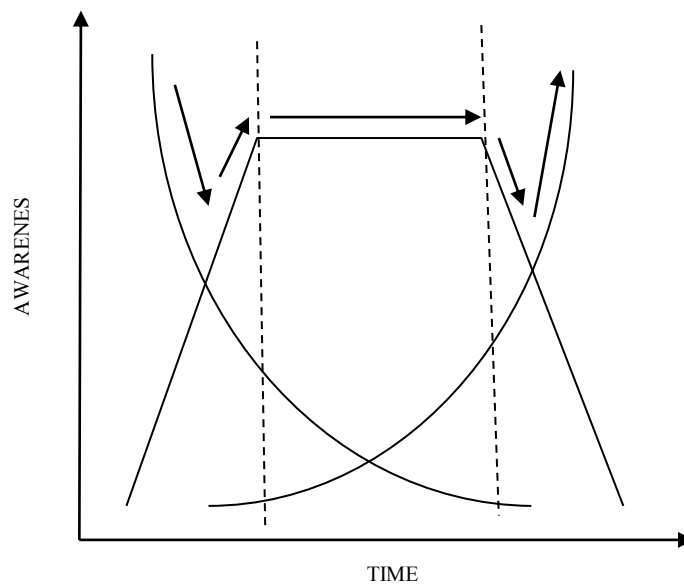


Fig. (10). Relation time-awareness.

The AIDS Model results are also interesting since these are in accordance with the Interface Theory of Perception [20]. These achievements demonstrate that using evolutionary algorithms in [20] or multi agent based systems in this work, perceiving correctly the reality instead of helping agents to survive provoke their own extinction. In this sense, according to these results and the results obtained in [20], the relation between individuals and reality should make us review some aspects of the Evolutionary Theory of Species from Darwin. It seems to exist a strong hypothesis that evolution is dependent of perception in the human beings. One of the aspects that contributes strongly to this is the role of the reverse effect on perception.

CONCLUSION

In this article, we proposed to analyse the role of perception and the way it can influence the definition of health policies by governments or other institutions under the umbrella of United Nations, for example. Real Statistics reveal that the number of individuals has been increasing over these years when it was expected to decrease. This takes in consideration the policies developed by governments to stanch proliferation of HIV virus and the control of AIDS disease. In order to understand this problem, we implemented a multi agent based model. The obtained results reveal that the higher is the gap and respective strength of sexual stimulus, the higher is the perception of agents about the danger of HIV and the higher is the percentage of the infected population. We called this the reverse effect of perception. It means that agents who perceive correctly the danger of HIV are the ones to have more propensities to be infected and disseminate the virus under contagious effect. This happens because those agents who perceive correctly the danger don't take the right measures to protect themselves from the virus. They feel more confident in their perception and knowledge and therefore do not adopt protective measures.

The output results also help us to demonstrate that there is a gap between what it is perceived by us and the awareness we have about the external reality. It was shown that agents take a long time to be aware of a danger when perception is fine. The results could be explained by the excessive trust of agents in their own perception, which gives them a false sensation of safety and confidence.

In this sense, we also conclude that policies like the one that encourages the free distribution of condoms are not correct, since it has the reverse effect of what would be expected. And for that reason, we recommend governments to put condoms for sell instead of distributing them for free.

CONFLICT OF INTEREST

The authors confirm that this chapter content has no conflict of interest.

ACKNOWLEDGEMENTS

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INTERACTION WITH HUMANS

CHAPTER 5

Lexicon-based Sentiment Analysis in Persian

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Abstract: Sentiment analysis is a field of study concerning the extraction of people's opinion and attitude from their writings on the Web. Most research efforts in the area of sentiment analysis have focused on English texts and few works considered the problem of Persian sentiment analysis. Persian is spoken by more than a hundred million speakers around the world and is the official language of Iran, Tajikistan, and Afghanistan. From a computational point of view, Persian is a challenging language due to its derivational nature and the use of Arabic words, informal style of writing, and different forms of writing for compound words. In this chapter, we present a lexicon-based framework for sentiment analysis in Persian. Specifically, we develop a Persian lexicon which associates sentiment words with their sentiment strengths. Furthermore, in the proposed framework, we address several problems of sentiment analysis in Persian, such as misspelling, word spacing, and stemming. We used the proposed framework in the problem of polarity detection and rating prediction of cell-phone reviews. The results show that our approach outperforms supervised machine learning techniques in terms of accuracy and mean absolute error.

Keywords: Lexicon-based review classification, Natural language processing, Opinion mining, Sentiment analysis, Text mining.

INTRODUCTION

Sentiment analysis (SA) aims to extract opinions, evaluations, and emotions from online sources such as product reviews, discussion forums and personal blogs [1, 2]. Due to its wide range of applications, SA has been successfully applied to academic and industrial applications in recent years [3]. From the industrial point of view, finding consumer and public opinions about services or products may support strategic market decisions [4]. On the other hand, since there are many challenging research problems which had never been studied before, sentiment

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analysis provides a strong motivation for academic research as well. Furthermore, in order to know the choice that best fits their preferences, potential consumers want to know the opinions of current customers of a product before purchasing. People also prefer to be aware of others' opinions about the candidates of a political election before making a voting decision [4, 5].

Although earlier studies on sentiment analysis have focused on English texts, some recent works deal with other languages such as Chinese, Turkish, Arabic, Urdu, and Russian [6 - 10]. However, there are few works for sentiment analysis in Persian [9, 11 - 13]. Persian is spoken in Iran, Afghanistan, and many states of former Soviet Union [9]. From a computational point of view, Persian is a challenging language for several reasons [12, 14]. Firstly, some Persian letters have three or four forms of writing. Secondly, there are several informal words in Persian documents. Thirdly, there are a lot of frequent exceptions in word order. Fourthly, declensional suffixes are widely used in Persian. Fifthly, there are some imported sounds from Arabic which may be written or ignored, resulting in various forms of writing for the word containing them [12, 14]. Therefore, in this paper we investigate these challenges and propose a new framework to dealing with them.

For the sentiment detection component of our framework we had two choices: either using corpus-based machine learning approaches or using lexicon-based methods [15, 16]. One of the advantages of machine learning approaches is that they can identify implied sentiment expressed with non-sentiment words [17]. Nevertheless, the main drawback of machine learning approach is that it requires a corpus of human-annotated texts to train a classifier. Moreover, for domains other than those used for training, they have a poor performance [1, 15]. On the other hand, lexicon-based methods are robust and domain-independent methods that may utilize multiple sources of knowledge to show better performance [15]. Furthermore, existing sentiment lexicons can be easily combined to improve the performance of lexicon-based approach [18].

However, pure lexicon-based approach is not adequate for sentiment analysis and hence, combined methods are sometimes more beneficial. Such combined approaches usually use additional information, such as semantic rules to handle negation and intensification [15], booster word list [19], and emoticon list [16, 20]. In this work, we preferred the combined approach.

Earlier researches on sentiment analysis have focused on subjectivity analysis [21 - 24] and polarity detection [25 - 27]. Subjectivity analysis aims to determine whether a given text is subjective or not, while the goal of polarity detection is to assign an overall positive/negative sentiment label to subjective texts. In more

recent works, some methods were proposed to detect the strength of sentiment [15, 16, 28]. These algorithms try to specify the degree of positivity or negativity of a given document. However, on Persian text, there are few works which all are proposed to detect sentiment polarity [11, 12]. In the current study, we consider the sentiment strength detection problem for Persian product reviews. Specifically, we proposed a new framework for lexicon-based Persian sentiment analysis and carry out our experiments on two collections of cell phone reviews.

The main contributions of this study are as follows:

- We propose an unsupervised, lexicon-based approach for sentiment analysis in Persian.
- We introduce two resources for Persian sentiment analysis: a Persian lexicon that associates Persian sentiment word and their sentiment strength. A manually gathered dataset that is annotated by human coders for rating prediction.
- We compare the accuracy of supervised machine learning methods and the proposed framework for the task of review rating prediction.
- We augment the proposed system with the ability to find the polarity and evaluate its performance on two datasets.

In the remainder of the paper we first review background and related work in Section 2; then, in Section 3 the proposed methodology and the proposed system will be illustrated; we report experimental results and discuss the examined methods in Section 4; finally, in Section 5 we conclude the chapter and present future work.

RELATED WORK

In this section, we first present a brief review of related research on sentiment analysis. Then, we provide an overview of existing sentiment analysis on Persian text. Finally, we talk about sentiment strength detection and its applications.

Sentiment Analysis

Sentiment analysis and opinion mining usually describe the same field of study and most researchers use them interchangeably [6]. Dave *et al.* used the term opinion mining for the first time in [29] and Nasukawa and Yi proposed the term sentiment analysis for the first time in [30]. However, the study of sentiments and opinions started earlier [22, 31, 32]. Since then, SA has changed to an active research area in natural language processing and data mining communities. Therefore, a huge amount of research literature exists on this field. However, instead of providing a detailed review of the field, we just review some relevant

studies in this section. More comprehensive surveys can be found in earlier studies [1 - 3, 5, 33].

SA has received an increasing attention in recent years [3]. Sentiment analysis has a wide range of applications, from financial to social and political. For examples, predicting sales performance [34], predicting election results [35], identifying important aspects of products [36], finding fake product reviews [37], and detecting customers' opinion about different aspect of products [38] are some important applications. Recently, social applications of SA has drawn the attention of researchers. Some examples of these applications include finding the differences of genders on emotional axes [39], predicting the stock market trends with the help of Twitter data [40], distinguishing social online relations [41], detecting sentiment flow in social networks [42], identifying differences between genders in sentiment expression in SNSs [43], and finding opinion leaders [44].

However, much of the sentiment analysis research has been done in English and there are few works on other languages [5]. The reason is that not only there are limited lexical resources and data collections for non-English languages but also building such resources is very time and labor-consuming [45]. According to [5], there are three main strategies for dealing with multi-lingual sentiment analysis:

1. Exploiting a source language classifier to classify the translated test sentences from the target language.
2. Building a corpus-based classifier that is trained on the translated training corpus from the source language.
3. Building a lexicon-based classifier in the target language to classify the translated lexicon of the target language.

For example, Kim and Hovy, compared the first two above-mentioned strategies for polarity detection on German emails [46] and Denecke proposed a similar approach for German comments [47]. Mihalcea *et al.*, used the third strategy to deal with subjectivity analysis on Romanian texts [48]. Similar approaches have been proposed for other languages such as Chinese [49, 50], French [51], Turkish [7], Spanish [52], Urdu [9], and Arabic [8]. However, we will not review all the literature on the subject; instead we shall describe some related works that were proposed for Arabic and Urdu that is based on Arabic orthography. These languages are more similar to Persian and typically have the same difficulties for sentiment analysis.

Abbasi *et al.*, utilized languages stylistic and syntactic features to classify Web forum opinions in English and Arabic documents [53]. Specifically, they proposed a new feature selection method, EWGA, and evaluated it on a movie review dataset and Web forum postings. This study is considered as one of the

first works on sentiment analysis in Arabic. Farra *et al.*, investigate Arabic sentiment analysis at sentence and document level [54]. They proposed two approaches for sentence-level classification. In the first one, a novel grammatical approach was used, while in the second approach, a statistical method based on the semantic orientation of words and their corresponding frequencies was employed. For document-level classification, they used sentences-level information. El-Halees proposed a combined approach to extract opinions from Arabic documents [55]. First, a lexicon-based approach was utilized to classify documents and then, the classified documents were used as training set for the maximum entropy method. Finally, to classify the rest of the documents, k-nearest neighbor method was used. More comprehensive and detailed surveys on Arabic sentiment analysis may be found in [56].

Mukund and Rohini proposed a co-training approach for subjectivity analysis in the Urdu language [57]. In particular, to deal with the imbalanced amount of labeled data required for training, their approach augmented the positive set and generated a negative set. This study is considered as one of the first works on sentiment analysis in Urdu. They also proposed a structural correspondence learning-based method for transferring SA learning from newswire data to blog data [58]. Another important study on Urdu texts was performed by Syed *et al.* in [9]. Their method identify and extract expressions containing the sentiment information in a sentence from the given text, using shallow parsing. Later on, they extended the previous model to handle comparative sentences and evaluated their model on the corpus of reviews about movies and electronic appliances [59].

Sentiment Analysis in Persian

The reported research on SA in Persian is very limited. In the literature, we found three main studies concerning the problem of Persian sentiment analysis. The first work is that of Shams *et al.*, who introduced PersianClues as a new lexical resource for SA in Persian [11]. They first employed an automatic translation method and then an iterative refinement approach to correct the incorrect words. In order to detect the polarity of documents, a two-step approach was used in this work. First, an unsupervised LDA-based method is utilized to extract topic-based Persian clues and then, SVM is used to identify the polarity of each document. To evaluate their method, three manually gathered resources about hotels, cell phones and digital cameras were used. The reported results indicate that their method outperforms a system which is only based on term frequency of unigrams.

The second study on Persian sentiment analysis was recently proposed by Bagheri *et al.* [12]. Their method uses the Naïve Bayes algorithm for classification. Moreover, they proposed a new mutual information-based feature selection

method, MMI, which uses the polarity relation between features and classes. They evaluated their method on a Persian review collection containing customer reviews about cell phones that was manually annotated by human coders at review-level. In fact, their work is considered as a document-level supervised polarity detection method. The reported results show that their method has a slightly better performance than the TFV approach and significantly outperforms MI method. A similar approach for sentiment analysis in Persian was proposed by the same authors in [13]. They reviewed and compared different feature selection methods for sentiment classification. Furthermore, they discussed some challenges of Persian texts and proposed a sentiment classification model for Persian documents.

Sentiment Strength detection

Sentiment strength detection aims at specifying the degree positivity/negativity of text [16]. There are few algorithms in the literature for detecting sentiment strength [60]. Sentiment strength detection may be formulated as a regression problem since the strength usually specified with ordinal rating scores [5]. An example of this kind of modeling was described by Ganu *et al.* [61] where they proposed a linear regression model for review score detection. Later on, they improved the previous model and proposed a quadratic regression model to fit their test dataset [62]. Nevertheless, other machine learning approaches have also been used to solve the problem. For instance, a comparison between SVM regression and multiclass SVM was presented by Pang and Lee where they report that the former slightly outperforms the latter [63]. Similarly, Goldberg and Zhu modeled the problem as a graph-based semi-supervised learning problem [64].

In addition to machine learning approaches, in some studies, lexicon-based or combined methods were used. For example, Neviarouskaya *et al.* proposed to combine the dictionary of terms and strength scores [28]. SO-CAL [15] and SentiStrength [16] are two recent and well-known lexicon-based tools for sentiment strength detection.

In SO-CAL (Semantic Orientation CALculator) a lexicons of terms was used in which every term is labeled with an integer in the range of -5 to $+5$ [15]. Human coders tagged strength and polarity of stemmed noun, adjectives, adverbs, and verbs of its lexicon from 500 documents. In SO-CAL positive amplifiers and negative downtoners were used in a percentage scale to model intensification (*e.g.*, “somewhat” with -50% and “very” with $+25\%$ modification impacts). Moreover, the strength of negative expressions were amplified while, the strength of frequent terms were decreased. The results showed that SO-CAL performs well on different kinds of web texts [15].

SentiStrength is a combined lexicon-based method that tries to solve the problem of negation, misspelling, and emoticons with the aid of additional linguistic information [19]. The main target of this software is to deal with short informal English text [16]. The basic idea of SentiStrength is that each text often states its writer's emotional state and also, people can distinguish mild and strong emotions by selecting words [16, 60, 65, 66]. The core of SentiStrength is a lexicon of 2,310 sentiment words [19]. The SentiStrength classifier's output for each text is a tuple of values in the form of $\langle P, N \rangle$, where P and N are two integers ranging from one to five and are interpreted as measures of positive and negative sentiment, respectively. Here, one and five correspond to no sentiment and strong sentiment, respectively. In the current study, we adopt SentiStrength for sentence-level sentiment detection in Persian.

PROPOSED SYSTEM

In order to design an effective system for sentiment analysis in Persian, several problems should be considered. One of the main problems is that there are different forms of writing for many Persian words. Another problem relates to the use of space which may appear within a word or between two consecutive words. Moreover, in Persian, short space is used to separate compound word's part. Thus, text segmentation and tokenization in Persian is more complex and challenging compared to other languages [14]. Another challenge of Persian language is its derivational nature which increases the probability of producing new words by concatenating existing words and affixes. Using informal words and the transliteration of foreign words that are common in social Web texts, is another challenge for Persian sentiment analysis. However, to our knowledge, no previous published research on Persian sentiment analysis has investigated these problems.

In this study, we propose a combined approach to deal with the above-mentioned problems. An overall view of the proposed system is shown in Fig. (1).

Normalization

This module is used to unify those words that may be written in several alternative forms. Typically, there are different ways of writing a word in Persian for the following reasons. First, some of the imported letters from Arabic may be utilized in several forms. Second, some letters in Persian have different Unicode. Third, word boundaries are not always indicated by space. These problems will be discussed in more details below.

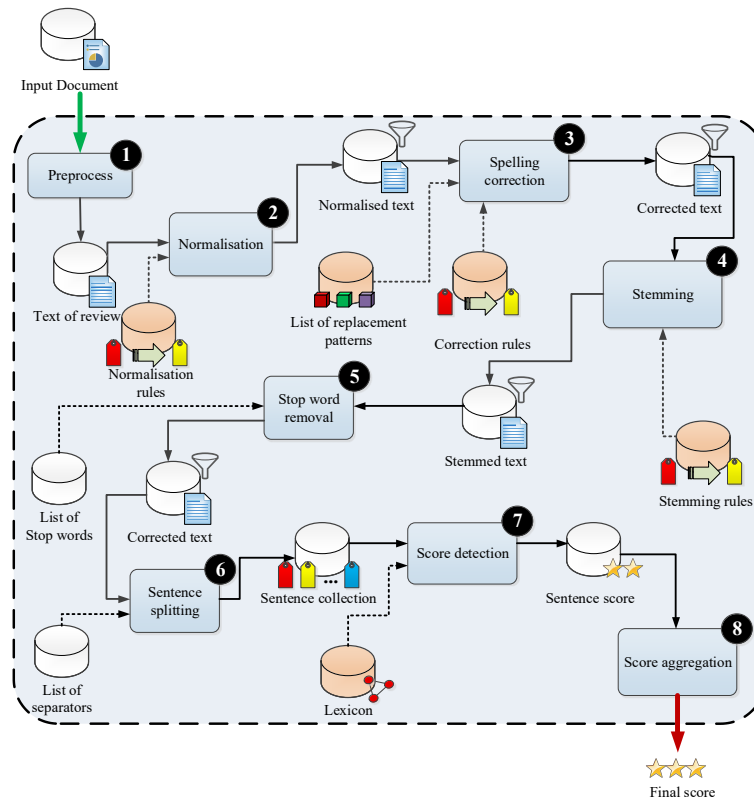


Fig. (1). The overall view of modules used in the proposed system.

The first problem relates to the use of some imported letters from Arabic. Persian has 32 letters which covers all 28 Arabic letters. Moreover, some imported sounds from Arabic such as “Tanwin” and “Hamza” are also used in Persian words as well as in the borrowed words from Arabic. The main problem with these sounds is that they may or may not be written in the word containing them. For example, “تأیید” and “تایید” are both conventional ways of writing the word “Tayied” which means “confirmation”. In the former, “Hamza” is used (*i.e.* “أ”) while in the latter, it was replaced by “Alef” (*i.e.* “ا”). Similarly, “Tanwin” which occurs in most adverbs in Persian, causes the same problem. Moreover, there are sometimes two possible ways to write words containing “Hamza”. For example, the word “Masoul” which means “responsible” may be written either as “مسؤول” or as “مسئول”.

The next problem is due to the Unicode ambiguity of Persian. In particular, this problem occurs for those words containing letters like “ي” or “ک” (for “i” and “k”, respectively). Because these letters have more than one Unicode, the same word may be written differently by different applications or software.

Finally, compound or multi-part words in Persian may have different styles of writing. In particular, a compound word may be written with space, semi space, or no space. For example, consider the following short review about a cell phone:

Example 1:

“سیپیوی این گوشی قویتر از اون هست اما تو پخش فیلم ضعیف تره” (“This cell phone’s CPU is more powerful than that cell phone, but it is weaker in playing video”)

The word “سیپیو” which is the transliteration of “CPU” was written using short space, while “قویتر” which means “more powerful” was written without any inter-word space and finally, the two parts of “ضعیف تر” that means “it is weaker” was separated using a space.

In order to deal with the above-mentioned problems, we follow a dictionary-based approach. In fact, we only consider different forms of writing for opinion bearing words. This would be sufficient, because our approach for sentiment prediction is lexicon-based [67]. In other words, since we compute the overall sentiment of documents based on their opinionated words, it is not necessary to unify non-sentiment words and this should not affect the performance of the proposed system. Moreover, following this strategy make our approach more computationally efficient.

Spelling Correction

This module is utilized in our system to correct misspellings. In addition to typographical and cognitive mistakes, there is another source of spelling errors in Persian, namely interchangeable letters [14]. Interchangeable letters are those which produce the same sound (in contrast to Arabic). For example, “T” may be written as either “ت” or “ط” and “Z” may be written using “ز”, “ذ”, “ض”, or “ظ”. Therefore, it is quite likely for a word to be written in tens of ways. A typical example would be the word “استهزاء” for “ridicule” that have 96 different ways of writing. The reason is that there are two interchangeable letters for “ت” and “ه”, three interchangeable letters for “س”, and four interchangeable letters for “ز”. Also, the final “Hamza” may be written or ignored. Therefore, spell checking in Persian language is more challenging than English.

Another type of spelling errors in Persian reviews is due to the widespread use of colloquial or informal words. This is common in social web text because these texts are known for their young writers, their short length and their informal writing patterns [19]. As a result of these factors Persian reviews, like English reviews, have common features including abbreviations and repeated letters or

punctuation that are used for emphasis. Moreover, informal Persian text frequently contains non-standard spelling. The main reason that leads to such non-standard spelling is that many Persian Web users tend to write words as they are used in everyday conversations. For example, consider the following short review about a typical cell phone:

Example 2:

این گوشی رنگا رو غیر واقعی نشون میده و صفحش هم کوچیکه. تا چند ماه دیگه ارزونتر
 “میشه پس نخرید پشیمون میشيد.” (“This cell phone does not show images normally and
 its screen is small. It will become cheaper in next months, so do not buy it, you
 will regret it”).

Although this is a short review, it contains several non-standard informal words. (Table 1) shows these words along with their standard form and their meaning.

Table 1. Description of informal non-standard words used in Example 2.

Informal word	Standard form	English Translation
رنگا	رنگ ها	Colors
نشون	نشان	Show
میده	مي دهد	Gives
صفحش	صفحه اش	Its screen
کوچیکه	کوچک است	It is small
دیگه	دیگر	Next
ارزونتر	ارزان تر	Cheaper
میشه	مي شود	Becomes
پشیمون	پشیمان	Regret

In order to deal with the problems of interchangeable letters, we follow the dictionary-based approach described in the previous section. However, it is not a trivial task to correct non-standard spelling errors using a dictionary-based approach. This is due to the fact that such errors, in contrast to that of interchangeable letters, are not limited to fixed type of letters. Therefore, we select a combined approach to reduce this type of spelling errors; in this approach, in addition to a predefined list of non-standard words, a rule-based method is utilized to correct more misspelling errors. Our rule-based approach works on the basis of common patterns of writing for Persian words as they are pronounced. The following is the list of common replacement patterns that are used in informal writing:

1. Successive “Alef” and “Noon” letters, “ان”, is usually replaced by “ون”.
2. The suffix “د” (“Dal”) is almost always replaced by “ه” (“Ha”) in present tense verbs.
3. The verb “است” (“Ast” which means “is”) is replaced by the letter “ه” which is concatenated to the previous word.
4. The verb “ام” (“Hastam” which means “am”) is usually replaced by the letter “م”. Similar to the previous case, the replaced letter is added to the end of the preceding word.

Some typical examples of common replacements are shown in Table 2.

Table 2. Typical examples of common replacement in informal writing.

Replacement Pattern	Standard word	Informal form	English Translation
“ان” by “ون”	گران	گرون	Expensive
	آسان	آسون	Easy
	آویزان	آویزون	Hanging
“د” by “ه”	مي دهد	مي ده	Gives
	مي خرد	مي خره	Buys
	مي شكند	مي شكته	Breaks
“است” by “ه”	بهتر است	بهتره	It is better
	كمتر است	كمتره	It is less than
	جالب تر است	جالب تره	It is more interesting
“ام” by “م”	خوشحال هستم	خوشحالم	I am happy
	مطمئن هستم	مطمئنم	I am sure
	متنفر هستم	متنفرم	I hate

Stemming

Stemming is a typical step used in text processing systems to reduce variant word forms to their common roots. Most stemming methods use rule-based approach in which word meanings are ignored [68]. These stemmers usually suffer from over- or under-stemming and hence, apply certain ad-hoc spelling correction rules to improve conflation accuracy. However, it has been shown that ignoring numerous verb forms and focusing mainly on nouns and adjectives leads to effective stemming [69].

Persian is an Indo-European language and its derivational morphology is formed by adding certain affixes to word stems or roots. In other word, in Persian by concatenating prefixes and suffixes the words, their meaning are changed. For

example, Plural of nouns in is formed by adding suffixes “ان” and “ها” for Persian words and by adding “ات” and “ین” for borrowed Arabic nouns. Suffixes in Persian can be concatenated to the word they alter (e.g., “احساسات” meaning “emotions” and “برادران” meaning “brothers”) or separated from it using an ordinary or short space (e.g., “برتریها” meaning “advantages” and “امتیاز ها” meaning “ratings”).

In order to remove suffixes described in this section, we used a light stemmer proposed by [68]. This stemmer does not consider verbal suffixes, although like in other languages they are frequent in the Persian too. However, this will not affect our lexicon-based sentiment analysis method because most opinion-bearing words in a typical lexicon are nouns and adjectives. Moreover, to reduce the size of document and to improve the accuracy, we removed frequently occurring words having no significant impact on sentiment detection process. To this aim, we use the existing stop word list that was suggested previously by [69]. Both the light stemmer and the stop word list are publicly available [70].

Another problem that exists in Persian stemming is due to the use of so-called “mokassar” or “broken” plurals. These plurals are formed by changing the vowel pattern of the singular, ignoring the above-mentioned rules. Some prevalent broken plurals in informal social Web texts are listed in Table 3. Because the employed light stemmer does not deal with such plurals, we used a manually constructed dictionary of common broken plurals to obtain better conflation results.

Table 3. Typical examples of broken plurals in informal writing.

Singular form	Plural form	English Translation
مزیت (Maziat)	مزایا (Mazaya)	Advantage
حسن (Hosn)	محاسن (Mahasen)	Pros
عیب (Eyb)	معایب (Ma'aayeb)	Cons
خاصیت (Khasiat)	خواص (Khavas)	Feature
علت (Elat)	علل (Elal)	Cause
دلیل (Dalil)	دلایل (Dalaal)	Reason
جنبه (Janbheh)	جوانب (Javaneb)	Aspect
نوع (No'e)	انواع (Anva)	Type

Sentence Splitting

There are basically two model of exploiting the textual content of user-generated reviews; the bag-of-words model in which every review is considered as a unit of

text and the bag-of-sentences model where every review is viewed as a set of sentences. The main disadvantage of the first model is that it ignores the sentence-level information of documents [61, 67]. Hence, the second viewpoint is usually preferable. An overview of these models is depicted in Figs. (2 and 3, respectively).

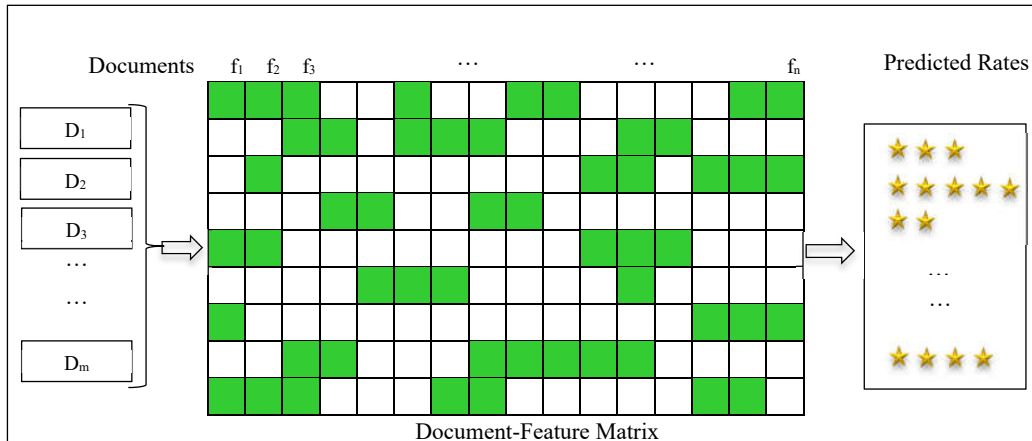


Fig. (2). The bag-of-words model for sentiment analysis; in this model any review is considered as a unit of text.

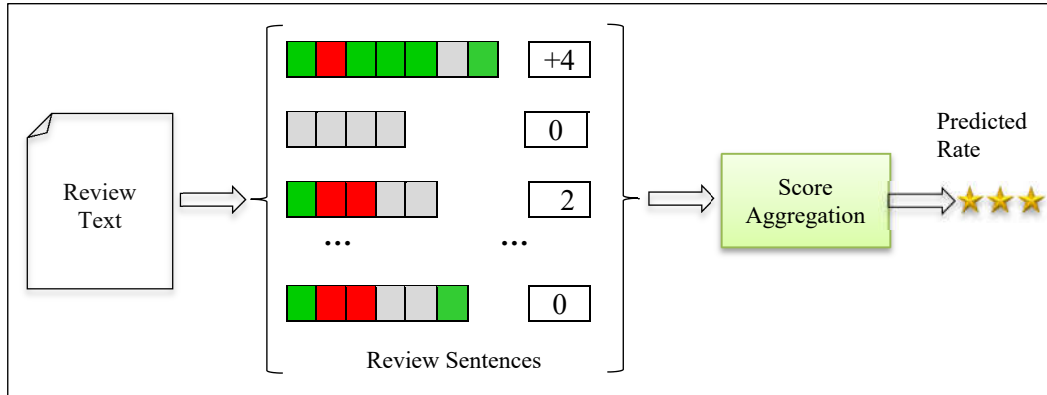


Fig. (3). The bag-of-sentences model for sentiment analysis; in this viewpoint every review is viewed as a set of sentences having their own sentiment score.

In the current study, we preferred the second approach. Therefore, the Sentence Splitting module uses information such as common sentence separators (*e.g.* colon), exclamation and question mark to split multi-sentence reviews into distinct sentences. The output of this module is passed to the Strength Detection component.

Strength Detection

As pointed out earlier, some methods were proposed in recent years to detect sentiment strength as well as sentiment polarity [15, 19, 28]. In fact, these approaches try to detect the degree of positivity/negativity of text. SentiStrength is such an approach that uses a combined method to detect sentiment strength of short informal social texts [19]. The following lists are used by SentiStrength for computing sentiment scores:

1. *Sentiment strength word list*: a collection of positive and negative terms with their corresponding five-star value.
2. *Booster word list*: a set of common words used for boosting or reducing the sentiment score of subsequent non-neutral words.
3. *Idiom list*: list of some common phrases and their sentiment scores.
4. *Negation word list*: a small collection of negation words that invert their subsequent sentiment words.
5. *Emoticon list*: a list of common abbreviations in short social Web texts. Table 4 describes some example words from the above-mentioned lists.

Table 4. Some typical examples of words listed in SentiStrength lexicon.

List Name	Sample Word	Score
Sentiment strength word list	Abject	-4
	Overjoyed	+5
Booster word list	Could	-1
	Incredibly	+2
Idiom list	Shock horror	-2
	What's good	+2
Negation word list	Won't	-
	Never	-
Emoticon list	:-	-1
	:-}	+1

Table 5. SentiStrength method to compute the sentiment score.

Input Sentence	Sentiment words	Positive score	Negative score	Binary score	Trinary output	Scale output
In their studies, they showed that it is neutral.	-	+1	-1	+1	0	0

(Table 5) contd.....

Input Sentence	Sentiment words	Positive score	Negative score	Binary score	Trinary output	Scale output
This book is beautifully written.	beautifully [3]	+3	-1	+1	+1	+2
I like this book.	like [2]	+2	-1	+1	+1	+1
It is a poorly made car.	poorly [-2]	+1	-2	-1	-1	-1
Who wants to waste his time on what is unfortunately complete trash?	waste [-2] unfortunately [-2] complete trash [-2] [-1 booster word]	+1	-3	-1	-1	-2
Although I really love the book but I hate its author.	love [3] [+1 booster word] hate [-4]	+4	-4	+1	-1	0

One the following ways may be chosen to show the output of SentiStrength: binary, trinary, scale, and default mode. The binary mode is used to show the overall polarity of documents with +1 or -1 scores for positive and negative texts, respectively. The trinary mode is similar to the binary mode except that it also considers neutral case. Therefore, the output in the trinary mode would be +1, -1, or 0, respectively. In the scale mode, a -4 to +4 scale is used. The default mode is ranges from +1 to +5 (neutral to extremely positive) for positive text and from -1 to -5 (neutral to extremely negative) for negative documents. In the scale and default mode, the format of the output is <P, N>, where P and N are the maximum positive and the minimum negative scores in a text, respectively [19]. Some examples of generating output by SentiStrength are shown in Table 5.

However, SentiStrength was designed for dealing with English texts and its lexicon and other lists should be adopted before using for sentiment analysis in Persian. Although automatic translation may be used to translate SentiStrength lists into Persian, but it cannot produce an accurate output. The reason is that in many cases there may be several translations for a single word in English which are not all suitable or even are not a sentiment word in Persian. Moreover, it is quite likely that different words with different sentiment strengths in English are mapped to a single word in Persian. Some typical examples of these words are listed in Table 6.

Table 6. Sample Persian words which have different translation in SentiStrength lexicon.

Persian word	English Translation	Sentiment score
ترس	Terror	-2
	Dread, Panic	-3

(Table 6) contd.....

Persian word	English Translation	Sentiment score
	Fear, Fright	-4
افسرده	Droop, Languish	-2
	Downhearted, Gloom, Glum, Cheerless	-3
	Sad, Depress	-4
دل‌تنگ	Stuffy, lone	-2
	Gloom, Homesick	-3
	Depress, Sad	-4

In order to deal with the above-mentioned problems we used manual translation to customize SentiStrength for Persian.

Score Aggregation

Aggregation methods are necessary for calculating the overall sentiment score of multi-sentence reviews. Score aggregation is a subclass of data fusion that takes sentence scores as multiple sources of information and generates a single review score [67]. Despite its importance, there are few works which directly address the problem of score aggregation. Some of the most important existing aggregation methods used in the literature are as follows.

- *SentiStrength*: This method first computes the overall positive/negative sentiment of each sentence. Then, it takes the maximum of positive and the minimum of negative sentence scores.
- *Maximum of scores*: In this method, the overall score of a review is the maximum of the absolute values of the positive/negative scores. It can be shown that when a review contains several weak positive sentences and a strong negative sentence this strategy does not work well.
- *Scaled rate*: the number of positive and negative sentence are used in this strategy to compute the final review score [61, 62]:

$$\text{Aggregated Score} = \left(\frac{P}{P+N} * 4 \right) + 1 \quad (1)$$

where P and N are the number of positive and negative sentences, respectively. The main problem of this method is that it ignores the strength of sentiment.

- *Sum of Predictions*: in this strategy, additional information from paragraph-level annotations are used to increase the accuracy of document-level sentiment classification [71]. This is achieved by first calculating the probabilities of each

paragraph belonging to positive/negative/neutral classes and then, summing the probability scores for each class across all paragraphs. At the end of the process, the class with the highest probability score is selected as the final output.

- *Sum of maximums*: similar to the *maximum of scores* strategy, this method uses maximum of positive and negative scores. But, in contrast to the *maximum of scores* strategy, it simply adds maximum of positive and negative scores to obtain the final score.
- *Majority Voting*: this method simply takes a majority vote of the probabilities assigned to every sentence. It has been first used in [71] for paragraph aggregation and was outperformed by the *sum of predictions* method in positive/negative/neutral document classification. Again, this strategy suffers from the same drawback of *maximum of score* strategy.
- *SimAvg*: this strategy are proposed in [72] for product review aggregation. The overall score of a product is computed based on the following equation:

$$V(P) = \frac{\sum_{i=1}^n (u(T_i(P)) * Polarity(T_i(P)))}{\sum_{i=1}^n u(T_i(P))} \quad (2)$$

where V is the overall score of a product P . Relative usefulness of individual review, $T_i(P)$, is used to weight it for calculating the final polarity [72]. In order to compute the aggregated polarity of a product based on *SimAvg*, $u(T_i(P))$ is replaced with 1 in Equation 2. In other words, the overall polarity is computed as a simple average of individual review polarities. Although *SimAvg* is a fair mechanism, it will be show in the next section that this strategy does not result in high accuracy.

- *PredAvg*: the overall polarity in this method is computed by replacing the weight assigned to each review T_i with usefulness score, $\hat{u}(T_i(P))$ in the weighted averaging mechanism of Equation 2. As pointed out in [72], a learning algorithm such as support vector regression (SVR) may be trained on discriminating features to distinguish useful and useless reviews.
- *GsAvg*: In this strategy, $u(T_i(P))$ was replaced by gold-standard usefulness score of review in Equation 2 to compute the aggregated polarity. As proposed by Zhang in [73] this score may be the percent of people who found this review useful. The results showed that *GsAvg* always outperforms *SimAvg* and *PredAvg* and in most cases *PredAvg* is slightly better than *SimAvg*.
- *Dempster-Shafer*: This strategy is based on Dempster-Shafer theory of evidence [74] and is proposed for sentence-level sentiment aggregation in [67, 75].

In this work, we follow the Dempster-Shafer strategy because it has been shown that it is not only a simple algorithm, but also is an efficient aggregation mechanism for document-level sentiment analysis [67].

The first step to apply DS theory to the score aggregation problem is to define evidence. Such evidence may be obtained from the output of the strength detection module of the proposed system (see Fig. 1). In this module, we used SentiStrength for sentence-level sentiment detection. Therefore, we consider the output of this module for each sentence (*i.e.* its score) as evidence for the overall score of a review. Defining the mass function is the next step in applying DS to our problem. In this study, normalized sentence score is used as follows [75]:

$$m(S) = \frac{senScore - lowScore}{highScore - lowScore}, \quad (3)$$

where S is a sentence, $senScore$ is its score computed by *SentiStrength*, $highScore$ and $lowScore$ are the maximum and the minimum scores of positive and negative sentences, respectively. The final step in using this strategy is to aggregate n evidence into overall evidence. This could be done using the following equation:

$$m_{1,...,n}(A) = \frac{\sum_{i=1}^n x_i = A (\prod_{j=1}^n m_j(x_i))}{1 - \sum_{i=1}^n x_i = \emptyset (\prod_{j=1}^n m_j(x_i))}. \quad (4)$$

However, to alleviate the computational complexity of the denominator of Equation (4), Equation (5) can be iteratively applied:

$$m(A) = \frac{\sum_{X \cap Y = A} m_n(X) m_o(Y)}{1 - \sum_{X \cap Y = \emptyset} m_n(X) m_o(Y)}, \quad (5)$$

where m_n and m_o depict the confidence from new and old existing evidence, respectively. Here, the old evidence is the mass m calculated in the previous iteration of Equation (5). The overall aggregated value is a number in range $[0,1]$. This number may be simply converted to a five-star scale as follows:

$$Score = round((m \times 4) + 1). \quad (6)$$

Research Questions

This study aims at proposing a lexicon-based approach for sentiment analysis in Persian. Since this is the first work that studies unsupervised sentiment analysis in Persian, our goal is to assess the viability of the proposed approach rather than proposing the optimal solution. Therefore, we should assess how well our method performs in comparison to existing supervised algorithms for sentiment analysis in Persian. Bagheri *et al.* results [12, 13] are used for this comparison since no other work exists in the literature for document-level sentiment analysis in Persian. However, their algorithm is proposed for polarity detection while our method detects sentiment strength. Thus, we should adopt our method to detect sentiment polarities and compare the performance. A secondary goal is to assess the effectiveness of our method in sentiment strength detection. The performance of standard machine learning approaches such as Support Vector Machines and Naïve Bayes is compared to the performance of our method since no other study on Persian perform this task. Therefore, we aim at answering the following research questions.

- Does the proposed method perform better than standard machine learning algorithms for sentiment strength detection?
- Does the proposed method perform as well as existing methods for polarity detection in Persian?
- Are the proposed steps for dealing with the problems of sentiment analysis in Persian necessary?

EXPERIMENTS

In the previous section, a detailed description of the proposed sentiment prediction system was presented. In this section, the datasets used in this study are briefly described and then, empirical evaluation results will be presented.

Datasets and Evaluation Metrics

In order to evaluate our sentiment analysis method, we used two datasets of online cell phone reviews written in Persian. The first dataset, *BG_Data*, was used in [12, 13] and contains short reviews about cell phones. The main limitation of this dataset is that it contains very short reviews. The average review length of this dataset is 1.91 sentences (25.47 words per review). Moreover, this dataset contains only positive/negative reviews and, hence, it may only be used for polarity detection. Therefore, we extracted the second dataset, *BS_Data*, from a well-known Persian website, *mobile.ir*, containing user comments about digital equipment. The average review length of this dataset is 4.26 sentences (75.23 words per review). Both datasets were manually annotated by human coders. In

our experiments, a random equally-sized sample of positive and negative reviews were picked.

For evaluation, two measures are used; Accuracy and Mean Absolute Error (*MAE*). Accuracy is defined as follows:

$$Accuracy = \frac{TP + TN}{TP + FP + TN + FN}, \quad (7)$$

where *TP* and *TN* are true positive and true negative, while *FP* and *FN* are false positive and false negative, respectively.

The *MAE* is the mean of the absolute differences between the predicted and the actual labels (*i.e.*, manually labeled scores). This is a common evaluation measure for comparing the effectiveness of sentiment analysis methods [61, 62, 67, 75].

Results and Discussions

In order to show the effectiveness of the proposed framework, we compare it with six wide-spread machine learning algorithms; decision tree (J48 classification), Support Vector Machines (Sequential Minimal Optimization variant, SMO), Bayesian networks, K-Star, linear regression, and Naïve Bayes [19, 67, 75]. These algorithms were implemented using *TagHelper*, a text analysis software which uses the *Weka* software [76]. Common features listed in Table 6 used to train the model using.

The first column of Table 7 shows features used to train the learning models, while the second column describe the features, and finally the third column shows the reason why we select them.

Table 7. Description of features used to train machine learning algorithms.

Feature	Description	Reason
Punctuation	Symbols such as period, comma, and question mark.	They can be used to decide about the mood of text, detecting questions.
Unigrams	Single words such as “well”.	They are easy to extract and the widely used features.
Bigrams	Ordered pairs of words such as “so well”.	They are used to capture negation or short sentiment patterns. Also may be combined with unigrams to improve classification results.
Line length	Number of words in the review.	It shows depth or level of details in the review.

(Table 7) contd.....

Feature	Description	Reason
Remove rare features	Those features that occur less than five times.	Removing features which do not generalize well.

The MAE and accuracy of the above-mentioned approaches are compared in Figs. (4 and 5), respectively.

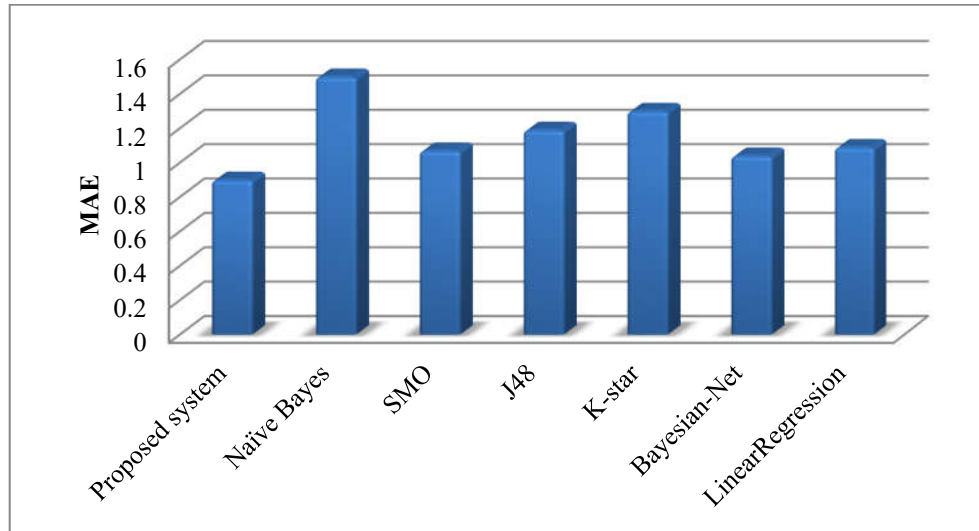


Fig. (4). The comparison of the MAE of machine learning algorithms and the proposed lexicon-based approach on *BS_Data* dataset.

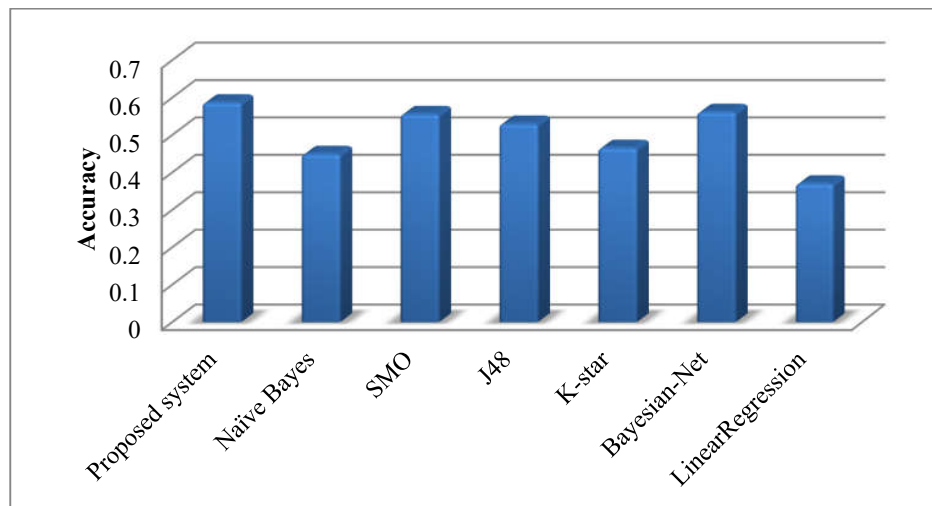


Fig. (5). The comparison of the accuracy of machine learning algorithms and the proposed lexicon-based approach on *BS_Data* dataset.

As can be seen in Figs. (4 and 5), the proposed approach outperforms machine learning methods in terms of both MAE and accuracy. This indicates that, overall, our method can better detect review sentiment scores. Moreover, as pointed out in [19, 67] the main advantage of lexicon-based approach is its lower computational complexity compared to machine learning methods. Therefore, the first research question is successfully addressed: the proposed method performs better than standard machine learning algorithms for sentiment strength detection.

In order to determine the answer to the second research question, we should test the proposed lexicon-based method on the polarity detection problem. Therefore, we should first devise a mechanism to convert five-star to binary labels. To this aim, three, four, and five-star reviews are considered as positive and one or two-star reviews are considered as negative. Two previously described review datasets are used in the experiments. The obtained results are shown in Figs. (6 and 7), respectively.

One can find two important results in Figs. (6 and 7). First, in comparison with the sentiment strength case (*i.e.*, Figs. 4 and 5), here, the overall performance of all methods is higher. This could be justified by the fact that our approach is lexicon-based and in a typical sentiment lexicon, binary labels can be more accurately specified than five-star ones. For example, consider the following review from Amazon.com:

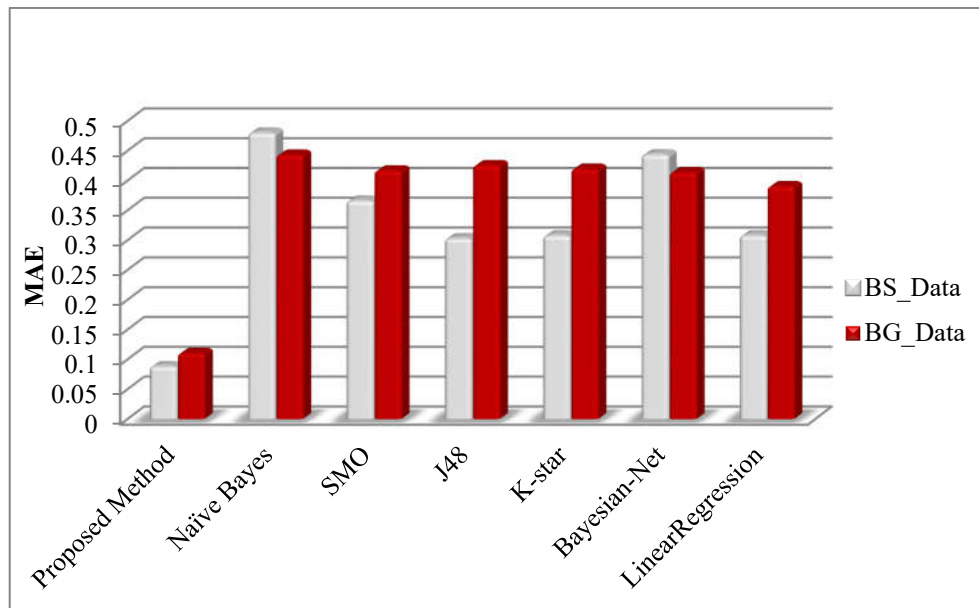


Fig. (6). The comparison of the MAE of machine learning algorithms and the proposed lexicon-based approach on *BS_Data* and *BG_Data* datasets.

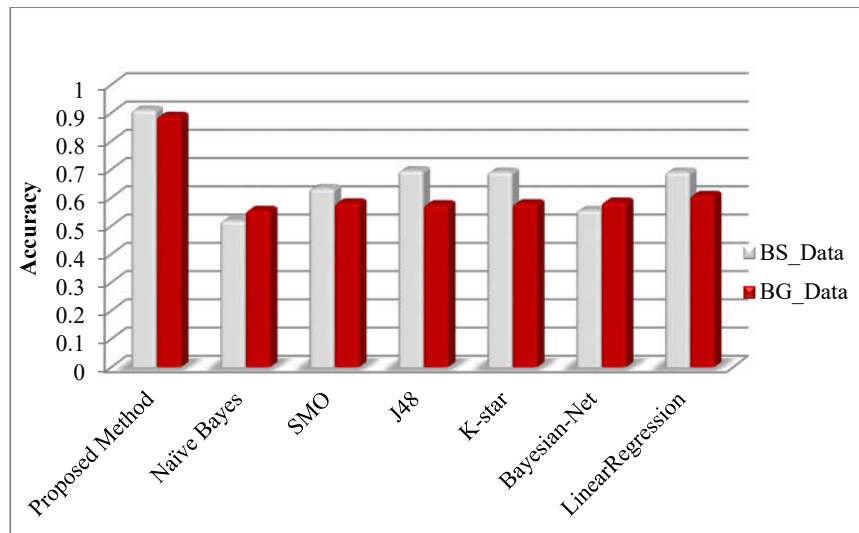


Fig. (7). The comparison of the accuracy of machine learning algorithms and the proposed lexicon-based approach on *BS_Data* and *BG_Data* datasets.

Example 3:

“Very interesting! There is a lot of fiction about artificial intelligence and this book gives a lot of good information on what artificial intelligence actually is. As a new advancement in technology AI can be very beneficial for operating more efficiently and making things easier.”

It is obvious that this is a positive review and all described methods can classify it correctly. However, due to use of just positive and neutral words in it, most algorithms classify it as five-star, while it is a four-star review as its author labeled. The story is the same for negative reviews.

The second observation is that in all cases the proposed approach outperforms other machine learning methods in terms of MAE and accuracy. This is an important advantage for our framework, because machine learning methods are not only computationally more expensive but also, are domain dependent. Moreover as pointed out by Bagheri *et al.*, “Persian text mining or specifically Persian sentiment analysis suffers from low quality” due to the fact that the size of feature space for training machine learning classifiers is very large [12]. This makes the training process very time consuming and leads to poor performance. Hence, unsupervised lexicon-based approaches are preferable for sentiment analysis in Persian. This could be used to answer the second question: the proposed lexicon-based framework is also effective for the polarity detection problem.

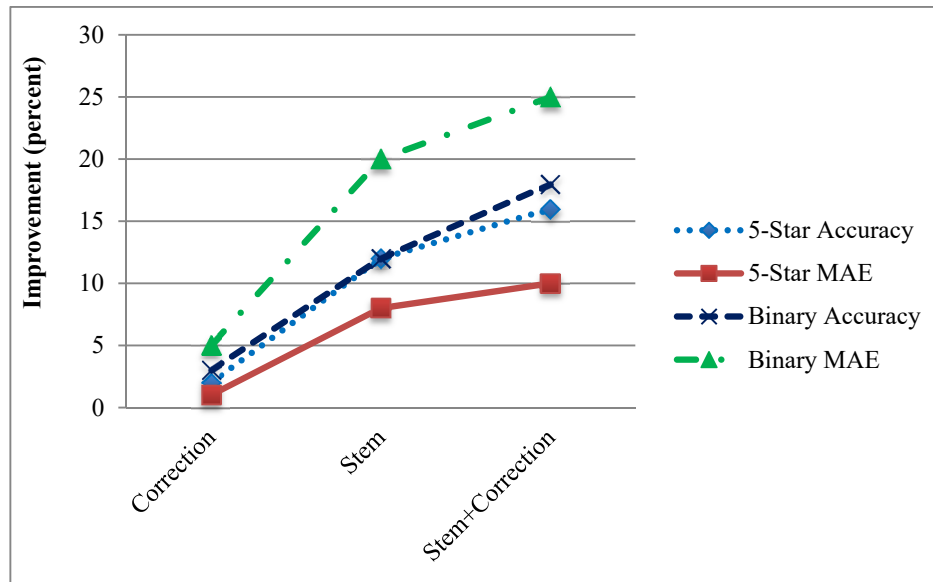


Fig. (8). The effect of using stemming and spelling correction on *BS_Data* datasets in terms of accuracy and MAE for polarity detection (Binary) and rating prediction (5-Star).

In order to show the effectiveness of the first three modules of the proposed framework, we assess three possible configurations; using stemming in isolation, using correction in isolation, and using stemming and correction together. The percentage of improvements in terms of accuracy and MAE for each configuration is plotted in Fig. (8).

As can be seen in Fig. (8), the effect of correction is less than stemming for both polarity detection and rating prediction. Moreover, the improvement of using the two steps jointly is higher than the sum of improvements for each step in isolation. This result emphasizes the importance of using the proposed steps for dealing with problems of Persian language for sentiment analysis. Therefore, the third research question was also successfully answered.

CONCLUSION

In this paper, we proposed a new framework for sentiment analysis in Persian. Our framework utilized several linguistic modules such as spelling correction and stemming to deal with the problems of sentiment analysis in Persian. Moreover, we customized the *SentiStrength* tool for Persian language to detect the strength of short informal customers' reviews. This study presents the first lexicon-based approach to sentiment analysis in Persian. Furthermore, it is the first study that directly considers the problems of Persian language for sentiment analysis.

Our framework, in contrast to supervised machine learning approaches, is robust to the size of feature space and training dataset. Moreover, the proposed framework can be used in cross-domain applications, whereas machine learning-based approaches are usually domain-dependent. We evaluated the performance of the proposed framework on two cell phone review datasets and compared it with supervised machine learning algorithms, namely Naïve Bayes, SMO, K-Star, Bayesian Networks, linear regression, and J48 decision trees. The results indicate that the proposed approach outperforms machine learning methods in terms of MAE and accuracy. Another finding is that the proposed method can be applied for polarity detection problem. Moreover, it significantly outperforms machine learning methods in the polarity detection problem.

The main novel contributions of this work are as follows: proposing an unsupervised lexicon-based approach for sentiment analysis in Persian; introducing two resources for Persian sentiment analysis, a Persian Lexicon that associates Persian sentiment word and their sentiment strength and a manually gathered dataset that is annotated by human coders for rating prediction; comparing the accuracy of supervised machine learning methods and the proposed framework in review score prediction; adopting the proposed system for polarity detection problem and assessing its performance on two datasets.

Persian is a challenging language for sentiment analysis and there are few resources and tools for processing Persian texts. Therefore, developing new lexical resources and large-scale datasets for sentiment analysis in Persian would be a suggestion for future research. Another promising direction for future work would be designing customized approaches for other tasks in sentiment analysis on Persian language such as emotion detection. Moreover, fine-grained sentiment analysis (*i.e.*, phrase- and aspect-level) using the proposed unsupervised approach can also be considered as future research.

CONFLICT OF INTEREST

The authors confirm that this chapter content has no conflict of interest.

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CHAPTER 6

The Age of the Connected World of Intelligent Computational Entities: Reliability Issues including Ethics, Autonomy and Cooperation of Agents

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Abstract: In this chapter, Internet of Things is perceived as a special case of Connected World which in turn is considered a step in tool making. Five major stages of tool making in the history of civilization are outlined and it is pointed out that passing from one era to the next one requires a new entity which are: energy, knowledge processing ability, intelligence, connectedness, and superintelligence. The eras thus identified are: hunter-gatherer and agriculture age, industrial age, information age (also called knowledge age, informatics age), cybernetics age, connected age, and post-human era. Then what may go wrong in a connected world is elaborated on; some counter-intuitive views about cooperation and autonomy are expressed and role of ethics is stresses especially in connected world.

'Would you tell me, please, which way I ought to go from here?' 'That depends a good deal on where you want to get to,' said the Cat.

'I don't much care where--' said Alice. 'Then it doesn't matter which way you go,' said the Cat.

'--so long as I get SOMEWHERE,' Alice added as an explanation. 'Oh, you're sure to do that,' said the Cat, 'if you only walk long enough.' [1].

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1. INTRODUCTION

We live in a connected smart world dominated by especially non-human autonomous entities with knowledge processing abilities (mostly software agents). The increase of the connectedness as well as the intelligence of the knowledge processing entities are accelerating. The increases of this connectedness and the ambient intelligence lead us to an era which is already identified by different terms such as Internet of Things (IoT) a term coined in 1999 by Kevin Ashton [2] and the variants of the term IoT such as Industrial Internet of Things, Military Internet of Things [3], and Internet of Nano-Things [4], [5]; infohabitants [6]; cyber-physical systems [7]; Internet of Services (IoS) [8]; and Industry 4.0 or the fourth industrial revolution [9]. Similar to the case of any new important technology which brings its own culture, the increasing connectedness of intelligent entities brings and will continue to bring its own culture. In addition to the desirable contributions, technological advancements may also bring undesirable and unwanted side effects.

The increased reliance on computerization, coupled with dynamic environments laden with uncertainty makes ethical decision-making become more pronounced with outcomes that have serious life-death consequences. Internet of things—mostly with software agents—is also being used widely and its domain of application is broadening rapidly. Another aspect of computerization is super-intelligence which may have some humanly uncontrollable and undesirable effects.

1.1. Significance of the Problem

As autonomous cars [10] and trains [11] transition into use and drones are deployed to conduct remote missions [12], there is an increasing fear of causing civilian casualties [13] and the question is raised on how these smarter computers will be used [14]. Concomitantly, recent reports [15] indicate that drone operations are becoming more demanding and stressful, leading to increased rate of turnover and cuts in flights. Moreover, as millions of vehicles are expected to be endowed with autonomy, taking algorithmic morality seriously has never been more urgent. We believe increased levels of autonomy can be allowed if and only if trust can be instilled in the moral decision-making capacity of cyber agents. Such ability can also assist human operators, who are prone to making mistakes in their technology-mediated inter actions with the social, physical, and natural environment [13]. Hence, there is a need for a balanced integrated approach to

support ethical decision-making that takes into consideration the person characteristics, as well as the situational factors.

1.2. Motivating Scenarios

Suppose an Unmanned Aerial Vehicle (UAV) is about to crash and needs to choose a crash site. There are two options: a small village and a location in the vicinity of where the operator's relatives live. Clearly, the operator has a conflict of interest and may not choose the action that is consistent with a moral principle. In this case, should the cyber agent predict the potential for deviation from ethical rules of behavior and take over the authority or act as an ethical advisor by explaining the ethical rationality of other courses of actions?

Similarly, suppose a natural disaster occurs, requiring immediate response from a diverse group of agencies and groups. Effective response requires timely situational awareness, which can be provided by autonomous systems. During the mission, the execution of a plan may require evaluation of decisions and consensus on measures of acceptable decisions: Is it the utility in terms of “greatest number of lives saved” or a policy aimed at “the number of years of lives saved”, which give priority to vulnerable young. Moreover, deciding on resource reallocation from one community to another based on predictions of best outcome for the most persons should also be moderated by the obligations that individuals vest in federal, state, and local governments. The duties perspective also necessitates protection of first responders, who have obligations to save members of the community. Such conflicts between consequences, duties, and obligations should be resolved while recognizing the significance of rights, fairness, and cultural norms.

In modeling and simulation (M&S), several techniques are used to assure the reliability of the models used. Once, relevant aspects of the characteristics of a model are assumed to be acceptable, its computerization is scrutinized using several verification techniques (V&V) [16, 17]. Failure avoidance (FA) was introduced as an additional layer of protection in M&S to assure that the problem related with the simuland will be solved properly without any undesirable consequences [18]. Most of the three aspects of reliability assurance techniques, *i.e.*, V&V, Quality Assurance (QA) [19], [20], and Failure Avoidance [18], [21] would be applicable in Internet of Things and in superintelligence studies.

However, additional reliability assurance (RA) issues [22] need to be resolved for Internet of Things as well as for superintelligence. Some vital issues include autonomy, cooperation, misunderstanding as well as unethical behavior by intelligent agents.

1.3. Organization of the Chapter

In section 2, the concept of connectedness and its several dimensions are clarified. Examples for and benefits of each type of connectedness are also given. We stress the fact that in each category of connectedness, the element which assures the connection is knowledge.

In section 3, we elaborate on how connectedness started and evolving as part of the evolution of tool development. We also elaborate on: (1) knowledge and knowledge processing, (2) knowledge processing devices, machines and/or systems, (3) entities with additional knowledge processing abilities, as well as (4) computational (or machine, or artificial) intelligence as well as superintelligence and (5) explain their role in a connected world.

In section 4, we briefly elaborate on reliability assurance as well as several categories of failure avoidance in systems.

In section 5, we discuss and give several references on what might go wrong in connected world and superintelligence. We elaborate on some of the undesirable side effects of connectedness and superintelligence. In addition to a brief review of traditional sources of failures, we point out some counterintuitive issues such as autonomy and cooperation as sources of failures in a connected smart world, especially at the age of superintelligence. We also point out the importance of ethics and values to avoid some of the possible failures in our connected world. We also point out limitations of ethics in uncivilized environments.

The final section is devoted to our conclusion and is followed by a list of references.

2. CONNECTED WORLD

From a systemic perspective, we realize that connectedness exists even in the universe where objects are connected, to attract or to repel, by several types of forces such as gravitational forces, weak and strong forces, and electromagnetic forces. At the other end, we elaborated on the connectedness of simulation models, *i.e.*, model coupling [23], [24]. The second article was for bio-inspired modeling and simulation.

In this chapter, we also focus on connectedness by knowledge including the case where knowledge processing is by superintelligence. Here the term knowledge is loosely used to also denote data and information. We also elaborate on reliability issues which may be raised.

The concept of “Connected World” (CW) is a generalized view of Internet of Things and Internet of People. However, it includes many other types of elements.

2.1. Characteristics of the Connected World

As seen in Fig. (1), Connected World has several characteristics:

	Characteristics	Aspects			
Connected World	consists of	elements	knowledge processing entities (including humans and other infohabitants) (- entities for knowledge processing and - especially entities with added knowledge processing abilities)		
	can sense	what	themselves	and/or	their environments
		by	sensors	and/or	transducers
	can process knowledge	located	locally	and/or	remotely - by dedicated computer(s) - by computation-as-a-service
		to be triggered	on demand	and/or	by subscription
	can decide	how	locally	and/or	centrally
		who	individually	and/or	collectively
		about what	themselves	and/or	their environments
	acts	how	actuators	and/or	knowledge sharing

Fig. (1). Some characteristics of connected world.

1. It consists of knowledge processing entities including humans and other infohabitants. “Infohabitants of the connected information systems include individuals, organizations, smart appliances, smart buildings, and other smart systems, as well as virtual entities acting on their behalf that can best be represented by software agents [25]. Hence, realistic cognitive abilities of software agents such as influence of personality to decision making and problem solving is of practical computational importance” [26]. Hence, it involves Internet of Things (IoT) [27] which consist of devices/machines/systems as well as Internet of People (IoP) [28], and Internet of Animals (IoA) [29].
2. Elements of a Connected World can sense themselves and/or their environments by sensors and sensor fusion and/or transducers [30].
3. Elements of a Connected World can process knowledge locally and/or remotely. In the case of remote computing, knowledge processing can be done

by dedicated computer(s) or as computation-as-a-service (on demand and/or by subscription). In the latter case, an element may receive pertinent knowledge from a remote computer to enhance its knowledge base.

4. Elements of a Connected World can decide locally or centrally to control themselves and/or their environments. They can decide individually and/or collectively. Ants are an interesting example for collective non-central control [31].
5. Elements of a Connected World can act using actuators and/or by knowledge sharing.

2.2. Some Examples for Connected Entities

Some examples of connected entities where the connecting agent is knowledge are:

1. Connected *computers* (or computer networks: intranets, Internet).
2. Connected *documents*: hypertexts. In a library, for example, books related to a domain normally are shelved together. Even though they are topically related, they are not connected. However, a hypertext is a way to connect documents on the same or different computers.
3. Connected *people*: Mobile phones and social media connect people through knowledge sharing. Internet-connected eye glasses (smart glasses) add another dimension to connect people to knowledge such as maps, e-mails, and to search engines. Some of the Internet-connected eye glasses allow holographic displays for augmented reality.
4. Connected things: *Internet of Things* (IoT). IoT can be specialized to application areas such as Industrial Internet of Things (IIoT) or connected weapons, sensors, and computers. Connected entities are also called *inhabitants* which can consist of things (including sensors and actuators as well as devices, machines, and systems), software agents, and humans.
5. Connected animals: *Internet of animals* is used to track animals, monitor their health, and to regulate their behavior.

All aspects of Connected World have their own benefits; however, like most technologies, they can also be used for malicious ends. For example, hypertexts ease access to information / knowledge; however, in addition to malware attached to hypertexts, potential problems of privacy and security also exist. On the other end, human rights violations are also shared on web.

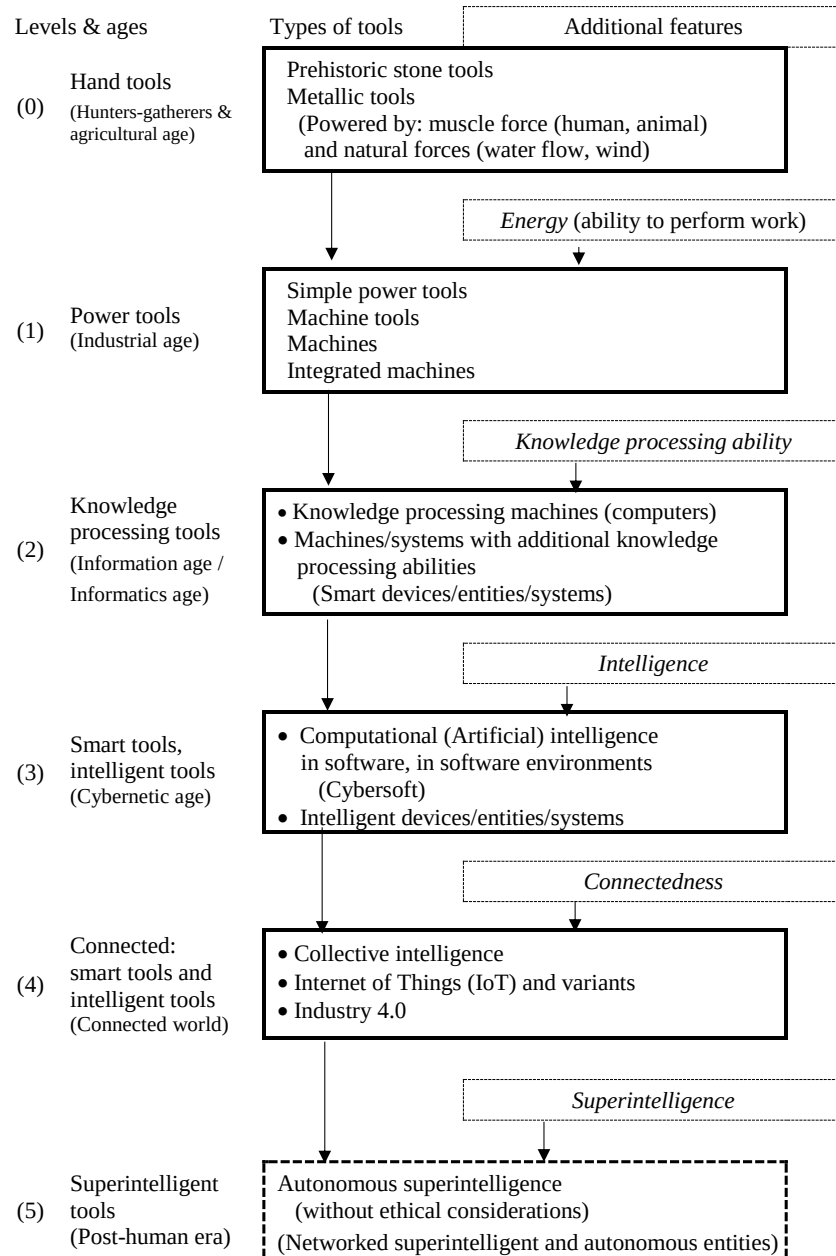


Fig. (2). Levels of tool developments and corresponding eras.

3. THE EVOLUTION OF THE CONNECTED WORLD

The concept of “Connected World” is an important step in tool development.

Major levels of tool development and corresponding major eras in human history are outlined in the sequel. Levels of tool developments are outlined in Fig. (2). where evolution from a level to the next is caused by an additional feature which may be energy (steam, electricity), knowledge processing ability, intelligence, connectedness, and superintelligence.

3.1. Hand Tools

History of tool making is as old as history of humankind. It is estimated that the earliest stone tools are developed “at least 2.6 million years ago” [32]. Many types of tools have been made and are still in use [33]. This long period of human history corresponds to eras of hunter-gatherers and pre-agriculture; and afterwards to agriculture era. During this long era, first, human and animal muscle forces and afterwards, natural forces such as wind and water flow were used to power early tools. Tools powered by human muscle energy are called hand tools.

As Stout suggests it, ancient tool making is of particular interest, since it may cast light about the human cognitive development: “So it may be premature to abandon the idea that ancient stone tools might provide important information about human cognitive evolution. Teaching and learning increasingly complex toolmaking may even have posed a formidable enough challenge to our human ancestors that it spurred evolution of human language. In fact, many neuroscientists now believe that linguistic and manual skills both rely on some of the same brain structures” [34].

3.2. Power Tools (Industrial Age)

Hand tools and other tools powered by human, animal, and natural forces, such as water flow and wind, drastically increased their usefulness and importance, after energy (or ability to perform work) such as steam and electrical energies, was integrated to them. At the basic level were simple power tools, machines, and machine tools. In assembly lines, power tools, machines and humans were working for manufacturing. Some interesting references document history of machines are [35], [36].

With power tools and power-driven machines, industrialization and all associated benefits as well as social problems started around 1760. This was the beginning of the industrial revolution.

However, at the beginning, there were reactions about industrialization, fearing that it would entail job losses. In England, textile workers who realized that with the new technology, their skills could be replaced by low-wage workers, rebelled between 1811 and 1816. They were known as Luddites or machine destroyers

[37]. Industrialization also required high number of workers who relocated from agricultural areas to the cities; coupled with poor planning, this entailed the birth of many slum areas around urban areas where factories were built. However, progress is inevitable and industrialization brought also many benefits.

3.3. Knowledge Processing Tools (Information Age/Informatics age)

Tools or machines for knowledge processing and with additional knowledge processing abilities are the essence of information age/knowledge age (better description is informatics age [38]). There are two categories of tools, devices, machines, and systems so far as their knowledge processing abilities are concerned: (1) tools for knowledge processing, including several types of computers and (2) entities which are not meant for knowledge processing, but with additional knowledge processing abilities, they can perform better their main goal of existence [39].

3.3.1. Advancements in Knowledge Processing Tools

Fig. (3), adapted from Ören [39], outlines the elements of knowledge processing tools, including several types of computers. Knowledge processing tools existed since antiquities. All of them can be considered wired or stored program devices. Wired devices can be fixed or variable wiring. The fixed-wiring devices, cited for historic reasons, include: abacus, astrolabe, Al-Biruni's gear calendar computer, odometer, antikyera mechanism, harmonic transformer linkages, and bar-linkage computers [39]. Astrolabe was used to locate and predict location of celestial objects such as sun, moon, planets, and stars [40]. Some information about Al-Biruni's gear calendar computer and antikyera mechanism are given by Sparavigna [41]. Variable-wired devices included unit records –punched card machines– as well as analog and hybrid computers.

Some of the textile machines such as Jacquard looms of the industrial era, were rather well advanced [42]. To be able to weave intricate patterns, Jacquard looms used chains of punched cards. To change the pattern, one had to change the chain of punched cards. Later, these punched cards were the source of inspiration to early punched card machines (unit records).

Stored-program devices –the focus of our interest– are digital computers which can be personal computer (PC), minicomputer, mainframe computer and supercomputer. Personal computers can be desktop computer, laptop, personal digital assistants (PDA), tablet, phablet, smartphone, wearable computer, E-textile (electronic textiles, smart fabrics, smart garments, smart clothing), implantable computer, and zero-size intelligence [43].

Tools (devices, machines, systems) for knowledge processing	Wired devices, tools, systems	Fixed-wired devices, tools, systems	Abacus Astrolabe Al-Biruni’s gear calendar computer Hodometer Antikythera mechanism Harmonic transformer linkages Bar-linkage computers		
		Variable-wired devices, tools, systems	Unit records Analog computers Hybrid computers		
	Stored-program devices, tools, machines, systems	Digital computers	Personal computer (Microcomputer)	Desktop computer Laptop	
				Personal Digital Assistants (PDA) Tablet, Phablet Smartphone Wearable computer (smart glass) E-textile (electronic textiles, smart fabrics, smart garments, smart clothing)	
				Implantable computer System-on-a-chip Zero-size intelligence	
			Minicomputer Mainframe computer		
			Supercomputer (High performance computer)	Terascale computer Petascale computer Exascale computer	
Quantum devices	Quantum computers				

Fig. (3). Knowledge processing tools

The significance of PCs is the facility they provide to connect people and software agents to knowledge, to other people, to other software agents, and to other knowledge processing devices. History of computers can be found in [44]- [46].

Supercomputers, also called High Performance Computers (HPC), such as petascale computers, or exascale computers, have even strategic importance in providing computational power to tackle very large scale and complex problems [47]. Exascale computing can perform over one exaFLOPS (exa floating point operations per second) where, exa = 10^{18} , or billion times billion).

3.3.2. *Advancements in Entities with Additional Knowledge Processing Abilities*

Fig. (4) outlines entities with additional knowledge processing abilities. The aim of these entities is not knowledge processing; however, with the additional

knowledge processing ability they have they can perform their original goal much better.

Entities with additional knowledge processing abilities	Wired devices	Fixed-wired	Automata	
		Variable-wired	Jacquard loom	
	Computer-embedded machines (CEM) / systems (CES)		Entities (devices, machines, things, buildings, systems, ...) which are: - <i>Smart entities</i> - <i>Intelligent entities</i>	Pre-programmable systems Re-programmable systems Self-programmable systems

Fig. (4). Entities with additional knowledge processing abilities.

Very early examples include several types of automata, developed firstly by al-Jazari in 12th century [48]. Next generation was punched-card controlled machines such as Jacquard loom –which was also a stepping stone to the information age [42].

Commonly used terminology for entities with additional knowledge processing ability is formed by adding the term “smart” at the beginning of such entities. For example, smart phone, smart grid, smart building, smart bridge, smart city, *etc.* Hence, in these entities, “smart” designates the fact that these entities have additional knowledge processing abilities to be able to satisfy their original goals better. Technically these entities are computer-embedded machines (CEM) or computer-embedded systems (CES) [39], or briefly, embedded systems. The type of computing is embedded computing. One should also distinguish the fact that all knowledge processing is not necessarily “intelligent.”

3.4. Smart Tools and Intelligent Tools (Cybernetic Age)

Cybernetics was defined by its founder Norbert Wiener in 1948 as “the scientific study of control and communication in the animal and the machine” [49]. We use the following generic definition for intelligence: “intelligence (human, animal, or machine) is an adaptive and goal-directed knowledge processing ability” [50]. Artificial Intelligence (AI) is also called –more appropriately– computational intelligence (CI) or machine intelligence (MI). Many tools augment human abilities. For example, telescopes augment ability to see at a distance. Similarly, when computational intelligence is perceived from this perspective, it is also called Intelligence Augmentation (IA). Software agents are often used to implement computational intelligence. “Agents are autonomous software modules with perception and social ability to perform goal-directed knowledge processing over time, on behalf of humans or other agents in software and physical environments. When agents operate in physical environments, they can be used in

the implementation of intelligent (smart) machines and intelligent (smart) systems and they can interact with their environment by sensors and effectors. The core knowledge processing abilities of agents include: goal-processing, goal-directed knowledge processing, reasoning, motivation, planning, and decision-making [51].

There are several types of intelligence [52]. As outlined in Table 1, different aspects of intelligence are elaborated on in another chapter of this book [53]. Since definitions are given in that chapter, they are not repeated here. The list is given here to show the richness of the concept of intelligence regardless whether they are still achievable or not in computational intelligence.

As it is the case of a calculator, mere knowledge processing does not imply intelligence. For this reason, it may be expected that some of the devices which are currently called “smart” later may become much more advanced so far as their knowledge processing abilities are concerned, then they may be labelled as “intelligent.”

Computational intelligence in software was also called Cybersoft [54]. “Smart computing is emerging as an important multidisciplinary area, which can be broadly classified into two major topics: how to design and build smart computing systems, and how to use computing technology for resource sustainability to improve the human experience. Applications of smart computing span different business areas including, but not limited to, transportation, energy, environmental protection, resource management, healthcare, security, banking, entertainment, and social media” [55]. Smart computing also includes cyber-physical systems [56]. “Cloud computing, also on-demand computing, is a kind of Internet-based computing that provides shared processing resources as well as data to computers and other devices on demand. It is a model for enabling ubiquitous, on-demand access to a shared pool of configurable computing resources” [57]. They can be pre-programmable systems, re-programmable systems, and self-programmable (or auto-programmable) systems.

Table 1. Several types of intelligence (adopted from [53].

Abstract intelligence	
	Linguistic intelligence
	Logical-mathematical intelligence
	Musical intelligence
Concrete intelligence (Mechanistic intelligence)	
	Visual-spatial intelligence

(Table 1) contd.....

	Naturalistic intelligence
	Contextual intelligence
Emotional intelligence	
	Interpersonal intelligence (Social intelligence)
	Intrapersonal intelligence
	Body-kinesthetic intelligence
Experiential intelligence	
	Fluid intelligence
	Crystallized intelligence (Learned intelligence)
	Practical intelligence
Componential intelligence	
	Neural intelligence
	Reflexive intelligence
	Learnable intelligence

3.5. Connected Tools(Connected World of Intelligent Computational Entities)

Connected tools can provide collective intelligence by Internet of Things (IoT) and its variants such as Industrial Internet of Things (IIoT), Military Internet of Things (MIIoT), Internet of nano Things, and wireless sensor networks. In industry, they are also referred to as Industry 4.0. A rich source of references about sensor networks is Libelium's page where over 60 sensor applications as well as additional references are cited under the following categories: smart cities, smart environments, smart water, smart metering, security and emergencies, retail, logistics, industrial control, smart agriculture, smart animal farming, domotic and home automation and e-health [58].

Several possibilities of the Connected World such as e-business, e-government, e-democracy are already part of the current culture, at least in some countries. Military Internet of Things has already a solid background by networked sensors and sensor fusion. Unmanned devices may be useful in collecting data, understanding and assessing context, and autonomously or semi-autonomously triggering actions based on situational awareness.

It appears that the future of connected smart tools and connected intelligent tools is promising. Maile reported even in 2013 "What will cloud computing in government look like in the future? Johnson says that as we become more surrounded by data-driven intelligence about our lives, perhaps gathered by our

devices, cars or even clothing, the power of aggregating information to the cloud has the potential to result in benefits and government services we have not yet imagined” [59].

3.6. Superintelligence (Post-human Era?)

This last level of tool development, *i.e.*, connected superintelligent autonomous entities (without any ethical considerations) and associated social order does not yet exist. However, it entails high and unprecedented risk for humanity. For this reason it is labelled “Post-human era” and it is worth considering all possible risks and take counter measures before it might be too late.

An important development in computational intelligence is the prospect of superintelligence [60]- [67]. The term superintelligence has two meanings: (1) a hypothetical entity that has intelligent knowledge processing abilities much more superior than humans and (2) the intelligence of such an entity. The original definition by Bostrom is: “By a ‘superintelligence’ we mean an intellect that is much smarter than the best human brains in practically every field, including scientific creativity, general wisdom and social skills. This definition leaves open how the superintelligence is implemented: it could be a digital computer, an ensemble of networked computers, cultured cortical tissue or what have you. It also leaves open whether the superintelligence is conscious and has subjective experiences” [60]. One of the features attributed to superintelligence is its ability to self-improve [62, p. 82].

In the history of tool development, all tools surpass (or extend) human abilities. For example, microscopes and telescopes allow people to see what they couldn’t see directly. An airplane or rocket allows humans to go to distances that they couldn’t go otherwise. The intelligence of computers is also advancing. For example, Google’s AlphaGo A.I. defeated, for the second time, a star human Go player [68]. And one would expect to have more capable computational intelligence applications.

4. WHAT MIGHT GO WRONG IN THE AGE OF THE CONNECTED WORLD

4.1. Approaches for Basic Sources of Failures

It is important and even vital to assure reliability of connected world of smart, intelligent, and superintelligent entities. Some relevant concepts and techniques developed for modeling and simulation over the years are also applicable for the reliability assurance of the connected world. They include several techniques of validation and verification (V&V), quality assurance (QA), and failure avoidance

(FA). For Validation and Verification see [16], [17], for Quality Assurance which systematizes quality evaluations, see [19], [20 [69]. Failure Avoidance was proposed to identify issues which could not be attacked easily by V&V and QA. For FA, see [18], [21].

Software reliability is of primordial importance since all knowledge processing of a connected world are done by software residing on computers [70], [71]. Reliability assurance for mission critical activities is very important [72]. Some software errors can even be lethal as it was in the case of Therac-25 radiation therapy device that administered –due to programming error– radiation doses hundred times over the normal dose and caused death of the patients [73]. Software bugs and glitches are still common. Many software errors are listed [74], [75]. Corrupted code being some of them [76].

One of the characteristics of advanced software agents is the ability to understand including understanding emotions. However, if a system's (or agent's) behavior would depend on understanding, then limitations of its ability to properly understand *i.e.* its misunderstanding– may have detrimental effect on the performance of the system. In another article, some of the many sources of misunderstanding are outlined after a review of well over 60 types of machine understanding in four categories [77].

It is a fact that computational intelligence is surpassing itself and the advancements are already very impressive. Even the prospect of superintelligence is sufficient to be alarming. See for example, Barrat who reported: “Why Stephen Hawking and Bill Gates are terrified of Artificial Intelligence [78]. The prospect of dominance of superintelligence is also called post-human era since the machines may become far more superior and powerful than humanity [79]. The prospect of Machine Machiavellianism may be even worst then human Machiavellianism [80].

In a hypertext, hidden malware may create serious damages. Logical errors in rule-based systems which should also be eliminated may be very dangerous. Misinformation may be disseminated (by non-erroneous software) to create havoc in systems. Hence, it is highly desirable that software controlled networked systems should be free of several types of errors which might be due to:

1. Software bugs, including logical errors;
2. Lack of defensive programming practices (for the Therac unit, for example, the output could be checked with respect to some allowable thresholds);
3. Dormant embedded malignant code in systems having some sensors can be triggered by a series of predetermined signals. For example, a radar can interpret x , y , z coordinates of a moving target as $x+\Delta x$, $y+\Delta y$, and $z+\Delta z$,

where Δx , Δy , and Δz would be random variables, hence, its acuity can be damaged temporarily when enemy is attacking or for ever.

4. Inconsistencies of the rules in a rule-based computational intelligence system.

4.2. Some Counterintuitive Views of Autonomy and Cooperation

4.2.1. Autonomy

Autonomy is an important and multifaceted concept with roots in philosophy. “Autonomy is an individual’s capacity for self-determination or self-governance. ... *Personal autonomy* is the capacity to decide for oneself and pursue a course of action in one’s life, often regardless of any particular moral content.” [82], [83].

To show the richness of the concept, (Table 2) lists several types of autonomy.

Table 2. List of several types of autonomy.

Absolute autonomy	National autonomy
Accountable autonomy	Normative autonomy
Adaptive autonomy	Open autonomy
Adjustable autonomy	Patient autonomy
Autonomy	Personal autonomy
Civilized autonomy	Physician autonomy
Cultural autonomy	Political autonomy
Diminished autonomy	Popular autonomy
Economic autonomy	Presidential autonomy
Energy autonomy	Professional autonomy
Ethical autonomy	Quasi-autonomy
Existentialist autonomy	Regional autonomy
Fiscal autonomy	Relational autonomy
Formidable autonomy	Responsible autonomy
Functional autonomy	Semiautonomy
Group autonomy	Social autonomy
Individual autonomy	Stoic autonomy
Irresponsible autonomy	Tamed autonomy
Judicial autonomy	Territorial autonomy
Kantian autonomy	Unaccountable autonomy
Learner autonomy	Untamed autonomy
Legal autonomy	Urban autonomy

(Table 2) contd.....

Moral autonomy	Work autonomy
Municipal autonomy	Workplace autonomy

“The importance and nature of the value of autonomy is debated within political theory, but is generally intertwined with the right to pursue one’s interests without undue restriction.

... *Ethical autonomy* concerns a person’s desires in the quest for the good life, in the context of the person’s values, commitments, relationships, and communities. *Legal autonomy* is thus the right not to be forced into a particular set of values and commitments, and is neutral toward them.

“*Political autonomy* concerns the right to participate in collective self-rule, exercised with the other members of the relevant community. Finally, *social autonomy* concerns whether an agent has the means to be an equal member of this community. Attending to social autonomy helps to demonstrate the responsibility of members of the community to consider each other’s needs, and to evaluate political and social structures in terms of whether they serve to promote the social autonomy of all of the members.

... Beauchamp and Childress accept that a patient can autonomously choose to be guided by religious, traditional, or community norms and values. While they acknowledge that it can be difficult to negotiate diverse values and beliefs in sharing information necessary for decision-making, this does not excuse a failure to respect a patient’s autonomous decision: “respect for autonomy is not a mere *ideal* in health care; it is a professional *obligation*. Autonomous choice is a *right*, not a *duty* of patients” [81, 83].

Autonomy is considered one of the salient features of software agents. For example, an early definition of agent is: “a software entity which functions continuously and autonomously in a particular environment, often inhabited by other agents and processes [84].” [25]. Similar to human societies, unchecked autonomy of software agents may become (extremely) dangerous, even for humanity. Mechanisms to ensure civilized or responsible autonomy need to be devised and additional approaches need to be explored against ways to circumvent untamed autonomy. Absolute autonomy by non-ethical entities may be undesirable and even be dangerous, especially with widespread use of communicating autonomous agents potentially controlling a myriad of entities [85, 86]. To avoid high risks due to the actions of autonomous weapon systems, development of several types of machine understanding techniques can be useful [87].

Relationships in a connected world may be either non-zero-sum game or zero-sum game. The case of non-zero-sum relationship is an ideal win-win situation. In zero-sum relationships, “a gain for one side entails a corresponding loss for the other side” [88]. Due to (uncivilized aspect of) human nature, zero-sum relationships are unfortunately more common. However, dishonesty is not limited to some people; sufficiently advanced any non-human intelligence such as software agents devoid of ethical values can have also dishonest behavior [85], [86]. An intelligent knowledge processing system with a goal non-compatible with human values and goals [89] may have detrimental effect for humans. Hence, for most beneficial relationships in the connected world, –if possible– it may be more prudent to take necessary precautions not to be abused. Using autonomous software systems to control lethal weapon systems has to be avoided. Even as early as mid-1980s, Parnas “took a public stand against the US Strategic Defense Initiative (also known as ‘Star Wars’)” [90]. Some scientist –realizing the dangers– want even to ban development of autonomous lethal weapons [91].

The spectre of superintelligence which may act autonomously is indeed a source of deep concern and has to be carefully studied and necessary countermeasures need to be taken before it may be too late for humanity. In the definition of intelligence, *i.e.*, “adaptive and goal-directed knowledge processing ability” there is no guaranty of protection from any wrong doing by superintelligence. A slight difference in the priority of values may become very dangerous. For example, Niccolò Machiavelli (1469-1527), in his well-known book, the Prince, gives priority to expediency (fitness for purpose) over morality [92]. “Machiavellianism has historically come to mean that effectiveness alone counts in politics; political actions should not be restricted by considerations of morality, of good or evil” [93]. Machine Machiavellianism (MM) may entail consciousness from the part of machine intelligence as it was the case of well-known science fiction: “2001 A Space Odyssey” by Clarke [94] where the computer (HAL) betrayed humans. Limited knowledge we may have to create machine consciousness may appear to be our safeguard against MM. However, this comforting feeling may not guaranty us from a potential danger. Any intelligence –superintelligence or not– to satisfy a goal non-compatible with (civilized) human values may become dangerous; and this danger may be much greater in the case of superintelligence in a connected world.

4.2.2. Cooperation

Cooperation is considered a desirable behavior [95]. “Cooperation is becoming an important paradigm for both civilian and military applications. Holonic systems are excellent candidates to conceive, model, control, and manage dynamically organizing cooperative systems. A holonic system is composed of autonomous

entities (called holons) that can deliberately reduce their autonomy, when need arise, to collectively achieve a goal. A holonic agent is a multi-agent system where each agent –called a holon– acts with deliberately reduced autonomy to assure harmony in its cooperation in order to collectively achieve a common goal” [96]. Holons were first introduced by Koestler [97]. A history of holons is written by Edwards [98]. Some examples of applications of holonic agents in simulation are given in [99]- [102].

There is a series of conferences for enhanced collaboration [103]. Within this conference, a track of sessions is devoted to “Adaptive Computing (and Agents) for Enhanced Collaboration (ACEC) [104].” Such simulation studies are beneficial for the development of advanced collaborative systems.

Although, most often, cooperation is a desirable feature, there are many possibilities where cooperation may become undesirable and even harmful. Forced cooperation as well as unethical cooperation may be undesirable. Autonomous entities such as software agents and holons need to have abilities to decide when not to cooperate, especially when they are coerced by a superintelligence. Development of appropriate mechanisms for software agents and holons to detect fake cooperation requests and deny cooperation would be desirable in the age of connected intelligent world. Even if not originated from malignant intelligence or superintelligence (such as hacker agents), such cooperation requests may be originated by human hackers.

4.3. Ethics and its Limitations (in Uncivilized Environments)

“Civilization is social order promoting cultural creation. Four elements constitute it: economic provision, political organization, moral traditions, and the pursuit of knowledge and the arts. It begins where chaos and insecurity end. For when fear is overcome, curiosity and constructiveness are free, and man passes by natural impulse towards the understanding and embellishment of life” [105, p. 1]. Respect for the rights of others is the foundation of ethics [106], [107]. The increased reliance on computerization, coupled with dynamic environments laden with uncertainty makes ethical decision-making become more pronounced with outcomes that have serious life-death consequences. Autonomous cars and driverless trains [11] are already transitioning into operational use in controlled environments. In Air Force, drones are being deployed to conduct remote missions. However, drone operations are becoming more demanding and stressful, resulting in the increased rate of turnover among drone operators and hence cuts in flights [15]. One option to help mitigate these problems is to endow drones with increased degree of autonomy. For tasks that require skill and rule-based control, drones are highly effective [108], but they may be required to share

control, make recommendations, or receive supervision when knowledge-based or expertise-driven decisions are necessary, especially under uncertainty and in the presence of conditions that can lead to ethical concerns. In such cases, increased levels of drone autonomy and decision-making can be allowed if and only if trust can be instilled in the moral reasoning ability of such agents [13]. Such ability can also help guide human operators, who are boundedly rational and therefore are prone to making mistakes.

Ethics play a very important role in civilized societies. However, even in some human societies, unfortunately, unethical behavior is common and may continue to be harmful to the societies. Since, finding mechanisms to protect humans and other infohabitants of a connected world from unethical behavior is an important issue [85], [86], the possibilities need to be explored to cast light for the realization of advanced moral agents as well as their protection from unethical agents (and unethical humans).

The field of machine ethics has generated wealth of information that involves methods, tools, and strategies for engineering artificial systems that can exhibit the characteristics of moral behavior. As a corollary, the use of computational methods is facilitating both the identification of gaps and the advancement of normative theories of ethical decision-making by providing an experimental testbed. Development of programs that simulate and engineer ethics into the decision-making cycle of autonomous systems brings the requisite level specificity and formality to modeling and exploring the consequences of these theories.

The most commonly used AI method in computational ethics are reasoning, including planning, deductive reasoning with deontic logic, analogical reasoning, constraint satisfaction, and (social) learning. Analogy-based reasoning has emerged as an effective method that has been successful in developing prototypes that can address practical problems. In practice, humans often examine moral judgments about a particular issue in a given context by recalling similar cases and contemplate the coherence of their beliefs with the characteristics of such previous cases. The use of search algorithms that explore problem and solution state spaces that satisfy specific constraints is also pervasive in AI. Many significant problems of interest in AI, including analogical reasoning can be transformed into a Constraint Satisfaction Problem (CSP). Constraint satisfaction is a process of finding a solution to a set of constraints that enforce conditions on the values of variables and their relationships. A well-known example of constraint-based ethical behavior generation in autonomous systems is the Ethical Governor model [109], which uses a constraint application algorithm to filter behavior according to explicitly defined constraints.

Machine learning has evolved from computational learning theory, which allows discovering patterns and relationships from data. The applications of machine learning techniques in ethics focused around discerning rules and principles that are often left implicit in discussions involving moral philosophy and psychology. Well-known examples of the application of inductive learning to ethics include the MedEthEx [110], and the GenEth [111] systems. Both systems use Inductive Logic to discern rules that resolve ethical dilemmas due to conflicting obligations and duties. By guiding a dialogue with ethicists in relation to hypothetical situations, these systems gather decisions made by individuals with expertise in moral psychology to identify general rules that can be inferred from the response data. Consequentialist theories of ethics are among the most common models for which agent-based solutions have been applied in the form of agents that are driven by utility-based cognitive architectures. In consequentialist theories of ethics, actions are evaluated by their consequences; that is, the objective is often to optimize the well-being of the largest group of individuals and achieve the most desirable situation possible among many options.

4.3.1. Design Strategies for Ethical Agents

There are three main types of design strategies for engineering ethical decision-making into agent systems: (1) Top-down, (2) Bottom-up, and (3) Hybrid.

4.3.1.1. Top Down Strategies

The top-down strategy involves implementing the selected theory so as to assure that the agent acts in accordance with the principles underlying that theory.

Consequentialist Theories:

In consequentialist theories, the actions are judged by the desirability and utility of the consequences. The best known scheme is utilitarianism, which dictates that the moral act is the one that produces the greatest amount of wellbeing.

Deontological Theories:

In deontological theory, the morality of an action is evaluated on the basis of adherence to a rule or set of rules. The obligations and rules play a critical role in guiding the behavior. For illustrative purposes, Gert proposes moral rules, which highlight the possibility of conflicts between rules in a rule-based moral system [112]. In Asimov's three laws of robotics, conflicts are resolved by ordering the rules for priority. Another common approach to resolve conflicts is to treat rules as dictating prima facie duties [113]. According to Ross, a moral theory should fit

the facts and when there is more than one applicable prima facie duty, the actual obligation is the “duty proper” that is more incumbent than the others (*e.g.*, non-maleficence is more incumbent than beneficence). However, there does not exist a ranking order among the prima facie duties applicable to all situations. Another rule-based approach is Kant’s categorical imperative theory of ethics. The categorical imperative strategy highlights the motive behind an action as a basis for making a decision. One of the formulations of categorical imperative proposed by Kant is “Act only according to that maxim by which you can also will that it would become a universal law”. A machine computable categorical imperative is provided in Powers [114].

Virtue-based Theories:

Virtue theory is a tradition that goes back to Plato and Aristotle that views ethics from the perspective of virtues or character as opposed to actions. Models of human behavior and personality such as presented in Ören and Ghasem-Aghaee [115] can be useful in agent behavior generation consistent with virtue-based rules.

4.3.1.2. Bottom-up Strategies

The bottom up approach to ethics can be characterized as developmental or learning. Ethical mental models emerge *via* the activity of individuals rather than articulated explicitly in terms of normative theories of ethics. Development and learning theories as well as evolutionary psychology are often used as explanations of formation and growth of mental models of ethical behavior. The capability to learn is a critical facet for ethical behavior, because artificial moral agents need to have capacity to acquire the norms of the context in which they operate while exhibiting awareness of social dynamics. By assimilating feedback about the acceptability and unacceptability of its actions based on its own observations (*e.g.*, reinforcement learning) as well as observations from peers (*e.g.*, social learning), the agent calibrates or improves its cognitive model of ethical behavior. Learning-based approaches break the rigidity of top-down rule-based systems, because the agents do not need to anticipate every potential contingency. On the other hand, bottom-up formation and development of the ethical routines of an agent can result or converge in an attractor state that is less than desirable, or even undesirable. Hence, they lack safeguards that are provided by top-down strategies that the ethical theories offer.

4.3.1.3. Hybrid Methods

Hybrid methods that integrate both top-down and bottom-up strategies can help alleviate the disadvantages of each strategy while leveraging their advantages.

Artificial moral agents that use learning or evolutionary methods to exhibit goal-directed behavior under uncertainty can use the top-down, theory guided capacity in selecting actions that both meet its goals and fall within acceptable (social) norms. Such theory-guided learning techniques extend computational cognitive science research, which focuses on the individual, by bringing constructs from ethical theory that is also concerned with constraints, rules, and social context. The social context brought by the ethics perspective is woven with the mechanistic view of moral reason, resulting in an integrated view.

CONCLUSION

Choice of courses of actions for future computerization for connected intelligent world is difficult but vitally important. When connected intelligent (and especially superintelligent) entities are autonomous, they may become dangerous. For example, sometimes car companies call back millions of cars with some defects. For example, an airbag recall affected over 40 million of cars [116]. What may happen if there is a software defect in a driverless car? Or what may happen when the software of such a car is compromised by a human and/or agent hacker? Ethics need to be part of autonomy. However, ethics has limitations in uncivilized and even in civilized environments. To be sure, some scientists would like to have bans on full autonomous lethal weapons [117], [118]. We fully support such bans which may be very useful. However, there is no guaranty that these bans can preclude the possibility of some scientists in some countries to develop such technologies as part of clandestine operations. After centuries of civilizations, even most, otherwise advanced, human societies lack full ethical behavior. Computational intelligence (or artificial intelligence) being so young, may need some time to attain civilized behavior –if at all.”

We may be far from realization of consciousness in computer controlled devices. However, the progress has been very rapid in a short span of time. Some predictions –reported by Cerf and Navasky [119, pp. 208-209]– about the worth and future of computers may be inspirational:

“‘I think there is a world market for about five computers.’ (Remark attributed to Thomas J. Watson, Chairman of the Board of International Business machines, 1943.)”

“‘There is no reason for any individual to have a computer in their home.’ (Ken Olson, President of Digital Equipment Corporation; Convention of the World Future Society in Boston, 1977).”

“‘Worthless’ was the report of Sir George Bidell Airy, Astronomer Royal of Great Britain, estimating for the Chancellor of the Exchequer the potential value of the

‘analytical engine’ invented by Charles Babbage. September 15, 1842. As a result of Airy’s opinion, British government discontinued the funding of Babbage’s experiments in mechanical computation.” (A detailed account can be found at [120]).

One can compare these predictions with some current facts such as the computational power of most telephones and some other personal computers listed in Fig. (3). Hence, advancements of connected intelligent and especially superintelligent autonomous systems may be very dangerous especially when they would be in control of lethal weapons.

CONFLICT OF INTEREST

The authors confirm that this chapter content has no conflict of interest.

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CHAPTER 7

P-UTADIS: A Multi Criteria Classification Method**Majid Esmaelian^{1,*}, Hadi Shahmoradi¹ and Fateme Nemati²**¹ *Department of Management, Faculty of Administrative Sciences and Economics, University of Isfahan, Isfahan, Iran*² *Department of Artificial Intelligence, Faculty of Computer Engineering, University of Isfahan, Isfahan, Iran*

Abstract: In this chapter, a new multi criteria classification technique is presented. This method is a developed/advanced UTilites Additives DIScriminantes (UTADIS) method which applies a polynomial function as its utility function for each attribute rather than a piecewise linear approximation. The method, named P-UTADIS, is applied for both nominal and ordinal group and by calculating coefficients of polynomials threshold limits of classes and weights of attributes, tends to minimize the classification errors. Unknown parameters of a classification problem are estimated through a hybrid algorithm including Particle Swarm Optimization algorithm (PSO) and Genetic Algorithm (GA). The results of implementing P-UTADIS on different data sets and comparing them with some other previous methods indicate the high efficiency of P-UTADIS.

Keywords: Classification, Genetic algorithm, PSO algorithm, UTADIS method, Utility function.

INTRODUCTION

Over the last 20 years, data has increased worldwide and according to the International Data Corporation (IDC), the total created and copied data has become nine fold within five years [1]. In order to manage information overload, techniques like machine learning are employed to organize and categorize it. Data mining as a joint effort from databases, machine learning and statistics, contributes to breaking large data into pieces, so it is used for automated processing of the huge amount data. A key element in data analysis procedure is the unknown data grouping through analysis. Classification is one of the important and widely-applied tasks in data mining when data arrangement and grouping is sought [2 - 5].

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Discrimination, classification and sorting are the most common terms, used in addressing specific problems where a limited set is mapped into known groups. In spite of the fact that these three terms refer to the assignment of a set of alternatives into predefined groups, a difference among the problems that they describe is evident. Discrimination and classification refer to problems, which cover nominal groups with different attributes and there is no preference relation between them. Iris classification and pattern recognition are two examples of this type. Sorting addresses problems that are defined in an ordinal manner, where bankruptcy risk evaluation problem is a typical example of this type. For simplicity the general term “classification” is mostly used instead [4]. Clustering is a data organization method, which structures data into clusters based on similarity. In fact, this method seeks to find hidden pattern(s) among data sets and group data objects into disjoint clusters are sought through this method [6].

It is necessary to understand the difference between classification and clustering: in classification, problems data is assigned into specific groups with known attributes; while in clustering, problems of the structure in data are identified and then categorized. In classification, the groups are defined in advance, so the analyst knows the results, whereas in clustering, the objective is to identify clusters (groups) and the analyst tries to manage the knowledge in a data set in an appropriate manner (Fig. 1) [4].

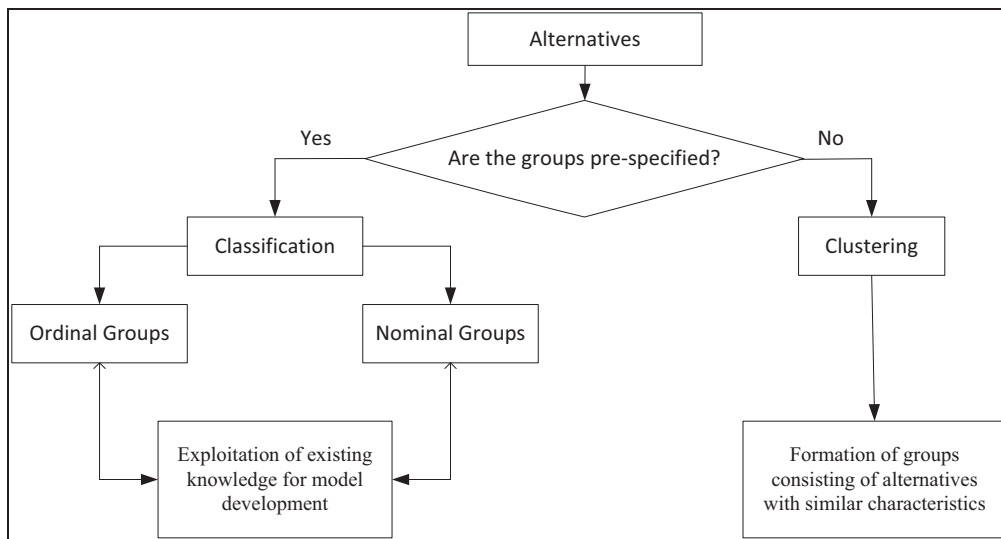


Fig. (1). Classification VS Clustering [4].

After a brief review of classification, the discussion will elucidate a technique in classification and compare it with some other methods.

CLASSIFICATION

The classification problem is very important in many research fields. The importance of classification is evident in many practical fields like Medicine [7, 8], Pattern recognition [9 - 11], Production management [12, 13], Marketing [14, 15], Environmental management and energy policy [16], and Financial management and economics [17, 18].

Data classification, as the most widely-applied technique, consists of grouping data instances into a specific class that can be used to classify new instances by measurements which are indirectly related to the class attributes. Data classification process involves learning and testing phases. In learning phase, the classification algorithm analyzes the training data, while in testing phase, the test data are used to estimate the accuracy of classification rules and assign a label to an unlabeled test instance. The rules can be implemented to the new tuples if the accuracy is acceptable. In fact, the classification rule or empirical correlation can be developed from a training data set, which has the known properties of interest and measurements. Then the rule can be implemented to predict the property of a new sample [3, 19].

In some cases, like lazy learning, there is no learning phase, so the classification is performed directly from the correlation of the training instances to the test instances. The instance-based methods like the nearest neighbor classifier are some other examples [5].

Most classification methods operate based on the regression philosophy and try to apply knowledge in the prior definition of the groups. The procedure of developing a classification model is presented in Fig.(2) [4].

In general, the existing classification methods address classification similar to that of traditional statistical regression. These methods tend to determine the functional relationship between a dependent variable and a vector of independent variables with a difference that in classification problem, the dependent variables are not real valued variables and are discrete. Therefore, the dependent variable, which identifies the classification of the alternatives, will be presented by C and its discrete groups will be presented by $C_1, C_2, \dots, C_q$, where, q is the number of the groups. Symbol G represents the independent variables' vector and they referred to as criteria or attributes. Attribute defines a nominal description of alternatives, while criterion defines an ordinal description; criterion can be used when an alternative is preferred over another [20].

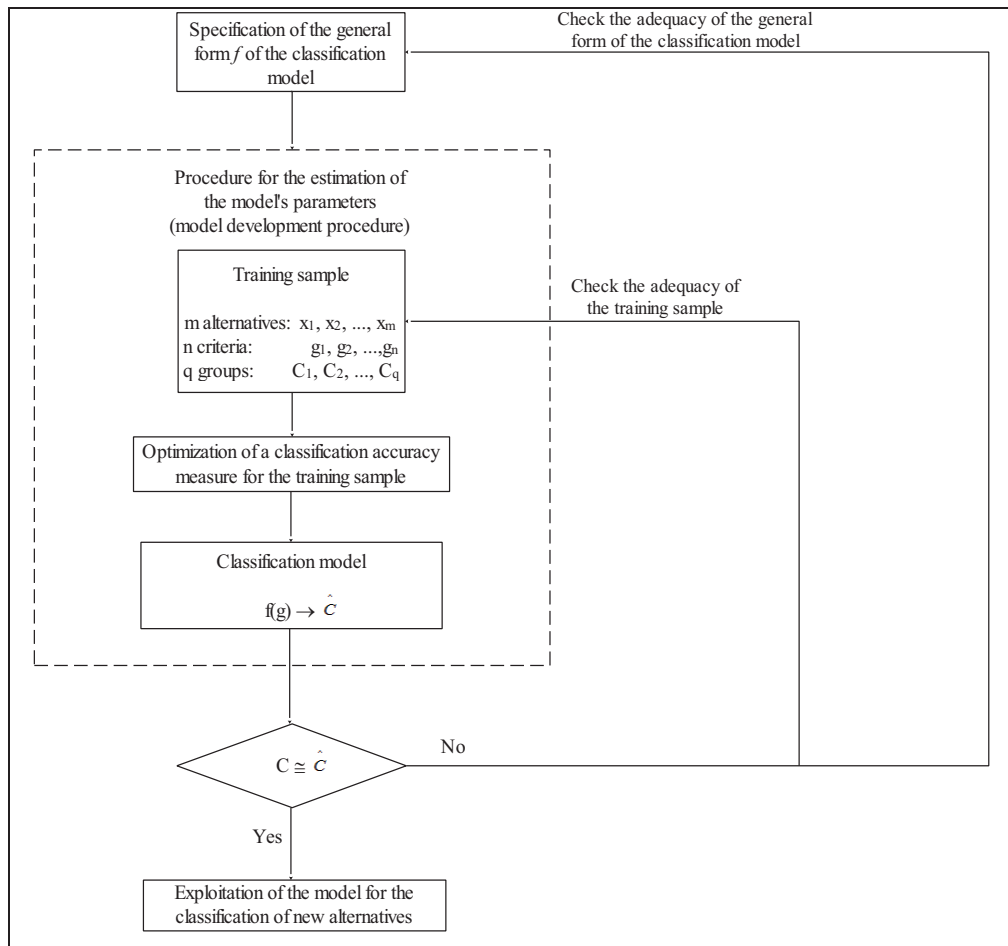


Fig. (2). Model of classification problems [4].

The training sample or reference set is the sample of observations applied in developing the classification model. The number of observations (alternatives) will be presented by m . Each alternative is represented as $\alpha = (g_1(\alpha), g_2(\alpha), \dots, g_n(\alpha))$, where, $g_i(\alpha)$ is the performance of alternative α on criterion g_i .

In classification, the developed model of the form $f(g) \rightarrow \hat{C}$ determines the classification of alternatives. If the developed method performs adequately in the sample data, it can be used in addressing classification of any alternative [4].

The result yield from the development of classification methods led to the development of other classification techniques. Some of the most well-known classification techniques are addressed in brief.

Review of Classification Techniques

Classification has an important role in classifying the available instances into predefined groups based on their criteria of concern. The classification problem, by using the associated training labels, determines the class label for a set of training data points with unlabeled test instance [21].

In data sets, every instance is introduced through the set of continuous, discrete or binary features.

In classification problems, there exist data sets with known features the learning pattern of which is named supervised learning.

In clustering problems, the instances in a data set are unlabeled and the learning is named unsupervised learning [21].

Common Techniques in Data Classification Problems

Some of the machine learning techniques (logical base algorithms) in classification consist of decision trees and learning set of rules. Decision trees are decision support tools, which can be used in classification problems. Each node of the tree is an attribute, the branches correspond to elementary conditions and the leaves are considered as the groups to which an alternative is assigned to [3, 4]. Decision trees classify instances from the root to leaf. With all the advantages, the decision tree likes simplicity and ease of interpretation, it is not without its limitations. By considering one variable at each node and splitting it at a certain point, no smooth decision boundary would be obtained. The finite probabilities of estimated classes, specific terminal node that is shared by all cases in that node and instability constitute some other drawbacks of the decision tree. Two versions of decision tree are applied in [22, 23].

The Classification based on Associations (CBA), which is an integrated classification and association rule-mining algorithm, is a new method for classification in data mining. Discovering a small set of descriptive rules that can accurately classify the entire data is the objective of classification rule mining. Association rule mining seeks to find all acceptable rules in data by minimizing support and confidence constraints. This method has more advantages than heuristic and greedy methods, in a sense that it could easily remove noise and enhance accuracy. The generated rule set is more complete in comparison with decision tree, while, the amount of time taken by this method is longer than that of the decision tree.

Loan T.T Nguyen *et al.* (2012) proposed a Lattice-based approach that prunes redundant rules in a rapid manner. Each one of the training instances in this method is classified by the rules, which satisfy it. Rule ranking is considered, for selecting the training instances with greatest rank. To yield the minimum error rate, the pruning method tries to choose a minimum number of rule sets. The remaining instances, which are not covered by any rule in the final classifier, are labeled as the majority class [24 - 26].

Domain application of CN2-SD algorithm is a recent proposal in subgroup discovery (SD) which offers promising results. This algorithm finds the subgroups of a population that have the most unusual statistical characteristic with respect to the property of interest. With the aid of heuristics, the best subgroups in terms of rule coverage and unusual distributional are discovered. The CN2-SD is a classification adaptation rule learner CN2 algorithm, based on a separate and conquer-strategy. The main features here are its covering algorithm, heuristic search, probabilistic classification of instances, and evaluation measures. Cano and *et al.* (2008) revealed that this algorithm can be applied for large-scale data set and the quality of the discovered subgroup is improved [27, 28].

RIPPER is developed based on the IREP algorithm and was introduced by Cohen (1995) [29]. Minimum Description Length (MDL) and Optimization phase are two main characteristics of this algorithm. According to the prior probabilities of classes, they are initially ordered in a manner that rules can be obtained from them, and pruned, and improved in the optimization phase. For stopping the process of rule learning for a class, the MDL measure is applied. When, the description length of the learned set of rules is at least 64, the algorithm stops adding a rule to the class. This length limitation is longer than that of the MDL. After finding the rules, they are pruned according to their description length allowing the rules with high costs to be eliminated from the learning process. Subsequent to learning the preliminary list of rules, RIPPER adds an optimization phase to IREP. In this phase, each rule in the decision list is replaced with two new ones, namely the revised and replacement rules, which are learned based on the entire set of instances that the rule covers in the training data. The revised rule begins with the antecedent of the original rule and adds a new feature, while the replacement rule learns a new rule and begins with an empty antecedent. Of the three rules, the one the corresponding decision list of which has the shortest description length is chosen and the other one is eliminated. Asadi and Shahrabi (2016) proposed a version of RIPPER for multi-class classification, which extends several aspects of RIPPER. In their approach, after the classes are sorted in an increasing order according to their prior probabilities, the rules for each class are leaned in succession and when the duration of a particular class is over, the

instances belonging to that class are labeled as positive, but the other instances are considered negative [30].

Neural Networks are networks of highly interconnected neural computing elements. These Networks include the two phase of learning and training. Although Neural Networks are good in establishing rules between input and output, they do not explain how the decisions are drawn. Various methods are applied in classification using this methodology. Single-layer Perceptron (SLP) [31, 32], Multi-Layer Perceptron (MLP) [33] and Radial basis function (RBF) Classifiers [34, 35] are some applications of this method in classification. Back-propagation classifiers form nonlinear discriminant functions by applying single- or multi-layer perceptron with sigmoidal nonlinearities. Using gradient-descent training techniques, called back-propagation, they try to minimize the squared error between the actual outputs of the network and the desired outputs. SLP can only classify linearly separable patterns and for nonlinearly separable patterns MLP is applied. Single-Layer Perceptron (SLP) is a traditional model for two-class classification problems. There is a corresponding weight for all inputs.

In order to compute the output, every input is multiplied by its corresponding weight. Then the weighted sum of all inputs is computed and the outcome is fed in to the limiter function that evaluates the final output of the perceptron. If the output value of an input is above a pre-specified threshold, it is categorized into the first class; otherwise, it is classified into another category. The sigmoid functions the output ranging between 0 and 1 which is usually used as the output node's transfer function. Besides SLP, the multi-layer perceptron (MLP) not only categorizes data for more than two classes, it also defines a learning rule for this kind of network. MLP is divided into three: input, hidden and output layers, where each transmits the input to the next. MLP can be viewed as a logistic regression classifier where the input is transformed into a space and becomes linearly separable. This intermediate layer is referred to hidden layer. Radial basis function (RBF) nets belong to the group of kernel function nets that apply simple kernel functions, distributed in different neighborhoods of the input space, where responses are essentially local in nature. The method consists of one hidden layer and one output layer. Every hidden node in a RBF represents one of the kernel functions. A kernel function is a local function and the range of its effect is determined by its center and width. Its output is high when the input is close to the center and it decreases rapidly to zero as the input's distance from the center increases. The Gaussian function is a popular kernel function and will be used in this algorithm. In general, an output node in this algorithm computes the weighted sum of the hidden node outputs. The design and training of a RBF net is involved with determining the number of the kernel functions to be used, finding their centers and widths, and finding the weights that connect them to an output node.

The basic idea of the proposed method is to cover a class region with a set of Gaussians of varying widths and centers.

Statistical methods in classification are: linear discrimination analysis (LDA) [36], quadratic discrimination analysis (QDA) [37, 38], logistic regression (LR) [39, 40], Naïve Bayes classifier (NBC) [41, 42], Bayesian Network [43], Kernel Density Estimation (KDE) [44], Projection Pursuit (PP) classification [45, 46], Casual Network [47], Probit Analysis [48], Alternating Conditional Expectation (ACE) algorithm [49] and Multivariate Adaptive Regression Spline (MARS) [50, 51].

Altman *et al.* (1994) mentioned that neural networks are not a clearly dominant mathematical technique compared to statistical ones. In fact, linear discrimination analysis (LDA) performs rather well in comparison with neural network. The LDA is applied in finding a linear combination of features that classifies two or more classes of alternatives. This technique can easily handle the situation(s) where within-class frequencies are unequal and their performance is examined on randomly generated test data. Maximizing the between-class variance to the within-class variance ratio would reduce the dimensionality, which is the main objective of LDA. Basically, LDA tries to find the boundaries around classes and project data points on a line as to separate the classes as much as possible with each class having a relative (close) distance to a centroid [36]. The Quadratic discrimination analysis is similar to linear discrimination, but here the distance among classes is computed through the sample variance-covariance matrix. Similar to LDA, QDA creates a quadratic boundary where the distance between the two class centroids is equal [37, 38].

Logistic regression (LR) predicts the probability of an outcome based on the use of one or several predictors (nominal and categorical). This method is developing a probability function that offers the chance for an input to be assigned to any of the various classes. In LR, the function is logistic, which is appropriate for binomial and multi-nominal data. The function accepts inputs in any values among $(-\infty, +\infty)$ and produces output values between 0 and 1 [5].

A Naïve Bayes Classifier (NBC) is a base probabilistic method that predicts the probability of the class membership based on the Bayes rule and a set of conditional independence assumptions. Adopting (NBC) is appropriate when the dimensionality of the inputs is high. Although it is a simple method, it can often outperform more sophisticated classification methods. The independency of attributes is often assumed as a drawback in Naïve Bayes Algorithm, thus, the reason for it to be labeled naïve [41, 42].

Bayesian networks are powerful tools with a performance almost as good as (NBC). These networks, as classifiers seek to classify the input into small number of classes. Classifiers based on Bayesian networks are usually learned with a fixed structure or a small subset of possible structures. This method represents dependencies among features and labels by a directed acyclic graph, which constructs the Bayesian network. After selecting a structure, the classifier parameters are usually learned using maximum likelihood estimation [43].

Kernel density estimation (KDE) is an efficient unsupervised feature learning method with encoded density information. In KDE, in order to get the density estimates in a given point, a distance-based influence of all points from training set on that point is computed. A kernel function is used to put a relatively greater emphasis on closer points than those placed further. The kernel's parameter which determines how much emphasis is put on the closest points is the Bandwidth [44].

Thomas *et al.* (1990) proposed the adaption of projection pursuit (PP) method in classifier design. These techniques work by constructing statistical knowledge base for every projection at a time. PP technique uses projections in order to assess the properties of multi-variate probability distributions. A typical PP algorithm begins with a single ridge function (linear combination of the observed features) chosen as the best model for the desired response. Each one of the subsequent iterations incorporates an additional ridge function to improve the model. The process stops as soon as the discrepancies between the model and the desired response become small. This method drives its name from the fact that it interprets high dimensional data through well-chosen lower dimensional projections [45, 46].

McErlean *et al* (1999) introduced an approach as a data mining tool addressing both discovery and updating the causal networks hidden in data base systems. Casual networks, which are directed acyclic graphs, provide a computational model. In evidential casual networks, the nodes represent Boolean algebras and the edges represent dependencies between related nodes. Conditional probabilities, which are stored in rule-strength matrices, constitute the strengths of dependencies. After each evidence and belief is acquired, it is necessary to update rule strengths and various belief measures by using the links in the network to direct and activate the data flow in various computations. After updating the belief function for any node, the complete network is updated through communication made between neighboring nodes [47].

Logistic regression and Probit models are almost similar with a difference that distribution of random variables (independent random variables in model) is assumed in Probit. The distribution function is fatter tails in Probit, but both are

linear. The Logit model has two practical advantages of simplicity and interpretability. Estimating the probability that an observation with particular characteristics will fall into a specific one of the categories is the purpose of the model. If the estimated probabilities are greater than 0.5, then they classify the instances into a predicted category. The Probit model is a type of binary classification model [48].

The Alternating Conditional Expectation (ACE) algorithm is a non-parametric automatic classification method. ACE tries to find a set of functions where the linear correlation of the transformed response variable and the sum of the transformed explanatory variables are maximized. The advantage of ACE over parametric regression is that, it is totally data driven and does not require a prior assumption of functional forms [49].

Multivariate Adaptive Regression Spline (MARS) is another nonlinear and nonparametric regression organization. NO ambiguity about functional connection between the dependent and independent variables is faced in this technique. This correlation is defined by a set of coefficients and basic functions that are engaged in regression data. A MARS model is implemented in two steps: 1) the model is built and basic functions are added to enhance the complexity until extreme complexity is attained; and 2) a backward computation is run to remove the minimum substantial basis function from the model.

Instance-Based Learning (Prototype or Model Free Classification Techniques) contains K-Nearest Neighbored (KNN) [52, 53], K-Means [54], Learning Vector Quantization (LVQ) [55, 56] and Gaussian mixture (GM) [57, 58].

The predefined mathematical functions to estimate a target variable are not applied in K-Nearest Neighbored (KNN) technique. A reference data set is searched for instances that are most similar to the target based on the selected input attributes or features. Apparently, the performance of technique largely depends on the goodness of selection of the 'most similar' (nearest) instances. The similarity between the target and the known instances are measured in terms of a metric considered here as the Euclidean distance [52, 53].

K-means clustering partitions N observations into K clusters where each observation belongs to the cluster with the nearest mean, serving as a prototype of the cluster. The main idea of this method is defining centers for each cluster. Since different locations of the centers lead to different results, these centers should be placed in a cunning manner. So, the best strategy is to locate centers as far away from one another, as possible. Next, each point belonging to a given data set is assigned to the nearest center. After considering all points, the first step is completed and an early age group is made. Therefore, the new centroids should be

re-computed as center of the clusters resulting from the previous step. Now, a new binding has to be made between the same data set points and the nearest new center. Here, a loop is generated, making the K centers change their location until centers do not move any more [54]

Learning Vector Quantization is a supervised classification scheme. The classifier is parameterized in terms of a set of labeled prototypes representing the classes in the input space in combination with a distance measure d . The classifier runs a nearest prototype classification, in order to label an unknown instance (*i.e.* the pattern is assigned to the class represented by the closest prototype with respect to d .) Nearest prototype classification is closely related to the popular k-nearest neighbor, but avoids the huge storage and computational efforts that is true with k-NN.

Gaussian Mixture Model (GMM) is a parametric probability distribution for continuous random variables where the density function is defined as the weighted sum of Gaussian densities. The parameters of (GMM) are estimated from the training dataset using a method known as expectation maximization (EM). In machine learning, GMM is mostly applied as unsupervised learning because it can dig out the data patterns and cluster those, which share similar data behaviors. This method provides learning phase of GMM from training data. As to the test data, GMM can be assigned to each sample the Gaussian it most probably belongs.

Support Vector Machine (SVM) is a specific type of learning algorithm. This classification method is simple, here each data is plotted as a point in d -dimensional space, where d is the number of features. Then the classification process tries to find the hyper-plane that differentiates the two classes in a good way. By using kernel trick, SVM can efficiently perform a non-linear classification [59, 60].

Fuzzy classification systems are able to solve different kinds of problems in different domains. The interest in learning and adaption is on increase in this field with purposes of classification among other abilities. In fuzzy classification, instances are grouped into fuzzy set the membership functionality of which is defined by truth-value of fuzzy propositional function. Dennis and Muthukrishnan (2014) proposed a classifier with better accuracy compared to the existing systems by applying Genetic algorithm in fuzzy system. Gou and Li (2011) proposed another version of fuzzy system that provides a high classification rate [61, 62].

Rough set theory is a tool for dealing with vagueness and uncertainty in data. The results of this approach are usually of a set of decision rules. The rough set theory is unable to deal with real-valued data, thus, a discretization method is usually

performed before it is applied. This method is a formal approximation of a crisp set in terms of a pair of sets which give the lower and the upper approximation of the original set [63, 64].

Common Techniques in Data Classification with Ordinal Class

AHPSort, a new version of AHP, is applied in sorting alternatives into predefined ordered categories based on decision makers' preferences. The categorization order is from the most to the least. In comparison with AHP, this new version requires less comparisons which facilitates decision making in large-scale problems [65].

FlowSort is a sorting method based on Promethee methodology for assigning alternatives to predefined ordered categories completely. The FlowSort assignment rules are based on the relative position of an action with respect to the reference profiles, in terms of incoming, leaving and net flows [66, 67].

In dealing with ordinal classification problems, the ELECTRE TRI methods are widely applied in multiple criteria decision aiding classification problems.

These methods try to assign each alternative to one or more predefined contiguous categories subject to the comparison made among them and the reference profiles, which separate the categories. They require the elicitation of preferential parameters like weights, thresholds, category limits and so on to construct a preference model [68 - 70].

The UTilites Additives DIScriminantes (UTADIS) is a version of the UTA method introduced by Devaud *et al.* [71], Jacquet-Lagrange and Siskos [72] and Jacquet-Lagrange [73] for making additive utility functions in segmentation problems [17, 74 - 77]. UTADIS is applied in many studies. Jacquet-Lagrange (1995) [73] applied this method to evaluate R&D projects, while after 1997 this method was widely applied for developing classification models in financial decision making problems [74], [78, 79]. Zopounidis *et al.* [17] proposed an alternative approach to the classical statistical methodologies that are widely used in studying financial classification problems. He combined the preference disaggregation approach with decision support systems to develop the FINancial CLASification (FINCLAS) multi-criteria decision support system, this approach is applied in credit granting to illustrate the capabilities of the system [75]. Zopounidis *et al.* [80] proposed the PREference DIScrimination (PREFDIS) multi-criteria decision support system to study sorting decision problems. The key advantage of this system is its involvement in its model based on four MCDA methods which are originating from the preference-disaggregation approach, that is the UTADIS method and three of its variants, referred to as UTADIS I,

UTADIS II and UTADIS III. With the assistance of applying these methods, the decision maker (DM) based on different sorting techniques can develop powerful interactive additive utility models to sort a set of instances into two or more predefined classes as accurately as possible. Kosmidou *et al.* [81] adopted the UTADIS multi-criteria method to compare domestic and foreign banks' performance over multiple criteria, such as profitability, liquidity, risk and efficiency by using a data sample including 26 domestic and 32 foreign banks operating in the UK since 1998 to 2001.

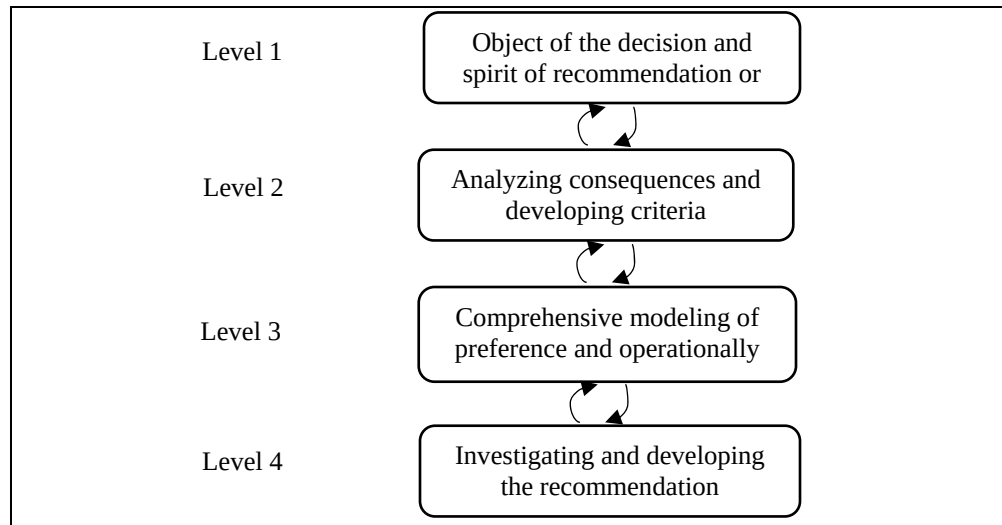


Fig. (3). The decision aiding process of MCDA methodologies [83].

Multi Criteria Decision Aid Classification Technique

Multi Criteria Decision Aid (MCDA) as an advanced field of operation research has evolved rapidly over the past three decades. The objective of MCDA is to provide a set of criteria aggregation methodologies that enable the development of providing assistance in decision support models. The major distinctive feature of MCDA is to provide assistance in decision making rather than developing it. These techniques deal with the process of making decisions multiple objective cases while being applicable in quantitative and qualitative criteria [4, 82]. For MCDA classification methods a great volume of information should be defined by decision maker. Extracting these information which include: (I) time constraints, (II) decision maker willingness to participate actively in the process and (III) the ability of analysis to interact effectively with decision maker, should be defined, thus a cumbersome task [4]. Roy (1981) introduced a framework describing the decision aiding process that underlies the operation of all MCDA methodologies (Fig. 3). where level one involves the specification of a set A of feasible

alternative solutions to the problem. The decision objective is determined, here as well. If set A is continuous, the set of feasible solution is determined by constraints imposed by decision maker or decision environment, while, in a discrete case, the decision maker can list some alternatives.

The next level involves identification of all factors that is related to the decision. In MCDA, these factors are in criteria form. A real function, which measures the performance of the alternatives on each characteristic, is a criterion. The set of an identified criterion must form a consistent family of criteria, which has properties like monotonicity, completeness and non-redundancy. In monotonicity, every criterion must meet the condition in Eqs. 1 and 2. Furthermore, if and only if for every pair of alternatives α and α' where, $g_i(\alpha) = g_i(\alpha')$ for every g_i it is concluded that α is indifferent to α' . If the elimination of any single criterion from a set of criteria that meets the monotonicity and completeness conditions leads to the formation of a new criteria set that does not meet these conditions, then the initial set of criteria is considered as non-redundant.

$$g(a) > g(a') \Leftrightarrow a \succ a' \text{ (} a \text{ is preferred to } a') \quad (1)$$

$$g(a) = g(a') \Leftrightarrow a \approx a' \text{ (} a \text{ is indifferent to } a') \quad (2)$$

In the third level, the analysis continues with the specification of the criteria aggregation model that meets the requirements of the objective or nature of the problem like the choice, ranking, classification or sorting, descriptions.

At last, the decision maker is provided with the necessary support required for understanding the recommendations of the model, that is, a crucial issue should be considered on the basis of the model's recommendations for the implementation of the results of the analysis and the justification of the actual decision [83].

The MCDA methods are usually developed to select and sort problems, and, thus, they are based on the measurement of the degree of preferences between alternatives of a given set. There exists a wide range of methods for classification in MCDA. In general, there are two types of methods for classification: (I) parameter-based methods; (II) the parameter-free methods. In (I), it is possible to form a model of decision maker's behavior based on parameters. Utility function-based and outranking relation-based are the two sub-types of this model. Type (II) contains so-called decision rule methods assumed to be too complex behavior for decision maker that could not be described by a formal model based on some parameters, but it could be defined by judgmental model based on a set of rules. Type (II) consists of verbal decision analysis, fuzzy sets and rough sets [84].

There exist a number of indirect utility function-based methods in the framework of preference disaggregation approach framework. This approach is based on one of the mathematical programming techniques that extracts decision maker preferences and assumes a linear correlation between the classification of alternatives and their attributes. UTADIS is one of the methods in preference disaggregation approach, which is the core of the classification approach that is introduced in this chapter.

Utilities Additives DIScriminantes (UTADIS)

The UTADIS was first presented by Devaud *et al.* (1980) [71], Jacquet-Lagrange (1995) [73], Zopounidis and Doumpos (1997,2001) [74, 75] and Doumpos and Zopounidis (2002) [4] for ordinal classification developed based on the UTA method and discriminant analysis. UTADIS as a modified version of UTA assumes the decision maker behavior according to the utility function. Utilities Additives (UTA) as a well-known preference disaggregation method is based on the ordinal regression analysis which is mainly oriented in ranking problems, proposed by Jacquet-Lagrange and Siskos [73] and Siskos and Yannacopoulos [85].

UTADIS, as a method for solving the sorting problem in multi criteria decision problems with ordinal groups, is based on the additive weighted sum utility function. It is a mixed-integer programming (MIP) model adopted to classify instance(s) (alternative(s)) in q diverse groups. The major structural parameters of the classification model developed by the UTADIS method involve the criteria weights, the marginal utility functions, and the utility thresholds. The objective of this method is to maximize the consistency between the estimated classification $\hat{C}$ and the predefined one, the C , accomplished through some mathematical programming techniques. The decision maker (DM) can develop powerful additive utility models to sort a set of instances into two or more predefined classes as accurately as possible, in an interactive manner based on different sorting techniques through this method [4, 84, 85].

In UTADIS, it is assumed that the set of alternatives $A = \{\alpha_1, \dots, \alpha_m\}$ is available and a set of criteria $G = \{g_1, \dots, g_n\}$ with verbal or numerical values is defined by linear or nonlinear criterion function. For each discrete criterion g_i , the scale of values $S(g_i) = \{g_i^1, \dots, g_i^t\}$ is defined, where t is the number of the values on the criterion scales and for continuous type, the function and its minimal and maximal values are available. Each one of the alternative has its specific utility value for each criterion. The marginal utility functions of the criteria $u_i(g_i(\alpha))$ which are assumed to be monotonic, whether linear or non linear, in a sense that the conditions $u_i(g_{i*}) = 0$, $u_i(g_i^*) = 1$ are met [74], where, g_{i*} and g_i^* are the least and

the most preferred values of criterion g_i , respectively. Essentially, the marginal function leads to reduction in scales, that is, from different type with different measures to a new scale in $[0,1]$ interval. The new scale represents the utility for the decision maker of each value of criterion.

After selecting the type of the aggregation function, the UTADIS method, the primary version, applies an additive utility function for the construction of the criteria aggregation model to compute the global utility of an alternative as follows:

$$U(a) = \sum_{i=1}^n p_i u_i(g_i(a)) \quad (3)$$

where, $U(a)$ is the global utility of the alternative, and $u_i(g_i(a))$ is marginal utility of the alternative a on the function of criterion g_i and p_i is the weight of criterion g_i . The set of the weights is non-negative and is normalized. The global utility of an alternative represents a measure of the overall performance with internal range. By comparing the global utility of each alternative in cut-off point defined on the utility scale, the classification is completed [84, 86]. In general, where q groups are considered, the classification of the alternatives is represented through the following classification rules [4]:

$$\begin{aligned} \text{if } U(a) \geq u_1 & \Rightarrow a \in C_1 \\ \text{if } u_{k-1} \leq U(a) < u_k & \Rightarrow a \in C_k, \quad k = 2, \dots, q-1 \\ \text{if } U(a) < u_{q-1} & \Rightarrow a \in C_q \end{aligned} \quad (4)$$

where, $u_1, \dots, u_{q-1}$ are the utility cut-off points that separate the group. These points refer to utility thresholds, which come in two consecutive groups.

A general outline of the procedure in UTADIS is presented as follows [4]:

A reference set consists of m alternatives with n criteria is used as the training sample. This set is classified into predefined groups of q and should be constructed in such a manner that it would include adequate number of comprehensive examples from each group. The objective of the UTADIS method is to develop a criteria aggregation model and a set of utility thresholds that would minimize the classification error rate. The difference between the estimated classification through the model and the pre-specified classification for alternatives of the sample data is the error rate and is presented by a binary variable E for each alternative as follows:

$$E(a) = \begin{cases} 0, & \text{if } a \text{ correctly classified} \\ 1, & \text{if } a \text{ misclassified} \end{cases} \quad (5)$$

In order to minimize the classification error, formulation and solution of a mixed-integer programming (MIP) problem is necessary. This formulation is a computationally intensive procedure. On the basis of the classification rule, two forms of the classification errors are expressed formally as follows:

$$\sigma^+(a) = \max \{0, u_k - U(a)\}, \forall a \in C_k, k = 1, 2, \dots, q-1 \quad (6)$$

$$\sigma^-(a) = \max \{0, U(a) - u_{k-1}\}, \forall a \in C_k, k = 2, 3, \dots, q \quad (7)$$

where, $\sigma^+(a)$ is the error, that is, the misclassified alternative a that actually belongs to group C_k . In order to correct this error, its global utility $U(a)$ should be increased by $u_k - U(a)$. The $\sigma^-(a)$ is the error, that is, the misclassified alternative a that actually belongs to group C_k . In order to correct this error, its global utility $U(a)$ should be decreased by $U(a) - u_{k-1}$.

The following constraints are the basis for formulation of a mathematical programming problem and are used in estimating the parameters of the additive utility classification model including utility threshold, marginal utility and criteria weights. Eq. (8) to (16) represent the general form of this mathematical programming model:

$$\min \left\{ \sum_{k=1}^q \left[\frac{\sum_{a \in C_k} (\sigma^+(a) + \sigma^-(a))}{m_k} \right] \right\} \quad (8)$$

$$U(a) - u_1 + \sigma^+(a) \geq \delta_1 \quad \forall a \in C_1 \quad (9)$$

$$U(a) - u_{k-1} + \sigma^+(a) \geq \delta_1 \quad \forall a \in C_k \quad (k = 2, 3, \dots, q-1) \quad (10)$$

$$U(a) - u_{k-1} + \sigma^-(a) \leq -\delta_2 \quad \forall a \in C_k \quad (k = 2, 3, \dots, q-1) \quad (11)$$

$$U(a) - u_{q-1} + \sigma^-(a) \leq -\delta_2 \quad \forall a \in C_1 \quad (12)$$

$$U(g^*) = 1 \quad (13)$$

$$U(g_*) = 0 \quad (14)$$

$$u_k - u_{k-1} \geq s \quad \forall k = 1, 2, \dots, q-2 \quad (15)$$

$$\sigma^+(a) \geq 0, \quad \sigma^-(a) \geq 0 \quad (16)$$

where, δ_1 and δ_2 are the positive constant numbers which prevent the occurrence of cases like $U(a) = u_k$. In the constraints, g^* and g_* indicate the vectors including the highest and lowest preferences of the criteria and is a positive constant number like $s > \delta_1 \delta_2$, used to ensure the order of the classes like C_1 is the most preferable and C_q is the least preferable.

The mathematical programming model of UTADIS has a nonlinear form, since the additive utility function is defined through two unknown parameters of: the attribute weight and the marginal utility. This leads to constraints, which take a nonlinear form. It is obvious that the solving process of the nonlinear programming problem is cumbersome. To overcome this drawback, Michael Doumpos and Constantin Zopounidis proposed a model by rewriting the additive utility function and simply replacing $u'_i(g_i)$ with $\rho_i u_i(g_i)$ followed by modeling the marginal utilities as piecewise linear function. This approach provides an approximation of the true marginal utility functions, therefore the problem could be solved as a linear form [4, 75]. Of course, this approximation is associated with a reduction in accuracy. The additive utility function is defined as Eq. (17):

$$\begin{cases} U'(a) = \sum_{i=1}^n u'_i(g_i(a)) \\ u'_i(g_i) = \rho_i u_i(g_i) \\ u'_i(g_{i*}) = 0 \\ u'_i(g_i^*) = \rho_i \end{cases} \quad (17)$$

In order to study other computational details and the procedure to make the marginal utility function linear and to convert the UTADIS mathematical model into a linear programming model, refer to [4, 75]. Three variants of the refer UTADIS method are proposed by Doumpos and Zopounidis [4]. The main difference in these variants is in their objective function. The first variant (UTADIS I) is involved in minimization of the classification errors and the maximization of the distances of the global utilities of alternatives from the utility thresholds; the second variant (UTADIS II) is in accordance with the mixed-integer programming formulation for minimizing the number of misclassifications instead of their magnitude. Considering the magnitude of the deviations from the utility threshold as the discrimination criterion may lead to suboptimal discrimination results and the third variant (UTADIS III) with the objective of

minimizing the number of misclassifications and maximizing the distances of the correctly classified alternatives from the utility thresholds combines UTADIS I and II. The mathematical model of these three UTADIS variants are presented as follows [75]:

UTADIS I method

$$\text{Minimize } p_1 \sum_{a \in A} [\sigma^+(a) + \sigma^-(a)] - p_2 \sum_{a \in A} [d^+(a) + d^-(a)] \quad (18)$$

$$\sum_{i=1}^n u_i [g_i(a)] - u_{k-1} - \sigma^-(a) + d^-(a) = -\delta, \quad \forall a \in C_k \quad (19)$$

$$\sum_{i=1}^n u_i [g_i(a)] - u_k + \sigma^+(a) - d^+(a) = 0, \quad \forall a \in C_k \quad (20)$$

$$\sum_{i=1}^n u_i [g_i(a)] - u_{q-1} - \sigma^-(a) + d^-(a) = -\delta, \quad \forall a \in C_q \quad (21)$$

$$\sum_{i=1}^n \sum_{j=1}^{\alpha_i-1} w_{ij} = 1 \quad (22)$$

$$u_{k-1} - u_k \geq s, \quad k = 2, 3, \dots, q-1 \quad (23)$$

$$w_{ij} \geq 0, \sigma^+(a) \geq 0, \sigma^-(a) \geq 0, d^+(a) \geq 0, d^-(a) \geq 0 \quad \forall i, j, \alpha. \quad (24)$$

UTADIS II method

$$\text{Minimize } \sum_{a \in A} [M^+(a) + M^-(a)] \quad (25)$$

$$\sum_{i=1}^n u_i [g_i(a)] - u_1 + M^+(a) \geq 0 \quad \forall a \in C_1 \quad (26)$$

$$\sum_{i=1}^n u_i [g_i(a)] - u_{k-1} - M^-(a) \leq -\delta, \quad \forall a \in C_k \quad (27)$$

$$\sum_{i=1}^n u_i [g_i(a)] - u_k + M^+(a) \geq 0, \quad \forall a \in C_k \quad (28)$$

$$\sum_{i=1}^n u_i [g_i(a)] - u_{q-1} - M^-(a) \leq -\delta, \quad \forall a \in C_q \quad (29)$$

$$\sum_{i=1}^m \sum_{j=1}^{\alpha_i-1} w_{ij} = 1 \quad (30)$$

$$u_{k-1} - u_k \geq s, \quad k = 2, 3, \dots, q-1 \quad (31)$$

$$\begin{aligned} w_{ij} &\geq 0, \quad s > 0, \quad \delta > 0, \\ M^+(a), M^-(a) &\in \{0, 1\} \quad \forall i, j, \alpha. \end{aligned} \quad (32)$$

UTADIS III method

$$\text{Minimize } \sum_{a \in A} [M^+(a) + M^-(a)] - \sum_{a \in A} [d^+(a) + d^-(a)] \quad (33)$$

$$\sum_{i=1}^n u_i [g_i(a)] - u_1 + M^+(a) - d^+(a) = 0 \quad \forall a \in C_1 \quad (34)$$

$$\sum_{i=1}^n u_i [g_i(a)] - u_{k-1} - M^-(a) + d^-(a) = -\delta, \quad \forall a \in C_k \quad (35)$$

$$\sum_{i=1}^n u_i [g_i(a)] - u_k + M^+(a) - d^+(a) = 0, \quad \forall a \in C_k \quad (36)$$

$$\sum_{i=1}^n u_i [g_i(a)] - u_{q-1} - M^-(a) + d^-(a) = -\delta, \quad \forall a \in C_q \quad (37)$$

$$\sum_{i=1}^n \sum_{j=1}^{\alpha_i-1} w_{ij} = 1 \quad (38)$$

$$u_{k-1} - u_k \geq s, \quad k = 2, 3, \dots, q-1 \quad (39)$$

$$\begin{aligned} w_{ij} &\geq 0, \quad d^+(a) \geq 0, \quad d^-(a) \geq 0, \\ M^+(a), M^-(a) &\in \{0, 1\} \quad \forall i, j, \alpha \end{aligned} \quad (40)$$

where, u_k is the utility threshold w_{ij} , ($w_{ij} = u_i(g_i^{j+1}) - u_i(g_i^j)$) is the difference between the marginal utilities of two successive values g_i^j and g_i^{j+1} of criterion g_i , and $\sigma_+(\alpha)$ and $\sigma_-(\alpha)$ are the classification errors. In these variant methods, we have added two variables $d^+(\alpha)$ and $d^-(\alpha)$, the distances of the classified alternatives from the utility thresholds. The binary variables $M^+(\alpha)$ and $M^-(\alpha)$ indicate the misclassification of an alternative. The symbol s is a positive constant used in

defining the minimum difference between two successive utility thresholds and, p_1 and p_2 are the weighting parameters of the two objectives in this method [75].

EXTENSION OF THE UTADIS WITH POLYNOMIAL AND GA-PSO ALGORITHM IN CLASSIFICATION

In this section, a new multi-criteria classification algorithm is presented for both the nominal and ordinal groups. This algorithm is an advanced UTADIS technique, named P-UTADIS with a Polynomial of a degree T as a utility function rather than applying approximation piecewise linear function. By applying a hybrid algorithm like Particle Swarm Optimization algorithm (PSO) and Genetic Algorithm (GA), the unknown UTADIS parameters are determined. The differences between P-UTADIS and UTADIS methods and preliminaries such as PSO and GA algorithms are clarified in this section, followed by the methodology. At last, by implementing the methodology on specific data sets, the results are compared to some other techniques.

P-UTADIS vs. UTADIS

UTADIS as a Multi Criteria Decision Analysis (MCDA) method combines a utility function-based framework with the preference disaggregation approach. The problems addressed by UTADIS involve sorting of the alternatives into predefined groups in an ordinal manner [4]. UTADIS in classification problem involves three restrictions that P-UTADIS does not meet. First of all, in UTADIS, the marginal utility functions are ascending or descending monotone functions and are estimated through the piecewise linear functions, (Fig. 4), in order to meet the conditions $u_i(g_{i*}) = 0$ and $u_i(g_i^*) = 1$, where g_{i*} and g_i^* are the least and the most preferred values of criterion g_i , specified as follows:

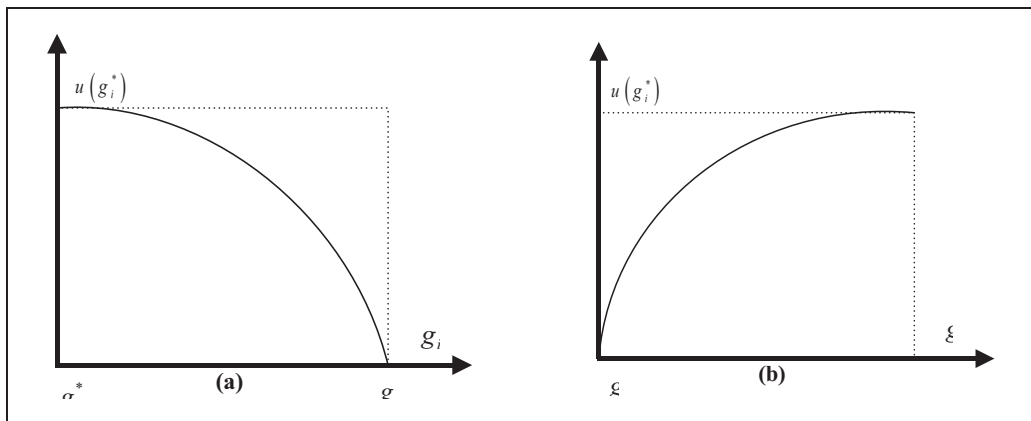


Fig. (4). Different forms of marginal utility functions [4].

- For increasing preference criteria: $g_i^* = \min_{\forall a \in A} (g_i(a)), g_i^* = \max_{\forall a \in A} (g_i(a))$
- For decreasing preference criteria: $g_i^* = \max_{\forall a \in A} (g_i(a)), g_i^* = \min_{\forall a \in A} (g_i(a))$

In the UTADIS model, decision maker is involved in defining the ascending or descending form of the marginal utility functions, as illustrated in Fig. (4), while these functions can come in other form.

Since UTADIS does not specify the non-linear functional form for these functions, it models the marginal utilities as piecewise linear functions through a process that is graphically shown in Fig. (5). The second one accrues when turning the form of marginal utilities functions into piecewise linear ones, as shown in Fig. (5). For this purpose the range $[g_i^*, g_i^*]$ of each criterion should be divided into some subintervals, indicating that the true estimation of marginal utility functions depends on the number of break points which if more, result in better estimation. The last one indicates that UTADIS model could only be applied in classifying the n alternatives $(\alpha_1, \dots, \alpha_m)$ to q ordered groups $(C_1 \succ C_2 \succ \dots \succ C_q)$ and if the groups are formed in a nominal manner, they are considered useless. To overcome these restrictions, a polynomial function is applied in P-UTADIS to form the marginal utility function of each attribute. To calculate the values of the marginal utility of each instance, a polynomial function of degree T fitted, Eq. (41):

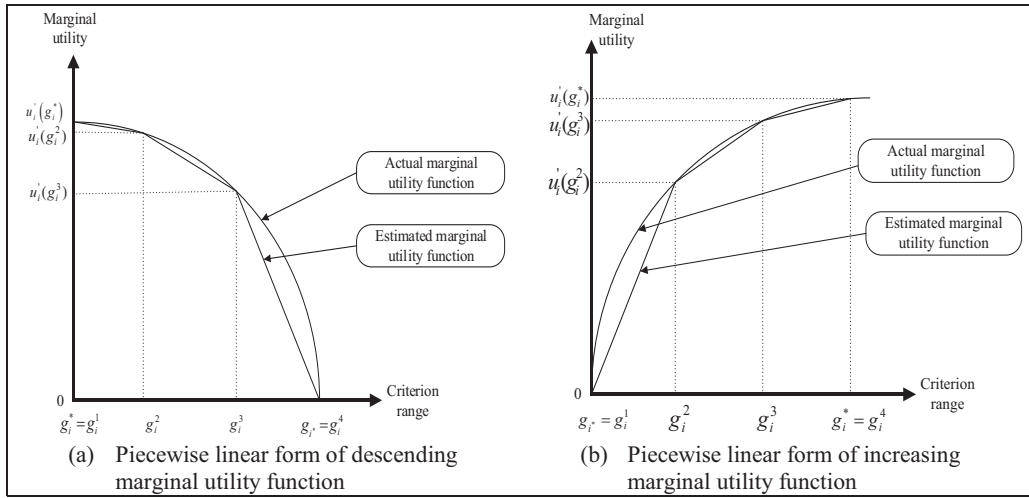


Fig. (5). Piecewise linear form of marginal utility functions [87].

$$u_i(g_i(a)) = \sum_{t=0}^T \beta_t(g_i(a))^t \quad \forall i=1,2,\dots,n, a \in A \quad (41)$$

The extension of polynomial function of degree T in Eq. (41) is presented as Eq. (42):

$$u_i(g_i(a)) = \beta_T(g_i(a))^T + \beta_{T-1}(g_i(a))^{T-1} + \beta_{T-2}(g_i(a))^{T-2} + \dots + \beta_1(g_i(a))^1 + \beta_0 \quad (42)$$

We consider the function u_i as the marginal utility function $u_i(g_i)$, and the additive utility function is calculated as $U(a) = \sum_{i=1}^n \rho_i u_i(g_i(a))$ where, $g = (g_1, g_2, \dots, g_n)$ is the vector of the attributes, ρ_i is the importance of attribute i at $0 \leq \rho_i \leq 1$.

The polynomial utility function can be shaped in various forms, able to be matched with any monotone increase, decrease and non-monotonic functions as shown in Fig. (6). In P-UTADIS, the number of misclassification is minimized, while in UTADIS the classification error value is minimized. Of course in some versions of UTADIS (UTADIS II and UTADIS III), the number of misclassification is minimized as well [75]. The objective function of P-UTADIS is presented as Eq. (43):

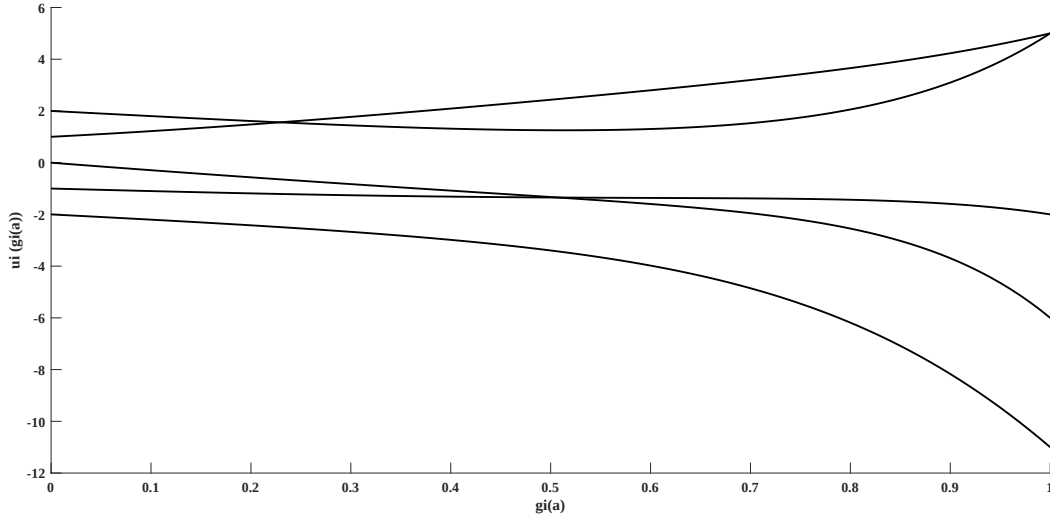


Fig. (6). Shape of polynomial function [87].

$$\text{Min } Z = \sum_{k=1}^q \left[\sum_{\forall a \in C_k} (\sigma(a)) \right] \quad (43)$$

where, $\sigma(a) \in \{0,1\}$ indicates a misclassified instance calculated through Eq. (44):

$$\begin{aligned} &\text{if } U(a) \geq u_1 \text{ then } \sigma(a)=0 \text{ else } \sigma(a)=1 && \forall a \in C_1 \\ &\text{if } u_{k-1} \leq U(a) < u_k \text{ then } \sigma(a)=0 \text{ else } \sigma(a)=1 && \forall a \in C_k, k = 2, \dots, q-1 \\ &\text{if } U(a) < u_{q-1} \text{ then } \sigma(a)=0 \text{ else } \sigma(a)=1 && \forall a \in C_q \end{aligned} \quad (44)$$

In P-UTADIS, marginal utility functions can take different forms (Fig. 6) and instead of using linear estimation for marginal utility functions, the non-linear form of polynomial functions are used. The hybrid classification algorithm introduced in this chapter, due to the integration of P-UTADIS with PSO-GA which contributes to find the coefficients of the polynomial functions, the attributes' weight and the utility thresholds [87].

Preliminaries

In order to introduce P-UTADIS algorithm, (GA), (PSO) and (UTADIS) should be well understood as a prerequisite.

Genetic Algorithm (GA)

According to Darwin's theory of evolution, the population of the society does not go through any significant changes during times and it stays almost constant. He believed that resource limitation is due to fatalities in populations. In other word, in every society, typically strong population uses more of the resources, so the probability of surviving for them is more than the weak sector. By reproduction, the remaining population of each generation gives birth to the children who form the next generation. Children inherit their genes or attributes from one of their parents. As the remaining population is usually the strong one, we expect children inherit superior genes from their parents thus a stronger generation. In fact, we expect a better generation. In some cases, children have some genes, which are not related to none of their parents. Actually, they have mutated genes. In mutation, some of the genes change in a random manner [88].

Based on this theory, in 1970, Genetic Algorithm (GA) was introduced as a heuristic search algorithm [89]. GA is a search method based on natural selection principles [90]. These algorithms are the numerical optimization algorithms and are applied in wide range of problematic issues. GAs are easy to understand and code [91].

In GA, the description variables of a search problem are encoded into binary or alphabet finite-length string. The strings, named chromosomes, are candidate solutions to the problem and the alphabets are referred to as genes. Unlike

traditional optimization techniques, GA works with the coding of parameters, instead of the parameters. In order to distinguish a good solution from bad, a fitness measure is applied. Fitness measure could be an objective function, a mathematical model or a computer simulation, or it can be a subjective function. The population notation is another important factor in GAs. GA relies on a population, the size of which is usually specified by the user. This fact is that, one of the most important factors affects GAs scalability and performance. For instance, small sized population would a premature coverage of the solution, while large sized population would lead to unnecessary solution(s) [91].

After encoding the problem in a chromosomal and a fitness function manner, the following steps are applied by GA to solve the problem [92]:

1. **Initialization:** The initial population, chromosomes, is usually generated on a random basis. Though, the domain-specific knowledge or some other information can be used at this phase.
2. **Evaluation:** This step contains evaluation of the fitness values of each chromosome.
3. **New Population:** The following phases will be repeated until the new population becomes complete:
 - a. **Selection:** Two parent chromosomes from the population are selected here according to their fitness values. The main idea of selection phase is to make a preference between the better and the worse solutions. Many selection procedures like the roulette-wheel, stochastic universal, ranking and tournament selection are usually used in this phase.
 - b. **Crossover:** The bites and pieces of two or more parental chromosomes are combined here to create new population, possibly better one. The primary idea of crossover is that the offspring subject to recombination will not be identical to any particular parent.
 - c. **Mutation:** Mutation of new offspring, locally but on random bases is probable, at each position in chromosomes. There exist many mutation methods, which are usually subject to one or more changes in an individual's trait or traits.
 - d. **Accepting:** The new offspring is placed in new population.
4. **Replacement:** The new generated population will be used for the next run of the algorithm. Techniques including elitist replacement, generation-wise replacement and steady-state replacement are used in GA.
5. **Test and Repeat:** Once the fixed number of new generations is obtained the algorithm ends with the best chromosomes from the outputs; otherwise, it is repeated from step 2 through 4.

As mentioned above, through selection, crossover, and mutation phases the GA will converge over successive generations towards the global or near global optimum. The reason that these simple operations produce a fast and practical method is largely because a combination of direction and chance in the search in an effective and efficient manner is involved in GA. Since population implicitly contains much more information than simply the individual fitness values, GA combine the good information hidden in a solution with good information from another solution to produce new solutions with good information inherited from both parents. The ability to both explore and exploit in a simultaneous manner, a growing amount of theoretical justification, and successful application in the realm of real-world problems allow the scientists to conclude that GAs constitute a powerful optimization technique.

Particle Swarm Optimization Algorithm (PSO)

The particle swarm optimization (PSO) is a population-based stochastic algorithm for optimization developed by Kennedy and Eberhart in 1995 [93]. As described by its developers, “particle swarm algorithm imitates human (or insects) social behavior. Individuals interact with one another while learning from their own experience, and gradually the population members move into better regions of the problem space” [94]. The (PSO) is similar to a crowd algorithm where a number of particles form a swarm, and constitute the candidate solutions of a function or a problem [95]. Unlike evolutionary algorithms, the (PSO) no selection takes place in (PSO), that is, the whole population members survive from the beginning to the end [96]. Each particle is an individual, and the swarm is composed of particles, therefore the quality improvement of problem solutions over time, is the consequence of the particles iterative interactions [97].

The particles move around the space testing new parameter values, and try to find the optimum solution in their search space based on the collective experiences and their individual experiences. Besides moving in a problem space, particles are typically enmeshed in a topological network that defines their communication pattern. Each particle is assigned a number of neighbors to which it is linked in a bidirectional manner [96]. The most common type of implementation defines the particles’ behaviors through two equations: the first determines the velocity of the particle, and the second moves the particle by adding the velocity to its previous position. Each particle moves according to its velocity and the particle movement is computed as follows [97]:

$$v_i(t+1) = w v_i(t) + c_1 r_1 (pbest_i(t) + x_i(t)) + c_2 r_2 (gbest(t) + x_i(t)) \quad (45)$$

$$x_i(t+1) = x_i(t) + v_i(t+1) \quad (46)$$

where, i is the target particle's index and $x_i(t)$ is the position of particle i at time t , $v_i(t)$ is the velocity, $Pbest_i(t)$ is the best position found so far by particle i , $Gbest(t)$ is the best position found by the whole swarm. Symbol w is an inertia weight, c_1 and c_2 are constants named acceleration constant, that scale the influence of the best personal position of the particle ($Pbest_i(t)$) and the best global position ($Gbest(t)$), and r_1 and r_2 are random numbers based on uniform random number generator $U(0,1)$.

The value of particle i in a function $f(x_i)$ is evaluated by the program and the result is compared to the $Pbest_i(t)$. If the current result is particle i 's best so far, the $Pbest_i(t)$ is updated with the current result. When the system is run, each particle cycles around a region centered on the centroid of the previous bests $Pbest_i(t)$ and $Gbest(t)$; as these variables become updated, through Eqs. (45 and 46), the velocity and position of each particle is updated, causing the particle to shift to new regions of the search space, and begin to cluster around optima, obtaining improved function results.

In order to restrict the particle velocity and decrease some unwanted results, the constriction coefficient χ introduced by [98] is used in this study. In PSO by applying χ , velocities are constructed by making the following changes for updating them, Eq. (47):

$$v'_i(t+1) = \chi \left(v_i(t) + c_1 r_1 (Pbest_i(t) - x_i(t)) + c_2 r_2 (Gbest(t) - x_i(t)) \right) \quad (47)$$

where, χ is the constriction coefficient factor, presented in Eq. (48).

$$\chi = \frac{2}{\left| 2 - \phi - \sqrt{\phi^2 - 4\phi} \right|}, \quad \phi = c_1 + c_2 > 4 \quad (48)$$

Typically value of ϕ is equal to 4.1 so that $c_1 = c_2 = 2.05$ and $\chi = 0.729$. As a conclusion, it can be said that PSO algorithm with constriction coefficient can be applied as the equivalent of Eq. (45) with constants c_1 and c_2 equal to 1.49618 and w equal to 0.7298 [98].

P-UTADIS Method

In this section, after describing the P-UTADIS methodology and its steps for classification, an example on IRIS data set is represented [87].

Methodology

This model includes two main parts: 1) one part uses PSO algorithm applied in finding coefficients of the polynomial and calculating the attributes' weights; and 2) GA is applied in finding the proper utility thresholds in order to minimize the misclassification rate. After solving the model, the global utility value of an instance could be calculated using the obtained coefficients of the polynomial functions and the attributes' weight (Eq. (41)) and its category could be determined by comparing this value with the utility thresholds (Eq. 41). The findings here are compared with the primary category of the instance; and if similar, the classification error remains zero, otherwise the value of a unit is increased. The classification error percentage (CEP) in data set for each problem is expressed by Eq. (49):

$$CEP = \frac{\text{Member of misclassified elements}}{\text{Size of testing set}} \times 100 \quad (49)$$

The flowchart of this proposed hybrid model, the P-UTADIS with PSO-GA algorithm is presented in Fig (7).

Algorithm Steps

Steps of the P-UTADIS algorithm are briefed in a two-part pseudo codes for both the PSO and GA parts [87]. Both parts have their own specific inputs and outputs. After polynomials coefficients and attributes weights are produced by PSO part, the global utility of each instance is computed as the inputs of GA, where the best utility thresholds are determined to minimize the classification error percentage. The PSO-GA hybrid pseudo code is represented in Fig. (8).

P-UTADIS PERFORMANCE ON IRIS DATA SET

To reduce the range space of global utilities of instances, first, all four attributes of Iris data are normalized within [0,1] range. Next, for each attribute, a polynomial marginal utility function of degree 10 is considered, and the coefficients of the utility function and the weights of each attributes are computed through PSO-GA algorithm, the (PSO part) Tables (1 and 2). The shape of the marginal utility function in features of Iris data is shown in Fig. (9). Through these parameters, the weighted marginal utility values of each attribute could be

computed. It is enough to sum these values to obtain the global utility value of each instance $U(\alpha)$.

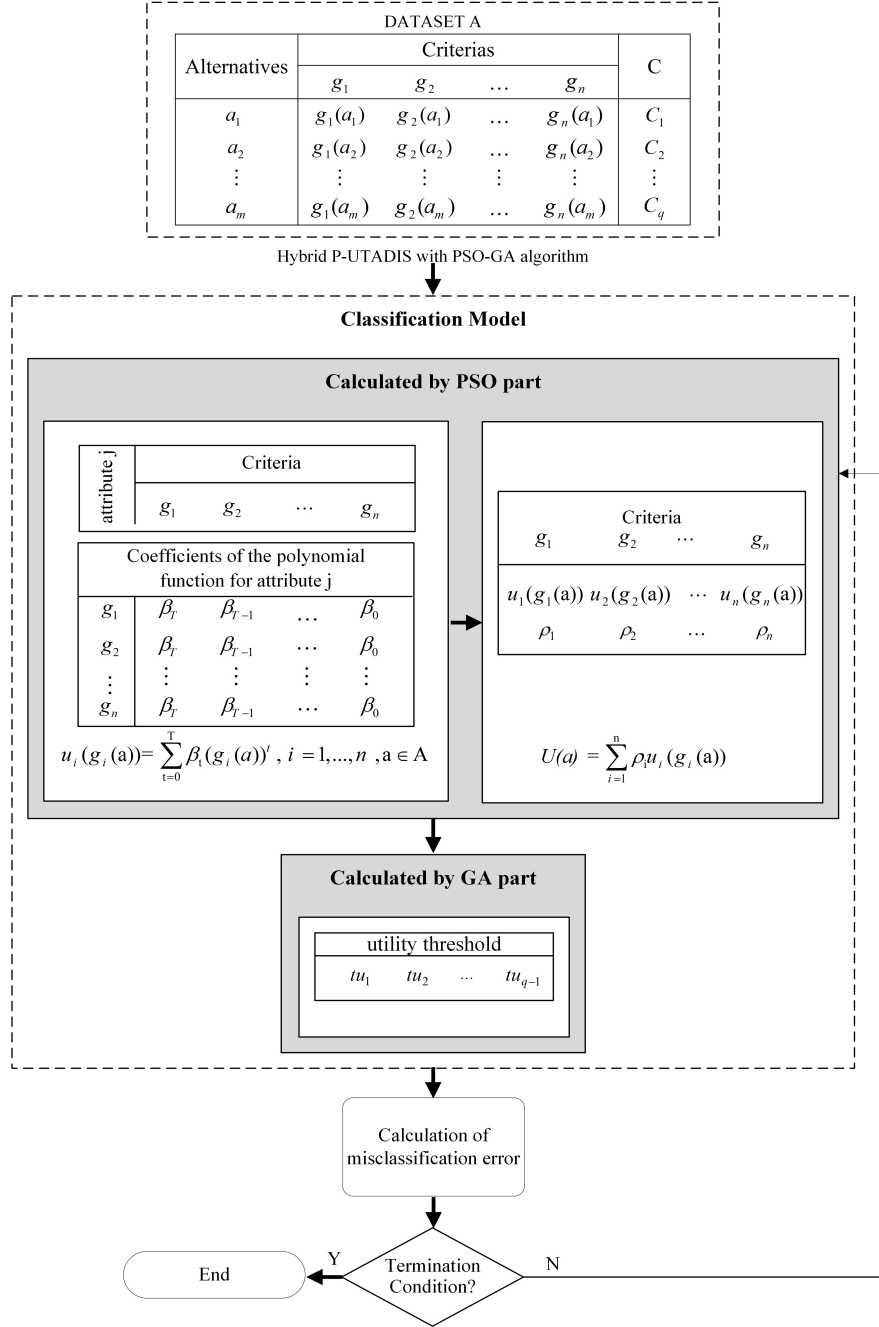


Fig. (7). Flowchart of the proposed hybrid model [87].

Inputs:

- Particle size ($n_{particle}$)
- Maximum number of iteration for PSO part ($Max_{PSOIter}$)
- Cognitive parameter (c_1)
- Social parameter (c_2)

Output:

- Polynomials Coefficients (β_T)
- Attributes weight (ρ_i)

Particle encoding:

Coefficients of the polynomial functions for each attribute:

attribute 1	β_T	β_{T-1}	$\dots$	β_0
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
attribute n	β_T	β_{T-1}	$\dots$	β_0

Attributes weight:

ρ_1	ρ_2	$\dots$	ρ

PSO Algorithm BeginLet iteration index $PSOIter = 1$

Generate an initial population of particles according to the encoding scheme.

Generate the initial positions and velocities for each particle randomly.

Calculate the CEP value of the current position for all initial population of particles.

While ($PSOIter \leq Max_{PSOIter}$) **do****For all Particles** ($n_{particle}$)**Reproduce and update particles**

Update the velocity and position for every particle.

Calculate the global utility value $U(a)$ and then go to GA part.

Run Genetic Algorithm

Evaluation and update best personal and global particleUpdate the personal best for each particle (P_{best})Update the global best (G_{best})**End for** $PSOIter = PSOIter + 1$.**End While**

Return the best solution.

Fig. 8 contd.....

Pseudo code of GA part**GA part:** (Calculates utility thresholds)**Inputs:**

- Global utility of attributes ($U(a)$) that computed with PSO Algorithm
- Population size (n_{pop})
- Maximum number of iteration (Max_{GAlter})
- Mutation rate (m_r)

Output:

- Near optimal solution with minimum CEP

Global utility of attributes: $U(a)$

u_1	u_2	...	u_{q-1}

GA Begin

Let iteration index

Generate initial solution: an array of random numbers between $\frac{m}{j=1} \text{Max}(U(a_j))$ and

$\frac{m}{j=1} \text{Min}(U(a_j))$ for the first generation. Then sort each member in descending order.

While ($Itr \leq Max_{Itr}$) **do****Generate offspring:**

Evaluate the fitness value of the chromosomes.

Perform selection operation using the roulette wheel and tournament procedures, and select a parent chromosome.

Apply mutation:

Generate a new offspring chromosome by a random change on a selected chromosome. A mutation rate m_r is associated to all positions. For selected position, generate a random normal distributed number with $\mu = 0$ and

standard deviation $Std = \sqrt{0.1 * (\frac{m}{j=1} \text{Max}(U(a_j)) - \frac{m}{j=1} \text{Min}(U(a_j)))}$, for selected chromoso

recalculate $u_i = u_i + N(\mu, Std)$ and sort chromosome in descending order.

Evaluation:

Evaluate the generated offspring according to CEP.

$GAlter = GAlter + 1$.

Fig. (8). The hybrid of PSO-GA pseudo code [87].

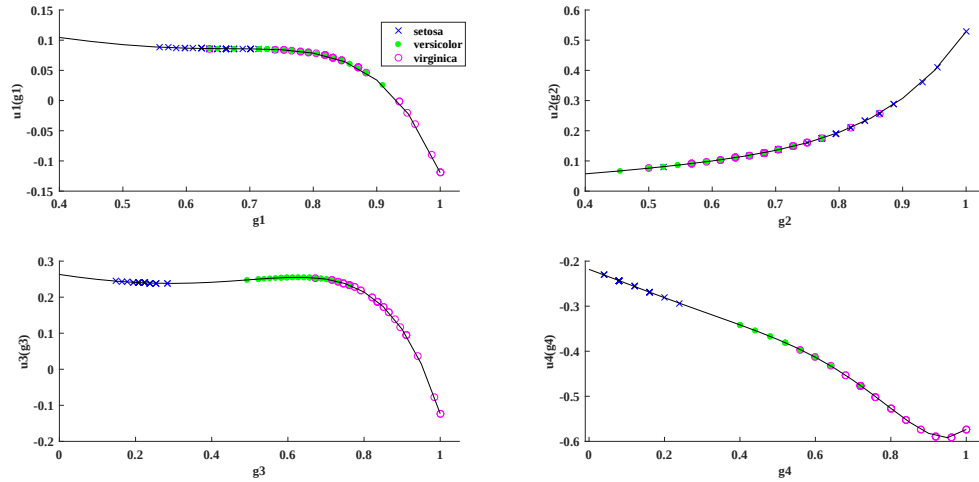


Fig. (9). The marginal utility function of each attributes in Iris data [87].

Then the threshold limits of the global utility are computed through the PSO-GA algorithm (the GA part), (Table 3). Finally, the classification of the instances is made by comparing $U(\alpha)$ with the values of the threshold limits.

Table 1. Coefficients of the marginal utility functions of each attributes.

attribute	β_9	β_8	β_7	β_6	β_5	β_4	β_3	β_2	β_1	β_0
attribute 1	0.563	-0.433	-0.404	0.072	0.522	1.099	-0.434	0.382	-0.974	-0.796
attribute 2	0.079	0.800	0.794	0.511	-0.425	0.412	-0.585	0.868	1.363	1.282
attribute 3	1.453	-0.891	1.262	0.636	0.458	-1.313	-0.822	0.093	-1.260	-0.297
attribute 4	-0.521	-0.737	-0.217	0.867	-0.253	-1.151	-0.561	0.495	-0.670	1.380

Table 2. Weights of attributes.

Attribute	ρ_1	ρ_2	ρ_3	ρ_4
Value	0.2964	0.1036	0.1810	0.4190

Table 3. Threshold limits of additive utility.

Utility thresholds	u_1	u_2
Value	-0.0132	0.1472

Global utility values of alternative, threshold limits and the classification of each class are shown in Fig. (10).

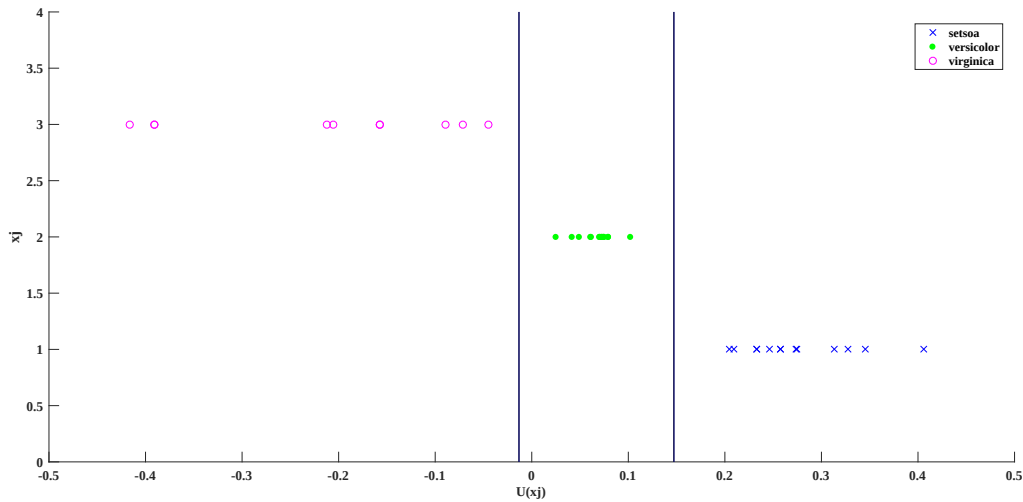


Fig. (10). Method of classifying of the Iris testing data based on the values and threshold limits of the additive utility function [87].

3.4. Comparison of P-UTADIS Performance *versus* UTADIS

In this section, seven classification problems with ordinal class are used to compare P-UTADIS performance *versus* UTADIS, UTADIS I, UTADIS II, UTADIS III methods. As mentioned before, the versions of UTADIS could be applied on only ordinal data sets. In this section, the comparison of P-UTADIS with UTADIS, on ordinal data set performance is sought. The constant parameters used in the UTADIS versions are tabulated in Table 4.

Table 4. The constant parameters used in versions of UTADIS.

UTADIS		UTADIS I					
s	δ	s	δ	p_1	p_2	d^+	d^-
0.05	0.01	0.05	0.01	0.9	0.1	≤ 1	≤ 1
UTADIS II		UTADIS III					
s	δ	s	δ	p_1	p_2	d^+	d^-
0.05	0.01	0.05	0.01	0.9	0.1	≤ 1	≤ 1

The first three problems are about classification of the countries according to their energy intensity, (EI) defined as the ratio of energy consumption per unit of output. It is the most commonly used measure to evaluate the energy effectiveness

of an economic system [16]. The study involves 13 EU countries and the USA and thirteen different indices are chosen to characterize the countries, in the years 1983, 1988 and 1993. The countries are different in terms of their EI level which three discrete classes of: 1) countries with lower values of EI; 2) the countries with intermediate values of EI; and 3) includes countries with higher values of EI. The number of instances, inputs and the number of classes of ordinal datasets are tabulated in Table 5.

Table 5. Properties of the country EI datasets.

Dataset	#Instance	#Input	#Class	Missing
1983	14	13	3	No
1988	14	13	3	No
1993	14	13	3	No

The results obtained through the P-UTADIS and the versions of UTADIS method are tabulated in Table 6, where, the classification accuracy of all methods is 100%.

The next four data sets are qualitative in nature. All the data sets are encoded as integers, where, 1 is the ‘worst’ or lowest possible value, 2 is the second ‘worst’, etc. The properties of the ordinal dataset are tabulated in Table 7.

Table 6. Misclassification error on country EI datasets.

DATA SET	UTADIS		UTADIS I		UTADIS II		UTADIS III		PUTADIS	
	# Error	% Error	# Error	% Error	# Error	% Error	# Error	% Error	# Error	% Error
1983	0	0	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0	0

Table 7. Properties of the ordinal datasets.

Dataset	#Instance	#Input	# possible values of each input	#Class	Missing
SWD	1000	10	4	7	No
LEV	1000	4	5	5	No
ESL	488	4	10	10	No
ERA	1000	4	15	10	No

The Social workers decision (SWD) data set contains real-world assessments made by qualified social workers regarding the children facing risk if they stay with their families this dataset is composed of ten features in four classes. The SWD is applied to judicial system to assist in deciding what is in the best interest of an alleged, abused or neglected child.

The Lecturers evaluation (LEV) data set contains examples of anonymous lecturer evaluations, taken at the end of MBA courses and is composed of four features in five classes. Students want to know their final grades from their lecturer before the results are posted. These results indicate a total evaluation of the lecturer's performance. Every dataset contain 1000 examples.

The Employee selection (ESL) data set is composed of 488 profiles about applicants for certain industrial jobs. The features here are based on psychometric test results and interviews with the candidates run by expert psychologists. The class assigned to every applicant is an overall score corresponding to the degree of fitness for the type of job.

The Employee rejection–acceptance (ERA) data set is collected during an academic decision-making experiment and is composed of 1000 instances. The objective of ERA, unlike ESL data set, is to determine the most important qualities of candidates for a certain type of job. Features of a candidate like past experiences, verbal skills, *etc.*, are considered as the input in the data set, and the subjective judgment of a decision-maker to which degree he or she tends to accept the applicant to the job or to reject him/her altogether is considered as output.

A comparative evaluation between classification error percentage(CEP) of this proposed algorithm is made through the previously mentioned 4 problems. The whole data are used in training process as the train set. The results obtained through the proposed P-UTADIS algorithm and UTADIS methods are tabulated in Table 8, where, the best value and the average value are yield in 10 runs. According to Table 8, P-UTADIS has the lowest CEP and exhibits superior performance in comparison with other UTADIS versions.

Table 8. Misclassification error on ordinal datasets.

DATA SET	UTADIS		UTADIS I		UTADIS II		UTADIS III		PUTADIS (Average)		P-UTADIS (Best)	
	# Error	% Error	# Error	% Error	# Error	% Error	# Error	% Error	% Error	% Error	% Error	% Error
SWD	452	45.2%	473	47.3%	413	41.3%	451	45.1%	397	39.7%	396	39.6%
LEV	484	48.4%	429	42.9%	382	38.2%	385	38.5%	364	36.4%	357	35.7%

(Table 8) contd.....

DATA SET	UTADIS		UTADIS I		UTADIS II		UTADIS III		PUTADIS (Average)		P-UTADIS (Best)	
	# Error	% Error	# Error	% Error	# Error	% Error	# Error	% Error	% Error	% Error	% Error	% Error
ESL	266	54.5%	268	54.9%	238	48.8%	241	49.4%	237	48.6%	236	48.4%
ERA	797	79.7%	773	77.3%	693	69.3%	692	69.2%	684	68.4%	683	68.3%

The marginal utilities of cut points, which are used in drawing marginal utility functions in the three versions of UTADIS, are tabulated in Table 9. The lines representing the marginal utility functions in features of LEV data based on versions of UTADIS are shown in Figs. (11 to 14). Coefficients of the marginal utility functions and weights of each one of the attributes and utility thresholds are computed through PSO-GA algorithm, Tables (10, 11 and 12, respectively). The shapes of the marginal utility functions in LEV data features based on versions of P-UTADIS are shown in Fig. (15). In P-UTADIS method, marginal utility functions could be in any form. (Fig. 16) shows additive (global) utility values of instances and the misclassification errors. Instances in class one are dense in highest value something through with other classes.

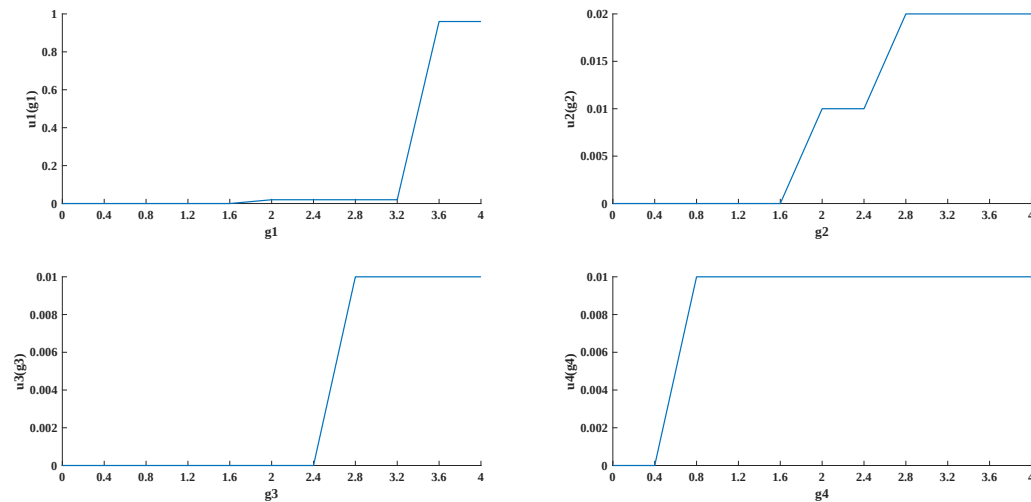


Fig. (11). The marginal utility function of each one of the attributes in LEVdata in UTADIS.

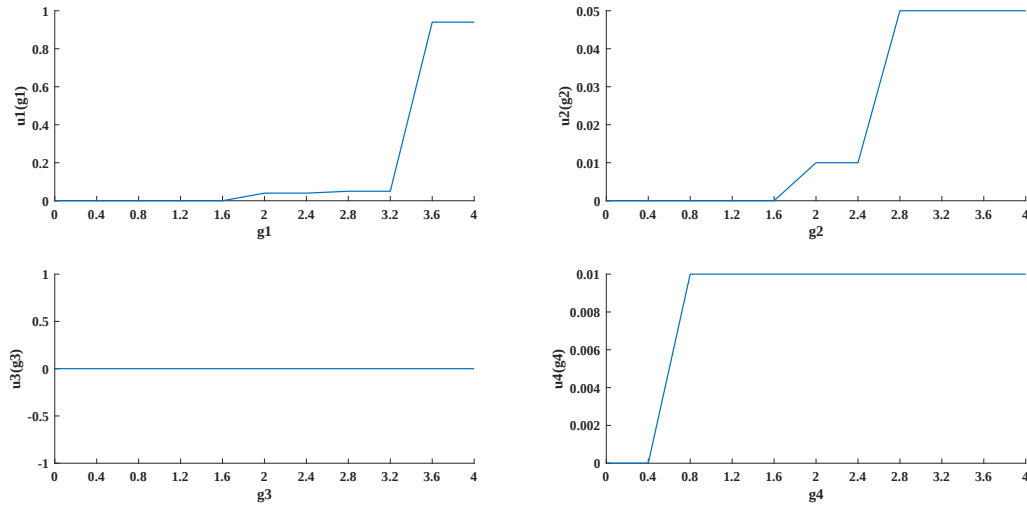


Fig. (12). The marginal utility function of each one of the attributes in LEVdata in UTADIS I.

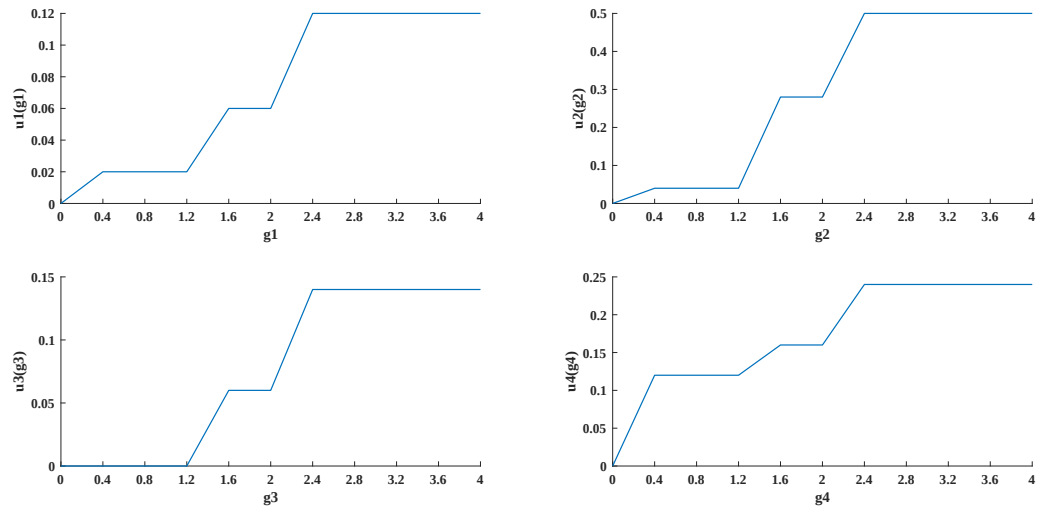


Fig. (13). The marginal utility function of each one of the attributes in LEVdata in UTADIS II.

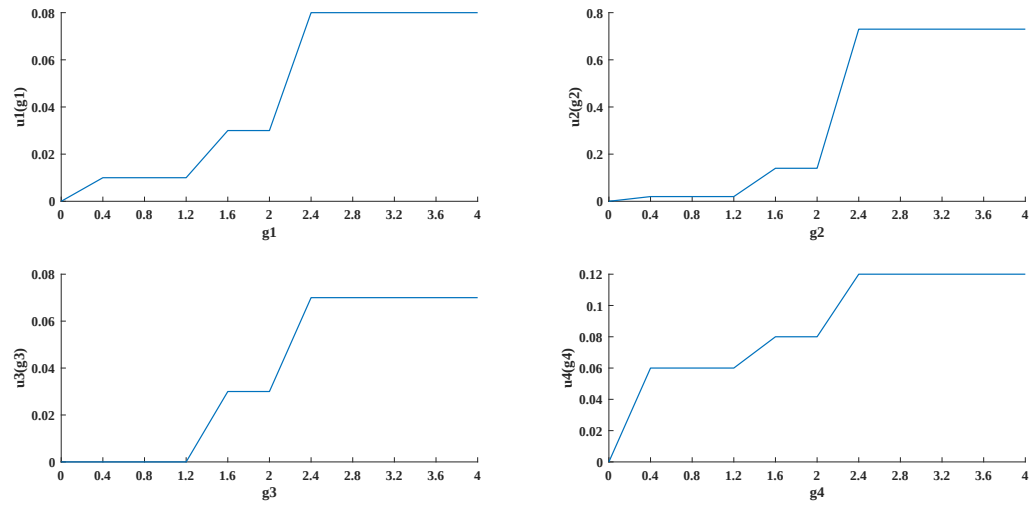


Fig. (14). The marginal utility function of each one of the attributes in LEVdata in UTADIS III.

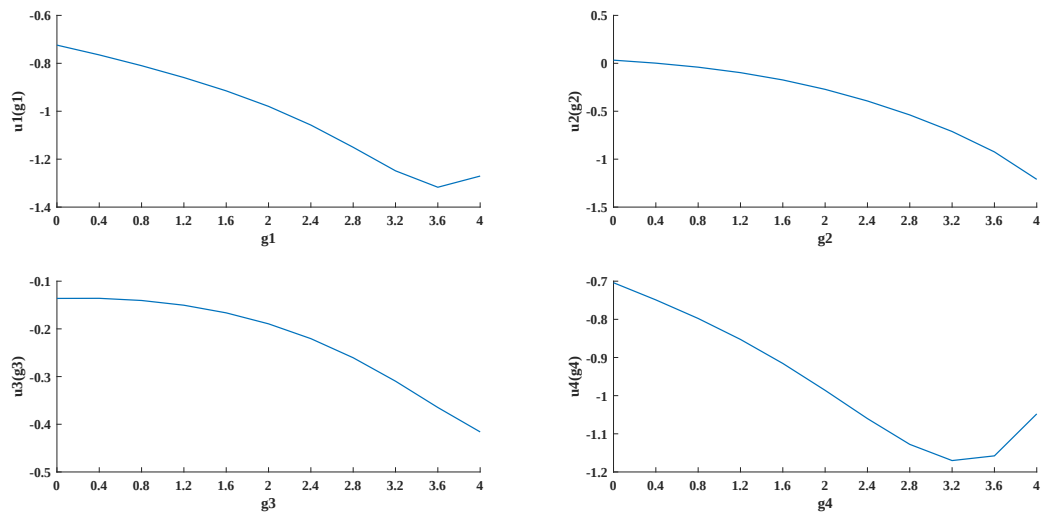


Fig. (15). The marginal utility function of each one of the attributes in LEVdata in UTADIS.

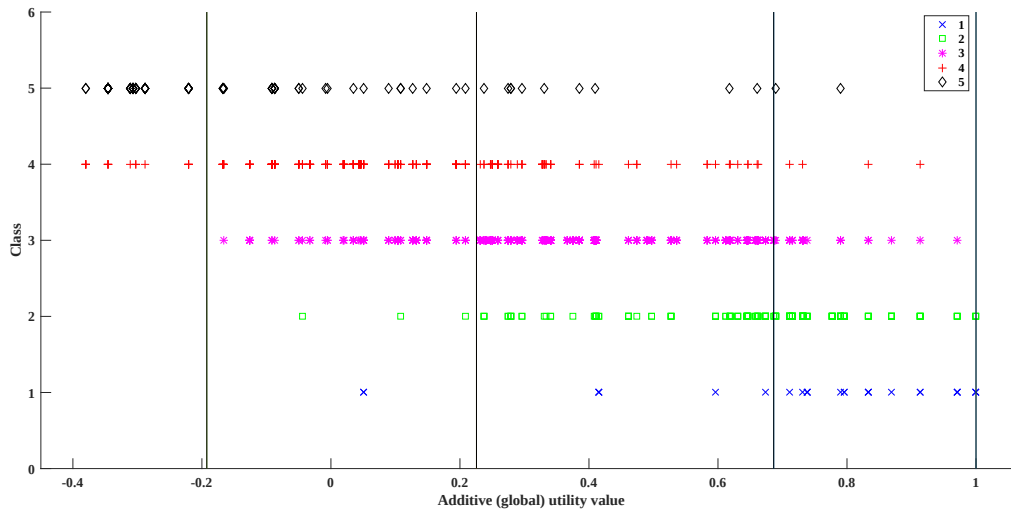


Fig (16). The additive (global) utility values of LEV data.

Table 9. The marginal utility value of each one of the attributes in LEV data.

Cut Point	UTADIS				UTADIS I			
	attribute 1	attribute 2	attribute 3	attribute 4	attribute 1	attribute 2	attribute 3	attribute 4
0	0	0	0	0	0	0	0	0
0.4	0	0	0	0	0	0	0	0
0.8	0	0	0	0.01	0	0	0	0.01
1.2	0	0	0	0.01	0	0	0	0.01
1.6	0	0	0	0.01	0	0	0	0.01
2.0	0.02	0.01	0	0.01	0.04	0.01	0	0.01
2.4	0.02	0.01	0	0.01	0.04	0.01	0	0.01
2.8	0.02	0.02	0.01	0.01	0.05	0.05	0	0.01
3.4	0.02	0.02	0.01	0.01	0.05	0.05	0	0.01
3.6	0.96	0.02	0.01	0.01	0.94	0.05	0	0.01
4.0	0.96	0.02	0.01	0.01	0.94	0.05	0	0.01
Cut Point	UTADIS II				UTADIS III			
	attribute 1	attribute 2	attribute 3	attribute 4	attribute 1	attribute 2	attribute 3	attribute 4
0	0	0	0	0	0	0	0	0
0.4	0	0	0	0	0	0	0	0
0.8	0	0	0	0.01	0	0	0	0.01

(Table 9) contd.....

1.2	0	0	0	0.01	0	0	0	0.01
1.6	0	0	0	0.01	0	0	0	0.01
2.0	0.02	0.01	0	0.01	0.04	0.01	0	0.01
2.4	0.02	0.01	0	0.01	0.04	0.01	0	0.01
2.8	0.02	0.02	0.01	0.01	0.05	0.05	0	0.01
3.4	0.02	0.02	0.01	0.01	0.05	0.05	0	0.01
3.6	0.96	0.02	0.01	0.01	0.94	0.05	0	0.01
4.0	0.96	0.02	0.01	0.01	0.94	0.05	0	0.01

Table 10. Coefficients of the marginal utility functions of each attributes in LEV data.

attribute	β_9	β_8	β_7	β_6	β_5	β_4	β_3	β_2	β_1	β_0
attribute 1	0.374	-1.399	-0.242	-0.241	-0.517	2.269	-1.174	0.244	-0.526	0.473
attribute 2	1.222	-2.438	-0.826	1.211	-1.665	0.810	-0.524	0.074	0.072	0.767
attribute 3	1.821	-1.703	1.340	-0.477	1.210	-1.279	-1.918	-0.265	1.421	0.706
attribute 4	1.252	-1.192	1.424	-0.458	-0.235	-1.011	-0.177	-0.439	0.040	1.100

Table 11. Weights of attributes.

Attribute	ρ_1	ρ_2	ρ_3	ρ_4
Value	0.4006	0.3118	0.1676	0.3534

Table 12. Utility thresholds.

Thresholds	u_1	u_2	u_3	u_4
Value	-0.1924	0.2256	0.6864	1.0000

3.5. Experimental Study

In this chapter, to evaluate the performance of P-UTADIS algorithm, 13 classification problems from the UCI database [75] are assessed to make the possible comparison. These data sets are also used in some other studies [99, 100]. The properties of the databases include instance, the number of inputs (numeric and symbolic) and the classes as shown in Table 13.

If any data is missing from the dataset, they are replaced with the average of the values taken on by the attribute. To assess the performance of the P-UTADIS method, first the algorithm is applied to train the sets to obtain the passive parameters, which are then used in obtaining the class of test instances. The train and test sets sizes are tabulated in Table 13. Similar to [99] and [100], firstly, the elements are shuffled, and then the first 75% of elements are used in the training process as a train set, and the remaining 25% are used in the testing process as a

test set. Results of the P-UTADIS method contain the geometric average of misclassification percentages on test data with 10 runs.

Test Problems

The test problems are taken from the UCI database. The balance dataset was generated to model psychological experimental results. Each instance is classified as having the balance scale tip to the right, tip to the left, or is balanced. The attributes are the left weight, the left distance, the right weight, and the right distance. The correct manner to find the class is directly related to the greatness of (*left distance * left weight*) and (*right distance * right weight*). If equal, it is balanced. The dataset includes 4 inputs and 3 classes. There exist 625 examples, divided into 469 for training and 156 for testing.

Cancer and Cancer-Int datasets are based on the datasets: “Breast Cancer Wisconsin (Original) Data Set” and “Breast Cancer Wisconsin (Diagnostic) Data Set”, respectively, diagnosed with 2 outputs of classifying a tumor as benign or malignant. Samples were collected periodically. Thus, the database reflects this chronological grouping of the data. The samples consist of visually assessed nuclear features of fine needle aspirates (FNAs) taken from patients' breasts. The first data set contains 569 patterns, 30 inputs and the second contains 699 patterns and 9 inputs.

Credit data set was provided by a large bank. Each instance concerns an application for credit cards based on a number of attributes with two decision classes. This dataset is interesting because there is a good mix of attributes - continuous, nominal with small numbers of values, and nominal with larger numbers of values. In general, there are 690 applicants; 518 for training and 172 for testing. The 14 attributes, involving 6 numeric and 8 discrete values which have 2–14 possible values are formed into 51 input values.

Table 13. Properties of the problems.

Dataset	#Instance	#Train	#Test	Input	Class	%Numeric Input	%Symbolic Input	Missing
Balance	625	469	156	4	3	100	0	No
Cancer	569	427	142	30	2	100	0	No
Cancer-Int	699	524	175	9	2	100	0	Yes
Credit	690	518	172	51	2	40	60	Yes
Dermatology	366	274	92	34	6	97	3	Yes
Diabetes	768	576	192	8	2	100	0	No
E.Coli	327	245	82	7	5	88	12	No

(Table 13) *contd....*

Dataset	#Instance	#Train	#Test	Input	Class	%Numeric Input	%Symbolic Input	Missing
Glass	214	161	53	9	6	100	0	No
Heart	303	227	76	35	2	100	0	Yes
Horse	364	273	91	58	3	32	68	Yes
Iris	150	112	38	4	3	100	0	No
Thyroid	215	162	53	5	3	100	0	No
Wine	178	133	45	13	3	100	0	No

The Pima Indian diabetes data set, expressed by Vincent Sigillito, is a collection of medical diagnostic reports of 768 examples from a population living near Phoenix, Arizona, USA. The samples consist of examples with 8 attribute values and one of the two possible outcomes, namely whether the patient is tested positive for diabetes (indicated by output one) or not (indicated by output two). From the total data: 576 are for the training set and 192 are examples for the test set.

Dermatology dataset constitutes the biggest number of classes. The diseases in this data set are psoriasis, seboric dermatitis, lichen planus, pityriasis rosea, cronic dermatitis, and pityriasis rubra pilaris. This database contains 34 attributes, 33 of which are valued linear and one of them is valued nominal. There are 366 samples: 274 for training and 92 for testing.

Escherichia coli is a database where the physical (protein-protein) and functional interactions within the context of an E. coli knowledgebase are integrated. This data set has 336 examples composed of 8 classes, but three classes are represented with only 2, 2 and 5 examples, therefore, these 9 examples are omitted and the total is 327: 245 for training and 82 for testing. The dataset contains 327 examples with 7 inputs and 5 classes.

Glass dataset is another big number class (6 classes) in the problems. The study of classification of types of glass was motivated by criminological investigation. At the scene of the crime, the left glass can be used as evidence, if it is correctly identified. Nine inputs are based on 9 chemical measurements with one of the 6 types of glass, which are continuous with 70, 76, 17, 13, 9, and 29 instances, respectively. From the 214 examples: 161 are examples for training and 53 are examples for testing.

Heart database is a set of attributes for heart disease diagnoses. This database contains 76 attributes, but all published experiments refer to its 14 subsets. In particular, so far only ML researchers use the Cleveland database. The “goal”

field refers to the presence of heart disease in the patient. It is an integer valued from 0 (no presence) to 4. Experiments with the Cleveland database concentrate on simply attempting to distinguish the presence (values 1, 2, 3 and 4) from absence (value 0). There are total of 303 examples: 227 for training and 76 for testing.

Horse dataset is about horse diseases where the task is to determine if the lesion of the horse was surgical or not. This is applied in predicting the fate of a horse with colic and to classify whether the horse will survive, die, or euthanized. The dataset is created based on Horse Colic data with 364 instances, each with 58 inputs from 27 attributes and 3 outputs. From the total instances: 273 are for training and 91 are for testing.

Iris dataset is perhaps the best-known database to be found in the pattern recognition literature. Fisher's article is a classic in the field and is referenced frequently to this date. The data set involves 150 instances of flowers of the Iris species: Setosa, Versicolor and Virginica. Each one of the 50 instances in each one of three classes has 4 variables. These variables are sepal length, sepal width, petal length, and petal width. From the total instances of: 112 are for training and 38 are for testing.

Thyroid dataset is the diagnosis of thyroid whether it is hyper or hypofunction. This dataset consists of 215 patients and 5 features. These features are T3-resin uptake test (A percentage), Total serum thyroxine as measured by the isotopic displacement method, Total serum triiodothyronine as measured by radioimmuno assay, Basal thyroid-stimulating hormone (TSH) as measured by radioimmuno assay, and Maximal absolute difference of TSH value after injection of 200 mg of thyrotropic-releasing hormone as compared to the basal value. This dataset consists of 3 classes: normal, hyperthyroidism and hypothyroidism. From the total instances: 162 are for training and 53 are for testing.

Wine data are the results of a chemical analysis of wines grown in the same region in Italy but derived from three different cultivars. The analysis determines the quantities of 13 constituents found in each of the three types of wines. In addition, there are 178 examples: 133 for training and 45 for testing.

Algorithms for Comparison

In this subsection, some classification techniques are applied on the test problems to be compared with the performance of P-UTADIS method. In [99], some classification techniques, in groups of Bayesian, ANN, lazy, meta-techniques, tree-based and rule-based are presented and compared with the PSO and ABC algorithms. The name of those techniques are: the Bayes Net [101] from the

Bayesian; the Multi-Layer Perceptron (MLP) [14] and the Radial Basis Function (RBF) [102] from the ANN; the KStar [103] from the lazy; the Bagging [104] and the MultiBoostAB [17] from the meta-techniques; the Naive Bayes Tree (NBTree) [96] from the tree-based ones; the Ripple Down Rule (Ridor) [105] from the rule based ones; and the Voting Feature Interval (VFI) [106], respectively. Parameter values used for any technique are those set as default in WEKA [18].

RESULTS AND DISCUSSION

In this section, by applying the previously mentioned 13-test problem a comparative assessment is run between classification error percentage (CEP) of the PUTADIS method and the CEP of the techniques mentioned before. The algorithms are run for 10 times and the average of acquired solutions is presented. The CEP of PUTADIS method and 11 techniques presented in [100] are tabulated in Table 14 [87]. The technical rankings of each problem are tabulated in Table 15 [87]. This ranking is based on the average classification errors of all the problems where, P-UTADIS technique is ranked first followed by ABC, PSO, respectively. Since the CEP average Table 16 is affected by the outlier data and the high error rate in some datasets, in the Tables 16 and 17 the two criteria – the sum of the ranks and the frequencies that a procedure has the best rank in different datasets – constitute the basis of ranking. The general ranking of the techniques in Table 17 is determined by calculating the sum of the techniques' ranks from Table 15. Here, the PUTADIS technique has the best rank.

Table 14. Average CEP on testing set given in [23] and the P-UTADIS algorithm on each problem.

Dataset	P-UTADIS	ABC	PSO	Bayes Nets	MLP Ann	RBF	KStar	Bagging	Multi Boosts	NBTree	Ridor	VFI	Min.
Wine	0	0	2.88	0	1.33	2.88	3.99	2.66	17.77	2.22	5.1	5.77	0
Thyroid	1.51	3.77	3.88	6.66	1.85	5.55	13.32	14.62	7.4	11.11	8.51	11.11	1.51
Iris	0.3	0	5.3	2.6	0	10	0.5	0.3	2.6	2.6	0.5	0	0
Horse	18.68	38.26	35.16	30.76	32.19	38.46	35.71	30.32	38.46	31.86	31.86	41.75	18.68
Heart	16.97	14.47	15.73	18.42	19.46	45.25	26.7	20.25	18.42	22.36	22.89	18.42	14.47
Glass	30.19	41.5	38.67	29.62	28.51	44.44	17.58	25.36	53.7	24.07	31.66	41.11	17.58
E.Coli	1.59	13.41	13.9	17.07	13.53	24.38	18.29	15.36	31.7	20.73	17.07	17.07	1.59
Diabetes	20.83	22.39	21.77	25.52	29.16	39.16	34.05	26.87	27.08	25.52	29.31	34.37	20.83
Dermatology	18.15	5.43	6.08	1.08	3.26	34.66	4.66	3.47	53.26	1.08	7.92	7.6	1.08
Credit	9.48	13.37	18.77	12.13	13.81	43.29	19.18	10.68	12.71	16.18	12.65	16.47	9.48
Cancer-Int	2.63	0	2.64	3.42	5.25	8.17	4.57	3.93	5.14	5.71	5.48	5.71	0
Cancer	2.8	2.81	3.49	4.19	2.93	20.27	2.44	4.47	5.59	7.69	6.36	7.34	2.44
Balance	9.94	15.38	13.12	19.74	9.29	33.61	10.25	14.77	24.2	19.74	20.63	38.85	9.29

Table 15. Ranking of the techniques given in [100] based on average CEP and the P-UTADIS algorithm on each problem.

Dataset	P-UTADIS	ABC	PSO	BayesNet	MLP Ann	RBF	KStar	Bagging	Multi Boost	NBTree	Ridor	VFI
Balance	2	6	4	7	1	11	3	5	10	7	9	12
Cancer	2	3	5	6	4	12	1	7	8	11	9	10
Cancer-Int	2	1	3	4	8	12	6	5	7	10	9	10
Credit	1	6	10	3	7	12	11	2	5	8	4	9
Dermatology	10	6	7	1	3	11	5	4	12	1	9	8
Diabetes	1	3	2	4	8	12	10	6	7	4	9	11
E.Coli	1	2	4	6	3	11	9	5	12	10	6	6
Glass	6	10	8	5	4	11	1	3	12	2	7	9
Heart	3	1	2	4	7	12	11	8	4	9	10	4
Horse	1	9	7	3	6	10	8	2	10	4	4	12
Iris	4	1	11	8	1	12	6	4	8	8	6	1
Thyroid	1	3	4	6	2	5	11	12	7	9	8	9
Wine	1	1	7	1	4	7	9	6	12	5	10	11

Table 16. Average CEP on testing set and general ranking of the techniques on all problems.

Dataset	P-UTADIS	ABC	PSO	BayesNet	MLP Ann	RBF	KStar	Bagging	Multi Boost	NBTree	Ridor	VFI
Average	12.62	13.14	13.95	13.17	12.35	26.93	14.71	13.31	22.93	14.68	15.38	18.89
Rank	2	3	6	4	1	12	8	5	11	7	9	10

Table 17. The sum of ranking of the techniques and general ranking based on the total ranking.

Dataset	P-UTADIS	ABC	PSO	BayesNet	MLP Ann	RBF	KStar	Bagging	Multi Boost	NBTree	Ridor	VFI
Total	40	51	72	58	57	138	91	69	114	88	99	112
Rank	1	2	6	4	3	12	8	5	11	7	9	10

In Table 18, the technique frequencies with the least classification error or the ones with rank 1, based on Table 15 constitute the basis of the final techniques' classification. In this measure also, the PUTADIS technique has the best rank. All these three measures indicate that classification with the P-UTADIS offers superior generalization capability and if it is applied in a classification problem, the accuracy of results would be guaranteed.

Table 18. Frequency of the best ranking of the techniques and general ranking based on the frequency of the best ranking.

Dataset	P-UTADIS	ABC	PSO	BayesNet	MLP Ann	RBF	KStar	Bagging	Multi Boost	NBTree	Ridor	VFI
Frequency of the best rank	5	5	0	2	2	0	2	0	0	1	0	1
Rank	1	1	4	2	2	4	2	4	4	3	4	3

3.9. P-UTADIS Time Complexity

In order to estimate the running time of the program, time complexity is applied as an easy way out. In fact, time complexity is the number of the machine instructions during the running time of a program. This number primarily depends on the size of the algorithm input. Finding the exact calculation of the algorithm time is a labor-intensive process and depends on many factors like compiler, the type of computer, the speed of the processors, main memory and access time to it, knowledge of the programmer, *etc.* Therefore, the measurement of a certain order of magnitude is usually made. The maximum number of primitive operations in an algorithm can be applied as a good approximation of complexity. According to P-UTADIS algorithm and principles of complexity, the time complexity of the algorithm is described as Eq. (50):

$$TimeComplexity = Max_{PSOIter} \times n_{particle} \times (mnT + Max_{GAlter} \times n_{pop} \times m) \quad (50)$$

where, n is the number of attributes, m is the number of alternatives and T is the degree of polynomial. Here, the values of $Max_{PSOIter}$, $n_{particle}$, Max_{GAlter} , n_{pop} and T are constant. With respect to these facts, time complexity of P-UTADIS is $O(mn)$. To represent the complexity, an artificial data set containing three classes, 5 to 10 attributes and 225 to 6750 alternatives was fed into the algorithm. In this data set, every attribute has random values from specific ranges of (10,15), (30,40) and (70,80) for class1, class2 and class3, respectively. By considering the polynomial function to be of degree 10, all the problems are addressed with $CEP = 0$ (without any classification error). Note, the curve of the running time of the algorithm for 30 different problems is shown in Fig. (17), and the number of variables with this corresponding running times are tabulated in Table 19.

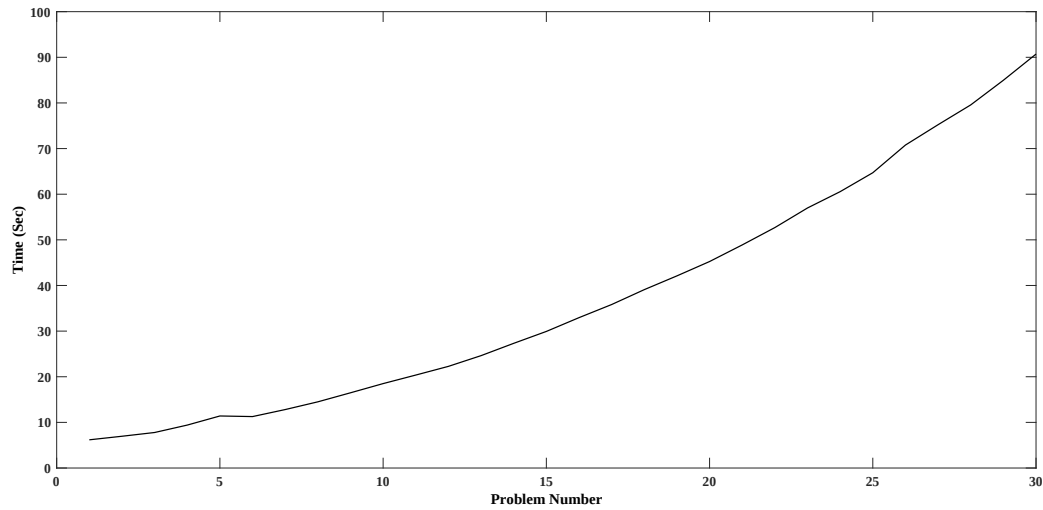


Fig. (17). Process of increasing the execute time of algorithm based on the number of variables [87].

Table 19. Comparison of the number of the variables and running time.

Problem Number	Num. of alternatives (m)	Num. of attributes (n)	Time (Sec)	Problem Number	Num. of alternatives (m)	Num. of attributes (n)	Time (Sec)
1	225	5	6.18	16	3600	80	32.95
2	450	10	6.98	17	3825	85	35.82
3	675	15	7.78	18	4050	90	39.09
4	900	20	9.41	19	4275	95	42.10
5	1125	25	11.40	20	4500	100	45.25
6	1350	30	11.27	21	4725	105	48.89
7	1575	35	12.81	22	4950	110	52.69
8	1800	40	14.50	23	5175	115	56.98
9	2025	45	16.48	24	5400	120	60.56
10	2250	50	18.50	25	5625	125	64.70
11	2475	55	20.37	26	5850	130	70.77
12	2700	60	22.27	27	6075	135	75.23
13	2925	65	24.63	28	6300	140	79.57
14	3150	70	27.32	29	6525	145	84.97
15	3375	75	29.93	30	6750	150	90.71

CONCLUDING REMARKS

In this chapter, after reviewing the principles, a new multi-criteria classification technique is proposed for both nominal and ordinal groups. The UTADIS method, named P-UTADIS is introduced where the heuristic methods (PSO and GA) are applied as steps. A polynomial of degree n was applied as the utility function rather than a piecewise linear function as an approximation of the utility function for each criterion. This algorithm could be applied for both nominal and ordinal data sets, while normal UTADIS is just considered in ordinal data sets. The purpose of this model is to develop a criteria aggregation model in order to minimize the misclassification of instances. In comparison with UTADIS method, P-UTADIS minimizes misclassification number, while the UTADIS minimizes the classification error value(s). The results of comparing the performance of the P-UTADIS method with (PSO) algorithm, ABC algorithm and nine other techniques widely applied by the researchers indicate that the P-UTADIS method can successfully be applied in classification of instances.

CONFLICT OF INTEREST

The authors confirm that this chapter content has no conflict of interest.

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APPLICATIONS

CHAPTER 8

Artificial Intelligence Techniques for Credit Risk Management

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Abstract: For calculating the expected loss besides the exposure at default two measures, namely the probability of default and the loss given default (LGD), have to be taken into account. While in literature much attention has been paid to the default rate the loss given default is still comparatively less investigated. Especially, as a consequence of the enhanced regulation by Basel II accord loss given default has become a much more critical measure for banks and other financial institutions as it has been before.

Therefore, in this study artificial intelligence and statistical techniques are used to predict the recovery rate of corporate bonds that defaulted between 2002 and 2012. Macroeconomic factors, bond characteristics and industry specific factors are taken into account as covariates for the techniques. Starting from the base case of a plain-vanilla Least Squares-Support Vector Machine (LS-SVM) two further modifications of a LS-SVM are presented. The performance of the LS-SVM happens to be significantly better than the performance of a casual linear regression approach. So, it is empirically shown that support vector regression is an approach to LGD modeling which has significant potential to be used for forecasts of the recovery rate both for banks and other financial institutions as well as for investors in distressed debt.

Keywords: Loss given default, Recovery rate, Credit Risk, Support Vector Machine.

1. INTRODUCTION

There are two sources of capital for companies. Equity financing gives the equity holders a residual claim on the companies' assets after all debt holders have been paid back the amount of debt, that is principal (the initial nominal amount of debt) and interest. In case of a bankruptcy the debtholders' claims are senior to the

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equityholders' claims. Therefore, if a company files for bankruptcy the debtholders' debt has to be paid back out of the remaining capital as long as there are any assets left.

The recovery rate, also known as $1 - \text{Loss given default (LGD)}$, denotes the remainder of the debt that is paid back to the creditors in case of a default. For calculating the expected loss besides the exposure at default (EAD) two measures, namely the probability of default (PD) and the loss given default (LGD), have to be taken into account. According to Schuermann *et al.* [1] the expecting loss amounts to:

$$\text{Expected Loss} = \text{EAD} * \text{PD} * \text{LGD} \quad (1)$$

While in literature much attention has been paid to the default rate the loss given default is still comparatively less investigated¹. Especially, as a consequence of the enhanced regulation by Basel II accord loss given default has become a much more critical measure for banks and other financial institutions as it has been before. According to Loterman *et al.* [2] within the required framework of Basel II loss given default has a linear impact on the minimum capital which banks and other financial institutions have to hold. Therefore any changes in the estimate of loss given default have a strong influence on the required minimum capital and more accurate forecasts can have immediate economic benefits. In the following we will focus on the recovery rate which is equivalent to $1 - \text{LGD}$. So higher recovery rates bring a lower LGD.

As stated by Schuermann *et al.* [1] the Basel II accord shows two different approaches for calculating the credit risk requirements: First a standardized approach using the results from rating agencies on a risk-weighted asset basis can be used. Alternatively, an internal ratings based (IRB) approach can be implemented. The IRB approach allows to use internal estimates for the risk parameters for the calculation of credit risk capital. Financial institutions using the latter method need to develop proprietary methods for estimating these key risk parameters. As one relevant parameter is loss given default both banks and supervisors need to know reliable calculation methods for this parameter.

Moreover, Jankowitsch *et al.* [3] conclude that the magnitude and variability of defaults during the global financial crisis have added additional weight to the importance of calculating accurate forecasts of loss given default. In a low default world inaccurate forecasts might have been less risky and might have been not detected for the simple reason that there occurred less default events.

Therefore, in this study artificial intelligence and statistical techniques are used to predict the recovery rate (RR) of corporate bonds that defaulted between 2002 and 2012. Macroeconomic factors, bond characteristics and industry specific factors are taken into account as covariates for the techniques. Starting from the base case of a plain-vanilla Least Squares-Support Vector Regression (LS-SVR) two further modifications of a LS-SVR are presented. The performance of the LS-SVR happens to be significantly better than the performance of a casual linear regression approach. So, it is empirically shown that support vector regression is an approach to LGD modeling which has significant potential to be used for forecasts of the recovery rate both for banks and other financial institutions as well as for investors in distressed debt.

There are a wide range of bond characteristics that have predictive power for the recovery rate of the respective bond. In our study we make use of these characteristics to predict the recovery rates of corporate bonds.

As far as we know and demonstrate in Table 1, very little attention has been paid in literature to predicting recovery rates with Support Vector techniques. However, there are two studies that have dealt with this topic. Loterman *et al.* [2] present a comprehensive comparison of 24 techniques for the prediction of recovery rates of diverse instruments such as corporate loans, mortgage loans and personal loans. They show a clear trend that non-linear techniques like Support Vector Machines and artificial neural networks have more predictive power than traditional linear models. Moreover, it is stated that two-stage models, a combination of non-linear and linear models, have similar predictive power like non-linear models with the advantage of an improved comprehensibility.

Table 1. sOverview of models in literature, based on Hochstotter and Nazemi [6].

Author	Models	Author	Models
Acharya <i>et al.</i> [7]	Linear Regression	Gurtler & Hibbeln [8]	Linear regression model
Altman <i>et al.</i> [9]	Multivariate regression	Han & Jang [10]	Generalized linear model, OLS
Altman & Kalotay [11]	Mixtures of Gaussian	Hartmann <i>et al.</i> [12]	OLS Regression, FMMs
Ando [13]	Bayesian Method	Hoechstotter <i>et al.</i> [14]	LR, NN, KNN, CHAID, CART, SVM
Bastos [15]	Fractional Response Regression, RT	Jacobs <i>et al.</i> [16]	beta-link generalized linear model
Bastos [17]	Fractional Regression, Neural Network	Jankowitsch <i>et al.</i> [3]	Linear Regression
Bastos [18]	Bagging Predictors	Jokivuolle & Viren [19]	Time-series models

(Table 1) *contd.....*

Author	Models	Author	Models
Bellotti & Crook [20]	macroeconomic variables, OLS	Khieu <i>et al.</i> [21]	regression
Bellotti & Crook [22]	OLS, Decision Tree and Tobit	Leow <i>et al.</i> [23]	OLS linear regression
Bijak & Thomas [24]	Bayesian	Leow & Mues [25]	two-stage model OLS
Bonini & Caivano [26]	Advanced credibility theory	Park & Bang [27]	Regression
Calabrese & Zenga [28]	Beta kernel, mixed random variable	Qi & Zhao [5]	RT, NN, FRR, Inverse Gaussian Regression
Calabrese [29]	BR, Mixed random variable, distributional	Loterman <i>et al.</i> [2]	OLS, LSSVM, NN, LR <i>etc.</i>
Calabrese [30]	Mixture Model, FED model, EM algorithm	Rösch & Scheule [31]	Fixed effect model, Random effect model
Caselli <i>et al.</i> [32]	Regression, Multivariate analysis	Renault & Scaillet [33]	Kernel estimation, Nonparametric, Monte Carlo
Cantor & Varma [34]	Regression	Nazemi <i>et al.</i> [35]	LR, RT, SVRs
Chen & Chen [36]	Logistic Regression	Tang & Yuan [37]	Multivariate models: Archimedean copulas & mixtures
Choro-Tomczyk <i>et al.</i> [38]	Hierarchical Archimedean Copulae	Thomas <i>et al.</i> [39]	Decision tree approach
Damme [40]	Beta distribution	Tobback <i>et al.</i> [41]	SVR, RT, Transformed linear, two-stage model
Dragomir & Tudor [42]	Linear regression, Stress testing	Tong <i>et al.</i> [43]	OLS-beat, Tobit regression
Filho <i>et al.</i> ([44]	Optimization, Text Mining	Yao <i>et al.</i> [4]	LS-SVR
Grunert & Weber [45]	Distribution of RR, regression	Zhang & Thomas [46]	LR, survival analysis, single & mixture distribution
Gupton & Stein [47]	Distributional		

A further study applying Support Vector methods to the prediction of the recovery rates of corporate bonds is from Yao *et al.* [4]. In their study three variations of a Least Squares-Support Vector Regression show significant outperformance compared to traditional modeling techniques like linear regression or fractional response regression. Beyond this, LS-SVR shows outperformance at a segmented level by bond seniority *versus* traditional approaches, too. Furthermore, Yao *et al.* [4] show that standard transformations of the recovery rate such as beta-transformation or log-transformation do not achieve significant gains in predictive accuracy.

Taking into consideration the relatively low R^2 -values in literature, further optimization of LGD modeling might be a worthwhile goal, too. Among the highest R^2 -values reported in literature so far are 0.5 in Loterman *et al.* [2], 0.53 from Qi and Zhao [5] and 0.7 from Yao *et al.* [4]. Hence, there seems to be a substantial random part in recovery rates' prediction which is not explainable by any methods, no matter how sophisticated they might be.

At first, in section 2 we present an overview of the models we have built for comparison. We will explain how we have chosen the variables for our models based on their significance in existing literature in section 3.1. Before we start to build our models an overview of the descriptive statistics of the data set is presented. In the following we will use a sample of 776 corporate bonds which defaulted between 2002 and 2012 for building our models. An ϵ -insensitive Support Vector Regression (ϵ -SVR) model, a plain vanilla LS-SVR model and two slightly modified LS-SVR models are built. As benchmark for our comparison a linear regression model is used.

2. SUPPORT VECTOR REGRESSION MODELING FOR RECOVERY RATES

So far according to our knowledge only very few studies, namely Loterman *et al.* [2] and Yao *et al.* [4], have tried to predict recovery rates using support vector techniques. From a general point of view we estimate that due to their properties Support Vector Machines can be a promising artificial intelligence technique for the prediction of recovery rates. In comparison with neural networks as used in Qi and Zhao [5] Support Vector Machines have the advantage that they can deal with convex objective functions and a lower effort for tuning the model's parameters is required.

In the following section we will present a short review of Support Vector Machine techniques and their origins. The original use case for Support Vector Machines is classification and pattern recognition. As outlined by Vapnik *et al.* [48] in doing so one selects only a small subset of the training data, the Support Vectors, to find a decision rule with good applicability for the entire data set. The optimal decision rule for the Support Vectors is also optimal for the entire data set. Later this method was also applied to real-valued functions allowing to expand high-dimensional functions to use a small basis constructed from Support Vectors. Vapnik *et al.* [48] also show that by using Support Vectors they are able to solve problems that would require estimating a large number of free parameters by using classical statistical approaches.

According to Baesens [49] in the classification case the following linear program has to be solved where x_{ni} denote the features, e_1 to e_{ng} respectively e_{ng} denote the differences between the realized and the predicted value of good and bad customers and w_1 to w_n denote the weight of the respective observation:

$$\begin{aligned}
 & \min e_1 + e_2 + \dots + e_{ng} + \dots + e_{nb} \\
 & \text{s.t. } w_1 x_{i1} + w_2 x_{i2} + \dots + w_n x_{in} \geq c - e_i, 1 \leq i \leq n_g \\
 & \quad w_1 x_{i1} + w_2 x_{i2} + \dots + w_n x_{in} \leq c + e_i, n_g + 1 \leq i \leq n_g + n_b, e_i \geq 0
 \end{aligned} \tag{2}$$

In the use case of credit scoring and following the derivation from Baesens [49] this linear program assigns a score above the cut-off value c to the good customers and a score below c to the bad customers. n_g and n_b are the numbers of good and bad customers. As perfect separation between goods and bads might not be feasible the error variables e_i are needed to make the linear program solvable. One problem of this approach is that there might be multiple solution boundaries in a perfectly separable case. To account for this problem a further objective is included in SVM modeling. Therefore SVMs aim not only on minimizing the errors but also on maximizing the perpendicular distance between the hyperplanes separating the data. Maximizing this margin is equivalent to minimizing the euclidean distances $\|\mathbf{w}\|$ where $\mathbf{w}$ represents the weights of each data vector. As consequence two new conditions are introduced setting y_k to 1 for good customers and to -1 for bad customers:

$$\begin{aligned}
 & \mathbf{w}^T x_k + b \geq 1, \text{ if } y_k = +1 \\
 & \mathbf{w}^T x_k + b \leq -1, \text{ if } y_k = -1
 \end{aligned} \tag{3}$$

For cases that are not linear separable again an error term e_i , that is weighted with hyperparameter C , is introduced. By using a nonlinear mapping $\phi(x)$ the input data is mapped to a higher dimensional feature space. So the optimization problem becomes:

$$\begin{aligned}
 & \min \frac{1}{2} \sum_{i=1}^N w_i^2 + C \sum_{i=1}^n e_i \\
 & \text{s.t. } y_k (\mathbf{w}^T \phi(x_k) + b) \geq 1 - e_k, \quad k = 1, \dots, n \quad e_k \geq 0
 \end{aligned} \tag{4}$$

According to Chalup and Mitschele [50] kernel methods can be described as kernelised versions of other fundamental machine learning techniques. These kernel methods are very popular and useful tools as they are suitable for a large variety of non-linear complex tasks. They have been applied successfully to a diverse range of topics such as genome sequence classification, time series prediction, face recognition and text categorization. As it is well known that financial data are noisy and non-stationary kernel methods with their ability to deal with non-linearity and complexity might be a promising technique in this field.

Following the explanation from Chalup and Mitschele [50] kernel methods make use of a non-linear feature mapping

$$\phi : X \rightarrow H \quad (5)$$

from an input space $\mathbf{X}$ to a high-dimensional feature space $\mathbf{H}$. ϕ transfers a potentially non-linear task from $\mathbf{X}$ to $\mathbf{H}$ where a satisfactory solution is searched for using traditional linear methods. The main idea is that the feature mapping ϕ is needed only implicitly does not need to be used explicitly during any computation. This approach is facilitated through the use of a continuous and symmetric function

$$K : X \times X \rightarrow R \quad (6)$$

which is used as similarity measure for the inputs. Mercer's theorem states that if K is positive semi-definite there exists a mapping ϕ from $\mathbf{X}$ into some Hilbert space $\mathbf{H}$ such that K is a kernel, that can be written as

$$K(x_k, x_l) = \phi(x_k)^T \phi(x_l) \quad (7)$$

To kernelize an algorithm it is necessary to ensure that only dot products of the variables $x_k^T x_l$ occur in the respective calculation. The replacement of x_i through $\phi(x_i)$ results in the dot products which can be substituted by the respectively chosen kernel function $\mathbf{K}$. Hence, the computations of kernelized methods do not require explicit knowledge of the mapping ϕ as they only have to know the kernel $\mathbf{K}$. This is called the *Kernel Trick*.

To make use of Mercer's Theorem an appropriate kernel function has to be chosen. As stated by Chalup and Mitschele [50] the only prerequisites a kernel has to fulfill are to be positive semi-definite and to represent a similarity measure

between pairs of input samples. According to Baesens [49] linear kernels, polynomial kernels, and radial basis function kernels are among the common choices for kernel functions. Due to its overall stable and high performance, as outlined in Hsu *et al.* [51], we have decided to use the radial basis function as a robust and well-performing kernel. We are using the Radial Basis Function (RBF) kernel in the following form measuring the distance between the features x_i and x_j :

$$K(x_i, x_j) = \exp\left(-\frac{\|x_i - x_j\|^2}{2\sigma^2}\right) \quad (8)$$

So a non-linear SVM classifier has the following form whereby α_k are the Lagrangian multipliers from the optimization. Thereby only Support Vectors will have nonzero α_k since they are used for the construction of the separating hyperplane using b as intercept:

$$y(x) = \text{sign}\left[\sum_{k=1}^n \alpha_k y_k K(x, x_k) + b\right] \quad (9)$$

As in our case we want to use the SVM for predicting the recovery rate, which is a regression application and the classical SVM formulation as we have it presented above is for a classification problem, we still have to make the necessary adjustments. As shown in Baesens [49] the intuition is to find a function $f(x)$ that produces at most ϵ deviation from actual values y_k , that is the actual recovery rates, and is thereby as flat as possible. So we arrive at the new SVM formulation of:

$$\begin{aligned} \min \quad & \frac{1}{2} \sum_{i=1}^N w_i^2 + C \sum_{i=1}^n \epsilon_k + \epsilon_k^* \\ \text{s.t.} \quad & y_k - \mathbf{w}^T \phi(x_k) - b \leq \epsilon + \epsilon_k \\ & \mathbf{w}^T \phi(x_k) + b - y_k \leq \epsilon + \epsilon_k^*, \quad \epsilon, \epsilon_k, \epsilon_k^* \geq 0 \end{aligned} \quad (10)$$

The hyperparameter C defines the trade-off between overfitting in case of a C , that is higher than optimal, and the amount of ϵ to which deviations are tolerated. Lagrangian optimization yields the following nonlinear regression function as result. α_k and α_k^* are the Lagrangian multipliers:

$$f(x) = \sum_{k=1}^n (\alpha_k - \alpha_k^*) K(x_k, x) + b$$

When using the ϵ -insensitive loss function there is an error insensitive tube with width ϵ wrapped around the optimal predicted function. Another common used loss function is the quadratic loss function where small errors have also smaller weights but are not neglected completely as in the case of ϵ -insensitive loss function. Therefore, we will also build a SVR with quadratic loss function making it a Least Squares problem.

We are using three different Least Squares-Support Vector Regression models. First, we are using the one defined as in Suykens and Vandewalle [52]. $\mathbf{w}$ is the vector of the covariates while b is the intercept. The regularization parameter C scales the error terms u_i^2 and $\phi(x)$ denotes the kernel function for the feature mapping. Using a quadratic loss function the model is defined as:

$$\begin{aligned} \min J(w, b, u_i) &= \frac{1}{2} \|w\|^2 + \frac{C}{2} \sum_{i=1}^n u_i^2 \\ \text{s.t. } y_i &= w^T \phi(x_i) + b + u_i, \quad i = 1, \dots, N, \end{aligned} \quad (11)$$

For the solution of the model its dual form is derived from a Lagrangian function with α_i as Lagrangian multiplier of the following form:

$$L(w, b, u_i, \alpha_i) = J(w, u_i) - \sum_i^N \alpha_i (w^T \phi(x_i) + b + u_i - y_i) \quad (12)$$

A solution of the dual form based on the Karush-Kuhn-Tucker (KKT) condition can be obtained with the following linear equation systems. $\mathbf{e} = (1, \dots, 1)^T$ denotes a $1 \times N$ unit vector, $\mathbf{y} = (y_1, \dots, y_N)^T$ is the target vector of recovery rates, $\alpha = (\alpha_1,$

$\dots, \alpha_N)^T$ are the Lagrangian multipliers and $\bar{\mathbf{K}} = \mathbf{K} + \frac{1}{C}\mathbf{I}$ where $\mathbf{I}$ is the identity matrix.

$$\begin{pmatrix} 0 & \mathbf{e}^T \\ \mathbf{e} & \bar{\mathbf{K}} \end{pmatrix} * \begin{pmatrix} b \\ \alpha \end{pmatrix} = \begin{pmatrix} 0 \\ \mathbf{y} \end{pmatrix} \quad (13)$$

So, the final estimated regression model is build as

$$f(x) = \sum_i \alpha_i^* K(x_i, x) + b^* \quad (14)$$

For further improvements in the predictive accuracy two slightly modified LS-SVR models similar to the ones used by Yao *et al.* [4] are introduced. First, we allow for different intercepts b_k for K different seniority classes. So we assume there is some kind of homogeneity within the seniority classes that can be represented by the different intercepts.

$$\begin{aligned} \min J(w, b_k, u_{kj}) &= \frac{1}{2} \|w\|^2 + \frac{1}{2} \sum_{k=1}^K b_k^2 + \frac{C}{2} \sum_{k=1}^K \sum_{j=1}^{n_k} u_{kj}^2 \\ \text{s.t. } y_i &= w^T \phi(x_{kj}) + b_k + u_{kj}, \quad j = 1, \dots, n_k, k = 1, \dots, K \end{aligned} \quad (15)$$

The corresponding Lagrangian function results in the following formula.

$$L(w, b_k, u_{kj}, \alpha_{kj}) = J(w, b_k, u_{kj}) - \sum_{k=1}^K \sum_{j=1}^{n_k} \alpha_{kj} (w^T \phi(x_{kj}) + b_k + u_{kj} - y_{kj}) \quad (16)$$

With $\mathbf{W}$ representing a block diagonal matrix such as $\mathbf{W} = \begin{pmatrix} \mathbf{W}_1 & & & \\ & \mathbf{W}_2 & & \\ & & \ddots & \\ & & & \mathbf{W}_K \end{pmatrix}$

and each $\mathbf{W}_k$ as a $n_k \times n_k$ - matrix with all elements equal to 1 the dual form problem can be written as

$$\min \frac{1}{2} \alpha^T \mathbf{K} \alpha + \frac{1}{2} \alpha^T \mathbf{W} \alpha + \frac{1}{2C} \alpha^T \alpha - y^T \alpha \quad (17)$$

As explained in more detail in Smola *et al.* [53] a possible solution for the optimization problem is an interior-point-solution. As consequence we are using the in-built interior-point-algorithm in MATLAB as part of the quadratic programming function while also making use of the MATLAB SVM toolbox by Gunn *et al.* [54]. Thereby an optimal solution to the primal-dual problem as defined above can be found.

Moreover, we are also constructing a model which assumes the impact from the different seniority classes to be linear. The dummy variables for the seniority classes are z_{kj} and β is a vector of fixed effects for the seniority of the respective group.

$$\begin{aligned} \min J(w, b, u_i) &= \frac{1}{2} \|w\|^2 + \frac{1}{2} \beta^T \beta + \frac{1}{2} b^2 + \frac{C}{2} \sum_{k=1}^K \sum_{j=1}^{n_k} u_{kj}^2 \\ \text{s.t. } y_i &= \mathbf{w}^T \phi(x_i) + \beta^T z_{kj} + u_{kj}, \quad j = 1, \dots, n_k, k = 1, \dots, K \end{aligned} \quad (18)$$

For this case the Lagrangian function is obtained as

$$L(w, b, u_{kj}, \alpha_{kj}) = J(w, b, u_{kj}) - \sum_{k=1}^K \sum_{j=1}^{n_k} \alpha_{kj} (w^T \phi(x_{kj}) + b + \beta^T z_{kj} + u_{kj} - y_{kj}) \quad (19)$$

Accordingly, with $\mathbf{Z}_{ij} = z_{kj}^T z_{kj}$ and $\mathbf{V}$ as a $N \times N$ -matrix with all elements equal to 1 the dual form is

$$\min \frac{1}{2} \alpha^T \mathbf{K} \alpha + \frac{1}{2} \alpha^T \mathbf{Z} \alpha + \frac{1}{2} \alpha^T \mathbf{V} \alpha + \frac{1}{2C} \alpha^T \alpha - y^T \alpha \quad (20)$$

For the implementation of the Support Vector Regression with an ϵ -insensitive loss function the LIBSVM library from Chang and Lin [55] is used. Then the problem is defined in the form of:

$$\begin{aligned}
& \min_{w, b, u_i, u_i^*} \frac{1}{2} \mathbf{w}^T \mathbf{w} + C \sum_{i=1}^N u_i + C \sum_{i=1}^N u_i^* \\
& \text{s.t. } \mathbf{w}^T \phi(x_i) + b - y_i \leq \epsilon + u_i, \\
& \quad y_i - \mathbf{w}^T \phi(x_i) - b \leq \epsilon + u_i^*, \\
& \quad u_i, u_i^* \geq 0, \quad i = 1, \dots, N.
\end{aligned} \tag{21}$$

$\mathbf{w}$ are the weights of ϵ -SVR, b is the bias, y_i are the targets, C are the costs, N is the number of observations, u_i and u_i^* are the errors and ϵ is the tolerance threshold for tolerated errors. Chang and Lin [55] are also using the radial basis function kernel in the following form with the parameter γ for the width².

$$K(x_i, x_j) = \exp(-\gamma \|x_i - x_j\|^2) \tag{22}$$

In case of the ϵ -insensitive loss function the three parameters C , γ and ϵ are tested for in the search interval from $[2^{-2}$ to $2^0]$, $[2^{-1}$ to $2^3]$ and $[2^{-3}$ to $2^3]$. For the quadratic loss function the parameters C and γ are searched for in the interval $[2^{-4}$ to $2^5]$ and $[2^{-4}$ to $2^3]$. For each training subsample the respective model is built and trained. The performance of the resulting model is evaluated on the validation set. The performances on the five different validation samples are averaged for each model configuration to determine the best model parameters. As performance metrics the root mean squared error (RMSE), the coefficient of determination (R^2) and the mean absolute error (MAE) are used.

$$\text{RMSE} = \sqrt{\frac{1}{n} \sum_i (y_i - \hat{y}_i)^2} \tag{23}$$

$$R^2 = 1 - \frac{\sum_i (y_i - \hat{y}_i)^2}{\sum_i (y_i - \bar{y})^2} \tag{24}$$

$$\text{MAE} = \sqrt{\frac{1}{n} \sum_i |y_i - \hat{y}_i|} \quad (25)$$

Finally the entire training data is used to train the model with the lowest average RMSE on the validation set. This model is used to predict the recovery rates on the test sample.

Two different model configurations regarding the covariates are tested: In the first model the instrument specific variables, which are the seniority, the coupon rate and the trading volume, are taken into account. In this model also industry specific variables indicating whether the respective industry was in a state of distress in the year preceding the default similar to Acharya et al. [7] are used. Macroeconomic covariates (High-yield index and overall number of defaulted bonds) are included in this model, too. For the second model the volatility and the performance of the stock in the year before the default are used additionally.

There is some evidence in literature like in Qi and Zhao [5] suggesting that linear regression models have substantial predictive ability for recovery rates in comparison with more sophisticated approaches. Therefore, we include a linear regression model for the purpose of comparability as basic benchmark for the SVR models we have built where y_i denotes the realized recovery rate, x_i denotes the features used to predict the recovery rate and ϵ_i denotes the $(0, \sigma^2)$ -distributed error variable:

$$\begin{aligned} y_i &= \beta^T \mathbf{x}_i + \epsilon_i \\ \epsilon_i &\sim N(0, \sigma^2) \end{aligned} \quad (26)$$

3. EMPIRICAL ANALYSIS

3.1. Selection of factors for modeling

The variables for our analysis are chosen based on a thorough overview of the literature on the determinants of recovery rates. Among others Altman and Kishore [56] show that a dummy variable for the utility sector has a significant positive impact on the recovery rate. A possible economic reason for this is that utilities might have more assets like power plants that are easier to sell than it might be the case for an average enterprise. Cantor and Varma [34] are one of the

studies showing the significant benefit of including the seniority class as covariate. In case of a default event the most senior bondholders are paid off first and the junior/subordinated bondholders are the last debtholders to be paid off. Bond characteristics like the coupon rate are said to have also significant influence according to Jankowitsch *et al.* [3]. As enterprises often try to issue their bonds at par higher coupon rates are equivalent to a higher perceived risk of the bond at the issue date. Acharya *et al.* [7] have shown that both the performance of an industry index and the growth of the industry sector have predictive power for the recovery rate. Additionally they have illustrated how industry distress dummy variables based on these two covariates have significant impact on the recovery rate. Among others there might be structural reasons for the distress of an industry which might induce also negative effects on the recovery rates the respective industry.

As a proxy for the volume of defaulted bonds which is significant in a study by Altman *et al.* [9] we use the number of defaulted bonds in the default year. The current level of a high yield index is used as a proxy for the aggregated market default rate which is a significant covariate in the study of Cantor and Varma [34]. In case of a higher market default there are more defaulted bonds to buy, that is there is a higher supply of distressed assets while the demand remains at best unchanged. So, prices will be depressed in that situation. The liquidity of the bond is a significant variable in Jankowitsch *et al.* [3] and as proxy for the liquidity we include the aggregated trade volume of the defaulted bonds in the 30 days after the default. This corresponds to a liquidity premium. For time dependent variables the time period of of the year of/before the default respectively the date of default have been used.

3.2. Exploratory data analysis

The initial data set consists of 794 bonds that have failed in the period 2002-2012. The companies that issued these bonds can be assigned to the following sectors: industry, consumer discretionary, consumer staples, telecommunications, raw materials, utilities, energy, financial services and information technology. One bond of the original record falls within the category of a diversified company (recovery rate: 83.00%) and another eight bonds with an average recovery rate of 77.08% cannot be assigned to any sector. These bonds are also excluded from further consideration to avoid any distortion. The same applies for the companies that defaulted as government institution (4 bonds of a company with an average recovery rate of 82.82%) and as public investment company (2 bonds of a company with an average recovery rate of 100.38%). Three bonds of the junior category, which together have an unusually high average recovery rate of 94.41%, were excluded from further analysis. This is because a theoretical explanation for

a higher recovery rate of a subordinated bond compared to a senior bond at the very same time of failure and with similar remaining maturities appears to be difficult. It remains for further analysis a sample of 776 defaulted bonds. The distribution of recovery rates for each seniority and default event type of corporate bonds used in this paper's analysis is shown in Fig. (1). Fig. (2) shows the average recovery rates as time series and per sector.

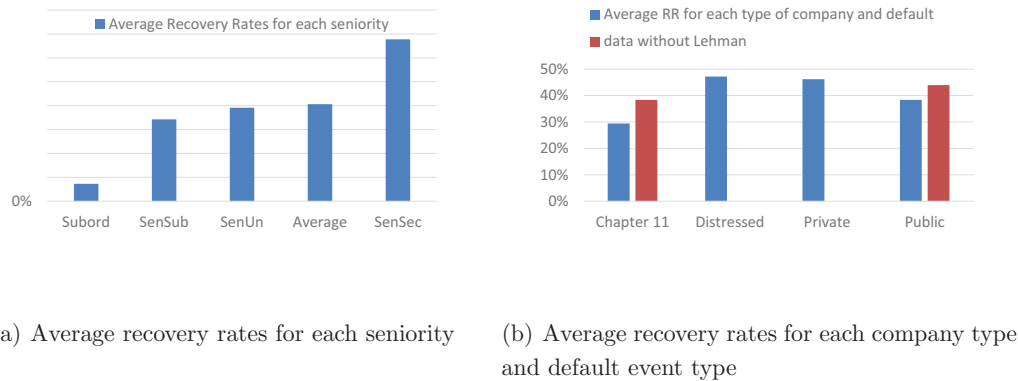


Fig. (1). Average recovery rates, shown under different perspectives.

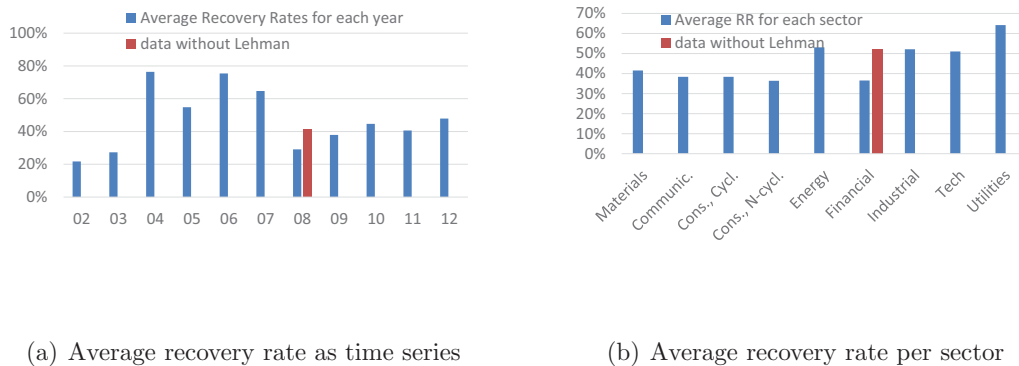


Fig. (2). Average recovery rates as time series and per sector.

Table 2 gives an overview of the descriptive statistics of the recovery rate and the observed factors. It is easy to recognize that the recovery rates for companies of an industry that is in distress are much lower than the overall average recovery rate.

Table 2. Descriptive Statistics for each factor over the 776 observations of the data set.

Variable	Average	σ	Average RR
Recovery Rate (RR)	40.5829%	29.6724%	-
Dummy Utility sector (UtilInd)	0.0399	0.1958	64.15%
Senior unsecured (SenUn)	0.7745	0.4179	39.11%
Subordinated (SenSub)	0.1237	0.3293	34.23%
Senior subordinated (Subord)	0.0116	0.1071	7.27%
Senior secured (Basis) (SenSec)	0.0876	0.2828	67.77%
Aggregated trade volume of the defaulted bond (TraVol)	105.3 Mill.	295.7 Mill.	-
Coupon rate (CpRate)	7.9738%	2.7493%	-
Performance of an industry index (PerfInd)	-18.3923%	24.5415%	-
Performance of sector-index worse than -30% (IndDis1)	0.4201	0.4936	30.59%
Number of defaulted bonds in the respective year (VolDef)	750.0503	468.4869	-
High Yield Index at time of default (HYInd)	11.9792%	4.0930%	-
Sector growth (IndSalGr)	126.3718%	763.7740%	-
Negative revenue growth of the sector (IndDis2)	0.4085	0.4916	32.72%

The average recovery rate in the data set is 40.58% and the standard deviation of the sample is 29.69%. Thus, the average recovery rate of the sample is close to the estimate from Altman *et al.* [56] that is commonly used in practice with an estimated value of 40%. When examining the seniorities, at first, the unequal distribution of observations on the various seniority classes is obvious. Hence, the Junior Subordinate and Subordinate classes are summarized under the main class Subordinate. In addition, the class of senior unsecured bonds represents with 601 observation points more than three quarters of the entire record. Since the average recovery rate in this seniority class is with 39.12% (with Lehman bonds) and 44.14% (without Lehman bonds) only slightly below the general average. Since, this average is in proximity to observations in the literature, for example to the average recovery rate of 41.70% for Altman and Kishore [56], this fact is expected to be no major distortion. Fig. (3) illustrates the shape of the distribution of recovery rates in our sample. As shown in Table 3, overall, the level of average recovery rates within the seniority classes complies with the expectations of rank: Senior secured bonds have the highest recovery rate of 67.77% followed by the senior unsecured. For senior subordinated bonds 34.24% is the average as the second lowest recovery rate and for subordinated bonds 7.96% (with Lehman) and 14.47% (determined without Lehman) are observed as average recovery rate. Furthermore, the frequency distribution of recovery rates across seniority classes is illustrated in Fig. (4).

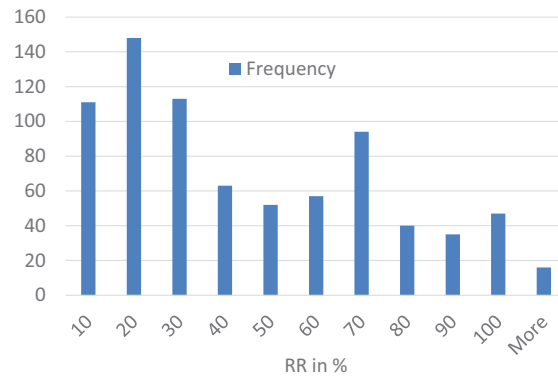


Fig. (3). Frequency distribution of the recovery rates: The histogram of frequency of the observed recovery rates in our sample exhibits two peaks. The class between 10% and 20% contains around 150 values while in general there seems to be some concentration on values between 0 and 30%. There is another peak of the distribution at the class of values between 60% and 70%. However, the observed distribution does not really look like a bimodal distribution.

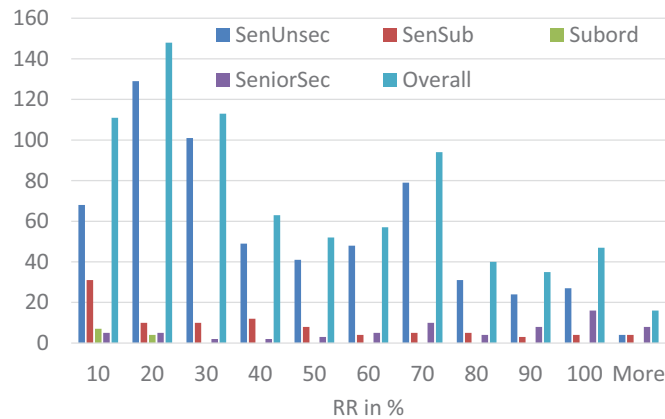


Fig. (4). Frequency distribution of the recovery rates for each seniority class as in Nazemi *et al.* [35]: The histogram of the frequency of the observed recovery rates in our sample shows that for both subordinated and senior subordinated bonds the frequency distribution is heavily skewed to the left side. In contrast, the frequency distribution of the two more senior seniority classes of senior secured and senior unsecured bonds exhibits two peaks. One peak lies in the class between 10% and 20% while there is another peak of the distribution at the class of values between 60% and 70% for senior unsecured bonds and between 90% and 100% for senior secured bonds. (from Nazemi *et al.* [35]).

Table 3. Overview of recovery rates across seniorities.

	Mean RR	Median RR	σ	# of Values	Percentage of Values
Subord	7.96%	4.32%	6.58%	11	1.42%
SenSub	34.23%	24.13%	31.97%	96	12.37%
SenUn	39.11%	30.59s%	27.34%	601	77.45%

(Table 3) *contd.....*

	Mean RR	Median RR	σ	# of Values	Percentage of Values
SenSec	67.77%	74.03%	32.37%	68	8.76%
Total	40.58%	32.79%	29.69%	776	100%

Besides, as shown in Fig. (1), it can be seen that the average recovery rate of bonds issued by unlisted public companies is 46.19% (350 observations) and therewith it is higher than the recovery rate of bonds of publicly traded companies with 36.38% (426 observations with Lehman) and 43.94% (307 observations without Lehman). One possible explanation is that the equity ownership in non-exchange quoted companies is more concentrated and thus, possibly the reputation of the equity owners is at stake in the repayment of the creditors. Further it evolves that with respect to the mode of failure events of default under section 11 of the Bankruptcy Code with 29.43% (Lehman) and 38.36% have a significantly lower average recovery rate than debt restructurings of distressed debt (47.22%). This is consistent with the expectancy of a higher recovery rate through the exchange of debt instruments than during a bankruptcy that might be caused by the denial of a debt swap. However, at this point it is not taken into account whether after a restructuring the company still declares bankruptcy at a later point in time.

The results from the literature are largely confirmed while examining the average recovery rates across different sectors, as illustrated in Fig. (2). As with Jankowitsch *et al.* [3] and Altman and Kishore [56], the bonds of companies from the energy and utilities sector exhibit the highest recovery rates, while Companies in the financial services sector and the industry of non-cyclic Consumer goods are among those with the lowest recovery rates. However, it appears that the relatively low recovery rates of the financial services sector can be traced back solely to the failure of Lehman bonds, since with the exclusion of Lehman's failure, the average recovery rate in the financial services sector increases from 36.55% to 52.48%. Thus, at this point, the results of the previous studies are confirmed only to a limited extent. When examining the average recovery rates of the respective sectors it has to be taken into account, that the standard deviations are different within each sector. For 18 out of the 776 observations there is no coupon rate available. These data points are filled up with the average coupon rate of 7.97%.

Table 4 shows the correlation coefficients between the recovery rate itself and the observed variables presented. For each variable in the first row there is the correlation coefficient while in the second row there is the respective p-value. A p-value below 0.05 indicates significance of the correlation on (1 - 0.05) - significance level. All observed factors in Table 4 are significantly correlated with

the recovery rate except the coupon rate, the trading volume of the defaulted bond and the industry sales growth of the defaulted company. Moreover, the correlation between the recovery rate and the observed factor has for all significant relations the expected sign. Obviously, the correlation between the single dummy variables of the seniority classes is negative. The same relationship holds for the observed industry variables that are also all significantly correlated with each other. In general one can say, that there are plenty of correlations between the variables which might be due to the fact that there are too many factors in relation to the size of the data set. Fig. (4) present frequency distribution of the recovery rates for each seniority class.

Table 4. Correlation coefficients of the recovery rate and its observed variables: For each variable the correlation coefficient is in the first row while the respective p-value is in the second row.

	RR	UtiInd	SenUn	SenSub	Subord	SenSec	TradVol	CpRate	PerfInd	IndDis1	VolDef	HYInd	IndSalGr	IndDis2
RR	1	0.162	-0.0916	-0.0803	-0.1217	0.284	-0.0109	-0.0424	0.3591	-0.2867	-0.3637	-0.3243	-0.015	-0.2201
	1	0	0.0107	0.0253	0.0007	0	0.7621	0.238	0	0	0	0	0.6773	0
UtiInd	0.162	1	-0.0316	-0.0766	-0.0221	0.1462	-0.0302	0.0074	0.2394	-0.1736	-0.1501	-0.17	-0.0327	-0.049
	0	1	0.3789	0.0328	0.5388	0	0.4004	0.8365	0	0	0	0	0.3625	0.1723
SenUn	-0.0916	-0.0316	1	-0.6963	-0.2007	-0.5743	0.0548	-0.2808	-0.2662	0.2031	0.1536	0.1018	0.0645	0.2038
	0.0107	0.3789	1	0	0	0	0.1275	0	0	0	0	0.0046	0.0724	0
SenSub	-0.0803	-0.0766	-0.6963	1	-0.0407	-0.1164	-0.084	0.2408	0.1796	-0.1691	-0.0918	-0.0397	-0.0336	-0.145
	0.0253	0.0328	0	1	0.2574	0.0012	0.0193	0	0	0	0.0106	0.2694	0.3499	0.0001
Subord	-0.1217	-0.0221	-0.2007	-0.0407	1	-0.0336	0.1694	-0.0537	-0.1052	0.1273	0.1431	0.0088	-0.0184	0.1303
	0.0007	0.5388	0	0.2574	1	0.3503	0	0.1351	0.0033	0.0004	0.0001	0.8057	0.6096	0.0003
SenSec	0.284	0.1462	-0.5743	-0.1164	-0.0336	1	-0.054	0.1612	0.2257	-0.153	-0.1734	-0.1048	-0.0479	-0.1741
	0	0	0	0.0012	0.3503	1	0.1328	0	0	0	0	0.0035	0.1823	0
TradVol	-0.0109	-0.0302	0.0548	-0.084	0.1694	-0.054	1	-0.1246	-0.0372	0.0355	0.0561	-0.1002	0.0911	0.0592
	0.7621	0.4004	0.1275	0.0193	0	0.1328	1	0.0005	0.3005	0.3228	0.1184	0.0052	0.0111	0.0995
CpRate	-0.0424	0.0074	-0.2808	0.2408	-0.0537	0.1612	-0.1246	1	0.3879	-0.3795	-0.4054	-0.1389	0.0672	-0.2486
	0.238	0.8365	0	0	0.1351	0	0.0005	1	0	0	0	0.0001	0.0614	0
PerfInd	0.3591	0.2394	-0.2662	0.1796	-0.1052	0.2257	-0.0372	0.3879	1	-0.8243	-0.7722	-0.7015	0.1559	-0.6033
	0	0	0	0	0.0033	0	0.3005	0	1	0	0	0	0	0
IndDis1	-0.2867	-0.1736	0.2031	-0.1691	0.1273	-0.153	0.0355	-0.3795	-0.8243	1	0.6706	0.6001	-0.1421	0.5408
	0	0	0	0	0.0004	0	0.3228	0	0	1	0	0	0.0001	0
VolDef	-0.3637	-0.1501	0.1536	-0.0918	0.1431	-0.1734	0.0561	-0.4054	-0.7722	0.6706	1	0.5508	-0.1627	0.5669
	0	0	0	0.0106	0.0001	0	0.1184	0	0	0	1	0	0	0
HYInd	-0.3243	-0.17	0.1018	-0.0397	0.0088	-0.1048	-0.1002	-0.1389	-0.7015	0.6001	0.5508	1	-0.1738	0.3519
	0	0	0.0046	0.2694	0.8057	0.0035	0.0052	0.0001	0	0	0	1	0	0
IndSalGr	-0.015	-0.0327	0.0645	-0.0336	-0.0184	-0.0479	0.0911	0.0672	0.1559	-0.1421	-0.1627	-0.1738	1	-0.1435
	0.6773	0.3625	0.0724	0.3499	0.6096	0.1823	0.0111	0.0614	0	0.0001	0	0	1	0.0001
IndDis2	-0.2201	-0.049	0.2038	-0.145	0.1303	-0.1741	0.0592	-0.2486	-0.6033	0.5408	0.5669	0.3519	-0.1435	1
	0	0.1723	0	0.0001	0.0003	0	0.0995	0	0	0	0	0	0.0001	1

4. EMPIRICAL MODELLING RESULTS

The general procedure for the different models is the following: First the covariates are scaled to the interval $[0,1]$ which enhances the performance of the LS-SVM according to [51]. 70 percent of the data (543 samples) are used as training set and the remaining 30 percent (233 samples) are used as test set. For the selection of the model parameters a five fold cross validation approach is used. The training data are randomly stratified for their seniority ranks divided into five different training subsamples of 434/435 observations and the validation set of 108/109 observations. The model with the lowest average Root Mean Squared Error (RMSE) on the validation set is finally taken to predict the recovery rates on the test set.

At first, both bond characteristics, such as seniority class and the coupon rate, and industry distress variables, which are a negative industry sales growth and an industry index performance worse than -30%, are included as covariates. For all examined performance measures the performance of ϵ -insensitive SVR is worse than the performance of our control model, a plain linear regression approach. So the ϵ -insensitive SVR does not look like a much promising artificial intelligence technique for predicting recovery rates. One reason for this might be that the ϵ of the best cross validated model is 8 which is a relative high value taking into account that the entire spectrum of predicted values reaches only from 0 to 100. So the predicted function is likely to be relatively flat which gives a low risk of overfitting at the cost of less accuracy. Regarding the width of 8 the different kernel formulations in the equations (4) and (14) explain the different values for LS-SVR and ϵ -SVR.

The three analyzed modifications of the LS-SVR exhibit R^2 -values in the range of 0.1815 to 0.2034 in comparison with values between 0.3566 and 0.5308 in the later analysis with the macro factors. The R^2 -value of the ϵ -insensitive SVR amounts to only 0.0423 while the value when including the macro factors is 0.1370. The same observation holds for the linear regression model. The R^2 -value decreases from 0.2099 with macro factors to 0.1771 without macro factors. So, it is shown that the addition of the macro variables improves the predictive ability of our models significantly.

When including the two macro variables, which are the overall number of defaulted bonds in the respective year and the current standing of an high-yield-index, the explicative capacity of all models is substantially higher than in the models excluding the macro variables.

All three LS-SVR models with basic covariates from Table 5 show distinctive outperformance compared to the linear regression model in all three performance metrics. Among the three tested LS-SVR techniques the semiparametric LS-SVR yields the best results. Its R^2 of 53.08% is more than twice the R^2 of 20.99% of the corresponding linear regression model. The relatively high regularization parameter C with a value of 16 might be prone to overfitting though this issue is in our opinion sufficiently addressed by using a five-fold cross validation for finding the hyperparameters.

Table 5. Performance measures and the respective standard deviations for the model excluding macro factors.

ss	Width	Cost	σ	RMSE	R^2	MAE
LS-SVR	2	4	-	26.7214	0.2025	22.9025
LS-SVR DB	2	4	-	26.7058	0.2034	22.8838
SP LS-SVR	8	8	-	27.0697	0.1815	23.1877
ϵ -insensitive	0.5	1	8	29.2816	0.0423	24.4952
Lin. Reg.	-	-	-	27.14137	0.177157	23.2295

CONCLUSION

Due to the increased importance of modeling LGD in times of stricter regulatory requirements as consequence of the Basel II/III accords, we have aimed to demonstrate the performance gain by using Support Vector techniques for predicting recovery rates. Especially, we have shown that LS-SVR enables predictions with higher accuracy than linear regression models. Moreover, we have also built two modified LS-SVR models. A LS-SVR model with different intercepts for the different seniority classes showed compared with the standard LS-SVR a lower predictive accuracy for the model with the bond characteristics and industry distress variables as covariates and a higher predictive accuracy for the model including also the macroeconomic covariates. A semiparametric LS-SVR model which takes the seniority indicator dummies as linear input showed significant outperformance not only *versus* the linear regression model but also in comparison with the standard LS-SVR approach. Last, we have also built an ϵ -insensitive SVR which exhibited weaker predictive performance than our benchmark of the linear regression model. Although comparability between studies is hard due to the specific nature of the data sets used the R^2 -value of 53.08% for the semiparametric LS-SVR can withstand the comparison with other studies. Only Yao *et al.* [4] report slightly higher R^2 -values whereas Loterman *et al.* [2] and Qi and Zhao [5] report R^2 -values that are a little lower than ours. As

mentioned before, the overall relatively low R^2 -values might be due to noisy nature of recovery rates. A similar observations for financial data in general is also made in Chalup and Mitschele [50].

As explained in Baesens [49] one common limitation of artificial intelligence methods like Support Vector Regression is the poor interpretability of results gained by such modeling approaches. This point might be potentially problematic for explaining the use of the technique to regulators. However, for internal decision making this is not a shortcoming. Better LGD estimates facilitate a more acute calculation regarding the regulatory capital requirements using internal risk models.

NOTES

¹ The idea to build a model for the prediction of recovery rates and the data set used in this study go back to my thesis at the chair of financial engineering and derivatives from Prof. Uhrig-Homburg at School of Economics and Business Engineering, Karlsruhe Institute of Technology

² The detailed implementation of their SVM is outlined in the documentation of Chang and Lin [55].

CONFLICT OF INTEREST

The authors confirm that this chapter content has no conflict of interest.

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CHAPTER 9

A Novel Task-Driven Sensor-Management Method in Multi-Object Filters Using Stochastic Geometry

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Abstract: Multi-object estimation refers to applications where there are unknown number of objects with unknown states, and the problem is to estimate both the number of objects and their individual state vectors, from observations acquired by sensors. The solution is usually called a multi-object filter. In many modern complex systems, multi-object estimation is one of the most challenging problems to be solved for satisfactory performance of the dedicated tasks by the system. A wide range of practical applications involve multi-object estimation, from multi-target tracking in radar to visual tracking in sport, to cell tracking in biomedicine, to data clustering in big data analytics. In the past decade, a new generation of multi-object filters has been developed and rapidly adopted by researchers in various fields, that is based on using stochastic geometric models and approximations. In such methods, the multi-object entity is treated as a random finite set (RFS) variable (with random variations in its cardinality and elements), and the stochastic geometric-based notions of density and integration, developed in the new theory of finite set statistics (FISST), are used to formulate Bayesian filters for estimation of cardinality (number of objects) and state of the multi-object RFS variable. Examples of such solutions include PHD filter, CPHD filter and the recent trend of multi-Bernoulli filters. In many applications, the observations are acquired through a controlled sensing procedure, either by controlling a mobile sensor (*e.g.* in radars and visual surveillance) or by selecting a sensor node (*e.g.* in sensor networks). This chapter reviews the most recent developments in sensor management (control or selection) solutions devised for multi-Bernoulli solutions in various applications. It first presents basics of random set theory and formulation of the cardinality-balanced and labeled multi-Bernoulli filters. The most recent sensor-control and sensor-selection solutions that have been proposed by the authors and other researchers active in the field are then presented and comparative simulation results are discussed.

Keywords: Stochastic Geometry, Random Sets, Point Process, Finite Set Statistics, Multi-Target Tracking, Sensor Management, Sensor Selection, Sensor Control, Multi-Bernoulli Filter, OSPA, PEECS.

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INTRODUCTION

Sensor fusion techniques have attracted substantial interest due to their increasing utilization in a variety of applications such as radar, sonar, guidance, navigation, and air traffic control [1], image processing [2 - 6], oceanography [7 - 9], autonomous vehicles and robotics [10, 11], remote sensing [12, 13] and biomedical research [14 - 16].

Relative to multi sensor systems, the information acquired by a single sensor system is very limited. Employing multiple sensors can provide sufficient information of the environment in an integrated manner, increase machine perception and improve awareness of the state of the world.

In recent years, due to the rapid progress in sensor technology development, sensors are becoming more common. In order to sense the complex nature of the environment in different scenarios, numerous sensors are needed. This increases the amounts of acquired data which is needed to be processed and motivates the emerging interest in research into intelligent management of sensor resources to improve performance of data fusion.

Multi-Sensor Management

Multi-sensor management is formally described as a system or process that designed to manage the usage of a set of sensors or measurement devices in a dynamic, uncertain environment. The aim is to improve the performance of data fusion and ultimately to improve the perception of the environment [17].

In a sensor network, multi-sensor management solutions may also be designed to avoid increasing amount of storage and computational requirements in a sensor network system by controlling the data gathering process such that only the necessary data are collected and stored [18].

The why and what issues of both single-sensor and multi-sensor management were thoroughly discussed in the papers [19 - 23].

The basic objective of multi-sensor management is to select the right sensors or choose the best states of controllable sensors to do the right task on the right object at the right time. The sensor manager is responsible for addressing questions like [24, 25]:

- Which observation tasks are to be performed and what are their priorities?
- How many sensors are required to meet an information request?
- When are extra sensors to be deployed and in which locations?
- Which sensor sets are to be applied to which tasks?

- What is the action or mode sequence for a particular sensor?
- What parameter values should be selected for the operation of sensors?

The fundamental task of sensor management is to choose the optimal sensor parameter values given a set of sensors with respect to a given task, see for example, the paper [26]. In general, sensor management solutions are decision making procedures in which the algorithm decides on what sensors to use and for which purposes, as well as when and where to use them.

Widely acknowledged is the fact that it is not realistic to continually observe everything in the environment, and therefore, selective perception becomes necessary, requiring the sensor management system to decide when to sense what and with which sensors. Typical temporal complexities, which must be accommodated in the sensor management process, were discussed in [27].

Sensor-Selection and Sensor-Control in Target Tracking Scenarios

Sensor management solutions are broadly used in multi-target tracking scenarios usually in the form of sensor-selection in sensor networks or sensor-control for a set of mobile sensors. Tracking targets in a sensor network could result in a large amount of sensor measurement data. However, as it was mentioned earlier, due to physical and computational constraints, it is required that at each epoch, only a subset of sensors is selected to communicate with the central processor. In such cases, the sensor-selection problem is to select the right sensor nodes that maximize observability of the network for tracking multiple targets. In general, sensor-selection problem comprises of two underlying frameworks,

- a multi-object filtering process,
- an decision-making method.

This is a sequential decision making process under stochastic uncertainties. These uncertainties stem either from the multi-target tracking process or from the effects of selecting different sensor nodes. An example of the sensor-selection problem is demonstrated in Fig. (1) in which a sensor network is used for traffic monitoring.

The sensor-control problem is fundamentally similar to the sensor-selection problem. In sensor-control, a set of sensor commands is used to change mobile sensors' states and applying the right command results in estimates of the number and states of targets with maximum expected accuracy. A practical example of sensor-control is shown in Fig. (2), in which a UAV needs to be navigated point by point in such a way that the number and states of multiple vehicle targets can be estimated with maximum expected accuracy.

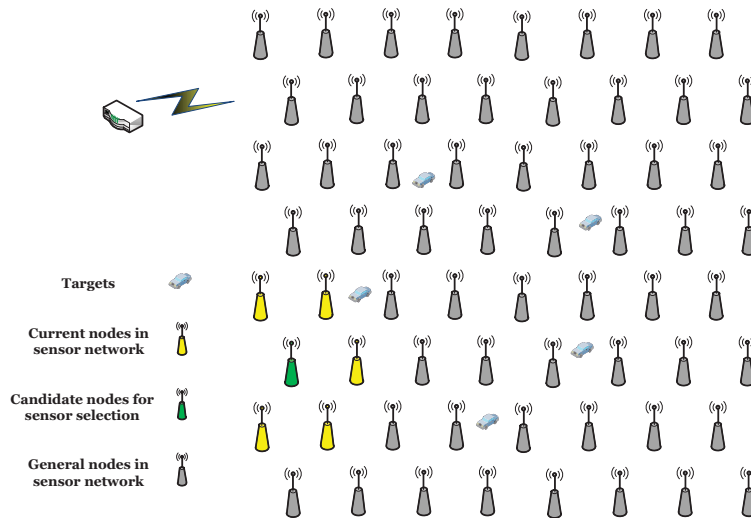


Fig. (1). Sensor-selection in a distributed sensor network for traffic monitoring: Due to energy and communication constraints, only the data provided by a limited number of nodes (one node in this example) can be processed to estimate the number and states of vehicles on the roads. At any time, out of a number of candidate nodes, one needs to be selected.

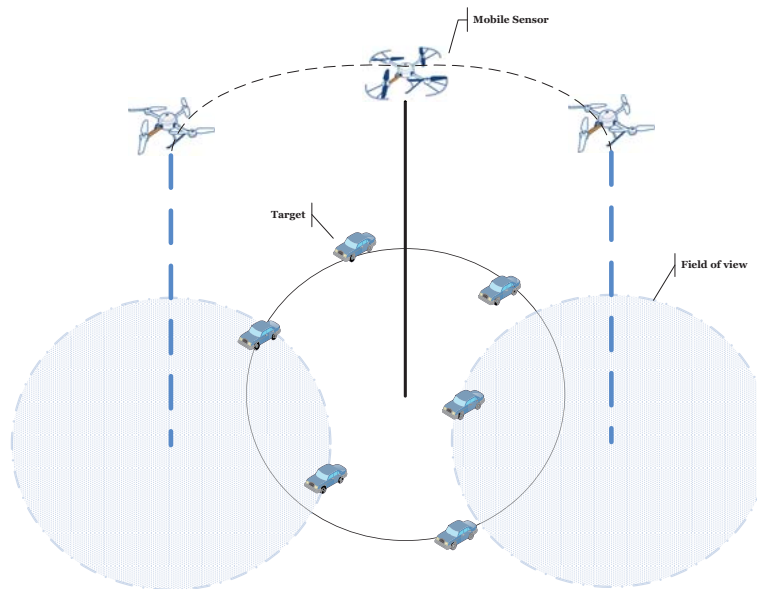


Fig. (2). An example of sensor-control: A UAV is tracking an unknown number of vehicles. Depending on the UAV's location the estimation of the number and states of the targets can be inaccurate. An effective sensor-control solution provides the UAV with a sequence of proper movement commands, that would maximize the accuracy of estimation and tracking.

In any sensor management framework, the selected actions/commands are the outputs of a decision-making component that selects the optimal sensor(s) state(s). This has steered the development of solutions towards devising and improving an objective function to address decision-making component, assuming that the multi-object filtering framework can return accurate estimates of the number and states of all targets. However, the multi-target tracking framework also plays a significant role in the overall performance of the scheme in terms of real-time accuracy and robustness.

A number of solutions proposed in the sensor management literature use a classical method for multi-target tracking [28 - 31] in conjunction with an objective function to decide the next sensor(s) state(s).

The objective functions are commonly information-driven, *i.e.* defined to quantify the information encapsulated in the posterior density. Examples of such objective functions include Rényi divergence [29], Kullback-Leibler divergence [32 - 34], and Shannon entropy [28, 35].

A number of novel multi-sensor management solutions have been recently developed for multi-target tracking scenarios within Finite Set Statistics (FISST) framework [36]. Unlike the classical multi-target tracking methods which struggle with two pertinent problems (data association and combinatorial growth) [37], FISST approach to multi-target filtering does not require explicit association of targets\ tracks with measurements this results in a significant reduction in computational complexity. However, similar to classical approaches, the general form of Bayesian recursion involved in FISST-based methods is not computationally tractable [36]. Consequently, several approximations are suggested. The Probability Hypothesis Density (PHD) filter and its extended version, Cardinalized PHD (CPHD) filter [38 - 42], Multi-Bernoulli filters [36, 43] and δ -GLMB filter [44] are the most well-known instances of such approximations.

Ristic *et al.* [45] introduced a sensor-control solution to work with an FISST-based multi-object Bayesian filter. This solution is only computationally tractable in presence of a small number of targets. Later, they presented a computationally tractable solution that would optimally select control commands within a PHD-based filter [38 - 42] with SMC implementation [46]. Alternatively, in [47, 48] the Cardinality Balanced multi-target Multi-Bernoulli (CB- Me MBer) filter [36, 43] is employed to tackle the sensor-selection problem.

As it was mentioned before, at the core of these solutions is an objective function. To define an appropriate objective function, two common approaches have been introduced:

- task-driven approach, and
- information-driven approach.

In the task-driven approach, the objective function is formulated as a cost function which normally depends on the performance metrics such as error variance, cardinality variance and other distribution-dependent measures.

In information-driven approach, the aim of sensor management is to improve the information content of the multi-object distribution by optimizing some measure of information gain [49]. Examples of such measures are Rényi divergence [30, 45, 46], and Kullback-Leibler divergence [32 - 34].

This chapter studies sensor management problems in which quantities such as variance or estimated states are utilized to enhance estimation performance. The work has three folds:

- utilizing a sensor management solution to be employed in Random Finite Set-based filter, in particular multi-Bernoulli and Labelled Multi-Bernoulli filters,
- developing a sensor management solution within multi-Bernoulli filter with robust behaviour without having any prior knowledge of the clutter distribution or the probability of detection profile, and
- developing a novel sensor management solution in which a measure of multi-target tracking filter is employed to choose the best sensor command.

The primary problem of interest is multiple object tracking and identification and application areas including sensor network management and multifunction radar control.

BACKGROUND

Automated sensor management is the process of “directing the right sensors to the right targets at the right time” [50]. A sensor management solution must consider a number of factors that affect its performance:

- constraints on target motion due to target dynamical limitations,
- the likelihood of the appearance and disappearance of targets,
- network bandwidth, and
- energy consumption.

The multi-sensor management problem generally involves stochastic variations in the number of targets, measurement/process noise and detections, and can be formulated in the form of an optimal stochastic control problem. These stochastic variations are due to

- randomly varying number of targets,
- randomly varying number of measurements, and
- randomly varying number of sensors.

Consequently, practical implementation of sensor management requires a principled approach. In this chapter, we follow a control-theoretic approach for the proposed sensor management solution. In the control-theoretic approach the goal is to determine an optimal selection of a set of sensors by defining an objective function which should be maximized or minimized. The control-theoretic approach to sensor management problem is in stark contrast to rule based solutions. The main difference between rule based and control-theoretic approaches are depicted in Fig. (3) and Fig. (4) [50]:

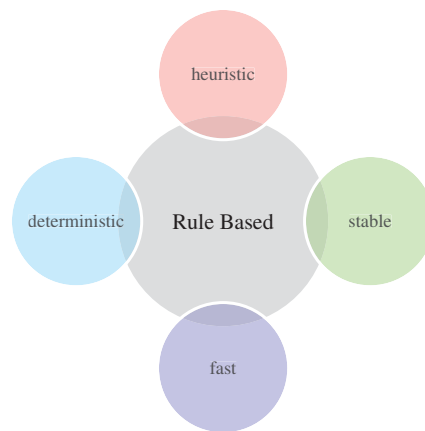


Fig. (3). Rule Based Approach.

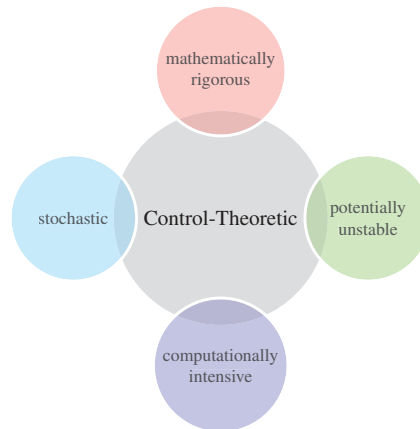


Fig. (4). Control-Theoretic Approach

However, in overall, the performance of the control-theoretic approach is more reliable because [50]:

- accumulated decisions in a rule based approach do not necessarily lead to desired performance,
- control-theoretic approach inherently achieves near-optimal decisions,
- rule based approach is incapable of addressing the infinite number of possible contingencies that arise in practice, and
- control-theoretic approach is capable of addressing this infinitude of contingencies.

From a theoretical point of view, sensor management can be modeled as a Partially Observable Markov Decision Process (POMDP).

Sensor Management Solution Framework

This chapter focuses on solving the sensor management problem in the context of choosing the optimal or near-optimal sensor command among a finite number of admissible commands. In this context, the quality of a sensor command needs to be evaluated in terms of an objective function. The defined objective function can be in the form of a reward function (to be maximized) or a cost function (to be minimized).

We formulate the sensor management solution in the Partially Observable Markov Decision Process (POMDP) framework. POMDP provides a rich framework for sequential decision-making under uncertainty in stochastic domains. POMDP is a generalized form of Markov Decision Process (MDP) [51] in which there is no direct access to the states, and information about the states are only received from observations. The POMDP model comprises the following elements at any time k :

The Partially Observable Markov Decision Processes (POMDPs) framework for sensor management and multi-object estimation problems.

- a finite set X_k of single-object states,
- a finite set of sensor commands $\mathbb{S} = \{s_1, \dots, s_n\}$
- a finite set of observations Z ,
- a stochastic measurement model $g_k(z|x)$, and
- a function $\mathcal{G}(s, X_k)$ that returns a reward or cost for transition from the multi-object state X_k to the state X_{k+1} via applying an action command $s \in \mathbb{S}$.

The overall procedure of sensor management solution in POMDP framework is shown in Fig. (5). Assume that at time k there are m sensors with the following possible future states $\mathbb{S} = \{s_1, \dots, s_n\}$. Assume that an unknown number of targets

are maneuvering in the surveillance area. The targets' motion model is based on Markov transition density of the form $f_{k+1|k}(X_{k+1}|X_k)$. The general approach to sensor management is a closed-loop version of the multi-target Bayes filter. The procedure of sensor management is as follows:

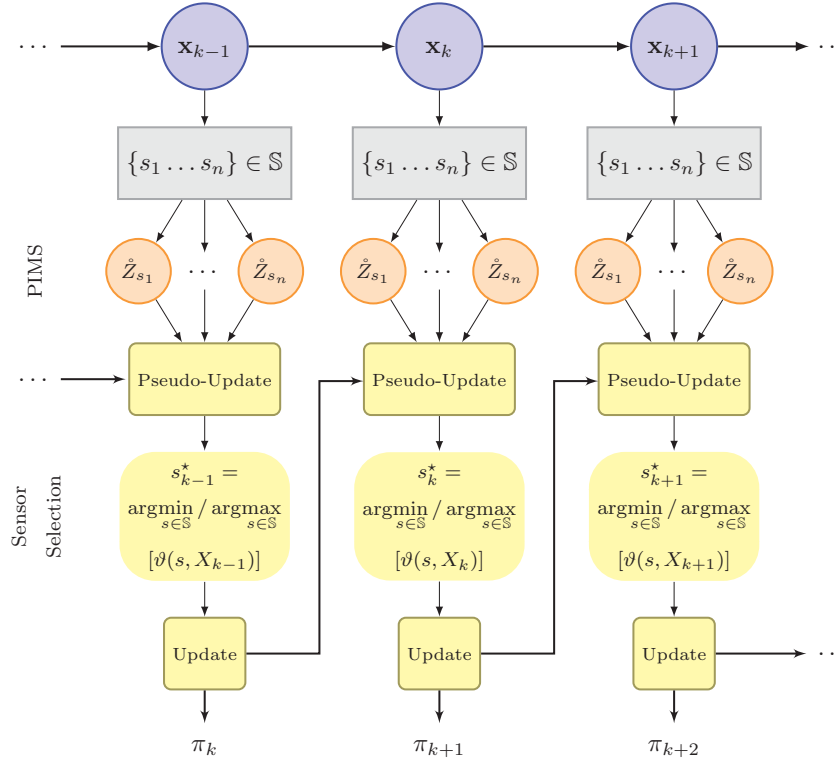


Fig. (5). The Partially Observable Markov Decision Processes(POMDPs) framework for sensor management and multi-object estimation problems.

• Prediction

Apply the multi-target filter prediction step to evolve the prior multi-target distribution from π_k to $\pi_{k+1|k}$ at time k .

• Pre-Estimation

Having the predicted multi-target distribution, estimate the number and states of the targets. This information will be used to generate pseudo-measurements.

• Pseudo-Measurements

Generate a pseudo-measurement set for each sensor command. In sensor management solutions, the pseudo-measurement set is a function of the chosen

sensor command. In principle, the whole distribution of all possible measurement sets is used to compute the updated distribution. However, using whole measurement distribution is computationally expensive if not intractable. Thus, to reduce the computational complexity, for each sensor-control command, only *the predicted ideal measurement set* (PIMS) is used [52].

• Pseudo-Update

Using the generated pseudo-measurements as the actual measurements, apply the multi-target filter update step to update the predicted multi-target distributions to $\pi_{k+1}(X|Z,s)$ (where Z is the pseudo-measurement set at the future time $k+1$).

• Objective Function

From the Pseudo-updated distributions $\pi_{k+1}(X|Z,s)$ compute the objective function $\mathcal{J}(s, X_k)$ to quantify the information encapsulated in the posterior density (for each possible command). To define the objective function, two common approaches have been introduced in the sensor-control literature: task-driven approach and information-driven approach.

• Decision Making

The most rewarding sensor command is then selected by minimizing/maximizing the objective function over all possible commands. The goal of sensor-control is to find the control command, s^* , which minimizes (or maximizes) the statistical expectation of the cost (or reward) function:

$$s^* = \underset{s \in \mathbb{S}}{\operatorname{argmin}} / \underset{s \in \mathbb{S}}{\operatorname{argmax}} \left\{ \mathbb{E}_Z [\mathcal{J}(s, X_k)] \right\}. \quad (1)$$

• Update

Collect the actual measurement set for the sensors managed based on the chosen sensor command(s) and use the multi-target filter update step equation to update π_k to π_{k+1} .

ASSUMPTIONS

In this chapter, sensor management problem for multi target scenario has been studied under various assumptions.

Single-Step Look-Ahead

In this work we consider single-step look-ahead (myopic) approach to determine

the optimal selection of sensors' command. Myopic approach is in contrast to multi-step look-ahead approach where in multi-step look ahead approach the aim is to optimally select sensors' commands throughout a certain future time-step.

The multi-step look-ahead approach is possible with accurate target state estimation in the entire future time-steps. However, in practice this is usually not the case and due to the complex nature of targets manoeuvring, the multi-target estimation is not accurate enough. In such cases, myopic approach is more desirable. Also, multi-step approach is computationally expensive compared to myopic approach, especially in presence of a relatively large number of targets.

Pseudo-Measurement Approximation

As it was mentioned, the objective function is a function of future measurements. The values of the future measurements are unknown. Thus, a set of pseudo-measurements for each hypothesized sensor command is generated. In principle, the whole distribution of all possible measurement sets is used to compute the objective function. However, using the whole measurement distribution is computationally expensive. In situations where the probability of detection is high and clutter rate is moderate, the multi target posterior density can be approximated under the assumptions of the PIMS (see [52]–section 4.1 and [53]). Thus, to reduce the computational complexity, for each sensor command, only *the predicted ideal measurement set* (PIMS) is generated.

Algorithm 1 Generating Predicted Ideal Measurement Set [52].

INPUTS:

- Estimates of the number of targets $\hat{M}_{k+1|k}$ and multi-target state $\hat{X}_{k+1|k} = \{x_{k+1|k}^{(\ell)}\}_{\ell=1}^{\hat{M}_{k+1|k}}$ after a prediction step, a sensor node $s \in \mathbb{S}$,
- a single-target measurement likelihood function $g(z|x;s)$ which is dependent on the location of the sensor node s .

OUTPUT:

- A clutter-free set of noise-free measurements, $\hat{Z}_s$.

```

1: function PIMS( $\hat{M}_{k+1|k}, \hat{X}_{k+1|k}, s, g(z|x;s)$ )
2:    $\hat{Z}_s \leftarrow \emptyset$ .
3:   for  $\ell = 1, \dots, \hat{M}_{k+1|k}$  do
4:      $\xi \leftarrow \arg \max_z g(z|x_{k+1|k}^{(\ell)}; s)$ 
5:      $\hat{Z}_s \leftarrow \hat{Z}_s \cup \{\xi\}$ 
6:   end for
7:   return  $\hat{Z}_s$ 
8: end function

```

Given the selected sensor command, the PIMS is comprised of the clutter-free and noise-free measurements that are most likely to be obtained from the selected sensor. Algorithm 1 shows a pseudocode to generate the PIMS returned by a selected sensor node in a sensor selection application.

OBJECTIVE FUNCTION

Sensor management in multi-object filters, is usually employed to control or select one or more sensors with the aim of acquiring the *best* measurements for filtering purposes [54 - 58]. There are two approaches in defining what the *best* measurement is [30, 59 - 63].

- Task-driven approach and
- Information-driven approach.

Task-driven approach

In the *task-driven* approach, the objective function is formulated as a *cost function* which normally depends on the performance metrics such as error variance, cardinality variance and other distribution-dependent measures (*e.g* [30]).

Task-driven objective functions attempt to devise mathematical formulas that, at least approximately, capture the intent underlying subjective tactical objectives. These objective functions are usually modelled using dynamic programming methods [64, 65]. Task-driven objective functions tend to be heuristic and often do not end up adequately modelling the actual mission objectives [50].

Information-driven approach

In *information-driven* approach, the aim of sensor management is to improve the information content of the multi-object distribution by optimizing some measure of information gain (uncertainty) [49]. Recently, due to the performance criteria independency of the information-driven methods [30], this approach has attracted substantial research interest [28, 29, 34, 35, 66, 67].

Objective of information-driven approach is to maximize the information gain produced by posterior multi-object densities [49]. The idea of measuring information gain as an objective function in sensor-control related problem, first appeared in [28] and [35]. Later in [66] the expected value of information gain was utilized to tackle sensor management problem. Some examples of information measures are:

- Rényi divergence [29, 30, 45, 46],
- Kullback-Leibler divergence [32 - 34, 68, 69],
- Shannon entropy [28, 35], and
- The Cauchy-Schwarz divergence [50, 70].

Information-derived objective functions are theoretically rigorous. However, they have no obvious relationship with operational requirements and do not even have a clear intuitive, physical interpretation.

COMMON OBJECTIVE FUNCTIONS IN SENSOR MANAGEMENT STUDIES

The aim of this chapter is to define an objective function in FISST framework in which establishes a common ground between information-derived approach and physical interpretation of task-driven approach. The minimal objectives of any sensor management tasks are:

- Maximize the number of observed targets, and
- Maximize the accuracy of the estimated states of the target.

The defined objective function should carry the fundamental notions of the information theory as well as addressing the problem of physical interpretation. In this work, we defined an objective function using notion of information theory while they have physical interpretation of task-driven approach.

For the sake of completeness, in the following brief definitions of the most common objective functions in sensor management framework are presented.

Rényi Divergence

The most common choice for an objective function in information-driven method is Rényi divergence function. Branko *et al.* [45, 46] used Rényi divergence as the objective function in conjunction with random set filter and CPHD filter for the scenarios where clutter rate and uncertainty in sensor Filed of View (FoV) are known.

In [29] and [46] Rényi divergence was employed as the generalization of the Kullback-Leibler divergence. Rényi divergence measures information gain between two densities:

$$I_\alpha(f_1, f_2) = \frac{1}{\alpha - 1} \log \int [f_1(X)]^\alpha [f_2(X)]^{1-\alpha} \delta X. \quad (2)$$

In target tracking applications, the first distribution is the updated distribution, $\pi_{k+1}(X_{k+1}|Z_{1:k}, u_{0:k-1}, Z_{k+1}, s_k)$, and the second distribution is the prediction distribution, $\pi_{k+1}(X_{k+1}|Z_{1:k}, u_{0:k-1})$. Thus, Rényi divergence is given by:

$$I_\alpha(Z_{k+1}, s_k) = \frac{1}{\alpha - 1} \log \int [\pi_{k+1}(X|Z_{1:k}, s_{0:k-1}, Z_{k+1}, s_k)]^\alpha \cdot [\pi_{k+1|k}(X|Z_{1:k}, s_{0:k-1})]^{1-\alpha} \delta X. \quad (3)$$

The α parameter emphasizes on different parts of distributions.

The objective is to maximize information gain by computing divergence between the updated and predicted distributions *via* choosing the right s_k while any choice of s_k can lead to different measurements Z_{k+1} . A common approach is to define, compute and maximize the reward function as the *statistical mean* of the Rényi divergence function,

$$\mathcal{D}(s_k) = \mathbb{E}_{Z_{k+1}} [I_\alpha(Z_{k+1}, s_k)]. \quad (4)$$

The Posterior Expected Number of Targets

In 2005, Mahler introduced a systematic and unified approach to sensor management using PHD filter [52, 71]. In this approach, he employed an objective function called the posterior expected number of targets (PENT).

In this approach, the aim is to maximize the value of the PENT, to direct the sensor FoV to those states where the sensors are most likely to collect the best PIMS. PENT can be generalized to include notions of target priority, in which case it is known as the predicted expected number of targets of interest (PENTI) [71, 72].

The direct effect of maximizing PENT is maximizing the expected number of targets in that region $N_{k|k}$. The following points indicate the characteristic of the PENT objective function [50, 72].

1. PENT can be defined in a mathematically rigorous manner from the multi-target statistics of the multi-target system.
2. PENT is a computational approximation of abstract information-theoretic objective functions.
3. PENT is more computationally tractable than information-driven objective functions.
4. PENT can be modified to include the notion of the *target of interest*.
5. PENT can address the following properties:
 - Abstract information-theoretic.
 - Physical interpretation.

The Cardinality-Variance Based Objective Function

In the previous section, it was mentioned that the PHD filters are used to devise PENT objective function. In other words, only the first-order information is used in PENT objective function. Also, the primary goals of the PENT objective functions are [50]: computational tractability, and physical intuitiveness.

Using multi-Bernoulli filters, cardinality distribution is also available, thus a similar but potentially more effective approach can be devised. This approach was proposed and applied by the authors of this work. Also, around the same time, Hoang *et al.* [48] defined a variance-based cost function. The main difference between our approach and Hoang *et al.* is that in [73], statistical variance of cardinality around its *mean* is chosen as the cost function, while Hoang *et al.* [48] used the variance of cardinality around its *MAP estimate* as the cost function.

RANDOM FINITE SET BASED MULTI-TARGET FILTER

A random finite set is a spatial point pattern on the space of interest in which it is defined by a set with randomly varying number of elements and the elements themselves are also random. The fundamental descriptor of RFS is the probability distribution or the probability density. Also the Probability Generating Functional (PGFL) serves as a primary descriptor of an RFS. Let $\mathbb{F}(\mathbb{X})$ denote the space of finite subsets of $\mathbb{X} \subseteq \mathbb{R}^n$. If X is an RFS on $\mathbb{X}$, the PGFL $G[\cdot]$ of is given by

$$G[h] = E[h^X] \quad (5)$$

Where E is the expectation operator and h is any real-valued function on X such that $0 \leq h(x) \leq 1$ and $h^x = \prod_{x \in X} h(x)$ with $h^\emptyset = 1$. The cardinality (number of elements) of $|X|$, denoted as X , is a discrete random variable whose probability generating function $G(\cdot)$ can be obtained by substituting the constant function $h(x) = y$ into the PGFL.

Multi-Target System Model

Assume that at any given time k , there are $N(k)$ number of target states denoted by $x_{k,1}, \dots, x_{N(k)}$ which take values from a state space $\mathbb{X} \subseteq \mathbb{R}^{n_x}$ and $M(k)$ number of measurements denoted by $z_{k,1}, \dots, z_{M(k)}$ which take values from an observation space $\mathbb{Z} \subseteq \mathbb{R}^{n_z}$; in RFS terminology they can be denoted as follows.

$$X_k = \{x_{k,1}, \dots, x_{k,N(k)}\} \in \mathbb{F}(X) \quad (6)$$

$$Z_k = \{z_{k,1}, \dots, z_{k,N(k)}\} \in \mathbb{F}(Z) \quad (7)$$

Stochastic Model for Multi-Target State Evolution

Suppose at time $k-1$ the multi-target state is given by X_{k-1} . Then each state $x_{k-1} \in X_{k-1}$ either continues to survive at next time step k with a survival probability $p_{s,k}(x_{k-1})$ and evolve to a new state x_{k-1} with probability density $f_{k|k-1}(x_k|x_{k-1})$ or disappear with a probability $p_{s,k}(x_{k-1})$. The most common approach to formulate this model is using the multi-Bernoulli RFS representation. Given the prior target state distribution at time $k-1$, at time k a single target state is modeled by a RFS $S_{k|k-1}(x_{k-1})$ with survival probability $r = p_{s,k}(x_{k-1})$ and probability distribution $p(\cdot) = f_{k|k-1}(\cdot|x_{k-1})$. Consequently the multi-target state X_k at time k is given by

$$X_k = [\cup_{x_{k-1} \in X_{k-1}} S_{k|k-1}(x_{k-1})] \cup \Gamma_k, \quad (8)$$

where Γ_k is the multi-Bernoulli RFS of spontaneous births and the above equation holds under the assumption that each Bernoulli RFS is independent from the others.

Stochastic Model for Multi-Target State Measurement

Given a single target $x_k \in X_k$ at time k , it is either detected with a probability $p_{D,k}(x_k)$ and generates an observation z_k with the likelihood given by $g_k(z_k|x_k)$ or missed with a probability $1 - p_{D,k}(x_k)$. Precisely each single target $x_k \in X_k$ generates a Bernoulli RFS $\Theta_k(x_k)$ with $r = p_{D,k}(x_k)$ and $p(\cdot) = g_k(\cdot|x_k)$ as its parameters.

The additional extraneous measurements (the clutter) is modeled by a Poisson RFS K_k with an intensity function $\kappa_k(\cdot)$. Therefore assuming that each of the measurements is independent from the others, the multi-target measurement Z_k generated by a multi-target state X_k at time k is given by

$$Z_k = [\cup_{x \in X} \Theta_k(x)] \cup K_k. \quad (9)$$

Multi-Object Bayes Recursion

Given the state space and observation space denoted by $\mathbb{F}(\mathbb{X})$ and $\mathbb{F}(\mathbb{Z})$ respectively, the multi-target posterior density at time k denoted by $\pi_k(\cdot|Z_{1:k})$ can be obtained by Bayes filter as follows with FISST set integrals.

$$\pi_{k|k-1}(X_k|Z_{1:k-1}) = \int f_{k|k-1}(X_k|X) \pi_{k-1}(X|Z_{1:k-1}) \delta X, \quad (10)$$

$$\pi_k(X_k|Z_{1:k}) = \frac{g_k(Z_k|X_k) \pi_{k|k-1}(X_k|Z_{1:k-1})}{\int g_k(Z_k|X_k) \pi_{k|k-1}(X_k|Z_{1:k-1}) \delta X}. \quad (11)$$

Here, $f_{k|k-1}$ and $g_k(\cdot|\cdot)$ are used to denote multi-target transition density and multi-target likelihood respectively. Following the most common employed RFSs in multi-target tracking literature are briefly explained.

Poisson RFS

A RFS X on $\mathbb{X}$ is parametrized by as a Poisson RFS if it has an intensity function v defined on $\mathbb{X}$ with a Poisson distribution with a mean $\bar{N} = \int v(x) dx$. The cardinality of varies according to the Poisson distribution, and for any finite cardinality, the elements of are i.i.d. according to the probability density $v(\cdot) \setminus \bar{N}$. A Poisson RFS can be completely characterized by its intensity function which is also known as Probability Hypothesis Density (PHD). A Poisson RFS with intensity function has a PGFl given by;

$$G[h] = e^{\langle v, h-1 \rangle} \quad (12)$$

where $\langle v, h \rangle$ is the standard inner product given by $\langle v, h \rangle = \int v(x) h(x) dx$. Also the probability density of Poisson RFS is given by

$$\pi(X) = e^{-\bar{N}} v^X. \quad (13)$$

IID Cluster RFS

If $p(n)$ is the cardinality distribution of an independent identically distributed (i.i.d.) cluster RFS X on $\mathbb{X}$, its the probability density function ϕ and intensity function $v(\cdot)$ are given by

$$\phi(X) = |X|! p(|X|) \prod_{x \in X} p(x), \quad (14)$$

$$v(x) = p(x) \sum_{n=1}^{\infty} np(n) \quad (15)$$

respectively.

Bernoulli RFS

A RFS X on $\mathbb{X}$ is defined as a Bernoulli RFS, if it has a probability $1-r \in (0,1)$ of being empty and probability $r \in (0,1)$ of being a singleton with its only element being distributed according to a probability p density defined on $\mathbb{X}$. The PGFl of a Bernoulli RFS is defined as

$$G[h] = 1 - r + r\langle p, h \rangle \quad (16)$$

while probability density is given by

$$\pi(X) = \begin{cases} 1-r & X = \emptyset, \\ r \cdot p(x) & X = \{x\}. \end{cases} \quad (17)$$

Multi-Bernoulli RFS

A multi-Bernoulli RFS X on $\mathbb{X}$ is defined to be a union of fixed number of independent Bernoulli RFSs $X^{(i)}$ with existence probability $r^{(i)} \in (0,1)$ and probability density $p^{(i)}$ defined on $\mathbb{X}$ for $i = 1, \dots, M$, which can be denoted as $X = \bigcup_{i=1}^M X^{(i)}$. The PGFl of a multi-Bernoulli RFS is given by

$$G[h] = \prod_{i=1}^M (1 - r^{(i)} + r^{(i)} \langle p^{(i)}, h \rangle) \quad (18)$$

Thus a multi-Bernoulli RFS is completely described by the multi-Bernoulli Parameter set $\{(r^{(i)}, p^{(i)})\}_{i=1}^M$. The mean of a multi-Bernoulli RFS is given by $\sum_{i=1}^M r^{(i)}$ while the probability density is given by

$$\pi(\emptyset) = \prod_{j=1}^M (1 - r^{(j)}) \quad (19)$$

and

$$\pi(\{x_1, \dots, x_n\}) = \pi(\emptyset) \sum_{1 \leq i_1 \neq \dots \neq i_n \leq M} \prod_{j=1}^n \frac{r^{(i_j)} p^{(i_j)}(x_j)}{1 - r^{(i_j)}} \quad (20)$$

LABELED MULTI-BERNOULLI FILTER

In this section the summery of the notion and formulation of the Labeled Multi-Bernoulli filter, which was introduced in [74], is presented. The notion of Labeled Multi-Bernoulli (LMB) RFS was introduced for the first time in [44]. LMB is a special case of generalized labeled multi-Bernoulli RFS. It is shown that LMB RFS is a conjugate prior with respect to the multi-object observation likelihood, and it is closed under the multi-target Chapman-Kolmogorov equation [44, 74].

In the following, we adopt the same notation used in [74] where the single-object states are denoted by lower-case letters, *e.g.* x , $\mathbf{x}$ and multi-object states by upper-case letters, *e.g.* X , $\mathbf{X}$. In order to distinguish between labeled and unlabeled states and their distributions, the labeled one is shown by bolded letters *e.g.* $\mathbf{x}$, $\mathbf{X}$, *etc*, spaces by blackboard bold *e.g.* $\mathbb{X}$, $\mathbb{L}$, $\mathbb{C}$, *etc*, and the class of finite subsets of a space $\mathbb{X}$ by $\mathcal{F}(\mathbb{X})$. Following [74], throughout this chapter, the standard inner product notation is used and denoted by

$$\langle f, g \rangle \triangleq \int f(x)g(x)dx,$$

the generalized Kronecker delta is denoted by

$$\delta_Y(X) \triangleq \begin{cases} 1, & \text{if } X = Y \\ 0, & \text{otherwise} \end{cases},$$

and the inclusion function, a generalization of the indicator function, by

$$1_Y(X) \triangleq \begin{cases} 1, & \text{if } X \subseteq Y \\ 0, & \text{otherwise} \end{cases}.$$

The multi-object distribution of a GLMB RFS with state $\mathbf{X}$ and discrete label space $\mathbb{L}$ is given by

$$\pi(\mathbf{X}) = \Delta(\mathbf{X}) \sum_{c \in \mathbb{C}} w^{(c)}(\mathcal{L}(\mathbf{X})) \left[p^{(c)} \right]^{\mathbf{X}}, \quad (21)$$

where $\Delta(\mathbf{X}) = \delta_{|\mathbb{X}|}(|\mathcal{L}(\mathbf{X})|)$ and $\mathbb{C}$ is a discrete index set and $w^{(c)}(L)$ is the non-negative weights that only depends on the labels of multi-object state and satisfies $\sum_{L \subseteq \mathbb{L}} \sum_{c \in \mathbb{C}} w^{(c)}(L) = 1$. Each $p^{(c)}(x, l)$ is a probability density and satisfies $\int p^{(c)}(x, \ell) dx = 1$. In (21), $h^{\mathbf{X}} \triangleq \prod_{x \in \mathbf{X}} h(x)$, denotes the multi-object exponential, where h is a real-valued function, with $h^{\emptyset} = 1$ by convention. Thus, the multi-object distribution of a GLMB RFS presented in (21), can be interpreted as a mixture of multi-object exponentials. Each term in this mixture consists of a weight $w^{(c)}$ that only depends on the labels of the multi-object state, and a multi-object exponential $[p^{(c)}]^{\mathbf{X}}$ that depends on the entire multi-object state. The projection $\mathcal{L} : \mathbb{X} \times \mathbb{L} \rightarrow \mathbb{L}$ is given by $\mathcal{L}(x, \ell) = \ell$ and $\mathcal{L}(\mathbf{X}) = \{\mathcal{L}(\mathbf{x}) : \mathbf{x} \in \mathbf{X}\}$ is the set of object labels of $\mathbb{X}$. A labeled RFS with state space $\mathbb{X}$ and discrete label space $\mathbb{L}$ is an RFS on $\mathbb{X} \times \mathbb{L}$ such that each realization has distinct labels [44, 75].

The LMB RFS is a special case of GLMB RFS and similar to the multi-Bernoulli RFS it is completely described by its components $\pi = \{(r^{(\zeta)}, p^{(\zeta)}) : \zeta \in \Psi\}$. The LMB RFS density is given by

$$\pi(\mathbf{X}) = \Delta(\mathbf{X}) w(\mathcal{L}(\mathbf{X})) [p]^{\mathbf{X}}, \quad (22)$$

where

$$p(x, \ell) = p^{(\ell)}(x) \quad (23)$$

$$w(L) = \prod_{i \in \mathbb{L}} (1 - r^{(i)}) \prod_{\ell \in L} \frac{1_{\mathbb{L}}(\ell) r^{(\ell)}}{(1 - r^{(\ell)})} \quad (24)$$

comprising a single component [74].

Similar to the general multi-target Bayes filter, the LMB multi-target Bayes recursion propagates multi-target posterior density at each time according to the Chapman-Kolmogorov (prediction step) and the Bayes rule (update step).

Prediction

Reuter *et al.* [74] proved that a LMB RFS is closed under the Chapman-Kolmogorov equation which means if the current multi-object posterior is of the form of LMB, then the predicted multi-object distribution is still LMB. Assume that the prior and birth labeled multi-Bernoulli sets are modelled as follows:

$$\pi(\mathbf{X}) = \Delta(\mathbf{X})w(\mathcal{L}(\mathbf{X})) [p]^{\mathbf{X}} \quad (25)$$

$$\pi_B(\mathbf{X}) = \Delta(\mathbf{X})w_B(\mathcal{L}(\mathbf{X})) [p_B]^{\mathbf{X}} \quad (26)$$

where

$$w(L) = \prod_{i \in \mathbb{L}} (1 - r^{(i)}) \prod_{\ell \in L} \frac{1_{\mathbb{L}}(\ell) r^{(\ell)}}{1 - r^{(\ell)}}, \quad (27)$$

$$w_B(L) = \prod_{i \in \mathbb{B}} (1 - r_B^{(i)}) \prod_{\ell \in L} \frac{1_{\mathbb{B}}(\ell) r_B^{(\ell)}}{1 - r_B^{(\ell)}}, \quad (28)$$

$$p(x, \ell) = p^{(\ell)}(x) \quad (29)$$

$$p_B(x, \ell) = p_B^{(\ell)}(x). \quad (30)$$

with state space $\mathbb{X}$ and label space $\mathbb{L}_+ = \mathbb{B} \cup \mathbb{L}$ and with the condition $\mathbb{B} \cap \mathbb{L} = \emptyset$. The predicted multi-object distribution is then a LMB RFS and given by

$$\pi_+(\mathbf{X}) = \Delta(\mathbf{X})w_+(\mathcal{L}(\mathbf{X})) [p_+]^{\mathbf{X}} \quad (31)$$

where

$$w_+(I_+) = w_s(I_+ \cap \mathbb{L}) w_B(I_+ \cap \mathbb{B}) \quad (32)$$

$$w_s(L) = \left(1 - r^{(\cdot)} \eta_s(\cdot)\right)^{\mathbb{L}} \left(\frac{r^{(\cdot)} \eta_s(\cdot)}{1 - r^{(\cdot)} \eta_s(\cdot)} \right)^L \quad (33)$$

$$\eta_s(\ell) = \langle p_s(\cdot, \ell), p(\cdot, \ell) \rangle \quad (34)$$

$$p_+(x, \ell) = 1_{\mathbb{L}}(\ell) p_{+,S}(x, \ell) + 1_{\mathbb{B}}(\ell) p_B(x, \ell) \quad (35)$$

$$p_{+,S}(x, \ell) = \frac{\langle p_s(\cdot, \ell) f(x|\cdot, \ell), p(\cdot, \ell) \rangle}{\eta_s(\ell)} \quad (36)$$

where $p_s(\cdot|\ell)$ is the survival probability of an object and $f(x|\cdot, \ell)$ is the single-object transition model. Thus, if the multi-target posterior density is an LMB RFS with parameter set $\pi = \{(r^{(\ell)}, p^{(\ell)}) : \ell \in \mathbb{L}\}$ with state space $\mathbb{X}$ and label space $\mathbb{L}$ and the birth model is also an LMB RFS with parameter set $\pi_B = \{(r_B^{(\ell)}, p_B^{(\ell)}) : \ell \in \mathbb{B}\}$ with state space $\mathbb{X}$ and label space $\mathbb{B}$ then the predicted multi-target density is also an LMB RFS with state space $\mathbb{X}$ and label space $\mathbb{L}_+ = \mathbb{B} \cup \mathbb{L} (\mathbb{B} \cap \mathbb{L} = \emptyset)$ and it is given by

$$\pi_+ = \{(r_{+,S}^{(\ell)}, p_{+,S}^{(\ell)}) : \ell \in \mathbb{L}\} \cup \{(r_B^{(\ell)}, p_B^{(\ell)}) : \ell \in \mathbb{B}\} \quad (37)$$

where

$$r_{+,S}^{(\ell)} = \eta_s(\ell) r^{(\ell)}, \quad (38)$$

$$p_{+,S}^{(\ell)} = \frac{\langle p_s(\cdot, \ell) f(x|\cdot, \ell), p(\cdot, \ell) \rangle}{\eta_s(\ell)}, \quad (39)$$

for more details see – [74] – proposition .

Update

In update step, if the multi-object density is an LMB RFS, then the multi-object posterior is not necessarily still an LMB RFS. Similar to multi-Bernoulli RFS [43], Reuter *et al.* [74] approximate the updated LMB RFS by its first moment. Thus, if the predicted multi-target density is an LMB RFS with parameter set

$\pi_+ = \{(r_+^{(\ell)}, p_+^{(\ell)}) : \ell \in \mathbb{L}_+\}$, the multi-target posterior is then given by

$$\pi(\cdot|Z) = \{(r^{(\ell)}, p^{(\ell)}(\cdot) : \ell \in \mathbb{L}_+\} \quad (40)$$

where

$$r^{(\ell)} = \sum_{(I_+, \theta) \in \mathcal{F}(\mathbb{L}_+) \times \Theta_{I_+}} w^{(I_+, \theta)}(Z) 1_{I_+}(\ell), \quad (41)$$

$$p^{(\ell)}(x) = \frac{1}{r^{(\ell)}} \sum_{(I_+, \theta) \in \mathcal{F}(\mathbb{L}_+) \times \Theta_{I_+}} w^{(I_+, \theta)}(Z) 1_{I_+}(\ell) p^{(\theta)}(x, \ell),$$

where Θ_{I_+} denotes the space of mapping $\theta : I_+ \rightarrow \{0, 1, \dots, |Z|\}$ and,

$$w^{(I_+, \theta)}(Z) \propto w_+(I_+) \left[\eta_Z^{(\theta)} \right]^{I_+} \quad (42)$$

$$p^{(\theta)}(x, \ell|Z) = \frac{p_+(x, \ell) \psi_Z(x, \ell; \theta)}{\eta_Z^{(\theta)}(\ell)}, \quad (43)$$

$$\eta_Z^{(\theta)}(\ell) = \langle p_+(\cdot, \ell), \psi_Z(\cdot, \ell; \theta) \rangle, \quad (44)$$

$$\begin{aligned} \psi_Z(x, \ell; \theta) &= \delta_0(\theta(\ell)) q_D(x, \ell) \\ &+ (1 - \delta_0(\theta(\ell))) \frac{p_D(x, \ell) g(z_{\theta(\ell)}|x, \ell)}{\kappa(z_{\theta(\ell)})} \end{aligned} \quad (45)$$

where, $g(z|x)$ is the single-sensor measurement likelihood, $p_D(\cdot, \ell)$ denotes probability of detection, $q_D(\cdot, \ell) = 1 - p_D(\cdot, \ell)$ is the probability of a missed detection, and $\kappa(\cdot)$ intensity function of the Poisson distributed clutter process.

Implementation

Details of sequential Monte Carlo implementation of the LMB filter are presented in [74]. In the implementation, the number of hypotheses grows exponentially. For computational reduction, targets and measurements are subjected to spatial grouping and gating and the update step is run in parallel for those groups. In order to keep only the most significant hypotheses, several methods of truncation are proposed in the literature [44, 74, 75].

In the prediction step, the K -shortest path algorithm is used to truncate the predicted LMB without computing all the prediction hypotheses and their weights [76]. To avoid computing all the hypotheses and their weights in the update step, the updated LMB multi-target posterior is truncated, *via* the ranked assignment algorithm. Murty's method is employed for the ranked assignment process in which only the M most significant association hypotheses are evaluated [77]. For more details see [74].

LABELED MULTI-BERNOULLI

Sensor-Control

As it was mentioned earlier, the POMDP approach to the sensor-control problem comprises of a multi-target tracking framework and a stochastic decision making solution to choose the optimal command *via* an objective function. Due to estimation accuracy of the LMB filter, in this study we choose LMB filter to carry out the multi-target tracking problem. The only drawback of this filter compare to the other RFS-based filters is the computational complexity of its update step.

To reduce the complexity of our proposed method, in the sensor-control step, instead of using the update formulation of the LMB filter, the multi-Bernoulli update [43] is employed. In order to use the update step of the multi-Bernoulli filter, first the predicted parameters of the LMB are computed and the augmented label state is discarded. Note that the unlabeled version of the LMB parameters is equal to the multi-Bernoulli parameters. Having the predicted parameters of the multi-Bernoulli distribution, the number and states of the targets are pre-estimated. For each sensor-control command, a set of pseudo-measurements are generated (according to the pre-estimated targets) using the Predicted Ideal Measurement Set (PIMS) approach [52], then the multi-Bernoulli update is performed. By acquiring posterior multi-Bernoulli densities for each admissible command, the command that maximizes the utility of the measurement is chosen and applied. After changing the state of the sensor(s) and receiving the actual set of measurements, the LMB update is performed. The main steps of the sensor-control with LMB filter are given in Algorithm 2.

Algorithm 2 The LMB multi-target filtering recursion with sensor-control.

INPUTS:

- dynamic model $f(x|\cdot, \ell)$,
- LMB birth model parameters,
- prior LMB parameters from time $k - 1$,
- detection probability $p_D(\cdot)$,
- measurement likelihood function $g_k(\cdot|x)$,
- clutter intensity $v(\cdot)$ and its integral λ_c ,
- current sensor(s) location(s),
- finite set of admissible sensor-control commands $\mathbb{S}$.

OUTPUT:

- The best control command $\hat{s}$,
- updated LMB parameters.

Prediction:

- 1: Compute the predicted LMB component parameters.
- 2: Extract unlabeled version of LMB parameters.

Pre-estimation:

- 3: Compute the prediction estimates of the number and states of objects.

Sensor-control:

- 4: **for** $s \in \mathbb{S}$ **do**
- 5: Construct the PIMS, $\hat{Z}(s)$.
- 6: Update the multi-Bernoulli distribution parameters.
- 7: Compute the cost $\vartheta(s; X)$
- 8: **end for**
- 9: $\hat{s} \leftarrow \operatorname{argmin}_s \vartheta(s; X)$

Measurement:

- 10: Apply the control command $\hat{s}$ to change the sensor state
- 11: Collect the actual measurements from controlled sensor(s).

Update:

- 12: Use the measurement set to update the LMB parameters.
-

Cost function

The most common approach to choose the optimal control command in the sensor-control solutions are based on maximizing an information theoretic reward function such as Rényi divergence [29, 45, 46]. The main rationale behind choosing such reward functions is that the information encapsulated by the

estimated multi-target distribution is expected to gradually increase as further measurements become available by time.

Following our preliminary study [73], we take a different approach in which the updated parameters of the multi-Bernoulli filter are used to define a new cost function. Note that the multi-Bernoulli parameters are updated by extracting the unlabeled version of the predicted LMB parameters. In the sensor-control step, these parameters are then updated by using the update formulation of the multi-Bernoulli filter. Our approach is to consider a cost function that quantifies the average uncertainty in all possible multi-target state estimates after each update step. This cost is not totally independent of the prediction outcomes, and state estimates extracted from predicted multi-Bernoulli density are used to calculate the proposed cost function. The main difference here is that our focus is on the quality of the updated density in terms of level of uncertainties, not the information gained from prediction to update (*e.g.* Rényi divergence function).

The updated distribution depends on the receiving measurement. The generated measurements set is also a function of the chosen sensor-control command. In principle the whole distribution of all possible measurement sets is used to compute the update distribution. However, to reduce the computational complexity, we adopt the predicted ideal measurement set (PIMS) [52] for the purpose of updating the multi-target distribution and computing the cost from it. To define the new cost function, we note that the predicted ideal measurement set depends on the chosen control command. For each command, we first compute the PIMS, then calculate an updated multi-object distribution by considering the PIMS as the acquired measurement. A linear combination of the normalized errors of the number of targets and their estimated states is considered as a measure of uncertainty associated with estimation of the multi-target state and as the cost function:

$$\vartheta(s; X) = \eta \varepsilon_{|X|}^2(s) + (1 - \eta) \varepsilon_X^2(s), \quad (46)$$

where $\varepsilon_{|X|}^2(s)$ denotes the normalized error of estimated cardinality of the multi-target state, $\varepsilon_X^2(s)$ denotes the normalized error of the multi-target state estimate, and $\eta \in [0, 1]$ is a user-defined constant parameter to tune the influence of the error terms on the total sensor-control cost. Appearance of the X_{k-1} as an argument of the cost function is to emphasize that the cost not only depends on the selected control command, but also on the prior distribution. The details of computing the PIMS, and defining and computing the normalized error terms, $\varepsilon_{|X|}^2(s)$ and $\varepsilon_X^2(s)$ for SMC implementation are presented in the next section.

The quality of sensor measurements usually depends on a sensor state (*e.g.* the sensor location) which is assumed to be controllable, and the sensor-control problem is focused on choosing the command that would lead to the best sensor state.

Implementation

Suppose that at the time $k-1$, the multi-target distribution is modelled by a LMB RFS with parameters $\pi = \{(r^{(\ell)}, p^{(\ell)}) : \ell \in \mathbb{L}\}$ and $\pi_{\mathbf{B}} = \{(r_B^{(\ell)}, p_B^{(\ell)}) : \ell \in \mathbb{B}\}$, in which each single target density $p^{(\ell)}(\cdot)$ is represented by a set of weighted samples $\{(\omega_i^{(\ell)}, x_i^{(\ell)})\}_{i=1}^{J^{(\ell)}}$ and the birth density is represented by $\{(\omega_{B,i}^{(\ell)}, x_{B,i}^{(\ell)})\}_{i=1}^{B^{(\ell)}}$. In the prediction step, the LMB filter propagates the LMB components based on the temporal information from the transition density, the probability of survival, and the predefined LMB birth terms. The predicted LMB density is denoted by $\pi_+ = \{(r_+^{(\ell)}, p_+^{(\ell)}) : \ell \in \mathbb{L}_+\}$ where each single target density $p_+^{(\ell)}(\cdot)$ is represented by a set of weighted samples $\{(\omega_{+,i}^{(\ell)}, x_{+,i}^{(\ell)})\}_{i=1}^{J_+^{(\ell)}}$.

For each label $\ell \in \mathbb{L}_+$, if the probability of existence $r_+^{(\ell)}$ is greater than a user-defined threshold (chosen at 0.5 in our simulation studies), the EAP estimate of a single-object state is computed as follows:

$$\hat{x}^{(\ell)} = \sum_{i=1}^{J_+^{(\ell)}} \omega_{+,i}^{(\ell)} x_{+,i}^{(\ell)}. \quad (47)$$

Each of the above estimates represent a predicted target. Following the PIMS approach [52], an ideal set of measurements are then generated from the predicted target state estimates. This hypothetical set of measurement would depend on not only the predicted number and states of targets, but also the new state of the sensor(s) after a sensor command is applied. Indeed, for each possible sensor-control command $s \in \mathbb{S}$, a different set of ideal measurements, $\hat{Z}(s)$, is computed. Considering this set as the actual measurement set, we can now run the update step and calculate the cost corresponding to that command.

We note that the LMB prediction step “actually coincides with performing the prediction on the unlabeled process and interpreting the component indices as track labels.”—Remark 3 from [74]. Therefore, we can simply remove the labels from the predicted LMB multi-object state, and update the existence probabilities

and density particles and weights through the CB-MeMBeR update step [43] in which $\hat{Z}(s)$ is taken as the actual measurement set.

It is important to note that this update step needs to be repeated for each hypothetical measurement set $\hat{Z}(s)$. By using the CB-MeMBeR update on the unlabeled components we avoid to repeatedly run the computationally expensive update of LMB filter. Hence, substantial savings are achieved in terms of computational cost of our sensor-control method.

Computing The Cost:

The cost defined in (46) comprises two normalized error terms, $\epsilon_{|X|}^2(s)$ as the error for the cardinality estimate, and $\epsilon_X^2(s)$ as the error for the multi-target state estimate. Both terms depend on the updated multi-object posterior which in turn depends on the PIMS computed for the command s . Assume that for each control-command $s \in \mathbb{S}$, the CB-MeMBeR updated *unlabeled* multi-Bernoulli is given by $\{r^{(i)}(s), p^{(i)}(s, \cdot)\}_{i=1}^{M(s)}$ where each single Bernoulli density $p^{(i)}(s, \cdot)$ is approximated by particles $\{\omega_j^{(i)}(s), x_j^{(i)}(s)\}_{j=1}^{J^{(i)}(s)}$.

We choose and calculate the statistical expectation of the cardinality variance as a meaningful measure for its estimation error. In terms of the updated probabilities of existence, it is given by:

$$\sigma_{|X|}^2(s) = \sum_{i=1}^{M(s)} \left[r^{(i)}(s)(1 - r^{(i)}(s)) \right]. \quad (48)$$

The above given value is maximum when $\forall i, r^{(i)}(s) = 0.5$ which leads to $\max\{\sigma_{|X|}^2(s)\} = \frac{M(s)}{4}$. Thus, the normalized cardinality error term can be computed as follows:

$$\epsilon_{|X|}^2(s) = \frac{4\sigma_{|X|}^2(s)}{M(s)}. \quad (49)$$

To arrive at a meaningful measure for the normalized state estimation error term $\epsilon_X^2(s)$ in the cost defined in (45), we consider the following total state estimation error:

$$\varepsilon_X^2(s) = \sum_{i=1}^{M(s)} \left[r^{(i)}(s) \varepsilon_{x^{(i)}}^2(s) \right] / \sum_{i=1}^{M(s)} r^{(i)}(s) \quad (50)$$

which is the weighted average of normalized estimation errors of the states of single targets associated with each single Bernoulli component. Before we present how the normalized error terms $\varepsilon_{x^{(i)}}^2(s)$ are computed, we note that the averaging weights are the updated probabilities of existence. The rationale behind this choice of weights is that Bernoulli components with larger probabilities of existence contribute more strongly to the EAP estimate of the multi-object state—see section IV-A.4 in [43].

To compute the normalized single Bernoulli component errors $\varepsilon_{x^{(i)}}^2(s)$, we first formulate the actual error denoted by $\varsigma_{x^{(i)}}^2(s)$, then its maximum, upon which a normalized measure will be given by $\varsigma_{x^{(i)}}^2(s) / \max \varsigma_{x^{(i)}}^2(s)$. In practice, we are commonly interested in minimizing the estimation error of *selected elements* of target states. For instance, in some applications, the prime interest is in *location*, and target speed is included in the single-target state vector due to its appearance in motion and perhaps measurement models. In such target-tracking applications, an intuitive scalar measure for the single Bernoulli component error is given by the product of the variances of the target location coordinates. If the stochastic variations of target location coordinates are independent, this measure will translate into the absolute determinant of the covariance matrix of the target location.

In case of tracking multiple-targets in 2D space, the single Bernoulli component error term, $\varsigma_{x^{(i)}}^2(s)$, is given by:

$$\varsigma_{x^{(i)}}^2(s) = \sigma_{x^{(i)}}^2(s) \sigma_{y^{(i)}}^2(s) \quad (51)$$

where x and y denote the x and y -coordinates of the single-target location (part of its state vector x). Having the updated particles and weights of each Bernoulli component, the single-coordinate errors can be calculated as follows:

$$\begin{aligned} \sigma_{x^{(i)}}^2(s) &= \sum_{j=1}^{J^{(i)}(s)} \omega_j^{(i)}(s) \left(x_j^{(i)}(s) \right)^2 - \left(\sum_{j=1}^{J^{(i)}(s)} \omega_j^{(i)}(s) x_j^{(i)}(s) \right)^2 \\ \sigma_{y^{(i)}}^2(s) &= \sum_{j=1}^{J^{(i)}(s)} \omega_j^{(i)}(s) \left(y_j^{(i)}(s) \right)^2 - \left(\sum_{j=1}^{J^{(i)}(s)} \omega_j^{(i)}(s) y_j^{(i)}(s) \right)^2 \end{aligned} \quad (52)$$

where $x_j^{(i)}(s)$ and $y_j^{(i)}(s)$ denote the coordinates extracted from the particle $x_j^{(i)}(s)$ and power operation is element-wise operation. To normalize the total state estimation error term $\zeta_{x^{(i)}}^2(s)$ in (51), we note that with equally weighted particles, *i.e.* when $\forall j, \omega_j^{(i)}(s) = 1/J^{(i)}(s)$, the particles representing the i -th single Bernoulli component do not convey any information and the above estimation variances adopt their maximum values as follows:

$$\begin{aligned} \max\{\sigma_{x^{(i)}}^2(s)\} &= \frac{1}{J^{(i)}(s)} \left(1 - \frac{1}{J^{(i)}(s)}\right) \sum_{j=1}^{J^{(i)}(s)} \left(x_j^{(i)}(s)\right)^2 \\ \max\{\sigma_{y^{(i)}}^2(s)\} &= \frac{1}{J^{(i)}(s)} \left(1 - \frac{1}{J^{(i)}(s)}\right) \sum_{j=1}^{J^{(i)}(s)} \left(y_j^{(i)}(s)\right)^2. \end{aligned} \quad (53)$$

Thus, the single Bernoulli error terms $\zeta_{x^{(i)}}^2(s)$ in (51) can be normalized as follows:

$$\varepsilon_{x^{(i)}}^2(s) = \frac{\sigma_{x^{(i)}}^2(s) \sigma_{y^{(i)}}^2(s)}{\max\{\sigma_{x^{(i)}}^2(s)\} \max\{\sigma_{y^{(i)}}^2(s)\}} \quad (54)$$

and the computed values can be used in (50) to calculate the normalized state estimation error term in the cost. Having the cost values computed for all admissible sensor-control commands, the best command $\hat{s}^*$ is then chosen as the one incurring the smallest cost:

$$\hat{s}^* = \underset{s \in \mathbb{S}}{\operatorname{argmin}} \vartheta(s; X). \quad (55)$$

As the cost function of the proposed method is a combination of posterior expected errors of cardinality and states, henceforward, we call it the *Posterior Expected Error of Cardinality and States* (PEECS).

OSPA METRIC

A commonly accepted measure for the performance of a multi-target tracking algorithm is Optimal SubPattern Assignment (OSPA) [78]. OSPA is a metric which measures the distance between track estimated and ground truth sets. In this correspondence we utilize the OSPA metric to act as an objective function in a

possible sensor management framework. General formulation of the OSPA metric is given in the equation (56):

$$\bar{d}_p^{(c)}(X, Y) := \begin{cases} \left(\frac{1}{n} \left(\min_{\pi \in \Pi_n} \sum_{i=1}^m d^{(c)}(x_i, y_{\pi(i)})^p + c^p(n-m) \right) \right)^{1/p} & \text{if } m \leq n \\ \left(\frac{1}{m} \left(\min_{\pi \in \Pi_m} \sum_{i=1}^n d^{(c)}(y_i, x_{\pi(i)})^p + c^p(m-n) \right) \right)^{1/p} & \text{if } n \leq m \end{cases} \quad (56)$$

where $d^{(c)}(x, y)$ is a baseline metric defined on single-target states $x, y, c > 0$ is a cut off radius and Π_k denotes all permutations of the set $\{1, 2, \dots, k\}$. As the order parameter p increases (assuming c is fixed), the OSPA metric becomes more sensitive to outliers. The cut-off parameter c determines how the metric penalizes cardinality errors as opposed to localization errors.

The OSPA error is comprised of two components given by they can be interpreted as localization and cardinality errors.

$$\bar{e}_{p, \text{loc}}^{(c)}(X, Y) := \left(\frac{1}{n} \cdot \min_{\pi \in \Pi_n} \sum_{i=1}^m d^{(c)}(x_i, y_{\pi(i)})^p \right)^{1/p}, \quad (57)$$

$$\bar{e}_{p, \text{card}}^{(c)}(X, Y) := \left(\frac{c^p(n-m)}{n} \right)^{1/p}. \quad (58)$$

NUMERICAL STUDIES

To demonstrate the performance of our method with measurements that guarantee full observability of the targets, we have run a case study involving a complex scenario. In this scenario, we choose a non-linear nearly-constant turn model reported in [43]. In this case, each single target state $x = [\bar{x}^\top \ \omega]^\top$ is comprised of location and velocity in Cartesian coordinates, denoted by $\bar{x}$ and turning rate, denoted by $\omega = [\dot{x} \ \dot{y}]^\top$. The state dynamics are given by:

$$\begin{aligned} \bar{x}_k &= F(\omega_{k-1})\bar{x}_{k-1} + G\epsilon_{k-1}, \\ \omega_k &= \omega_{k-1} + T\gamma_{k-1}, \end{aligned}$$

where

$$F(\omega) = \begin{bmatrix} 1 & 0 & \frac{\sin \omega T}{\omega} & -\frac{1 - \cos \omega T}{\omega} \\ 0 & 1 & \frac{1 - \cos \omega T}{\omega} & \frac{\sin \omega T}{\omega} \\ 0 & 0 & \cos \omega T & -\sin \omega T \\ 0 & 0 & \sin \omega T & \cos \omega T \end{bmatrix},$$

$$G = \begin{bmatrix} \frac{T^2}{2} & 0 \\ 0 & \frac{T^2}{2} \\ T & 0 \\ 0 & T \end{bmatrix},$$

$T = 1$ s, $\varepsilon_{k-1} \sim \mathcal{N}(\cdot; 0, \sigma_\varepsilon^2 I)$, $\sigma_\varepsilon = 15$ m/s², and $\gamma_{k-1} \sim \mathcal{N}(\cdot; 0, \sigma_\gamma^2 I)$, $\sigma_\gamma = (\pi/180)$

The birth RFS is a multi-Bernoulli with density

$$\bullet \pi_\Gamma = \{(r_\Gamma^{(i)}, p_\Gamma^{(i)})\}_{i=1}^4$$

where

$$\bullet r_\Gamma^{(1)} = r_\Gamma^{(2)} = 0.02,$$

$$\bullet r_\Gamma^{(3)} = r_\Gamma^{(4)} = 0.03 \text{ and}$$

$$\bullet p_\Gamma^{(i)}(x) = \mathcal{N}(x; m_\gamma^{(i)}, P_\gamma)$$

where

$$\begin{aligned}
m_{\gamma}^{(1)} &= [-1500 \ 0 \ 250 \ 0 \ 0]^{\top}, \\
m_{\gamma}^{(2)} &= [-250 \ 0 \ 1000 \ 0 \ 0]^{\top}, \\
m_{\gamma}^{(3)} &= [250 \ 0 \ 750 \ 0 \ 0]^{\top}, \\
m_{\gamma}^{(4)} &= [1000 \ 0 \ 1500 \ 0 \ 0]^{\top},
\end{aligned}$$

and $P_{\gamma} = \text{diag}(50^2, 50^2, 50^2, 50^2, (6 \times \frac{\pi}{180})^2)$. The sensor can detect an object in location $\mathbf{o} = [x_o \ y_o]^{\top}$ with the following probability that depends on the location of both the sensor and object locations:

$$p_D(\mathbf{s}, \mathbf{o}) = \begin{cases} 1, & \text{if } \|\mathbf{o} - \mathbf{s}\| \leq R_0 \\ \max\{0, 1 - \mathfrak{h}(\|\mathbf{o} - \mathbf{s}\| - R_0)\} & \text{otherwise.} \end{cases} \quad (59)$$

Overall, there are five objects in the surveillance area, positioned relatively close to each other. Their initial state vectors are:

- $[800 \ 600 \ -1 \ 0]^{\top}$,
- $[650 \ 500 \ 0.3 \ 0.6]^{\top}$,
- $[620 \ 700 \ 0.25 \ -0.45]^{\top}$,
- $[750 \ 800 \ 0 \ -0.6]^{\top}$, and
- $[700 \ 700 \ 0.2 \ -0.6]^{\top}$,

where the units of x and y are meters and $\dot{x}$ and $\dot{y}$ are m/s. The objects move according to the constant velocity model. Each measurement includes a set of ranges and bearings, and the observation model is given by:

$$z_k = \left[\arctan\left(\frac{x_k}{y_k}\right) \quad \sqrt{x_k^2 + y_k^2} \right]^\top + \zeta_k,$$

where $\zeta_k \sim \mathcal{N}(\cdot; 0, R_k)$ is the measurement noise with covariance $R_k = \text{diag}(\sigma_\theta^2, \sigma_r^2)$ in which the scales of range and bearing noise are $\sigma_\theta = (\pi/180)\text{rad}$ and $\sigma_r = 5\text{m}$. The clutter RFS follows the uniform Poisson model over the surveillance region $[-\pi/2, \pi/2], \text{rad} \times [0, 2000], \text{m}$, with $\lambda_c = 1.6 \cdot 10^{-3} (\text{radm})^{-1}$

The sensor initial position is at $x=0$ and $y=1500$. Targets enter the scene with the following position, velocity, turning velocity, birth and death time:

$$\begin{aligned} x_{T_1} &= [1000 \ -20 \ 1500 \ -20 \ \frac{\pi}{180}]^\top, \quad k_{T_1}^b = 1, \quad k_{T_1}^d = 35, \\ x_{T_2} &= [-250 \ 20 \ 1000 \ 3 \ \frac{\pi}{270}]^\top, \quad k_{T_2}^b = 5, \quad k_{T_2}^d = 50, \\ x_{T_3} &= [-500 \ 11 \ 250 \ 10 \ \frac{\pi}{180}]^\top, \quad k_{T_3}^b = 20, \quad k_{T_3}^d = 50, \\ x_{T_4} &= [-500 \ 14 \ 250 \ 0 \ 0]^\top, \quad k_{T_4}^b = 15, \quad k_{T_4}^d = 50, \\ x_{T_5} &= [250 \ 11 \ 750 \ 5 \ \frac{\pi}{360}]^\top, \quad k_{T_5}^b = 10, \quad k_{T_5}^d = 50. \end{aligned}$$

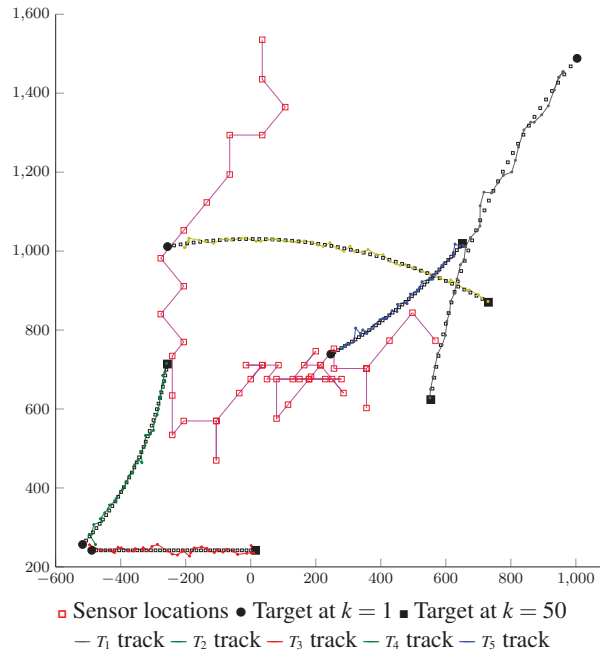


Fig. (6). Sensor and target locations during $k = 1, \dots, 50$.

Intuitively, we expect the sensor start moving toward the targets and for each time step remains in vicinity of them. As it is shown in Fig. (6), sensor start moving from the initial position and as it was expected, after a few steps it remains among the manoeuvring targets.

The estimation error are computed based on the Optimal SubPattern Assignment (OSPA) metrics introduced in [78] (cutoff parameter $c = 100$ and order parameter $p = 2$). The comparative averaged error performance of LMB PEECS sensor-control and CB-MeMBer PEECS sensor-control are shown in Fig. (7) over 200 Monte Carlo runs.

Fig. (8) and Fig. (9) show the cardinality and localization errors for both methods respectively.

At first the cardinality and localization errors are high due to uncertainty in the number and states of targets. After the time step $k = 20$ both the cardinality and localization errors are fixed through the rest of the simulation.

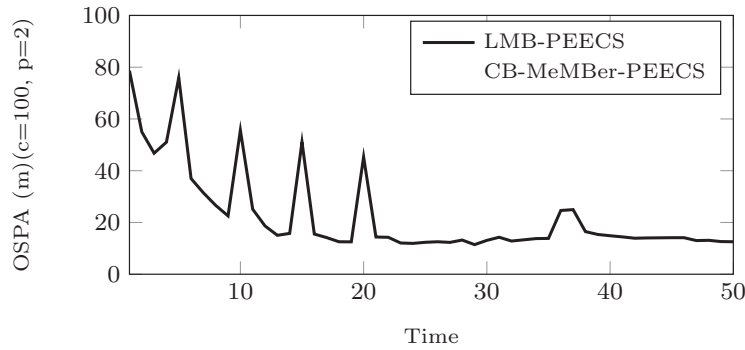


Fig. (7). Estimation errors of the PEECS sensor-control method.

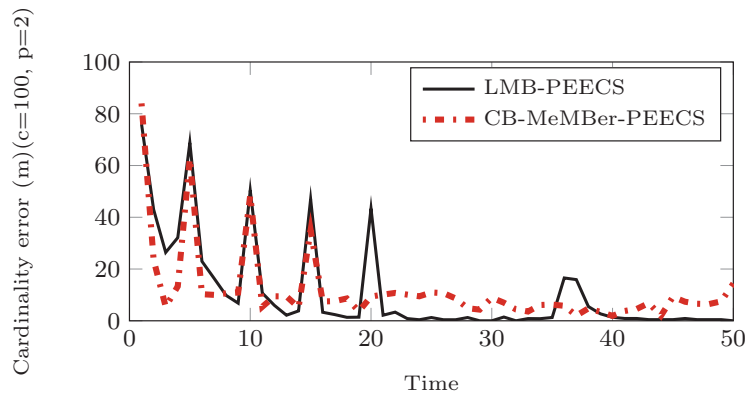


Fig. (8). Cardinality errors of the PEECS sensor-control method.

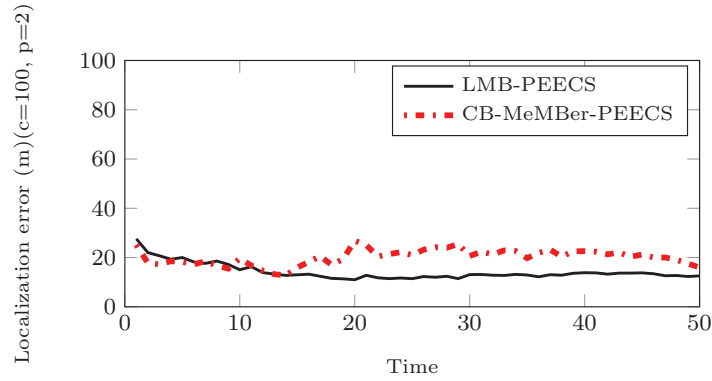


Fig. (9). Localization errors of the PEECS sensor-control method.

The LMB PEECS errors are comparatively lower than the CB- Me Mber PEECS error. The total OSPA error are shown in Fig. (7). The superiority of the LMB PEECS method is due to accuracy of the LMB filter which is the result of proper approximation in update step of the LMB filter. Unlike multi-Bernoulli filter the LMB filter uses a more accurate update approximation. More precisely, the LMB filter uses a more accurate update approximation than the CB- Me Mber filter by exploiting the conjugate prior labeled RFSs [74].

CONCLUSIONS AND FUTURE STUDIES

In this chapter, a novel sensor-control method was introduced, for controlling mobile sensor(s) in such a way that minimum expected errors are achieved in a multi-target tracking application. This method works based on choosing the sensor-control command that is expected to lead to the lowest cost, and the cost is defined and formulated in terms of cardinality and single-target state estimation errors. Implementation of the cost computation and its minimization within a labeled multi-Bernoulli filter was elaborated and a step-by-step algorithm was presented.

In a challenging simulation scenario, our proposed method demonstrated success in optimal guidance of a mobile sensor in tracking of up to 5 targets which can appear and disappear in/from the scene. Compared to the scenario where a similar cost function was used within a CB-MeMBer filter, we showed that our new method developed for the labeled multi-Bernoulli filter performs better in terms of OSPA errors in the same challenging scenario. This can also be due to the advantageous nature of the labeled multi-Bernoulli filter in terms of its better accuracy in approximating the update step.

This work can be extended to applications where detection and tracking of targets of interest are required. In this case, a new task-driven cost function would be needed in which not only the estimation errors are considered but also the track labels produced by the labeled multi-Bernoulli filter are utilized. Such a sensor-control routine would guide the sensor(s) towards sensor states which are likely to lead to better estimates of the states of the targets of interest (with particular labels) only.

CONFLICT OF INTEREST

The authors confirm that this chapter content has no conflict of interest.

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Parallel Processing in Holonic Systems

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Abstract: Scheduling is a basic activity in large scale systems with unexpected and high complexity demands. Instances of these complex systems are found in manufacturing, logistics, economics, traffic control, and biology. The number of entities and their interconnections are the reasons motivate researchers to find solutions which are not based on central control structures. Multi-agent based architecture is a distributed collections of interacting entities which function without a supervisor. The advantage of holonic self-organization concepts lies in the fact that they contribute to achieve more efficient performance. According to these principles, several approaches have been and are being designed, which are considered weak in handling emergency demands in an industrial environment. The concepts of multi-agent and holonic systems are addressed and discussed in this chapter where their advantages and weak points are revealed with a focused in holonic control architecture in overcome the weak points. The main objective of this architecture is to reduce time and complexity overload. The concept of parallel processing and task priority are of concern here. Task priority reduces time delay in an unexpected situation causes for handling critical tasks. The techniques like self-organization methods, high percentage of autonomy for controller holons, use of common data source, and increasing parallel processes are applied in reducing output delivery time. This newly proposed architecture is tested in a simulation environment.

Keywords: Holonic systems, Multi-agent systems, Parallel processing, Scheduling, Self-organization, Task priority.

INTRODUCTION

For the purpose of developing new approaches regarding parallel process, time reduction in this case, there exist several definition. Multi-agent systems consist of multiple interacting computing factors known as agents. Agents are computer systems with two important abilities: 1) they are, at least to some extent, capable of the autonomously deciding what they need to do to accomplish their goal and

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2) they are able to interact with other agents not by exchanging data, but by engaging in analogues of the kind of social activities like cooperation, negotiation, coordination, *etc.* which everyone is a part of daily life [1]. In the related literature, the agents provide viable solution in complex systems modeling. In particular, Multi-Agent Systems successful manner in a large variety of distributed intelligence settings [2].

The organization of a multi-agent system consist of the set of roles, authority and structures' relation which control its behavior. All multi-agent systems contain some or all of these features, therefore, they all have some form of organization, although it might be implicit and unofficial. Just as with human organizations, such agent organizations determine how the members of a given population interact, not necessarily on a moment by moment basis, but in long-term with respect to a particular objective(s). The above mentions facts, might affect data flow, authority relation, coordination patterns, resource allocation, or any number of other system features [3 - 6].

Many researchers have demonstrated that in an organizational design where the agent system is adopted, a significant effect on of performance is observed. A series of organizational strategies are developed in this line of research, where each strategy has its own strengths and weaknesses. Hierarchy, holarchy, and absolute autonomous are the types of multi-agent systems organizations.

The hierarchy or hierarchical organization is the earliest type of structured organizational design for multi-agent system and earlier distributed AI architectures [8]. The data made by lower-level agents in a hierarchy usually flow upwards to get a general view, while the control signal or supervisory orders flow downwards [9].

A holon, just like an agent, is an intelligent entity able to interact with the environment and to take decisions in solving a specific problem; holons are able to be a whole and a part at the same time. This unique nature of holons affect the organization systems in three levels: holarchy functions as autonomous wholes in supra-ordination to their parts, as affiliate parts in sub-ordination to control on upper levels, and in coordination with their environment [2]. A comparison between holarchies and hierarchies in organizations reveals that holarchies are more easily applied to domains where the objectives can be broken down into subtasks which can be allocated to individual holons in a recursive manner. The degree of autonomy in an individual holon is undefined and could differ between the levels or even between the holons at a same level. It is assumed that the level of autonomy is neither complete nor completely absent [7].

The holonic organizations are derived primarily from the partially autonomous and encapsulated nature of holons. Holons are usually endowed with enough autonomy to define how efficiently assess the requests they receive. Because the requester does not need to know exactly how the order will be completed, the holon has the great flexibility degree in its choice of behaviors, which can enable it to nearly coordinate potential conflicting or complementary tasks. This feature decreases the knowledge burden placed on the requester and allows the holon's behavior to adapt to new situations without coordination in future in a dynamic manner, so long as the original commitment's needs are met [10].

Many architectures and developments in holonic structure are presented with different application domains, like scheduling, manufacturing and control, material handling, machine controller and assembly systems [11].

LITERATURE REVIEW

The concept of Agent-oriented programming and the concept of agent centering software were first applied by Yoav Shoham in 1990. His developed agents follow a specific pattern as one method with a single parameter [12].

Multi-agent systems consist of agents and their environments. Typically, studies regarding multi-agent systems are software agent oriented. However, the agents in a multi-agent system could be a team of robots or humans [13]. Topics of research in MAS contain scientific ([14, 15]), agent-oriented software engineering, and robotic issues [16].

Horling and his team conducted a survey on multi-agent organizational patterns, including: hierarchies, holarchies, teams, coalitions, congregations, societies, federations, and matrix organizations. He provides an explanation for each one of the above mentioned organizations, by considering their advantages and disadvantages, and offering examples of how they may be instantiated and maintained [7].

The term 'holon' was first defined by Arthur Koestler in his book, *The Ghost in the Machine*. According to his description, a holon (Greek: ὅλον, holon neuter form of ὅλος, holos "whole") is something which is simultaneously a whole and a part [17].

Holonic organizations have proven to be effective and efficient solutions to many problems with hierarchical and self-organizing structures [18] and have been and are being applied in a grate range of complex systems in a successful manner, (e.g. in transportation [19], manufacturing systems [20], adaptive mesh problem [21] and health organizations [22]).

Traditionally, manufacturing control systems use hierarchical control structures that centralize the processing power of a shop-floor control in one central node. They increase optimization and performance; while, when conditions change, they do not function appropriately and lack predictability and scalability. These rigid, monolithic control structures are not sufficient in confronting the current requests coming from manufacturing environments which demand flexibility, robustness, responsiveness and re-configurability. Consequently, new manufacturing patterns have developed, of which the common denominator is the distribution and decentralization of processing power over many entities, albeit with reduction of system performance in process optimization. The early instances of these patterns were Reconfigurable Manufacturing Systems (RMS) [23], and Multi-agent Systems (MAS) [24], followed by Bionic Manufacturing Systems (BMS) and then Holonic Manufacturing Systems (HMS) [25]. Finally, Evolvable Production Systems (EPS) [26] were developed in 2006. RMS is a concept suggesting speedy change in the factory's structure using modifications in software and/or hardware so as to control the production functionality and capacity quickly [27]. An RMS system should demonstrate the following features [23]: integrality, customization, modularity, diagnosable and convertibility. MAS [24] is both a technology and a pattern which advocates the design of systems based on the societies of distributed, decentralized, intelligent and autonomous entities known as agents. In these systems, each agent has a sectional view of the environment and must therefore cooperate with others in order to achieve the global goals; the behavior of the global system stems from the cooperation between individual agents. An HMS [25] is a pattern which interprets the concepts of living organisms and social organizations developed by Koestler [17] for the manufacturing.

The improved version of MetaMorph [28], the MetaMorph II [29] are the projects where attempts for the first time, first, to provide an agent-based approach to the management and develop of agent communities in distributed manufacturing environments, and, followed by, to integrating cross-enterprise activities like planning, design and scheduling. AARIA (Autonomous Agents at Rock Island Arsenal) was introduced in 1997, the early years of agent based architectures, with the particularity of using internet as the communication means between agents, for military purposes [30]. One of the best-known practical samples in applying multi-agent systems is the one in Daimler Chrysler production lines ([31, 32]). The agent technology is applied in both flexible and dynamic transportation and control systems through this architecture. One of the most notable HMS samples is the PROSA (Product-Resource-Order-Staff Architecture), which describes the main guidelines for developing a generic manufacturing control layer [33]. A real application of PROSA was implemented at Cambridge University by applying a packaging cell [34], where cooperation is organized between resource and order holons in order to meet clients' requirements. Order holons apply negotiation

techniques to ensure reliable and fast production and are accountable for tracking production progress as well. The main objective of resource holons is to maximize the return on the implementation of their services, and, finally, the product holon is responsible for buying and selling goods.

The ADACOR (ADaptive holonic COntrol aRchitecture for distributed manufacturing systems) [35] is a holonic architecture developed by merging the advantages of hierarchical and heterarchical control structures using an adaptive mechanism which aimed to represent an adaptive production control approach equilibrium from a static state to a transient state, in unexpected and normal situations.

Jose Barbosa *et al.*, improved the ADACOR holonic control architecture inspired by biological and evolutionary theories, where, a two-dimensional self-organization mechanism is presented for behavioral and structural vectors under consideration. Behavioral self-organization is at micro level, where each individual holon can change its behavior in different external conditions. Structural self-organization is at macro level and assists the system to evolve by changing the relations between the holons, in a significant manner [36]. Jose Barbosa evaluated his own model with the case study system known as AIP-PRIMECA Flexible Manufacturing System (FMS) [37].

To the knowledge of the authors of the chapter, the drawbacks observed in the respected studies above consist of time and complexity over load. In this section, a new model is proposed for large scale, complex and dynamic systems to overcome the above mentioned drawbacks. The behavioral and structural self-organization in holonic structures are applied here to develop a model that is flexible, robust and nonstop in critical conditions without time and complexity over load.

FIPA STANDARD AND AGENTS COMMUNICATION LANGUAGE

The Foundation for Intelligent Physical Agents (FIPA) is an international organization dedicated to promoting the industry of intelligent agents through extended specifications supporting interoperability among agents and agent-based applications. FIPA-compliance is a reference point for many researchers. Some platforms are fully compliant whereas others adopt only some of the available specifications. For instance, JAS and Agent Factory platforms support only specifications which refer to the agent lifecycle, whereas AGLOBE and Jason support specifications which refer to the communication principles and language, ACL and KQML, respectively.

ACL, Ontology, Content Language and RFP (Requests for Proposal) are the necessary established standards through which agents would communicate with each other and discuss domain entities in different conditions.

Messages must have a well-defined semantics that is computational and visible. Thus, standardized Agent Communication Languages (ACL) are required to allow different parties to be interpreted through agents. Furthermore, they must have formal semantics so different implementations would preserve the essential features of the ACL. By specifying an ACL, the basic elements of interaction between agents are efficiently codified.

Compliance with FIPA specifications has specific advantages useful or even crucial in some cases. For instance, being in compliance with FIPA guarantees the system's architecture and performance due to the powerful and well-tested protocols that enable agent cooperation and interoperability. Hence, FIPA standards are required in studying dynamic, flexible, and reconfigurable cases. Moreover, FIPA specifications are popular in agent-based research, indicating that exist sufficient knowledge and support in the research community; consequently, researchers decide whether or not FIPA compliance is required and to what extent should it be studied [38, 39].

DESIGNING A HOLONIC MODEL

In the following sections, a new holonic model will be designed and the role of data transfer methods in accomplishing maximum parallel processes and handling critical conditions is discussed. To begin with, the fundamentals of a holonic structure design are explained.

Steps of structure design are shown in Fig. (1). The sequence and accuracy of design for each step is important and will affect the model performance. Designers must consider the generality or use cases of the model and be conscious about exceptional cases. Exceptional cases will appear when the designer applies the model in some different study cases.

As demonstrated by previous researches, holonic structures are appropriate for large scale and complex systems, where many heterogeneous entities with unanticipated interactions are involved. Instances of these large and complex systems can be found in manufacturing, logistics, economics, traffic control and biology. Large scale systems have a number of technical challenges which still remain to be met through IT research. These challenges are associated with the characteristics of the systems' scale magnitude, complexity, heterogeneity, flexibility, trustworthiness, distributed operation and administration.

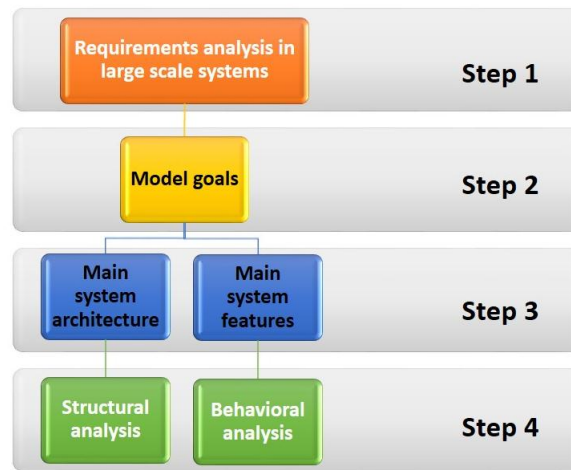


Fig. (1). Steps in model design.

As observed in Fig. (1), in the model design step 1 is the analysis of requirements, indicating that, to present an efficient model for large scale systems, the details of system characteristics must be reviewed.

1. **Scalability:** In these systems, scalability is of a great significance. The number of components in the system, the number of users supported by the system, and the component connection in quantity and quality constitute the metrics for scale recognition in large scale systems. According to Bondi, scalability is the capability of a system, network, or process to handle a growing amount of work, or its potential to be enlarged in order to accommodate that growth. For example, when resources (typically hardware) are added to increase their total output subject to an increased load, this addition is referred to as the capability of a system. Due to new evolved services, unpredictable conditions, and demands in large scale systems, scalability is essential in this practice [40].
2. **Complexity:** It is often the case that a single component, or even a small group of components, is unable to sense, comprehend, and control the overall functionality of the system. Hence, predicting the performance is incredibly difficult and failures in one part of the system can propagate throughout the system in unexpected manners.

Complex systems present problems both in the mathematical modeling and philosophical foundations. The obtained results of studies on complex systems provide new approaches in science to assess how relation among parts give a rise to the collective behaviors of a system and how does the system interact and relation with its environment [41].

There exists a direct relation in the interaction between scale and complexity, that is the IT systems become larger, complexity increases and vice versa. Attempts are made to build systems where a gain in complexity would not end up in an increase in scale.

As a result, the demand must be met not by a direct scaling up in the system, but by a parallel and distributed process, which introduces additional complexity associated with data replication and reconciliation.

3. **Heterogeneity:** Large-scale IT systems are becoming increasingly heterogeneous. In the past, a vendor provided a stand-alone system, while now, in contrast, a large scale system is provided by some vendors, where the final achievement depends on cooperation, coordination, and the compliance between components. This process results in a high level of heterogeneity within systems and highlights the need for interoperability among components. Designing large systems by applying out-of-the-box components requires proper techniques, especially when they are mixed and matched in unexpected manners. How to design trustworthy systems from untrustworthy components is an important issue of concern. More advanced techniques are needed in designing robust, reliable, and secure software in this new and highly challenging environment.
4. **Flexibility:** Flexibility is important both during the design process and after it is implemented. The development of large-scale IT systems can take so long that may cause a delay in mission requirements and a change in component technologies before the system is fielded. Inability to accommodate these changes and to integrate subsystems designed and implemented separately is the main reason that many major IT systems are rarely applied. If applied, large IT systems go through long lifetimes, during which the old components must be replaced—often with more modern technology—or the scale of the system must be expanded in order to provide additional functionality. The need for upgrading system and making expansions can be particularly despairing for private sector, the requirements of which change more rapidly than those of state. Companies want to produce new products and provide better services in a better manner for competing with and matching their opponents' innovations in the market. Doing so almost requires reconfigured information systems; the challenge is to “change the software as fast as the business”. As a result, flexibility —specifically, the ability to meet changing needs rapidly—has become one of the most fundamental and important requirements in many applications.
5. **Trustworthiness:** Because the industry, government, and other social organizations, increasingly support mission-critical functions, large-scale IT systems must be extremely trustworthy. Consequently, they must do what they are required to do—and nothing else—despite environmental disruption,

human user and operator error, and attacks made by hostile parties. They must be available for providing service when needed (perhaps continuously) and perform their tasks reliably, with adequate security and no error. Failure to meet these standards can disrupt the service IT systems provide, causing loss of business revenues or even human life. An increase in trustworthiness is recognized as being one of the most important challenges in IT, because support critical functions are on significant increase in networks, and can introduce new vulnerabilities. Ensuring trustworthiness is particularly difficult in large-scale IT systems because of their size and complexity. The trustworthiness of systems and applications encompasses a number of issues, including security, reliability, and availability.

- **Security:** Large-scale information systems are vulnerable to malicious attacks that can make them unable to perform their intended tasks, that is, loss of confidential information or cause information to be lost, modified, or destroyed. Large-scale systems are especially vulnerable to security flaws. The large number of client computers attached to them means an even larger number of portals at which a lapse in security (*e.g.*, a weak or divulged password) can allow entry into a system. Furthermore, many such systems are distributed among several administrative domains, making security more difficult to manage and assure. Additional vulnerabilities are introduced large-scale IT systems become connected to the Internet. Despite the fact that the attraction made by many of today's large-scale systems stem from their attachment to the global network, the same makes the systems vulnerable to misuse or attack.
- **Availability and Reliability:** As IT applications are on an increase in addressing critical needs such as disaster recovery, e-commerce, and health care, the requirements for availability (*i.e.*, assurance that a system is available for use when and as needed) and fault tolerance (*i.e.*, assurance that a system can function even when problems arise) increase almost at the same rate. Large-scale system designs obviously differ from, desktop office suites in a sense that they must operate in unknown, changing environments. While unfortunately, most algorithms and design techniques for computer hardware and software assume a benign environment and correct operation of every component. There is an urgent need for new algorithms based on different assumptions that will lead to algorithms that work correctly in spite of failures. The study of distributed computing (*i.e.*, computer systems interconnected by networks) has begun to address this major issue. Algorithms have been and are being developed that work correctly even when a data packet sent into the network from a computer fails to arrive at its intended destination. The algorithms applied to route packets through the Internet are not only robust in the presence of dropped packets but also adapt

to changes in network performance (*e.g.*, when a communication link fails or resumes operation after failure). Although considerable progress is made in critical algorithms, they are far from perfect (*e.g.*, routing algorithms cannot always prevent network congestion) and they fulfill only a small fraction of the requirements of today's large-scale systems.

6. **Distributed Operation and Administration:** The challenges inherent in large-scale IT systems are further complicated by the frequent distribution of their operation and administration across different organizational units. In the past, most IT applications were compartmentalized into individual organizations with independent administration. Now, applications—whether designed for social, information access, or business purposes—are executed across a networked computing infrastructure covering all organizations and enterprises, and indeed multiple enterprises and consumers. Such an infrastructure cannot be administered in a centralized fashion in an effective manner, since there is no central administrative authority. New tools and automated operational support methodologies could improve the operation and administration of such distributed systems. These potential solutions have yet to be considered seriously by the research community; network management is an area that has long needed more research [42].

The first step of holonic model design is accomplished by analyzing the requirement. As presented in Fig. (1), in the second step the model objectives are determined according to the requirements and challenges of large scale systems.

This new model is designed to control large scale, complex, and dynamic systems. The motive and the objective of this analytic study is to design a model to reduce time and complexity overload in these systems so as to provide flexible, robust and contentious system in critical conditions.

The third step has two subsets.

- First: Recognizing the general architecture:

According to the findings since 1990, agent based architectures and especially holonic models are most adaptable to large scale system requirements and characteristics including: scalability, flexibility, trustworthiness, having heterogeneous components, and distributed operation and administration, to overcoming complexity and to recognize the general architecture.

- Second: Embedding programmable features and methods in the architecture to reach model objectives.

Designers must focus on this second subset. The introduced features must have the ability to operate both the hardware and software, while each added feature has its side effects on the system. For example, adding a function to control the

critical condition may increase model complexity; therefore, there must be a trade-off between advantages and disadvantages of the features. Sometimes, the only manner to validate the quality of features is validating the whole model performance with the considered metrics.

According to researchers, of this field holonic based architecture is a set of distributed collections of interactive entities that function without supervision.

The main software features considered in the model are:

- applying a mixture of common data source and messaging between holons for data transfer throughout the model
- applying task priority for critical task handling
- applying dynamic autonomy in each holon for each condition
- applying structural and behavioral self-organization for fault tolerance and prevention of bottlenecks

These features are incorporated into the holonic hierarchy (also known as 'holarchy') in full filling the aforementioned objectives.

The fourth step is involved in structural and behavioral analysis for each independent part of the system.

Structural analysis: Here, the designer decides on the creation, placement and external interactions of holons in holarchy [43].

Behavioral analysis: Here, the designer defines the interconnections, role, and details of programming in order to accomplish the holons and system objectives [43].

Structural and behavioral analytic aspects are interdependent, and, in a complete and general model, they must be analyzed and designed in a simultaneous manner. For general models, the designer must consider the comprehensiveness of the model, and the model must not be dependent on any special system and it must have the ability to be customized for different systems and environments.

After designing the model, it must be evaluated by different real systems and the results must be compared so as to prove the assumptions.

In the following subsections, step 4 is discussed in the suggested model, and the real environments for each level of holarchy architecture are studied in a simultaneous manner: The model design process indicates how do the independent workstations/machines work and how do they reduce complexity and simplify in large scale systems. In this subsection, different methods and strategies such as self-organization in holonic based architectures for scalability are presented.

MODEL DESIGN AND ANALYSIS

In this section, a new model is designed and implemented for large scale systems (production workstations and service workstations). This model is considered as the Trihedral hierarchy in holonic organization. Models with hierarchical organization in holonic systems are named holarchy. In this model, according to the previous section, the mentioned features are molded based on agent-based architecture and holarchy organization.

Here, three levels are considered to get orders from the external environment, process orders, and schedule workstations or machines in the system designed to work on tasks to reach the final product or service which must be delivered with high quality within minimum time so as to increase system performance. The design of each level is based on the structural and behavioral analysis. To better understand this model, its design is matched with one service provider and one product provider. Special entities and are environmental challenges are considered in each test case -service provider or product provider- and explained in model matching.

The design of each holarchy level includes 4 subtitles:

- I. structural analysis
- II. behavioral analysis
- III. matching the model to an airport control systems
- IV. matching the model to a factory control systems

- First level of the model

This model is designed as the general model for large scale systems which provide products or services. For example, factories produce a variety of products; each product contains some components and each component is produced in a different part of the factory, provided that components are assembled together to make it final product as the production line output. Therefore, the system must get orders as system input and divide the orders into some sub-orders for the purpose of generation or handling.

I. **First level:** Structural analysis

In this analysis, according to previous parts, holons together with their responsibility and external level connections are defined. A holon, just like an agent, is an intelligent entity able to interact with the environment and make decisions to solve a specific problem. Holons have low dependency on other operations.

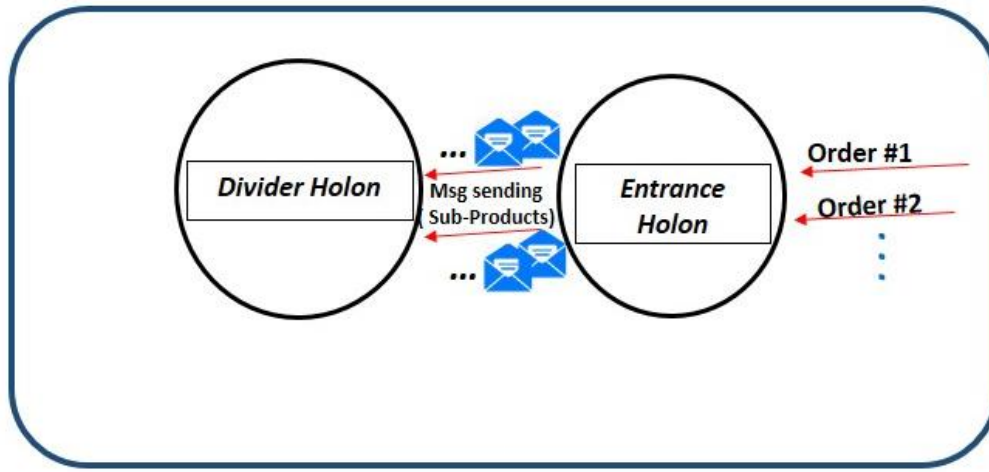


Fig. (2). First level - structural analysis.

At this level, two holons are recognized: Entrance Holon (known as “EH”) and Divider Holon (known as “DH”). The EH receives orders from the environment, break each order in to sub-orders, and send the name of each sub-order to DH receives message(s) from EH and carry out order fulfillment preparations. There is a longitudinal or transverse relation between holons in systems: in the longitudinal relation, first a holon uses the output of another holon as its input, while in transverse relation, holons are independent and try to prepare an independent part of general objective in the system so that they can work in parallel. By definition, EH and DH have longitudinal relations and DH is fed by EH output. The structural analysis of these two holons are exhibited in Fig. (2). In this exhibit, circles represent holons and arrows represent the connections in-between.

II. First level: Behavioral analysis

Behavioral analysis in each holon proceeds with defining sub-holons or functions to implement holon responsibilities. In Fig. (3), each numeric circle is a sub-holon or function which expresses a code block for programmers. Hence, numeric circles in EH includes codes to the received orders from the external environment, and breaking them up pre order to smallest atomic parts known as sub-orders. EH apprises DH of the orders by sending the sub-orders to DH *via* ACL messages. Fig. (4) show an ACL message code in this position.

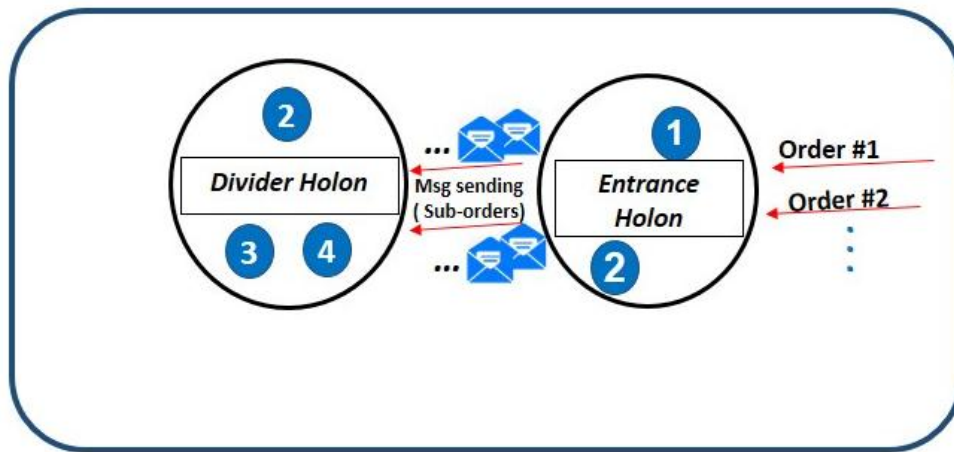


Fig. (3). First level - behavioral analysis.

```
msg.addReceiver(new AID(" DH ",AID.ISLOCALNAME));
msg.setLanguage("English");
msg.setOntology("Social-ontology");
msg.setContent("sub-order ");
```

Fig. (4). ACL message structure.

Due to the cyclic behaviors and capabilities of holons, DH has no limitation for receiving parallel orders from EH. DH receive messages from EH *via* codes illustrated in Fig. (5). Messages contain sub-orders and DH sends the name of each sub-order to the related MH. The DH can match the orders to MHs according to its knowledge of the system. Fig. (6). illustrates the DH output.

```
ACLMessage R_msg= receive();
    if (R_msg!=null)
    {
        _
        _
    }
```

Fig. (5). Receive ACL message code.

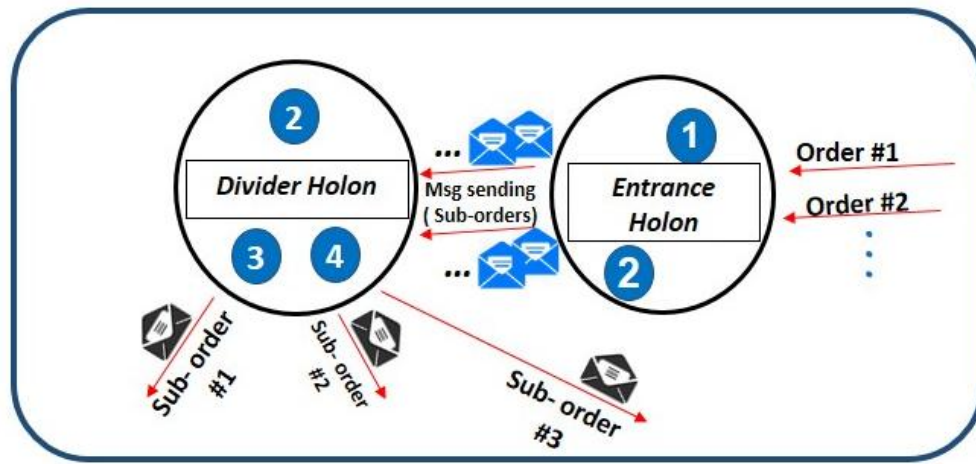


Fig. (6). First level of holarchy.

III. First level: Matching the model to an airport control systems

In order to assign the model to each test-case environment the main component must be defined, that is, in the airport environment, the concepts of agent and holon must be explained and clarified.

- **Agent:** In linguistics, an agent is a person or thing that takes an active role or exerts a specified effect. In computer science, agents are computer systems with two important abilities: at least they are autonomous in deciding to act in order to achieve their objectives. and, they can interact with other agents not by exchanging data, but through daily social activities like: cooperation, negotiation, coordination [1].

By definition, in an airport, passenger, pilot, stewardess, airplane, aircraft refueling tanker, airport gate, airport control center, and air traffic controllers all serve as agents; therefore, an airport is a multi-agent environment where autonomous agents interact with one another. While each agent attempts to accomplish its own objectives, it participates in organized interactions to contribute to the collective objective of the system. Hence, recognizing system agents is dependent on recognizing system roles and entities.

- **Holon:** A collection of independent agents subject to similar rules and connections can make a holon. A holon, just like an agent, is an intelligent entity able to interact with the environment and to make decisions in solving a specific problem. A salient attribute of holon is that it can play the role of a whole and even a part at the same time. In an airport, the airport gate and airport control center do not have direct dependency, they are independent entities that can manage their operations *via* their components and entities in an autonomous

manner. In an airport, each entity, based on its rules and limitations, is a member of a holon. For example, all employees in air traffic control have the same work protocol; therefore, each employee is defined as an agent in the air traffic control holon. Holons in the same or different holarchy levels interact with each other.

- Matching the model concepts in the airport: assume the following scenario where order number one is: Tokyo flight to Rome at 11 am, order number two is: Paris flight to New York at 12 am. EHget orders and separates them to several sub-orders or sub-services as:
 - Handle passengers when they enter airport to board the plane
 - Prepare plane for fight on time
 - Prepare airport condition like airport runway for flight

Separating sub-orders will continue until the atomic sub-orders appear, following this, EH sends each atomic sub-order to DH, which is a systemic holon and not a physical part in the airport. DH receives messages from EH and sends them to the related MH which is already informed about sub-order preparing process.

IV. First level: Matching the model to factory control systems

The model performance is evaluated with this test case in numerical manner. The model is applied workstations, scheduling in a factory which produces English words for teaching language to children. The case study applied in this work is available in details in ([36, 37]). The applied case study system is AIP-PRIMECA Flexible Manufacturing System (FMS) and includes five workstations which are linked through a conveyor system. The system is able to produce three products, namely the words “AIP”, “BELT” and “LATE”, each of which comprises of sub-products (*e.g.* the product “AIP” is composed of the sub-products “A”, “I” and “P”). The parts are assembled by the workstations according to a process plan or instruction presented for each part, (Table 1). The workstations can perform a set of operations based on their skills, (Table 2) where the processing time, in seconds, of each operation is observed. The images of products, components, jobs and relations among these elements are exhibited in Fig. (7).

Table 1. Production sequence for each type of job.

[illegible]

(Table 1) contd.....

	B	E	L	T	A	I	P
#4	Axis mounting	Axis mounting	Axis mounting	r_comp mounting	Axis mounting	I_comp mounting	r_comp mounting
#5	r_comp mounting	r_comp mounting	I_comp mounting	L_comp mounting	r_comp mounting	Screw_comp mounting	L_comp mounting
#6	r_comp mounting	r_comp mounting	I_comp mounting	Inspection	L_comp mounting	Inspection	Inspection
#7	I_comp mounting	L_comp mounting	Screw_comp mounting	Plate unloading	I_comp mounting	Plate unloading	Plate unloading
#8	Screw_comp mounting	Inspection	Screw_comp mounting		Screw_comp mounting		
#9	Inspection	Plate unloading	Inspection		Inspection		
#10	Plate unloading		Plate unloading		Plate unloading		

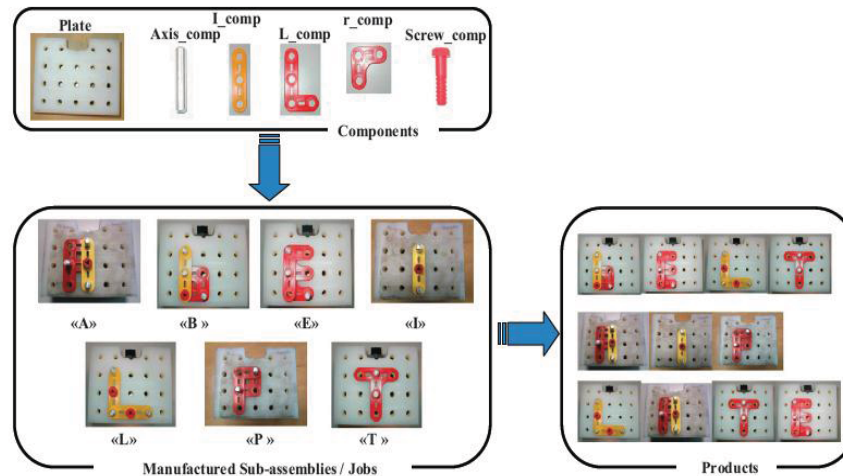


Fig. (7). Components, Jobs and Products.

Table 2. Machine skills and processing times (in seconds).

operation	M1	M2	M3	M4	M5
Loading	10				
Axis		20	20		
r_comp		20	20		

(Table 2) contd.....

operation	M1	M2	M3	M4	M5
I_comp				20	
L_comp		20		20	
Screw_comp			20	20	
Inspection					5
Unloading	10				

A product is completed if its latest job is accomplished. A client's order serves as a collection of products where each one of the products is considered a collection of jobs. In addition, each one of the jobs is considered as a set of machine tasks. Thus, the delivery due date of the order can be assigned to this total set of jobs. Experimental simulation scenarios are developed to evaluate this proposed model. In the first scenario, the system has an order consisting of two set of jobs ("BELT" and "AIP") with any perturbations. The product delivery time is computed. (According to scenario #0 of the benchmarking platform [37]).

In this model, EH holon receives the orders and sends 7 ACL messages to DH holon, each message including a letter ("B", "E", "L", "T", "A", "I", "P"), DH receives the messages and based on its knowledge of the system, sends each sub-product to one maker.

- Second level of the model

This level contains only sub-order Maker Holons, named "MH".

I. Second level: Structural analysis

Instruction of manufacturing or preparation of sub-orders depends on the system. These holons are placed on the second level of holarchy. Here, the number of MHs and the instruction in these holons are not general; they depend on the system and must be customized for the implementation environment. The relation between DH and MH is longitudinal, where output of first level of holarchy is MH input. If the preparation of sub-orders for manufacturing final order is not prioritized in the implementation environment, Maker Holons can work independently. In this level, parallel processes in MHs can reduce the delivery time for the final order so that Maker Hlons have transverse relations (Fig. 8).

II. Second level: Behavioral analysis

MHs are responsible for sequence control on sub-order preparation steps according to related instructions. The second level behavioral analysis is exhibited in Fig. (9).

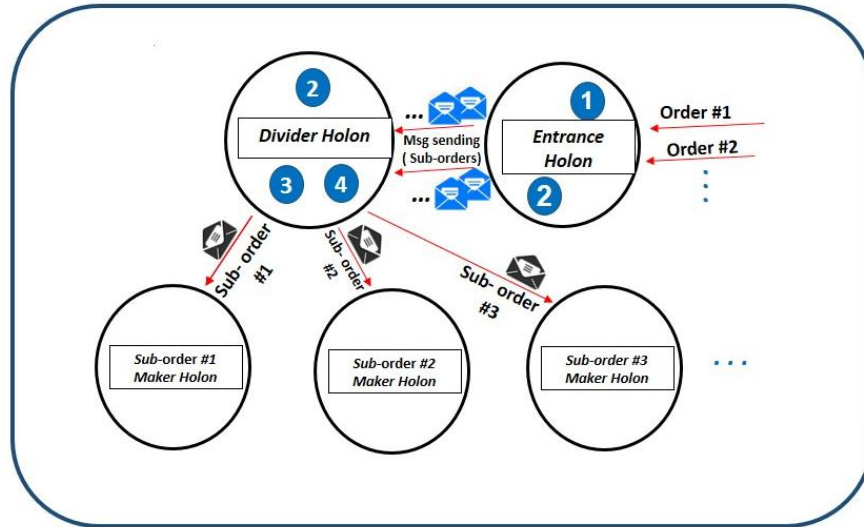


Fig. (8). Second level-structural analysis.

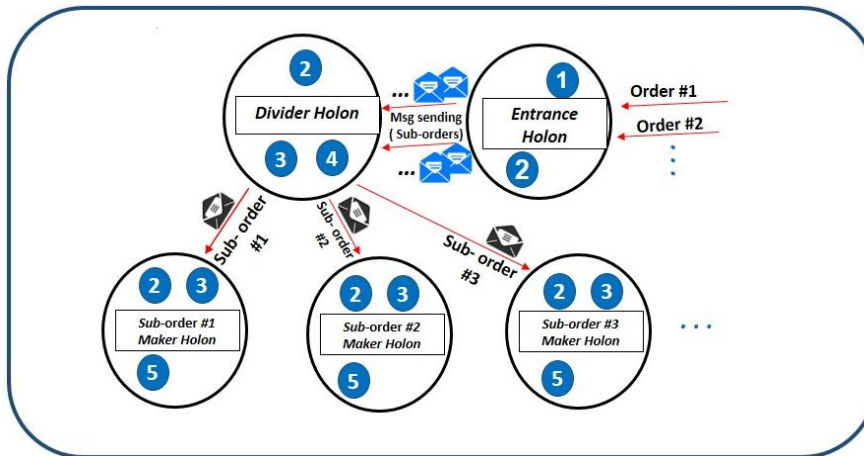


Fig. (9). Second level- behavioral analysis.

A MH receives messages from the DH, puts the first task of sub-order preparation in the common data source according to instructions and waits for one machine Controller Holon to announce the message ‘this task is performed by a machine’ in the common data source. Afterwards, this holon continues its work to the end of sub-order preparation instruction.

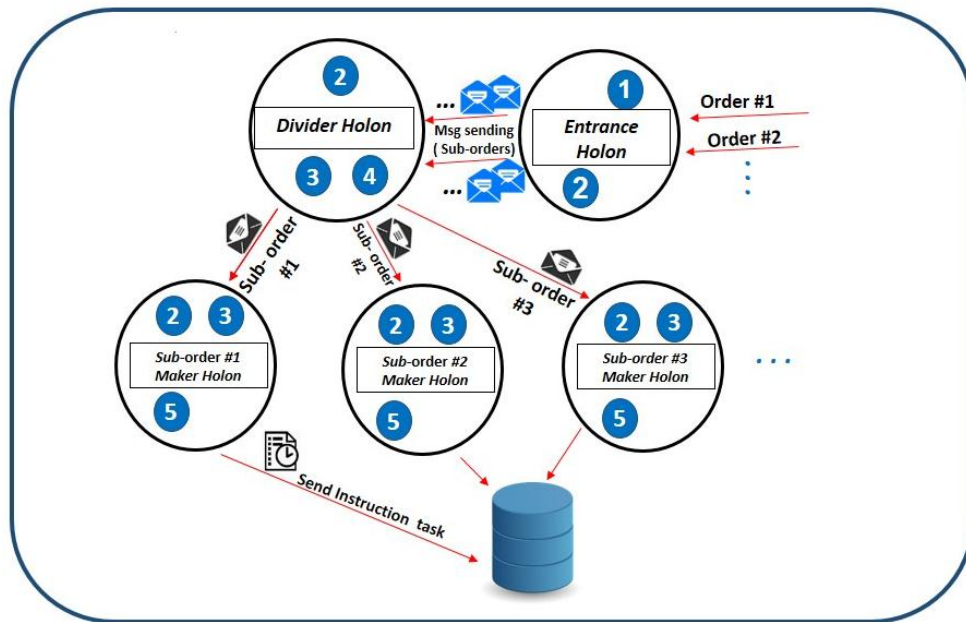


Fig. (10). Second level of holarchy.

This instruction enables this holon to make schedules and plans regarding machines and to specify input and output parameters and task implementation sequence for manufacturing sub-orders.

As shown in Fig. (9), sub-holons 2 and 3 in MH can send and receive ACL messages. Sub-holon 5 monitors the implementation steps of the instruction. The previous models send tasks to workstations for implementation [36].

In this proposed model, In contrast, MHs send tasks to the common data source, and machine controllers can choose tasks according to their skills, (Fig. 10).

III. Second level: Matching the model to an airport control system

According to the first level sub-orders in the airport, corresponding MHs are of the following types:

- Maker Holon #1: Handles passengers
- Maker Holon #2: Prepares plane
- Maker Holon #3: Prepares airport runway

Each Maker Holon has a special instruction to follow in order to accomplish the EH objective. For example, MH #1 has this sequence of tasks:

- Notifying travelers: obtain boarding pass
- Passenger ticket inspection
- Boarding pass issuance
- Baggage delivery
- Departure lounge entry
- Passengers approaching the gate
- Boarding pass control
- Boarding the aircraft

Since MHs are capable of performing parallel processes, implementation of this instruction is controlled for all passengers in a simultaneous manner. MH #1 assigns each task to the common data source and awaits task complementation through a workstation.

IV. **Second level:** Matching the model to a factory control system

In this level, MHs are responsible to produce the letters constituting words “BELT” and “AIP”; hence there are 7 Maker Holons. MH #1 produces “B” based on instructions presented in Table 1. The MH puts the first task (plate loading) in the common data source and waits for machine #1 (according to Table 2) to complete plate loading. Afterwards, MH #1 can continue doing tasks to the end of “B” manufacturing instruction. Parallel working of MH #1, MH #2... MH #7 can reduce the final delivery time. In addition, in scenarios with 2 or more “B” orders, MH #1 can prepare them in a parallel manner.

- **Third level of the model**

Maker Holons and Controller Holons have access to the common data source. The relation between the two types of holons is explained in this level.

I. **Third level:** Structural analysis

Machine Controller Holons (known as “CH”) are located in the third level of holarchy. A controller has a list of skills and abilities related to its machine. The number of controllers in a model are based on the system, environment and number of workstations. CH senses the state of its related machine as it being:

- busy or not
- broken-down or online and ready to work

The relation between CHs is transverse and they can cooperate to prepare different parts of a sub-order. The CH placement is exhibited in Fig. (11).

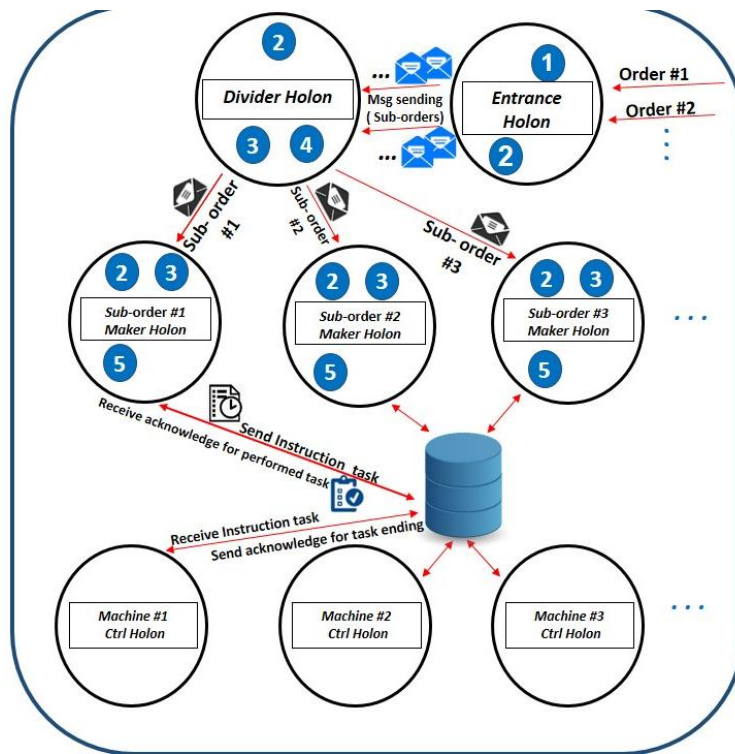


Fig. (11). Third level-structural analysis.

Due to the autonomy rate and cyclic functions in CHs, they can work in parallel and have a major contribution in critical condition control.

II. Third level: Behavioral analysis

These types of holons have the highest autonomy rate and never receive direct order or command from other holons. In this category, each holon is related to a workstation or machine in the environment and is able to command it to perform the given activity. Therefore, if the related machine is not busy, its controller searches the common data source in a continuous manner. So as to find a job fit to the machine skills. Time is the criterion for selection between 2 jobs which are matched with machine skills. Priority in a selection belongs to the task which is sent sooner to the common data source. CH selects the task and commands the workstation to prepare.

During the machine work, CH stops and is unable to pick out new tasks. This method helps the machine to work without interruption and prevents long queues of tasks. After the machine work is completed, CH sends notification to the

common data source regarding task completion. Another responsibility of CH is preventing machines with the same skills from choosing and working on the same task, (Fig. 12).

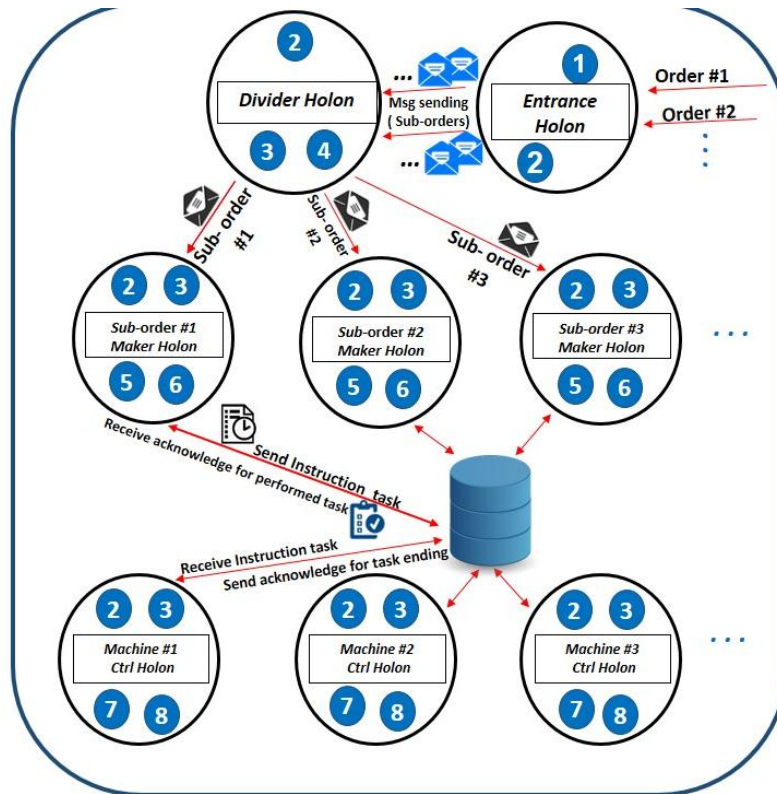


Fig. (12). Third level-behavioral analysis.

Sub-holons 2 and 3 are responsible for sending and receiving ACL messages in CHs.

Sub-holon 7: searches in the common data base and finds tasks according to this controller related machine.

Sub-holon 8: updates the common data source to notify other holons of completion of a task.

In order to follow up the instructions, MHs require sub-holon 8; therefore, sub-holon 6 is added to MHs in order to monitor the common data source and to issue notifications regarding the completed tasks of the instruction. The input, output, and behavioral and structural analysis of the first, second and third levels of this

proposed model holarchy are shown in Fig. (13). The holarchy model which is appropriate for large scale systems is shown in this figure.

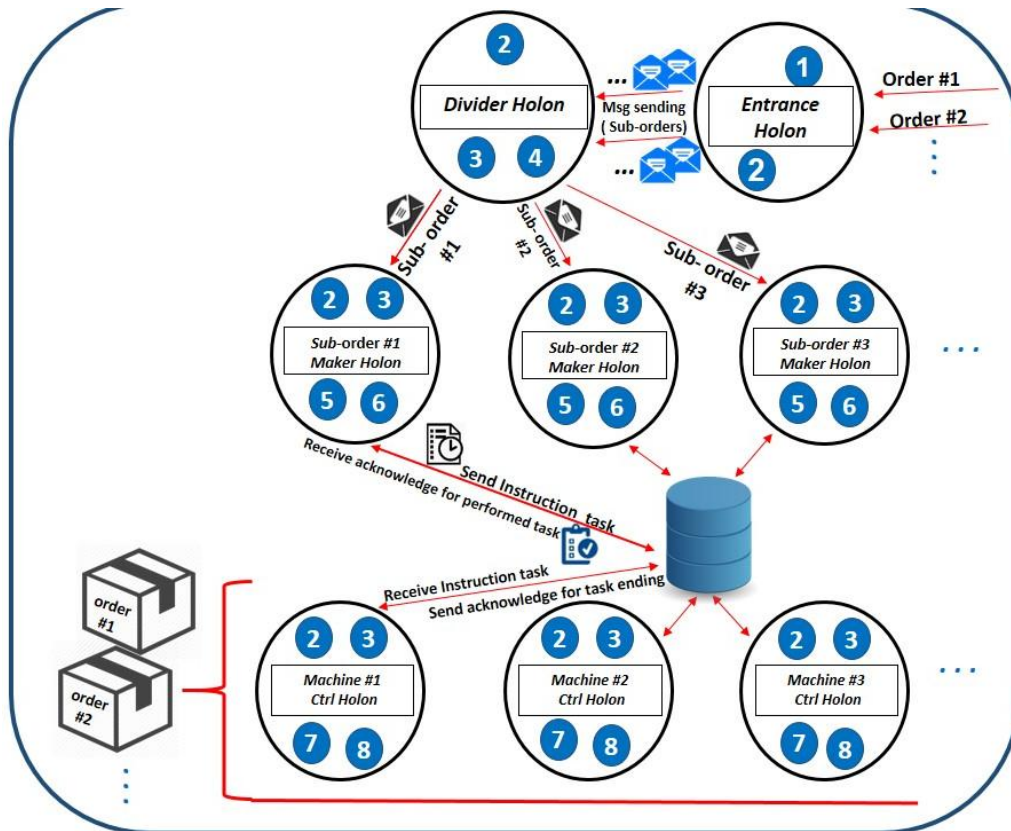


Fig. (13). Third level of holarchy.

As exhibited in Fig. (13), the output of the third level is the final orders, ready for delivery to the customer. Improving the control and scheduling plan in this model reduces system order delivery time and increases final order quality.

III. Third level: Matching the model to airport control systems

The common data source information is accessible to workstations/machines. The CHs include boarding pass issuance unit, baggage delivery unit, boarding pass control unit, *etc.* The boarding pass issuance CH, as a third level holon, runs a non-stop search in the common data source to find a task according to its workstation. As soon as the boarding pass issuance task is placed within the data

source, the first free workstation receives that task and begins performing it. When the task is completed for all the passengers, CH reports the situation in the data source and MH #1 (Handle passengers) continues instruction implementation.

IV. **Third level:** Matching the model to factory control systems

In the factory control system, “B” MH places “plate loading” as the first task of instruction in the common data source. Afterwards, as soon as machine #1 is free, its controller chooses this task and sends it to the machine. The controller stops for 10s (according to Table 2), and, if the task is completed successfully, the controller reports it to the data source and MH continues “B” instruction. This is the general process for all makers and CHs in the system. The pseudo-codes of a MH and a machine controller are shown in Figs. (14 and 15).

PREPARING THE MODEL FOR CRITICAL CONDITIONS

One of the prevalent crises in large scale systems is the machines breakdown. Therefore, this suggested model must offer a strategy to withstand this kind of crisis. Since machine controllers can sense changes in machines, they are the best holons for alarming the condition(s) to the system. In this suggested model, when a CH informs its adjacent holons (holons at the same level) of a crisis, all CH respond with messages that include their common skills of the broken machine.

Afterwards, the broken machine controller selects the most similar machine for replacement and sends the message “Delivery common tasks” to it. If the replacement holon (according to all machine skills) knows of at least one other holon which can perform the non-subscriber tasks, its own skills reduce to common skills of the broken machine. Therefore, it can perform these tasks in a professional manner. This function of the system can prevent bottlenecking. If the breakdown machine is repaired and returned to the system, its controller sends a “crisis removal” message to the replaced holon. As a result, the replaced holon reverts to its own skills in normal condition. The behavioral changes introduced to CHs to implement this strategy is shown in Fig. (16).

Sub-holon 9 is responsible for finding the best replacement for the related machine confronted with crisis. Sub-holon 10 is responsible for changing (increasing or decreasing) machine skills. This is a kind of behavioral self-organization for the system.

```

public class L_maker extends Agent{

    protected void setup() {

        addBehaviour(new CyclicBehaviour(this)

        {

            public void action()

            {

                // receive order to make sub-product from Divider Holon

                ACLMessage R_msg= receive();

                if (R_msg was not null and it was "L")

                {

                    // send message to Operator holon to insert new row in DB for this sub-product

                    Sendmessage ("Operator","L");

                    // block holon to receive row id from Operator holon

                    ACLMessage msg= blockingReceive ();

                    row_id=Integer.parseInt (msg.getContent ());

                    // control sequence stream for "L" making according to instruction

                    // each below row shows one step as DB situation during this sub-product making

                    Axis ("L", 1, row_id);

                    Axis ("L", 2, row_id);

                    Axis ("L", 3, row_id);

                    I_comp ("L", 4, row_id);

                    I_comp ("L", 5, row_id);

                    Screw_comp ("L", 6, row_id);

                    Screw_comp ("L", 7, row_id);

                    Inspection ("L", 8, row_id);

                    Unloading ("L", 9, row_id);

                }

            } //end of if message null

        } //end of action

    }); // end of cyclic Behaviour

} //end of setup

} // end of class

```

Fig. (14). Pseudo-code of a Maker Holon.

```

public class M1_Ctrl extends Agent{
    protected void setup() {
        addBehaviour(new CyclicBehaviour(this)
    {
        public void action()
        {
            Sense system situation; //for checking breakdown machines
            If machine #1 is free {
                Select a crisis/old task from common data source according to M1
                skills, which no other machine work on it;

                //to prevent other machines selecting

                Update sub-product state to "Processing";

                wait_fun (); //holon wait to end of task implementation
            } //end of if
        } //end of action
    }); // end of cyclic Behaviour
} //end of setup

    protected void wait_fun()
    {
        change state of machine #1 to "Working";
        addBehaviour(new WakerBehaviour(this, 10000) {
            protected void onWake() {
                Update sub-product's sequence number in common data source;
                // to notify for sub-product maker about "this task done"

                Update sub-product state to "Not processing";

                //to allow other machines selecting

                Change state of machine #1 to "Workless";

                } // end of on wake ()

            } ); //end of addBehaviour
        } //end of wait_fun()
    } //end of class

```

Fig. (15). Pseudo-code of a Controller Holon.

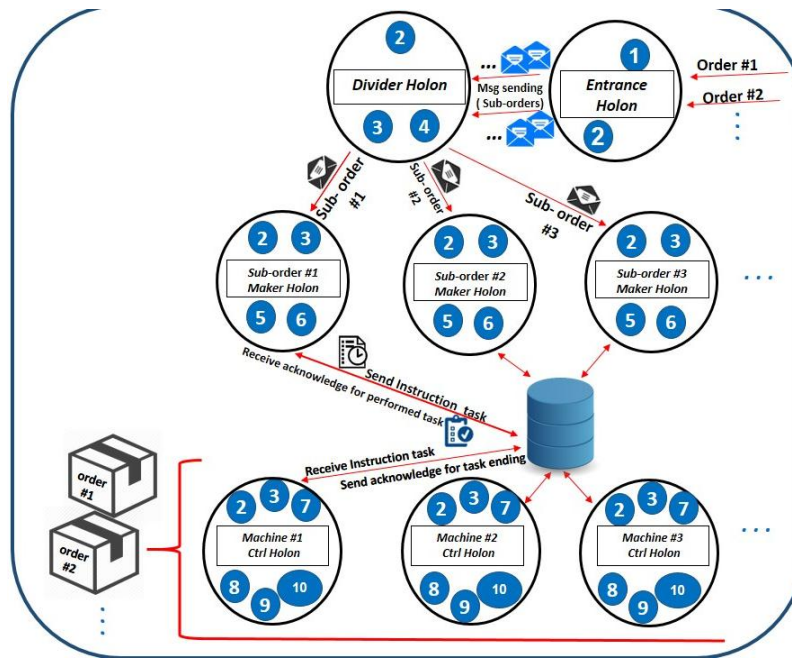


Fig. (16). Behavioral change in Controller Holons to handling critical condition.

This model supports structural self-organization, as well. Based on the following cases, the structural self-organization is essential and necessary for large and dynamic systems:

- If according to environment changes, a workstation is added to the system, its CH must be added to level 3 of holarchy
- If a workstation is going out of the system forever, its CH is counted useless and is removed from the system after a certain period of time; the CH will be removed by itself
- If the model is allowed to create new skills for machines (*i.e.* M2 skills transfer to M5), agents would be able to change their holons, thus the possibility of structural self-organization existence.

IMPLEMENTATION AND NUMERIC EVALUATION IN THE FACTORY TEST CASE

For practical reasons, the model and the test case are executed in JAVA and the agents are created by the JADE platform. The communication applies a direct interaction message exchange through the FIPA Request Protocol. The main control loop in the agents is executed by applying JADE's cyclic behavior to

increase the reactiveness of the system. The programs are tested on Intel Core i5-2410M, 6GB RAM and running Windows 7 64b.

Three experimental simulation scenarios are developed to assess this proposed architecture as follows:

- i. The system has a client order of a set of two jobs (“BELT” and “AIP”) with no perturbations. Time for product delivery is computed. (According to scenario #0 of the benchmarking platform [37]).
- ii. On the basis of the first scenario, failures occurred in workstation M2 at a rate of 25% (according to scenario #PS12 of the benchmarking platform [37]). This means that the machine would breakdown after every four runs. In this situation, the work order is affected and the subsequent ones need to be re-scheduled. In manufacturing period for “BELT” and “AIP”, at least two failures occurred and M3 tolerated all the pressure in the failure time.
- iii. In this scenario, the model applied behavioral self-organization to handle crises in the second scenario. In correspondence to the model features, the system can sense M2 situation. In each period, when M2 breaks down, according to the skills table, M3 (the most similar machine to M2 in skills) as M2 alternate, devolves Screw_comp task completely to machine #4 and reduces its duties to axis and r_comp (common skills with M2) for handling the situation. After 60s, M3 will revert to normal skills. This scenario can show the behavioral self-organization and high level of autonomy in the system.

All scenarios are implemented in full on the case study system through this suggested model as a holarchy control structure for machines and the results are recorded. In this work, the comparison between the control approaches considers the manufacturing of “BELT” and “AIP” products. The objective here is to reduce the time range to finish orders (C_{max}). A GANTT diagram for scenario#1 in its best implementation is shown in Fig. (17). There are jobs and types of operation tables as the legend on the figure. The work sequence and each task duration for M1-M5 in the system are displayed in each row of Fig. (17). This figure is comparable with Fig. (9) in the benchmark article [37].

This comparison indicates that the machines M2 and M3 have better scheduling and do not waste time in a system with this suggested model; therefore, C_{max} is reduced in this approach in the first scenario. In each execution, this suggested model present different C_{max} s due to lack of memory storage, in order to save the best sequence of handling sub-products and tasks; consequently, the maximum time in 10 executions is presented in Table 3 for each scenario.

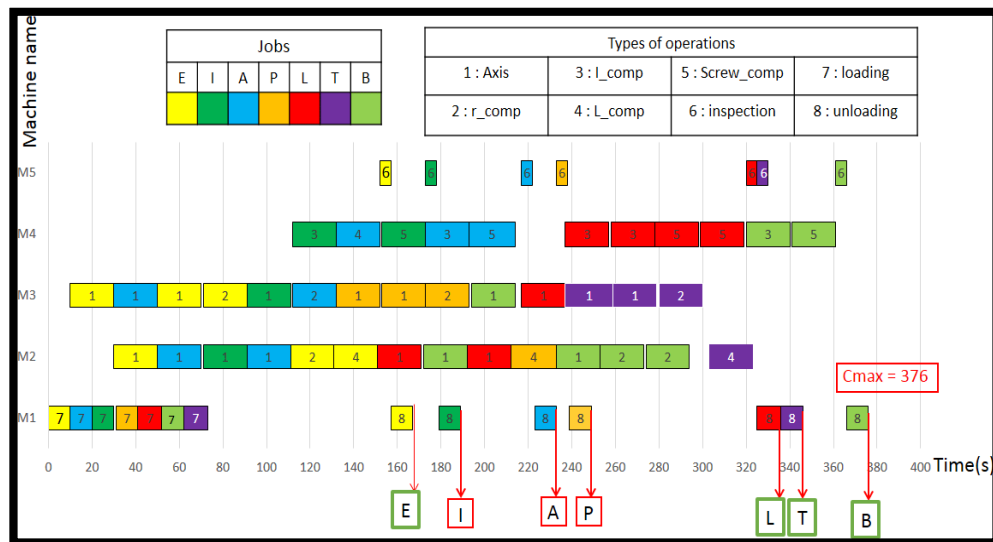


Fig. (17). GANTT diagram for scenario#1.

Table 3. Suggested model results.

	Suggested model
Cmax with no perturbations (s)- scenario#1	404.0
Cmax with perturbations (s)-scenario#2	470.6
Impact of perturbations (%)in compare with scenario #1	16.48
Cmax with perturbations (s)with behavioral self-organization	450.2
Impact of self-organization(%)in compare with scenario #2	4.34
Impact of self-organization (%) in compare with scenario #1	11.43

The results reveal that M2 breakdown effects the system performance and can increase the make span by 16.48%.

However, self-organization can change individual holon's behavior according to the external conditions and decrease the impact of perturbations to 11.43%. A GANTT diagram for a scenario with M2 critical conditions and self-organization in the best implementation is presented in Fig. (18).

The M2 breakdown and M3 activity as a replacement holon in self-organization process is exhibited in Fig. (18).

The results for each control approach in [36] and the results obtained through this suggested model in each case are tabulated and compare in Table 4. As observed, suggested model has 11.28% improvement in scenario #1(with no perturbations)

in comparison with ADACOR2. In the scenario #3 (with perturbations) where this newly proposed approach applies self-organization, it can reduce performance degradation due to M2 breakdown by approximately 3.37%.

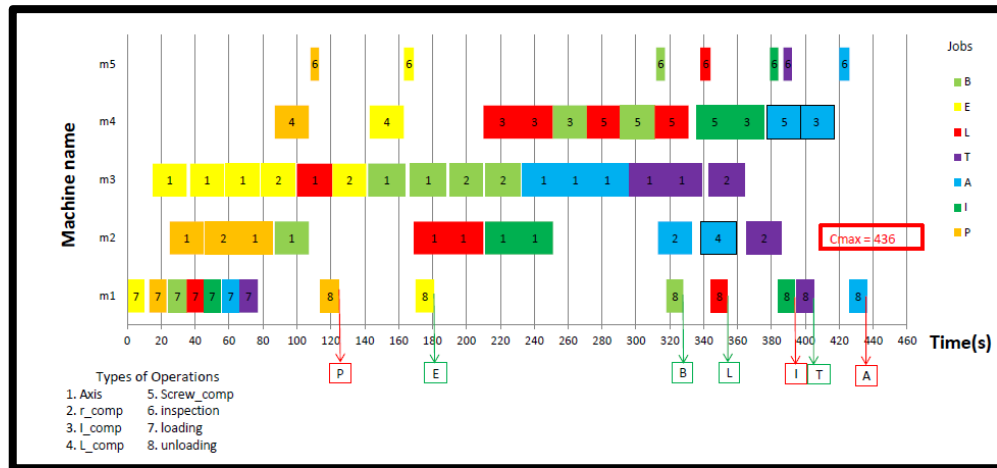


Fig. (18). GANTT diagram for scenario#3.

Table 4. Results experiments.

	ADACOR	ADACOR2	Suggested model
Cmax with no perturbations (s)	455.4	455.4	404.0
Cmax with perturbations (s)with behavioral self-organization	535.4	522.8	450.2
Performance degradation (%)	17.6	14.8	11.43

REVIEW OF PROPOSED MODEL FEATURES

This proposed model is designed to find optimized scheduling and planning for several workstations or machines in an environment. Optimized scheduling and planning has some parameters which are considered in this model as follows:

- Machine time is managed in machine activated time, where it has high performance. In other words, due to lack of proper planning, unit inactivity makes a loss for the whole system. On the other hand, when a machine is busy, there are not untimely orders to disrupt machine process.
- The system can apply maximum parallel task implementation, according to real

environment facilities and instruction limits.

- The system senses the state of each machine in order to solve machine breakdown problems.
- Autonomy level of each entity is flexible during work. It is necessary for the self-organization step to work in crisis conditions.
- Priority degree of each task can be defined. It is essential for handling orders with limited delivery time.

There are four types of holons in the proposed model:

– **Holon type I** (Entrance Holon)

It receives production orders from the environment, breaks each order into sub-orders, sends the name of each sub-order as an ACL message to holon type II.

– **Holon type II** (Divider Holon)

It receives message(s) from Entrance Holon and sends the name of each sub-order to the related MH. It can match orders to MHs according to its knowledge of the system.

– **Holon type III** (Sub-order Maker Holon)

It receives messages from Divider Holon, assigns first task to the sub-order preparation according to its own instruction in the common data source. It waits until one machine CH in common data source declares: 'one machine performed this task', after this declaration, this holon continues its work to the end of sub-order to prepare instruction. Instruction enables this holon to perform scheduling and planning regarding machines, and to specify input and output parameters and sequence of tasks implementation for preparing the sub-order.

– **Holon type IV** (Machine Controller Holon)

These types of holons have the highest percentage of autonomy and never receive direct orders or commands from other holons. Each holon in this group is linked to a workstation/machine in the environment and is able to command it to perform activity. These holons have the authority to choose tasks from the common data source according to their related machine skills, and they send notifications regarding the end of task to the common data source.

CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

A new model with holarchy structure and self-organization is designed, flexible in expected and unexpected conditions. Four experimental simulation scenarios are developed to assess this proposed architecture. The results indicate that this proposed model does not have time and complexity overload for the system. Even in the case study for scenario #1 it reduced the make span by 10.14%. The success factor in reducing make span is due to changing the data transfer method in the model and combining traditional ACL messaging between agents and the

common data source. Sometimes designers can increase the holons' or agents' autonomy and define some rules to replace the order method with selection method for them, because messaging in multi-level hierarchy is time-consuming; consequently, in environments, where work quality of workstations is the same, and there is no requirements supervisor, the common data source is useful in method selection.

This architecture can be a base for other scheduling problems.

Attempts should be made in future studies, to incorporate machine learning algorithms into this model, which would guarantee that the system uses maximum resource capacity without wasting it in every implementation. The mission is preparing an autonomous system in high level with high performance.

CONFLICT OF INTEREST

The authors confirm that this chapter content has no conflict of interest.

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CHAPTER 11

Robot-Assisted Language Learning: Artificial Intelligence in Second Language Acquisition

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Abstract: The wide spread and development of Technologies in our daily lives provides lots of opportunities for language teachers and learners to benefit though it may also result in some pedagogical difficulties. At its first stage, this chapter aimed at introducing Computer-Assisted Language Learning (CALL) as the first step in applying Artificial Intelligence (AI) to language learning and teaching; then, the new concept of Robot-Assisted Language Learning (RALL) defined both theoretically and applied to show the new trends in the educational purposes of AI.

Keywords: Artificial Intelligence (AI), Computer-Assisted Language Learning (CALL), Robot-Assisted Language Learning (RALL), Second Language Acquisition (SLA), Language learning, Language teaching.

INTRODUCTION

Shifting from a pedagogical paradigm is not always necessarily successful. Similarly, language teaching and learning have the same position. The wide spread and development of Information and Communication Technologies (ICT) in our daily lives provides lots of opportunities for language teachers and learners to benefit though it may also result in some pedagogical difficulties. Learning a foreign language (such as English, Spanish, French, *etc.*) has increased in popularity, and therefore evolved into a necessity in our communicative world. Moreover, the need to combine both technology and language has become a vital part of language scholars and researchers' jobs. The literate, communicative, and technology-based world has to accept the challenges of applying this new movement in education regardless of being either negative or positive. Several e-learning technologies are available to be used in educational contexts. Although its forms are different in different contexts based on the economical situations,

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almost all of the settings are trying to apply technologies in their educational programs to meet the demands of both learners and teachers.

The concept of “Artificial Intelligence” (AI) specified to certain software besides computer programs in general [1]. Therefore, it would not be possible to consider all the data processors programs (*i.e.* calculators) as an artificial intelligent device. The non-artificial intelligent devices are predictable based on their finite number of alternative procedures. On the other hand, artificial intelligence can learn new procedures to solve a problem by which it could be considered as a proper assistant for language teachers and learners. At its first stage, this chapter aimed at introducing Computer-Assisted Language Learning (CALL) as the first step in applying AI to language learning and teaching; then, the new concept of Robot-Assisted Language Learning (RALL) defined both theoretically and applied to show the new trends in the educational purposes of AI.

THE BEGINNING OF AI: COMPUTER-ASSISTED LANGUAGE LEARNING

Levy defined Computer-Assisted Language Learning (CALL) as “the search for and study of applications of the computer in language teaching and learning” [2, p.1]. Although the name includes “computer”, the term CALL embraces any application of Information and Communication Technologies (ICT) to teaching and learning foreign languages. Two different terms such as CALI (Computer-Assisted Language Instruction) and CAI (Computer-Assisted Instruction) were used instead of CALL before the early 1980s [3]. Around the early 1990s, alternative terms such as TELL (Technology-Enhanced Language Learning) also emerged.

The application of technology in education is not a recent story; however, applying technology in language learning is very new for language learners, teachers and scholars. Computer-assisted instruction was first used in 1950s for other purposes than language teaching. Learning from a colleague in physics [4], used the university’s mainframe for computer-assisted instruction in a French program. A computer-based diagnostic French test was reported [5]. Individual language teachers such as Rex Last and Graham Davies started to use technology for language learning purposes in the UK [6]. Richard Atkinson and Patrick Suppes initiated the best-known early CALL project at Stanford University, in the US. This project, in collaboration with IBM, was based on Atkinson’s mathematical learning theory rather than language learning theories [7]. The importance of this project came from the point that Atkinson and Suppes formed the Computer Curriculum Corporation in 1967, which continued to provide instruction in English as a Second Language [8 as cited in 6].

The Computer-Assisted Learning Exercises for French (CLEF) project began by the cooperation of three universities in Canada to teach basic French grammar [9]. The Programmed Logic for Automatic Teaching Operations (PLATO) and the Time-Shared, Interactive, Computer-Controlled Information Television (TICCIT) projects were developed to teach different languages. The former system was used for English, French, German, Spanish and Italian in 1980 [10]; and the later for those languages in addition to many others such as Arabic, Chinese, Hindi, Hebrew and Swedish. The courseware developed on PLATO system supported audio, graphics and flexible response analysis which Hart found it very successful [11].

The 1983 annual TESOL (Teaching English to Speakers of Other Languages) convention in Canada was the milestone in CALL from two aspects: 1. The CALL was the expression agreed upon. 2. A suggestion was made to establish a professional organization titled “CALICO” (Computer-Assisted Language Instruction Consortium). By that time, CALL flourished in education and market settings: a course on CALL at Lancaster University, EuroCALL professional organization, production of introductory materials, and publication of a large number of books on CALL.

Computer-assisted language learning and teaching provides students and teachers with lots of opportunities. The gradual development of the role of the technology in language courses has introduced a few different phases. Each phase relates to a certain level of technology and pedagogical level. These phases are called: behavioristic CALL, communicative CALL, integrative CALL [cf. 12 - 14]. Each phase has its own advantages and disadvantages.

Phases of CALL

Behavioristic CALL

This phase was conceived in the 1950s and implemented in the 1960s and 1970s. In that time, three main factors affected the use of CALL: (a) programmed instruction based on behaviorism; (b) the enhanced sophistication of data processing; and (c) the use of time sharing system for CALL purposes [15]. As the psychological basis of this phase declared, (according to the behaviorism) activities should be entailed “drill and practice”. In that time, the role of the computer was limited to a vehicle to deliver instructional materials to learners. Taylor stated that such function was the same as that of a tutor, where the delivered materials were repetitive language drills, vocabulary, grammar and translation tests [16]. The most famous tutorial system was PLATO which was based on a behavioristic learning pattern. Dina and Ciornei established a series of advantages for repetitive language drills and practice:

- providing whenever necessary access to the same learning material is essential to acquiring a language;
- allowing students to access the same material over and over again and offering immediate and non-judgmental feed-back every time is ideal for mastering a language;
- presenting such language materials on an individualized basis, without time keeping and deadlines, offering students the choice to study in their own rhythm is beneficial for owing a language [17 p. 249].

Communicative CALL

The second phase of CALL was based on communication. The communicative approach of teaching, as a reaction to the behavioral approach, was the prominent approach in the years 1970s and 1980s. The advocates of this approach argued that “all CALL courseware and activities should build on intrinsic motivation and should foster interactivity—both learner-computer and learner-learner” [18, p. 41]. They also put the focus on using forms rather than on the forms themselves. Among different types of programs developed during those years, computer games were the dominant and significant programs. Taylor and Pérez defined the role of the computer as stimulus [19]. This CALL approach was used for activities involving communication such as conversations, written tasks, critical thinking, *etc.* Some activities such as spelling, grammar checks and text reconstruction programs were other models of computers in the communicative phase which refer to the computer as a tool. They helped learners to learn and use the language easier. But how is it possible to evaluate an activity as communicative? Higgins and Johns declared that the courseware, which was based on text reconstruction and consisted of variations on cloze exercises, was communicative [20]. Chapelle added that:

“... variations included: “words deleted on a fixed-ratio basis, words deleted on the basis of some criteria, or all words deleted, texts that the teacher entered into the program, texts that came with the program, or texts other learners constructed; with help options and scoring, or with simple yes/no judgments concerning the correctness of the learners’ entries; with the end result begin the completed text, or the end result responses to comprehension questions about the text” [6. p. 10].

Another significant invention in the early 1980s was borrowed from corpus linguistics – computer-assisted concordance activity. The Concordancer software is used to identify words or expressions requested by the user and display them with reference to the lines in which they occurred in a text. This courseware strengthened the learner to find questions of vocabulary use and grammatical collocation on their own [6].

Integrative CALL

Moving from the cognitive view of communicative language learning and teaching to socio-cognitive, educators integrated different language skills – listening, speaking, reading and writing – into language learning. This goal was made possible by incorporating technology into language teaching and learning, too. The aim of the last phase of CALL was to overcome the obstacles of language learning and teaching, and therefore to optimize the opportunities for integrating new technologies in language classrooms. Different educators and scholars tried to find more integrated manners of teaching instead of the structure-based one. Therefore, task-based approaches tried to integrate learners in more authentic environments. Fortunately, developments and advances in technology have provided the above-mentioned opportunities. In the mid-1990s, multimedia computers and the World Wide Web (WWW) were the base of the integrative CALL. Nowadays, it is very easy for most of the learners to click a mouse to access lots of multimedia resources on the Internet. Network-based technology made the greatest contribution by which people can share information and communicate with each other whenever and wherever.

Warschauer in 2000 changed the name of the first phase from behavioristic CALL to structural CALL (Table 1). Moreover, he revised the dates as followings:

- Structural CALL: 1970s to 1980s.
- Communicative CALL: 1980s to 1990s.
- Integrative CALL: 2000 onwards [21].

In 2003, Bax proposed other three similar phases [22]:

- Restricted CALL - mainly behaviouristic: 1960s to 1980s.
- Open CALL: 1980s to 2003 (*i.e.* the date of Bax's article).
- Integrated CALL - still to be achieved [22].

For further readings on Bax's proposed phases, refer to [22 - 24].

Table 1. Phases of CALL based on [21. p. 65].

Phase	Structural CALL	Communicative CALL	Integrative CALL
Dates	1970s-1980s	1980s-1990s	21 st Century
Technology	Mainframe	PCs	Multimedia and Internet
English-teaching paradigm	Grammar Translation & Audio-Lingual	Communicative Language Teaching	Content-Based, ESP/EAP

(Table 1) *contd.....*

Phase	Structural CALL	Communicative CALL	Integrative CALL
View of language	Structural	Cognitive	Socio-cognitive
Principal use of computers	Drill and practice	Communicative Exercises	Authentic discourse
Principal objective	Accuracy	Accuracy & Fluency	Accuracy, Fluency & Agency

Applications of Technology in Language Classes

Using technology in pedagogy is important for both teachers and students. Technology can handle a range of activities and carry out programmed functions in different situations. However, technologies have not yet gotten to the point where it can make real difference in educational environments. Perhaps the most important aspect of applying different technologies in language classes is to gain computer competence. Most of the students in this study have had little or no experience with computers; some even have technophobia. But we can use more user-friendly technologies in classes.

Mobile Learning

Mobile learning (m-learning) is a kind of e-learning, which has modified the instructional methodology and learning strategies of the 21st century language learners. The instrument of this new emergence of language learning consists of mobile phones, laptops, tablets and multimedia players. According to Vavoula's definition, m-learning is "any sort of learning that happens when the learner is not at a fixed predetermined location, or learning that happens when the learner takes advantage of the learning opportunity offered by mobile technologies" [25]. Several researchers counted different features for m-learning [26 - 28]. According to Valk, Rashid and Elder, m-learning (a) improves access to education, (b) promotes learning that is learner-centered, personalized, collaborative, situated and ubiquitous [26].

Cell phones are one of the most wide spread and available devices for educational purposes which are almost available for every university student. Most of them have different functions like accessing to the Internet, working as mp3/mp4 players, digital camera and video recorder. Many of them are also Flash-enabled and/or Java-enabled and can run multimedia contents including audio and video. Among different disciplines which took advantage of mobiles we can mention the field of language learning. Today Mobile Assisted Language Learning (MALL) is moving into the field of language acquisition and is used as a device to improve different aspects of language learners' proficiency [29].

Kukulska-Hulme believed that MALL provides language learners with more learning opportunities than traditional language learning [30]. Another feature of

MALL is the connectivity. In other words, it provides the more meaningful real-context interactions [27, 25], which may lead to collaborative learning. Mobile devices have the potential of moving language learning from predominantly classroom-based learning contexts into contexts that are free from time and space and in which learning is to a larger extent defined by learners' participation, engagement and context awareness [31]. Mobile devices, such as mobile phones, enable the learners to learn from context and in context, gathering information from the environment and requiring support and assistance when it is needed. This kind of appropriate support can be seen as a form of scaffolding [32].

Literature of Mobile-Assisted Language Learning (MALL) revealed that a number of studies have been conducted on the use of mobile phones [33 - 37], PDAs [38, 28], and tablets [39]. Moreover, different language skills and component have been investigated by different scholars: grammatical accuracy [33], speech fluency [39], vocabulary [40], students' attitudes towards MALL [41, 42, 39], reading comprehension [38], idioms [28]. Song and Fox found that some learners were capable of using a mobile device to support and extend their learning in self-directed ways [43]. Michelsen suggested a self-directed and learner-centered design of mobile learning which enables second language learners to practice language by their own pace [44]. Stockwell has explored vocabulary learning on a mobile device [41]. They found that mobile phones facilitated vocabulary learning among their subjects. Several studies tried to integrate cell phones into language learning, for example using text messages to teach English language [45, 46].

Audio Files: Podcasts and RAs

One of the first tools in language classes is audio files on CDs, flash memories and other devices. Davies claims that the single piece of technology that has mostly affected language learning is the cassette recorder [47]. After the above mentioned files, today other audio files such as podcasts are available. Podcasts are audio files that are in MP3 format and can be easily downloaded from the internet. Podcast or audio blogs are downloadable broadcasts with Really Simple Syndication (RSS) feeds which allow listeners to subscribe to them [48]. Podcasting allows teachers to expand the confinements of their classrooms by delivering on-demand audio files *via* the web. Podcasts have the flexibility to be played by different devices such as laptops, personal computers, MP3 players and mobiles. Moreover, podcasts enable learners to have access to the files whenever and wherever they like. In spirit of making the most out of the technology, podcasting became popular in late 2004 [49]. It is a new way in teaching languages and provides better materials [50 - 52]. The major difference of traditional Internet audio or radio broadcasts is that podcasts can be listened

whenever and wherever the user prefers. They are also automatically delivered to subscribers [53, 54].

Real Audio (RA) is another audio file that may help us in language classes. Nunan believes that allowing students to choose the information they will listen to or watch is inherently motivating [55]. Tuzi in a study mentioned that “RA sound clips are intrinsically motivating as the materials themselves are of interest to the students” [56]. He also claimed that RA has some benefits to students such as:

“...listening to information that interests them, listening to sound clips over and over again, listening to a variety of voices which strengthens listening ability, being encouraged to become more independent learners, listening to spontaneous speech, and reading and listening at the same time” [56].

Internet & Web 2.0

The Internet has become a very powerful tool in our daily life. Using email, weblog, social networks, *etc.* has become a vital part of modern life. This amazing invention becomes popular in education, too. With the widespread use of the Internet, many online tools are increasingly available for using in educational and non-educational settings. In view of the need for CALL researchers and practitioners to find, choose, use and evaluate educational tools for further development and implementation of CALL, it seems fruitful to introduce new and useful tools that can be used for language learning and teaching.

Bicknell stated that the Internet and its applications can act as a motivational apparatus which gives students the chance to use all four language skills [57]. The Internet also allows students to connect with each other in ways they normally would not be able to do so. Web-based activities such as message boards, chat rooms, email, and discussion groups provide learners with a healthy forum to communicate. The above activities give learners a direct and immediate communication between peers while using genuine language. Psychologically, Warschauer and Whittaker noted greater participation by the so-called “shy” students when using the Internet as a language-learning tool [58].

Internet Communication Tools

Communication tools enable students and teachers to make audio and video calls on the Internet. By these tools, it is necessary for users to have a microphone and audio capabilities. Some scholars used the Internet communication tools in their education [59, 60]. One of the main features of these tools is cross-cultural exchanges with other students in different countries. Eaton believes that Skype, a

proprietary Voice over IP service and software application, can be used to provide a variety of authentic learning experience to students [60].

Emails

Email as one of the Internet-based devices, “the mother of all the Internet applications” [61] has been under investigation by so many scholars finding it a useful device in education [62 - 67]. Wilkinson tries to encourage other teachers to introduce e-mail into their classrooms by giving the most basic guidelines for teachers and students, together with the URLs of places to find teacher partners to set up a successful e-mail connection [67]. Nagel deals with more advanced issues connected with the use of e-mail in teaching, and specifically with how to be most effective and to get optimal results in the use of e-mail as an instructional tool [68]. According to Gonglewski, Meloni & Brant [69], emailing has so many benefits in pedagogy as it:

“...extends language learning time and place, provides a context for real-world communication and authentic interaction expands topics beyond classroom-based ones, promotes student-centered language learning, encourages equal opportunity participation, and connects speakers quickly and cheaply” [69].

Concordancing

Hasselgård defined that corpora, plural form of 'corpus', refer to electronic authentic language databases that can be available *via* the Internet or as software installed on desktops [70]. A concordance is a list of the occurrences of either a particular word, or part of a word or a combination of words in context and it is drawn from a text corpus, which is presented in context. A corpus is a large body of text often in electronic format [71, 72]. Nowadays, concordancing is a tool that has been used by teachers, linguists and researchers in different disciplines as it provides authentic context. There are some free online resources on the Internet such as British National Corpus (BNC), Virtual Language Center (VLC), and the International Corpus of English (ICE). Moreover, Gaskell and Cobb believe that learners can also use concordance feedback for writing errors [73].

Weblogs

Godwin-Jones describes weblogs as “one, large, loosely interwoven net of information, as blog entries are linked, referenced, and debated” [74]. Weblog is another useful device that has some features such as interactivity, collaboration and achievability. The number of educational blogs soars in recent years. Some papers are published and presented about the potentiality of weblogs in education [76, 74].

Word Clouds

“Wordle” is a kind of data visualization tool. Data visualization tools as devices which are used for representing information in the form of charts, maps, tag clouds, animation or any graphical means that make content easier to understand [75]. Friendly mentioned that data visualization serves as a way to communicate information clearly and effectively through visual representation [77]. These tools can help make the understanding of complex concepts easier because they provide data in multi aspects incorporating visual, textual animated input and *etc.* Wordle.net is a useful web 2.0 tool as an English for foreign or second language (EFL/ ESL) classes which enables teachers and students to provide word clouds for language classrooms. Tafazoli used some techniques for teaching different language skills and components in which teachers benefit from and use them in their classes [78].

Video Files: Video clips and Vodcasts

Using films in classes has been a popular method of teaching for many years. Some research papers reported the positive effects of language learning with video clips [79]. Naturally, watching full-length films is not always the best approach [80]; rather, it is a way to spend classroom time with our students. By the way, it is possible to bring some movies and trailers into classrooms. Vodcast is a combination of “vod” and “cast”. Vod is an acronym for “video on demand” and “cast” stands for broadcasting [46, 81]. Vodcasts are posted on the Internet and can be played back on mobiles, personal computers, or laptops. Vodcast, that is called video podcast, has one advantage over podcasts and which is its ability to connect visuals to audios. Vodcasts as well as podcasts have potential to support learning in a range of settings and across multiple disciplines. Kargozari & Tafazoli in a study claimed that the use of vodcasts is a valuable means of instruction [46]. Students had access to the material of instruction whenever and wherever they like. Wahab and Ghafoor find vodcast as a medium which motivate students in enhancing their listening and speaking skills [81].

Video Games

New technologies have changed the ways of playing games. Nowadays, video games are substituted traditional games all over the world. In contrary to the traditional games, nowadays, video games are more than simple means of entertainment. One of the sub-categories of video games is educational video games. Adams stated that “educational video games are considered a type of serious game, as these games have a strong purpose other than pure entertainment” [82]. The educational video games are a combination of education and entertainment; thus some people call these types of games “edutainment”.

Recently, the shift of video games from pure entertainment to educational device has changed the attitudes and views of people towards video games, in view of the fact that video games have historically received more criticism than other forms of recreational learning because they are often perceived issues such as mindless entertainment, enhanced social recluse, sexism and consumerism. Today's children can benefit from educational video games because they are already exposed to a society with vast dependency on digital technology. Playing video games seems to be a detachable part of every child's life. Although there is a tendency towards using new technology in language classes, there is a less tendency towards video games. Some teachers believe that video games are time consuming and they are not very efficient tools. Game-Based Learning (GBL) refers to different kinds of software applications that use games for learning or educational purposes. In recent years, there has been a growing interest in doing research on the potentials of computer games as learning and teaching tools as well as their use. So many studies supported the applications of video games in language classes [83, 84].

Integrating game-based learning into more coherent view of learning relies upon two factors: (a) preparation of learners to adapt to a new learning tool, and (b) institutional support. Oblinger says "Games also offer advantages in terms of motivation. GBL has this ability to integrate different cognitive tools, such as discussion forums, bulletin boards and concept mapping software" [85]. Whitton stated that "games researchers tend to be highly motivated to play games themselves, and do not consider those individuals for whom game playing is not motivating, or indeed is actually demotivating" [86].

Merits and Barriers of CALL

Nowadays, CALL is gaining more popularity in language learning and teaching. Different scholars considered several merits and barriers for applying CALL, but most of them have the same items [14]. Warschauer and Healey mentioned different beneficial aspects of CALL: 1) multimodal practice with feedback; 2) individualization in a large class; 3) pair or small group work on projects; 4) the fun factor; 5) variety in the resources available and learning styles used; 6) exploratory learning with large amounts of language data; and 7) real-life skill building in computer use.

On the one hand, Cabrini Simões mentioned some advantages of applying the technology, mostly the Internet, in language education [87]. According to this paper, teachers have the opportunity to draw students' attention by using sounds, images, colors, different types of letters *etc.* Thus, it helps the students to visualize the contents in a better and more efficient way. Also, technology allows learners

to participate in the culture of the target language, which in turn can enable them to further learn how cultural background influences one's view of the world [88]. Moreover, students not only have access to other people's work, but they may also generate their own work to be published [88]. Furthermore, students may use the Internet to search for additional language activities [88]. It also mentioned that the use of the Internet has also been shown to promote higher-order thinking skills. The Internet may increase student's motivation [89]; and the Internet provides greater interaction [89]. There are some activities in the Internet that give positive and negative feedbacks to students by automatically correcting their on-line exercises [89]. From the larger perspective, the Internet provides global understanding [89]. Also he noted that, exchanging e-mail provides students with an excellent opportunity for real, natural communication [90]. Finally, the Internet allows students around the world to interact with one another cheaply, quickly and reliably [87. pp. 31-33]. On the other hand, sometimes it may take time to access information [88]. Also, lack of training on the part of the teachers to implement the Internet in the language classroom is another negative factor [88]. Moreover, the Internet offers access to all types of issues and topics, some of which are unsuitable for children which may cause various problems [88]. The lack of infrastructure and/or facilities is a barrier for implementing technology in language classes [91]. Finally, surfing the net can be fun and/or time consuming [91. p. 33].

Han stated that: a) CALL programs could offer second language learners more independence from classrooms; b) Language learners have the option to study at anytime and anywhere; c) CALL programs can be wonderful stimuli for second language learning; d) Computer can promote learning interaction between learners and teachers; e) Computers can help classroom teaching with a variety of materials and approaches [18. pp. 41-42]. Han further identified some negative points: a) Financial barriers are the main outstanding problems; b) Computers cannot handle unexpected situations due to technological barriers; and c) Both teachers and students need training to learn how to use computers [18. pp. 42-43].

AbuSeileek and Abu Sa'aleek mentioned that: a) computers can facilitate a variety of learning tasks, and have enormous potency as teaching tools [92]. They can help both the students and the teachers because of their special properties [93]. b) Software vendors (and language teachers) no longer feel bound to grammar practice as the main goal of computer use in the language classroom [94]. c) Computers are good to motivate students. d) Students' learning becomes more individualized and autonomous. e) The computer provides a platform for communication between teachers and students. f) The teaching resources can be stored for a longer time and shared by other teachers and students. g) Language learners have the option to study anytime and anywhere. h) CALL programs can

be wonderful stimuli for second language learning. i) The computer can promote learning interaction between learners and teachers. j) The random access to Web pages would break the linear flow of instructions. And k) CALL programs, besides teaching a foreign language, will provide the learner with some sort of computer literacy [92, 94]. On the contrary: a) CALL requires computers and software as well as other equipment all of which are expensive [94]. b) Computers can only do what they are programmed to do. c) Both teachers and students need training to learn to use computers. d) Some students can never really adjust to using computers. And e) Computers cannot handle unexpected situations due to technological barriers [92. pp. 30-32].

Wang mentioned three advantages for network English teaching. In this study, creating a better English communicative environment for students, improving the efficiency of class teaching, and improving the teaching mode are the main beneficiary points for network English teaching [93. pp. 155-156]. The researcher also mentioned key disadvantages of this mode of teaching like financial barriers, students' difficulty in adapting to this new teaching mode, and some English teachers' vexation [93. pp. 156-157].

Based on Shyamlee and Phil's study, language teachers should use technology to: 1) cultivate students' interest in study; 2) promote students' communication capacity; 3) widen students' knowledge to gain an insightful understanding to Western culture; 4) improve teaching effect; 5) improve interaction between teacher and student; 6) create a context for language teaching; and 7) provide flexibility to course content [95. pp. 151-153]. Whereas, language teachers should not use technology as: 1) major means replaced by the assisting one; 2) loss of speaking communication; 3) the restriction of students' thinking potential; and finally 4) abstract thinking replaced by imaginable thinking [95. pp. 153-154].

In another review study on the advantages of technology in language education [96], considered the followings based on other studies: a) Technology increases students' motivation [97, 14, 89, 98]. 2) Technology improves language learners' academic ability [97]. 3) Technology makes a shift from teacher-centered to learner-centered approaches in language learning and teaching [98]. 4) Technology enables learners to assess their own work in a more meaningful way, become better aware of the quality of their work and accept feedback more willingly [98]. 5) Technology provides the encouragement of collaboration and communication in learning activities [99, 100]. 6) Technology has the potential to lower anxiety among learners [2, 6, 101-102, 96. pp. 25-26]. Quite the opposite, 1) lack of access to technology resources that requires an Internet connection [103]; 2) financial barriers [104 - 106]; 3) lack of teacher training, lack of knowledge and practice [107, 108]; 4) teachers' [negative] attitude [109 - 113]; 5)

students' [negative] attitude; and 6) lack of time and technical support [114 - 116] are the disadvantages of technology in language education [96. pp. 26-27].

In a recent paper, Dina and Ciornei mentioned that: a) computer can promote language interaction between teacher and learners; b) it offers the possibility to simulate some processes and phenomena in motion through animation, and thus some experimental demos; c) methods and manners of organizing efficiently and modern the educational / learning process; d) getting used to computer technology from an early age influences students intellectual development; e) it offers the possibility of realizing a string of didactic operations which are very important for evaluation, and also for developing students creativity [17. p. 251]. However, a) deterioration of the teacher role in the learning process; b) division in small sections and well delimited of content leads shortening the matter, favoring those students with analytic thinking, but not those with synthetic thinking; c) controlling step by step students mental activity by the teacher stops them from developing creative abilities and entrepreneur spirit and initiative; and d) excessive individualization of learning can lead to denial of the teacher – student dialogue and leads to the isolation of the learning process from its psycho – social context, are mentioned as the barriers of CALL [17. p. 251].

THE NEW BEGINNING OF AI: ROBOT-ASSISTED LANGUAGE LEARNING

Whereas the development of educational robots is still in its first places, different scholars have investigated the applications of robots in education [117 - 119]. After validating the use of robots for engineering and technical fields such as mathematics and physics [120], science [121], technology, and engineering [122 - 125], a new term called “robotic revolution” coined for the same application, but for non-engineering and non-technical fields [126]. Cooper and his colleagues found robots suitable for disabled students in which “robots can be enabling in themselves” [120]. Disabled students would be benefits from robots by enabling them to undertake a wide range of tasks. Moreover, robots provide equal opportunities for disabled students to participate with peers in learning activities.

Investigation of Harwin, Ginige and Jackson based on the RTX robot showed the advantage of robot-based system in compare to a software simulation in a structured teaching context for students with special needs [127]. Weinberg and Yu offered three important factors which made the robot a distinguished vehicle for supporting education [128].

Robots are the physical representative of computations; therefore they provide special learning experience for students. According to Chang *et al.*, robots “provide a wide design space for students to explore, to make hypotheses about

how things work, and to conduct experiments to validate their beliefs and assumptions. Students can receive strong, visceral feedback from physically experiencing their work” [129, p. 13]. Another factor is the cost of robots. Marín *et al.* believed that it is possible to equip schools with robots even with modest budgets [130]. The last factor is the “plug-and-play feel” of the new robot platform [129].

The literature of application of robotics in education shows a demand for using new technologies in educational system. However, the value of this application in language learning and teaching is not rich enough.

Characteristics of Robots

Chang *et al.* [129] counted some common characteristics in robots which might facilitate language learning and teaching: 1) repeatability; 2) flexibility; 3) digitization; 4) humanoid appearance; 5) body movement; 6) interaction; and 7) anthropomorphism. Repeatability helps teachers to practice more oral activities with their students. Teachers benefited from flexibility of robots by designing their own materials. This flexibility does not limit them to a specific material. Saving digital data such as teachers’ performances and activities in the classroom, and also designing different tasks and data based on the digital nature of robots are other advantages of robots for learning and teaching. Humanoid appearance of robots might motivate students to practice language skills in a more natural way. Gestures as a metalinguistic feature of a language help a more effective communication. Gestures of robots are other beneficial factors of RALL which teach learners how to use their body movements in conveying the message. Interacting with humans is one of the vital functions of robots by which teachers and students might easily interact with robots in a role of a teaching assistant or a classmate. Being aware that robots are not real humans might reduce their anxiety and improve their willingness to communicate in the target language.

A comparison of different types of robots in educational research provides two categories of non-humanoid and humanoid robots. Non-humanoid robots are less expensive, simple and easy to use for creating interesting interactions. These robots are in different forms such as animal, car, toy, *etc.*; and in some cases they perform better than humanoid robots. Non-humanoid robots are animal and non-humanoid mobile robots. Animal robots look like pets. Although they generate strong interactions, they do not mimic human-human interactions like Pleo. Other non-humanoid robots are non-humanoid mobile robots which are able to complete specific tasks. Moreover, they do not attempt to correspond to any living form; also they cannot imitate human-human interactions like Labo-1 [131, 121 p. 4356]. On the other side, humanoid robots are more expensive and more

complicated; and they may engage learners in imitation activities. Humanoid robots are android, mascot, and mechanical robots. Android robots look like humans, but remain predictable and repeatable like FACE [132]. Mascot robots are those with cartoonish appearances but with a humanoid form like Keepon [133]. Mechanical robots are built with humanoid form, but with visible mechanical parts; therefore, the focus of the learners would be on the mechanical parts rather than the interactions like Infanoid [121, p. 43 - 56, 133].

Theoretical Framework of RALL in SLA

Applying a new phenomenon in Second Language Acquisition (SLA) should be rooted in its methodological principles. To justify the proper and suitable applications of RALL in SLA different beneficial aspects of this vehicle in SLA methodology were considered. In Audio-Lingual Method (ALM) the focus was on memorizing and manipulating the target language grammar through manipulating, substituting, transforming and applying drills [134]. According to this method, students should spend a huge amount of time on active oral practice. As Celce-Murcia [135] puts that: “new materials presented in dialogue form. Mimicry and memorization are used. Pronunciation is stressed from the beginning”. These features of ALM are in line with the RALL in which the robots could lead students to recite vocabulary and sentences. Furthermore, students can imitate the pronunciation, intonation, and the rate of speaking of the robots.

The Robot-Assisted Language Learning (RALL) might be supported by the Total Physical Response (TPR) method proposed [136]. In this method, Asher [136] emphasized on acting based on imperative utterances. The association of the forms and the physical activities shows the meaning of the utterances [134]. In RALL context, robots can act as a teaching assistant or a classmate in performing the commands of the teacher.

Communicative Language Teaching (CLT) is a methodology which focuses on helping students to communicate meaningfully in a target language. Another option of RALL is individual- and group-chat situations for learners. In the individual-chat situation, a robot can chat directly with a student; and the student assumes the robot as a foreign student. It is the same for group-chat situation in which, the robot might join a group of students and chat about a specific pre-programmed topic.

Moreover, the focus of communicative and Task-Based Language Teaching (TBLT) approaches is on guiding learners to communicate and to do meaningful tasks using the target language [137], such as visiting a doctor or writing an application form. Littlewood's paper concerned with some affective factors in using TBLT in language classrooms like class management, avoidance of English,

and minimal demands on language competence [138]. Acting as a stimulator, manager or foreign student in TBLT activities might reduce the above-mentioned problems [139].

Finally, Papert proposed “constructionism”, a theoretical framework, based on the theory of intellectual development by Piaget. Papert’s definition of constructionism is “the actual concrete design and construction of a project is the basis upon which students learn, and technology can provide opportunities for this design and construction” [140 as cited in 123. p. 7].

Applications of RALL

Robovie is a humanoid robot which is designed by Kanda and associates [141] in order to act as an English peer tutor for Japanese elementary students. Although in their study Robovie did not improve students’ English speaking and listening skills, it motivated students to learn. After obtaining such a great funding, they conducted another research study in 2005. This study showed that a humanoid robot can teach students. The findings of this study, based on the interaction between the robot and students, revealed that there was a positive correlation between frequency of interacting with the robot and learning performance.

IROBI is a teaching assistant robot in Jeonghye and colleagues’ research [142]. His job was to help instructors to present material *via* a monitor in the belly. To benefit from gestures, IROBI moves his arms to point to students and the monitor. This study aimed to compare the effects of non-computer-media and web-based instruction with the effects of RALL for children. They concluded that RALL improved learners’ concentrations, interest and academic achievement.

Sapien is a robot used by Chang *et al.* in an elementary school in Taiwan for five different teaching modes. These teaching modes include storytelling, oral reading, cheerleader, action command, and question-and-answer modes. This study aimed to investigate the teachers’ opinion and students’ reactions to RALL in the above-mentioned modes. Although the findings of the study revealed that “robots could create an interactive and engaging learning experience” [129. pp. 21-22], the extended use of language instructional robots faced many challenges and limitation. These challenges and limitations include “lack of adequate teacher training, complicated technologies, decaying motivation, and the inability of robots to adequately portray emotion” [129. p. 22].

Mero, a head-only robot, and Engkey, a penguin-like robot, are designed with expressive faces, and have typical face and speech recognition systems for communication in Lee and his colleagues’ study [143]. These two robots have Human Robot Interaction (HRI) features such as automatic speech recognition,

language understanding, dialog management, and emotional expression. Their study was on 21 English elementary students in Korea in order to investigate the cognition effects of the RALL approach on their oral skills. The findings showed no significant difference in the listening skill, but the speaking skill improved. Moreover, the study confirmed RALL as an enjoyable and fruitful activity for Korean language learners.

Nao, a CRR robot, showed that teaching to a robot cause to achieve effective learning and to maintain the interests of the learners at the same time. The Care-Receiving Robot (CRR) is a robot that in contract to other robots receives attention, instruction, cooperation and help from its human user [144 - 146]. In these kinds of robot, the learner's educator or even the parents decide first decide the topic to be learned; then, the learner teaches the topic to the robot. After that, making mistakes purposely by the robot invokes a caretaking response from the learner. This caretaking response would be teaching the topic. This teaching provides the possibility of learning by the learner – learning by teaching. Matsuzoe and Tanaka applied Nao for teaching English to 19 Japanese children whose ages were ranged from 4-8. To meet their end, they introduced three modals of CRRs: a CRR that made no mistake, a CRR that had the ability to learn, and a CRR that did not have the ability to learn, and compared their effects on children's learning [147. p. 340]. The results of this study revealed that the slow-minded CRR had smaller effect on the participants' learning new English words. Moreover, the CRR that had the ability to learn could engage the participants' interests in the learning subject [147. pp. 343-344]

CONCLUSION

Robots may be a vital supplementary tool for English language teaching and learning, however, we have to consider all the aspects of using RALL in our classes. Considering technology's double face is the key factor in applying new technology in our classrooms [148. p. 41]. We have to pay attention to technocentrism and the lack of experimentation in applying CALL [149. cited in 148. p. 46]; and RALL. Warschauer and Whittaker gave some suggestions for successful planning and implementing technology in language courses [58]. They believed that teachers should carefully consider their goals, since little is gained by adding random on-line activities into the classroom. Clarifying course goals acts as an important first step toward the successful use of technology in classrooms. The next vital aspect of the technology-based instruction is integration, and the teacher should think about how to integrate technology-based activities into the syllabus. Also, the teacher should be aware of all the complexities of using technology in learning environment, such as cultural, infrastructural or structural difficulties. According to CALL advantages, it is not

logical to judge CALL as a substitute for language teachers, but we have to consider technology as the vital supplementary tool in language classes. Technology offers learners opportunities for much more valuable communicative interaction in the target language than what was ever possible in the traditional language classes [150]. We would urge language teachers to make use of technology in their language classrooms. Having such projects are good way of motivating students to use technology outside the classroom and to make learning a part of their daily lives. Although it is to some extent impossible to present all RALL advantages and disadvantages in a paper, this paper has reviewed a range of projects, papers and studies on CALL and RALL. The researchers believe that choosing, planning and applying the RALL courseware will be provided wide range of opportunities for language teachers and learners.

The findings of the present chapter can be looked upon as a general driving force to the educational policy makers to allocate more budgets on providing state-of-the-art RALL in schools and universities. In addition, course designers can benefit from the outcome of the present study by allocating more artificial intelligence-based activities in schools and universities curriculum.

We have to be careful that technology cannot change the role of teachers, but it is used to support and assist teachers and learners in different situations. Technology offers learners opportunities for much more valuable communicative interaction in the target language than what was ever possible in the traditional language classes.

CONFLICT OF INTEREST

The authors confirm that this chapter content has no conflict of interest.

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