UNIVERSITY OF SOUTH CAROLINA

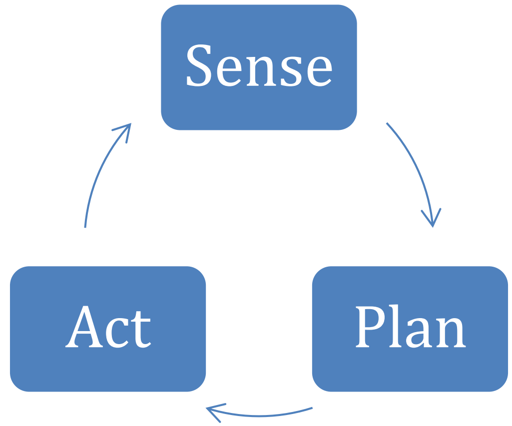
CSCE 574 ROBOTICS

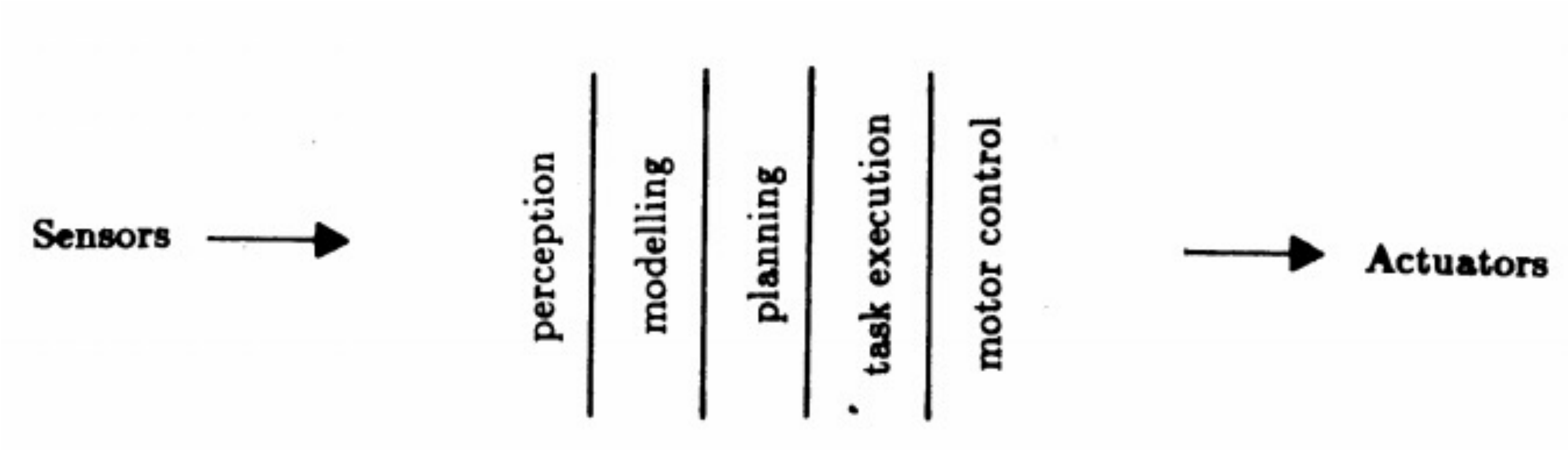
Research Robotic Software Design, Development, and Testing

Alberto Quattrini Li
albertoq@cse.sc.edu

Main Robot Architectures

- Deliberative
  - Top-down approach

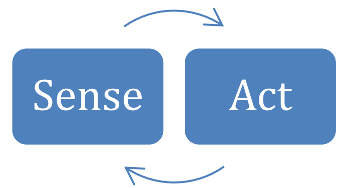


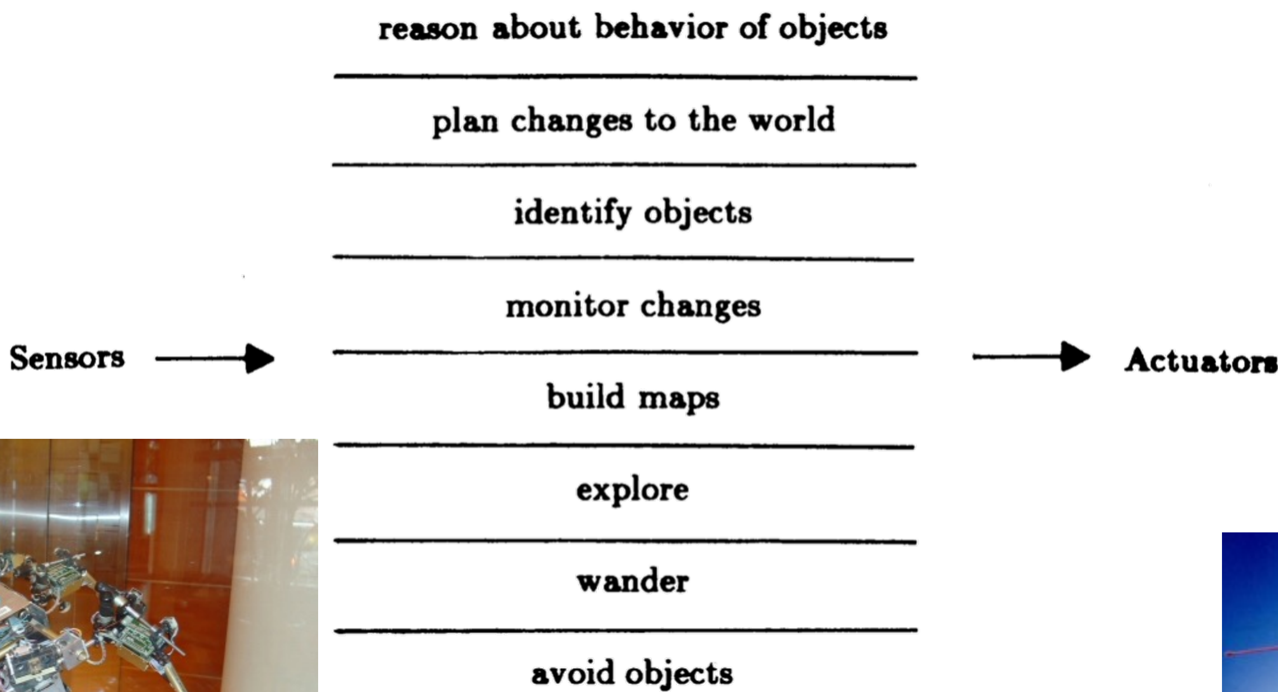


Source: [Brooks, 1985, MIT]

Main Robot Architectures

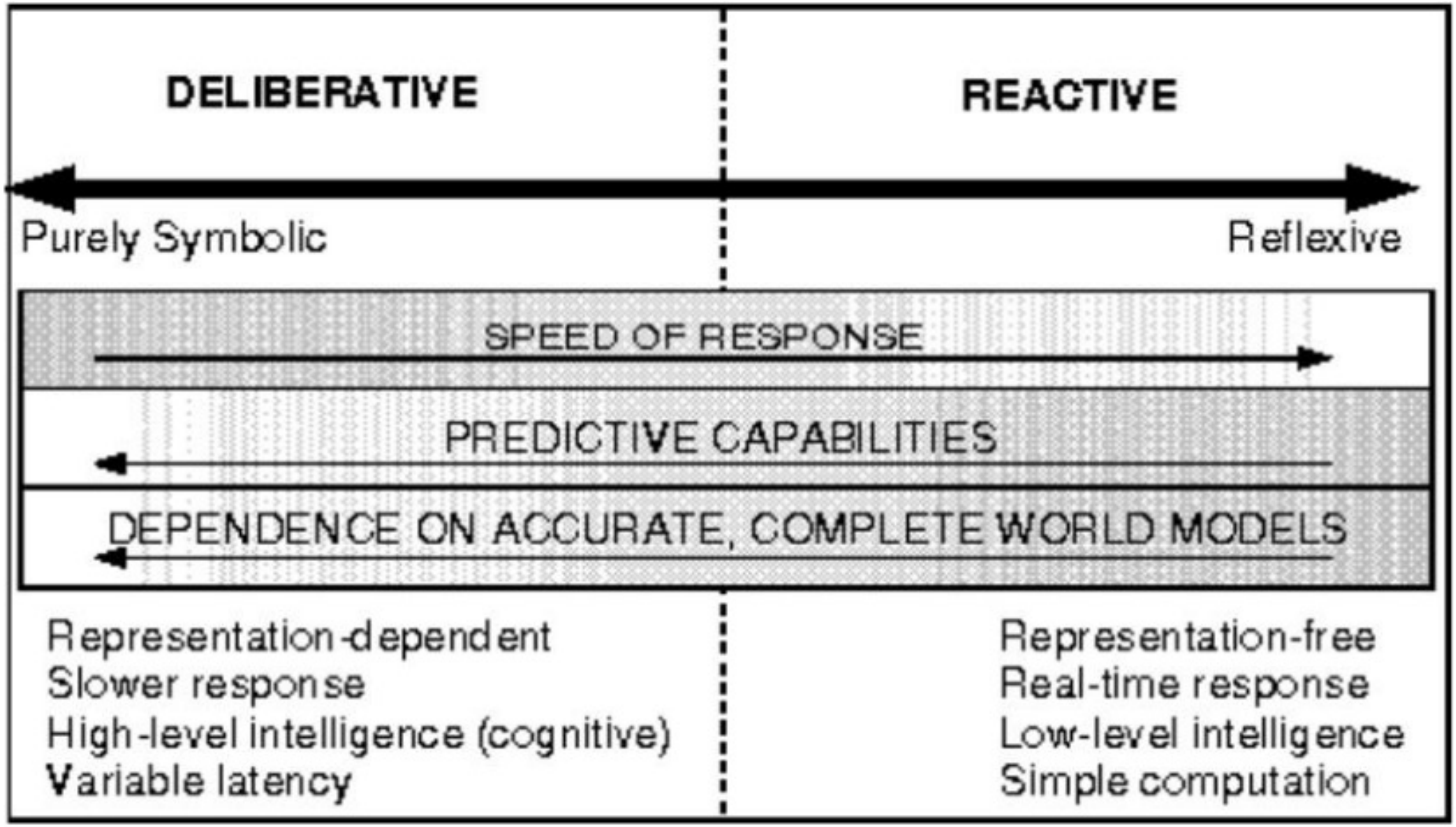
- Reactive/Behavior-based/Subsumption
  - Responsive to dynamic changes





Source: [Brooks, 1985, MIT]

Spectrum of control



Source: [Arkin, 1998, MIT Press]

Three-Layer Architectures

- The Controller (low level, tight coupling)
- The Sequencer (selecting low level behaviours)
- The Deliberator (time-consuming computations)

See: http://www.flownet.com/gat/papers/tla.pdf

CLARAty

- A two layer architecture
- Developed at NASA/JPL
- Supporting different h/w

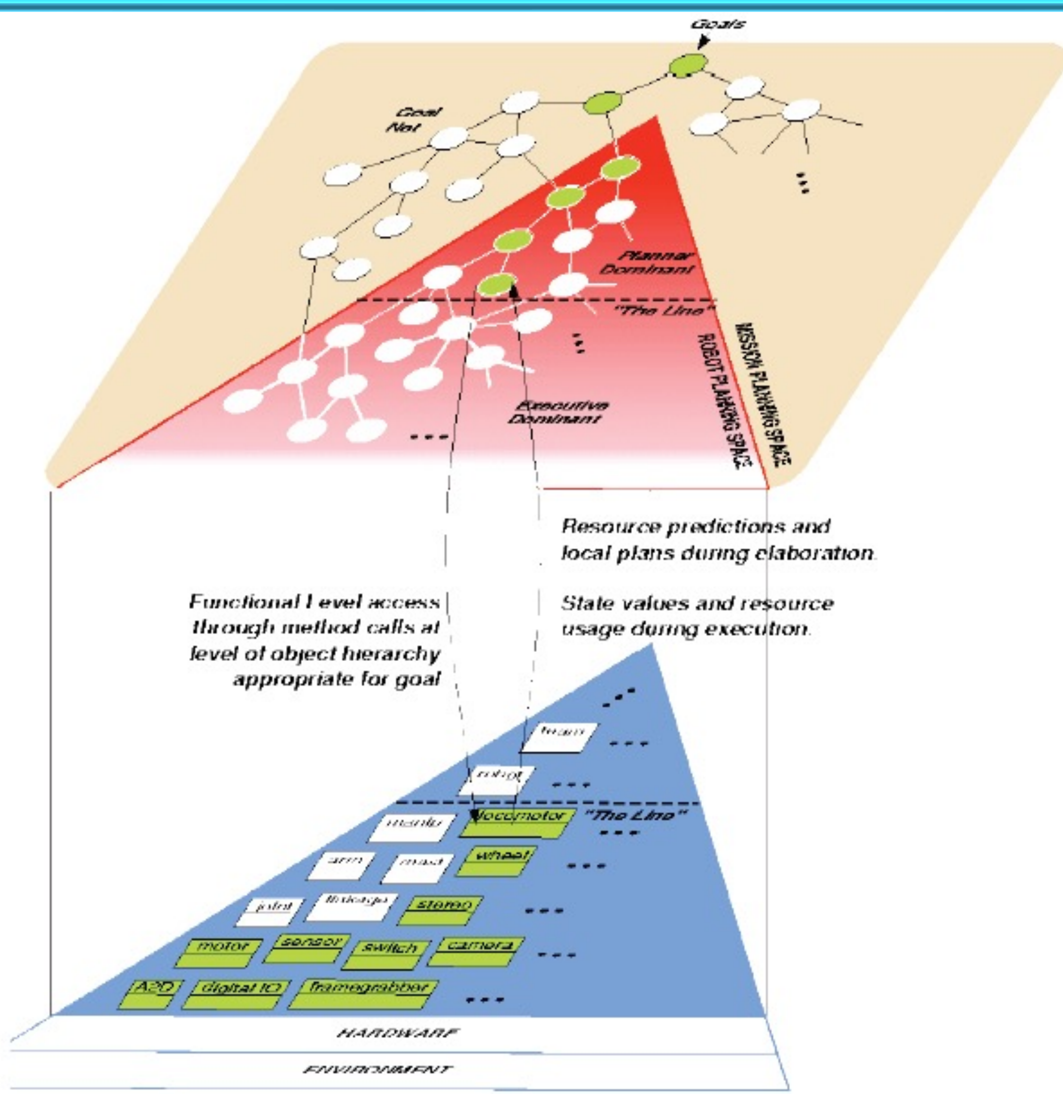
See: http://claraty.jpl.nasa.gov/man/overview/index.php

Approach

- Develop
  - Common data structures
  - Physical & Functional Abstractions
    - E.g. motor, camera, locomotor. Stereo processor, visual tracker
  - Unified models for the mechanism
- Putting it together
  - Start with top level goals
  - Elaborate to fine sub-goals
  - Choose the appropriate level to stop elaboration
  - Interface with abstractions
  - Abstractions translate goals to action
  - Specialize abstractions to talk to hardware
  - Hardware controls the systems and provide feedback

From: http://claraty.jpl.nasa.gov/main/overview/presentations/FY05/FY05_claraty_jtars.pdf

Two Layer Architecture



THE DECISION LAYER:

Declarative model-based
Global planning

INTERFACE:

Access to various levels
Commanding and updates

THE FUNCTIONAL LAYER:

Object-oriented abstractions
Autonomous behavior
Basic system functionality

Adaptation to a system

Research Process

- Identify problem of interest
  - Why is it important to solve it
  - What has been done in the literature
- Study, design, and develop the algorithm for robotic applications
  - Approximability, approximation
  - Space and computational complexity
  - Heuristics
- Deploy algorithm
  - Simulation
  - Fielded robots
- Evaluate performance of algorithm on experiments

Software for a robot

- Robots are complex systems that involve a large number of individual capabilities
- Robot architecture is the set of principles, building blocks, and tools for designing robots
  - Architectural structure: system into subsystems with interaction
  - Architectural style: how communication happens
- Currently in a robot there might be multiple robot architectures
- However, a well-conceived architecture can have significant advantages for specification, execution, and validation

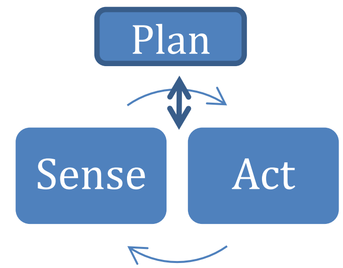
Robot Architectures Decomposition

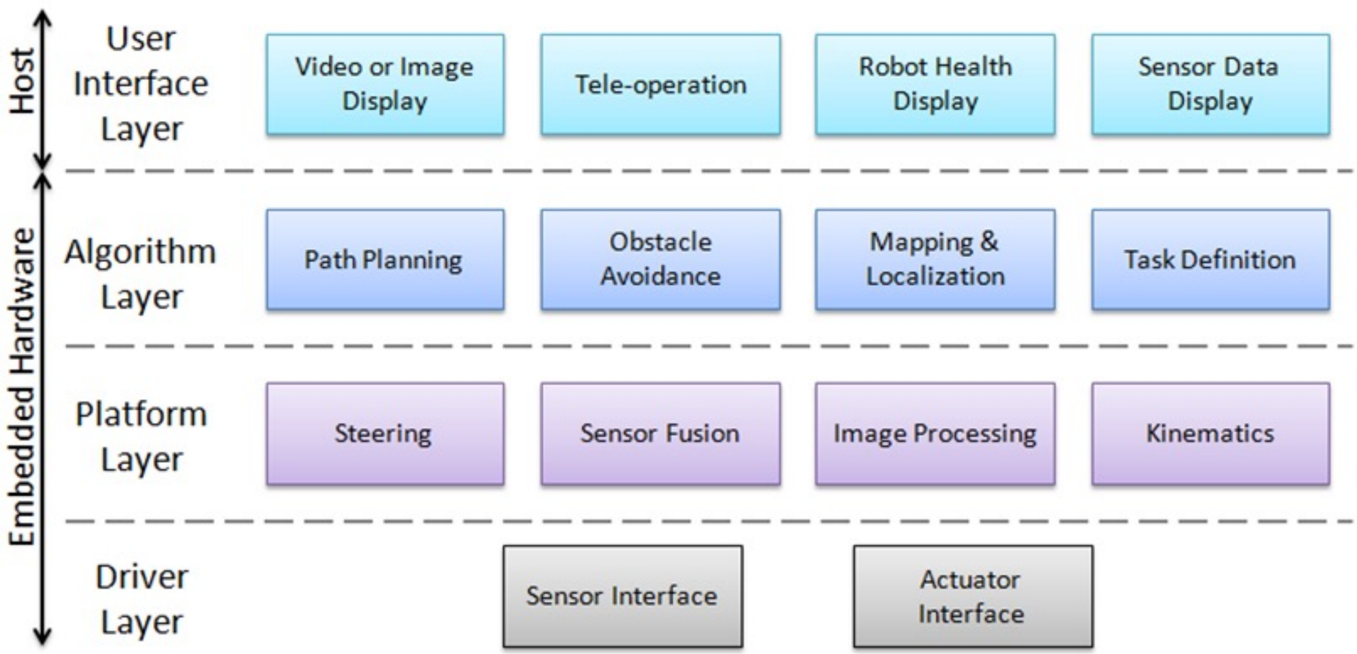
- *Modular* decomposition reduces complexity bu decomposing systems into simpler independent pieces

- *Hierarchical* decomposition reduces system complexity through abstraction

Main Robot Architectures

- Layered
  - Integration between reactivity and deliberative



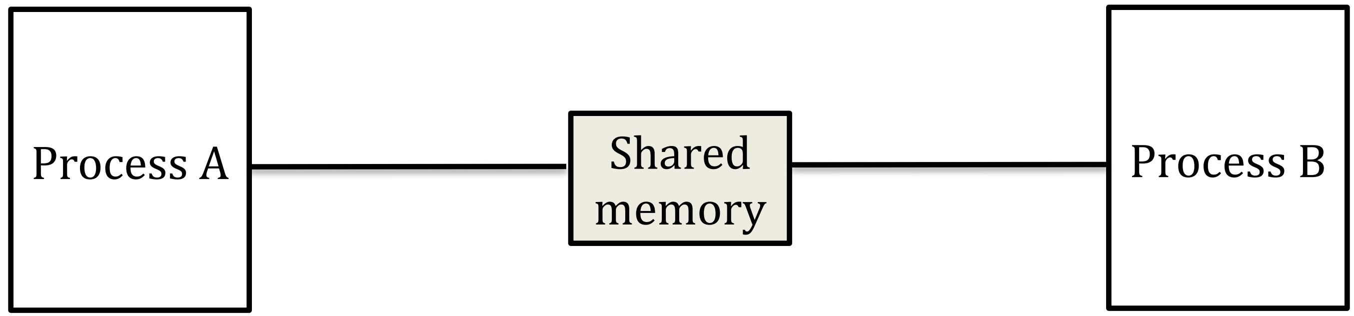


Source: ni.com

Middleware

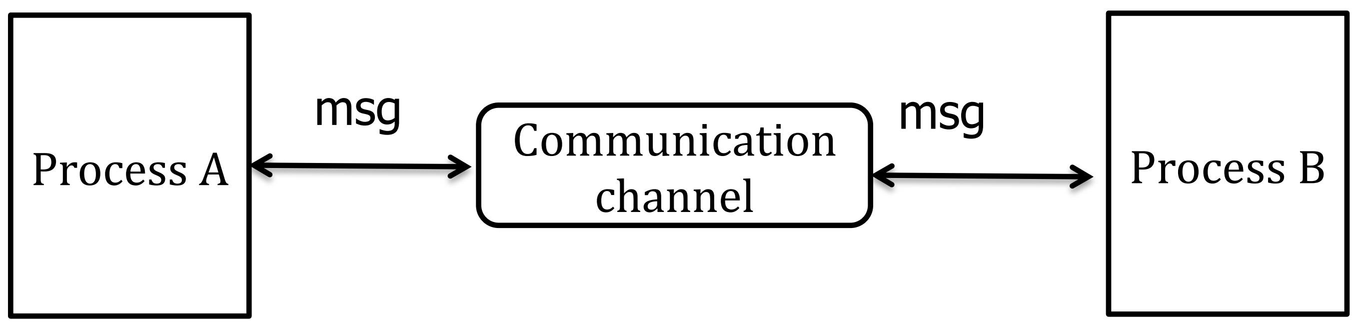
- Components need to share information

Direct



- To make the system modular, a *middleware* can be designed, i.e., the way that components in a robot architecture communicate

Message passing



Basic approaches for message passing

- Client/server: send information as generated by producer (push) or as requested by consumer (pull)
- Publish/Subscribe: consumers request a subscription to a producer and producer sends generated subscribed data to consumers
  - Peer-to-peer: direct connection with producer that sends timestamped data
  - Blackboard-based: middle entity that stores the last instance of data

How to design a robot architecture

- Drawing from software engineering, first all of the requirements and desiderata should be explicitly defined
  - What are the tasks?
  - What actions are necessary to accomplish them?
  - What data is necessary to do the tasks?
  - What capabilities the robot will have?
  - Who are the robot's users?
  - Will the robot architecture used for other tasks/robots?

Robot Architecture Features for Research

- Hardware abstraction
- OS independent
- Open access
- Robustness
- …

Robot Architecture Features for Research

- Modularity
  - Support for multiple components
  - Communication between components
  - Easy way to write own components
  - Possibility to replace individual components
- Support for decentralized components
- ...

Robot Architecture Features for Research

- Support for setting at runtime parameters, handled centrally
  - Fixed, through files
  - Dynamically
- Support to log data (timestamped)
- Way to visualize the system and the data
- …

Robot-Dependent Frameworks

- Ndirect, seriald (Nomadics)
- RHeXLib (University of Michigan - Ann Arbor, McGill)
- ...

Robot Independent Frameworks

- ROS (Willow Garage)
- MOOS (Paul Newman, Oxford)
- IPC (Reid Simmons — CMU)
- LCM (Albert Huang, Edwin Olson, David Moore — MIT)
- Player (Bryan Gerkey, Richard Vaughan, Andrew Howard — USC)
- OROCOS (Herman Bruyninckx, Peter Soetens, KU Leuven)
- OpenRTM (Japan's National Institute of Advanced Industrial Science and Technology)
- YARP (Italian Institute of Technology)
- Microsoft Robotics Studio
- ...

Best practices

- All modules should use
  - The same units (SI units)
  - The same coordinate frames (or provide relations between a common reference frame)

Best practices

- When writing software given the modularity it is advisable to follow some style guide
- Also properly documenting the code is important
- Unit testing should be performed to ensure no problem with other components

ROS example

- ROS suggests to follow some style guide
  - http://wiki.ros.org/StyleGuide
- For documenting, the code, Doxygen is used
- For unit testing, basically unittest and gtest are used
- Debug for C++ node can be performed through gdb by using `launch-prefix="xterm -e gdb --args“` when running the node

Best practices

- Sound experimental methodologies should be in place, following scientific principles
  - Comparison
  - Reproducibility
  - Repeatability
  - Justification/explanation
- For properly assessing the goodness of an algorithm, the following aspects should be considered:
  - Realism of environments and robot setup
  - Evaluation criteria
  - Sensitivity analysis
  - Statistical analysis (e.g., ANOVA)
  - ...

Best practices

- Logging data is important so that
  - No continuous human supervision
  - Collecting training data
  - Some post-processing can be applied
  - Performance evaluation
  - Debugging and reproducing failures
  - …
- The type of data to log depends on the specific task, algorithm being evaluated, …
- Visualization is important especially in robotics given the grounding to the real physical world

Simulations

- Simulators partially model the world and as such will never replace real world experiments
- "Simulations are doomed to succeed"
  - Simulations must be verified

- However, if critically used, simulations are useful because
  - Easy to compare results with ground truth
  - Control the amount of noise
  - Control the time
  - Possibility to execute thousands of runs
  - No hardware problems
  - Ease the debugging process
  - ...

Robotic Simulator

- Gazebo (OSRF)
- Stage (Vaughan – Simon Fraser University)
- UWSim (Prats, Perez, Fernandez, Sanz – Universitat Universitat Universitat Jaume I)
- USARSim (Carpin – UC Merced, Lewis , Wang – U Pittsburgh, Balakirsky, Scrapper – NIST)
- v-rep (Coppelia Robotics)
- RHeX SimSect
- Webots (Cyberbotics)
- MORSE (LAAS-CNRS)
- Nclient, server (Nomadics)
- RD11 (McGill)
- …

Best practices

- Before performing any field experiments, carry out any calibration process needed for the system to work properly
  - e.g., collecting footage for calibrating cameras

Best practices

- For field experiments, it is important to plan missions
  - Where to perform experiments
  - What are the goals for the experiment
  - Estimate time and energy
  - Mission logistics
  - Is there any regulation that must be complied?
  - Plan the data to be logged and collected and the parameters to be set
- Note that before actually going for a field experiment
  - Ensure everything is tested and software is updated and running
  - Batteries are fully charged

Discussion

- Currently no single architecture has proven to be suited for all applications
- Robot architectures should provide
  - Transparent flexible message-based communication network
  - Easy to use and transparent logging and playback capabilities
  - Centralized parameter handling
  - Abstraction of the actual hardware to focus on higher level components