

Physics Informed Machine Learning Part II: Applications in Structural Response Forecasting

Austin R. J. Downey^{1,2}, Eleonora Maria Tronci³, Puja Chowdhury¹, and Daniel Coble¹

¹Department of Mechanical Engineering, University of South Carolina

²Department of Civil and Environmental Engineering
University of South Carolina

³Department of Civil and Environmental Engineering
North Eastern University



UNIVERSITY OF
SOUTH CAROLINA

Work along GitHub Example

Goal: In this tutorial we will use GitHub codespaces to develop a physics constrained model of a 1-DOF system under free vibration.

Requirements

- A Github account that you can sign into
- Access to the repo (best to use QR code on right). May be best to email the link to yourself from your phone to your computer.

github.com/ARTS-Laboratory/Physics-Constrained-Machine-Learning-Example



Work along GitHub Example

Goal: Setup codespace by selecting the “glorious Carnival” codespace in the “demonstration” branch.

The screenshot shows the GitHub interface for the repository "ARTS-Laboratory / Physics-Constrained-Machine-Learning-Example". The page is annotated with three blue arrows indicating the steps to create a codespace:

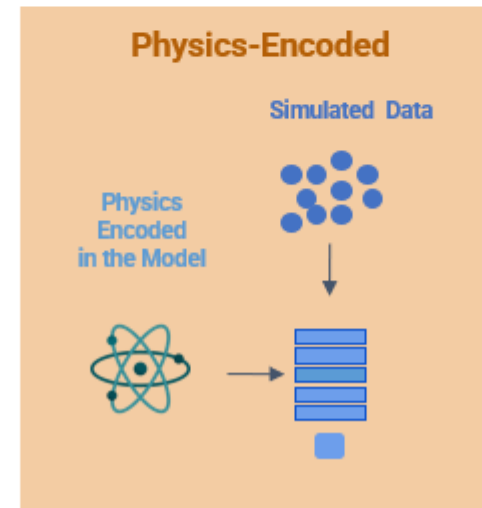
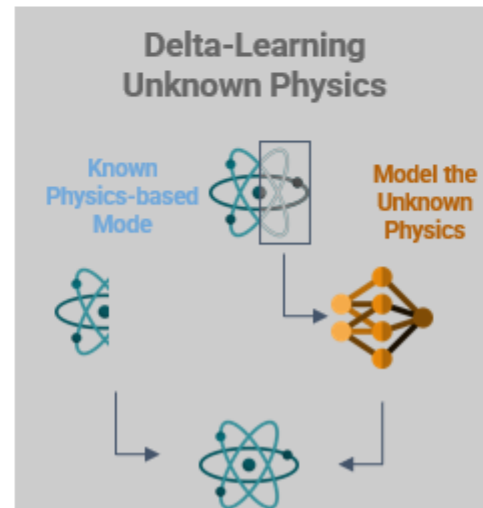
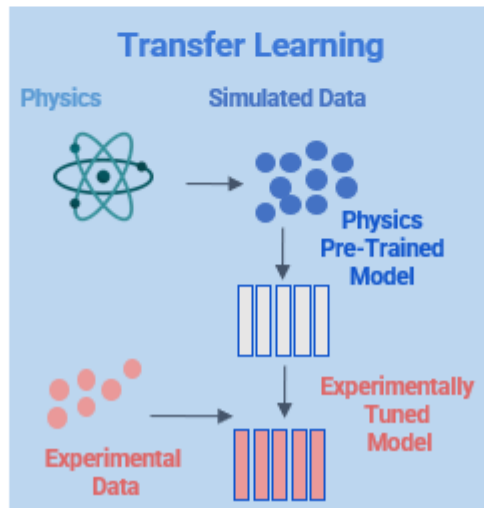
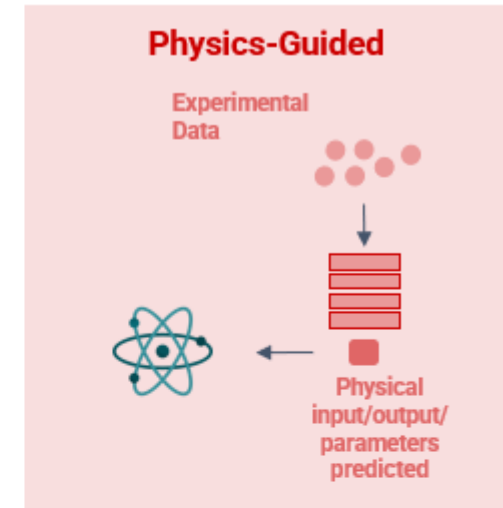
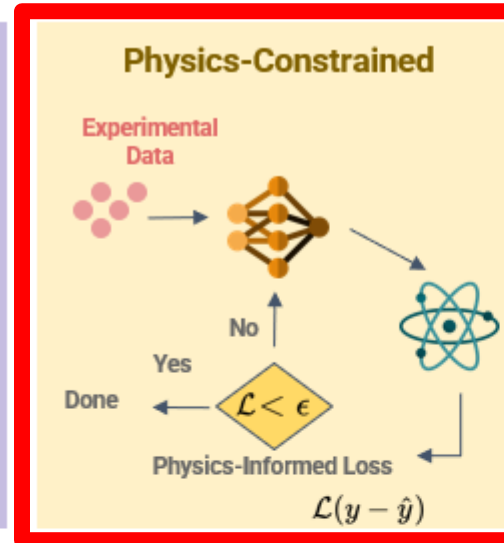
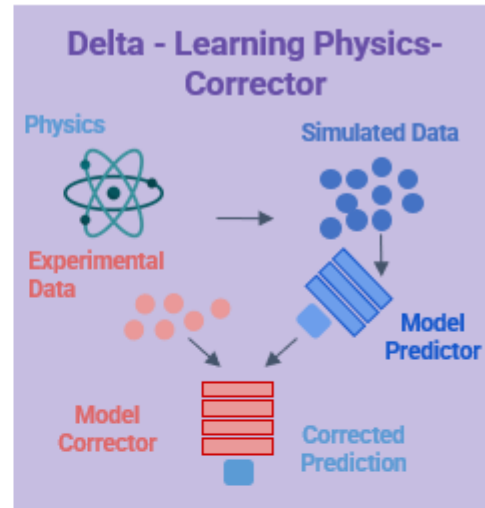
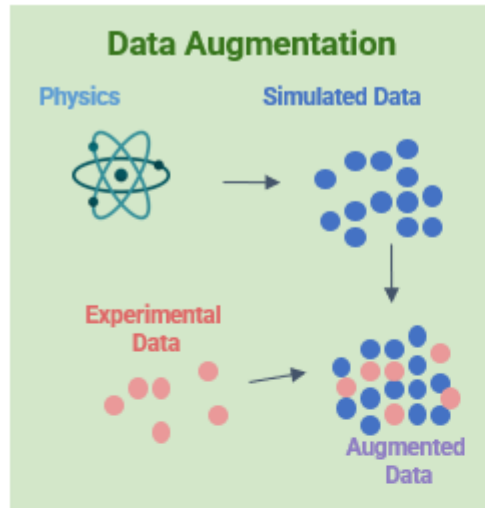
- Arrow 1:** Points to the "Code" button in the top navigation bar.
- Arrow 2:** Points to the "Code" dropdown menu in the file explorer.
- Arrow 3:** Points to the "Create codespace on main" button in the "No codespaces" dialog.

The "Code" dropdown menu is open, showing options for "Local" and "Codespaces". The "Codespaces" section is selected, displaying a message: "No codespaces. You don't have any codespaces with this repository checked out." Below this message is a green button labeled "Create codespace on main".

A QR code is visible in the bottom right corner of the page, which likely links to the "glorious Carnival" codespace mentioned in the goal.

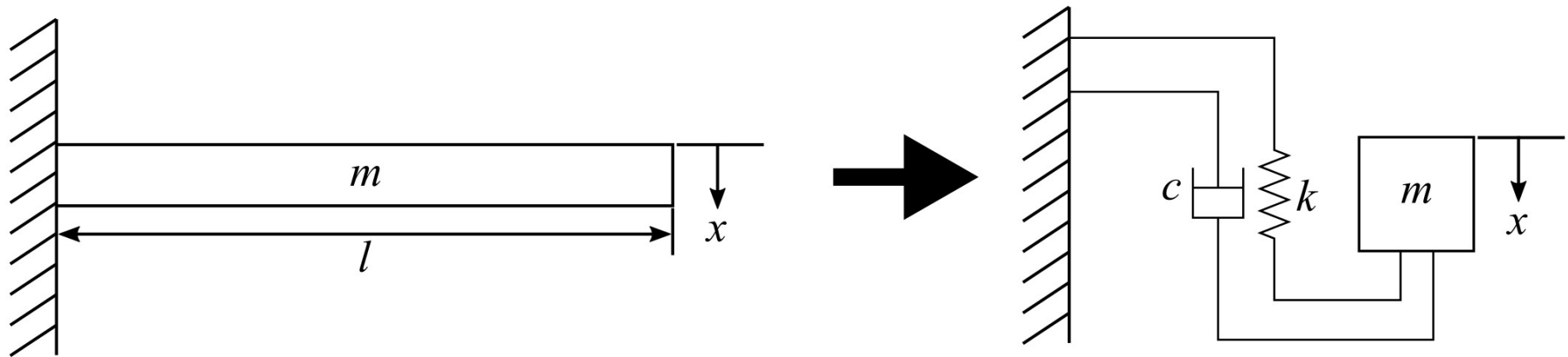
Physics-constrained vs Other Physics-ML Approaches

- In this example we will try to develop a physics-constrained



First, we need a Model of a Physical System

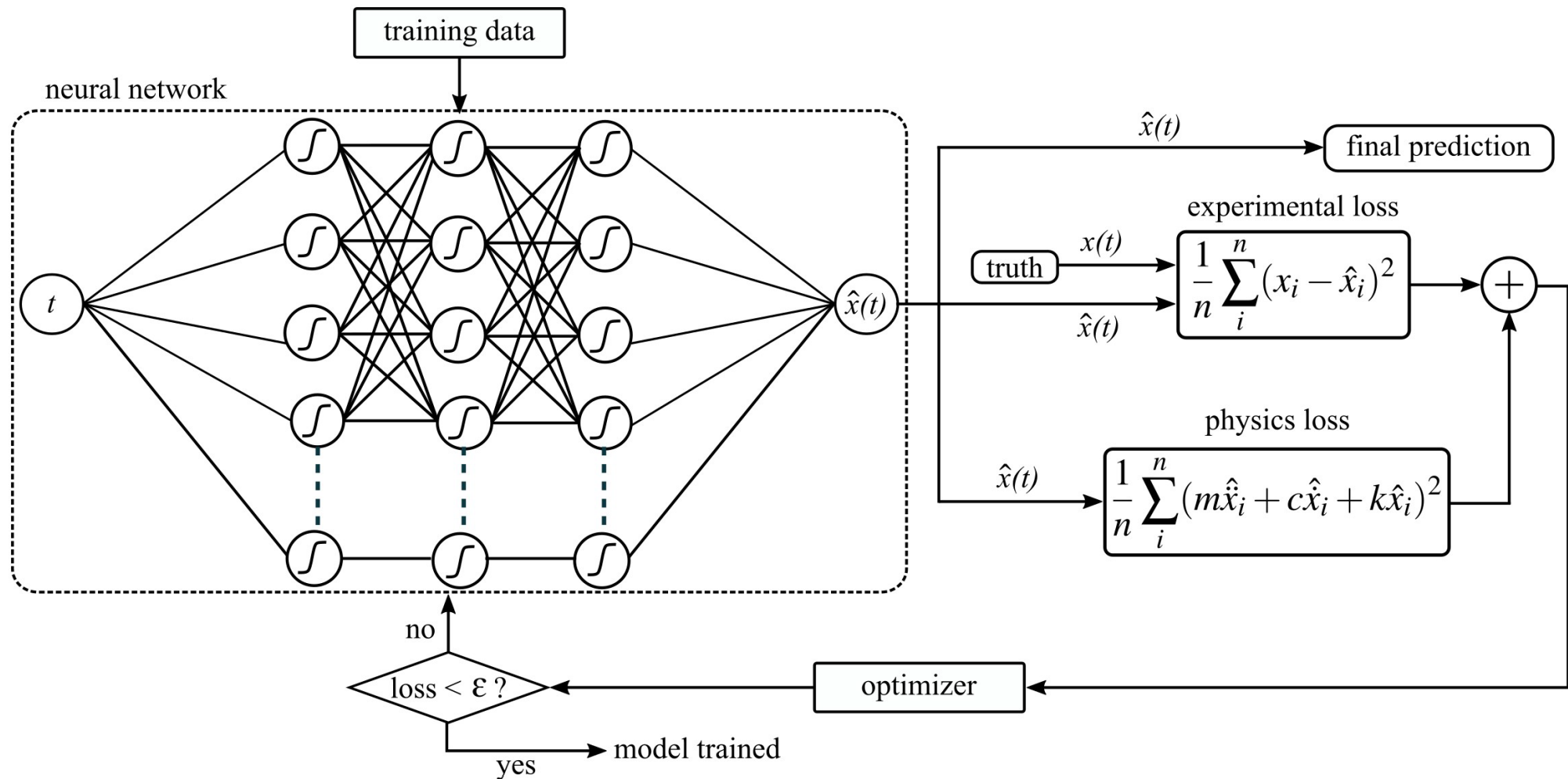
- Consider a cantilever beam modeled as a 1-DOF spring-mass-damper system



$$m\ddot{x} + c\dot{x} + kx = 0$$

Next, we build a Physics-Constrained ML Model

- We use a MLP with constrained by the equation of motion to develop a “physics constrained ML model”



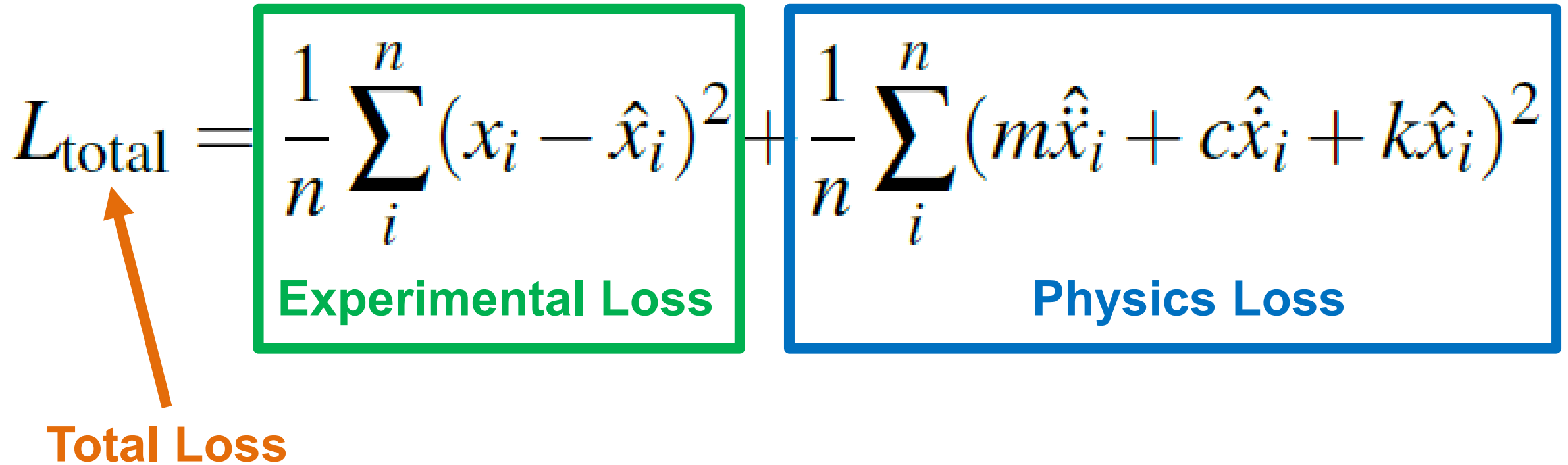
The Loss function is the Key

- We use both loss functions to train the model.
- Model is trained on a dataset with n data points.

$$L_{\text{total}} = \frac{1}{n} \sum_i^n (x_i - \hat{x}_i)^2 + \frac{1}{n} \sum_i^n (m\hat{x}_i + c\hat{x}_i + k\hat{x}_i)^2$$

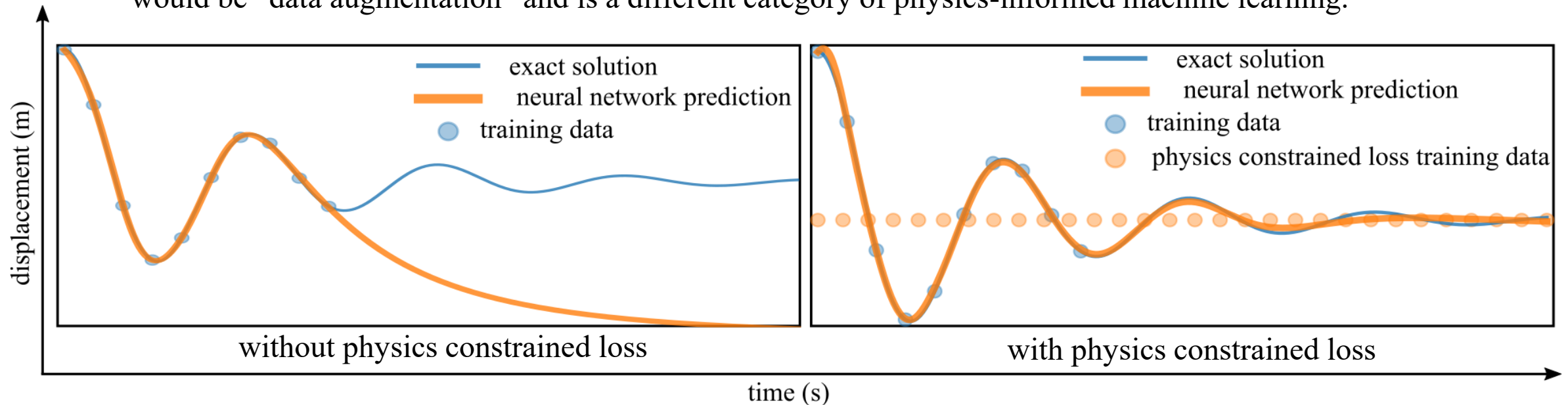
Experimental Loss **Physics Loss**

Total Loss



Using the Physics-constrained Model

- For this example, $k = 625$ N/m, $m = 1$ kg, $c = 25$ kg/s, $\omega_0 = 4$ rad/sec, and $\zeta = 0.080$.
- Key take aways form this example:
 - The model without physics constrained loss perfectly trains on the data available but is not able to correct the model for the area of the time domain that does not have data.
 - The model with physics constrained loss is able to correct the model where there is no experimental data.
 - **Note:** using the equation of motion to solve for additional training points that are used to train the model would be “data augmentation” and is a different category of physics-informed machine learning.



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THANK YOU!



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