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

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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

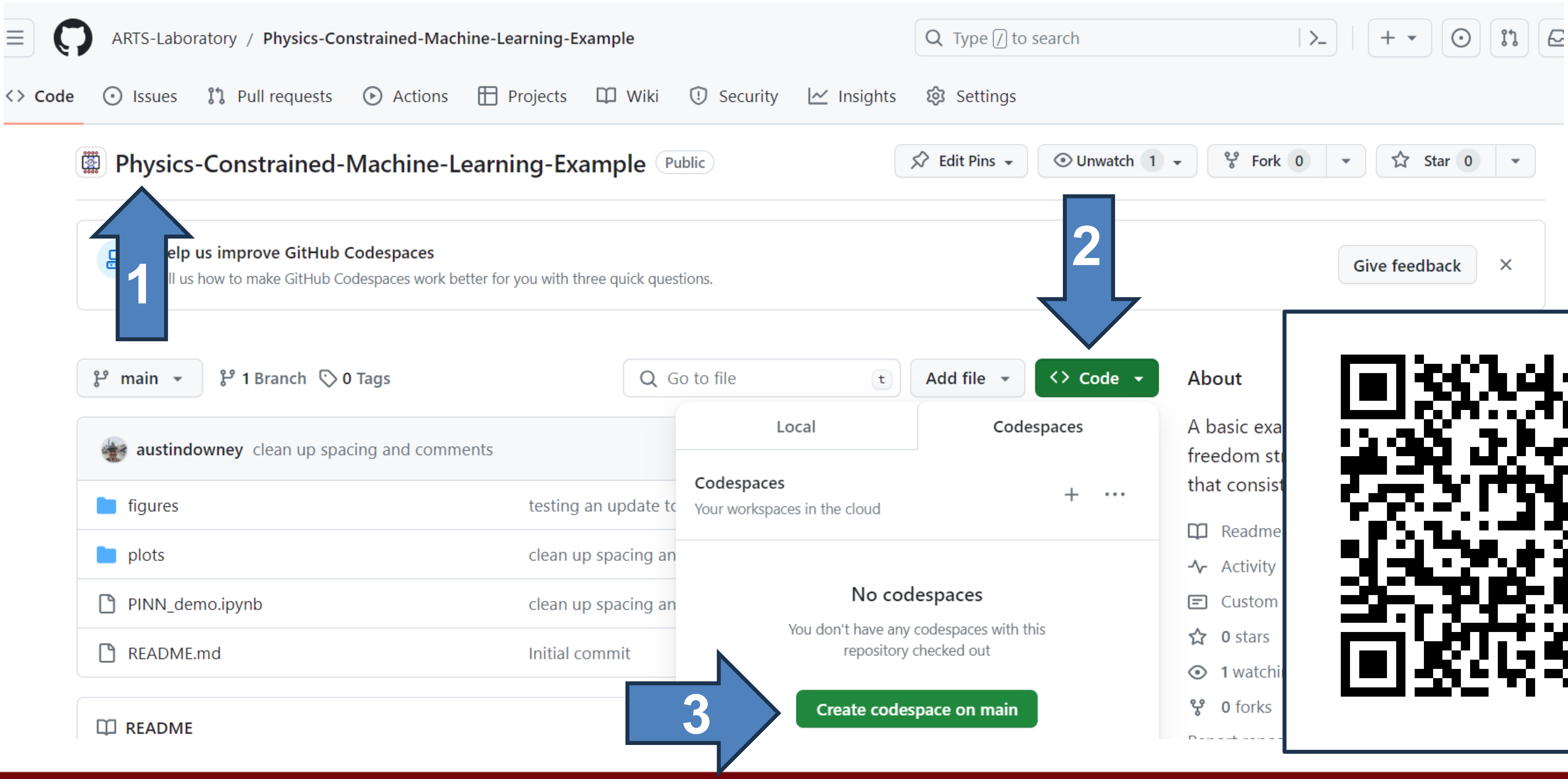
- A Github account that you can sign into
- Access to the repo (best to use QR code on right). May be best to email the link to yourself from your phone to your computer.

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

South Carolina

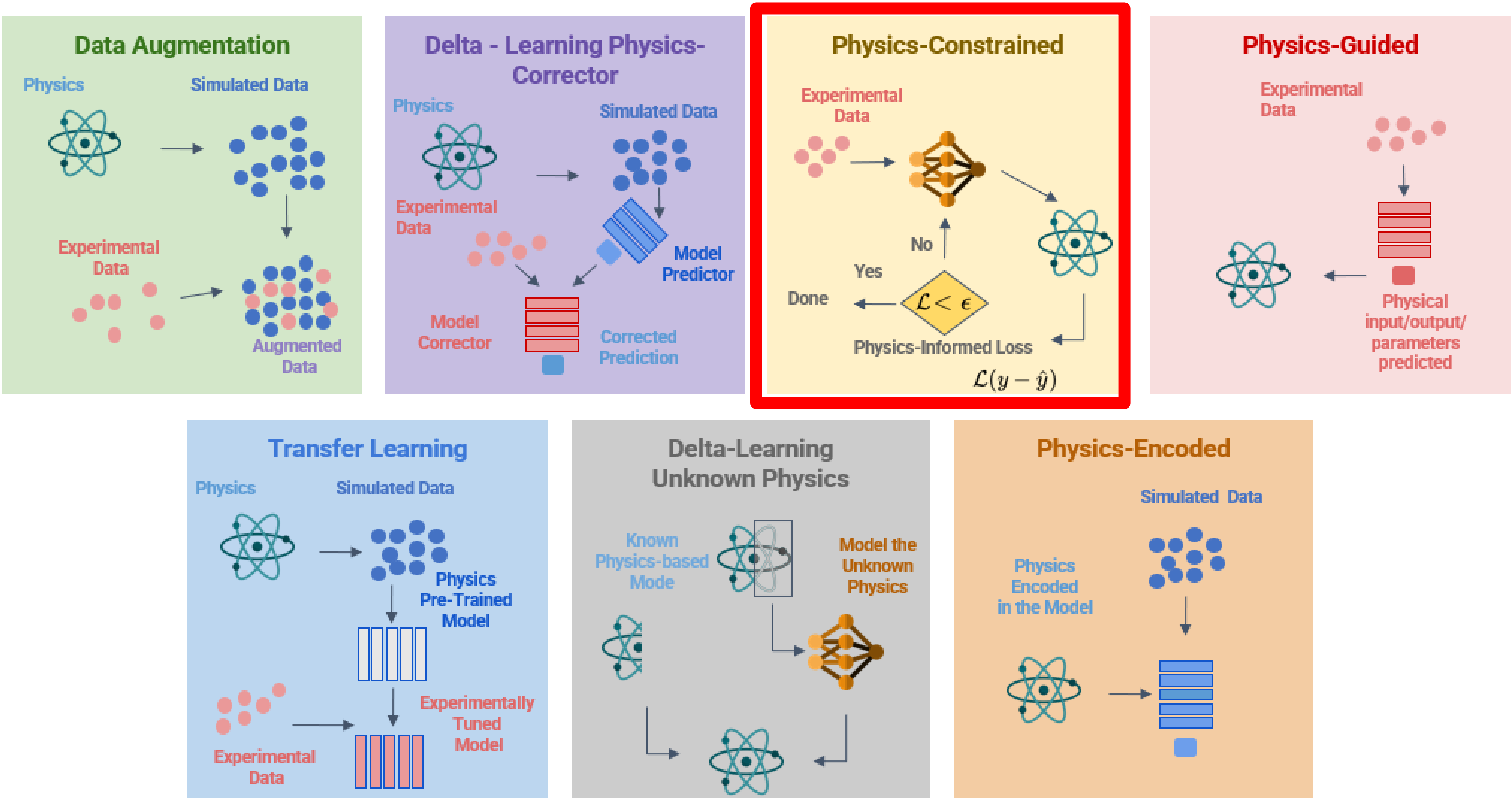
Work along GitHub Example

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



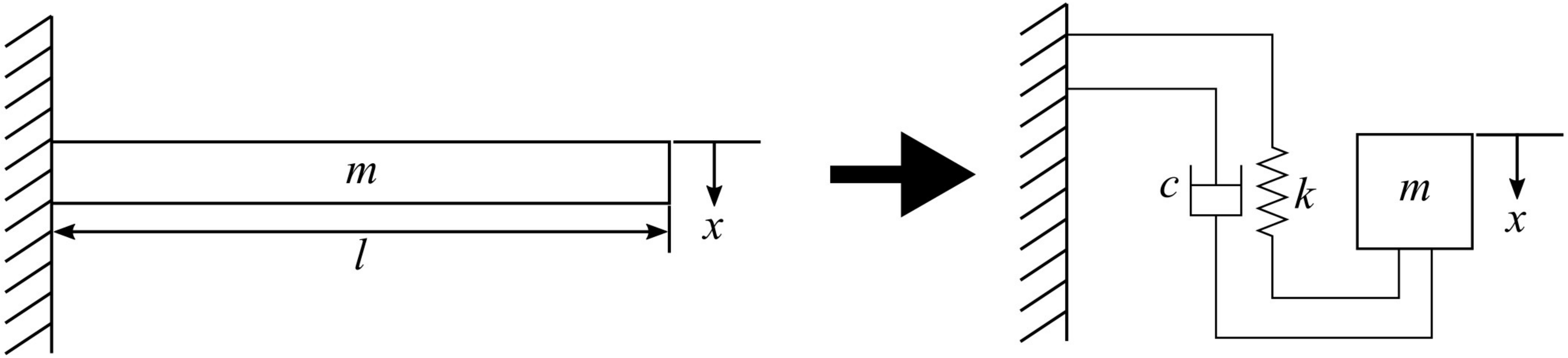
Physics-constrained vs Other Physics-ML Approaches

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



First, we need a Model of a Physical System

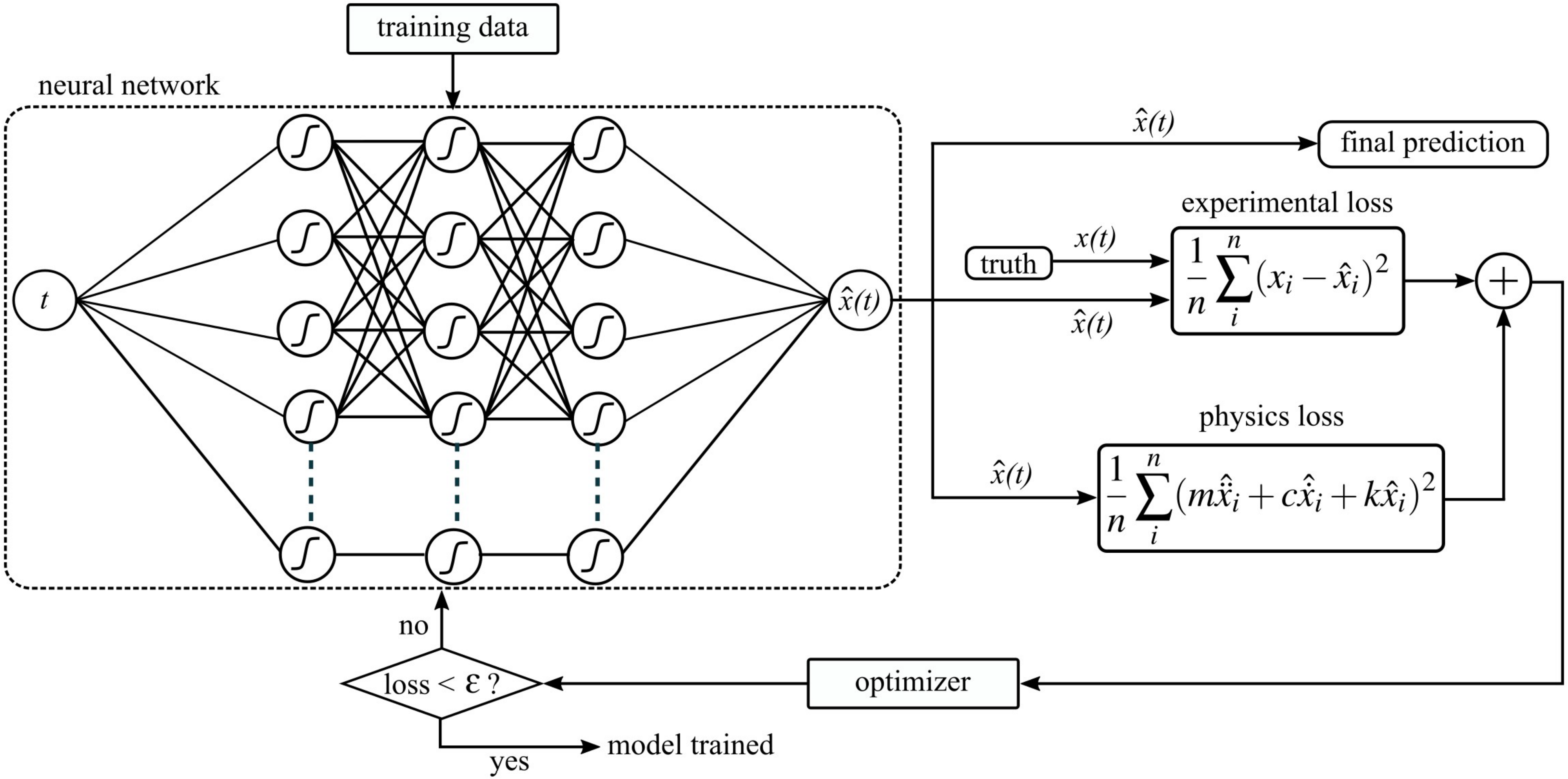
- Consider a cantilever beam modeled as a 1-DOF spring-mass-damper system



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

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.

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

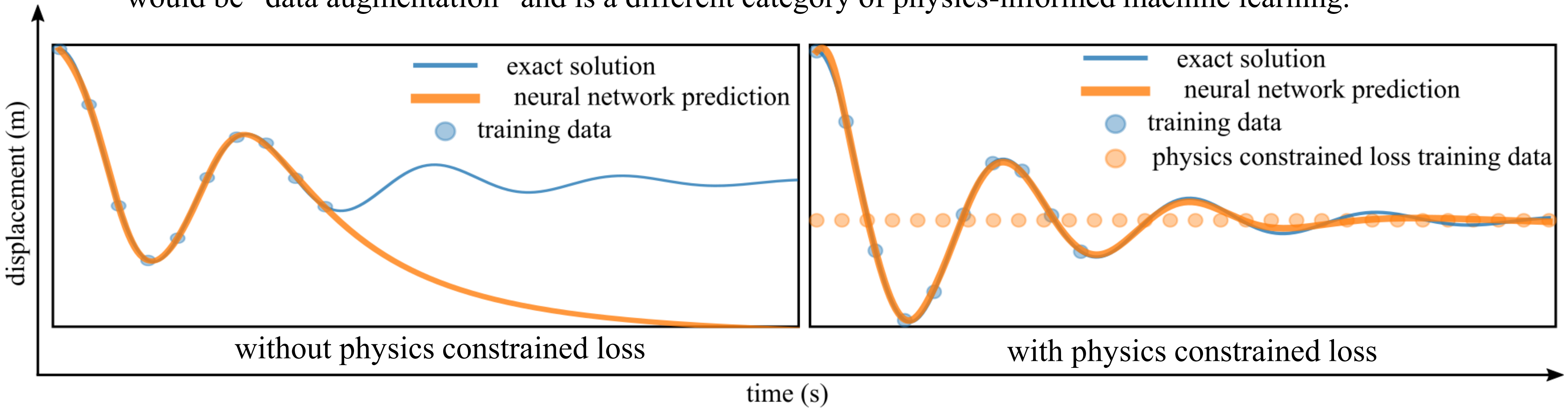
Experimental Loss

Physics Loss

Total Loss

Using the Physics-constrained Model

- For this example, k = 625 N/m, m = 1 kg, c = 25 kg/s, ω_0 = 4 rad/sec, and ζ = 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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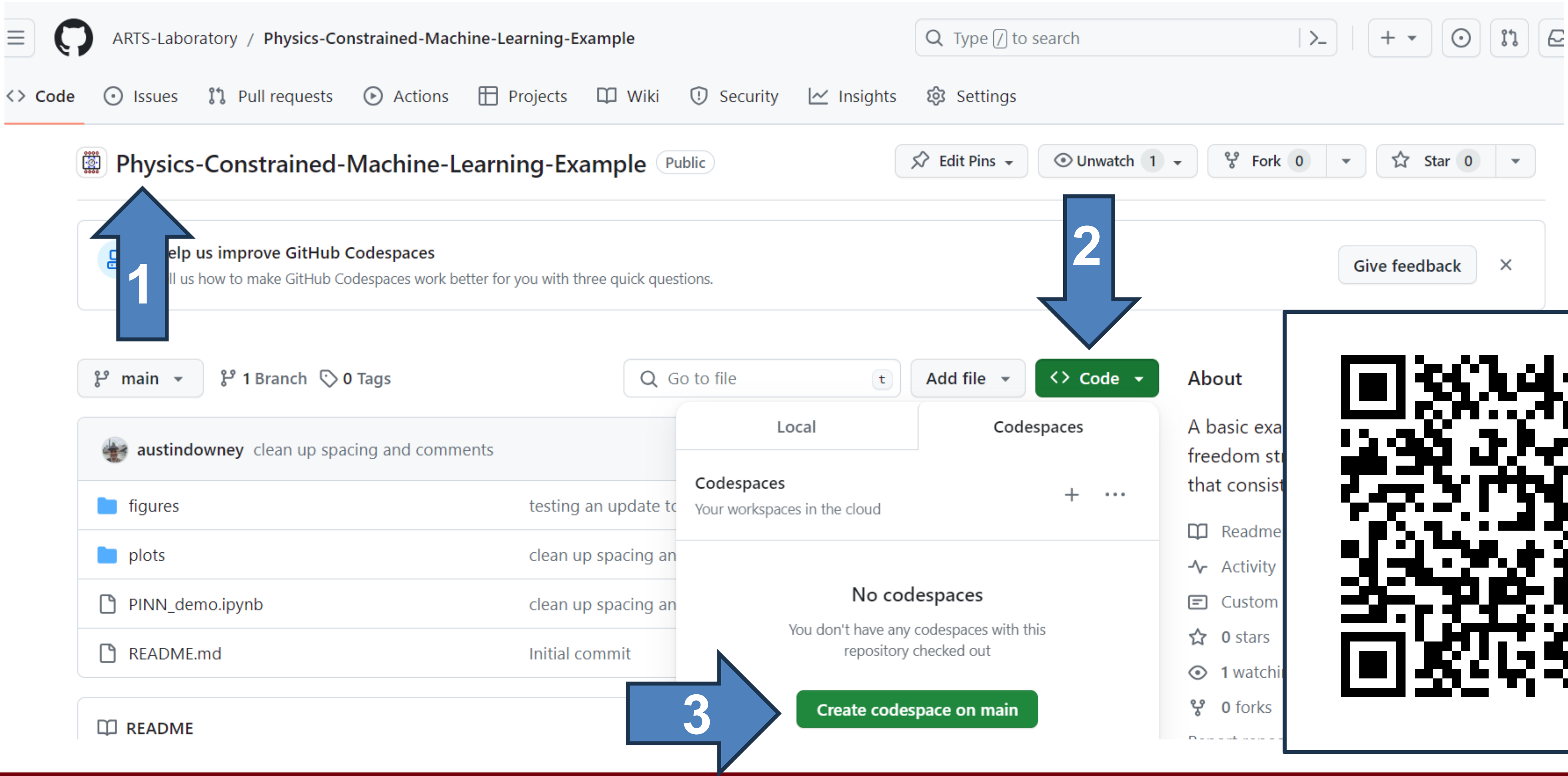

THANK YOU!

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