Universität
Bremen

Center for Industrial
Mathematics (ZeTeM)
Faculty 03
Mathematics / Computer science

Introduction to TorchPhysics

Parameter studies

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Renningen, 21.11.2025

Yesterday

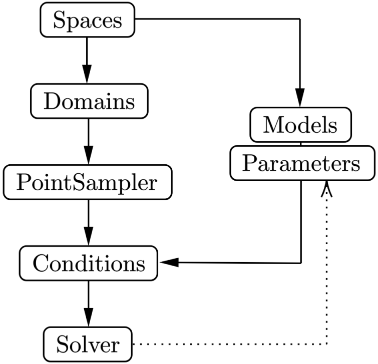
- PINNs:

$$\min \sum_{x_i} ||\partial_t u(x_i) - \Delta u(x_i)||^2$$

- TorchPhysics
  - Domain construction

```
bar    = tp.domains.Parallelogram(X, ...)
circle = tp.domains.Circle(X, ...)
omega  = circle - bar
```

  - Point sampling
  - Conditions



Parameter Studies and Parameter Identification

Realization with PINN and TorchPhysics

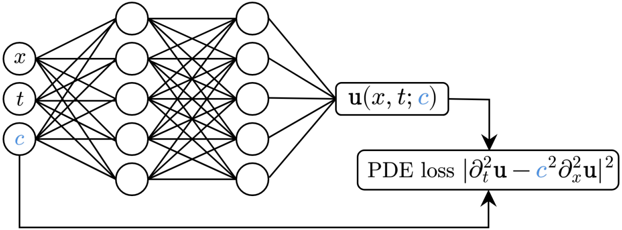
Parameter-dependent wave equation:
$$\begin{cases} \partial_t^2 u = c\,\partial_x^2 u, & \text{in } I_x \times I_t, \\ u = 0 & \text{in } \partial I_x \times I_t, \\ \partial_t u(\cdot, 0) = 0 & \text{in } I_x, \\ u(\cdot, 0) = \sin(x) & \text{in } I_x, \end{cases}$$

Many industrial applications involve:

- **Parameter studies:** Solving the same PDE for many different choices of c
- **Parameter identification:** Finding the c that leads to given solution data $\{\hat{u}_i\}$

Parameter Studies with PINNs

Solving the same PDE for many different choices of c

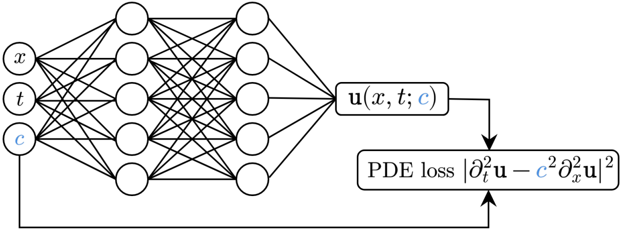


Method:

- Include parameter(s) as additional input(s) to the PINN
- Training: Sample parameter range together with function domain

Parameter Studies with PINNs

Solving the same PDE for many different choices of c



Method:

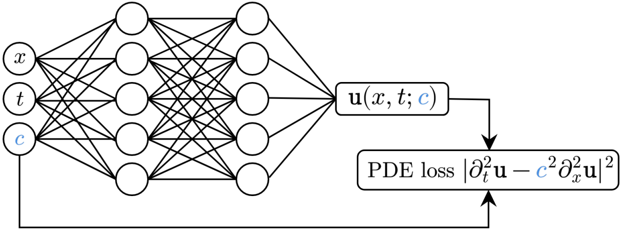
- Include parameter(s) as additional input(s) to the PINN
- Training: Sample parameter range together with function domain

```python
model = tp.models.FCN(input_space=X*T*C, output_space=U)

def pde_residual(u, t, x, c):
    return ...
```

Parameter Studies with PINNs

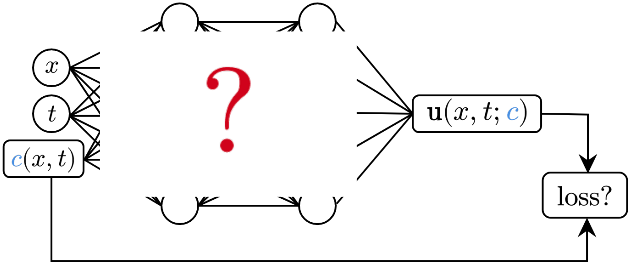
Solving the same PDE for many different choices of c



Result:

- Inference of solution for new parameter by a forward pass to the trained network
- Very little additional effort in evaluation of the network
- Increased amount of training points necessary

Function-Valued Parameter Studies

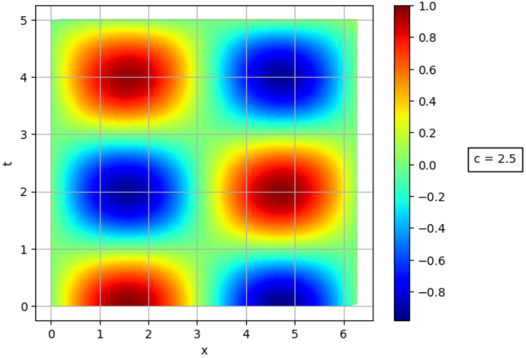


How to use a function-valued parameter as an input to the NN?

$\rightsquigarrow$ **Track 2: Operator Learning**

Exercise: Wave equation

$$\begin{cases} \partial_t^2 u = c\,\partial_x^2 u & \text{in } I_x \times I_t, \\ u = 0 & \text{in } \partial I_x \times I_t, \\ \partial_t u(\cdot, 0) = 0 & \text{in } I_x, \\ u(\cdot, 0) = \sin(x) & \text{in } I_x, \end{cases}$$



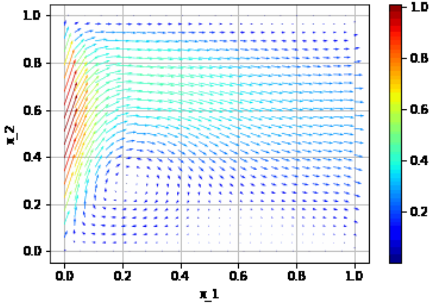
Parameter Study (`Exercise_6.ipynb`)

- Learn the solution for multiple c

Exercise: Stokes equations

- Learn flow profile for different inflow angles α

$$\begin{cases} -\frac{\mu}{2}\operatorname{div}(\nabla u + \nabla u^T) + \nabla p = 0 & \text{in } \Omega, \\ \operatorname{div}(u) = 0 & \text{in } \Omega, \\ u = u_{in}(\alpha, x) & \text{on } \Gamma_D, \\ -\frac{\mu}{2}(\nabla u + \nabla u^T)\cdot n + pn = 0, & \text{on } \Gamma_N. \end{cases}$$



- Flow field $u(x) \in \mathbb{R}^2$ and pressure $p(x) \in \mathbb{R}$
- Template: `Exercise_7.ipynb`