Physics-Informed Neural Networks for the solution of Differential Equations
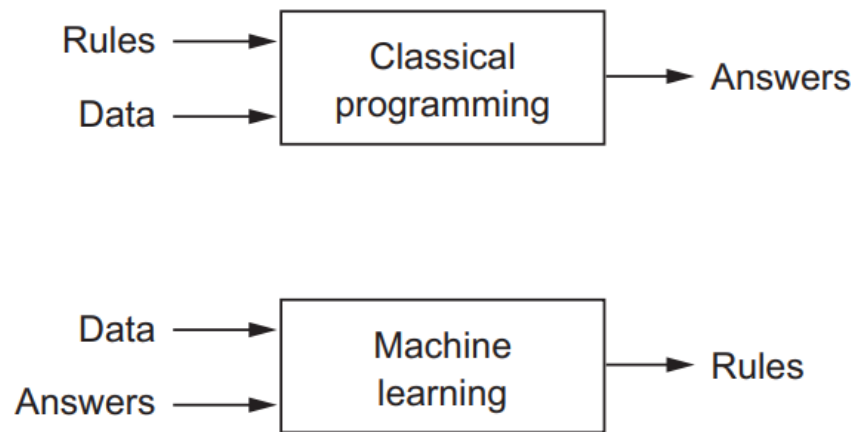
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C4AI - USP

Machine Learning

- In classical programing data is analyzed via a set of pre-defined rules

- With machine learning, these rules are extracted from the data itself

Chollet, F. Deep Learning with Python, Manning Shelter Island Editor, 2018.
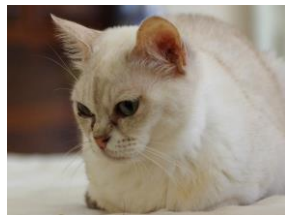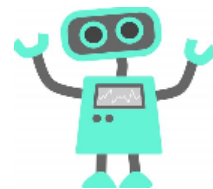
Data-driven approach

Dog

Cat

Dog

Cat

Training → Supervised learning → Inference

?

Applications

Image recognition and generation

Text classification and generation

Time series prediction

Digital twins

Anything we can get enough data out of

What if we don't have enough data?

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Example: Port of Santos

- Can't place sensors everywhere

- Faulty sensors

- Limited collection time

- Climate change

Physics-Informed Machine Learning

Augment physics with data

- Use data-driven models to correct the output of a physical model (Xu and Valocchi, 2015)

- Improve physical approximations with data-driven models (Wu et al., 2018)

Augment data with physics

- Add physical restrictions to data-driven models (Beucler et al., 2021)

- Use physical knowledge as the ground-truth for training (Raissi et al., 2019)
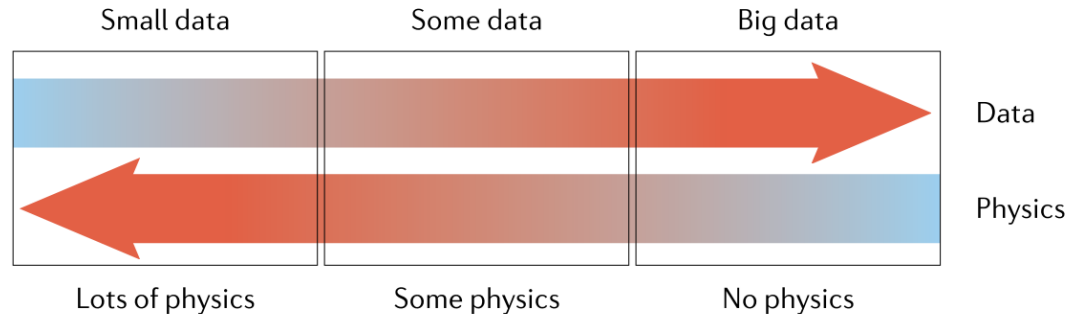
KARNIADAKIS, G. E. et al. Physics-informed machine learning. Nature Reviews Physics, v. 3, n. 6, p. 422–440, 2021

XU, T.; VALOCCHI, A. J. Data-driven methods to improve baseflow prediction of a regional groundwater model. Computers and Geosciences, v. 85, p. 124–136, 2015.
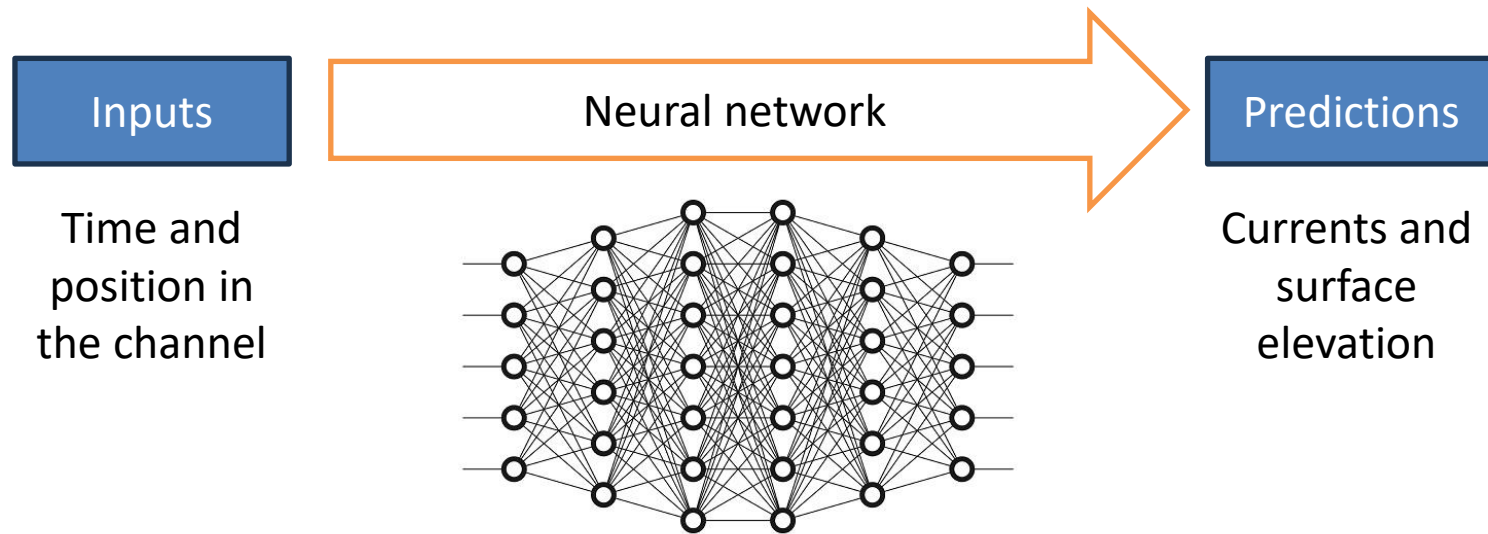
WU, J. L.; XIAO, H.; PATERSON, E. Physics-informed machine learning approach for augmenting turbulence models: A comprehensive framework. Physical Review Fluids, v. 7, n. 3, p. 1–42, 2018.

BEUCLER, T. et al. Enforcing Analytic Constraints in Neural Networks Emulating Physical Systems. Physical Review Letters, v. 126, n. 9, 2021.

RAISSI, M.; PERDIKARIS, P.; KARNIADAKIS, G. E. Physics-informed neural networks: A deep learning framework for solving forward and inverse problems involving nonlinear partial differential equations. Journal of Computational Physics, v. 378, p. 686–707, 2019.
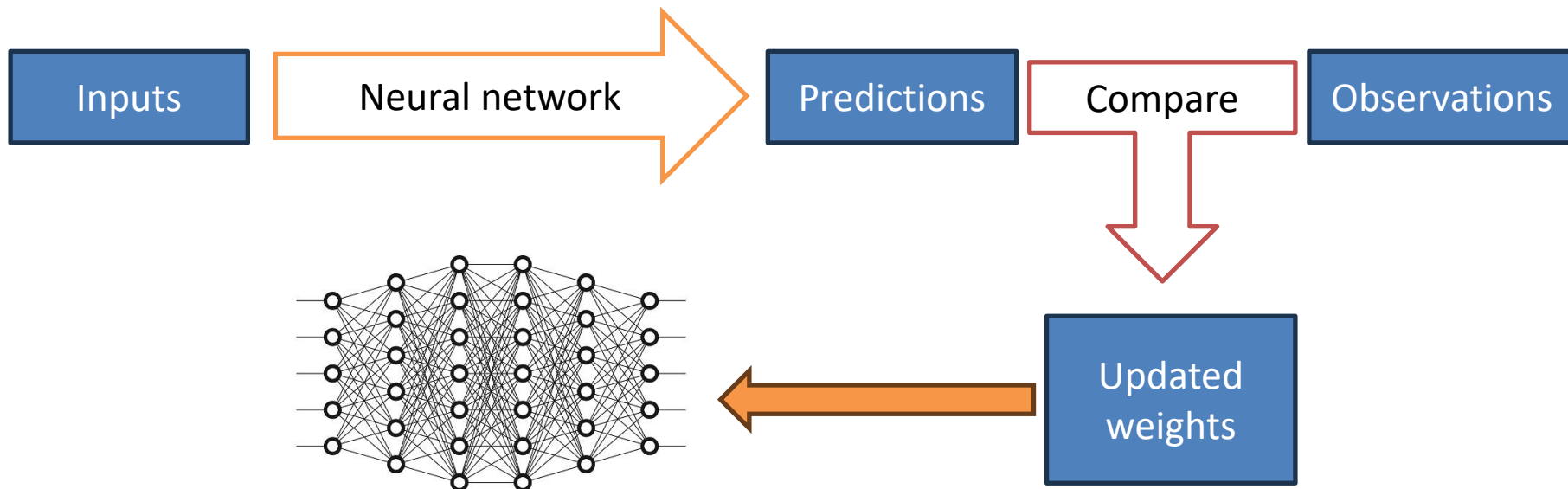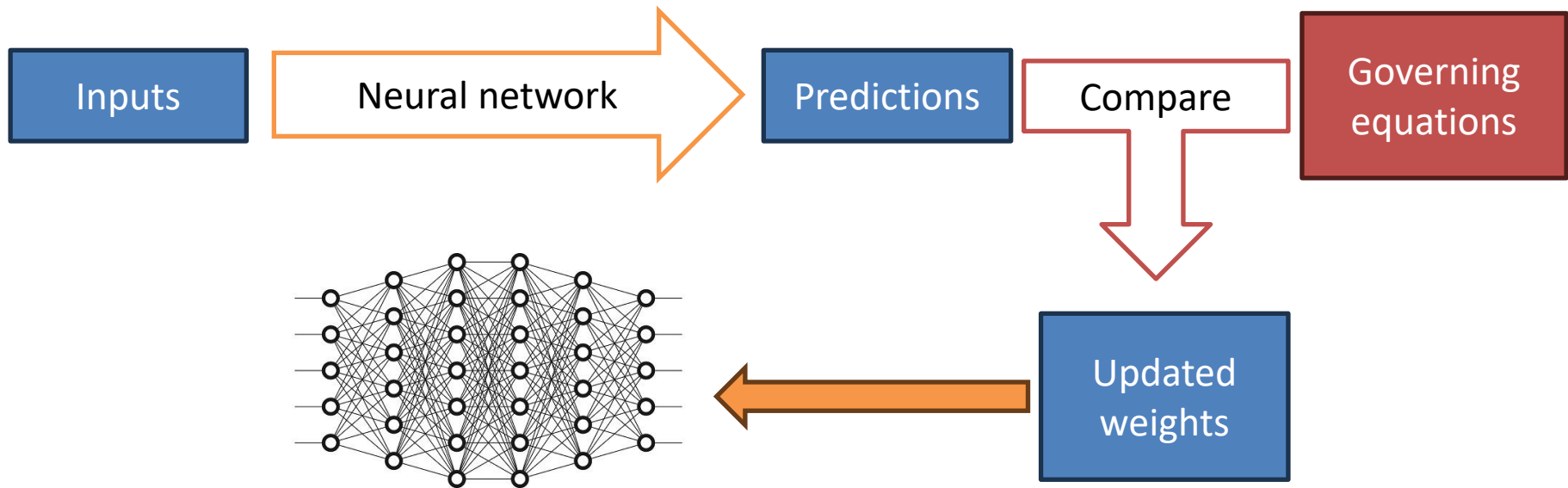
Neural Networks

Inference

Inputs	Neural network	Predictions

Time and position in the channel

Currents and surface elevation

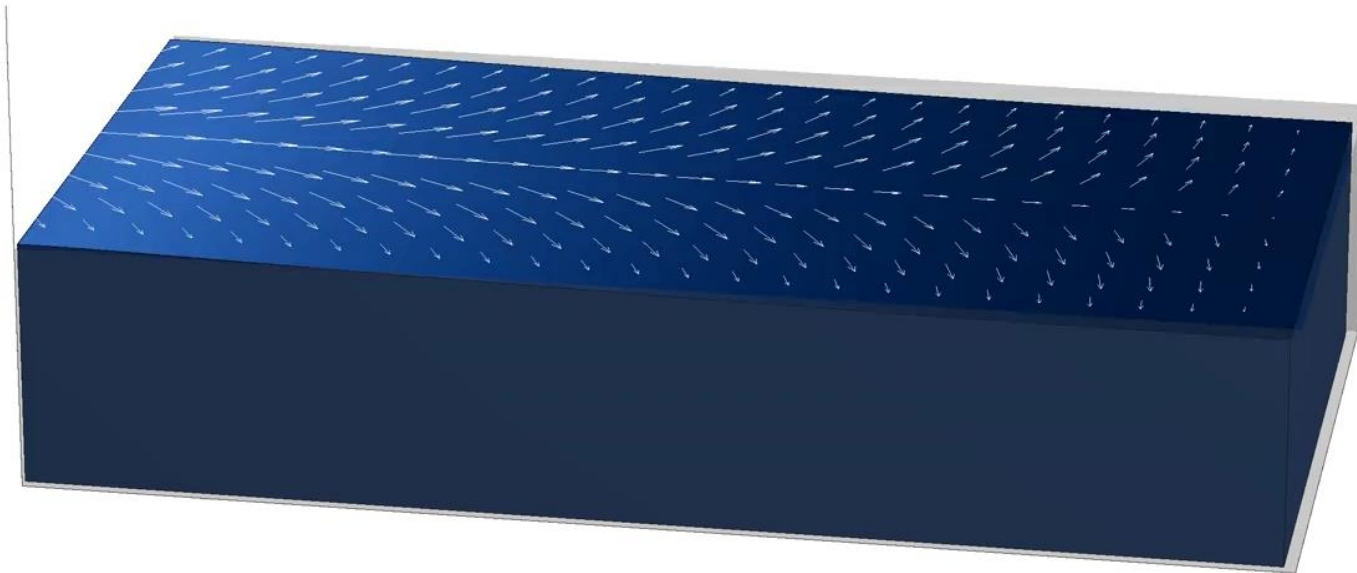# Neural Networks

Training

Physics-Informed Neural Networks

Training

Physics-Informed Neural Networks

Example of a port channel

In this hands-on lab

- Methods of Physics-Informed Machine Learning
  - Adding physical knowledge to data-driven methods
  - Reduce data needs
  - Prepare for changing scenarios

- Implementation of Physics-Informed Neural Networks
  - Solve Differential Equations
  - Able to also use data

Center for Artificial Intelligence (C4AI-USP)

- FAPESP Engineering Research Center in partnership with IBM
- Headquartered at InovaUSP
- About 250 people
- Challenges
  - Natural language processing
    - Portuguese and Indigenous Languages
  - Food distribution chains
  - AI Observatory
  - Blue Amazon Brain
  - Oceanography-Informed Machine Learning