Artificial Intelligence in Engineering and Sciences

by

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at

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Agenda

1. **What are the AI Tools?**
   (scope)
2. **What problems do they solve?**
   (domain)
3. **How do they solve problems?**
   (algorithms)

What we want to know

1. to understand the data
   (data collection, processing, and modelling)

2. to make some prediction
   (forecasting)

3. to optimize some systems
   (discovering appropriate parameters, variables, and settings)

Artificial Intelligence

to create intelligent machines that think (react) and act (work) like human beings


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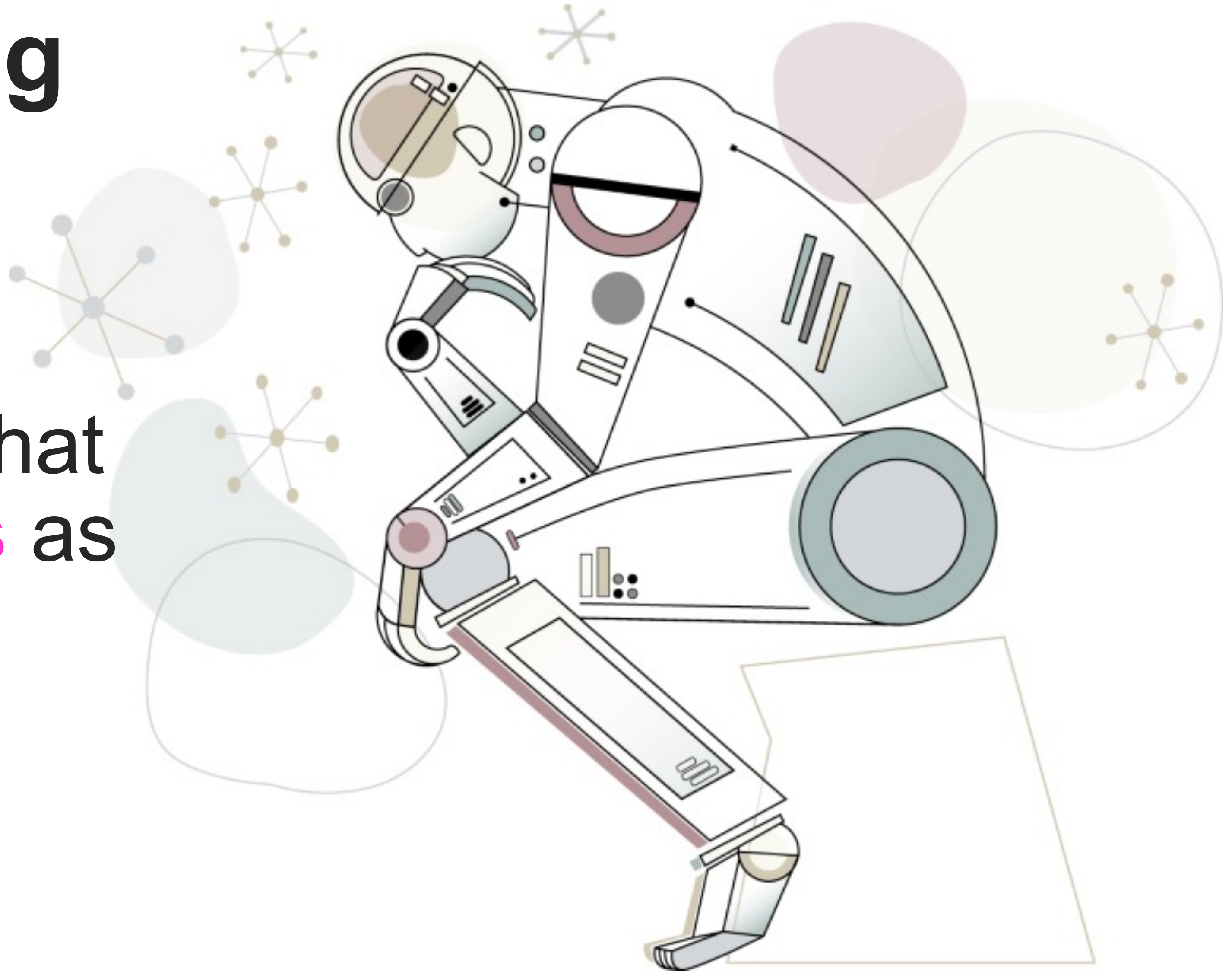
Machine Learning

to create **machines** that learn from examples as living beings do

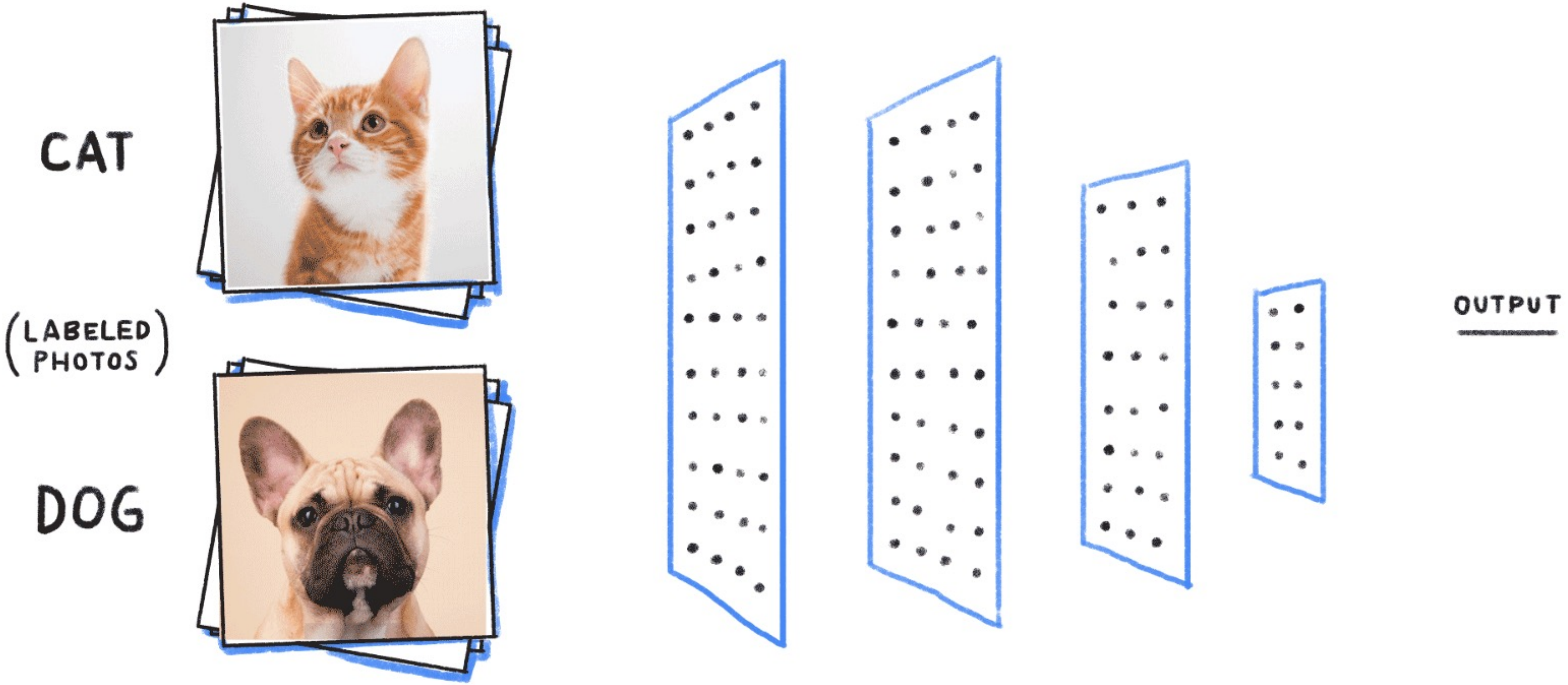


Learning

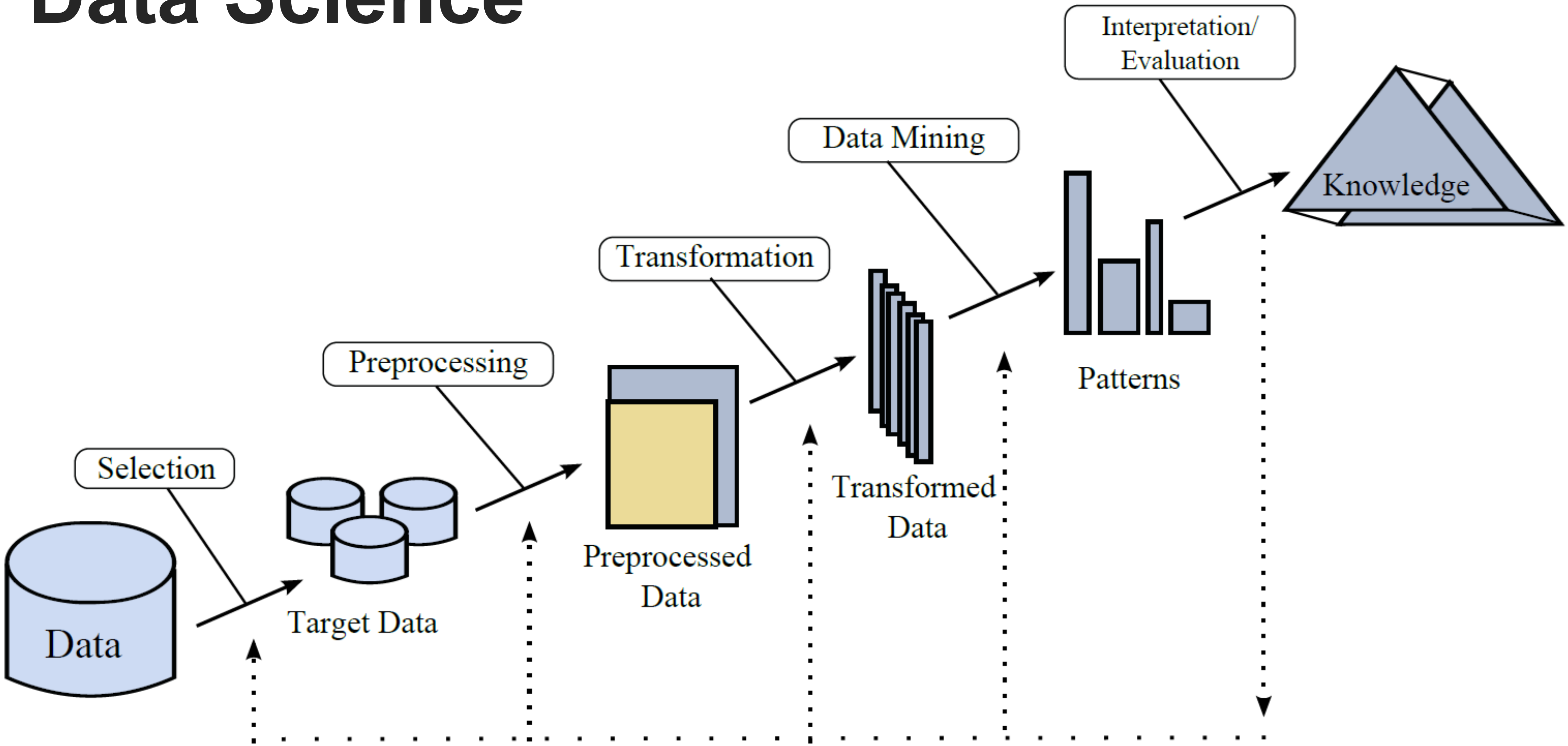
Video Source:
https://www.youtube.com/watch?v=Ak7bPuR2rDw
(Accessed on 21 February 2021)

Deep Learning

Source: https://becominghuman.ai/building-an-image-classifier-using-deep-learning-in-python-totally-from-a-beginners-perspective-be8dbaf22dd8



Data Science



Optimization

Optimization

to solve a **problem** that has a number of influencing factors that **need to attain certain value** in order to offer a **solution**

Applications of AI

1. Engineering
2. Pharmacy & Drugs
3. Environment (Physiology & Architecture)
4. Civil Engineering
5. Physics
6. Biology
7. Hydrology
8. Climate Science

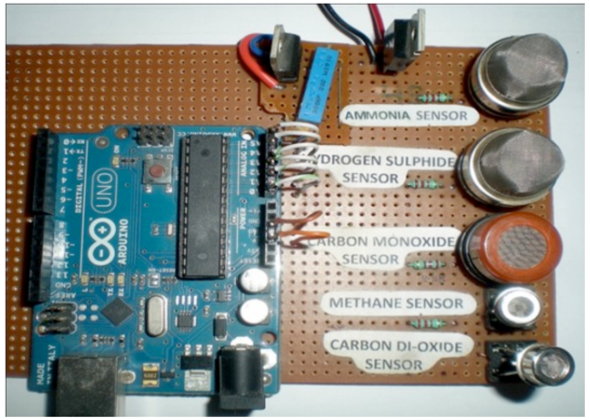
Electronics Engineering

Protection of health and life of sewer pipeline workers

Pattern Recognition

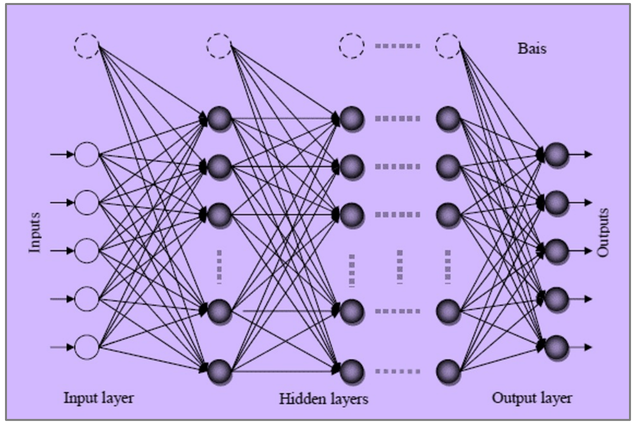
Intelligent recognizer for the component analysis of toxic mixture of (sewer) gases

Gas mixture collection



Sensor array formation

Data collection and simulation

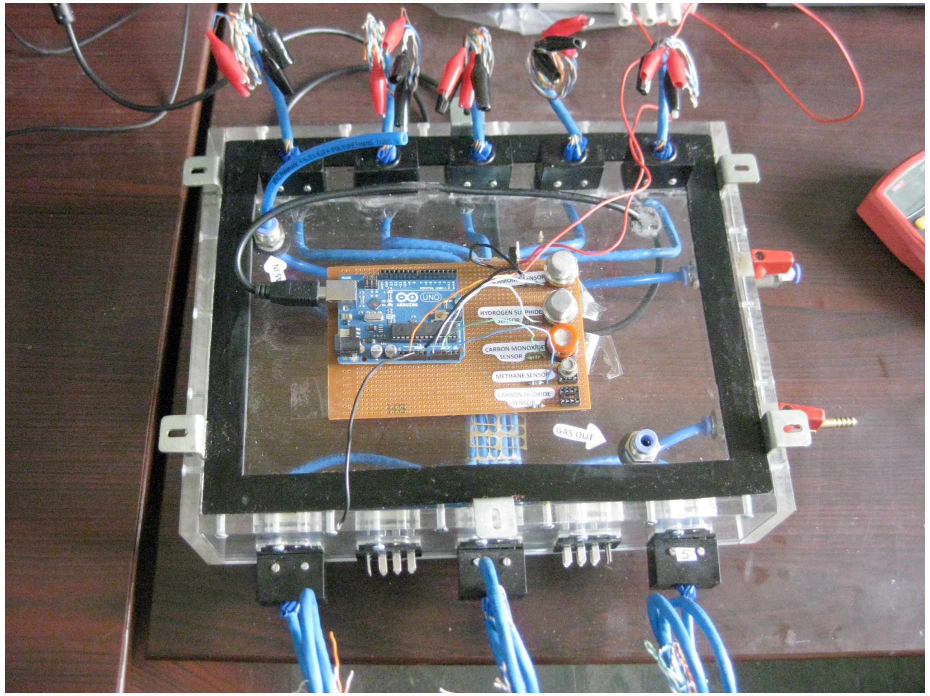


Pattern Recognition

Ojha et al. (2017) *Neural Computing and Applications: https://arxiv.org/abs/1707.00561*

Prototype of Intelligence Sensor

This was the objective ☺



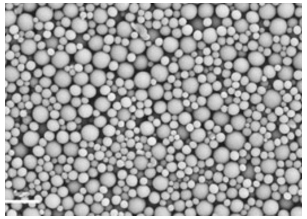
We managed to get this one nonetheless! (2011-2013)

Pharmaceutical

Drug manufacturing process variables and drug property analysis

Pharmaceutical (Drugs Production)

Pharmaceutical



Particle Properties

(Material type, density, size, shape and etc.)

Powder Properties

(Flowability, compactibility) + (Roller gap and roller speed)

Ribbon Properties

(Density, Hardness, Porosity) + (Milling speed etc.)

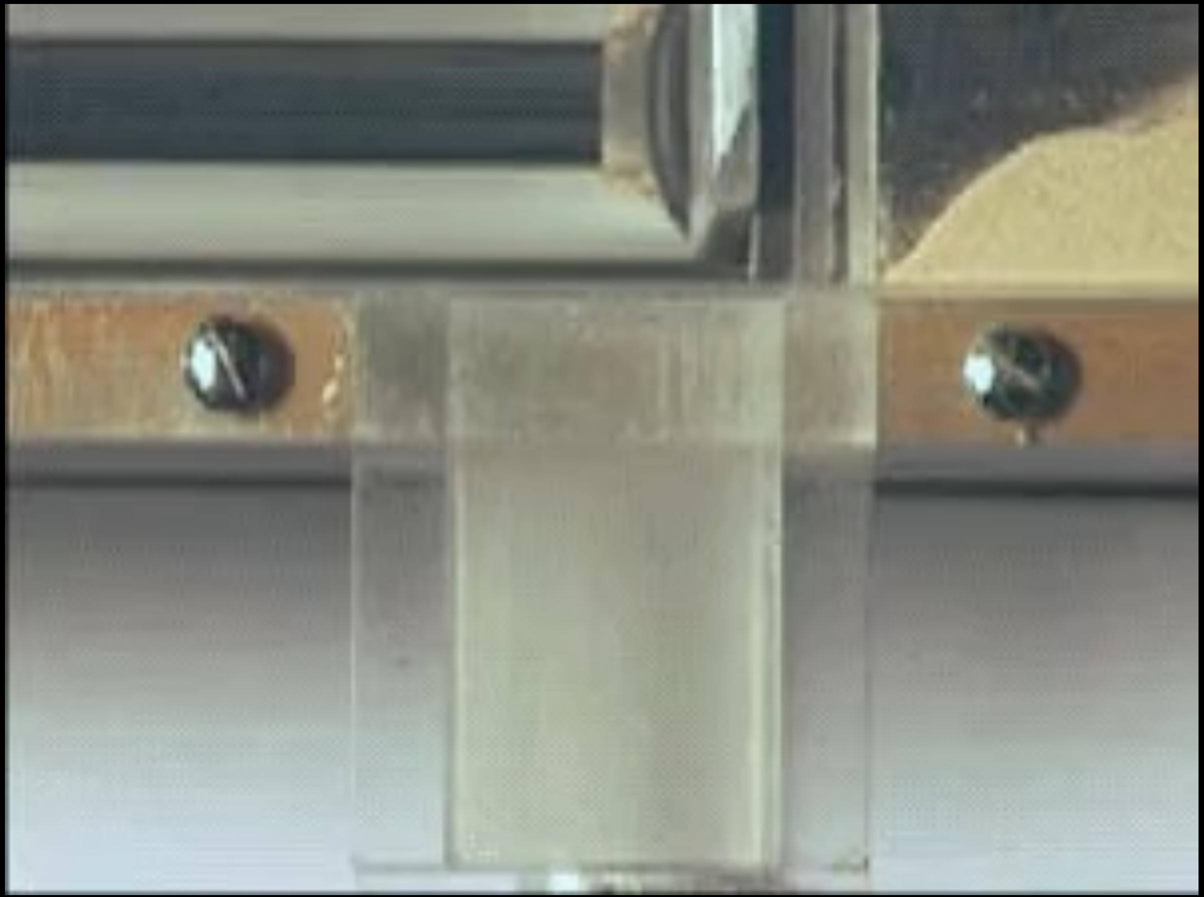
Granule Size Distribution + (die filling process)

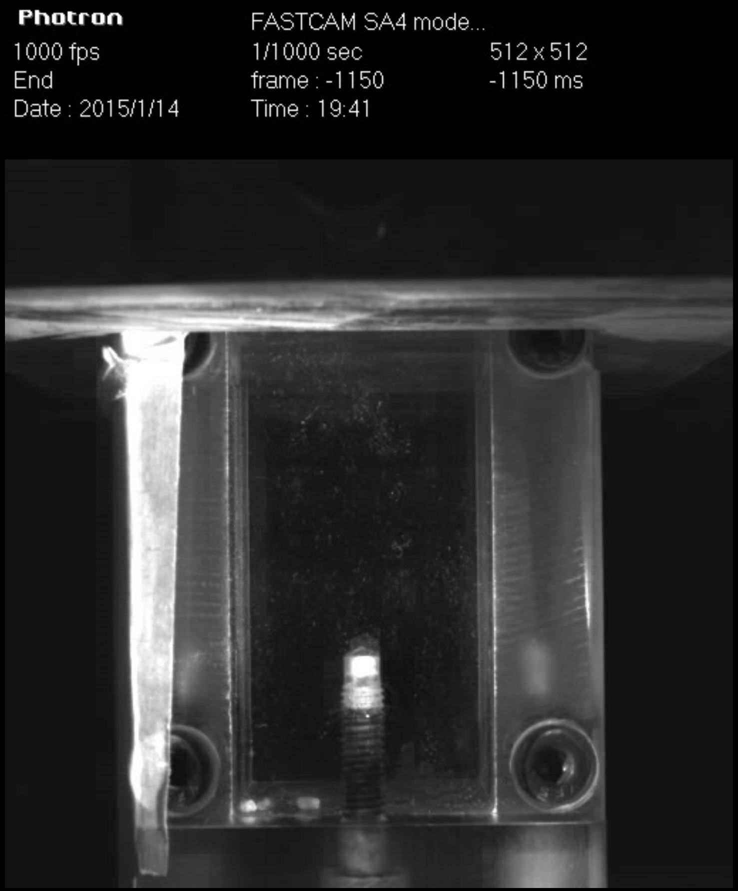
Tablet Properties

(Compressibility)

Variable Identification of Pharmaceutical Industrial Processes

Prediction of the mass of deposited drug powder





Ojha et al. (2017) *Neural Computing and Applications*

Drug Dissolution

Ojha VK et al. (2015) International Journal of Nanomedicine

Three Hundred Descriptors of Drug Properties

PLGA: poly(lactic-co-glycolic acid)

Sl No	Group name	No of features	Importance
1	Protein descriptors	85	Describes the type of molecules and proteins used
2	Formulation characteristics	17	Describe the molecular properties such as molecular weight, particle size, etc
3	Plasticizer	98	Describe the properties such as fluidity of the material used
4	Emulsifier	99	Describe the properties of stabilizing/increase the pharmaceutical product life
5	Time in days	1	Time taken to dissolve
6	% of molecules dissolved	1	Output

Abbreviations: PLGA, poly(lactic-co-glycolic acid); Sl, serial; No, number.

Ojha et al. (2015) *International Journal of Nanomedicine*
https://doi.org/10.2147/IJN.S71847

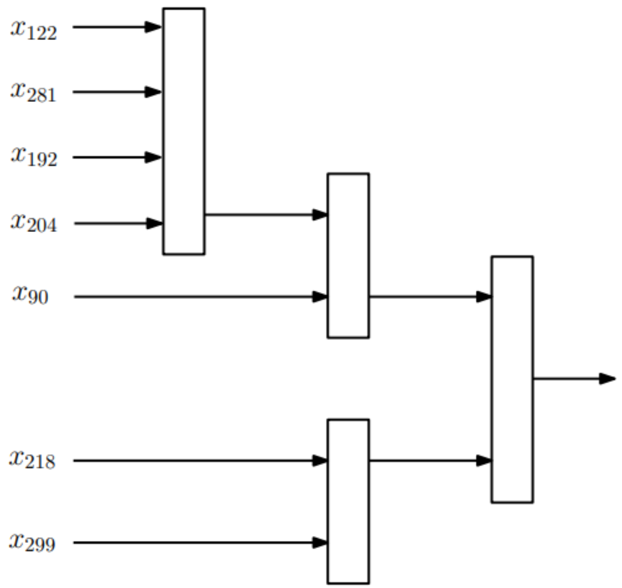
Balancing Prediction and Feature Selection

Algorithm	RMSE E_t	No. of features
MLP	14.3	17
Neural Tree	13.2	15
REP Tree	13.3	15
GPR	14.9	15
MLP	15.2	15
MLP	15.4	11
Type 1 Tree	18.6	7
Type 2 Tree	15.2	4

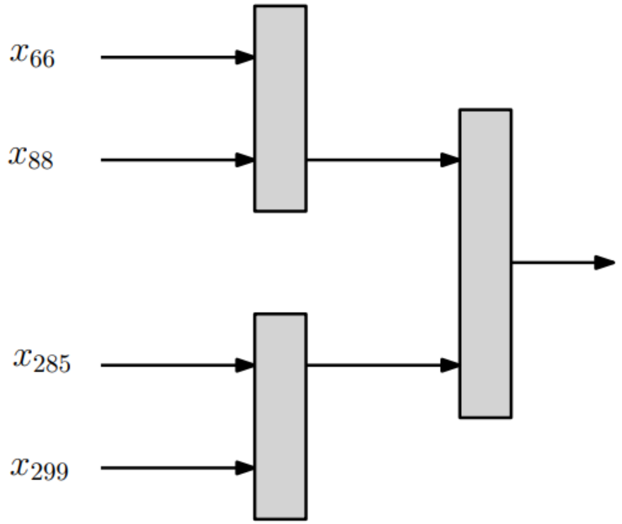
Ojha et al. (2018) *IEEE Transactions on Fuzzy Systems*
https://arxiv.org/abs/1705.05769

A Tree Model for Future Use

Can we also explain how the prediction was made?



Type 1 Tree



Type 2 Tree

If *protein* is **A** and *plasticizer* is **B**, **Then** % *molecule dissolution* is **X**

Ojha et al. (2018) *IEEE Transactions on Fuzzy Systems*
https://arxiv.org/abs/1705.05769

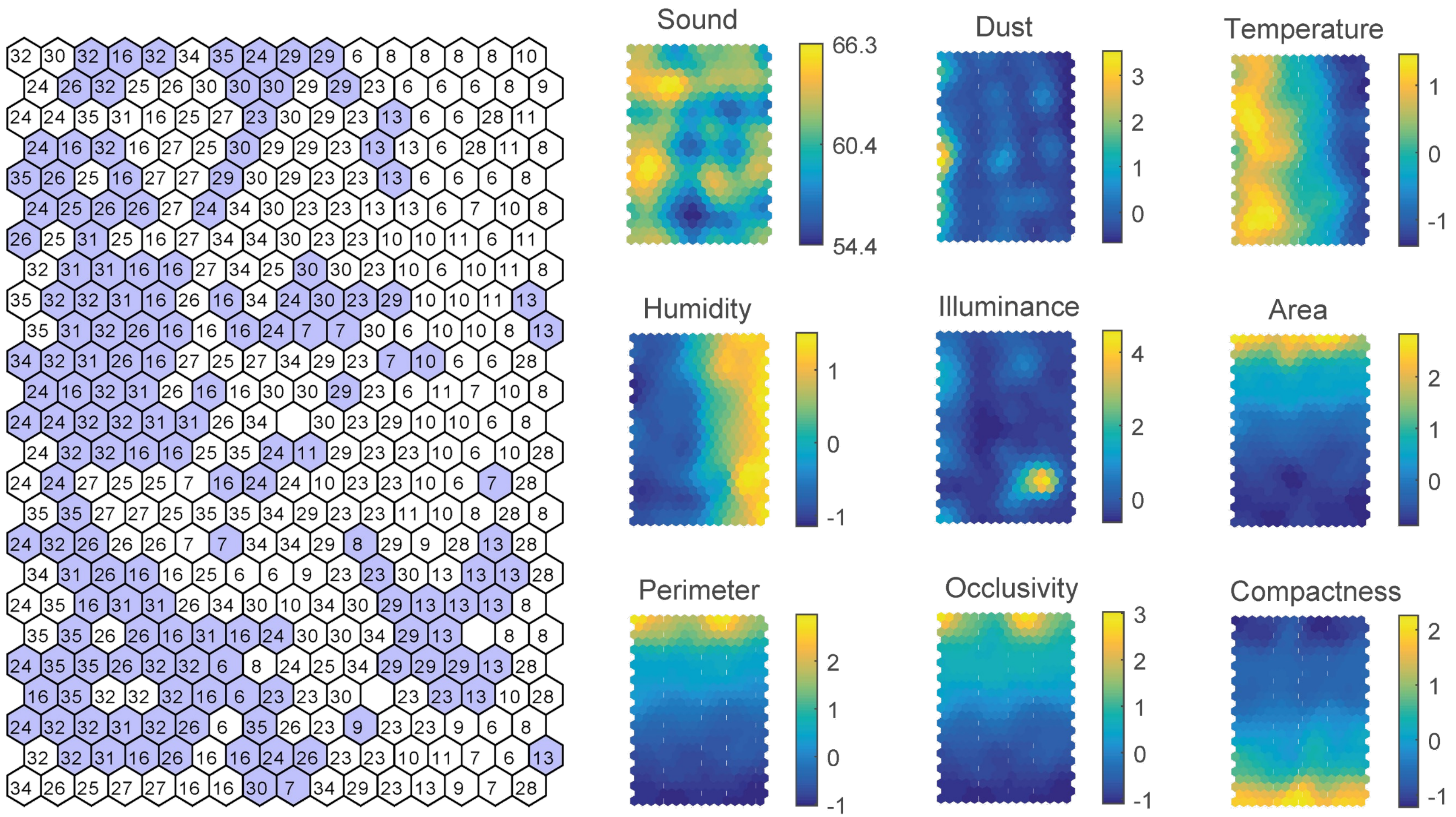
Build Environment

Understanding impact of environment and urban dynamics on humans

Perception of the Environment

Ojha et al. (2019) *Information Sciences* | Buš & Ojha (2017), *ETH Zurich*

Perceptual Experience



Ojha et al. (2019) *Information Sciences* | Buš & Ojha (2017), *ETH Zurich*
https://arxiv.org/abs/1812.06128

Civil Engineering

Structure buckling analysis

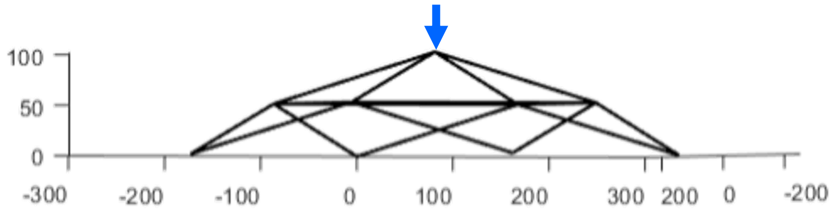
Civil Engineering Problem

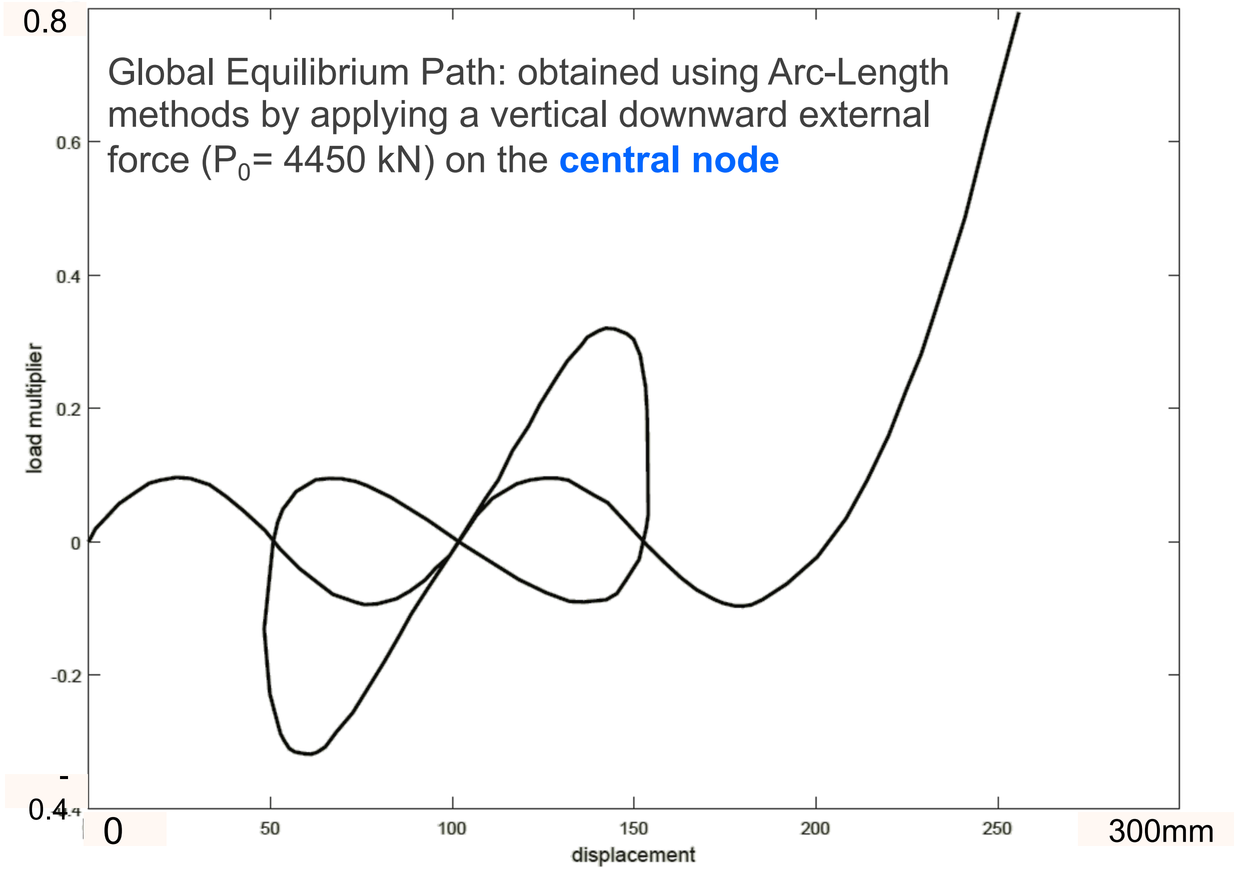
Civil Engineering Problem

A tiny version of Millennium Dome can be the following structure

External force (P_0= 4450 kN)



Dimensions in mm



Hrinda, G. (2010, April). Snap-through instability patterns in truss structures. In 51st AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference 18th AIAA/ASME/AHS Adaptive Structures Conference 12th (p. 2611).

Civil Engineering Problem

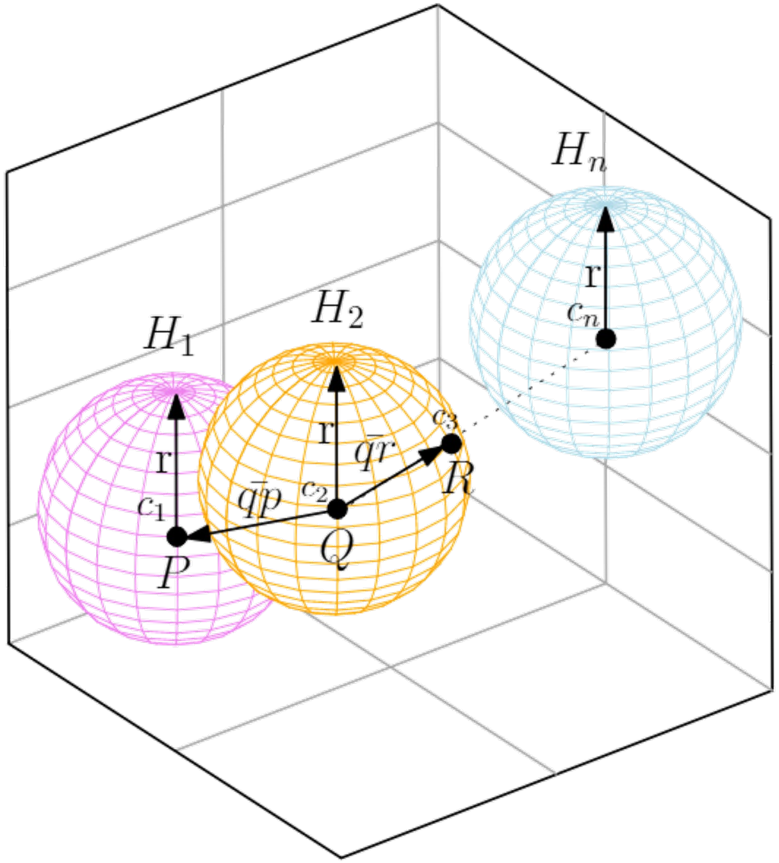


Fig A. Adaptive Hypersphere Search Algorithm for Structural Static Analysis

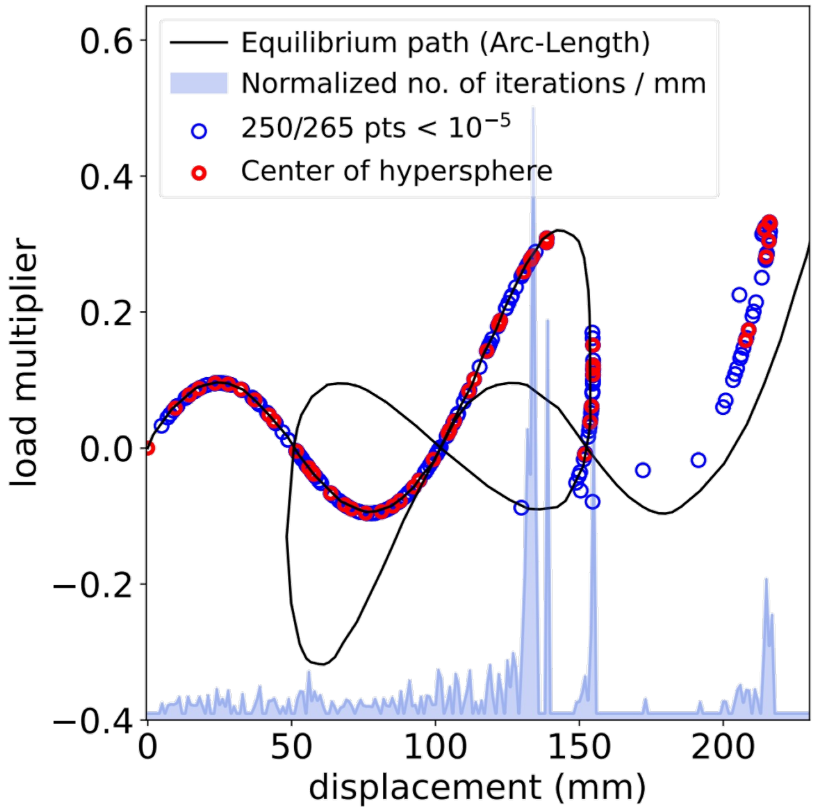
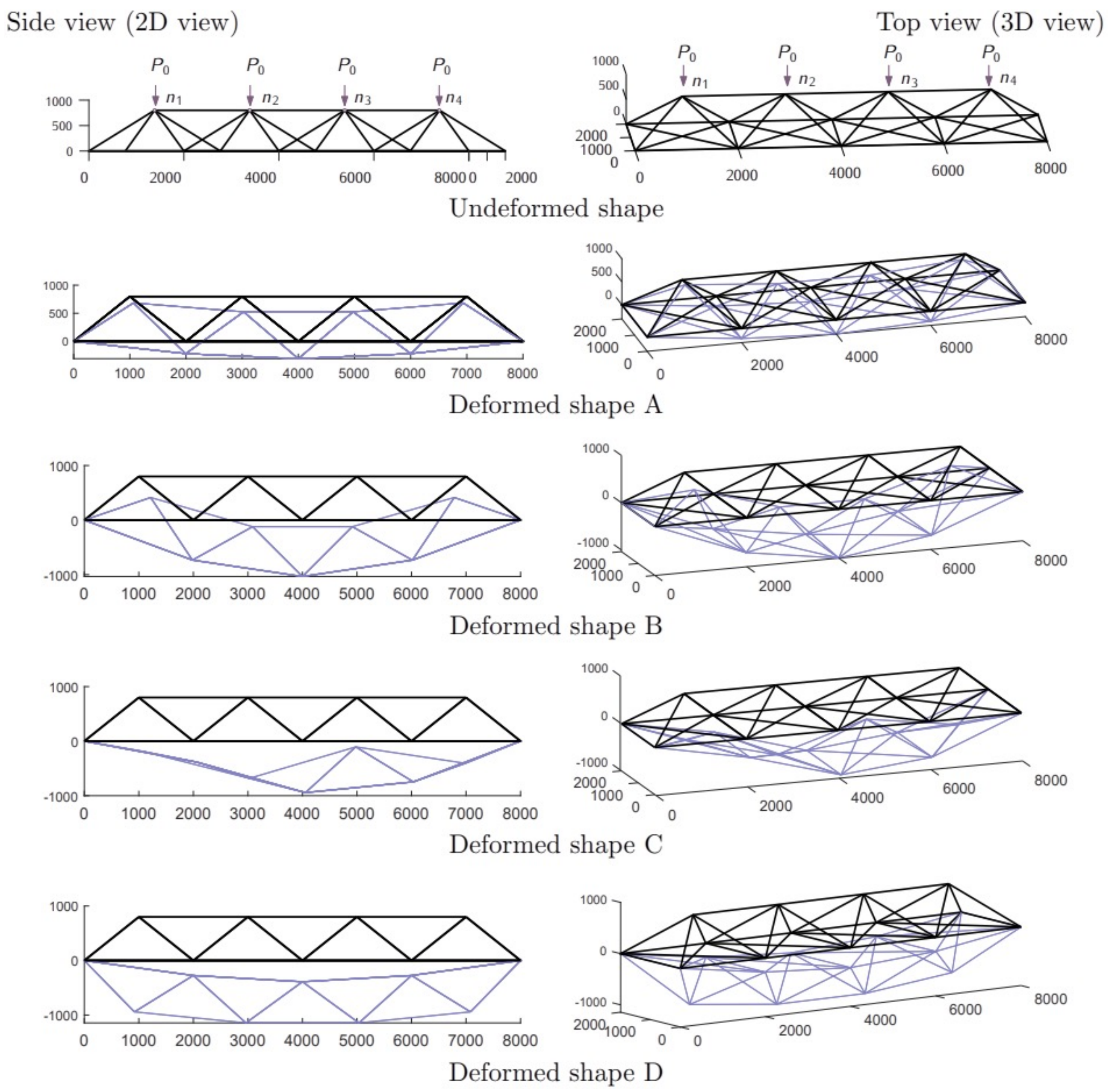
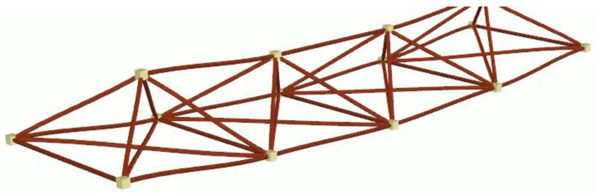
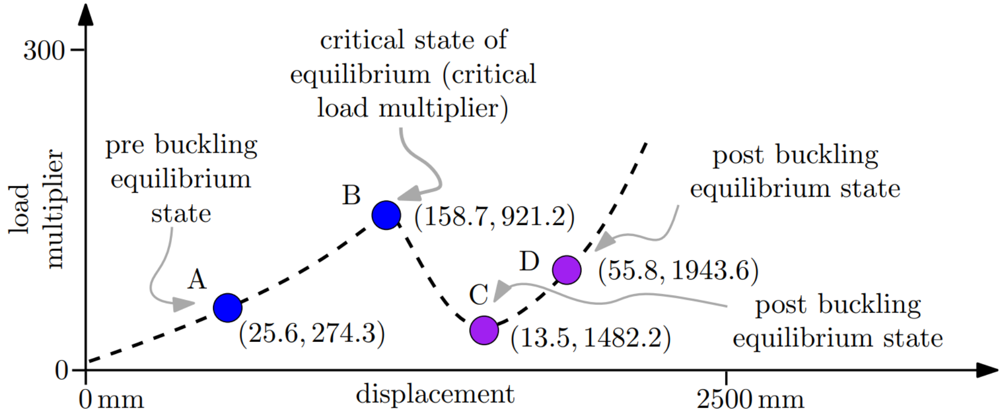


Fig B. Equilibrium Path traced using Adaptive Hypersphere Search Algorithm

Ojha et al (2022), *Engineering Application of Artificial Intelligence*
https://arxiv.org/pdf/2211.07519.pdf





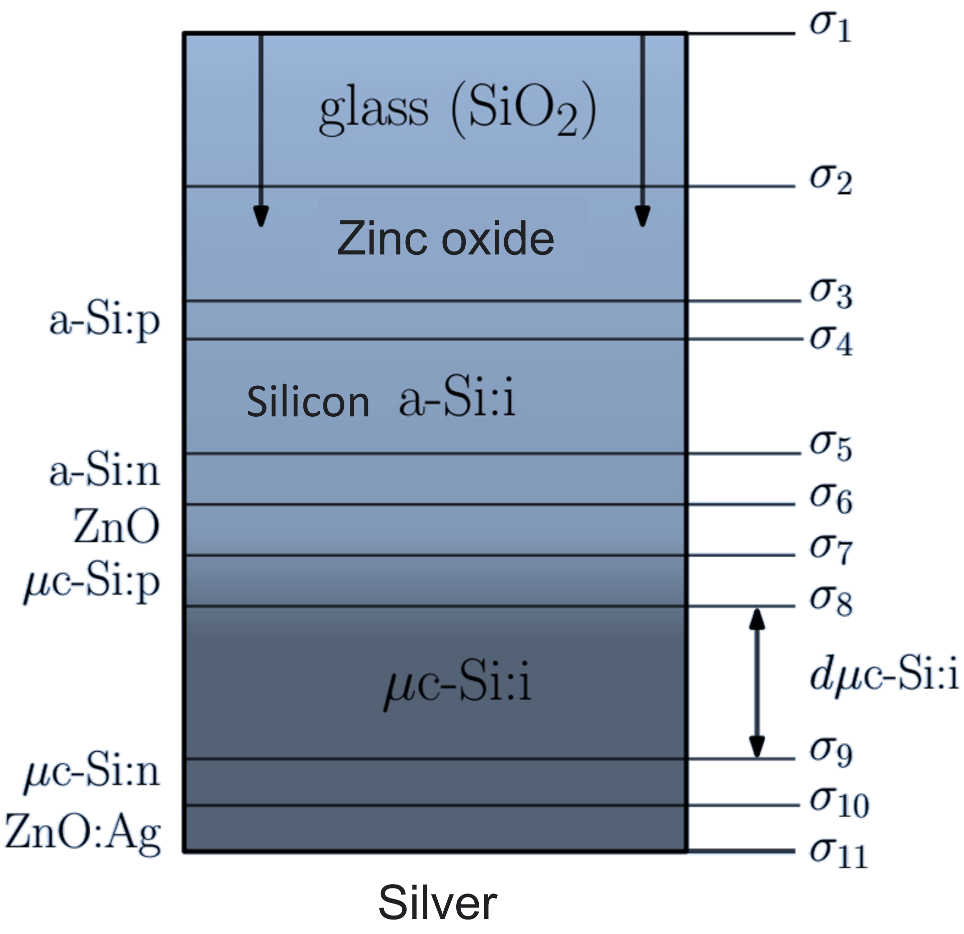


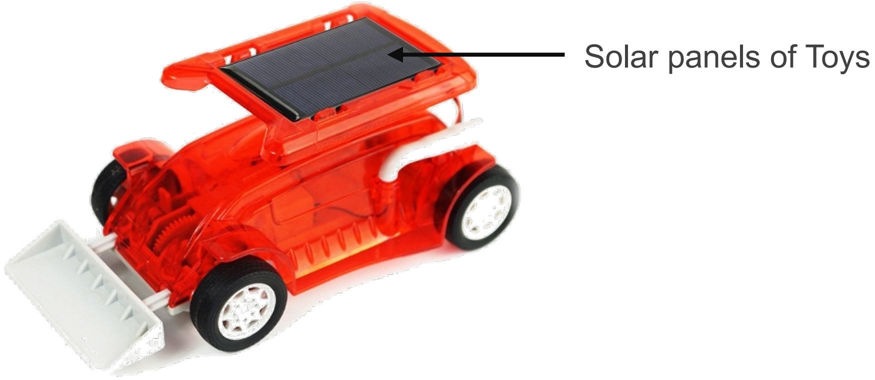
Ojha et al (2022), *Engineering Application of Artificial Intelligence*

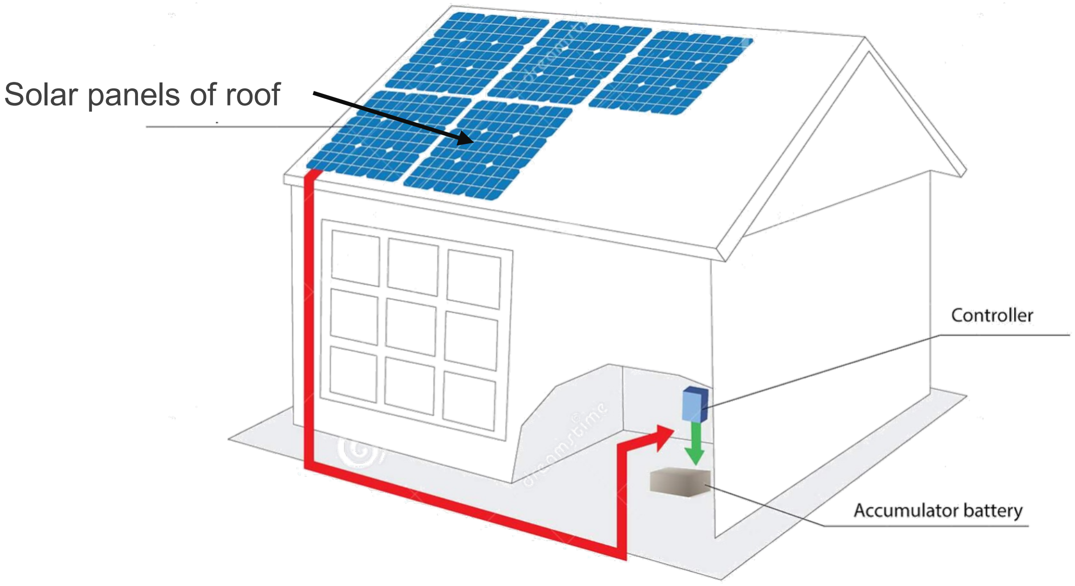
Physics

Solar cell design and characterization

Solar Cell – Energy Optimization



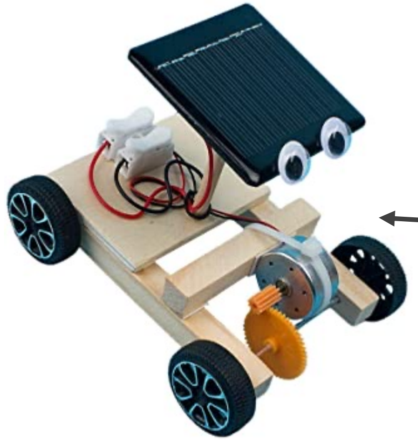


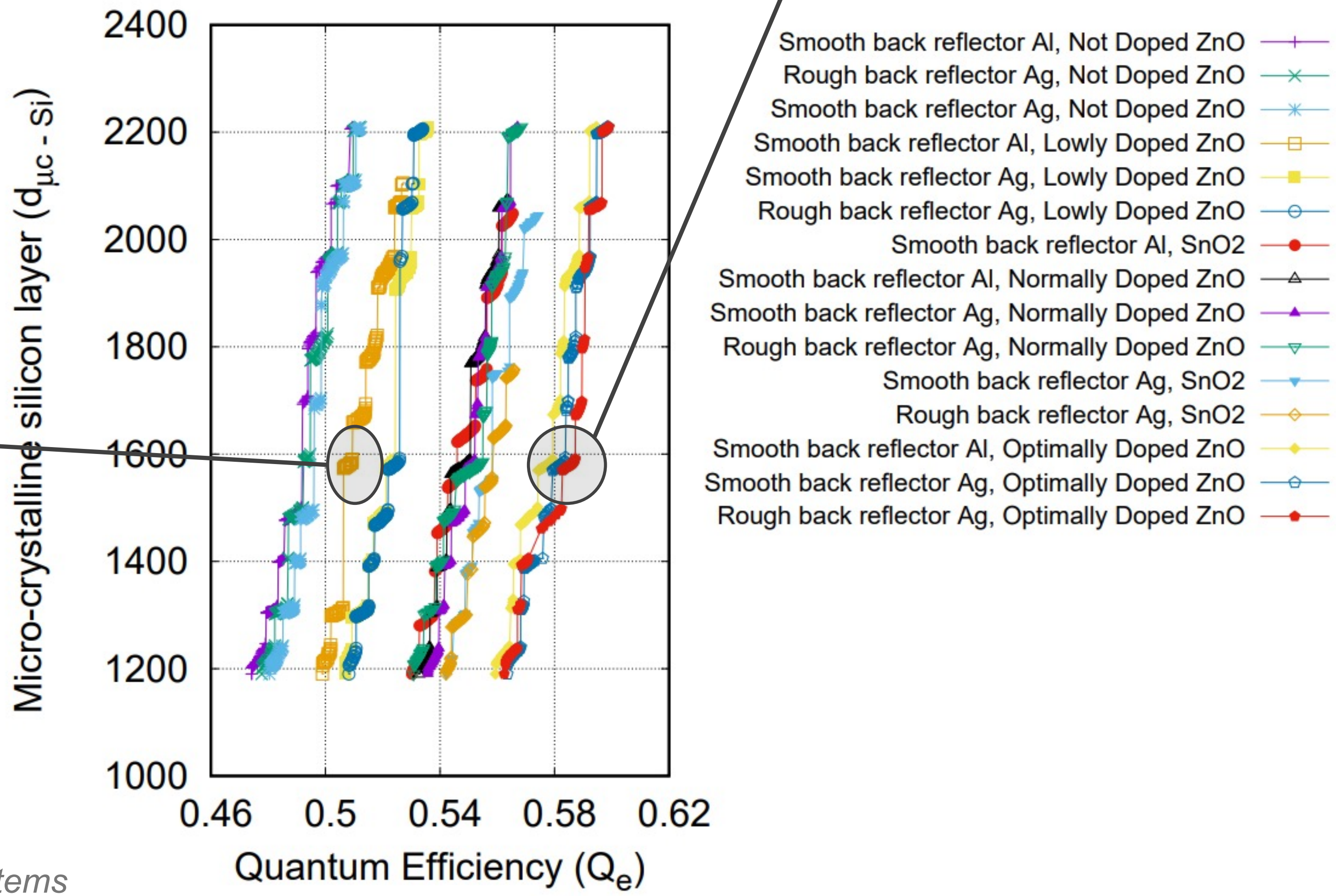


Ojha et al. (2021) *Energy Systems*
https://arxiv.org/abs/2109.07279

Solar Cell

Cost and Efficiency Trade-offs for its Usage



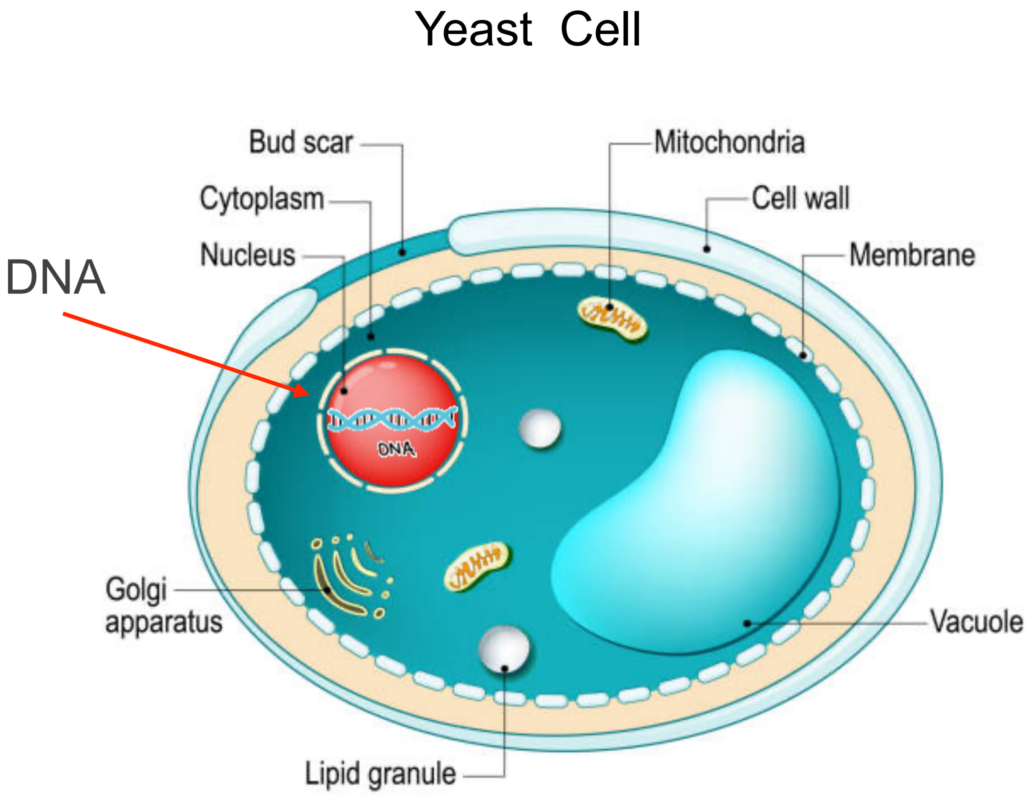


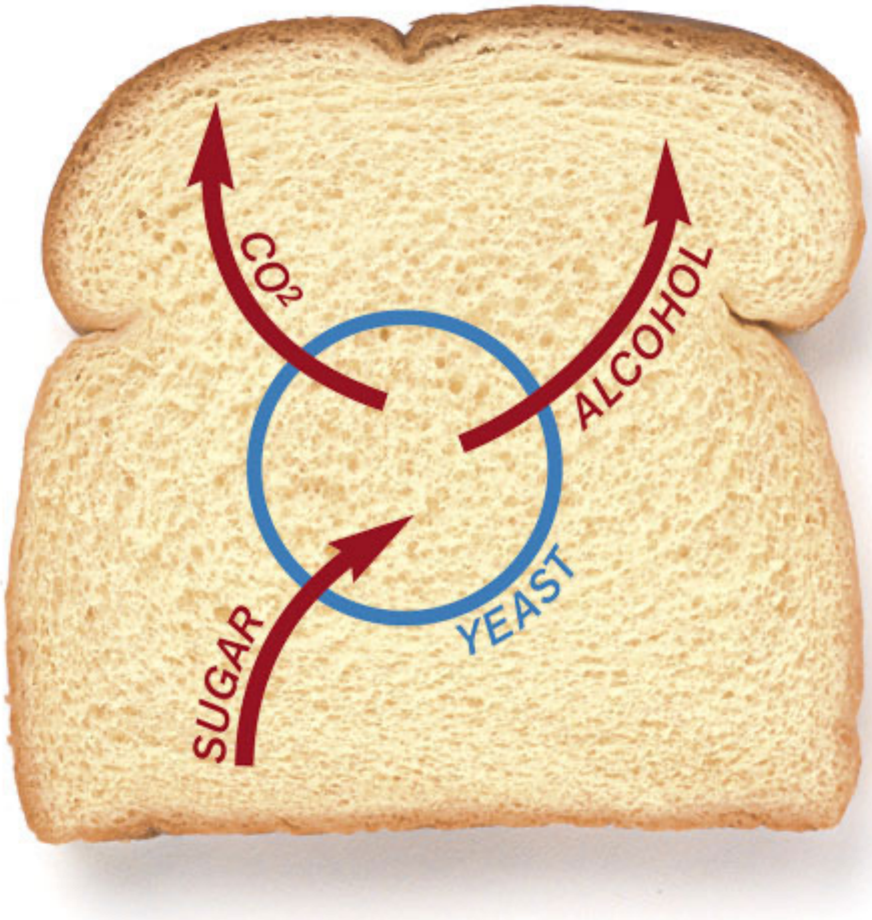
Ojha et al. (2021) *Energy Systems*
https://arxiv.org/abs/2109.07279

Biology

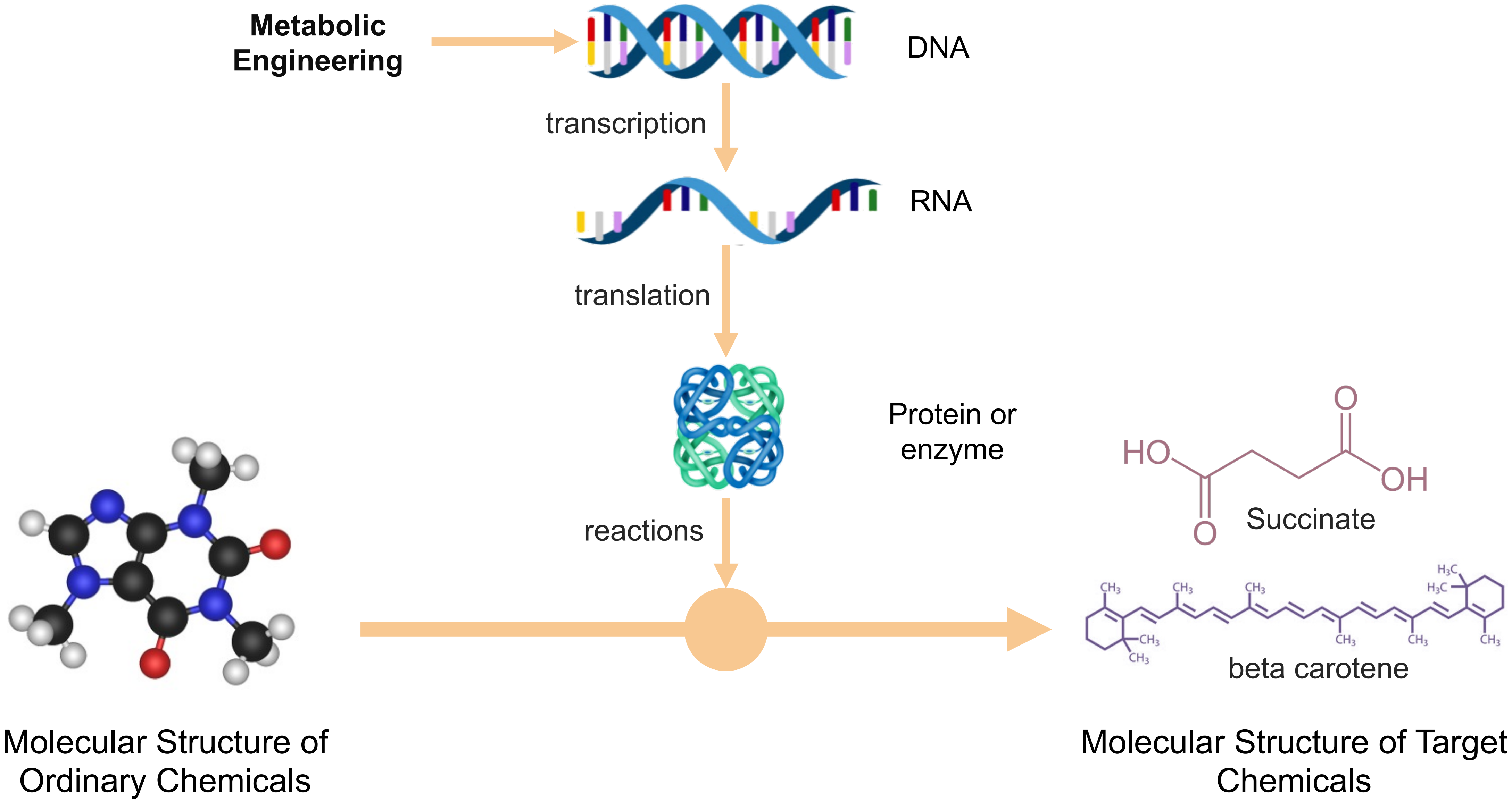
Metabolic engineering (searching for best strains)

Role of Yeasts in Food Production



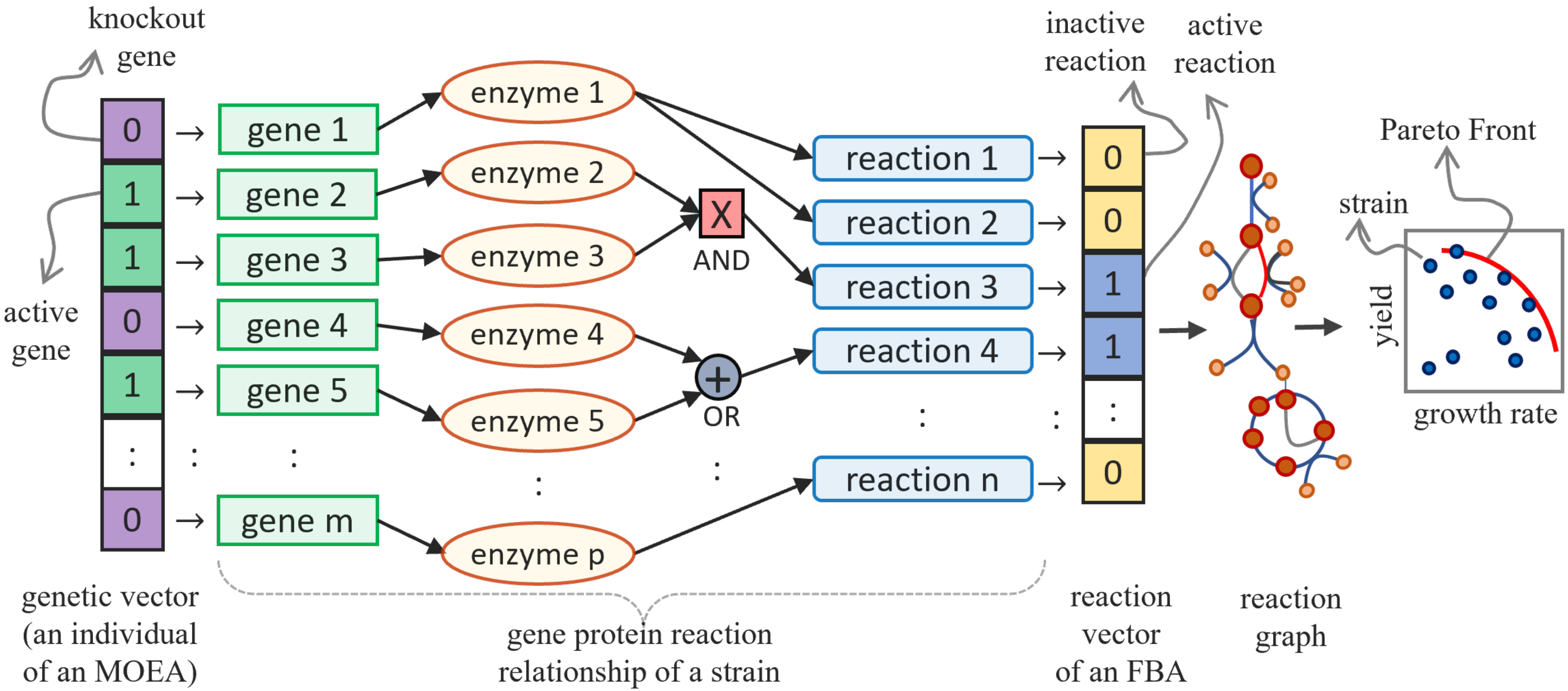


Ojha et al. (2022) *Bioengineering & Biotechnology*
https://doi.org/10.1002/bit.28103



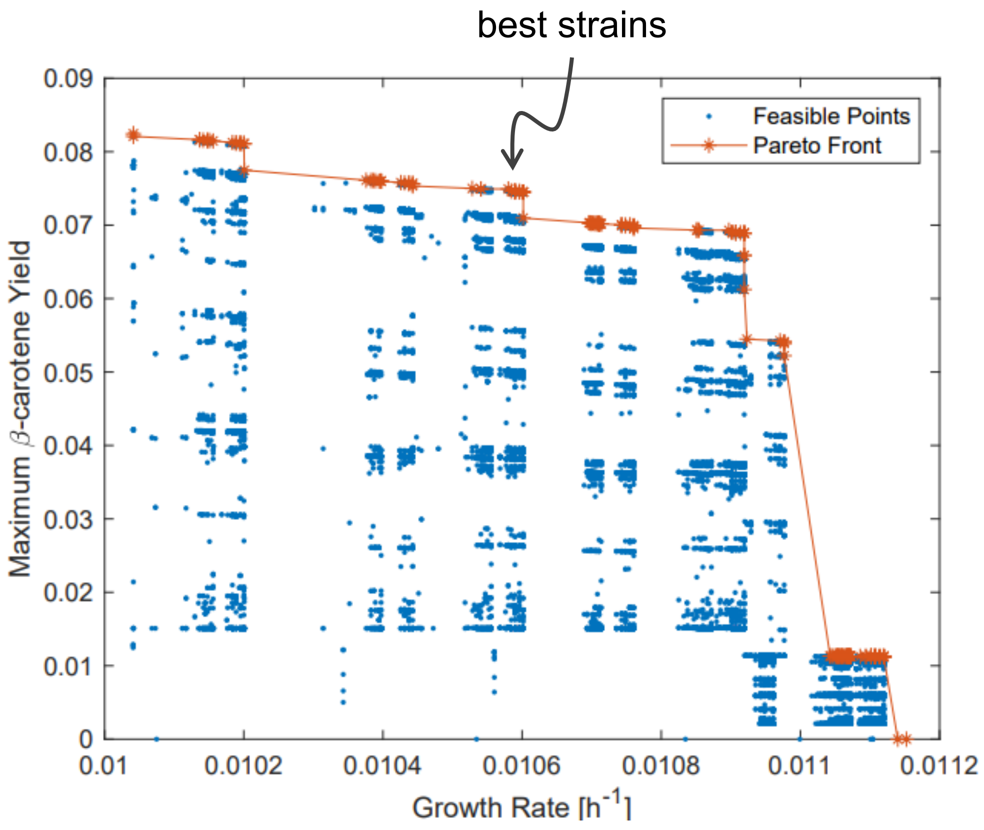
Ojha et al. (2022) *Bioengineering & Biotechnology*
https://doi.org/10.1002/bit.28103

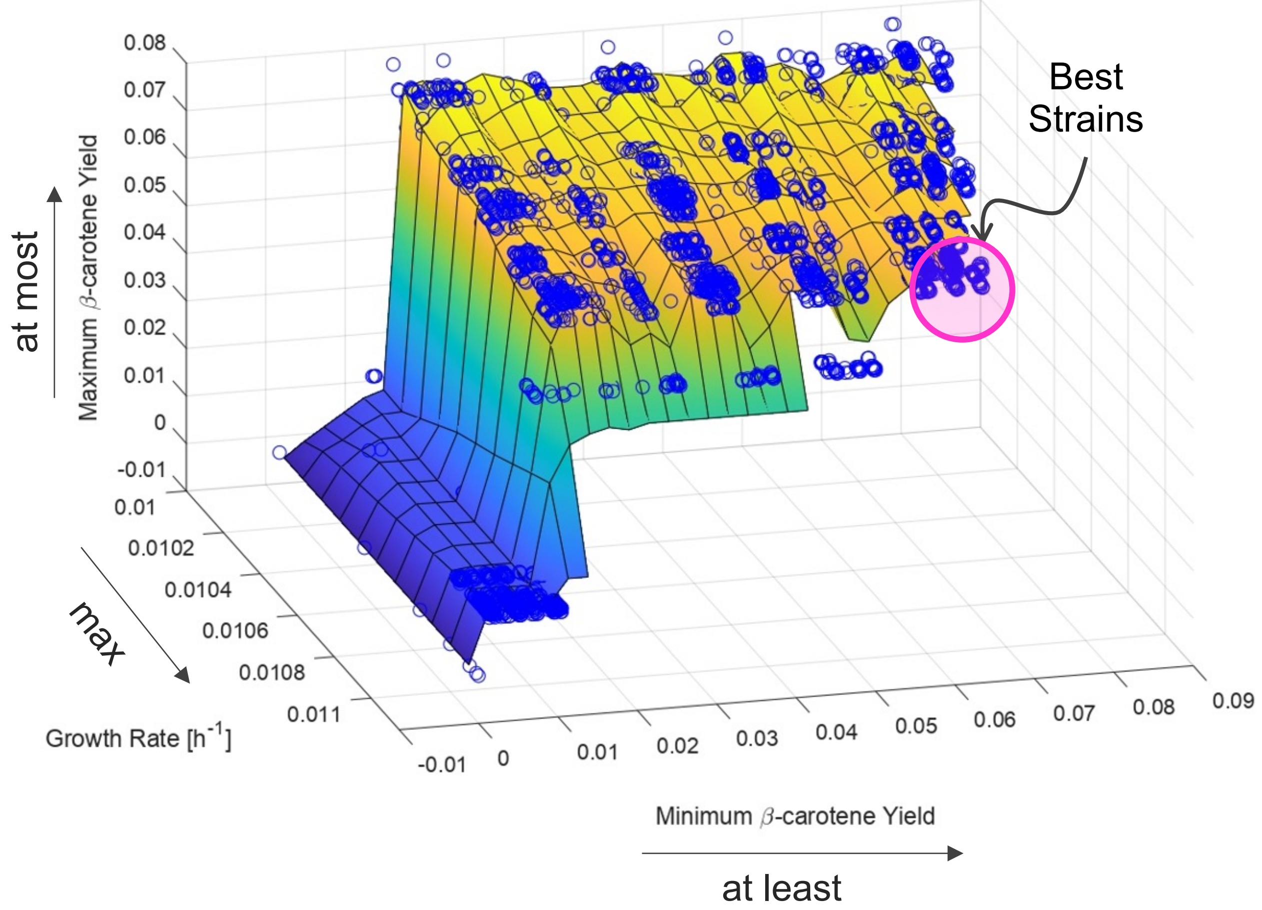
Metabolic Engineering for Chemical Production



Ojha et al. (2022) *Bioengineering & Biotechnology*
https://doi.org/10.1002/bit.28103

Optimal Strains of Yeast





Ojha et al. (2022) *Bioengineering & Biotechnology*
https://doi.org/10.1002/bit.28103

Hydrology

Prediction of flood events

Hydrology: Flood Event Prediction

A collaboration with Meteorology (Prof. Sarah Dance and Remy Vandaele)

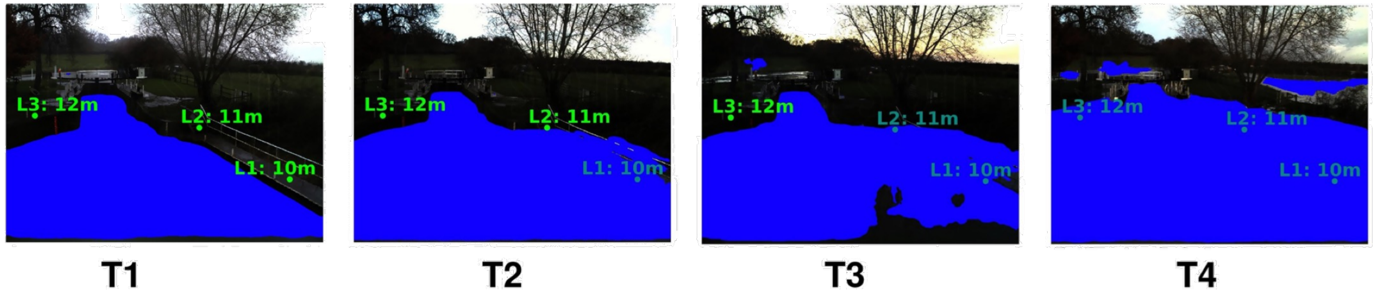


Fig. Time-series sequence of images of river. Blue pixels are water segmentation by using deep learning models

Credit: Farson Digital Watercams
https://www.farsondigitalwatercams.com/locations/keswick_greta

Vandaele, Dance, and Ojha, (2020), *GCPR*

https://doi.org/10.1007/978-3-030-71278-5

Hydrology: Flood Event Prediction

A collaboration with Meteorology (Prof. Sarah Dance and Remy Vandaele)

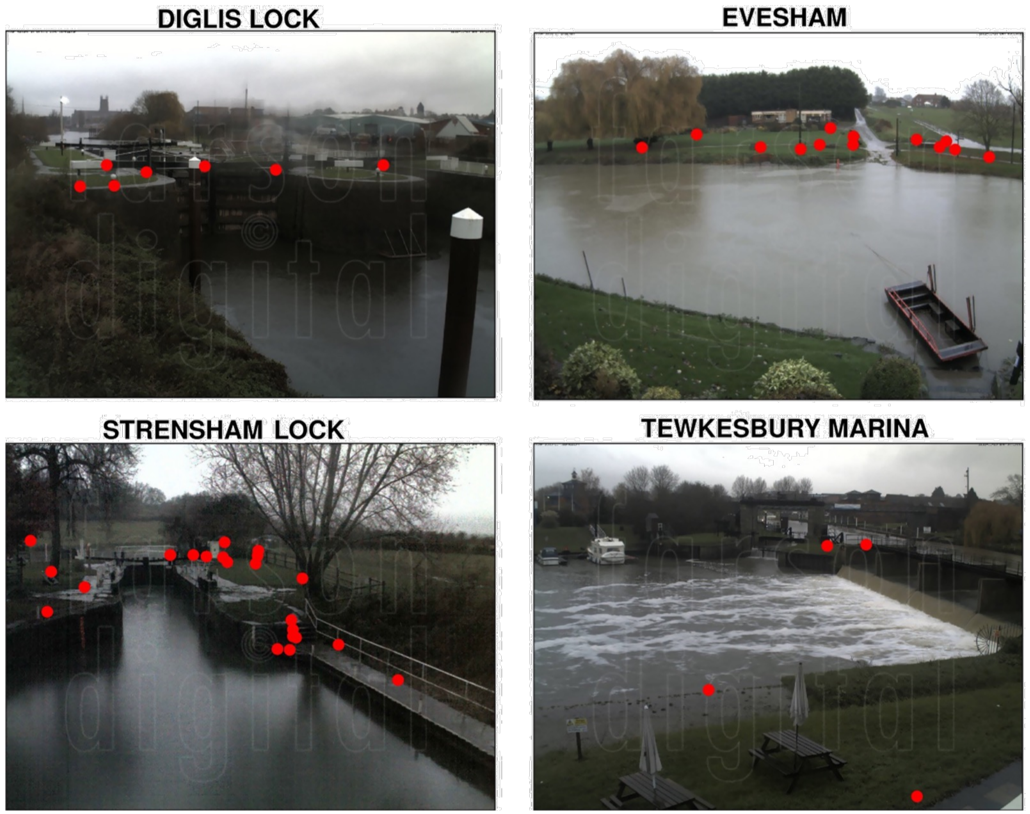


Fig A. Customized dataset:

Landmark annotation of waterline

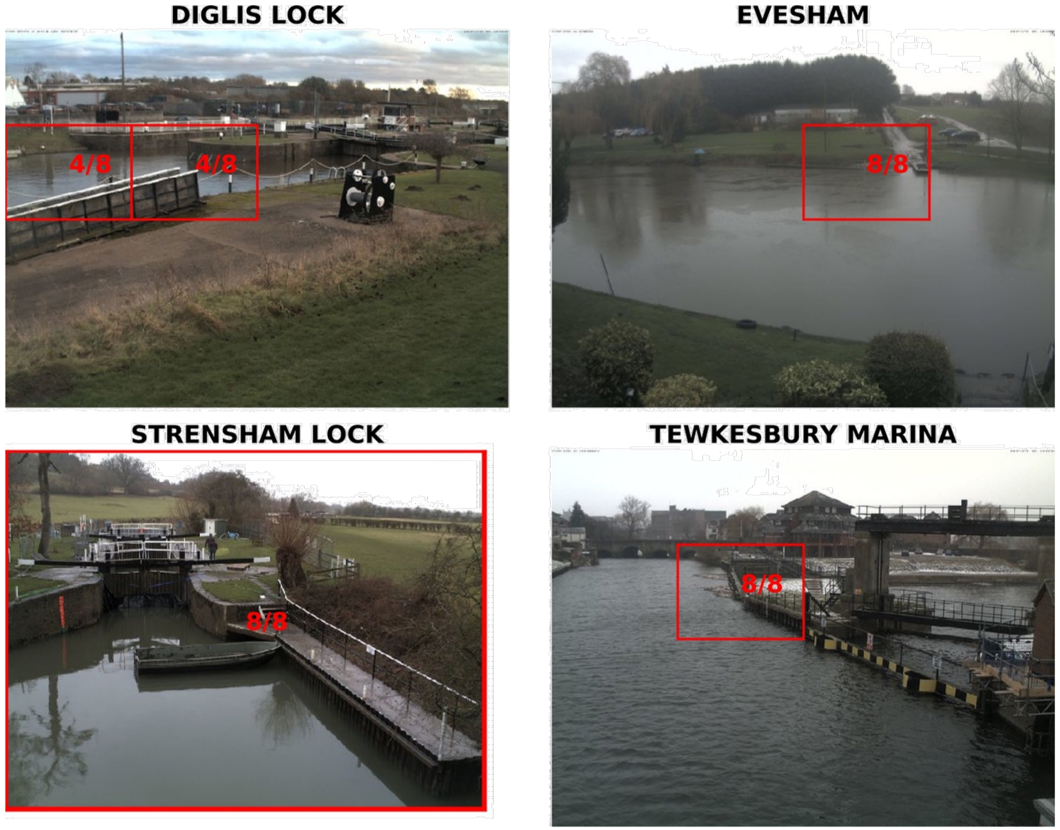


Fig B. Best window identification for prediction accuracy.

We achieve 94% accuracy in correctly predicting real flood events.

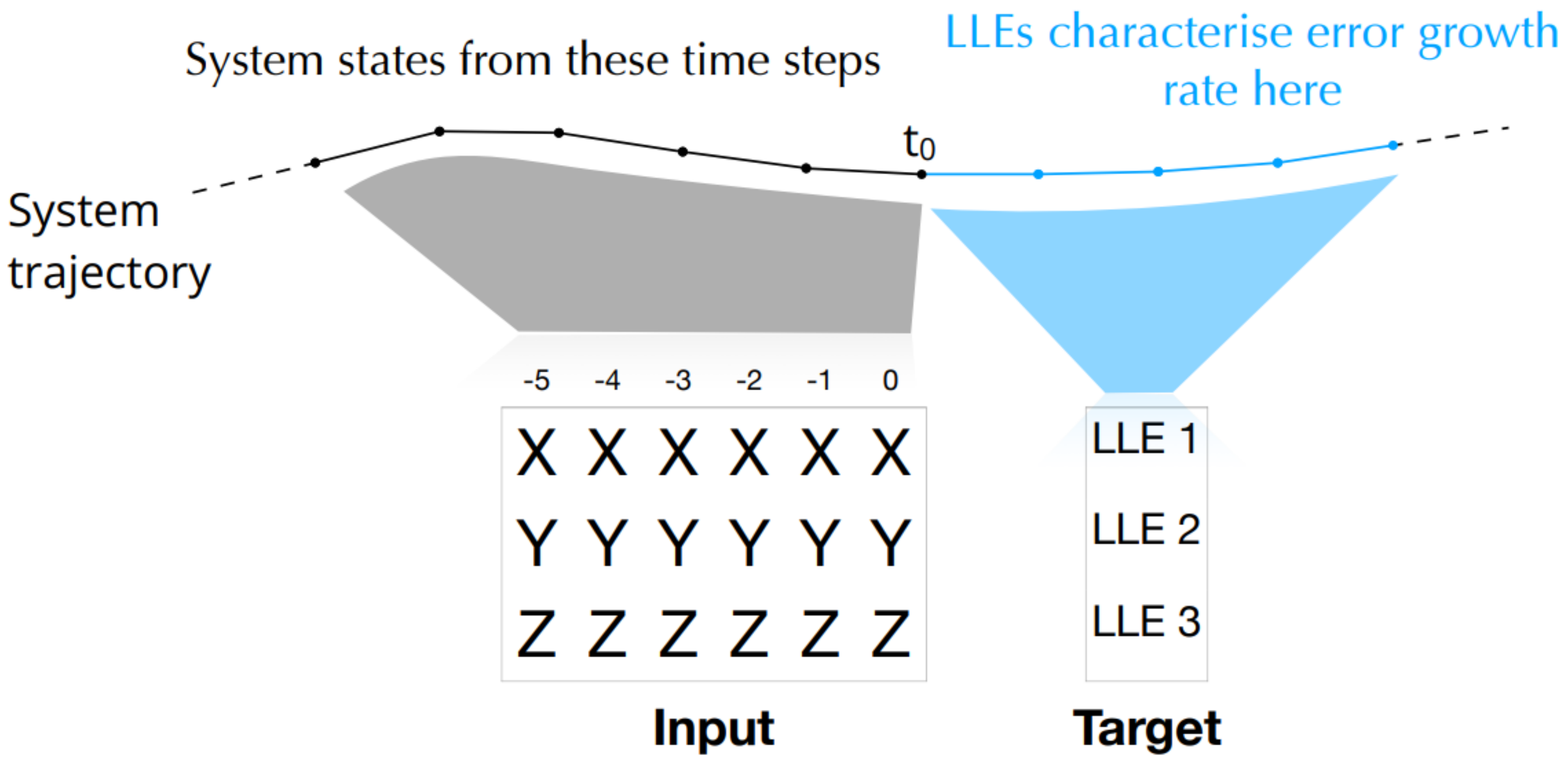
Vandaele, Dance, and Ojha, (2021) *Hydrology and Earth System Sciences*

https://doi.org/10.5194/hess-25-4435-2021

Climate Science

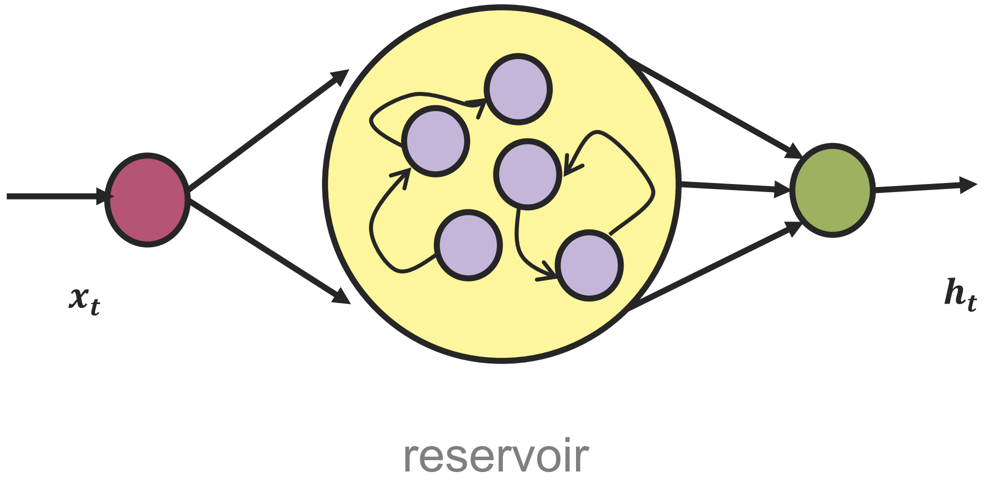
Non-intrusive modelling of dynamical systems

Predicting Instabilities in Chaotic Systems

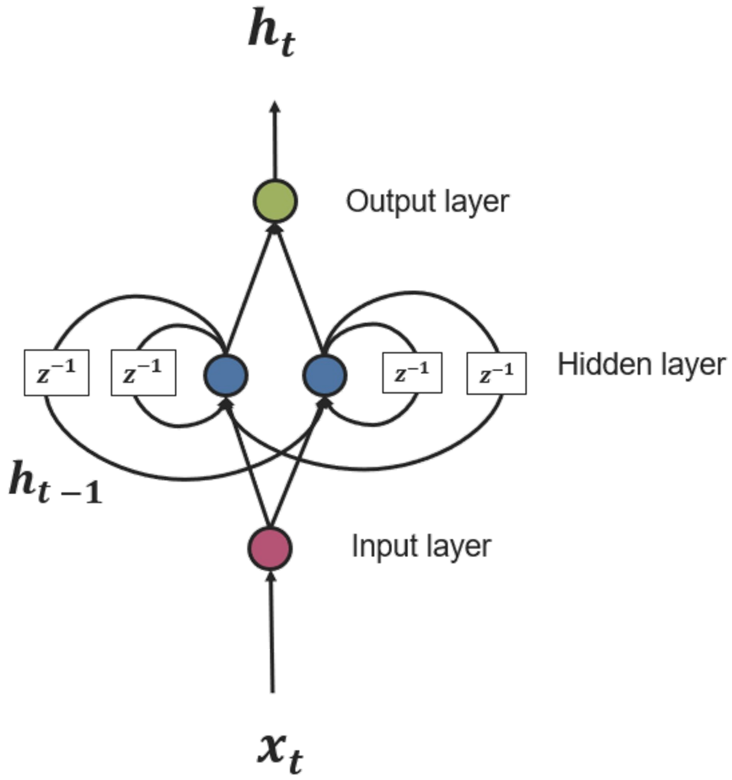


Machine Learning Algorithms to Use

Supervised **recurrent neural networks** for the reconstruction short term dynamics



Eco State
Network



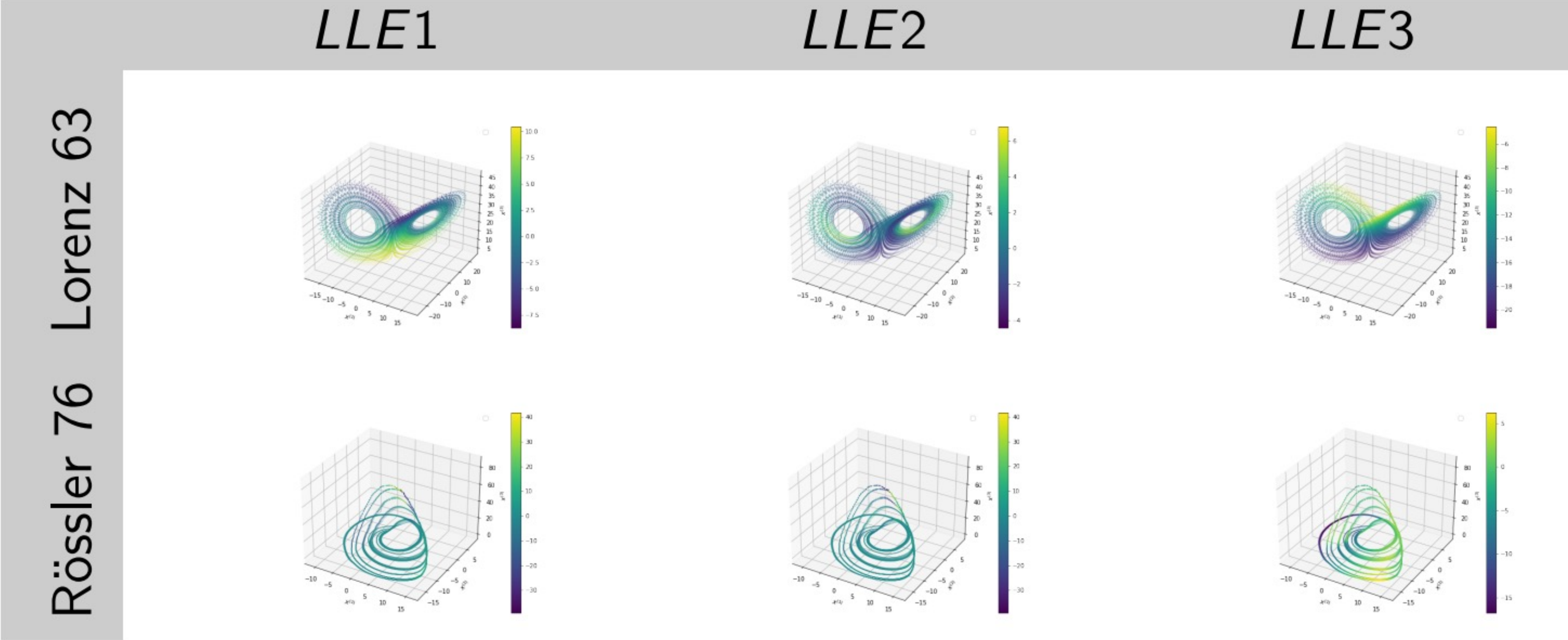
Long Sort Term
Memory

What LOSS function can we use?

We can consider two types of losses:

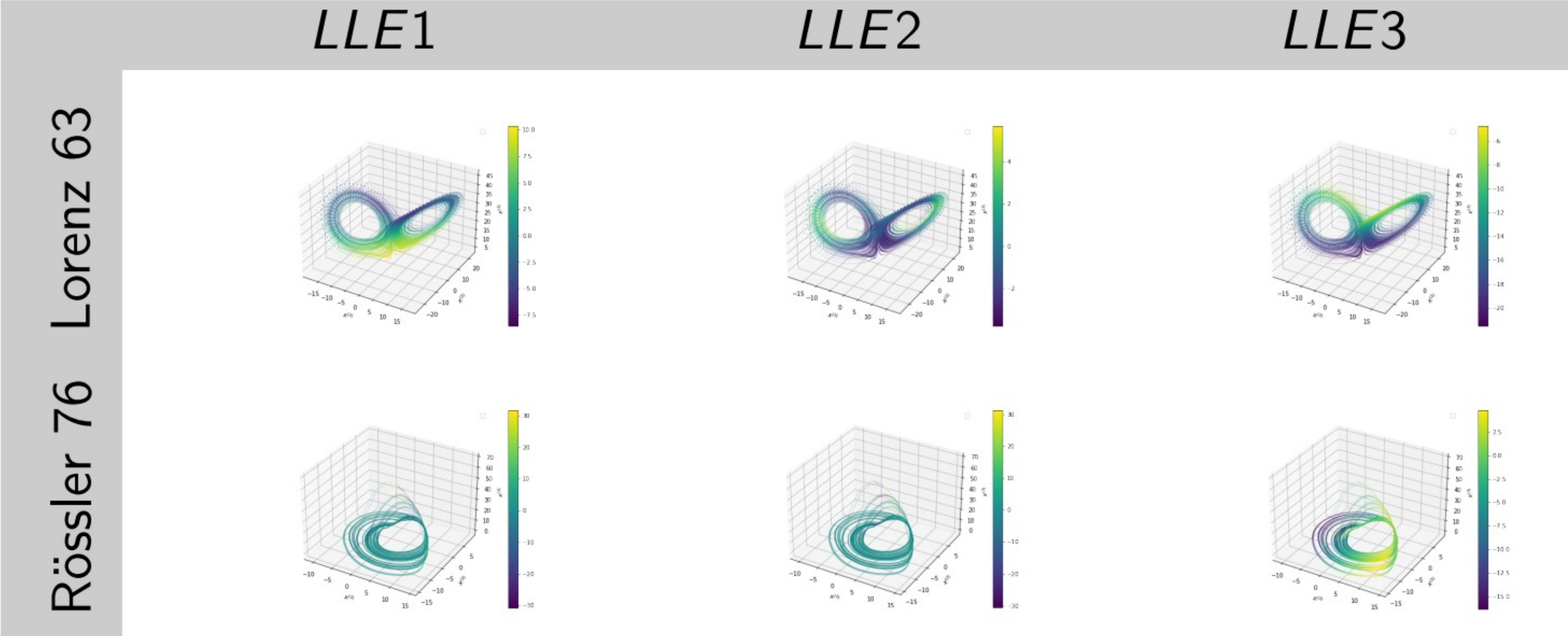
- **Purely Data Driven loss (Neural Nets):**
  - $loss = \frac{1}{N}\sum\left(x_{t+1} - f(x_t)\right)^2$
- **Physics Informed loss (Physics Informed Neural Nets)**
  - $loss = \frac{1}{N}\sum\left(x_{t+1} - f(x_t)\right)^2 + \mathrm{physics}\ (\mathrm{e.g}, |\mathrm{RK}_4\ (\mathrm{x_t}) - \mathrm{RK}_4(\mathrm{f}(\mathrm{x_t})|)$

Data Driven Neural Nets
(prediction of short term dynamics)

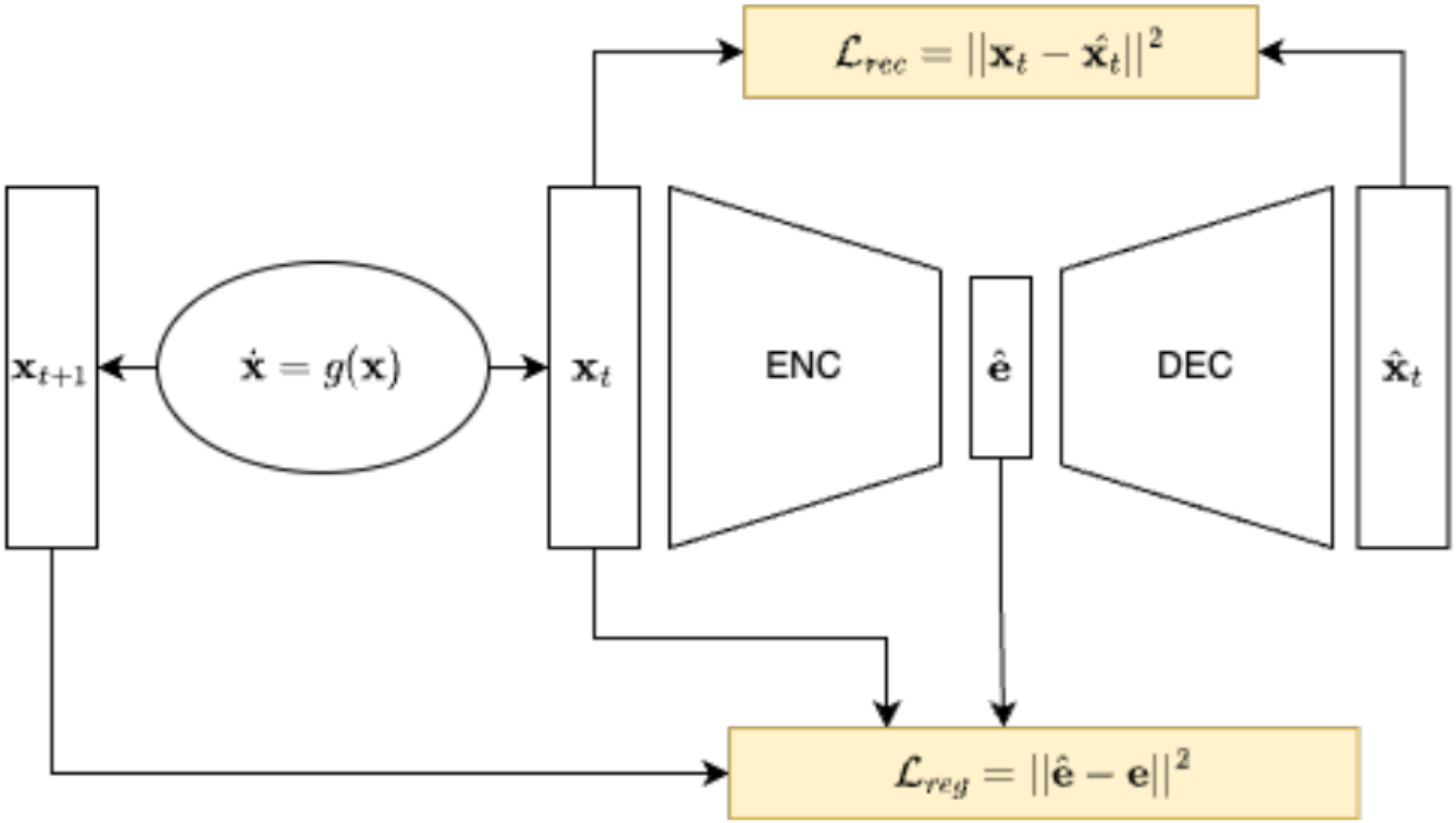


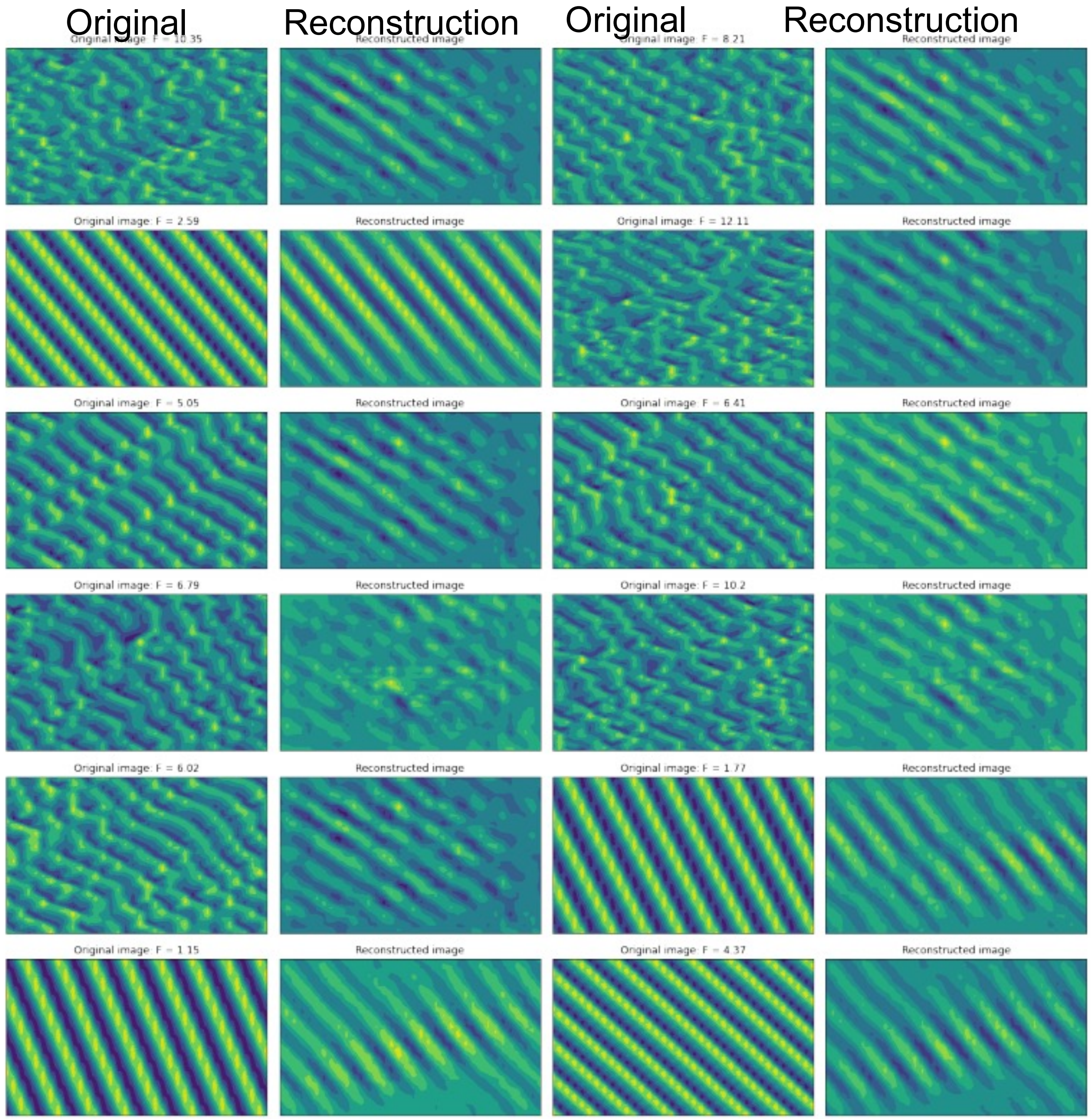
Physics Informed Neural Nets

(prediction of short term dynamics)



Symmetric Convolutional Autoencoder




Original
Reconstruction
Original
Reconstruction
Original image: F = 10.35
Reconstructed image
Original image: F = 8.21
Reconstructed image
Original image: F = 2.59
Reconstructed image
Original image: F = 12.11
Reconstructed image
Original image: F = 5.05
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Original image: F = 6.41
Reconstructed image
Original image: F = 6.79
Reconstructed image
Original image: F = 10.2
Reconstructed image
Original image: F = 6.02
Reconstructed image
Original image: F = 1.77
Reconstructed image
Original image: F = 1.15
Reconstructed image
Original image: F = 4.37
Reconstructed image

Plastic Waste Pollution
(Input Video)

AI Solution
(Output Video)

Jaikumar P et al. (2020) ISDA, https://centaur.reading.ac.uk/98569/

v.k.ojha@reading.ac.uk