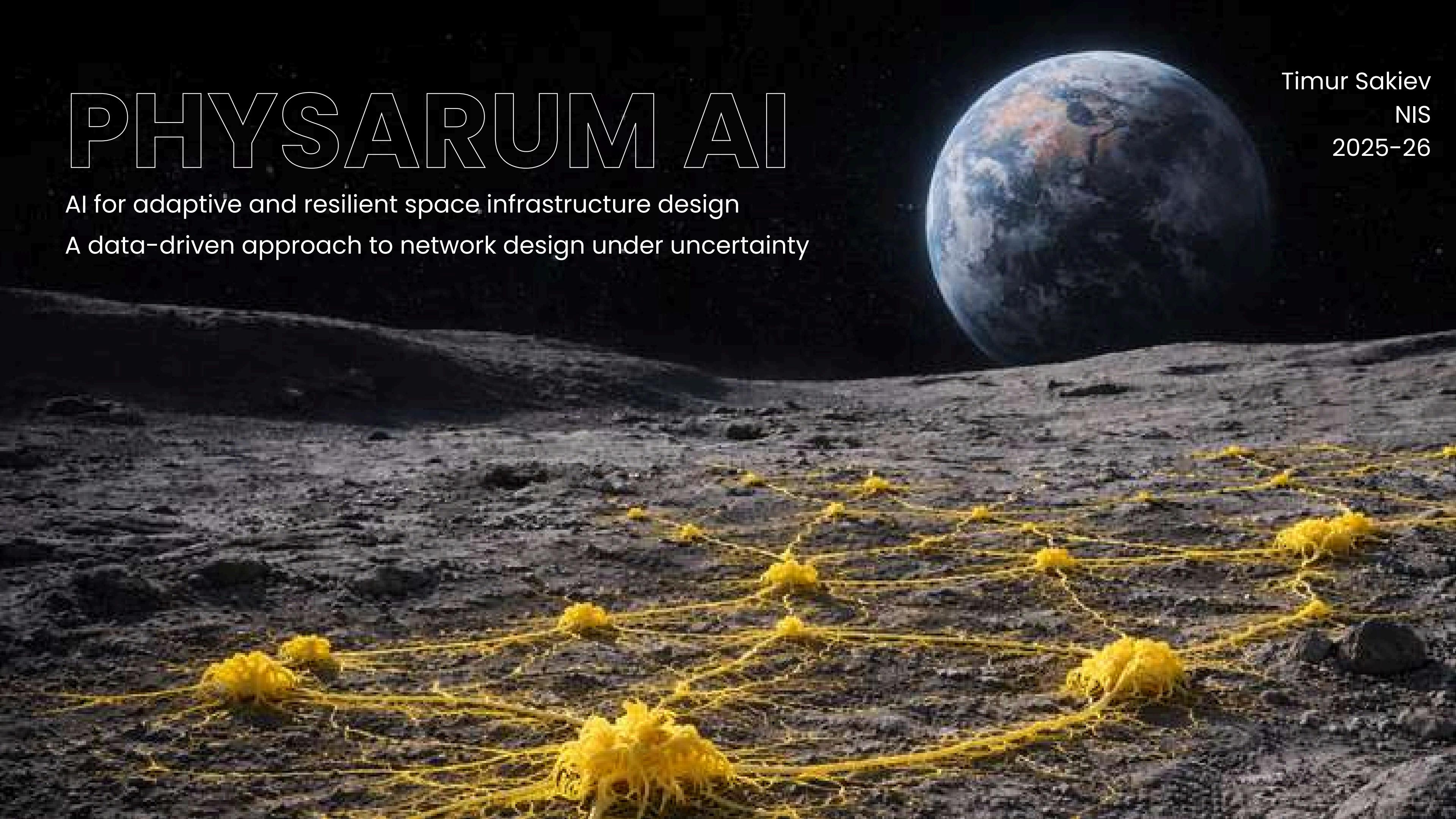


PHYSARUM AI

AI for adaptive and resilient space infrastructure design

A data-driven approach to network design under uncertainty

Timur Sakiev
NIS
2025-26



Problem

Future missions to the Moon, Mars, and deep space require reliable infrastructure: energy, water, logistics, and communication networks.

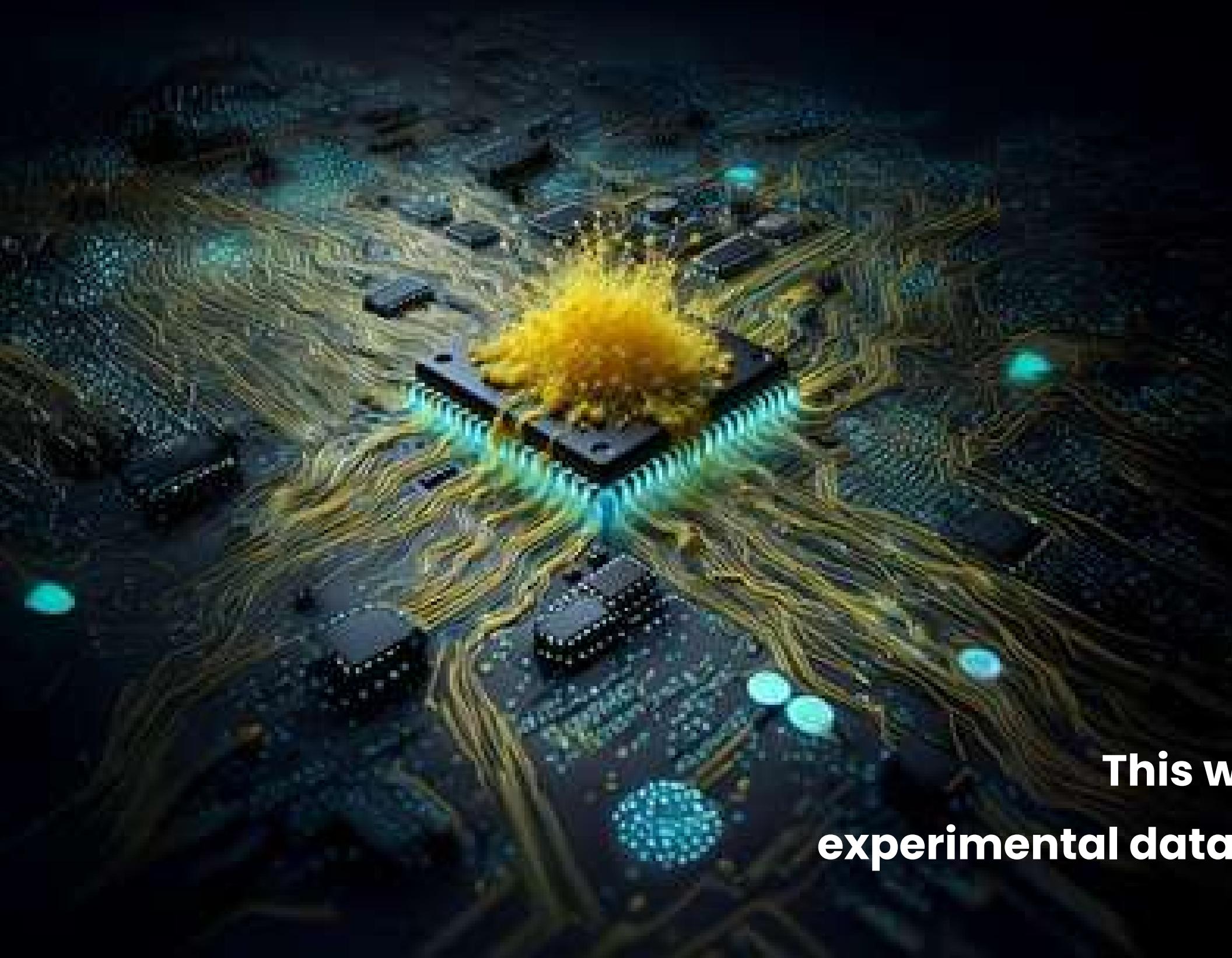
These systems must operate for decades in alien environments, under uncertainty, changing conditions, and without the possibility of redesign.

Classical engineering relies on static, pre-defined optimization, which limits adaptability and resilience in extraterrestrial settings.



Our solution

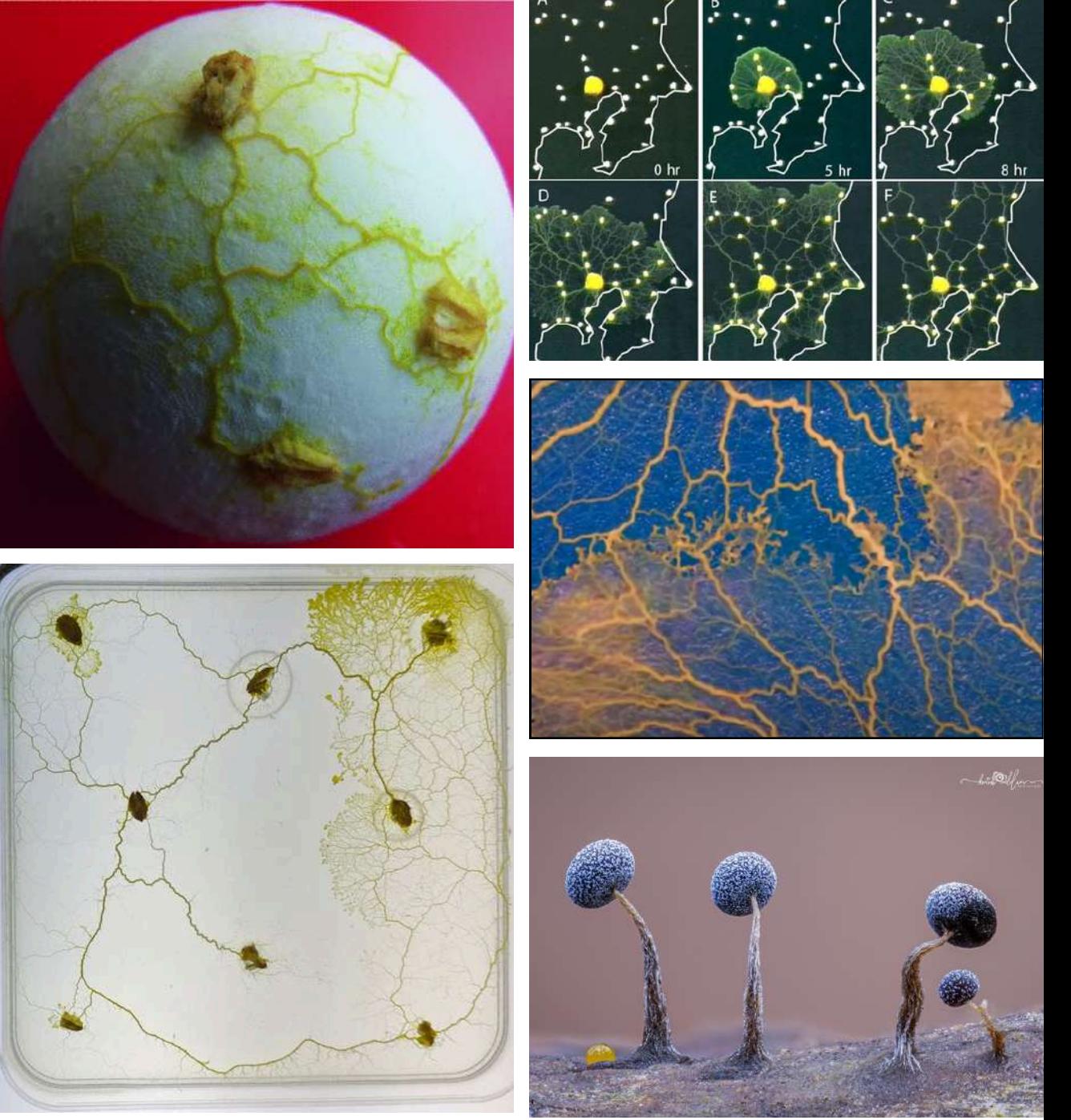
PhysarumAI introduces a new paradigm:
infrastructure as a probabilistic, adaptive
system, not a fixed deterministic graph.



We train AI on data from the living organism
Physarum polycephalum,
collected independently through real
experiments.

This organism is evolutionarily adapted to
optimize networks
and to adapt to changing conditions.

**This work is based on a new, openly published
experimental dataset and a trained probabilistic AI model.**



Why *Physarum polycephalum*?

Physarum polycephalum is a living organism that forms optimal transport networks without a brain or central control.

By exploring space, it removes inefficient connections and reinforces effective pathways, creating a resilient and adaptive structure.

This process is remarkably close to the challenges of designing infrastructure for space environments.



Capabilities of *Physarum*

- Efficient network formation
- Solving Boolean logic tasks
- Solving combinatorial problems
- Memory and learning
- Prediction of environmental changes

Based on peer-reviewed scientific publications

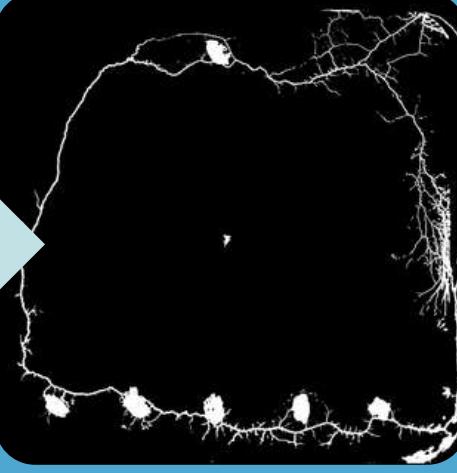
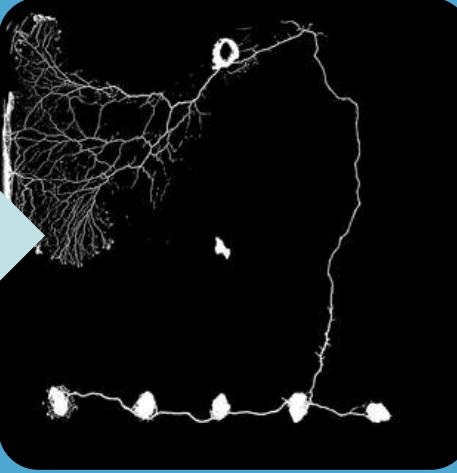
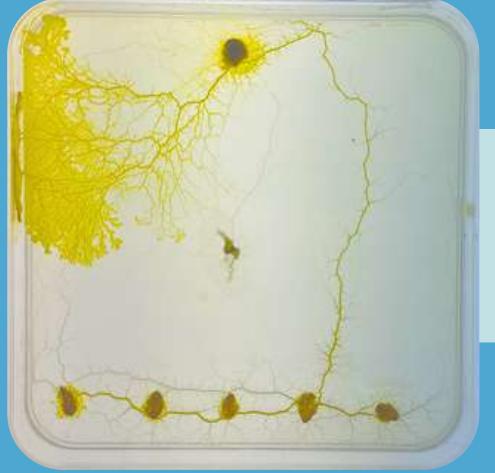
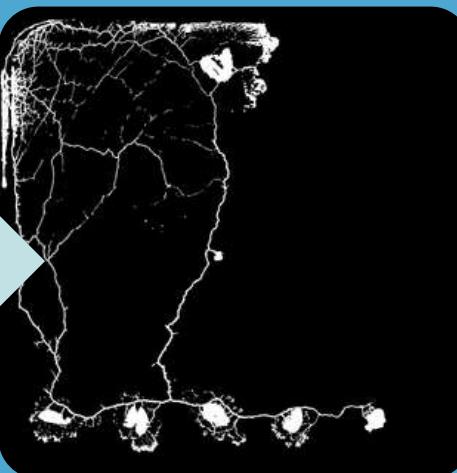
- Wang M.-H., vom Saal F. S. Maze-solving by an amoeboid organism.
- Авсневич Т. Примитив не приговор, или *Physarum polycephalum* разумный, Химия и жизнь №4, 2016.
- Adamatzky A. Bio-Evaluation of World Transport Networks (World Scientific, 2012).
- Nakagaki T. Smart behavior of true slime mold in labyrinth, Research in Microbiology, vol. 152, 2001.
- 10. Bonifaci V., Mehlhorn K., Varma G. *Physarum* can compute shortest paths, Journal of Theoretical Biology, Volume 309, 21 September 2012
-
- and others...

DATA Collection

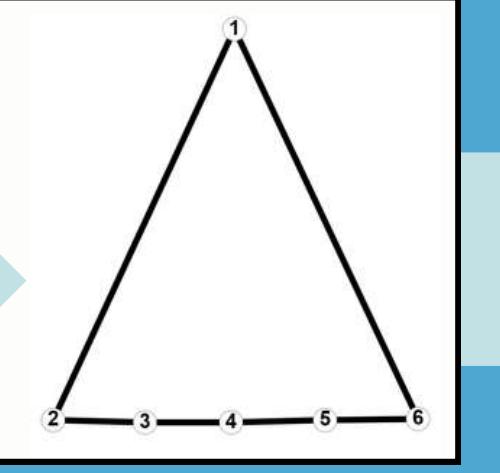
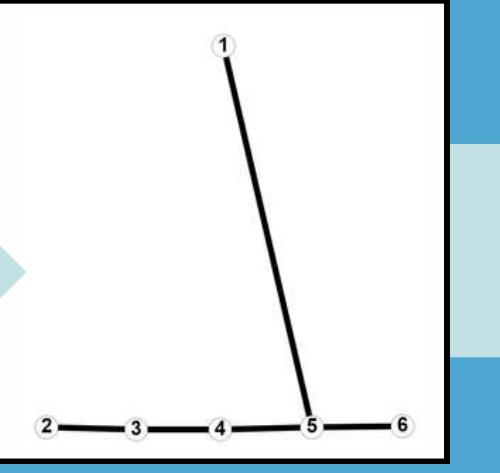
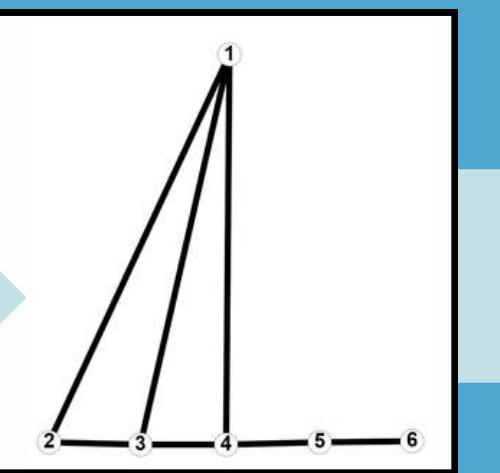
Experiments

*10-18 repeats per configuration
30 configurations
390 in total

Binary masks



Graphs



Adjacency matrices

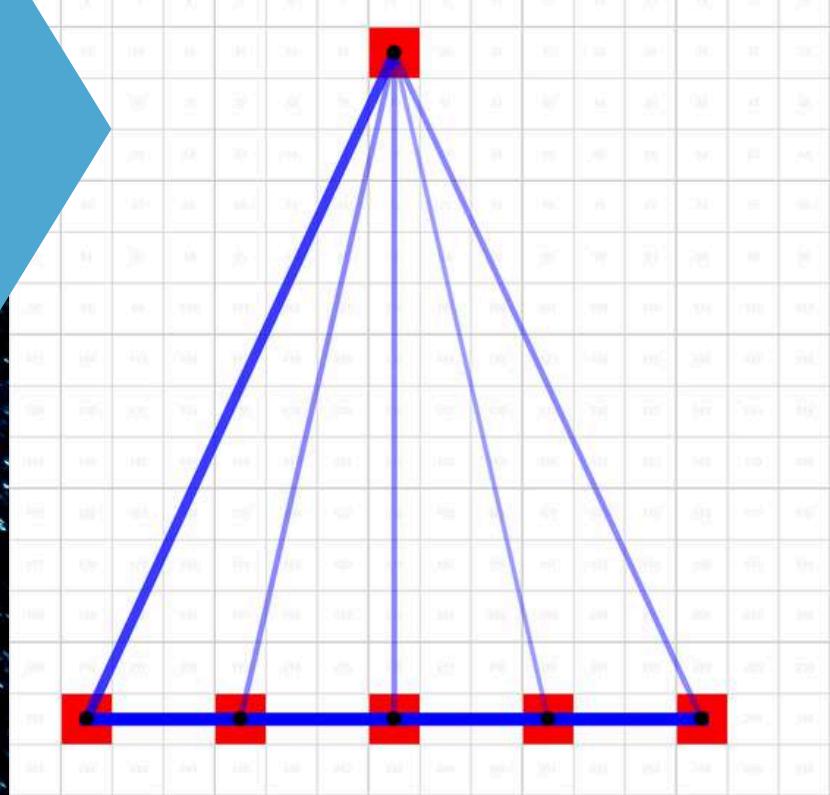
0, 1, 1, 1, 0, 0,
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1, 1, 0, 1, 0, 0,
1, 0, 1, 0, 1, 0,
0, 0, 0, 1, 0, 1,
0, 0, 0, 0, 1, 0,

0, 0, 0, 0, 1, 0,
0, 0, 1, 0, 0, 0,
0, 1, 0, 1, 0, 0,
0, 0, 1, 0, 1, 0,
1, 0, 0, 1, 0, 1,
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0, 1, 0, 0, 0, 1,
1, 0, 1, 0, 0, 0,
0, 1, 0, 1, 0, 0,
0, 0, 1, 0, 1, 0,
0, 0, 0, 1, 0, 1,
1, 0, 0, 0, 1, 0,

Probability matrix & graph (aggregated over 10-18 repeats)

0.0, 0.7, 0.4, 0.4, 0.3, 0.4
0.7, 0.0, 1.0, 0.0, 0.0, 0.0
0.4, 1.0, 0.0, 1.0, 0.3, 0.0
0.4, 0.0, 1.0, 0.0, 1.0, 0.1
0.3, 0.0, 0.3, 1.0, 0.0, 1.0
0.4, 0.0, 0.0, 0.1, 1.0, 0.0



DATASET PHOTOS

Open dataset available on Zenodo
DOI: [10.5281/zenodo.18411398](https://doi.org/10.5281/zenodo.18411398)



BINARY MASKS

Open dataset available on Zenodo

DOI: [10.5281/zenodo.18411398](https://doi.org/10.5281/zenodo.18411398)

PROBABILITY GRAPHS

Each graph shows not a single solution, but the probability of each connection forming across repeated experiments.

Dataset Structure (csv)

run_ID	attractant	General Matrix	distance matrix	Probability adjacency matrix
601	17, 25, 31, 241, 249, 255	0, 11, 8, 11, 11, 6 11, 0, 14, 8, 9, 7 8, 14, 0, 7, 10, 10 11, 8, 7, 0, 14, 6 11, 9, 10, 14, 0, 14 6, 7, 10, 6, 14, 0	0.00, 6.00, 10.50, 10.50, 12.09, 14.85 6.00, 0.00, 4.50, 12.09, 10.50, 11.42 10.50, 4.50, 0.00, 14.85, 11.42, 10.50 10.50, 12.09, 14.85, 0.00, 6.00, 10.50 12.09, 10.50, 11.42, 6.00, 0.00, 4.50 14.85, 11.42, 10.50, 10.50, 4.50, 0.00	0.000, 0.688, 0.500, 0.688, 0.688, 0.375 0.688, 0.000, 0.875, 0.500, 0.563, 0.438 0.500, 0.875, 0.000, 0.438, 0.625, 0.625 0.688, 0.500, 0.438, 0.000, 0.875, 0.375 0.688, 0.563, 0.625, 0.875, 0.000, 0.875 0.375, 0.438, 0.625, 0.375, 0.875, 0.000
602	21, 26, 31, 111, 191, 226	0, 13, 5, 7, 6, 10 13, 0, 12, 10, 6, 6 5, 12, 0, 12, 4, 5 7, 10, 12, 0, 11, 6 6, 6, 4, 11, 0, 9 10, 6, 5, 6, 9, 0	0.00, 3.75, 7.50, 8.39, 10.61, 10.01 3.75, 0.00, 3.75, 5.30, 8.39, 11.45 7.50, 3.75, 0.00, 3.75, 7.50, 13.79 8.39, 5.30, 3.75, 0.00, 3.75, 11.45 10.61, 8.39, 7.50, 3.75, 0.00, 10.01 10.01, 11.45, 13.79, 11.45, 10.01, 0.00	0.00, 0.93, 0.36, 0.50, 0.43, 0.71 0.93, 0.00, 0.86, 0.71, 0.43, 0.43 0.36, 0.86, 0.00, 0.86, 0.29, 0.36 0.50, 0.71, 0.86, 0.00, 0.79, 0.43 0.43, 0.43, 0.29, 0.79, 0.00, 0.64 0.71, 0.43, 0.36, 0.43, 0.64, 0.00

All data from 390 experiments are stored in structured CSV files, **fully parsed and ready for analysis.**

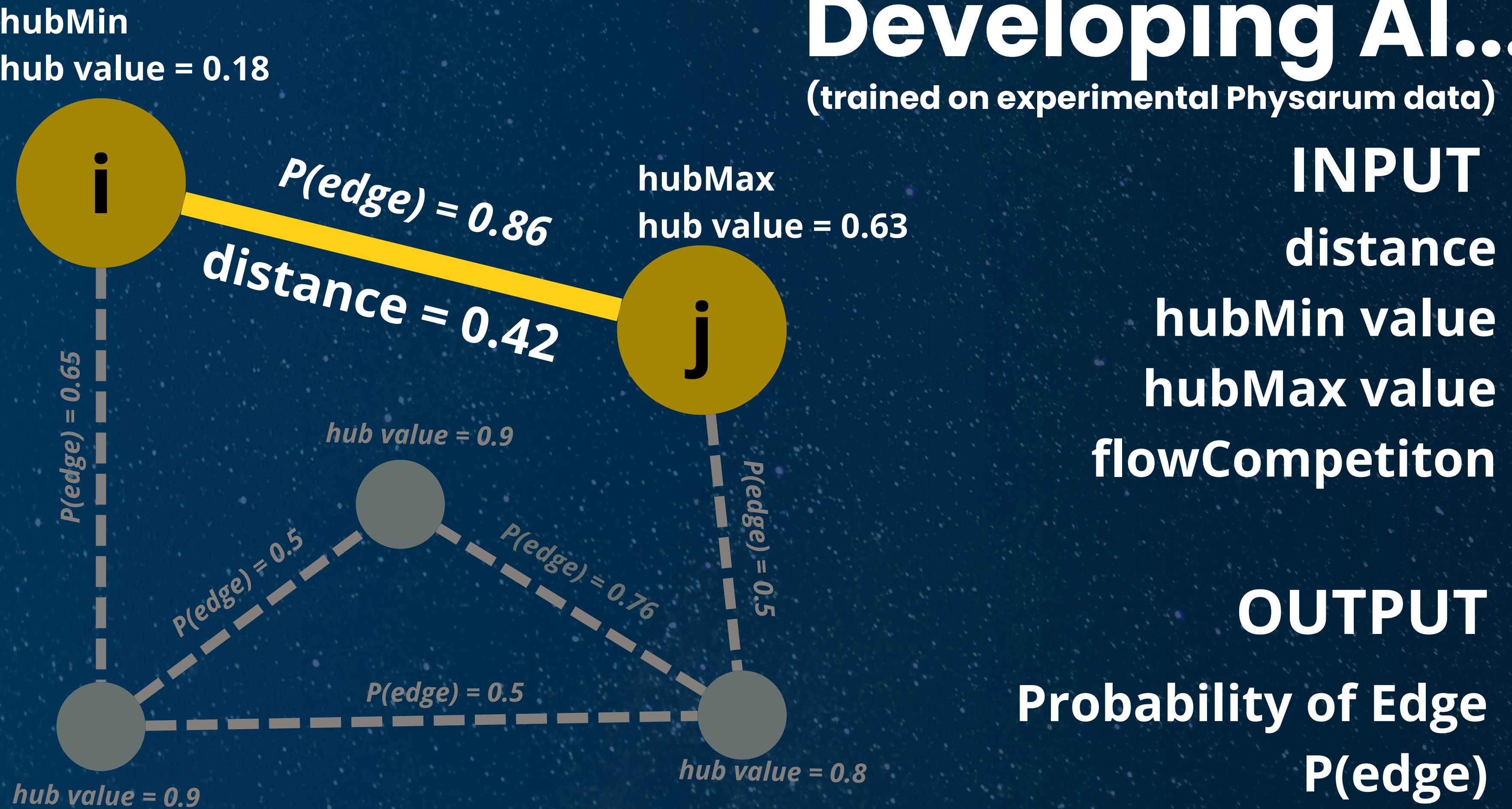
The dataset is publicly available on Zenodo, including raw images, binary masks, and structured CSV tables.

- **390 EXPERIMENTS**
- **REPEATED MEASUREMENTS**
- **READY-TO-TRAIN PROBABILITY MATRICES**
- **OPEN AND REPRODUCIBLE DATASET**

*The dataset is continuously being expanded with new experiments.

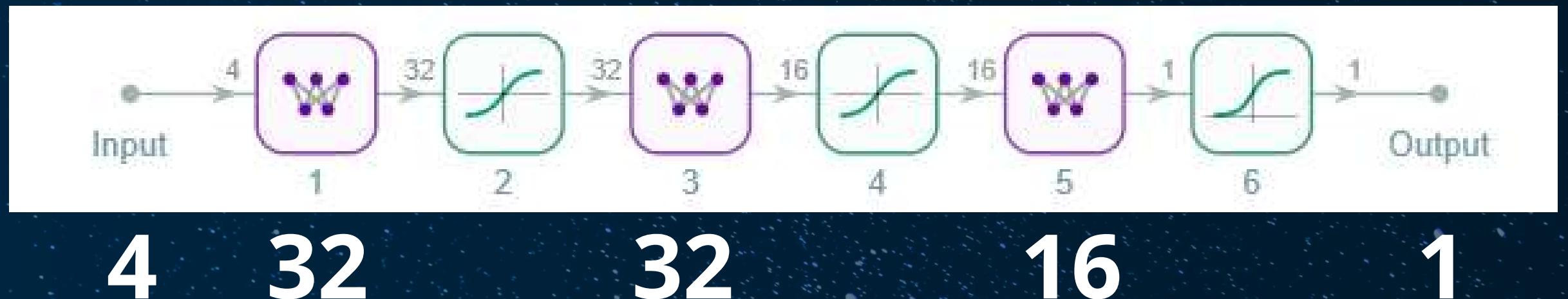
Developing AI...

(trained on experimental Physarum data)



Model Architecture

MLP (Multi-Layer Perceptron)



Training details

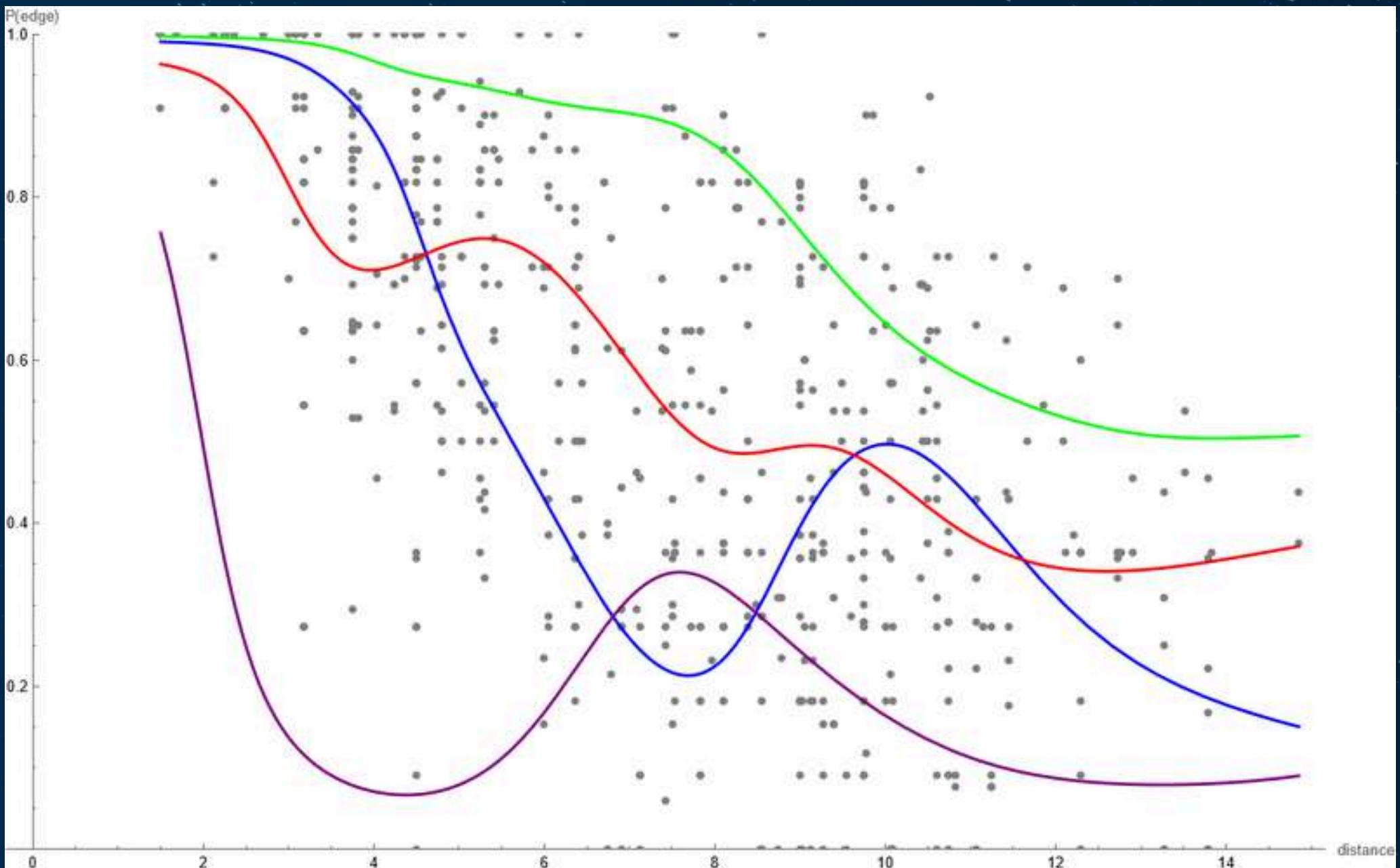
- Supervised learning on experimental probability data
- Optimizer: ADAM
- Batch size: 256
- Training rounds: up to 1800
- Train / validation split by configurations

*The model architecture is still evolving and being refined.

Preliminary metrics

*Final metrics will be reported after dataset scaling and architectural stabilization.
The model captures non-trivial network structure beyond distance-based rules.

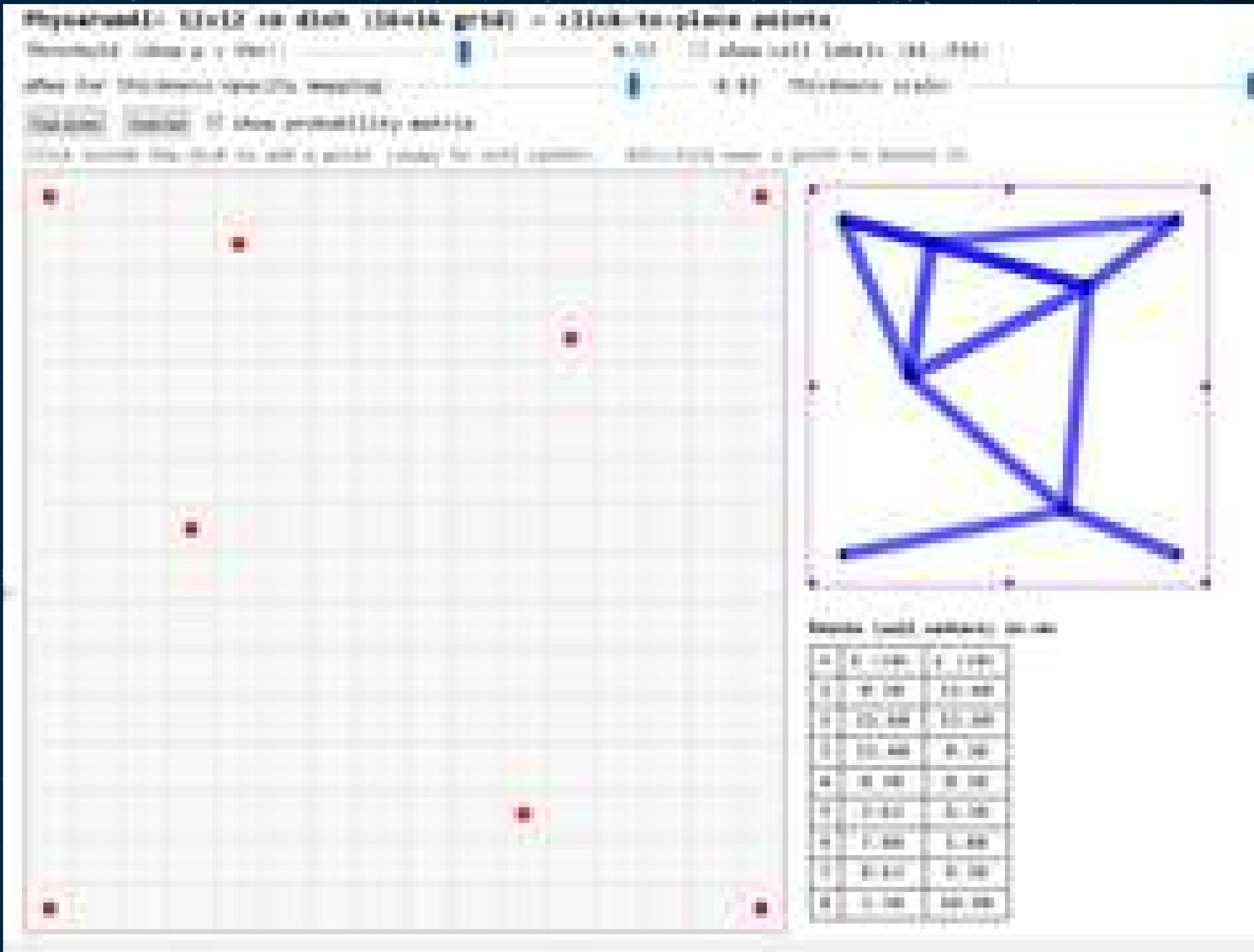
TEST MAE = 0.152943 TEST RMSE = 0.203927 TEST Corr = 0.68918



X-axis: distance between two nodes
Y-axis: probability that an edge forms between them
Grey dots: individual observations from all experiments
Colored curves: fitted probability models under different network conditions

Interactive Network Generation by Trained Model

The model connects given points in a Physarum-like manner, offering multiple solutions with different weights.



Why this matters for space missions

Space infrastructure must:

- operate for decades without maintenance,
- adapt to partial failures,
- function under uncertainty.

PhysarumAI does not produce a single “optimal” network.

Instead, it learns a space of probabilistic solutions, where the system remains functional even when nodes or links fail.

This matches real conditions: the Moon, Mars, and deep space are not laboratories — they are dynamic environments.

From biology to future space systems

PhysarumAI is a biologically inspired AI approach that learns from living systems to design adaptive infrastructure networks for energy, water, logistics, and distributed space systems, connecting biology, data, and AI to address real challenges of future space exploration.

