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Extracting Symbolic Models of Collective Behaviors

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Novel Engineering for Swarm Technologies

https://github.com/NESTLab/Extracting-Symbolic-Models-of-Collective-Behaviors

Why invent when you can steal?*

- Biomimicry

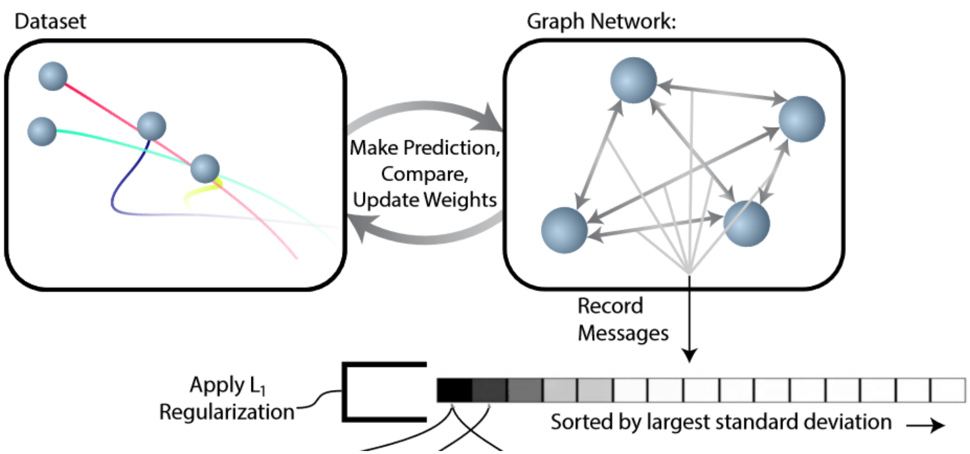
- Two options for me:
  – Become a biologist
  – Make friends with a biologist

- When in doubt, throw an AI at the problem
  – NNs are popular, use them?
  – Evolutionary Algorithms?

* the presenter does not endorse stealing in any way from any sentient being.... the morality regarding stealing from non-sentient beings is a topic for very different presentation

Combining the two

- GNNs
  - Learn
  - Isolate relationships

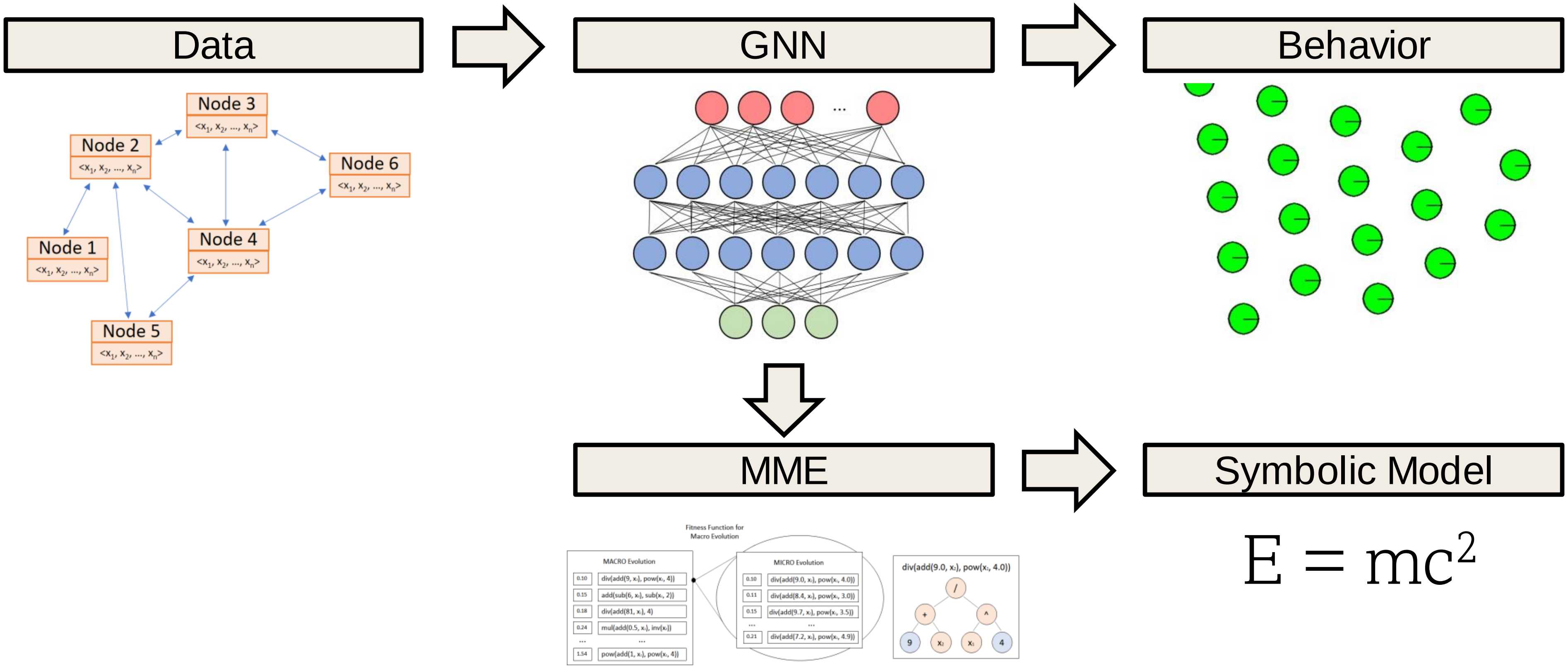


Discovering symbolic models from deep learning with inductive biases. Cranmer et al. [1]

- Evolutionary Algorithms
  - Symbolic models (able to be studied and manipulated)

[1] Cranmer, M.D., Sanchez-Gonzalez, A., Battaglia, P.W., Xu, R., Cranmer, K., Spergel, D.N., Ho, S.: Discovering symbolic models from deep learning with inductive biases.

Our system

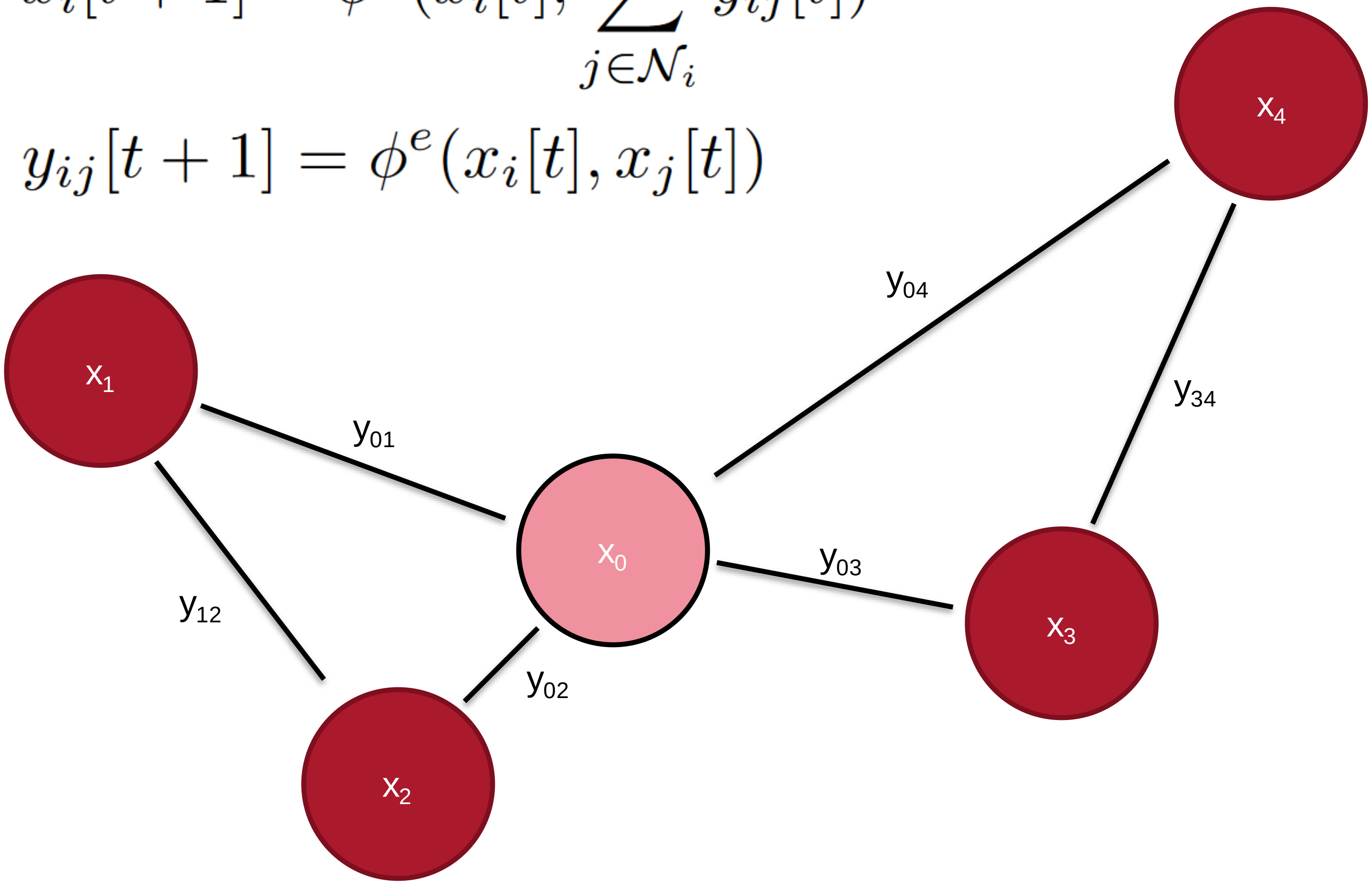


Data
GNN
Behavior
MME
Symbolic Model
Node 1
Node 2
Node 3
Node 4
Node 5
Node 6
MACRO Evolution
MICRO Evolution
Fitness Function for Macro Evolution
div(add(9.0, x₂), pow(x₁, 4.0))
E = mc²

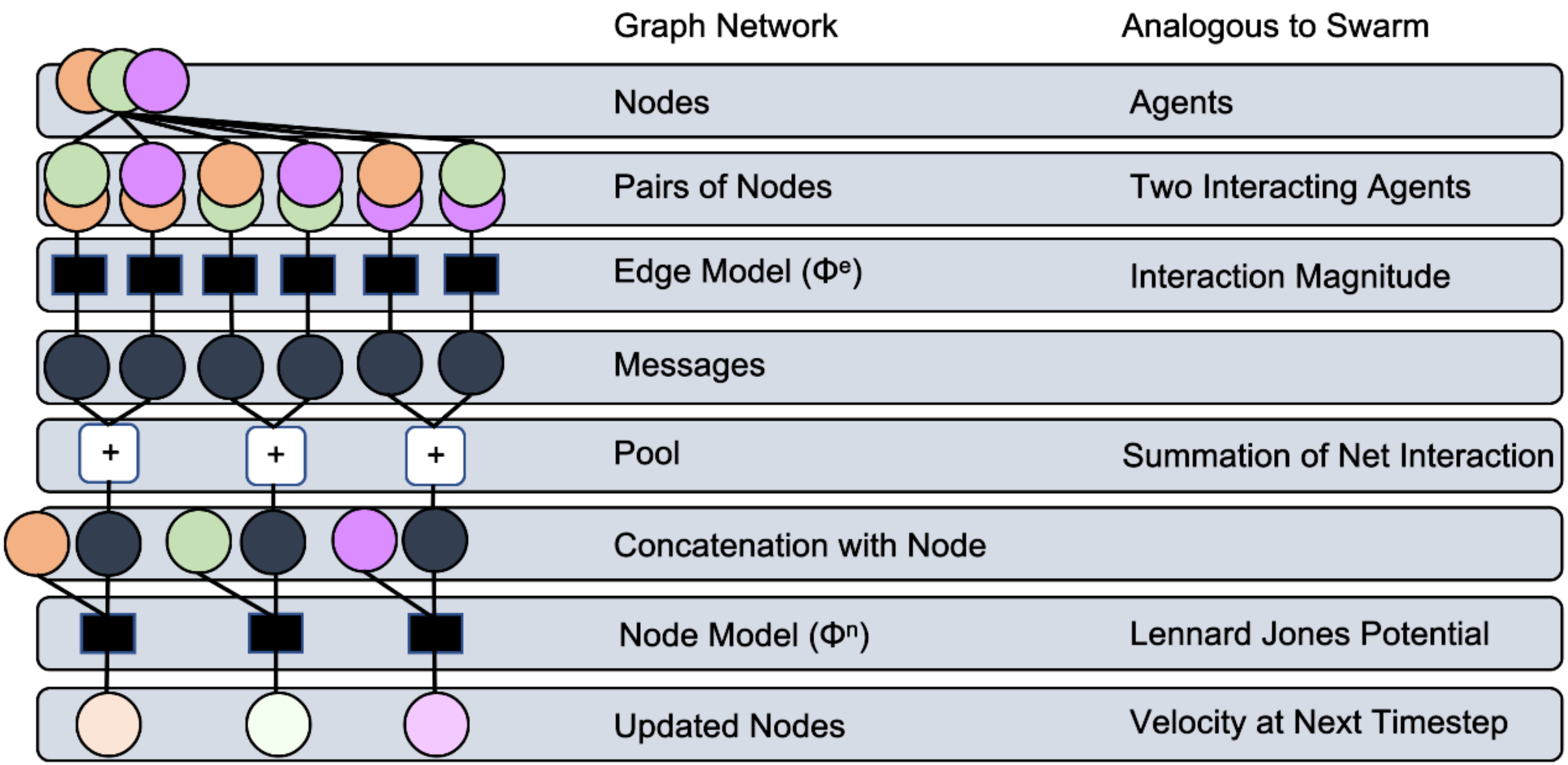
GNN

$$x_i[t+1] = \phi^n(x_i[t], \sum_{j \in \mathcal{N}_i} y_{ij}[t])$$

$$y_{ij}[t+1] = \phi^e(x_i[t], x_j[t])$$

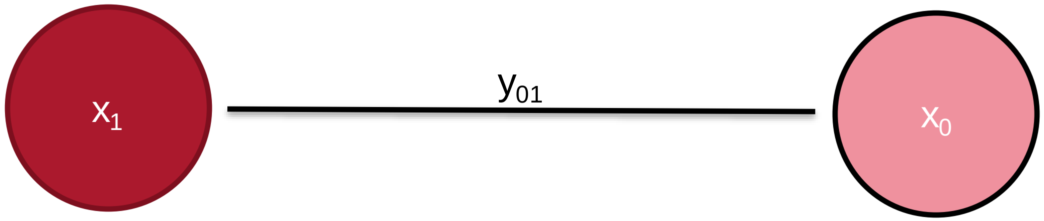


How to use the GNN

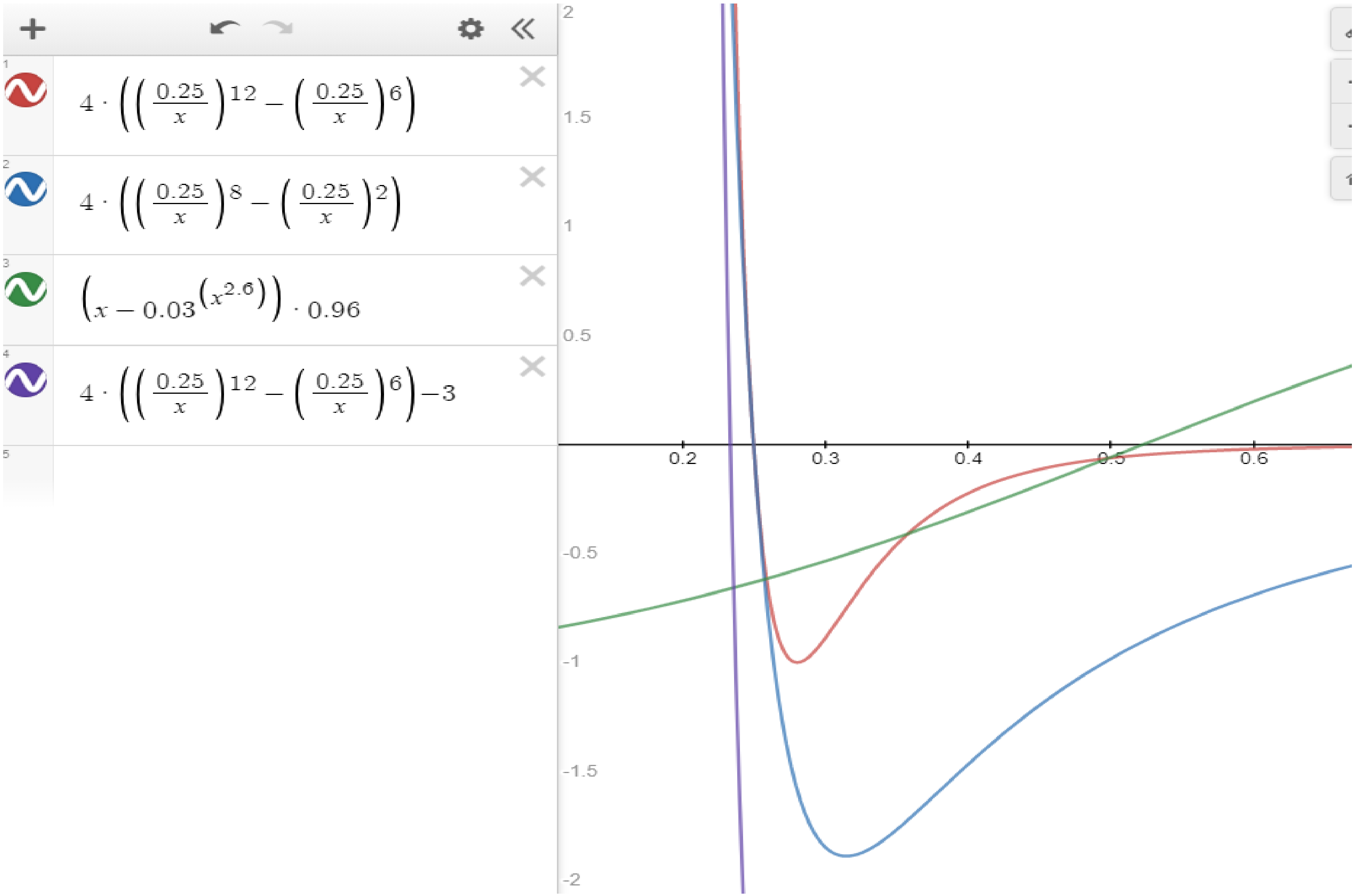


Result

$$x_i[t+1] = \phi^n(x_i[t], \sum_{j \in \mathcal{N}_i} y_{ij}[t])$$

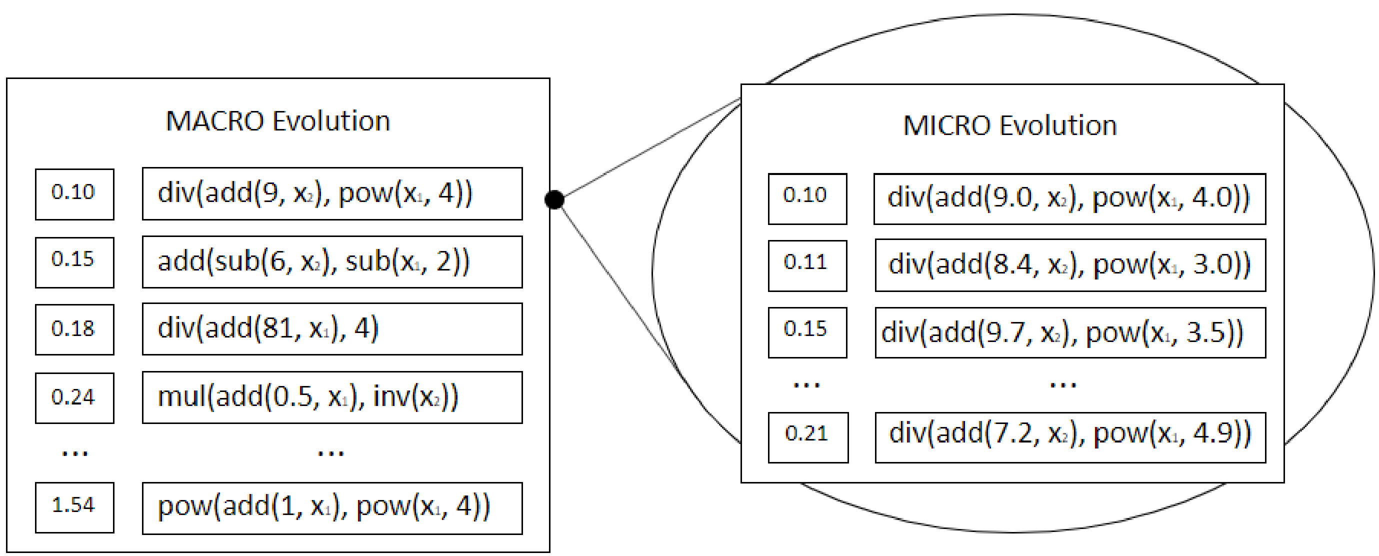


Problem: Which one is the closest?

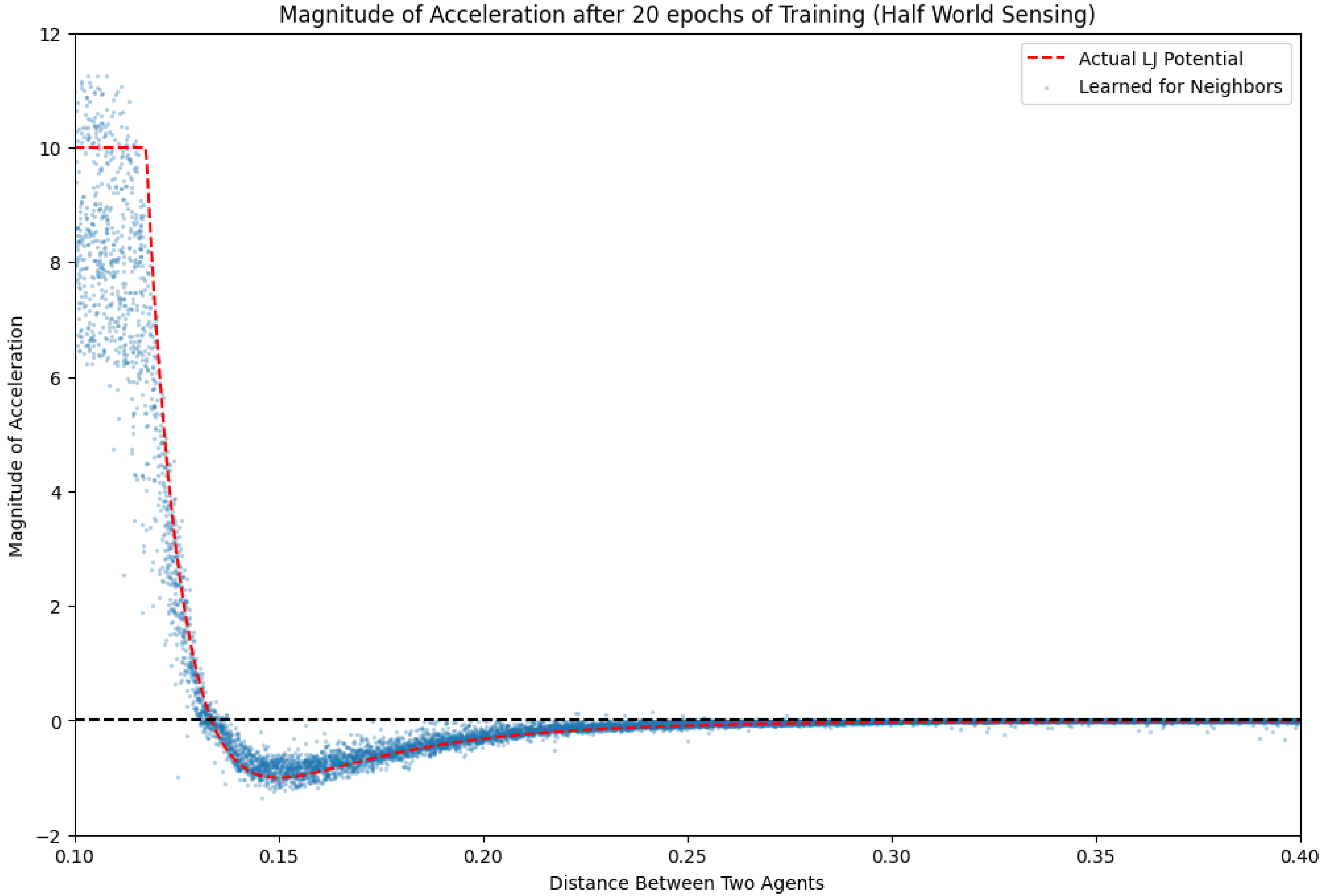


Solution

- Embedding an EA inside an EA
  - Two optimizations:
    - Structure vs Params
  - Rank via MSE
    - Top survivors go through micro-evolution
      - More MSE! YAY!



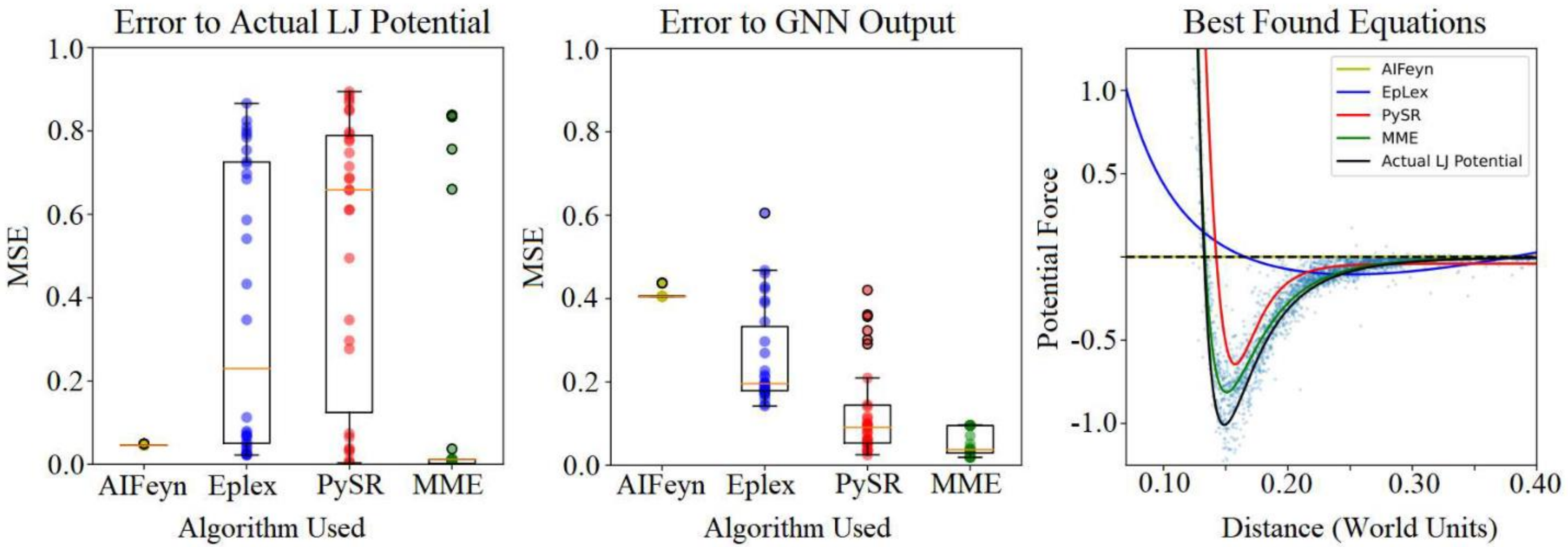
GNN Output



Magnitude of Acceleration after 20 epochs of Training (Half World Sensing)
Actual LJ Potential
Learned for Neighbors
Magnitude of Acceleration
Distance Between Two Agents
12
10
8
6
4
2
0
−2
0.10
0.15
0.20
0.25
0.30
0.35
0.40

Symbolic Regression Results

- Each run 30 times



MME Output

- Actual Equation (simplified)

$$\left(\frac{1.2e-10}{x^{12}}\right)-\left(\frac{2.2e-5}{x^{6}}\right)$$

- MME Found Equation

$$\left(\frac{8e-9}{x^{10.07}}\right)-\left(\frac{9.8e-6}{x^{6.54}}\right)$$

Competition Output

$$\left(\frac{1.2e-10}{x^{12}}\right)-\left(\frac{2.2e-5}{x^{6}}\right)$$

- EpLex

$$2.38x-1.3+\left(\frac{0.15}{x}\right)$$

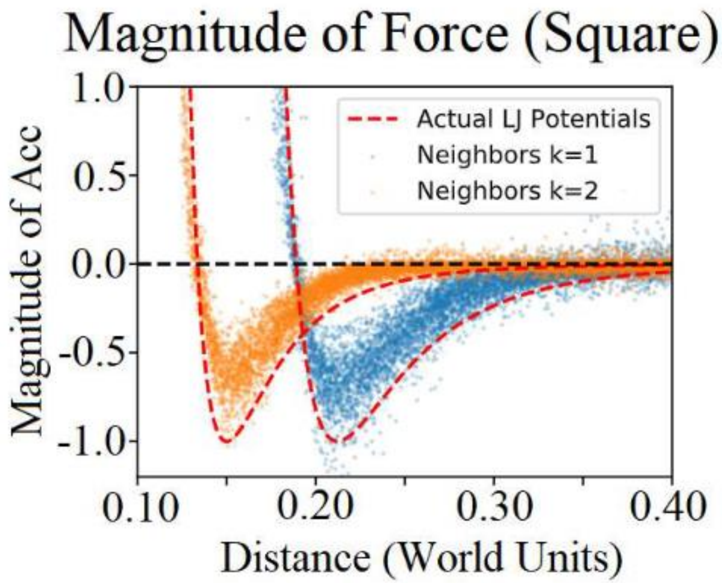
- AIFeynman

$$\left(5.6e-5\left(x+\frac{x^{0.5}}{-(x+2)}\right)\right)^{0.5}$$

- PySR

$$\frac{-\left(0.42-\frac{0.06}{x}\right)}{(x-0.02)\,(8.14e8x^{11.66}-x+0.272)}-0.04$$

Square Lattice Results



- Actual Equations

$$\text{Square (Kin)} \quad \left(\frac{7.84e-9}{x^{12}}\right) - \left(\frac{1.7e-4}{x^{6}}\right)$$

$$\text{Square (Non-Kin)} \quad \left(\frac{1.2e-10}{x^{12}}\right) - \left(\frac{2.2e-5}{x^{6}}\right)$$

- Found Equations

$$\text{Square (Kin)} \quad \left(\frac{6.8e-7}{x^{9.75}}\right) - \left(\frac{1.9e-5}{x^{7.75}}\right)$$

$$\text{Square (Non-Kin)} \quad \left(\frac{1.58e-9}{x^{10.67}}\right) - \left(\frac{4e-6}{x^{6.79}}\right)$$

BOID Results

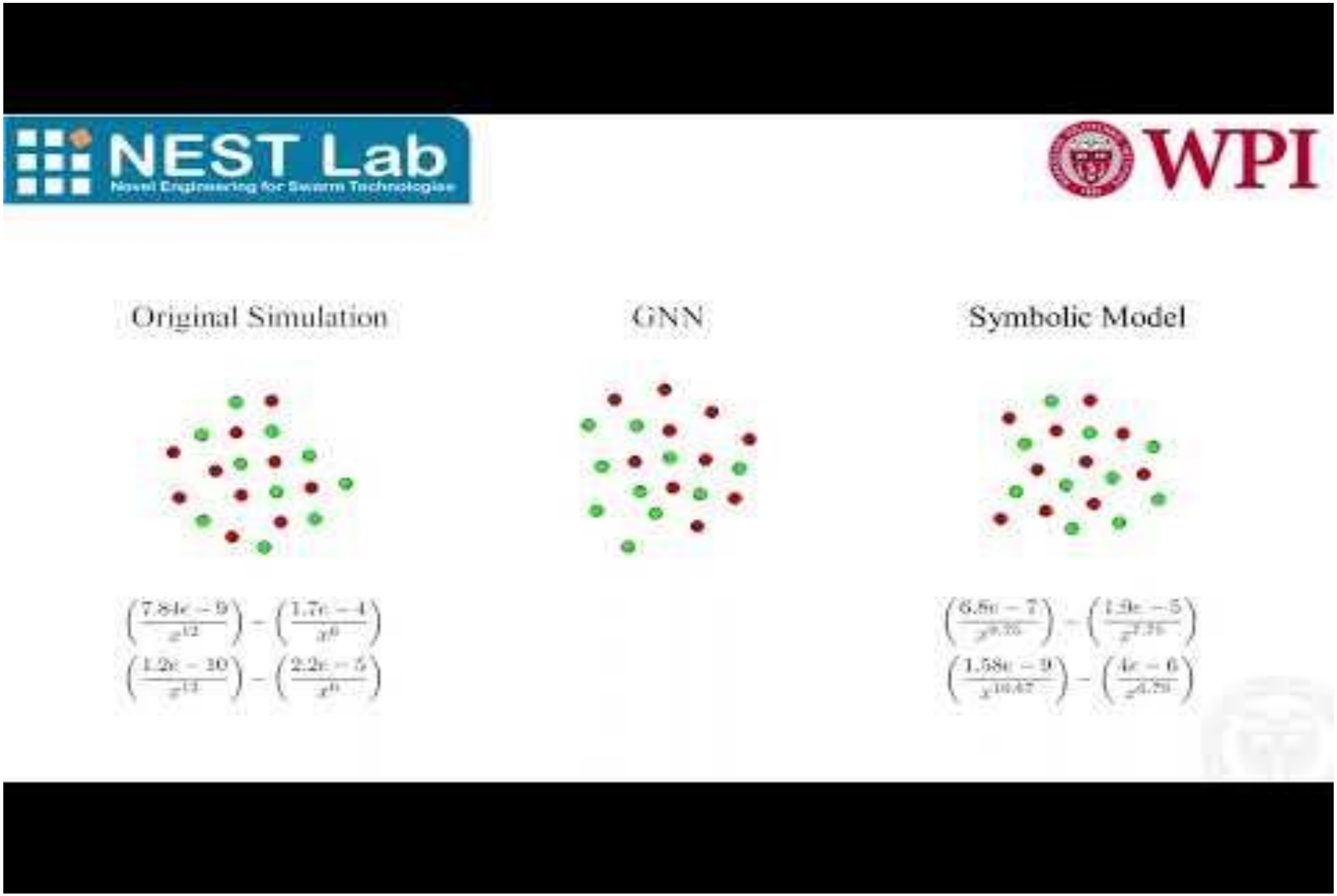
- Target Equation

$$2\frac{\vec{x}}{||\vec{x}||} - \left(\frac{75}{||\vec{x}||}\right)\frac{\vec{x}}{||\vec{x}||} + 3\dot{\vec{x}}$$

- MME Found Equation

$$0.59\frac{\vec{x}}{||\vec{x}||} - \left(\frac{1}{||\vec{x}||}\right)\frac{\vec{x}}{||\vec{x}||} + \left(\frac{1}{||\dot{\vec{x}}||}\right)\dot{\vec{x}}$$

Visual Results



Conclusion

- Wanted to find a way to model natural swarms
  - Not knowing original equations
  - Add in our potential knowledge of the situation

- Two stage system
  - GNN isolates relationships
  - MME performs symbolic regression

- Tested on Hex lattice, square lattice, and boids
  - Results match original equations more closely than other symbolic regression algorithms

Questions?

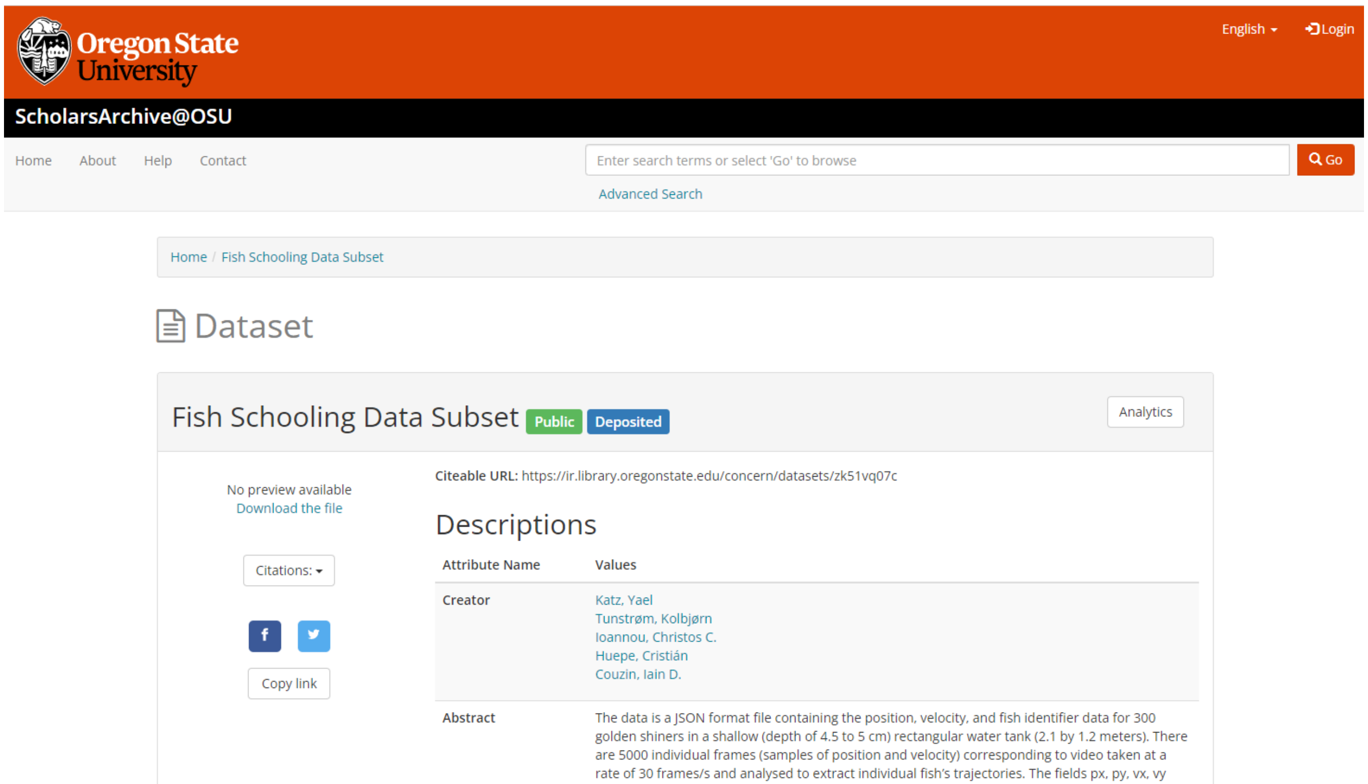
[1] Cranmer, M.D., Sanchez-Gonzalez, A., Battaglia, P.W., Xu, R., Cranmer, K., Spergel, D.N., Ho, S.: Discovering symbolic models from deep learning with inductive biases. CoRR abs/2006.11287 (2020), https://arxiv.org/abs/2006.11287

Holy cow, MME must take forever.

- Kinda no, but sorta yes.
  - It does NOT scale well relative to amount of data
    - Linked to the complexity of the target equation
      - Can be reduced by priors
  - Planning to submit extended version of work with MME analysis

Cool story, where's the real data?

- FISH!



https://ir.library.oregonstate.edu/concern/datasets/zk51vq07c

Sneak Peak!

REAL fish data:
~300 fish

GNN generated fish:
~50 fish

Turing Learning. It's nifty.

- Yes. It is. Look out for our next papers!