Evolving Robust and Reconfigurable Multi-Objective Controllers for Advanced Power Systems

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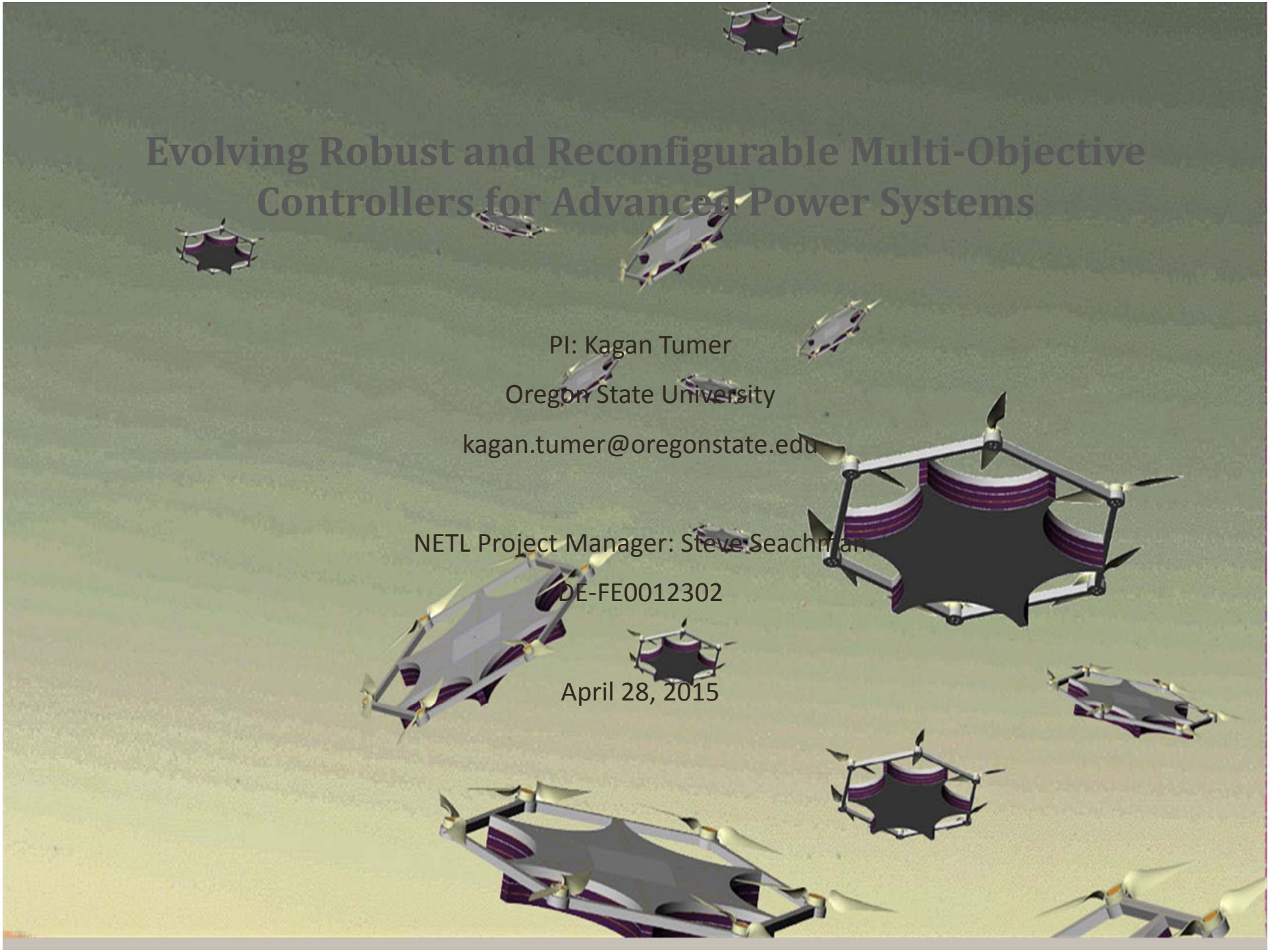
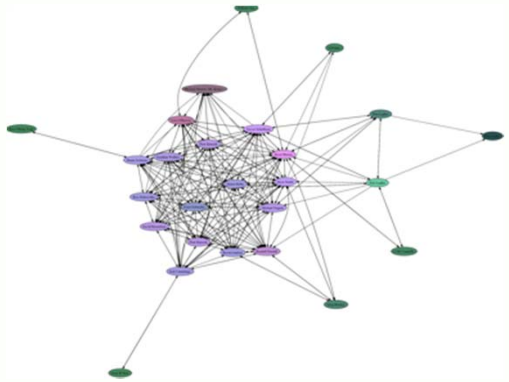


Motivation: Energy Systems

- Where are we?
  - Advanced energy systems becoming more interconnected
  - Computation pushed further down the pipe
  - More powerful, cheaper, smaller devices



- Where are we going?
  - Hybrid systems
  - Competing objectives
  - Smart sensors, actuators

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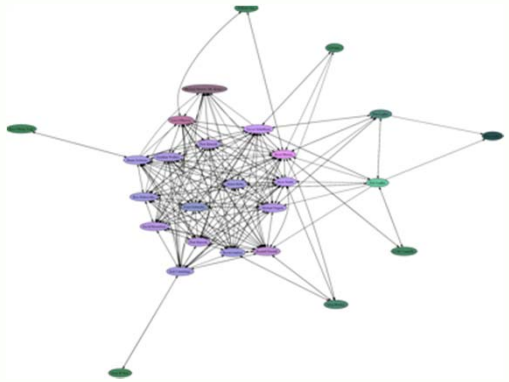
Motivation: Energy Systems

- Where are we?
  - Difficult to model
  - Distributed decision making
  - Scaling



- Where are we going?
  - Even more difficult to model
  - Even more distributed decision making
  - Even more scaling

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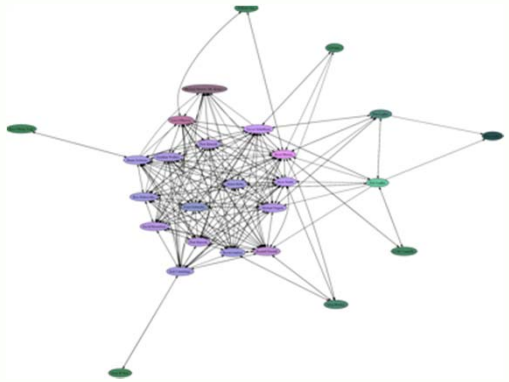
Motivation: Energy Systems

- We need to account for?
  - Difficult to model systems
  - Thousands of actors (sensors, controllers, users)
  - Failing components
  - Competing objectives
  - Dynamic and stochastic environments



  - And still control systems to result in safe, efficient operation

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Outline

- Motivation
- Concepts

- Milestones
  1. Abstract simulator for advanced power system
  2. Bio-mimetic control algorithm for advanced power system
  3. System metrics to measure tradeoffs of objectives

  4-5-6: Next Year

- Project Status

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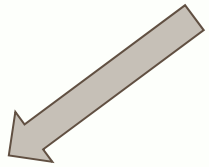
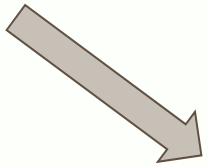
Distributed multi-objective Control?

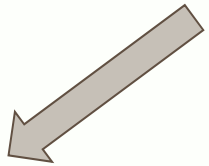
Multiagent control



Many agents, one objective

- Who does what ?





Many agents , many objectives

Roadmap and Objectives

- Learning-Based Control

Objective 1

- Multiagent
  - Biomimetic distributed subsystem-level control
  - System-level results

Objective 2

- Multi-objective
  - Simultaneously optimize multiple competing objectives

Objective 3

- Reconfigurable
  - Adapt to changing power system needs
  - Develop new policies with previously un-considered objectives

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Project Milestones

- Milestone 1: Abstract simulator for advanced power system
- Milestone 2: Bio-mimetic control algorithm for advanced power system

- Milestone 3: System metrics to measure tradeoffs of objectives
- Milestone 4: Multi-objective control algorithm for advanced power system

- Milestone 5: Robust controller for advanced power system
- Milestone 6: Reconfigurable, multi-objective controller for power system

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Milestone 1: Abstract simulator

- Use statistics to generate “simulator”

- No physics
- Map inputs to output given

- Use function approximation: multi-layered feed-forward neural network

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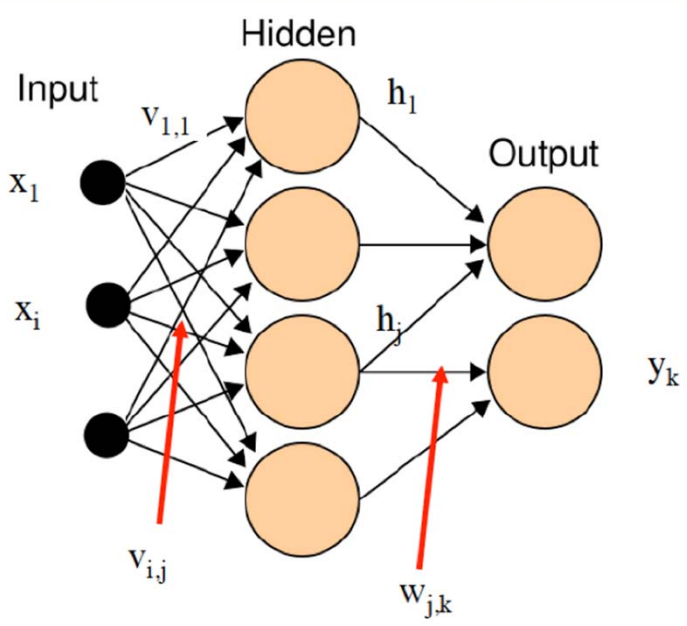
Training a Neural Network

- Given: input *x*, target *y*, and network weights *W*
- Find: change in weights ΔW to minimize network error
  - Gradient descent



NN Plant Simulator

- Use data from real HyPer runs to train abstract simulator
  - Neural network maps current plant state and control actions to next plant state
  - Can use neural network to make a time domain simulator of the plant
- Are we claiming you can replace high-fidelity simulator ???

  ABSOLUTELY NOT

Claim: You can approximate high-fidelity simulator in parts of state space to develop policies you can test/tune on the real simulator

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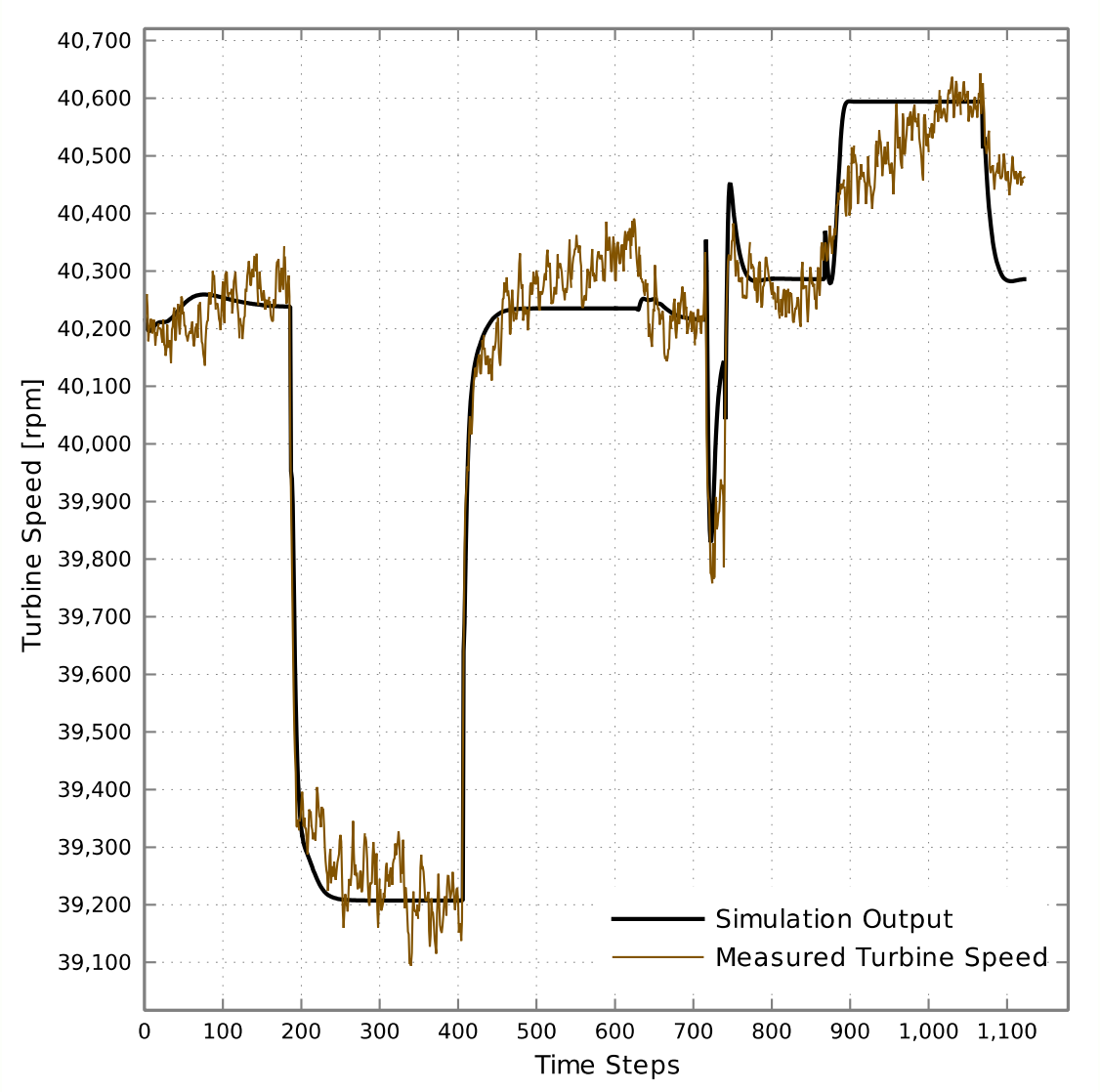
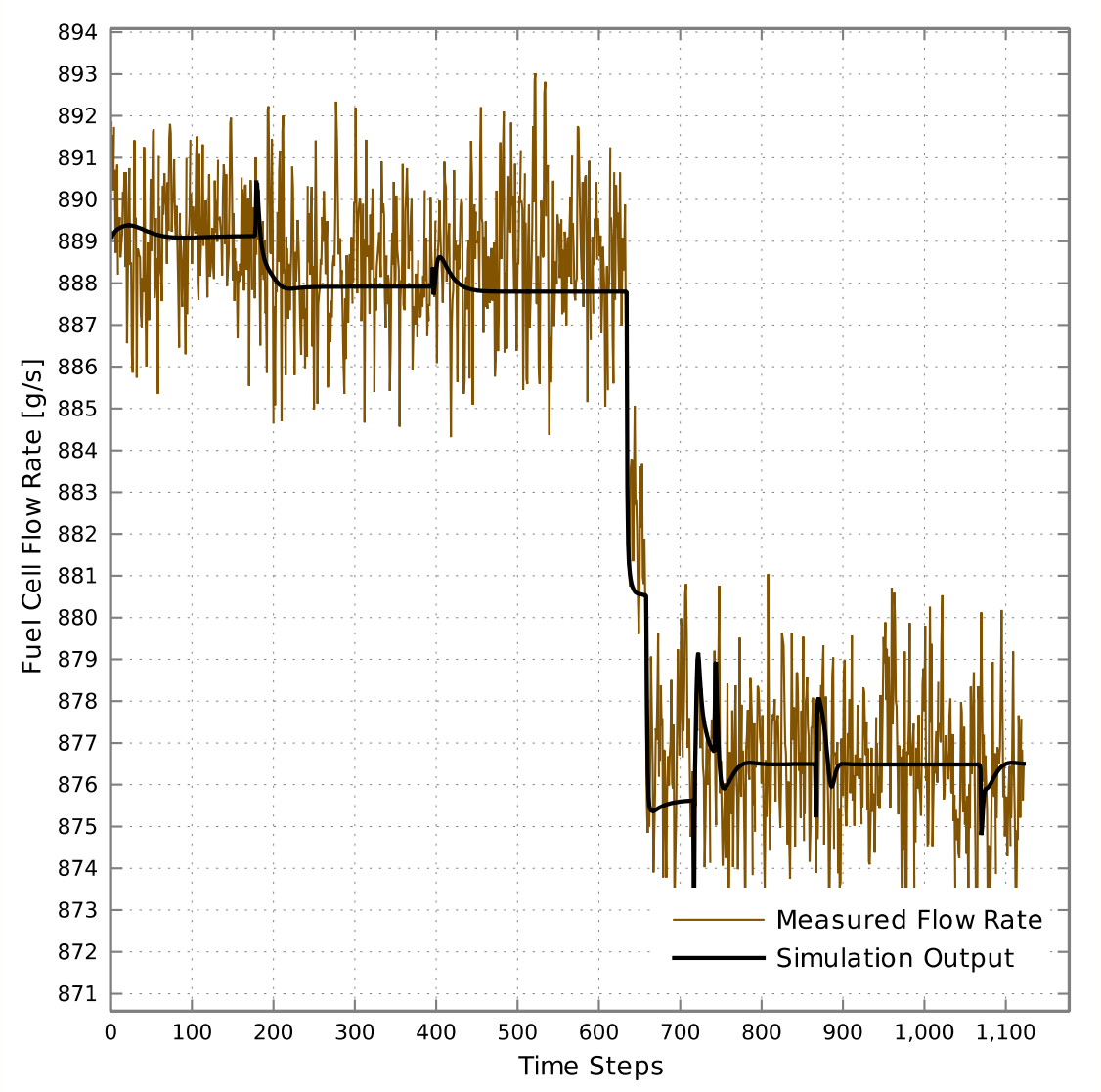
NN Plant Simulator: Results (Turbine Speed)



NN Plant Simulator: Results (Fuel Cell Flow Rate)



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Evolutionary Algorithms

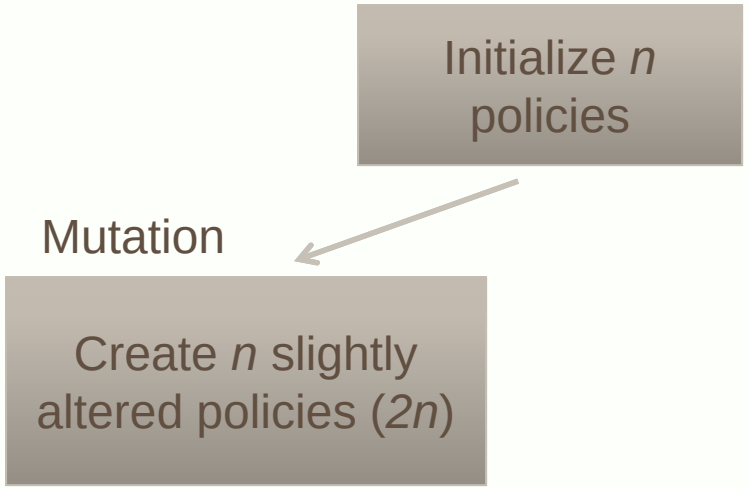
- Stochastic, population-based search algorithm
- Operators: Mutation, Fitness Assignment, Selection

- Useful in problems where gradient information is not available

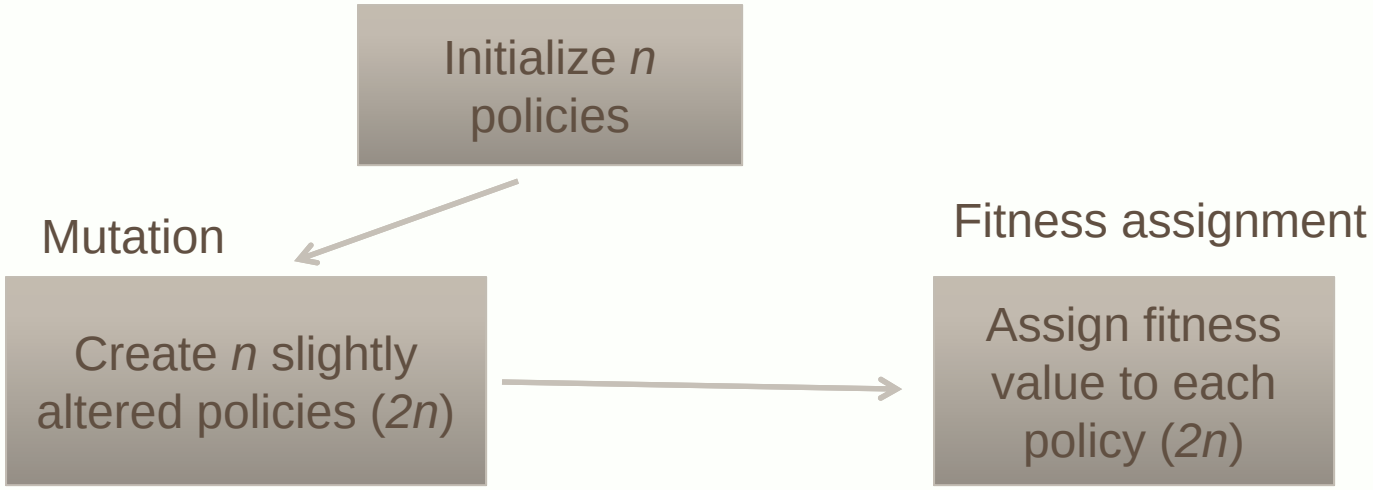
Evolutionary Algorithms

Initialize *n* policies

Evolutionary Algorithms



Evolutionary Algorithms



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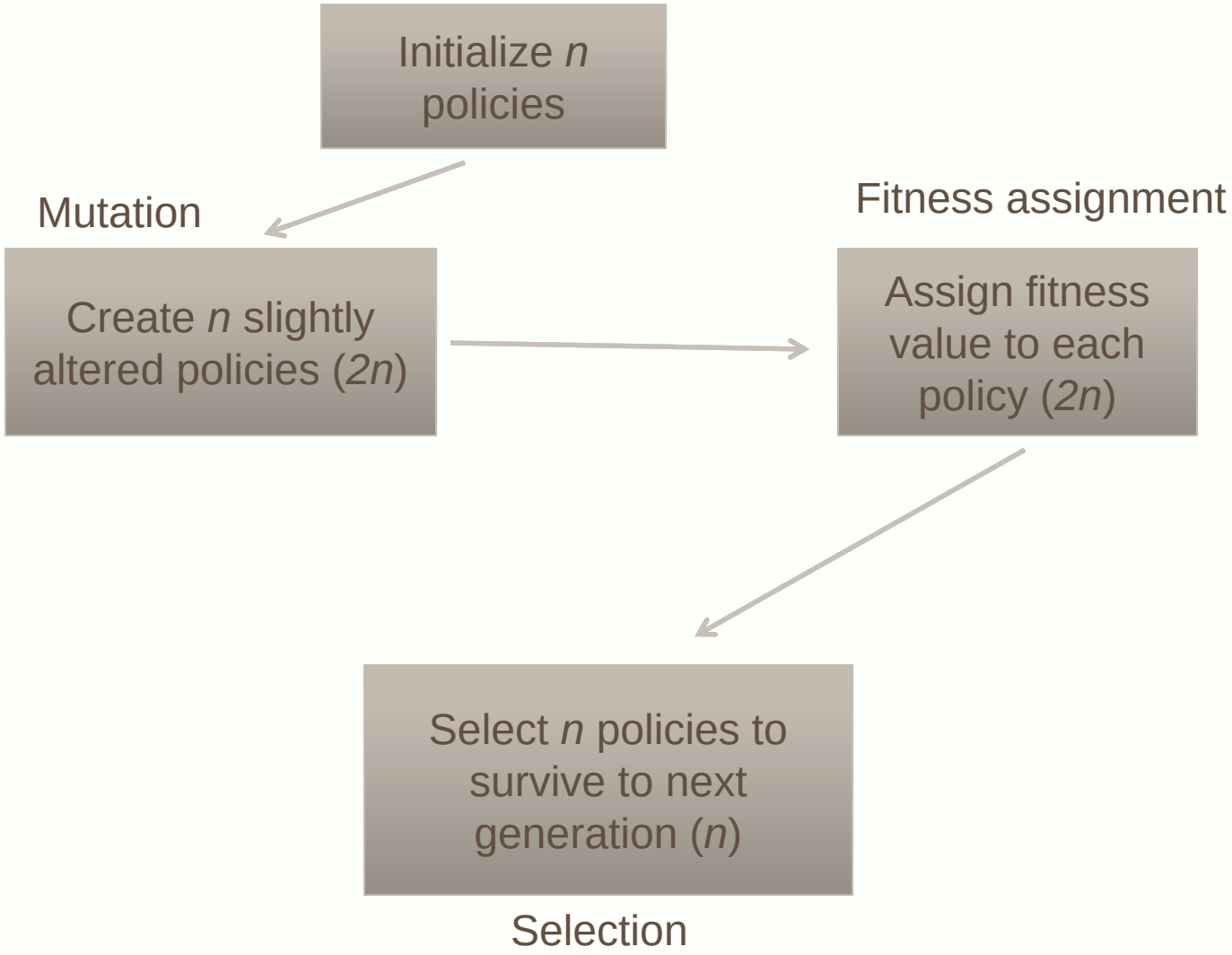

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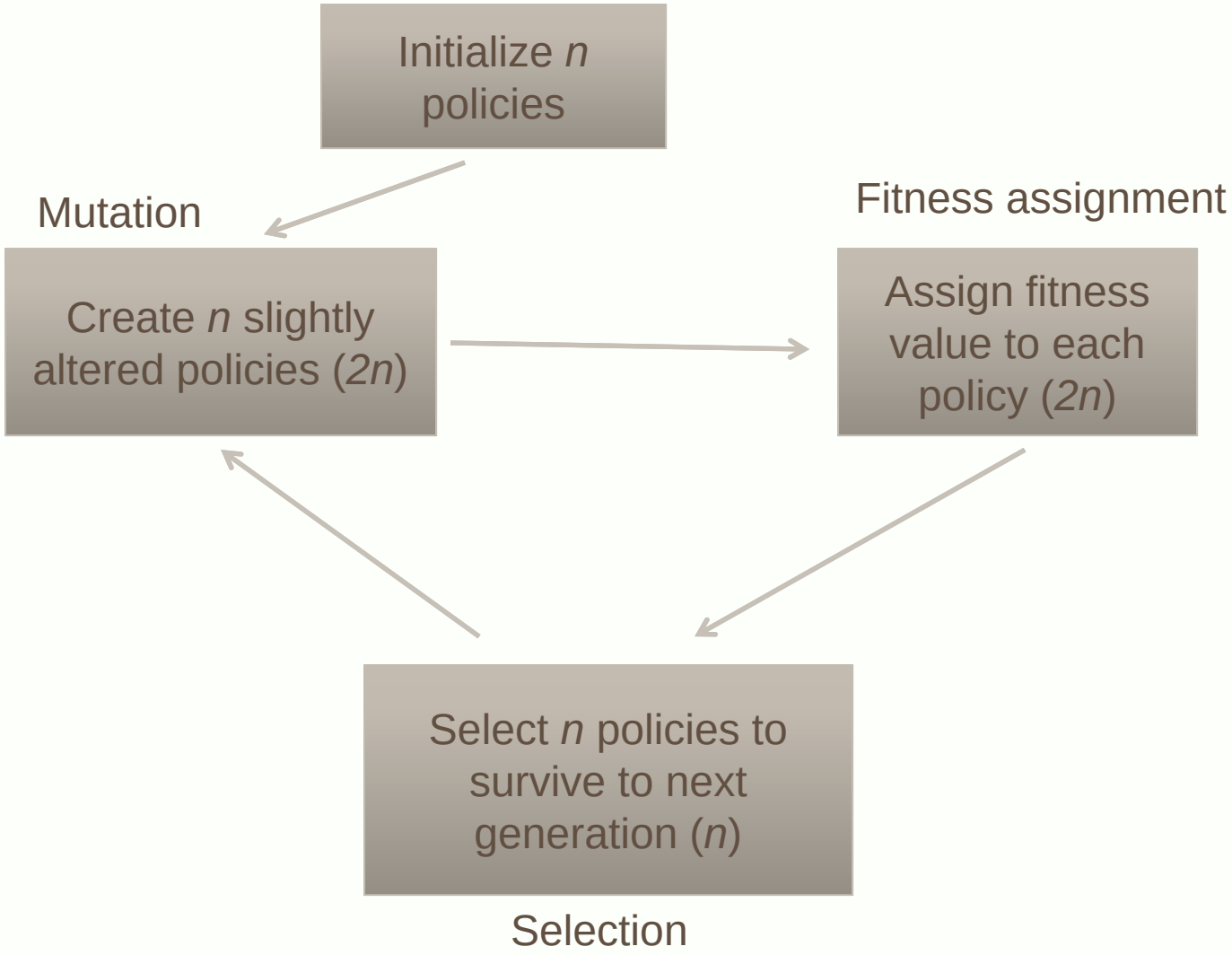
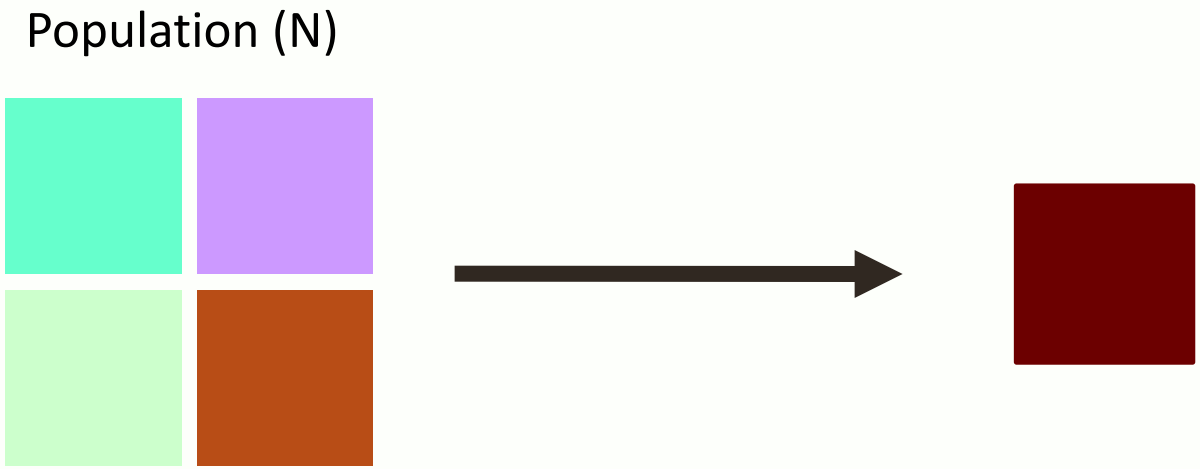


Evolutionary Search



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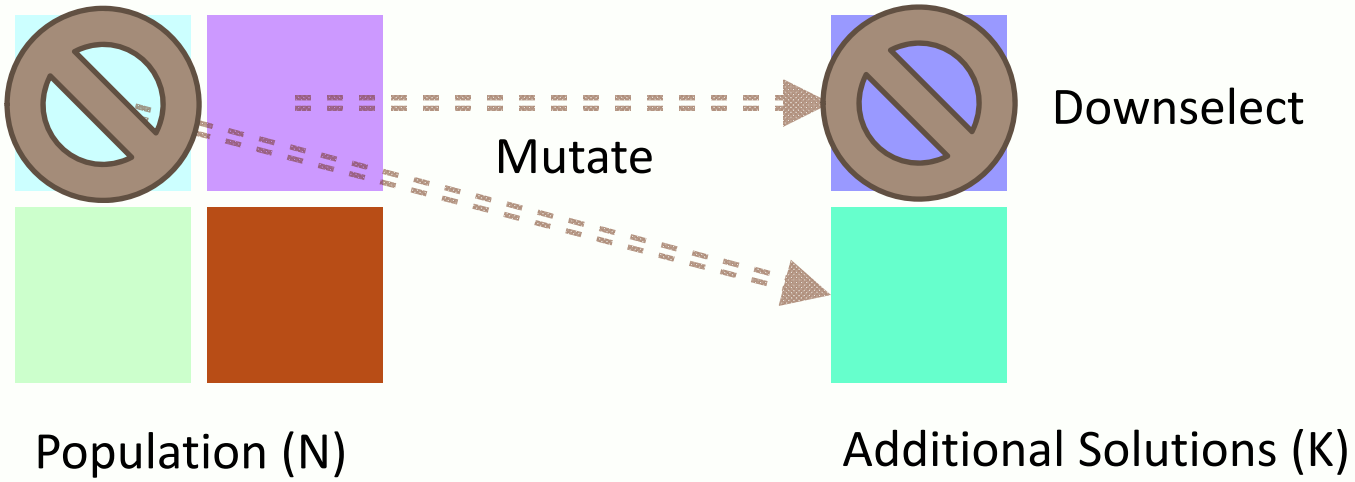
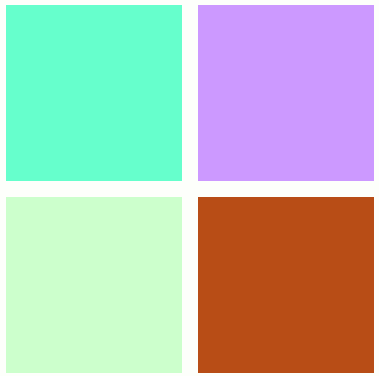
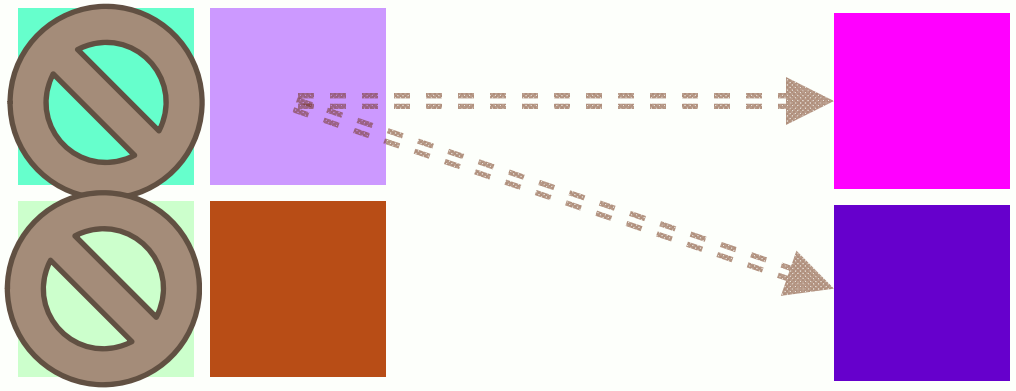
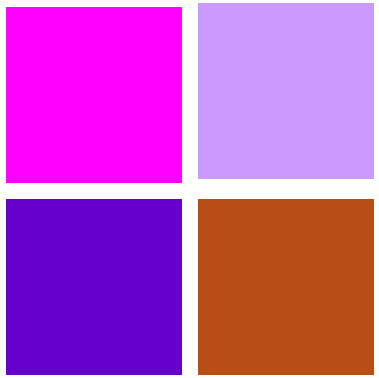




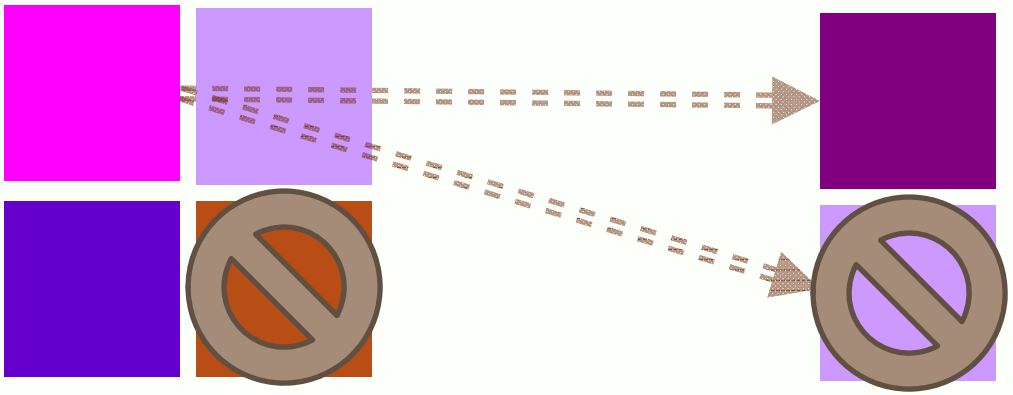
New Population (N)

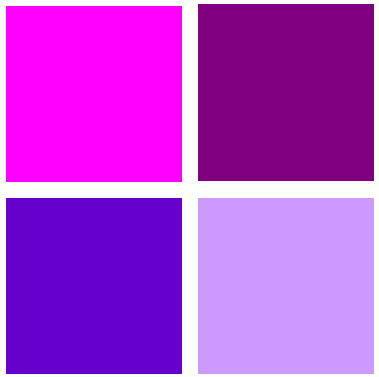
Evolutionary Search





Evolutionary Search





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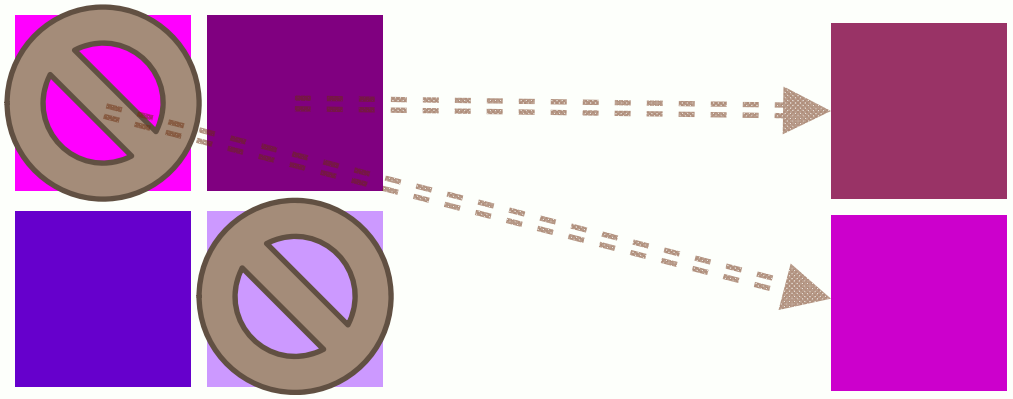

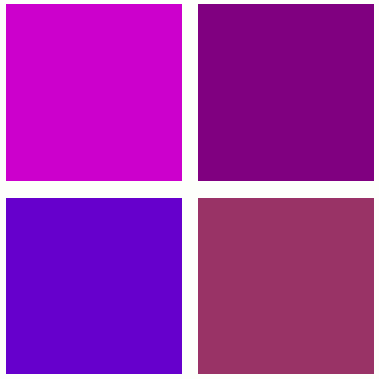

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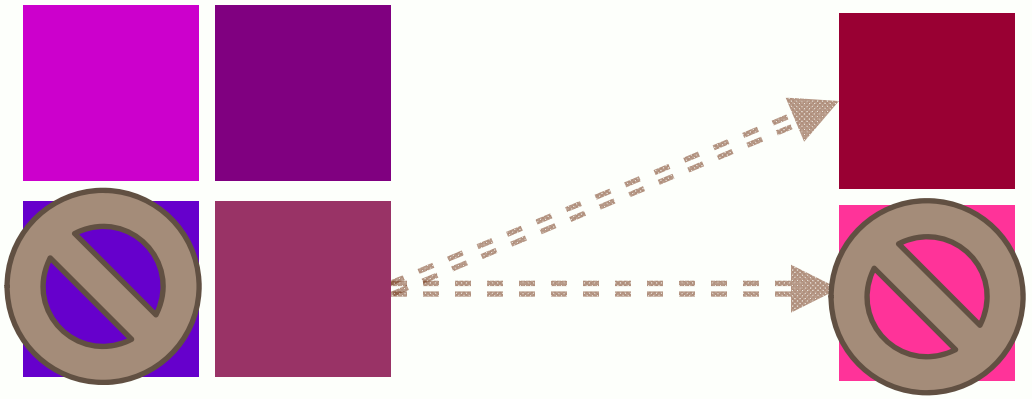

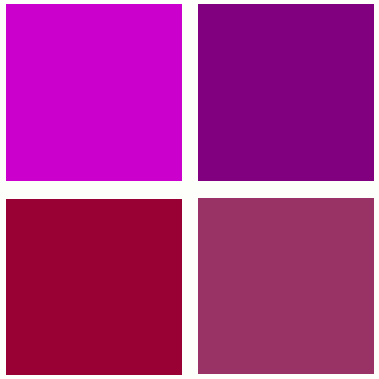

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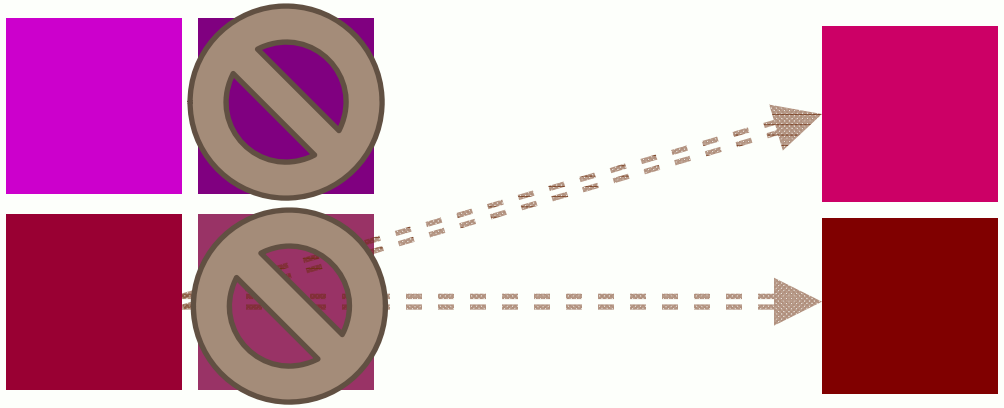

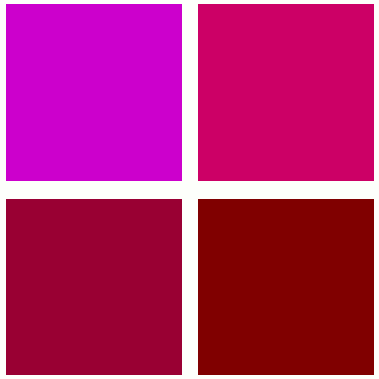

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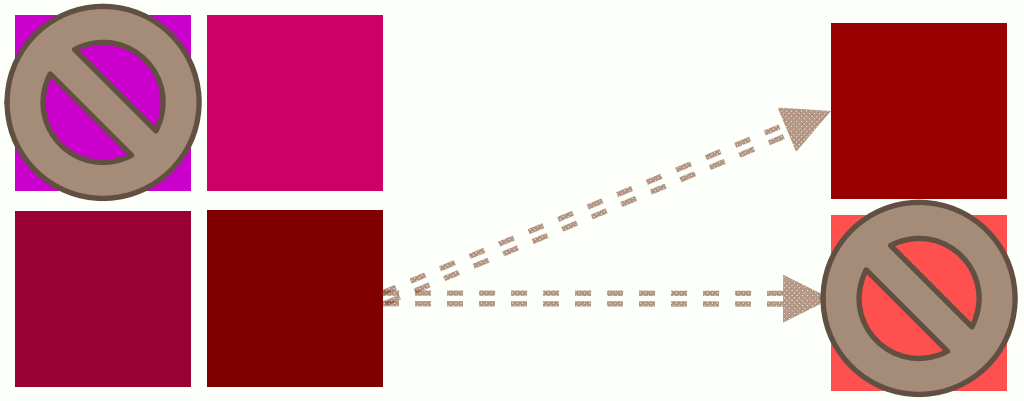

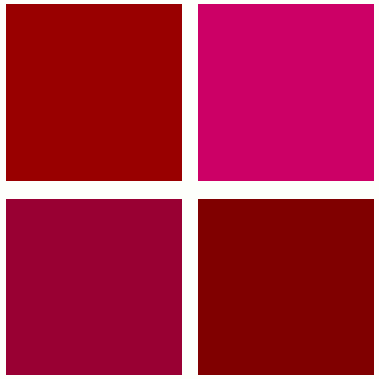

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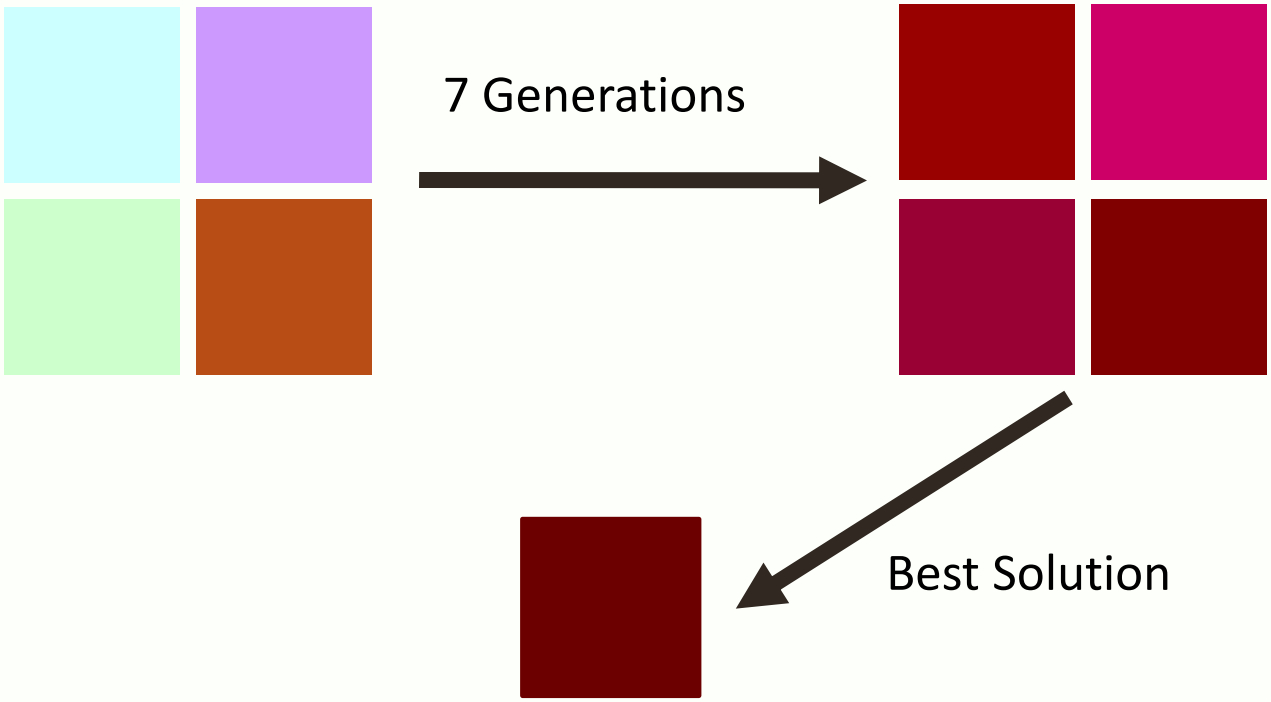
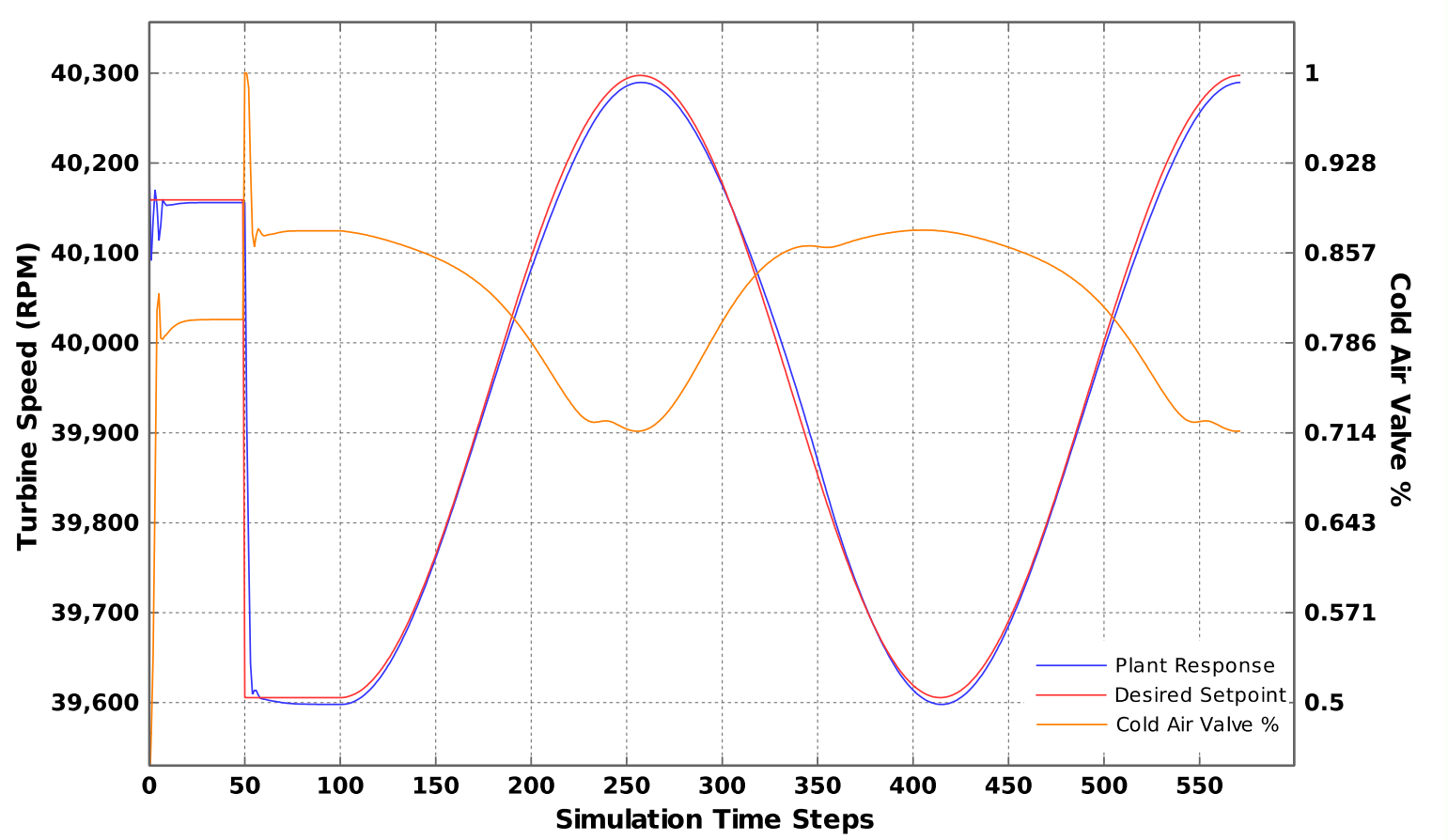


Neuro-evolutionary Control

- Evolve neural network controllers
  - Explore weight space — weight mutation
  - Determine effectiveness of control policies — selection
- Goal: track an arbitrary turbine speed trajectory

Control Results: Track step+sinusoid



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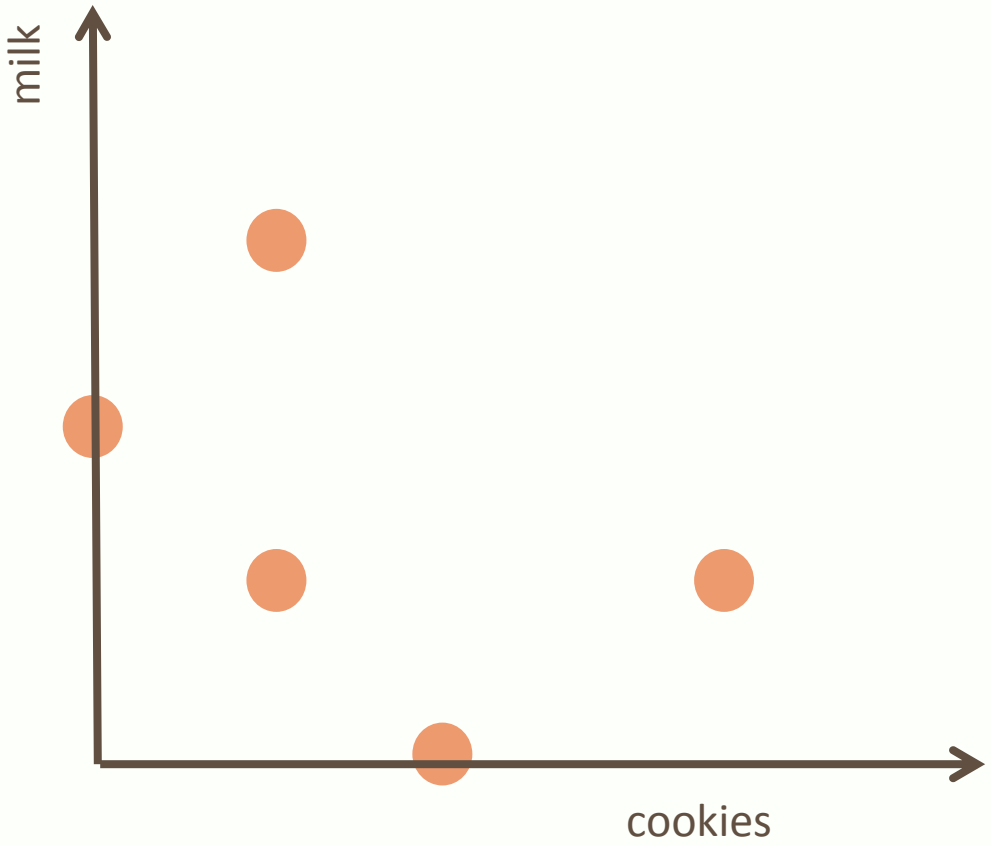
Key Issue in many Real World Problems

- You have one than one objective

- How do you trade-off one for the other

Key Issue in many Real World Problems

- You like milk and cookies
  - Choose:
  - No milk 2 cookies
  - 2 glasses of milk , no cookies
  - 1 cookie, 1 glass of milk
  - 1 cookie, 3 glasses of milk
  - 1 glass of milk, 4 cookies



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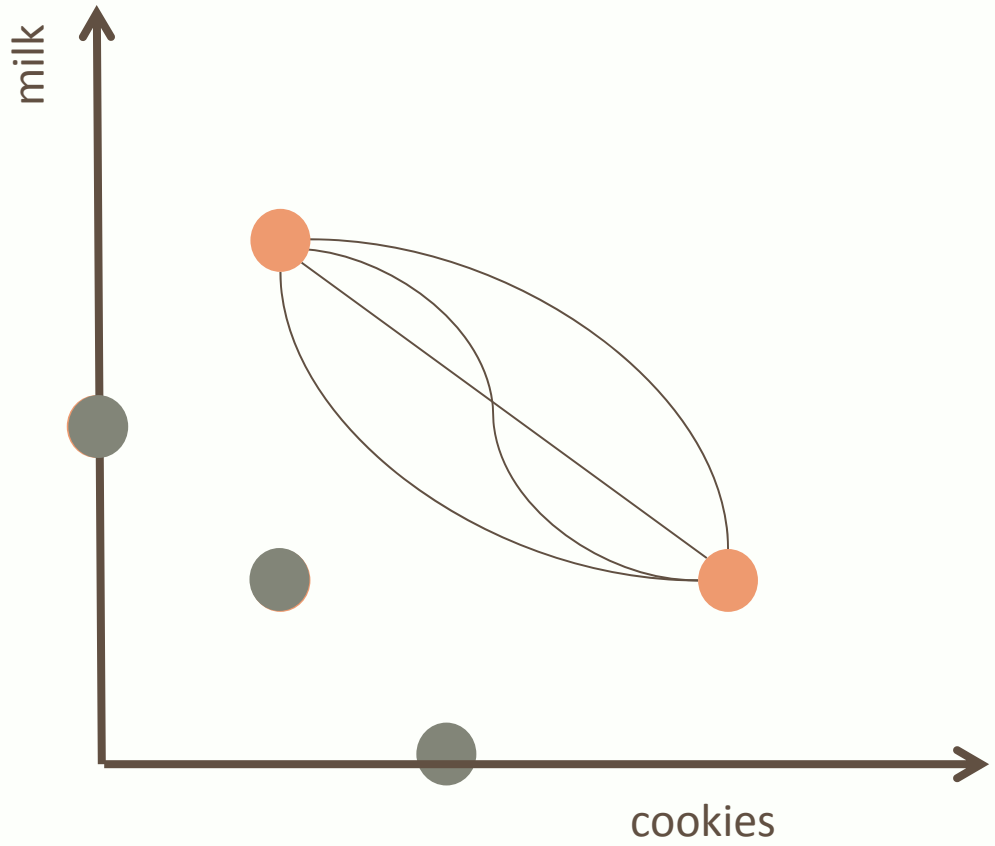

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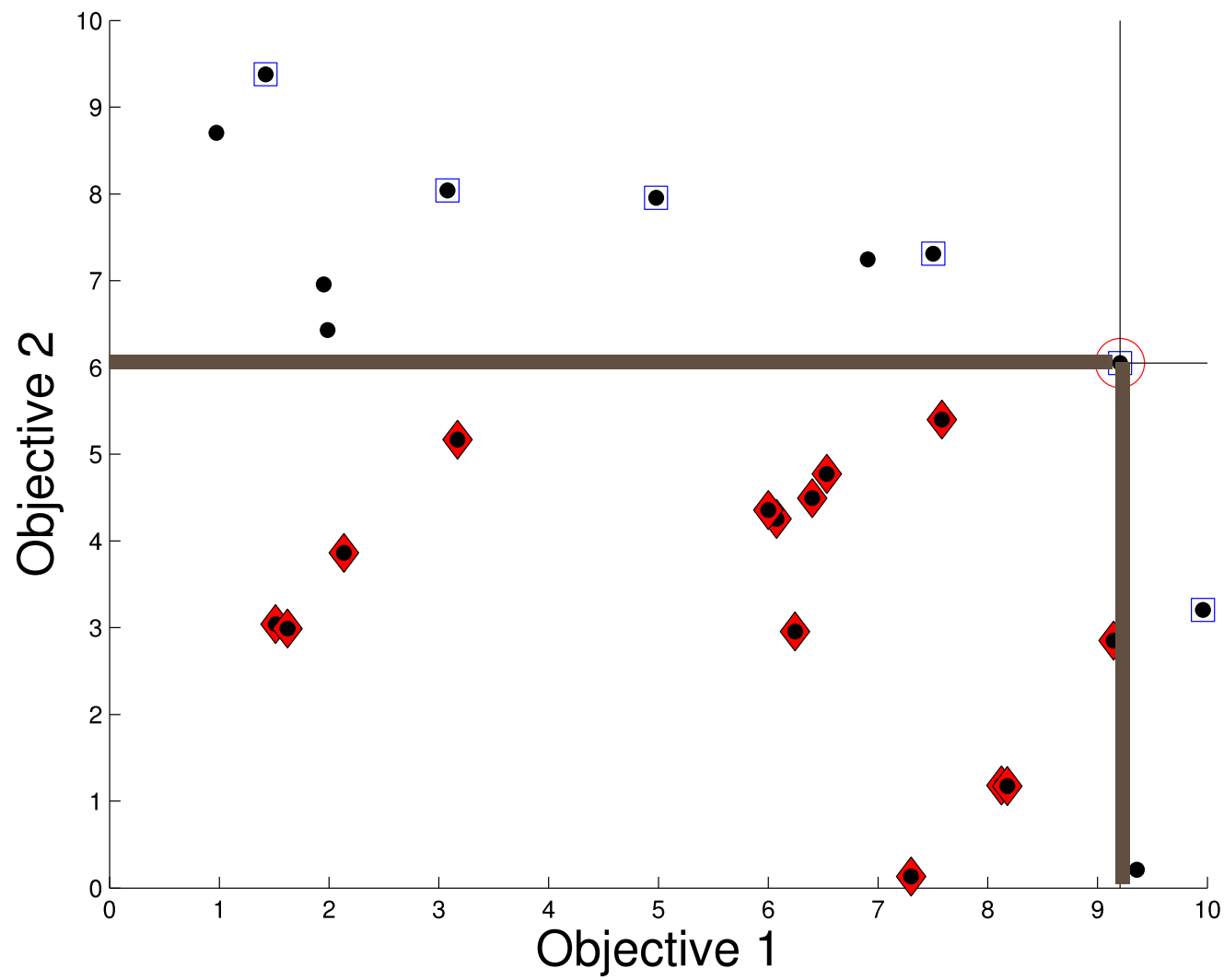
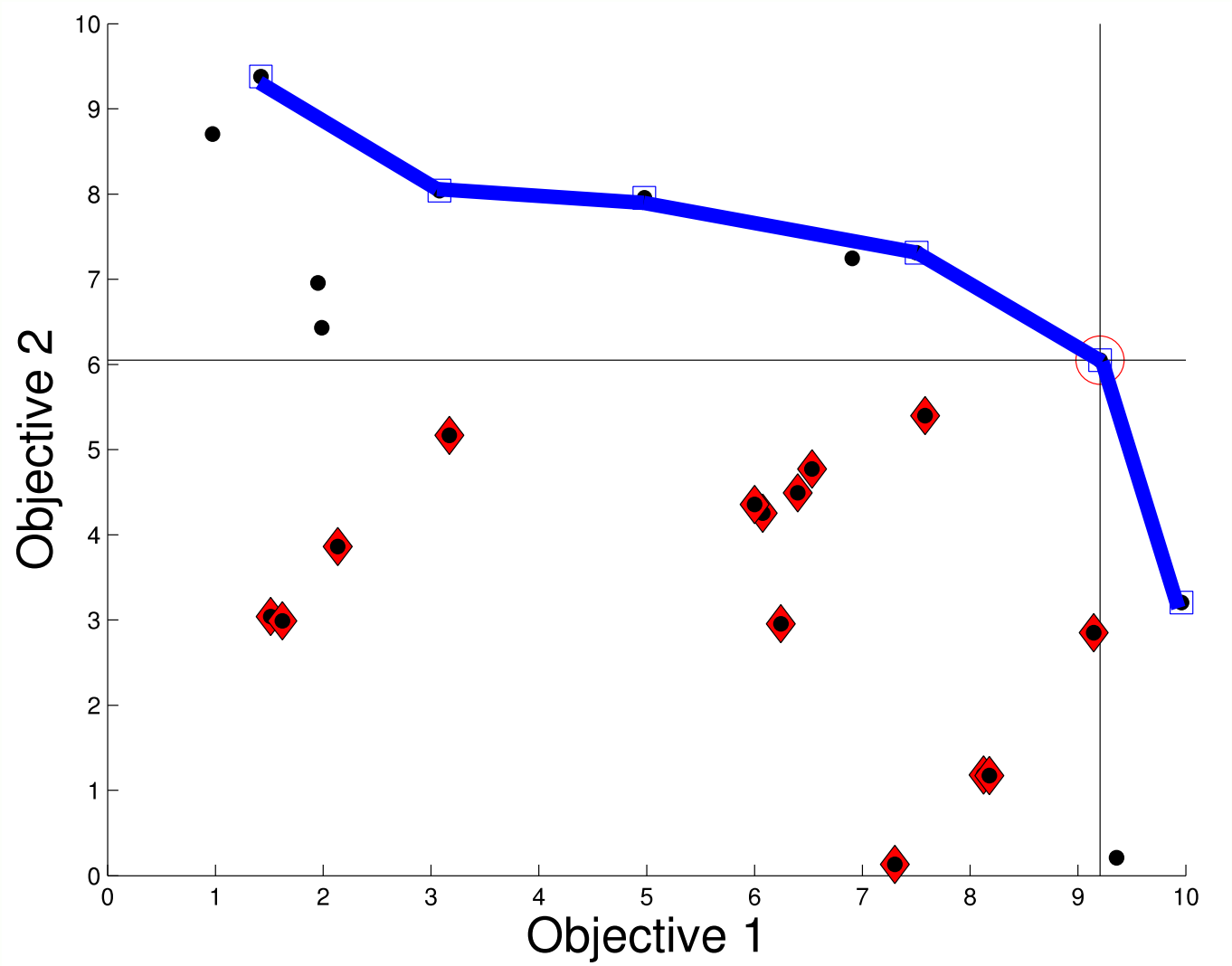
Multi-Objective Concepts: Dominance



Multi-Objective Concepts: Pareto Front



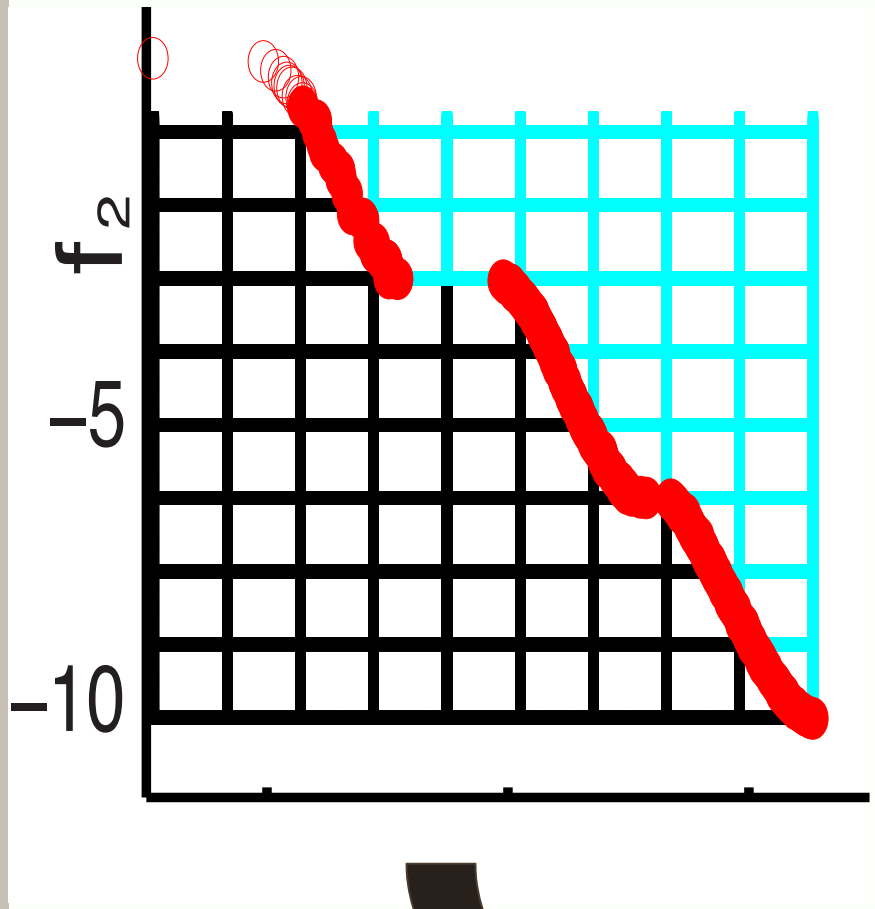
Key Points

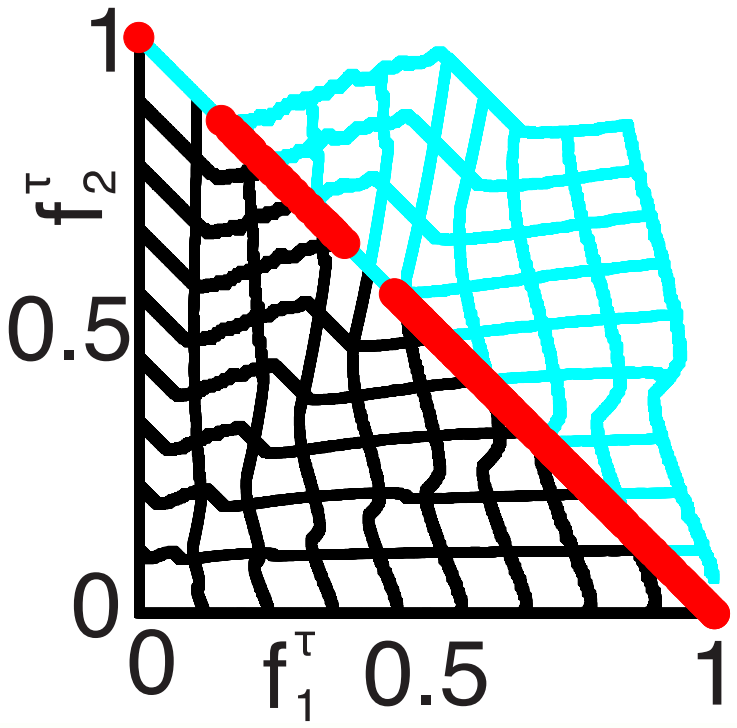
- "Seeing" the performance is easy with two objectives
- With higher than three objectives, it is very difficult

- Linear combination misses entire areas of search space
  - Suboptimal
  - Poor trade-offs

- Population based searches are slow. Very, very slow

New Result





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Project Status

• Milestone 1:	6/30/2014	✓
• Milestone 2:	9/30/2014	✓
• Milestone 3:	3/30/2015	✓
• Milestone 4:	9/30/2015	
• Milestone 5:	6/30/2015	
• Milestone 6:	9/30/2015	

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- Milestone 1: 6/30/2014 ✓
- Milestone 2: 9/30/2014 ✓

- Milestone 3: 3/30/2015 ✓
- Milestone 4: Multi-objective control 9/30/2015 ←

- Milestone 5: Robust Control 6/30/2015 ←
- Milestone 6: Reconfigurable multi-objective control 9/30/2015

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Publications

1. *Learning Based Control of a Fuel Cell Turbine Hybrid Power System.* A. Gabler, M. Colby, and K. Tumer. In Proceedings of Genetic and Evolutionary Computation Conference (GECCO) 2015 (Extended Abstract). Madrid, Spain. July 2015.
2. *Approximating Difference Evaluations with Local Information*. M. Colby, W. Curran, and K. Tumer. In Proceedings of the Fourteenth International Joint Conference on Autonomous Agents and Multiagent Systems (Extended Abstract). Istanbul, Turkey, May 2015.
3. *A Replicator Dynamics Analysis of Difference Evaluation Functions*. M. Colby and K. Tumer. In Proceedings of the Fourteenth International Joint Conference on Autonomous Agents and Multiagent Systems (Extended Abstract). Istanbul, Turkey, May 2015.
4. *An Evolutionary Game Theoretic Analysis of Difference Evaluation Functions*. M. Colby and K. Tumer. In Proceedings of Genetic and Evolutionary Computation Conference (GECCO) 2015. Madrid, Spain. July 2015.
5. *Theoretical and Implementation Improvements for Difference Evaluation Functions*. M. Colby. Ph.D. Dissertation, Oregon State University.
6. *Approximating Difference Evaluations with Local Knowledge*. M. Colby, W. Curran, C. Rebhuhn, and K. Tumer. In Proceedings of the Thirteenth International Joint Conference on Autonomous Agents and Multiagent Systems (Extended Abstract). Paris, France, May 2014.
7. *PaCcET: An Objective Space Transformation to Iteratively Convexify the Pareto Front*. L. Yliniemi and K. Tumer. In *The Tenth International Conference on Simulated Evolution And Learning (SEAL 2014)*, Dunedin, New Zealand, December 2014.
8. *Multi-Objective Multiagent Credit Assignment Through Difference Rewards in Reinforcement Learning*. L. Yliniemi and K. Tumer. In *The Tenth International Conference on Simulated Evolution And Learning (SEAL 2014)*, Dunedin, New Zealand, December 2014

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Phd, 2015

MS, 2015

Phd, 2014

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Questions?

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