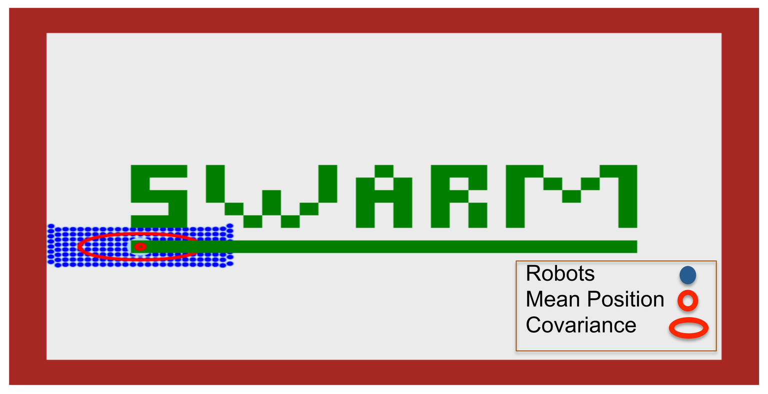

Controlling the Shape of 1,000 Robots with Just *Two* Inputs

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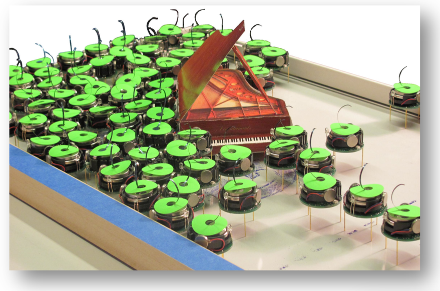
Why a Swarm?

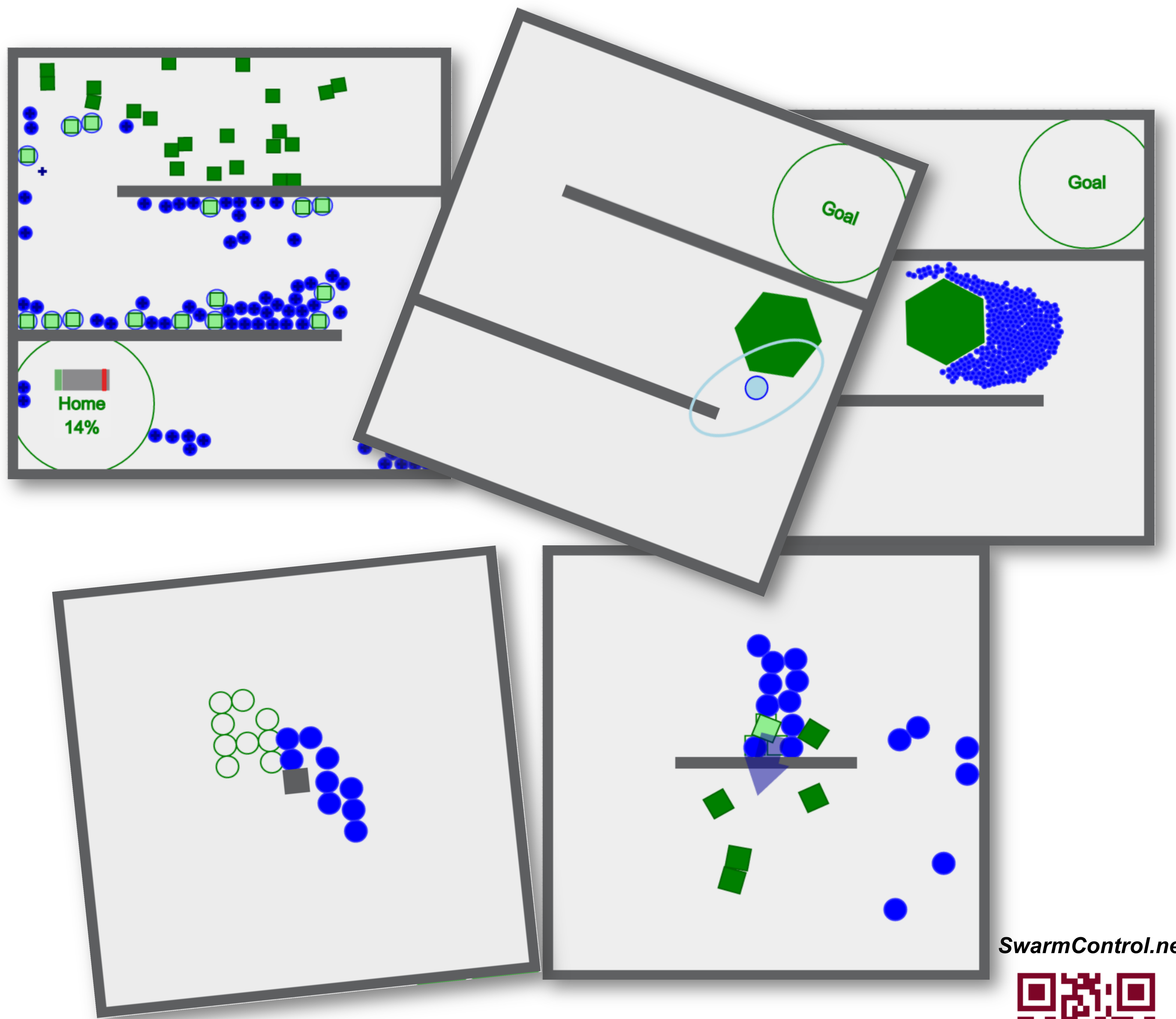
Swarm robots:

- Can pass through constrictions
- Can bend around obstacles
- Can be simple:
  - ✓ Easy to design, build, test
  - ✓ Disposable/ replaceable
  - ✓ Small, tiny, nano/micro robots



Swarm Piano Mover's video

How Do Humans Control Swarms?



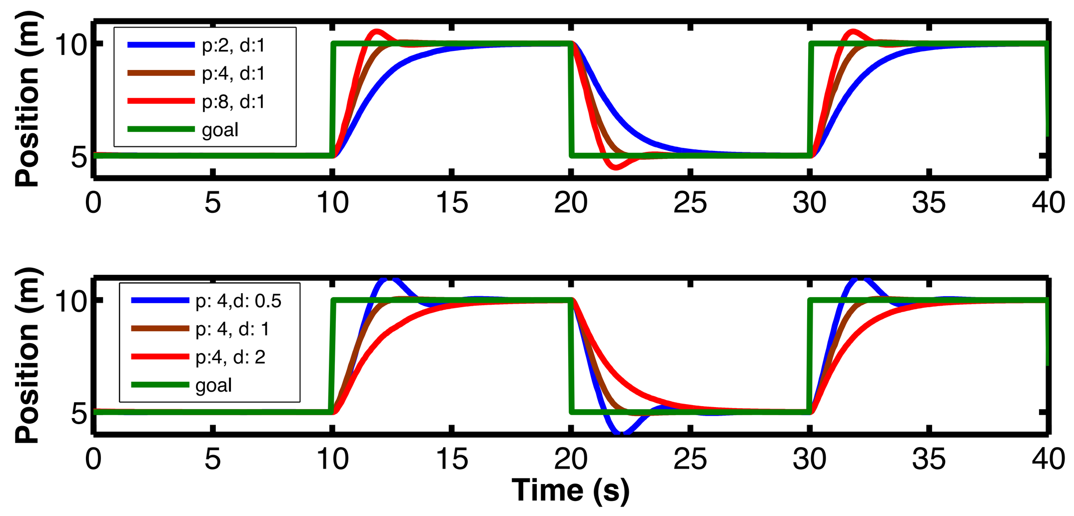
SwarmControl.net

Humans can control swarms. Our gamification research with ***SwarmControl.net*** has run 10,000s of experiments. Can **machines** learn how to control a swarm?

Rules: Inputs are simple & global: all robots receive exactly the same commands

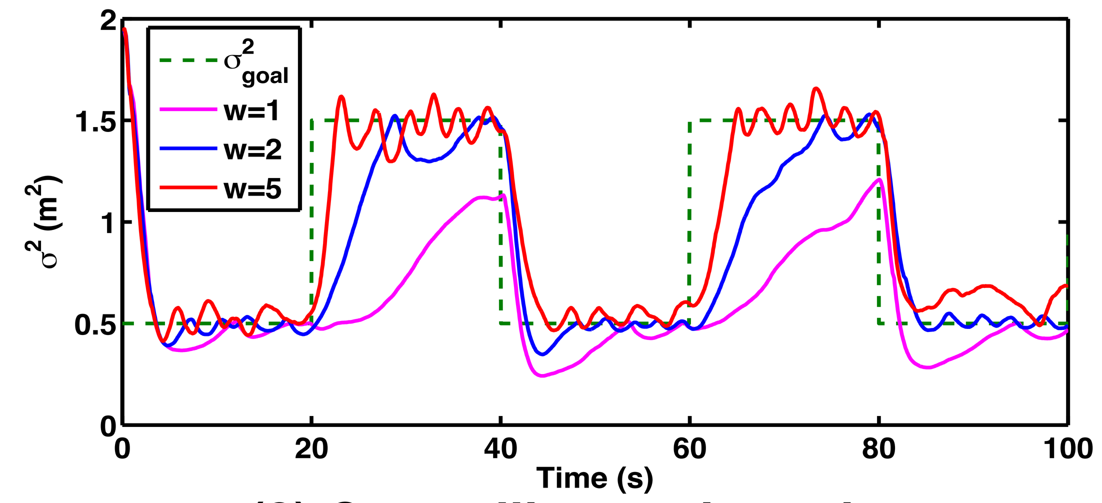
Result 1: Without any *obstacles* and *noise*, the robots cannot be steered to arbitrary positions. Adding *obstacles* and/or *noise* breaks symmetry and enables controlling the position of every robot.

Three Controllers



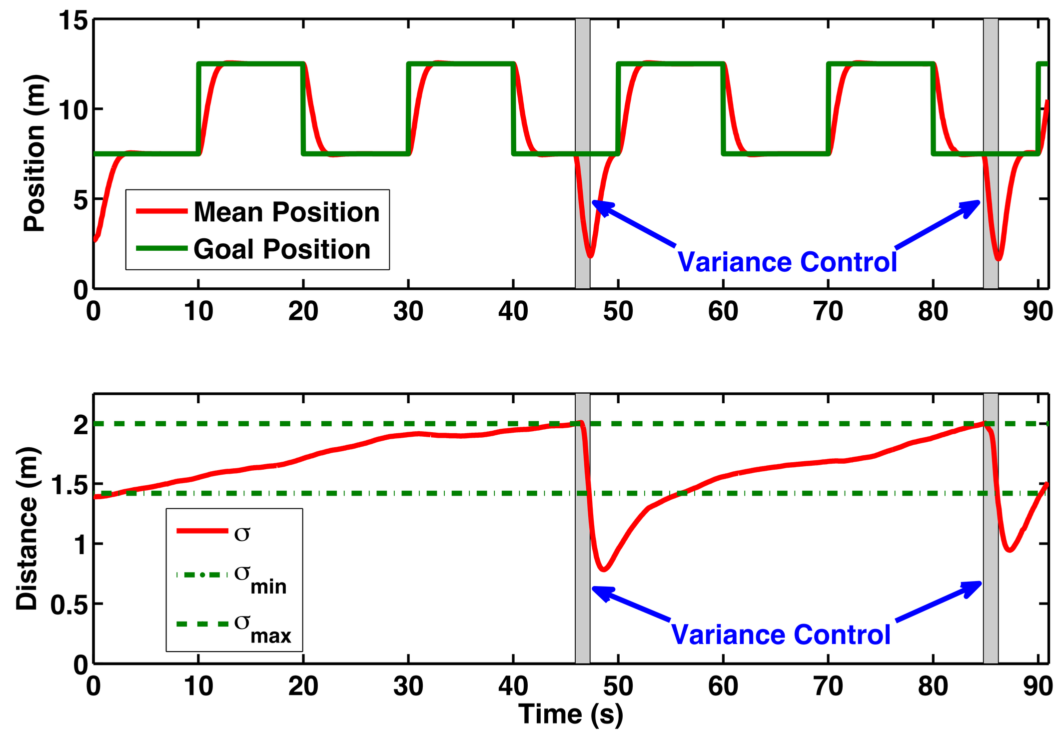
(1) Controlling *mean position* of 200 robots with different gain settings

- Proportional gains, K_p, increase the response, but also increase overshoot
- Derivative gains, K_d, reduce overshoot, but slow the response



(2) Controlling *variance* by exploiting Brownian noise

Robots *wait* to increase variance and *go to corners* to decrease variance



(3) Hybrid hysteresis mean-variance control

- Robots go to corners if variance is bigger than max
- Mean Control if variance is less than min

Opportunities

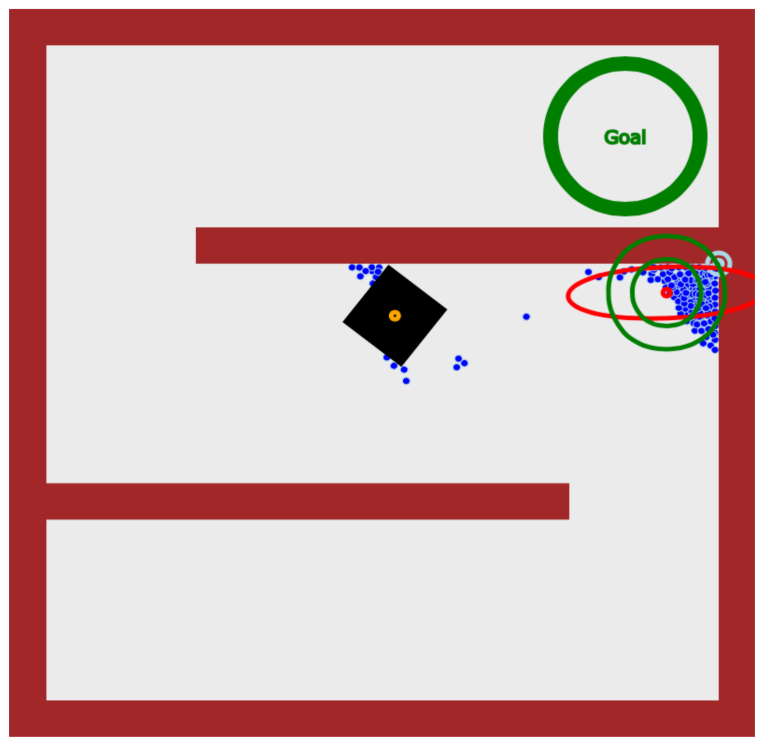
- How could the swarm be optimally partitioned using the same input? What is the ideal obstacle shape?
- What if we do not know the environment? How can the swarm learn the environment?
- What is the advantage of heterogeneity? Could a leader robot increase performance by measuring a stochastic environment?
- What obstacle shapes are ideal for controlling a given moment?

Results

Block Pushing with 200 robots

Block-pushing video

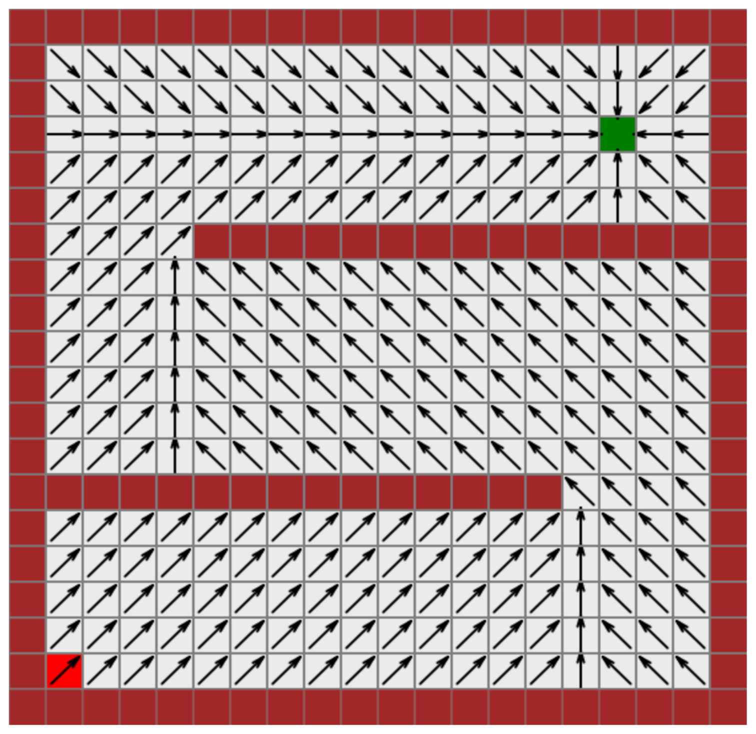
- **Problem**: push a block through a maze using a swarm of robots with *global inputs*
- All robots get the same global input and use hybrid hysteresis mean-variance control to reach the goal
- We choose *local goals* to steer the swarm: aggregate behind the block to push the block forward



Block Pushing

If variance is larger than desired maximum, we direct swarm to nearest corner to gather robots

Flip



Gradient

We use BFS values to find local goals and direction that we should go from starting point to goal

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BFS

Bread-first search (BFS) to find the shortest path from starting point 52 to the goal 0

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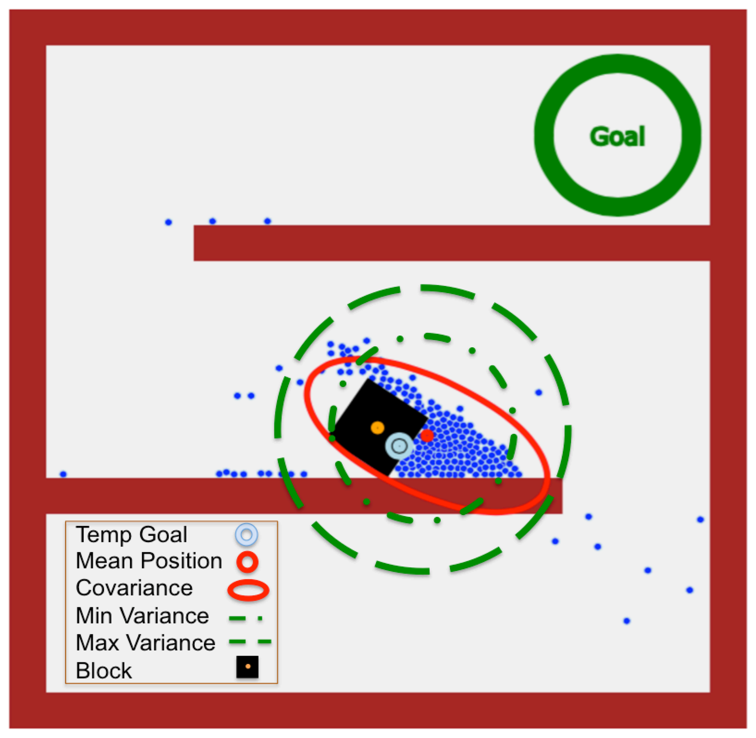

Block Pushing

In this experiment, 200 robots push the black block in the maze to the goal, by controlling the swarm mean and variance

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