From Ants to Robotic Explorers: Using Biologically-Inspired Robots to Map the Unknown

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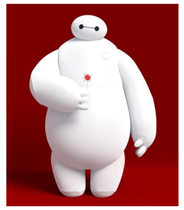
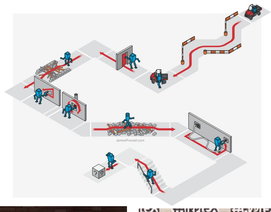
Motivation: Pop-Culture to Reality

- Robots, related technology increasingly pervasive
- Nearly everyone has opinions/expectations about future of robotics
  - Great potential to assist, not replace, humans
- My focus is using robots to aid in disaster relief
  - Not there yet, as shown by DARPA Robotics Challenge
  - Actually...humanoids may not be the solution

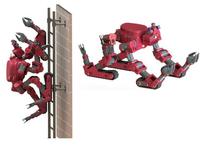






Basics of Biologically Inspired Robots

- Look for inspiration in nature - what organisms are most successful?
- Humans are intelligent and versatile but expensive, requiring many sensors and lots of energy
  - In harsh environment like disaster site, communication and localization are not guaranteed
  - Single robot can be stopped
- Top-placing DARPA team partially recognized limitations of humanoids so sought different biologic inspiration


https://gifts.worldwildlife.org/gift-center/gifts/species-adoptions/chimpanzee.aspx


https://en.wikipedia.org/wiki/Common_chimpanzee

https://honeysun.wordpress.com/2008/11/18/chimfunshi/

- Go further toward individual simplicity: ants and bees
- Cooperative insects are much more robust and less expensive
  - No individual robot is instrumental to success
  - Potentially more efficient for exploring/mapping
- As increase robot simplicity and number of robots, move into relatively new domain of swarm robotics


Arizona State University:
https://research.asu.edu/stories/read/insect-research-gives-humans-six-legs

SSR Lab Harvard:
https://www.youtube.com/watch?v=CN6wZoYOEUQ

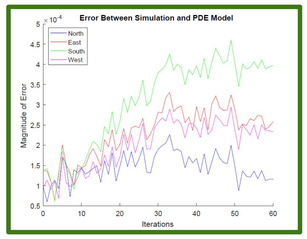
How can we use swarms for mapping?

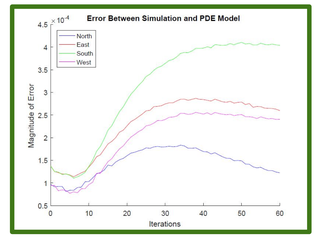
- Though individuals have simple actions, complex patterns emerge in a swarm as individuals interact with each other and the environment
  - Ex. Foraging patterns or hive structures of ant colonies
- Get a unique distribution of robots depending on individual behavior as well as environmental features
  - Connecting observed robot distribution to corresponding environment basically becomes a pattern recognition challenge
- Humans are fantastic at pattern recognition due to years of experience
  - Ex. Predicting presence of obstructions in a river for kayaking


- Can also “train” robots but need thousands of examples to link local behavior to emergent behavior
  - Takes hours or even days for single scenario
  - Ultimately need a “library” of environmental features and corresponding robot distribution - impractical scale for simulation much less implementation!

Environment Identification

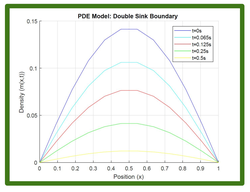
- Can use emergent behavior to identify environmental features
  - Robots do not need to communicate or known their position
  - First observe number of robots in middle of simulation with unknown boundaries
  - Compare to density obtained by solving PDE models at equivalent time and position
- Ex. In a 2D environment, can determine in which wall a door lies
  - Results for simulation with a single door in north wall are shown below for 10^4 (left) and 10^7 (right) robots
  - Increasing the number of robots makes visual identification more clear but get statistical difference with fewer robots
  - After fewer than twenty moves can see north PDE model has the lowest error when compared to simulation

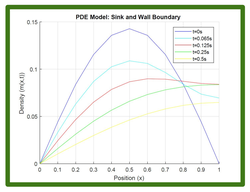


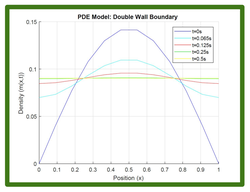


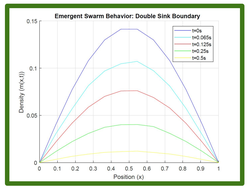
Novel Methodology to Model Emergent Behavior

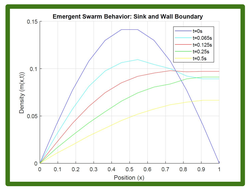
- Rather than observe resulting emergent behavior for each scenario, derive model for emergent behavior directly from local rules
  - Use mathematical process involving continuum limits
  - Extend known behavior of individual robots to a continuous-time domain
- Resulting model is a partial differential equation (PDE) which is quickly solved
  - Boundary conditions of PDE encode environmental features like ‘doorway’ or ‘wall’
  - Can solve PDE to predict number of robots in a given position at a given time for each environmental model

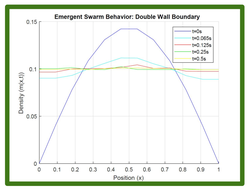










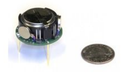


Why do we care about developing a model?

- Quickly compare locally observed swarm behavior to library of environment models to identify features throughout environment
- Have direct mapping between local and emergent behaviors to develop efficient mapping behaviors using individual robot behaviors
- It costs money to build robots - can use model to inform where money makes biggest impact in robot functionality

Concluding Remarks

- The random motion and limited sensing of the robots in our initial work represent a worst-case scenario
  - Can still use swarm to identify environmental features
  - Need to expand potential robot behaviors for more efficient mapping and richer library of environment features
- Current work shows a swarm of robots can be used to locate exits in a room or mine tunnel
- Novel methodology has several benefits over currently proposed swarm techniques:
  1. Derive model of emergent behavior from local behavior so has physical significance
     a. Work is on algorithm level so applicable for robots of any size and actuation (walking, rolling, flying)
  2. Observations are made locally without reliance on shared information - extremely robust
  3. System is fully scalable and ad hoc




Thank You!

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