Swarm Robotics

Collective Construction

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CEQ Reminder!
Collective Construction

- Social insects build physical structures (nests, hives, mounds) that are impressive in their size and intricate functionality.
- Swarms of robots that could build structures autonomously might be useful in these situations:
  - Structures in hazardous environments (e.g. space, underwater)
  - Ad hoc structures for emergency needs
Why Build with Swarms?

* Collective construction methods inherit the usual advantages of swarm robotics
  * Scalability: Larger structure? More robots!
  * Fault-tolerance: Individual robots can fail, but the rest continue
  * Robustness: Damage to the structure is repaired simply by continuing the construction process
Early Work: Blind Bulldozing

* Parker et al (2003) took inspiration from ants that build circular nets in flat cavities between rocks ("rock ants")
Early Work: Blind Bulldozing

- There is little light to guide the ants
- “Blind bulldozing”:
  - An ant pushes granules of sand until the force of pushing the material is too great
  - The ant leaves what it was pushing (i.e. deposits it) then turns in a random direction
Blind Bulldozing Robots

- Parker et al. programmed their simple robots with two basic behaviours:
  - Move in a straight line, pushing whatever dirt lies ahead
  - If resistance exceeds a threshold then turn by a random angle and resume pushing
- Shape of the nest is unaffected by the number of robots

Fig. 7. Nests constructed by one, two and four robots after two hours. The nest retained its initial circular shape and has uniform walls because the blind bulldozers enlarge the nest by distributing their pushes against the nest wall along its entire length.
Werfel et al (2014) have developed a technique allowing a group of robots to build any structure which satisfies these criteria:

- Composed of identical rectangular bricks providing alignment cues and attachment points
- Bricks stacked vertically
- Paths exist on the growing structure to support the movement of construction robots
from social insects challenges associated with engineering a complex guarantees of correct completion of that structure. The final target structure and provide provable generation from a high-level representation of the structure; an offline compiler converts it to a "structpath" representation (Fig. 3), which is provided to all robots; robots follow local rules that guarantee correct completion of the target structure (movie S1).

Fig. 1. Natural and artificial collective construction. (A and B) Complex meter-scale termite mounds (A) are built by millimeter-scale insects (B), which act independently with local sensing and limited information. (C) Physical implementation of our system, with independent climbing robots that build using specialized bricks. (D) System overview for building a specific predetermined result (Fig. 2, A and C): A user specifies a desired final structure; an offline compiler converts it to a "structpath" representation (Fig. 3), which is provided to all robots; robots follow local rules that guarantee correct completion of the target structure (movie S1).
The "structpath"

* Werfel et al’s robots have the usual swarm characteristics:
  * Local sensing
  * No centralized control
  * All robots follow the same rules
  * To design a particular structure, the robots consult a special map called the structpath
  * The structpath is compiled from a model of the desired structure
The seed block (dot shown) provides a landmark for the robots and is used to guide their building: any single row is built in order according to distance from the seed.
Is this Cheating? Is this SR?

Option 1: Yes. This work is not true SR

- This structpath sounds like a “master plan” that the robots carry out (i.e. instructions from above)

Option 2: No. This work really belongs to SR

- The structpath is given to all robots at the beginning, and does not change---similar to the genetic programming of an animal
- It guides the robots much like traffic rules guide drivers, but it does not specify the exact behaviour of each robot
How Can We Tell?

* If a collective construction system exhibits the desired properties of a swarm-based system, then we’ll call it SR

- Scalability: Larger structure? More robots!  
  - Yes

- Fault-tolerance: Individual robots can fail, but the rest continue
  - Partially (a broken robot could block construction)
  - Yes — At least to a degree (consider the movie that follows)

- Robustness: Damage to the structure is repaired simply by continuing the construction process
  - Yes
So... Yes, the swarm can repair a damaged structure (assuming the damage doesn't violate the construction constraints)
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References
