Educating Genghi: 
A Complexity Perspective on 
Designing Reactive Swarms

Todd Wareham

Department of Computer Science 
Memorial University of Newfoundland

September 17, 2015
Introduction: Why swarms?

- Swarm = group of active, mobile entities.
- Characteristics of a swarm:
  - Large number of entities (100+)
  - No centralized control or synchronization
  - Entities are simple
  - Entities are autonomous
  - Entities sense and communicate locally
  - Entities are incapable of task $T$ as individuals but capable of $T$ as a group.
EXAMPLE: Termite Nest Construction
EXAMPLE: Robot swarm Morphogenesis
Many methodologies proposed to design robot swarms; no method to date is both general and efficient.

**How difficult is swarm design in general?**

**What restrictions do (and don’t) make swarm design easy?**
Organization of this Talk

1. Defining Swarms
2. Defining Swarm Design
3. Complexity of Swarm Design
4. Conclusions and Future Work
Defining Swarms: Robot Architecture

- Use reactive subsumption architectures (Brooks, 1986).
- Architecture = sensors + layers + total order on layers + layer subsumption interactions (inhibit/override)

Sensors → Wander → Avoid → Hide → Hungry? → S

S → Actuators
Defining Swarms: Swarm Architecture

- Three policies: individual robot movement + robot communication + movement conflict resolution.

- Restrictions:
  - Synchronized robot movement.
  - No inter-robot communication.
  - No movement conflict allowed.

- Modifications:
  - **Reconfiguration**: Modify up to $c$ layers and layer-linkages in a robot (relative to provided layer library $M$)
  - **Selection**: Add / delete up to $c$ robots in a swarm (relative to provided robot library $A$)
Defining Swarm Design

- **GIVEN SWARM NAVIGATION (GSN)**
  Can a given positioned swarm get from $s$ to $d$?

- **SELECTED SWARM NAVIGATION (SSN)**
  Can a selected swarm be positioned to get from $s$ to $d$?

- **GIVEN SWARM NAVIGATION WITH REC. (GSN-REC)**
  Can a given positioned swarm be reconfigured to get from $s$ to $d$?

- **SELECTED SWARM NAVIGATION WITH REC. (GSN-REC)**
  Can a selected swarm be reconfigured and positioned to get from $s$ to $d$?
Complexity of Swarm Design

- All swarm design problems except GSN are provably polynomial-time intractable in general; need to restrict these problems if we are to get tractability.
- Many restrictions on swarm robots or overall swarm architecture do not matter, either individually when restricted to constant value or in combinations.
- What is important is restrictions on the sensory / perceptual complexity of the swarm robots $\Rightarrow$ ignorance is (computational) bliss!
Conclusions and Future Work

• Swarm design is intractable in general for the simplest types of worlds, tasks, and robot / swarm architectures; however, there are plausible restrictions that may allow instances of interest to be solved exactly.

• Future work:
  • Establish complexity of GSN.
  • Extend analysis to more restrictions.
  • Analyze swarm design relative to other types of worlds, tasks, and architectures.
  • Investigate related problems, e.g., reactive morphogenesis.