Educating Genghi: A Complexity Perspective on Designing Reactive Swarms

Todd Wareham

Department of Computer Science
Memorial University of Newfoundland

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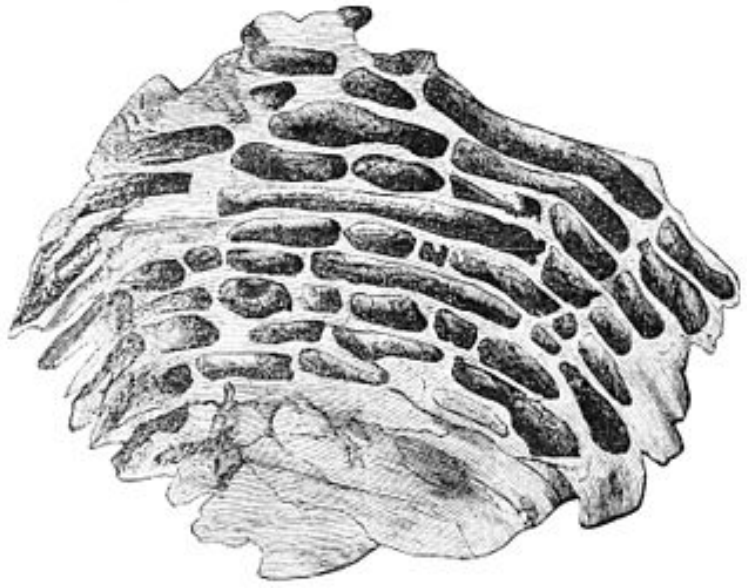
Introduction: Why swarms?

- 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

Introduction: Why swarms? (Cont'd)

- Many methodologies proposed to design robot swarms; no method to date is both general and efficient.

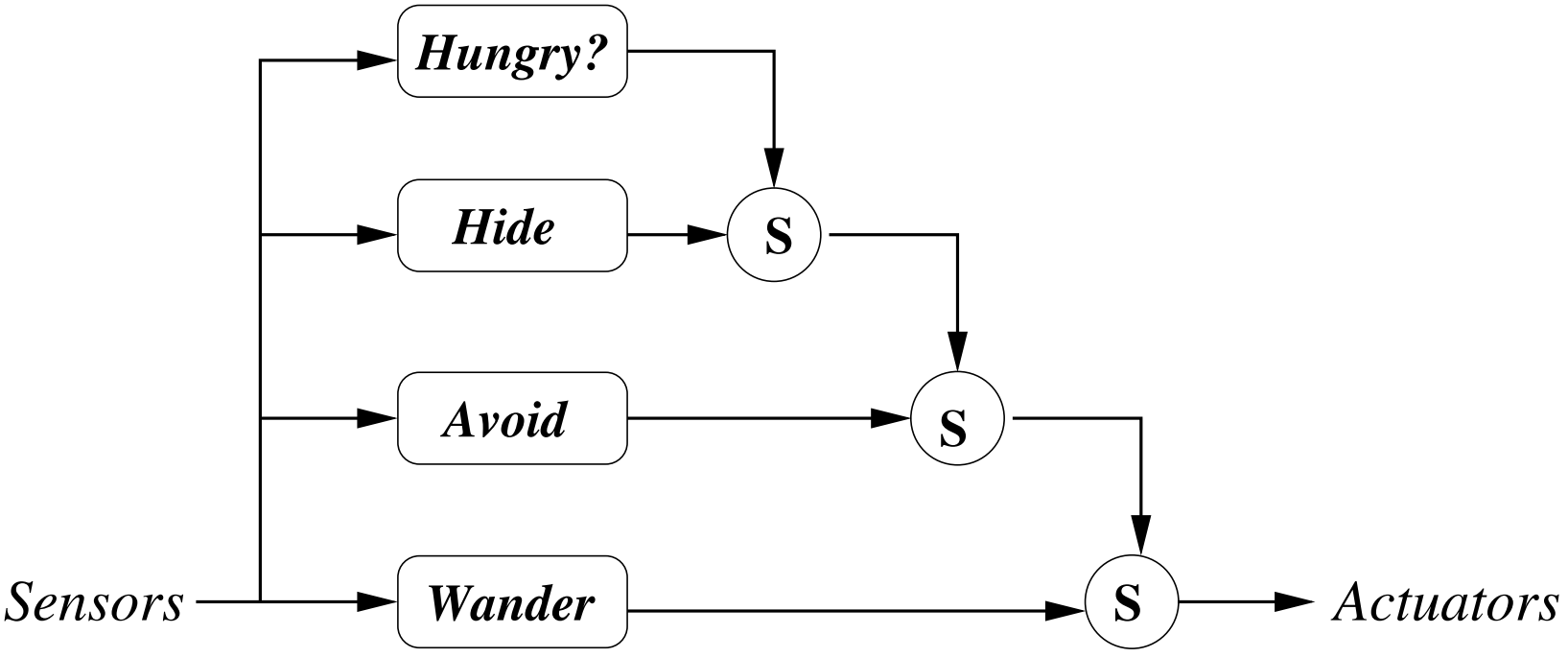
HOW DIFFICULT IS SWARM DESIGN IN GENERAL?
WHAT RESTRICTIONS DO (AND DON'T) MAKE SWARM DESIGN EASY?

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)



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.