Less is more? New approaches for swarm control and inference

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Note that some of the images and videos have been removed in this version.
Swarms
Technological motivations

1. Fault tolerance
2. Scalability
3. Miniaturization
Outline

1. Control
2. Inference
3. Tools
1. Control
Swarming

Environment

Agent

Agent
Rendezvous
Two wheels

\[ s_l \in [-1,1] \]

\[ s_r \in [-1,1] \]
Binary sensor

Control without computation

\[
\text{if } (I(t) = 0) \\
\quad \text{set speed}(s^0_l, s^0_r) \\
\text{else} \\
\quad \text{set speed}(s^1_l, s^1_r)
\]
Reactive controllers

Experiments with e-pucks
• Video available on

http://www.ijrr.org/ijrr_2014/525244.htm
http://naturalrobotics.group.shef.ac.uk/supp/2013-001/

Video

- [http://naturalrobotics.group.shef.ac.uk/supp/2014-003/](http://naturalrobotics.group.shef.ac.uk/supp/2014-003/)

Gauci et al. AAMAS 2014. Finalist Best Student Award
Cooperative transport

Jianing Chen
Occlusion-based strategy


17/12/15
Roderich Gross, The University of Sheffield
Analysis


17/12/15

Roderich Gross, The University of Sheffield
• Video available on
http://naturalrobotics.group.shef.ac.uk/supp/2014-002/
Binary propulsion

Evo-bots project. Escalera JA, Mondada F, Gross R. IROS 2014 Workshop
Novel platforms
2. Inference
Inferring rules through observation
System identification

- Builds models producing similar behavior
- Requires similarity metrics
Turing Learning

• No pre-defined metrics needed
• Builds models producing behavior that is indistinguishable

Li et al., GECCO 2013 & 2014
Clustering agents
Coevolution

• Population of models
  – controls the replica (red)
  – rewarded for misleading classifiers

• Population of classifiers
  – judges whether a trajectory is from replica or agent
  – rewarded for correct judgments

Li et al., GECCO 2013 & 2014
Physical setup

Li et al, TEVC (under review)
Inferred model parameters

Li et al., TEVC (under review)
Inferred model parameters

Li et al., TEVC (under review)
3. Tools
Design automation

• Supervisory control theory (Ramadge & Wonham 1987)
• Discrete event systems
  • Controllable events
  • Uncontrollable events
• Modeling using regular language
System capabilities

G1

\[ q_1 \xrightarrow{move} q_2 \xleftarrow{stop} q_1 \]

G2

\[ q_1 \xrightarrow{active} q_2 \xleftarrow{inactive} q_1 \]

Lopes et al., *Swarm Intelligence* (pending rev.) & ANTS 2014 Best Paper Award Finalist
Specification (E)

Lopes et al., *Swarm Intelligence* (pending rev.) & ANTS 2014 Best Paper Award Finalist
Supervisory synthesis

• Create target language $K = (G_1 \parallel G_2) \parallel E$
• Extract supervisor $S$ from $K$ such that
  • $S$ is controllable
  • $S$ is deadlock free

Lopes et al., *Swarm Intelligence* (pending rev.) & ANTS 2014 Best Paper Award Finalist
Automatic code generation

- Nadzuro tool to support the design process
- Supervisors run on virtual machines
  - E-puck
  - Kilobot
- Call-back functions
  - Controllable events
  - Uncontrollable events

Lopes et al., *Swarm Intelligence* (pending rev.) & ANTS 2014 Best Paper Award Finalist
• Videos on
  http://naturalrobotics.group.shef.ac.uk/supp/2015-001/

Lopes et al., *Swarm Intelligence* (pending rev.) & ANTS 2014 Best Paper Award Finalist
Portability

- First OS to run on microcontroller-based robots
- Monolithic kernel
- 12 kB ROM & 1 kB RAM
- Multi-tasking
  - preemptive (native)
  - cooperative (native)
- Robot hardware abstraction

http://openswarm.org

Trenkwalder et al., ICRA 2016 (under review)
Conclusion

• Swarming without computation
  – Binary sensing
  – Binary propulsion
  – Analysis
  – Miniaturization
  – Applications at the macroscopic scale?
Conclusion

• Turing Learning
  – Inferring rules without metrics
• Trajectories can be looked at in isolation
Conclusion

• Tools for real-world transition
  – Automated design
  – OpenSwarm OS for platform independent solutions
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• www.dars2016.org

• Keynotes
  – Nikolaus Correll (UC Boulder)
  – Vijay Kumar (UPenn)
  – James Marshall (Sheffield Robotics)
  – Katia Sycara (CMU)