Evolving Coordination in a Modular Robotic System

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- Conclusion
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  - Future work

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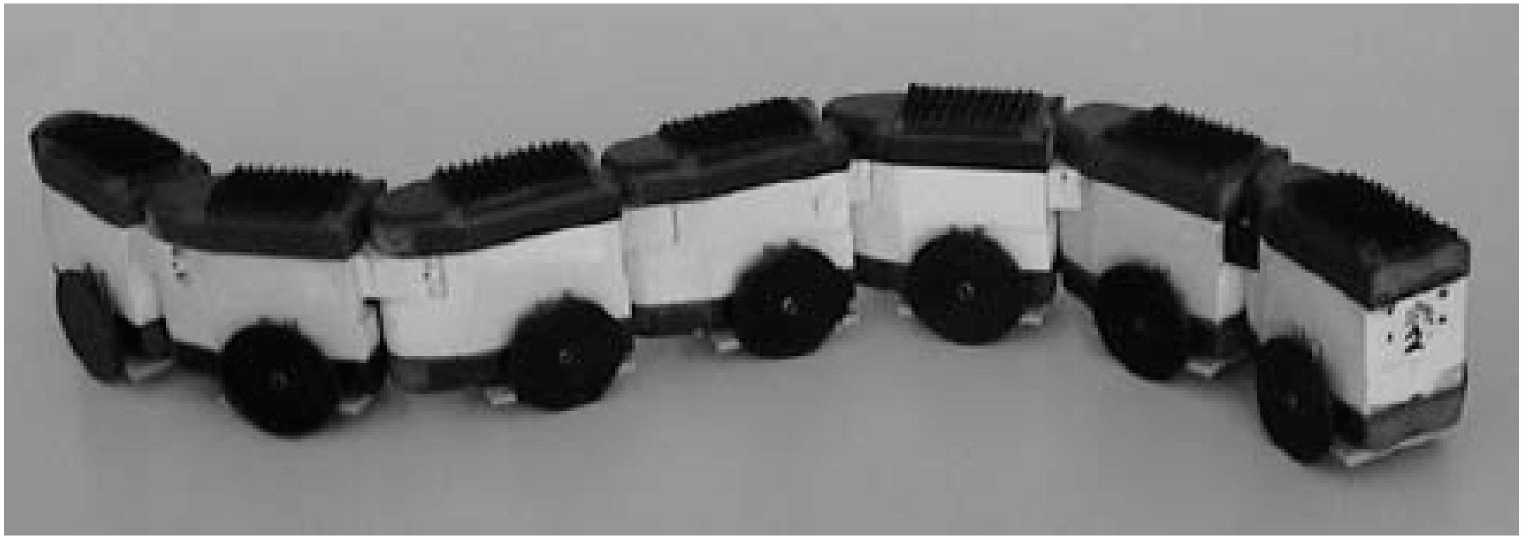
Introduction: modular robotics (1/3)

Salamander locomotion (Ijspeert *et al.*)

- oscillations in a multi-segment chain, starting from random initial states, rapidly self-organize into travelling or/and standing waves
- salamander locomotion is related to coordinated patterns of rhythmic neural activity



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Introduction: modular robotics (2/3)

Swarm robotics (SWARM-BOT, Dorigo *et al.;* Baldassarre *et al.*)

- coordinated motion in a swarm collective is a self-organized activity
- the emergent *common direction* of motion, with the chassis orientations of the robots spatially aligned, allows the group to achieve high coordination
- a method to capture this spatial alignment via Boltzmann entropy

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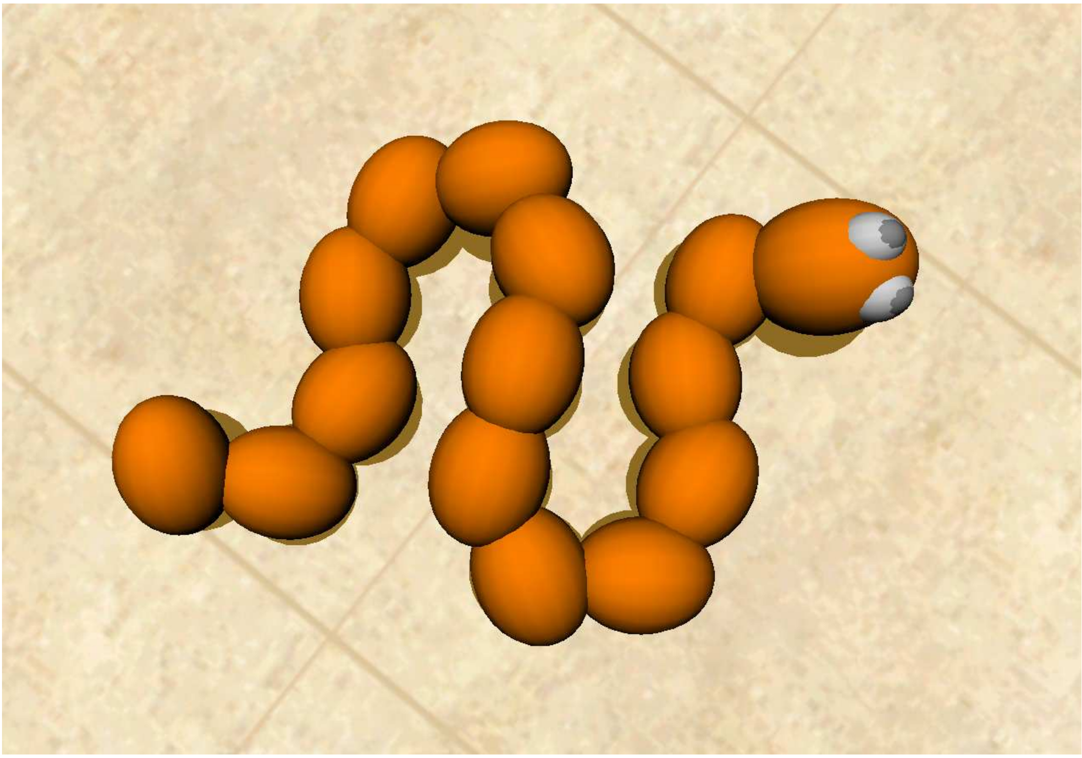
Introduction: modular robotics (3/3)

Side-winding locomotion (Tanev *et al.*)

- emergent as a result of morphology and control sequences of individual segments
- superior speed characteristics for considered morphology
- adaptability to challenging terrain environments and partial damage



Information-driven evolutionary design

- Motivation:
  - to detect and characterise *emergent* coordinated rhythmic patterns
  - to measure a degree of coordination among modules
  - to contribute towards a generic methodology of *information-driven evolutionary design*

- Examples of intrinsic selection pressures
  - dynamics of the rule-space's entropy
    (Wuensche, 1999; Prokopenko *et al.*, 2005)
  - maximization of information transfer in perception-action loops
    (Klyubin *et al.*, 2004, 2005)
  - minimization of Boltzmann entropy in swarm-bots' states
    (Baldassarre *et al.*, 2005)

Methodology (1/2)

- The actuators states (horizontal and vertical turning angles) are constrained by the interactions between segments and the terrain

- The *actual turning angles* provide an underlying *multivariate* time series

- Definition:

  maximal coordination among actuators = minimal "irregularity" in the multivariate time series

- Conjecture I:

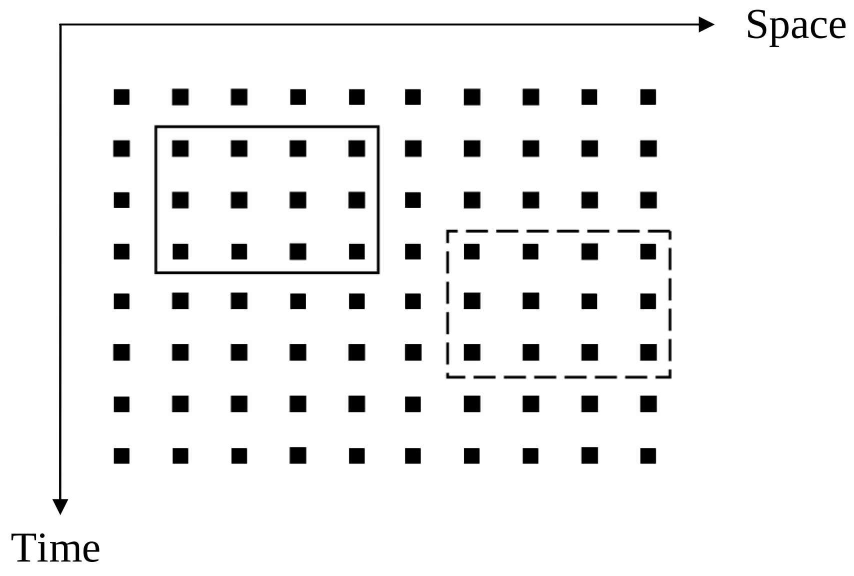
  fast locomotion → well-coordinated actuators

- Conjecture II:

  robust locomotion → well-coordinated actuators

Methodology (2/2)

- Experiment:
  - Evolve snakebots for coordination
- Technical question:
  - How to estimate “irregularity” of the multivariate time series in space and time?
  - How to estimate “structure” within the series?



Solution

1. Kolmogorov-Sinai entropy, also known as entropy rate, is a measure for the rate at which information about the state of the system is lost in the course of time – it measures the irregularity or unpredictability of the system

2. A complementary quantity is the *excess entropy* – it may be viewed as a measure of the apparent memory or structure in the system

3. In well-coordinated Snakebots:
   - entropy rate should be small
   - excess entropy should be large

Results: actual angles

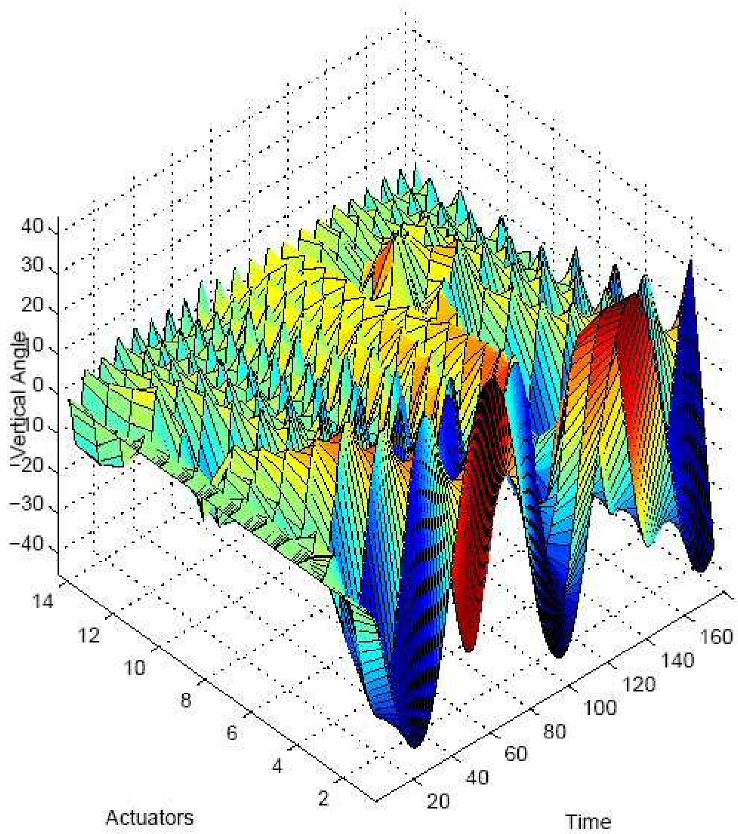


Fig. 3: First offspring: actuator angles.

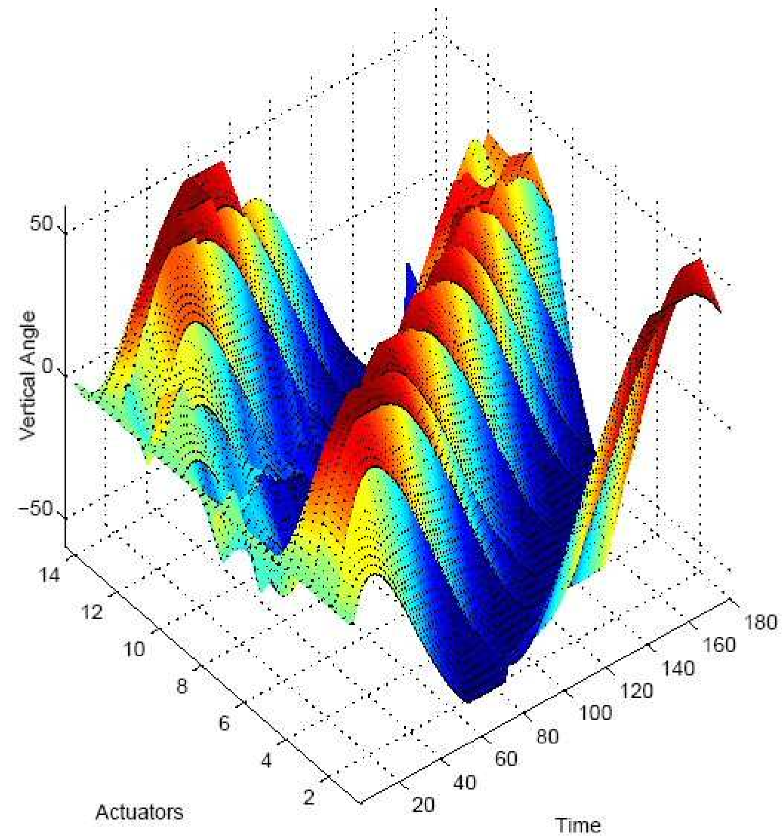


Fig. 4: Evolved solution: actuator angles.

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Results: correlation entropy and excess entropy

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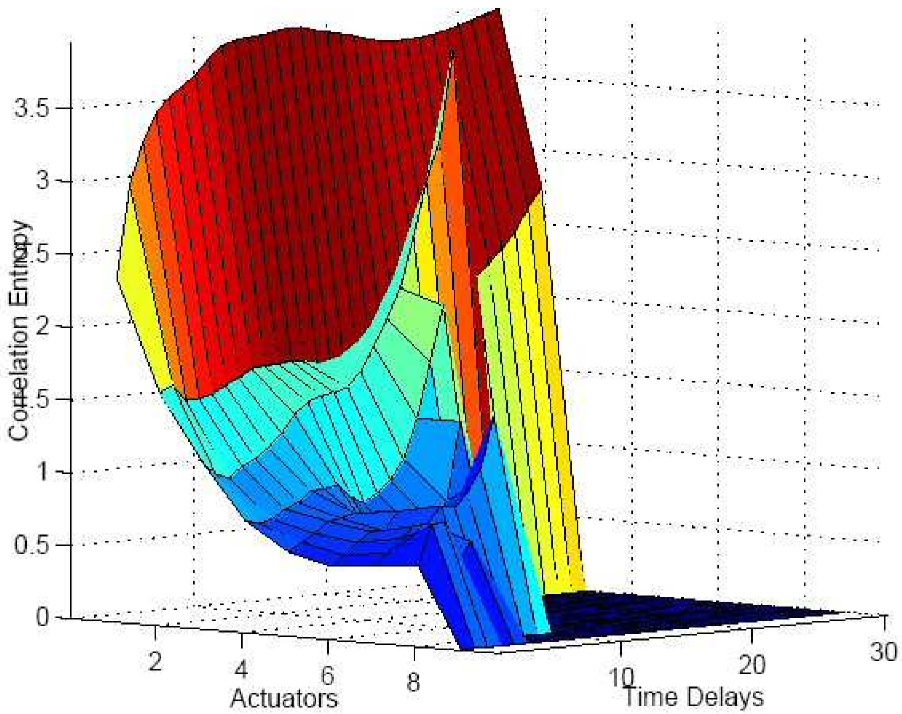

Fig. 5: First offspring: correlation entropy.

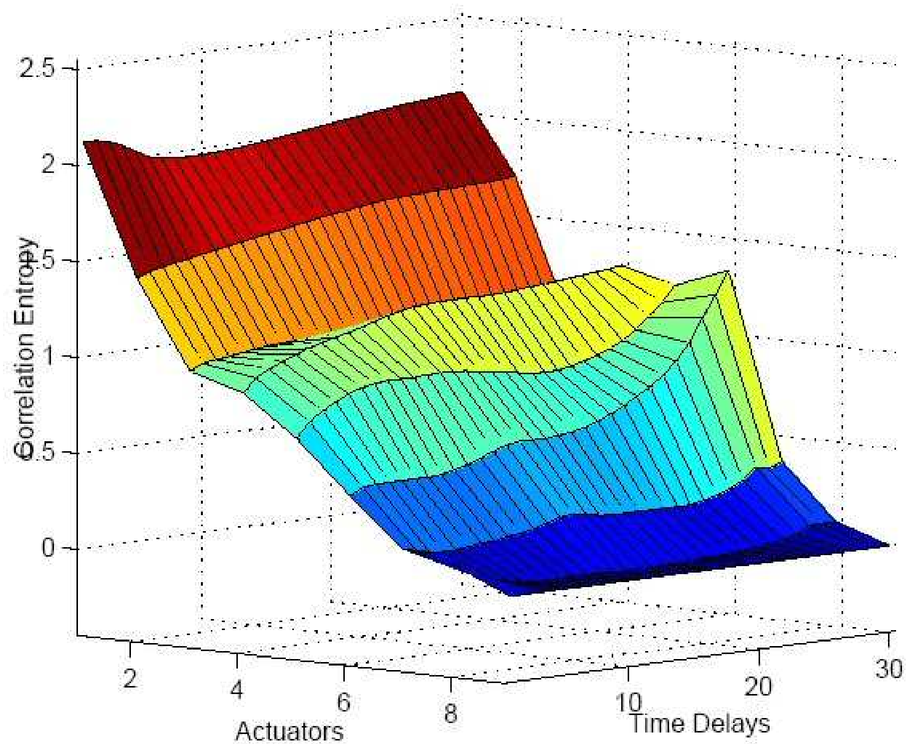

Fig. 6: Evolved solution: correlation entropy.

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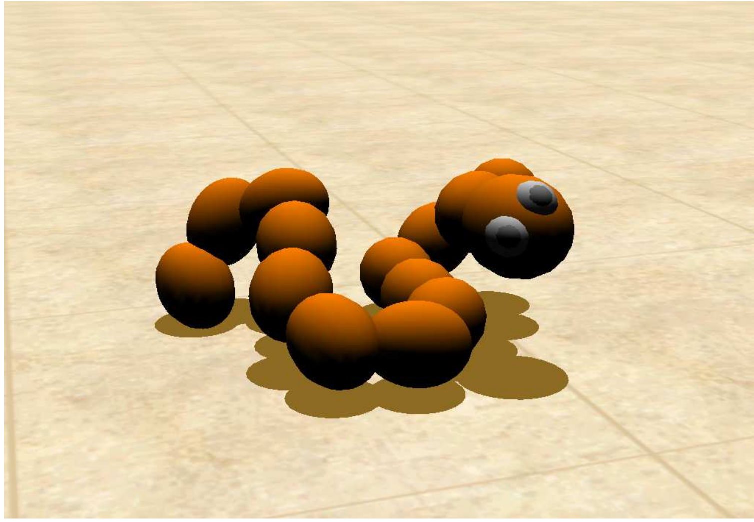
Results and Future Work

- a successful approximation of the direct measure (velocity) with generalized spatiotemporal excess entropy (ALifeX-2006, SAB-2006)



- a contribution to information-driven evolutionary design
- new measures may be used in rugged terrains
- robustness to failures of individual segments
- self-diagnostics and adaptation:
  - *relative excess entropy e2*
  - *e2* is increased in partially damaged Snakebots – the amount of transferred information in the coupled locomotion has to increase
- a connection to *information transfer* via excess entropy

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