Motivation

The concept of self (self-awareness, agency) is an important yet hard subject:

- It may lead to consciousness.
- It may be necessary for social interaction.
- It may play an important role in cognition (Block 1995).
Research Question: Self-Awareness

Why did self-awareness (or the sense of self) evolve?

- Self-awareness is an internal state that may be transparent to the process of evolution (cf. high-performance zombie).

- This is a hard question to answer without getting tangled in philosophical debate.

**Strategy:** Investigate the necessary condition of self-awareness that may be less controversial.
Approach

Identify **necessary conditions** of self-awareness:

- Sense of self and agency are closely related.

- **Authorship** is a key ingredient: “I” prescribe my actions, and “I” own them.

- Important property of authorship: My actions are highly predictable while others’ are not.

**Necessary condition identified:** Need to be able to predict one’s own internal state (cf. Nolfi et al. 1994).
Method (Task): 2D Pole-Balancing

- Physical parameters of the pole balancing system: position \((x, y)\); velocity \((\dot{x}, \dot{y})\); pole angle \((\theta_x, \theta_y)\); angular velocity \((\dot{\theta}_x, \dot{\theta}_y)\).
Method: Neuroevolution Controller

- Recurrent neural network for 2D pole balancing.
- Trained with standard neuroevolution.
- Investigate the internal state trajectories.
1. Evolve controllers to meet a fixed performance criterion (fitness does not measure predictability) in pole-balancing tasks.

2. Group high-performance individuals into high- and low internal state predictability (ISP) groups.

3. Test the two groups in harder tasks.
Method: Experimental Setup

- **Neuroevolution:**
  - population size 50
  - mutation rate 0.2; cross over rate 0.7.

- **2D pole balancing task:**
  - Pole should be balanced within $15^\circ$ within a 3 m $\times$ 3 m arena.
  - Force applied to cart every 0.1 second (= one step).
  - Success if pole balanced over 5,000 steps.
Method: Measuring Predictability

\[ \hat{x}(t + 1) = f \left( x(t), x(t - 1), x(t - 2), \ldots, x(t - N + 1) \right). \]

- Neural network predictor for a time series.
Method: Experimental Setup

- Neural network predictor:
  - 2,000 training data.
  - 1,000 test data.
  - Back-propagation (learning rate 0.2).
Results: Internal State Predictability (ISP)

- Trained 130 pole balancing agents.
- Chose top 10 highest ISP agents and bottom 10 lowest ISP.
  - high ISPs: $\mu = 95.61\%$ and $\sigma = 5.55\%$.
  - low ISPs: $\mu = 31.74\%$ and $\sigma = 10.79\%$. 
Comparison High ISP and Low ISP

- A comparison of the average predictability from two groups: high ISP and low ISP.
- The predictive success rate of the top 10 and the bottom 10 agents.
## Results: Learning Time

**Learning Time**

- No significant difference in learning time
Performance and Int. State Dyn.

- Made the initial conditions in the 2D pole balancing task harsher.
- Performance of high- and low-ISP groups compared.
- High-ISP group outperforms the low-ISP group in the changed environment.
Behavioral Predictability

- Success of high-ISP group may simply be due to simpler behavioral trajectory.

- However, predictability in behavioral predictability is no different between high- and low-ISP groups.
Examples of internal state dynamics from the high ISP

- Internal state dynamics show smooth trajectories.
Examples of internal state dynamics from the low ISP

- Internal state dynamics show abrupt and jittery trajectories.
Examples of cart x and y position from high ISP

- Behavioral trajectories of x and y positions show complex trajectories.
Examples of cart x and y position from low ISP

- Behavioral trajectories of x and y positions show complex trajectories.
Related Work

• Bayesian self-model (Gold and Scassellati 2007).

• Continuous self re-modeling for resilient machines (Bongard et al. 2006).

• Autonomous mental development (Weng et al. 2001; Han et al. 2002).

• Role of self-awareness in cognition (Block 1995).

• Emergence of self-awareness from self-representation (Menant 2007).
Conclusions

• Simpler (more predictable) internal dynamics can achieve higher levels of performance in harsher environmental conditions.

• The increased survival value is not always due to smoother behavior resulting from the simpler internal states.

• Initially evolution-transparent internal agent properties can affect external behavioral performance and fitness in a changing environment.

• An initial stepping stone in the evolutionary pathway leading to self-awareness and agency could have formed in such a way.
Why Do We Have a Brain?

Tree
(no Brain)

Tunicate
Free-floating
(w/ Brain)

Tunicate
Settled
(w/o Brain)

- Brain vs. no brain (cf. Llinás et al. 1994).

References


