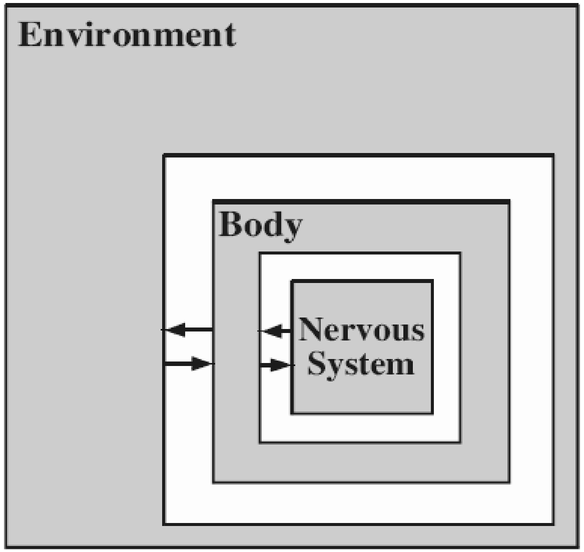
An enactive approach to social cognition

Detection of social contingency
- or -
stability of interaction dynamics?

Tom Froese & Ezequiel Di Paolo

Cognition: A new paradigm

- **Situatedness**
  - "The world is its own best model" (Brooks 1991)
- **Embodiment**
  - The actions of an agent are bodily and form a dynamic with the world such that they have immediate feedback on its sensations
- **Emergence**
  - *Behavior is a dynamic property of the brain-body-world systemic totality*



Beer (1997)

Communication is Information Transfer

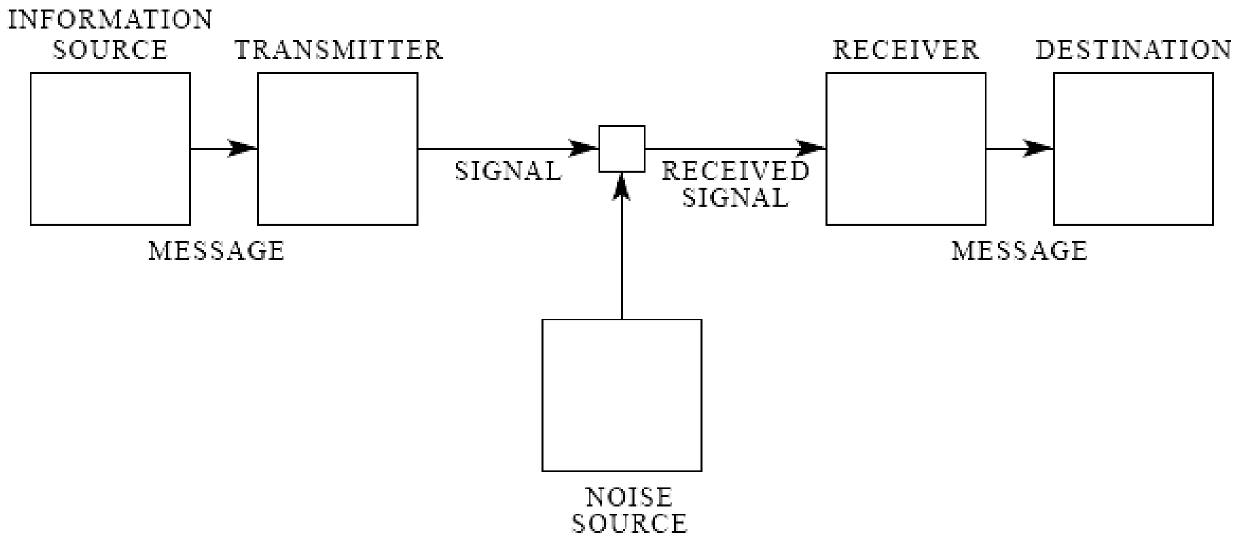


Fig. 1—Schematic diagram of a general communication system.

Shannon (1948)

"Communication is the transfer of information via signals sent in a channel between a sender and a receiver." (Hailman 1977)

Communication is Behavioral coordination

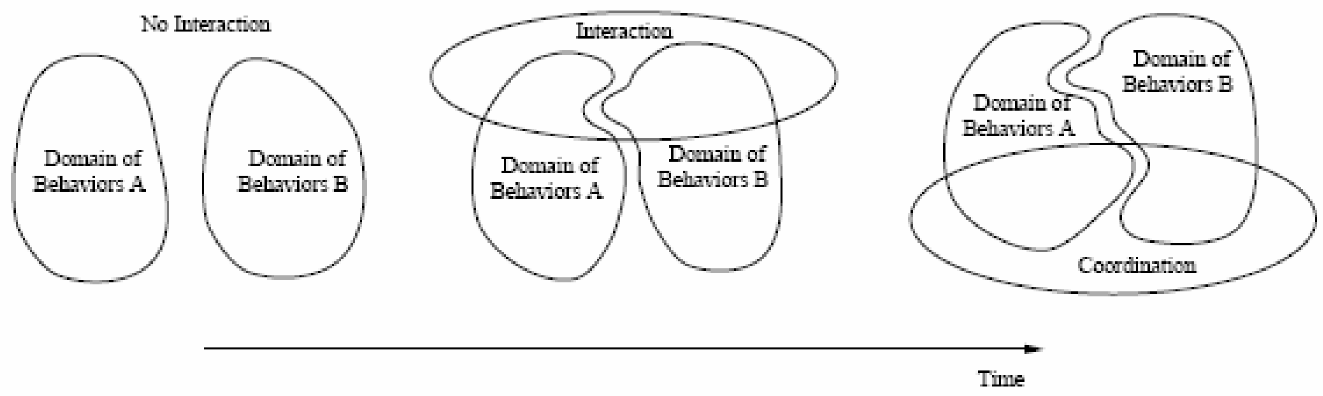


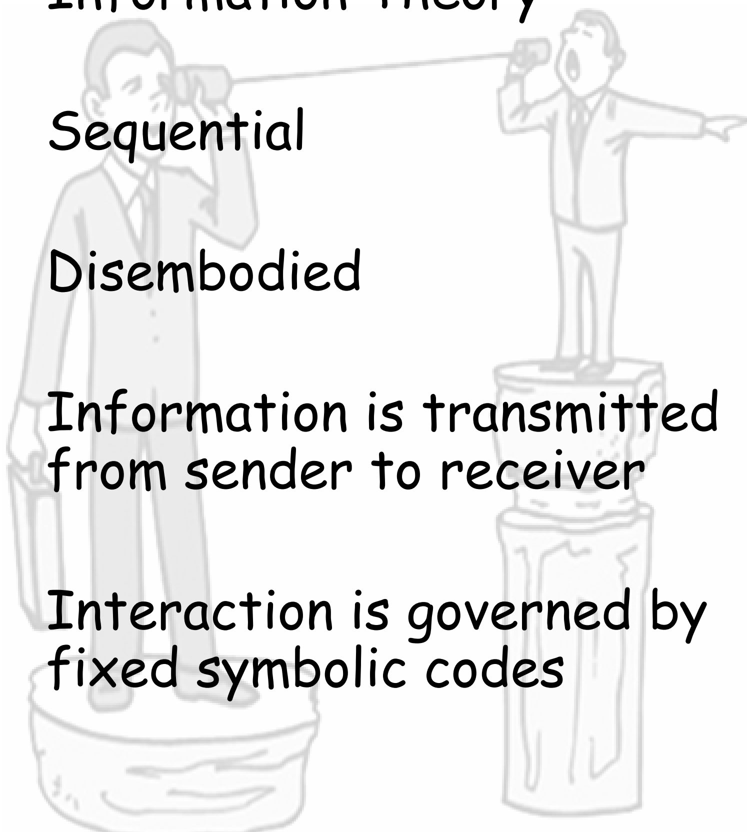
Figure 2.1: Illustration of the concept of coordination.

"Coordination is shown as the additional behavioral coherence which depends on the existence of another (parallel or previous) interaction, and the internal operation of each system."

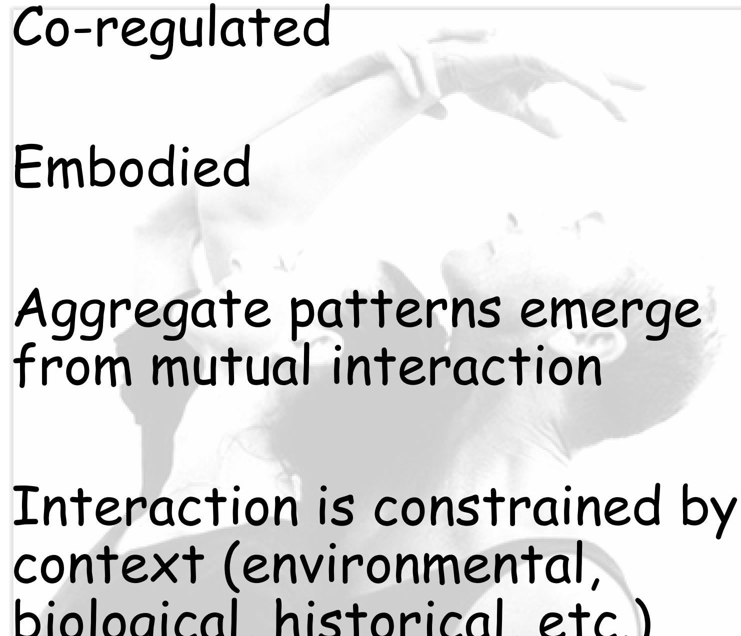
Di Paolo (2000)

A choice of metaphors

"Information Transfer" vs. "Dance"?



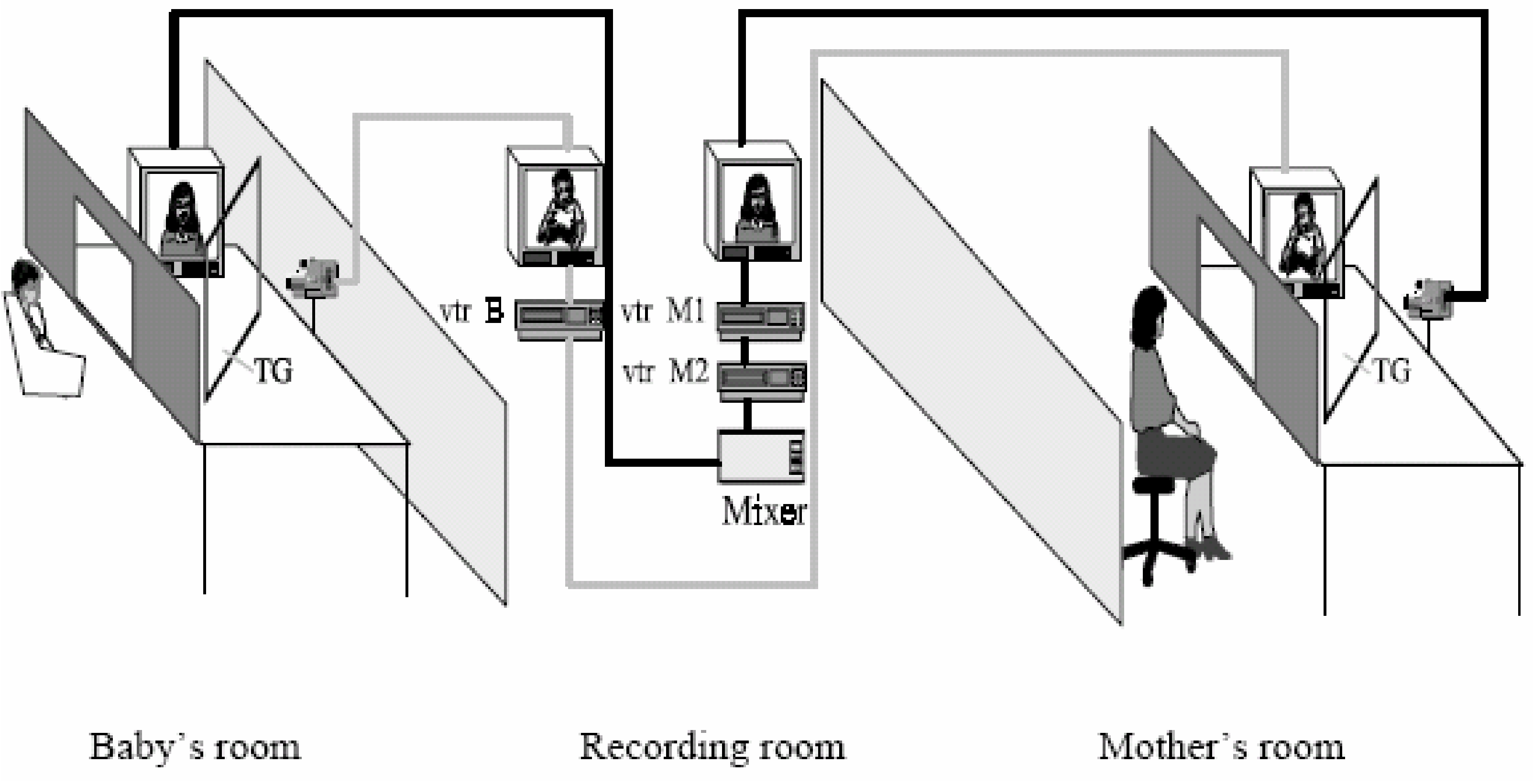
- Information Theory
- Sequential
- Disembodied
- Information is transmitted from sender to receiver
- Interaction is governed by fixed symbolic codes



- Dynamical Systems Theory
- Co-regulated
- Embodied
- Aggregate patterns emerge from mutual interaction
- Interaction is constrained by context (environmental, biological, historical, etc.)

Let's put these approaches to work!

The double TV monitor approach



Result: 2 month old infants are sensitive to social contingency

Murray & Trevarthen (1985); Nadel et al. (1999)

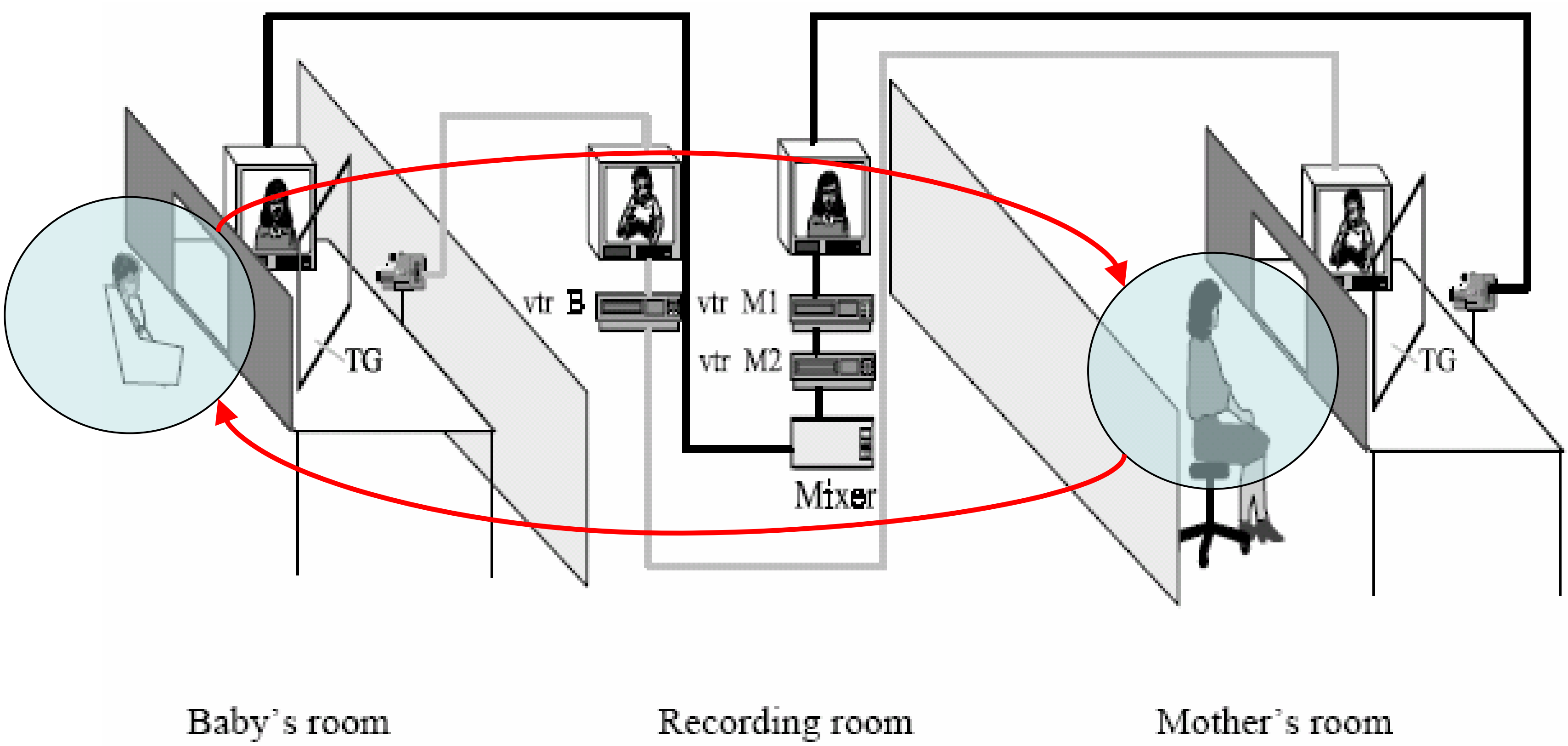
Traditional explanations

- Three main indices are commonly used to account for infant sensitivity to social contingency (Nadel et al. 1999):
  - *detection, response and expectancies*
- Gergely and Watson (1999) postulate the presence of an innate module which enables the detection of social contingency.
- Russell's (1996) hypothesis is that there is an innate capacity to understand intentionality and to process agency.
- Does an explanation of the infant's behavior *necessarily* have to involve such complex individual perceptual capacities?

Methodology of minimal assumptions

- Evolutionary robotics (e.g. Harvey et al. 2005)
  - Minimal and controllable impact of design assumptions
  - Can determine minimal conditions for a behavioral capability
- Synthetic ethology (e.g. MacLennan 1992):
  - An attempt to combine the simplicity and control of behaviorist methods with the ecological and contextual validity of empirical ethology
- Dynamical systems framework (e.g. Beer 1997)
  - The autonomous system is no "black box"
  - Minimal prior assumptions with regard to the required cognitive capabilities

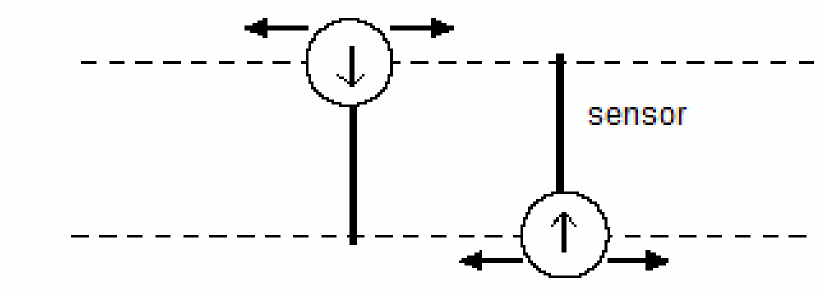
The double TV monitor approach



"The double TV monitor approach"

Murray & Trevarthen (1985); Nadel et al. (1999)

Simulation model



- The agents are 40 units wide, only able to move horizontally, and equipped with a single on/off sensor. They face each other in an unlimited continuous 1-D space.

- Agents are controlled by *identical* 3-node CTRNNs: 1 left motor node, 1 right motor node, sensory input is distributed to all 3 nodes.

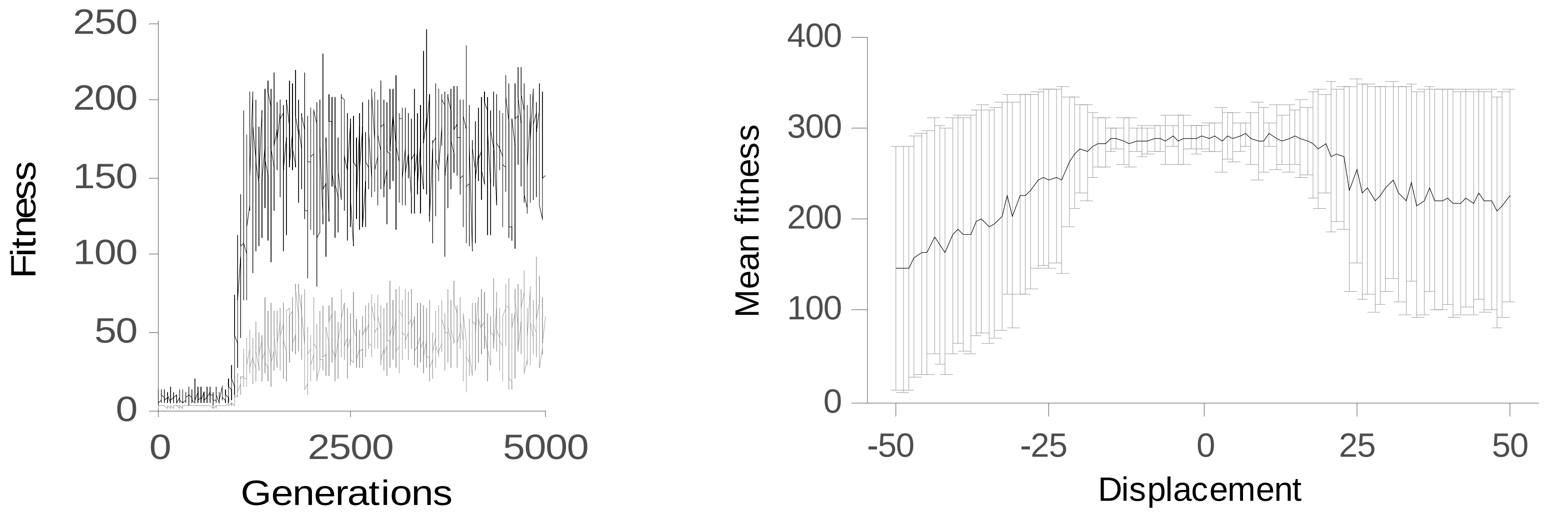
- This setup builds on work by Iizuka and Di Paolo (2007). But in this case the goal of the agents is to coordinate such that they cross their sensors as far away as possible from their starting positions.

- *The issue we want to test is whether termination of interaction behavior under playback conditions is a more general phenomenon than previously assumed.*

Methodology

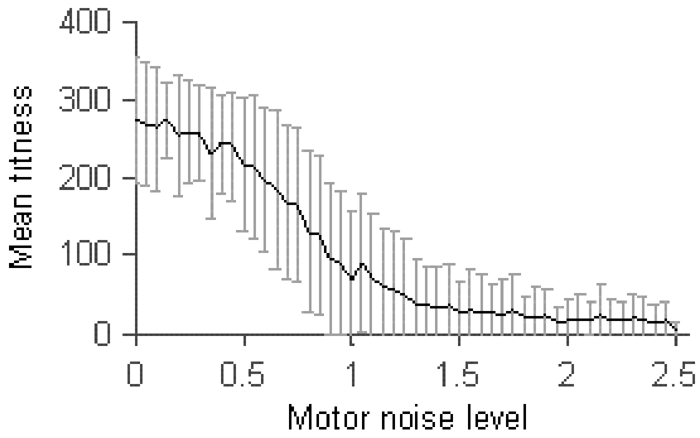
- We took measures to make it less likely that coordination performance will be negatively affected when the movement of one agent is replaced with ‘playback’ of a previous recording:
  - Evolutionary fitness is only measured in terms of the ability to establish and maintain a stable coordination pattern under a variety of initial conditions and with sensorimotor noise.
  - To further increase robustness the worst score out of 15 trials was chosen as the overall fitness score.
  - Taking the best evolved agent we then searched for especially favorable initial conditions.
  - We then recorded the best coordination behavior emerging under those conditions.

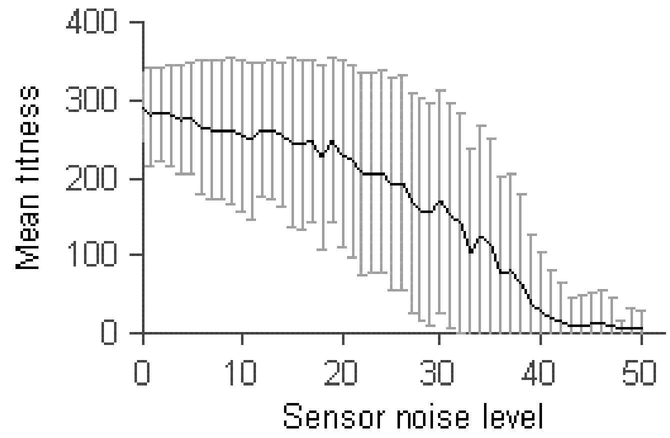
Evolutionary algorithm



- *Left:* Evolutionary run which produced the fittest solution at generation 3477; black represents the best score of each generation, gray is the population average.
- *Right:* Robustness to variations in initial relative displacement. Average fitness score achieved over 150 trials by the fittest solution starting from various initial positions, with standard deviation.
- Best initial position was found to be a relative displacement of 11.

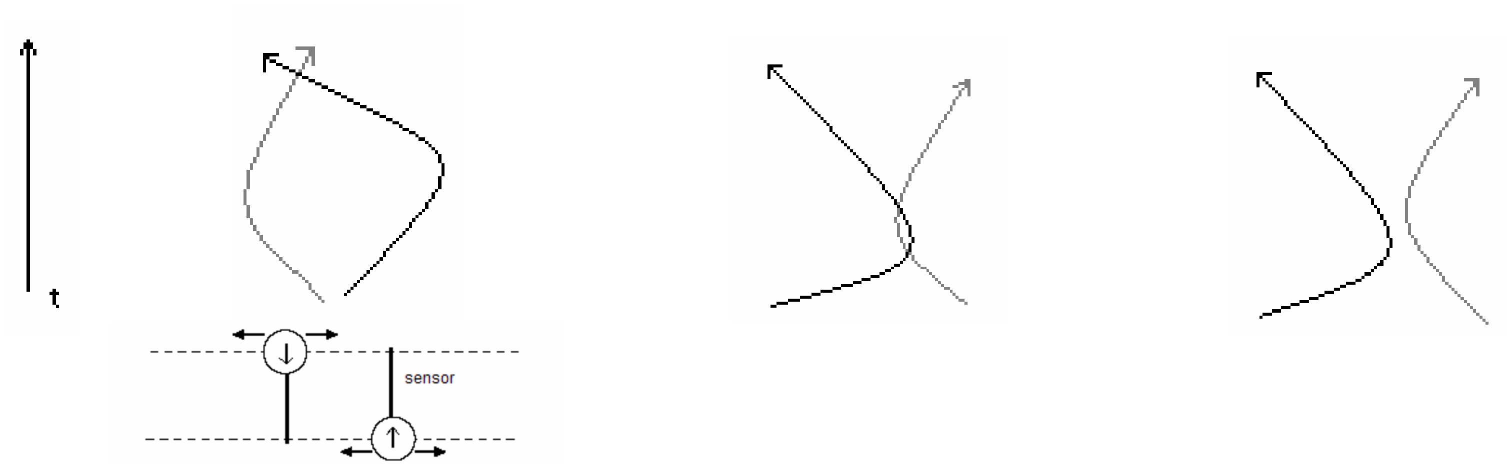
Robustness to noise





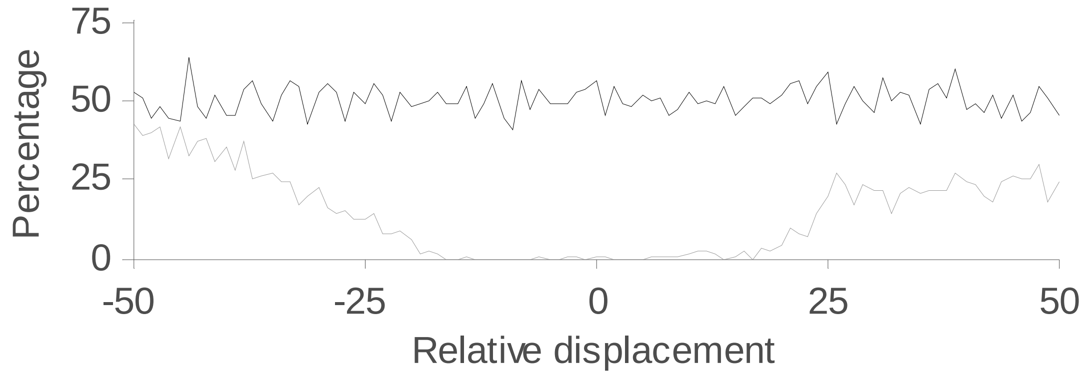
- Mean fitness score achieved by the fittest evolved agent starting from position 11 for a range of noise levels (150 trials at each level), plotted with standard deviation.
- Noise during evolution is 0.05 for motor and 5% for sensor noise.
- What do agents do? Their behavior can be broken down into 3 important aspects: (i) localization, (ii) alignment, and (iii) coordination.

Initial localization



- *Left:* agents locating each other when agent 'up' starts on the right of agent 'down' (positive displacement).
- *Middle:* agents locating each other when agent 'up' starts on the left of agent 'down' (negative displacement).
- *Right:* the only possibility for the agents to miss each other is if agent 'up' is initially displaced too far on the left of agent 'down'.

Alignment behavior

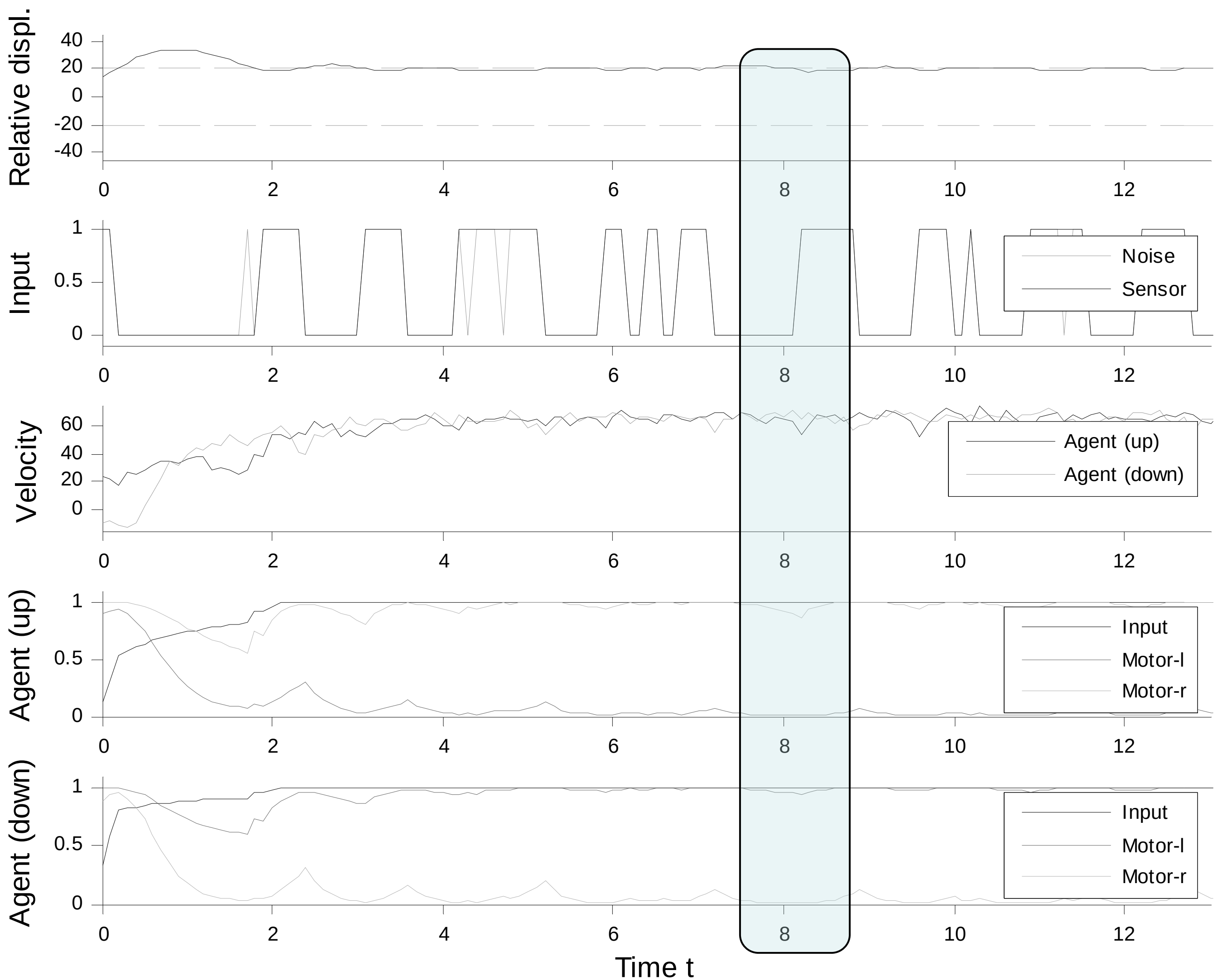


- Percentage out of all 150 trials resulting in no successful coordination (gray), and percentage of successful trials resulting in 'rightward' coordination (black), plotted against an extended range of initial relative displacements.

- But: *Agent 'up' always ends up on the right-hand side.*

- With this clever little maneuver the agents have significantly reduced the complexity of their coordination task!

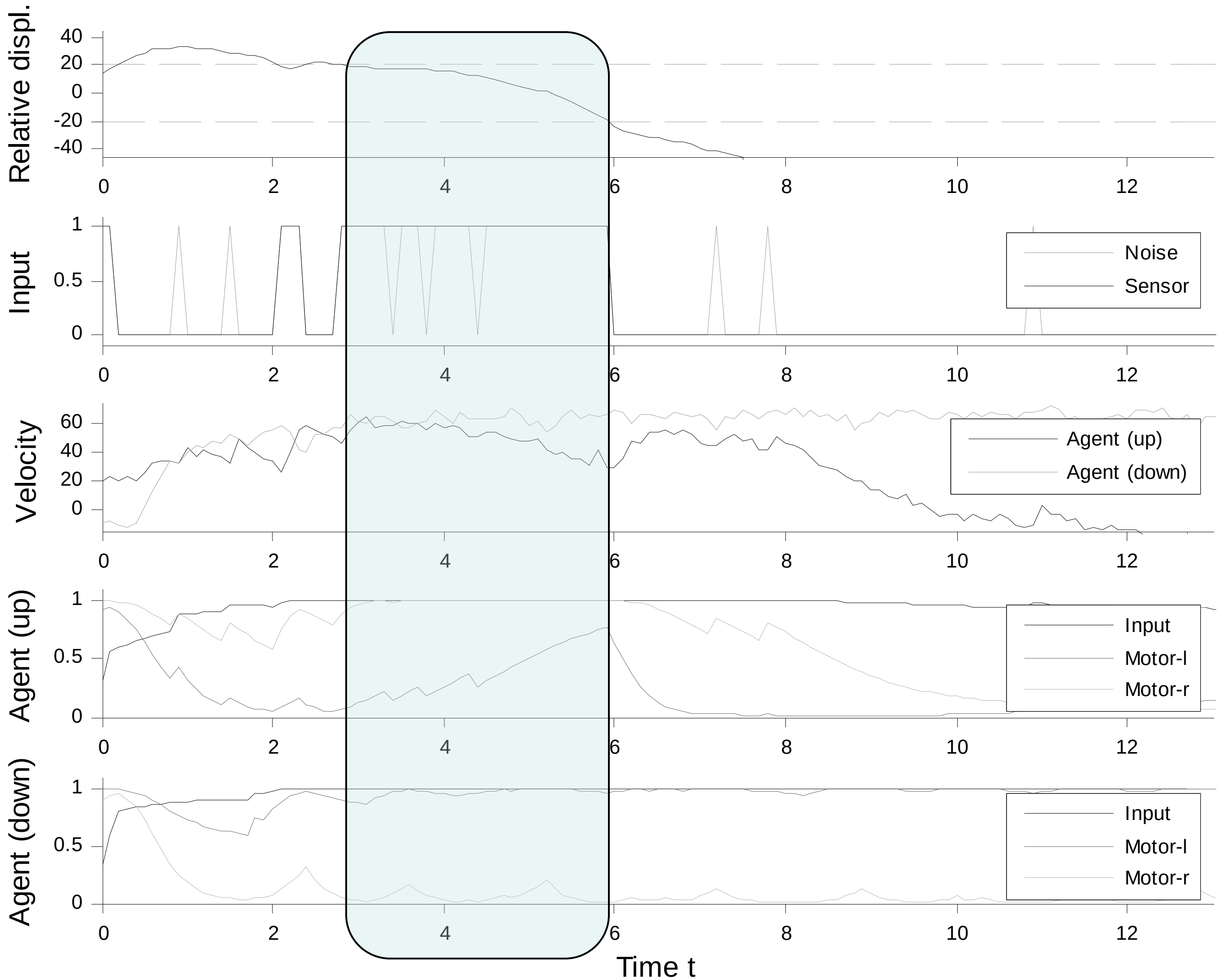
Initial activity during *best* trial



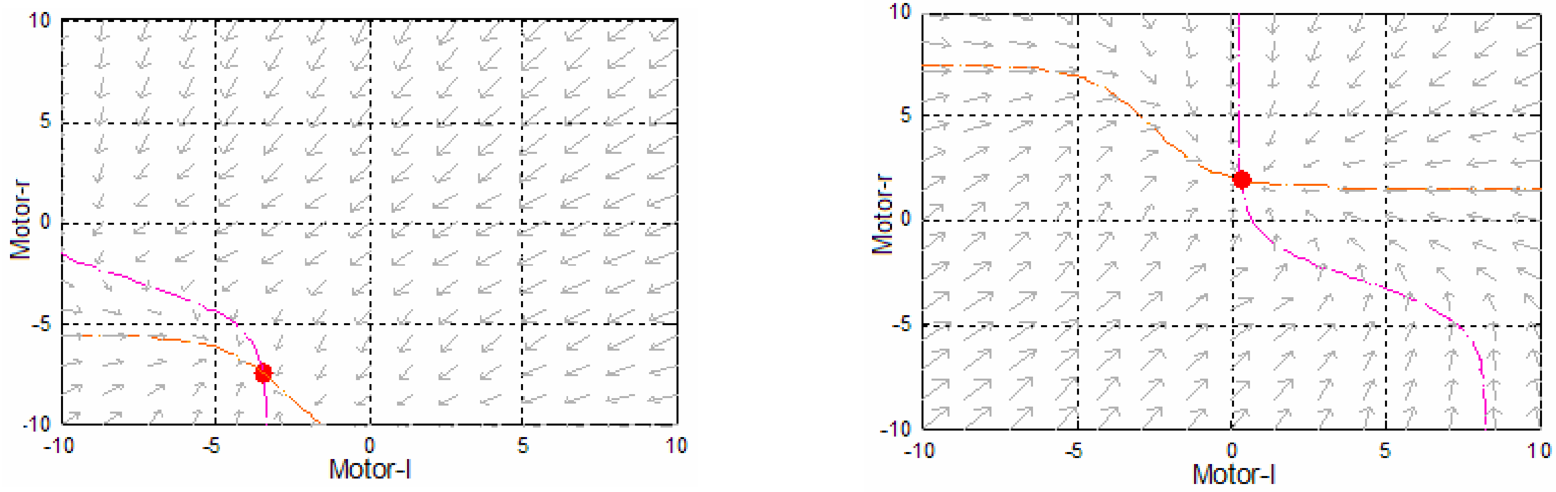
Coordination under playback conditions?

- Under normal conditions the coordination pattern is robust against various forms of noise, and able to cope effectively with an extended range of initial conditions.
- The original 150 trials of mutual (two-way) interaction at initial position 11 were highly successful (mean score: **268**).
- The 150 trials of playback (one-way) interaction in this situation were a drastic failure (mean score: **19**).
- *The active agent terminates its interaction behavior when confronted with a non-responsive 'partner'.*
- Does it have an innate module to detect social contingency?

Initial activity during *playback* trial



Internal dynamics

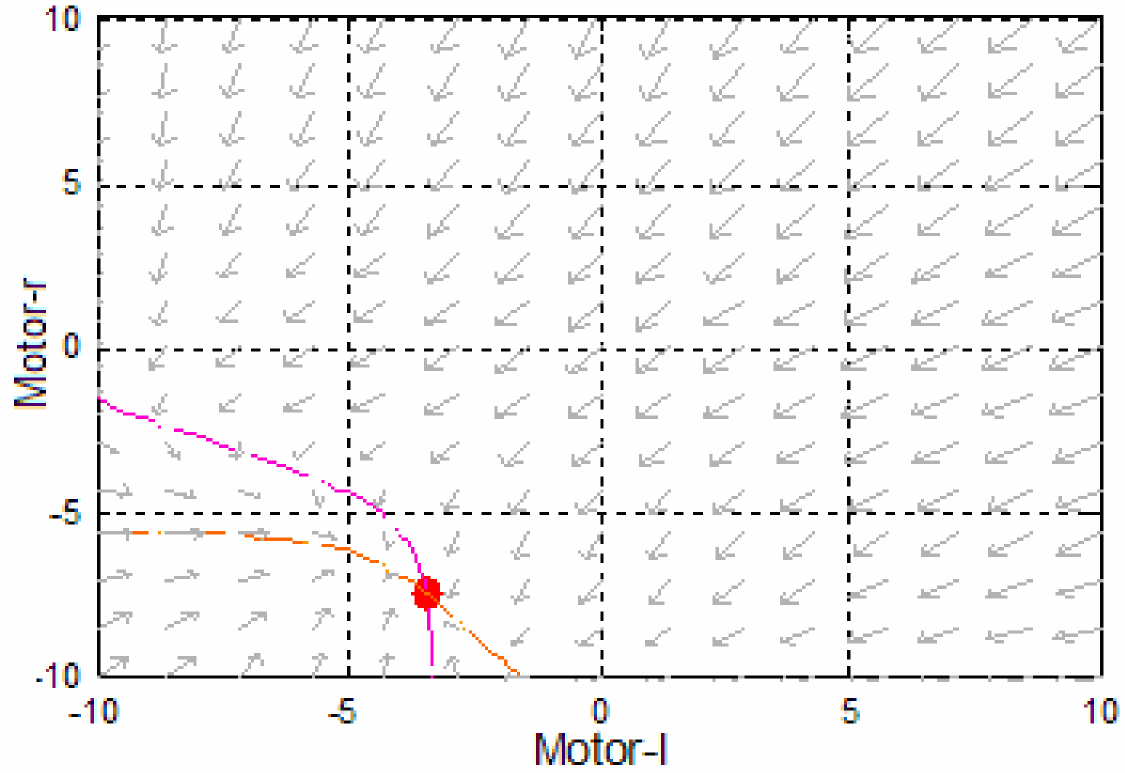


- The vector fields of the autonomous dynamical system consisting of the left and right motor nodes only. The input node's output is treated as a constant parameter set to 1.

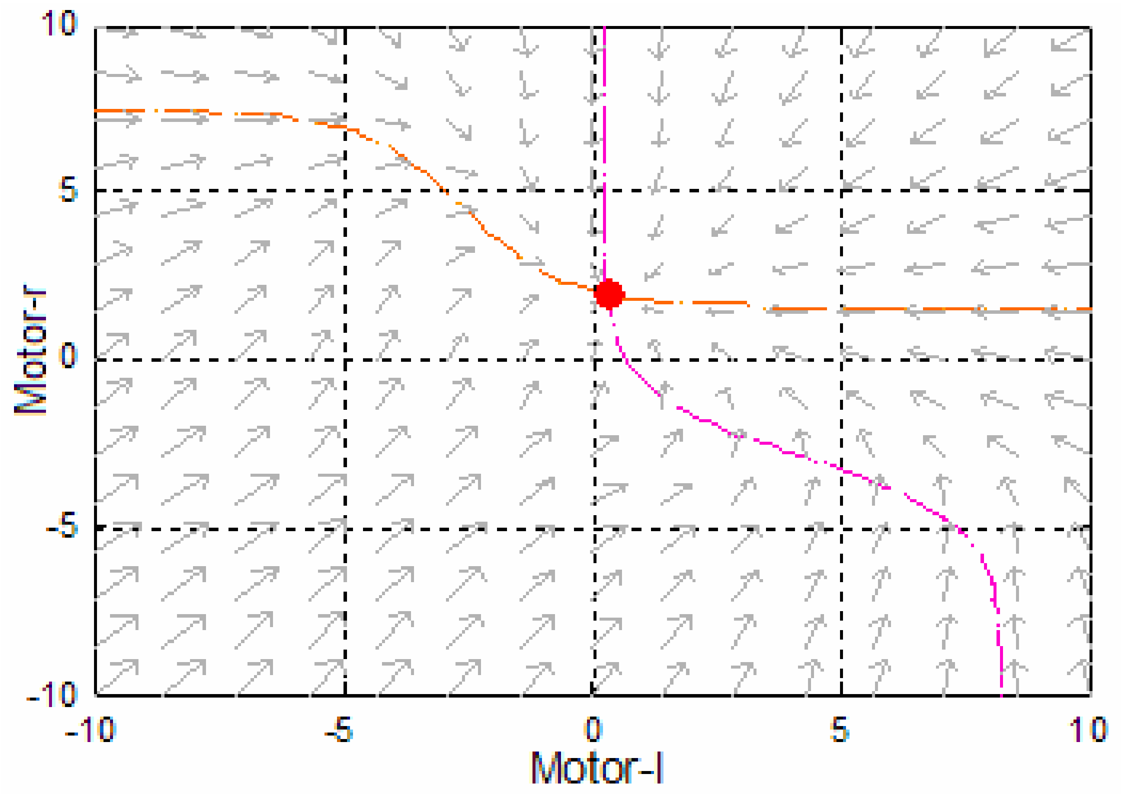
- *Left:* sensory input = 0, and there is a globally attracting stable equilibrium point at (-3.4, -7.5).

- *Right:* sensory input = 1, and the equilibrium point is at (0.3, 1.9).

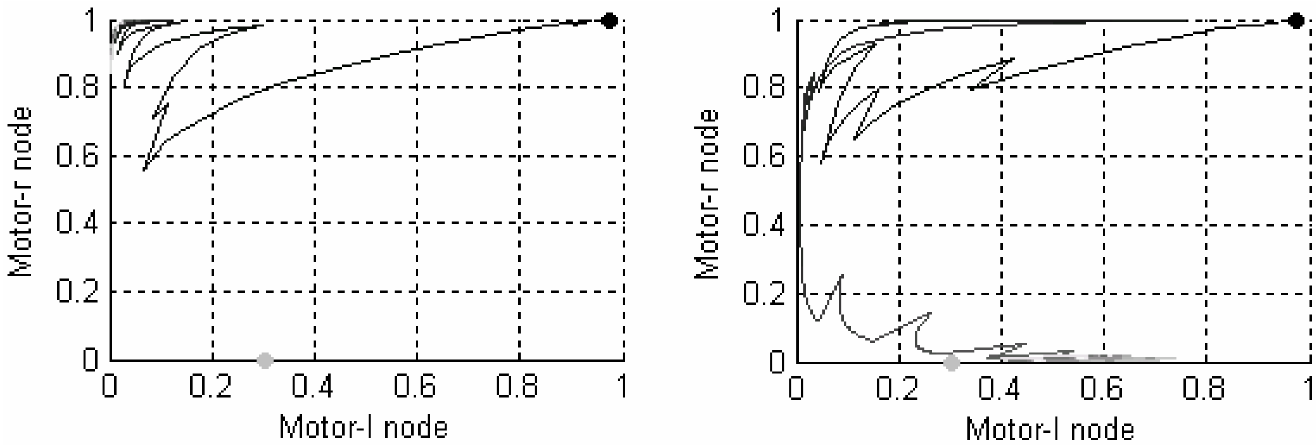
Sensory input = 0



Sensory input = 1



Behavioral dynamics

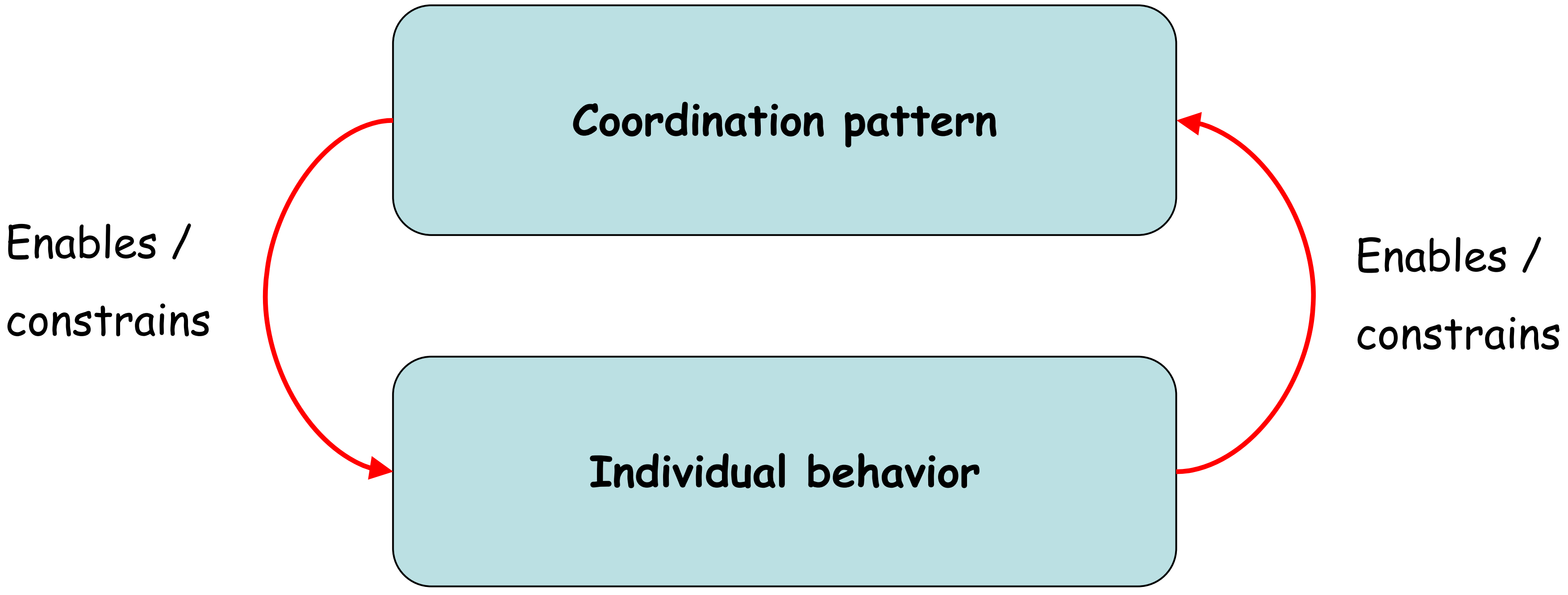


- The state trajectory of output of the motor nodes of agent 'up'.
- (a): During the live (two-way) interaction the trajectory settles on an oscillatory pattern tracing the corner near (0, 1).
- (b): During playback (one-way) interaction the trajectory first moves into the same region of state space, but then fails to settle down into the appropriate oscillatory pattern, and eventually drifts away.

Discussion

- *Without appropriate interaction the agents are incapable of producing oscillatory movements!*
- Behavior and interaction dynamics are closely interrelated:
  - (i) the behavior of the individual agents brings forth the interaction process, and
  - (ii) that interaction process enables the behavior of the individual agents.
- In other words, the individual behavior and the interaction process are both *constituted by* and *constitutive of* each other.
- This makes a *reduction* of the observed coordination breakdown to an agent's capacity to detect social contingency impossible.

Autonomous dynamics of the interaction process



Conclusion

- Embodied interactive approach: "in contrast to the contentions of theory of mind approaches, we do not simply observe others; we are not passive observers. Rather we interact with others, and in doing so we develop further capabilities in the contexts of those interactions" (Gallagher 2007)
- The reciprocal constitution between behavior and coordination pattern points to the *autonomy* of the interaction process, as postulated by an *enactive* approach to social cognition (De Jaegher & Di Paolo 2007)
- We argue that an explanation for the termination of interaction behavior that is observed when confronting infants with a video recording rather than a live stream of their mother needs to take into account the role of the interaction process.

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