Sensitivity to social contingency or stability of interaction? Modelling the dynamics of perceptual crossing

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Abstract. We introduce a series of evolutionary robotics simulations that address the behaviour of individuals in socially contingent interactions. The models are based on a recent study by Auvray, Lenay and Stewart (2006) on tactile perceptual crossing in a minimal virtual environment. In accordance, both the empirical experiments and our simulations point out the essential character of global embodied interaction dynamics for the sensitivity to contingency to arise. Rather than being individually perceived by any of the interactors, sensitivity to contingency arises from processes of circular causality that characterise the collective dynamics. Such global dynamical aspects are frequently neglected when studying social cognition. Furthermore, our synthetic studies point out interesting aspects of the task that are not immediately obvious in the empirical data. They, in addition, generate new hypotheses for further experiments. We conclude by promoting a minimal but tractable, dynamic and embodied account to social interaction, combining synthetic and empirical findings as well as concrete predictions regltiilir3374(ut)-u07(r)-0.401892(eg)0.(s)-ic-nieran,

Introduction

In recent years, a dynamical systems turn has become increasingly popular in psychology and cognitive science (Beer, 2000; Port & van Gelder, 1995; Thelen & Smith, 1996). Some dynamical systems approaches attempt to capture observed psychological phenomena or theoretical constructs in terms of the properties of phenomenological mathematical models that describe a cognitive system in more or less qualitative terms (Kelso, 1995; Thelen & Smith, 1996; Van Geert, 1991). Others attempt to model minimal embodied systems from the ground-up; such generative models are not necessarily data-driven but cash out their scientific value in terms of the study of dynamical patterns observed and by linking these patterns to existing or new theoretical ideas (Beer, 1996, 2000; Webb, 1995). These two poles, the descriptive and the generative, define a continuum of dynamical approaches all of which go beyond the previous use of dynamical metaphors in psychology, (e.g., Heider, 1958; Lewin, 1951; Newcomb et al., 1952).

It is now widely acknowledged that investigating psychological phenomena in the context of situated interaction with an environment makes it possible to explain aspects of behaviour that are hard to grasp otherwise. This is especially true for the case of *social interaction* where two or more individuals are mutually coupled in perception–action loops. Their interaction can dynamically create phenomena that do not directly result from the individual capacities or behaviours of any of the partners if investigated on their own. However, to this date, most dynamical approaches to problems in social interaction have been located toward the qualitative end of the spectrum. Such models are sometimes disembodied in the sense nize the mutuality and contingency of the coupling? Or are there global dynamical structures of the whole social process that are sufficient for keeping an interaction under way?

Empirical evidence, such as Murray and Trevarthen's double TV monitor experiments and its successors (Murray & Trevarthen, 1985; Trevarthen, 1993; Nadel et al., 1999), indicates that individuals are not infinitely malleable and adaptable to the demands of an interaction if their partners do not themselves behave in a responsive manner. Two-month-old infants are able to interact with their mothers via a live double video link. However, when shown videos of their mothers generated during a previous interaction they do not engage in coordinations with the unresponding recording (which maintains intact the mother's expressiveness) and become distressed and removed. This seems to indicate that the recognition by the infant of the ongoingness and contingency of the interaction plays a fundamental role in its unfolding. Early involvement in socially contingent interactions, and its implied connectedness, plays a fundamental role in the infant's affective and experiential development (Tronick, 2004). Sensitivity to social contingency in two-month-olds is inferred from these results (N905847(,)-367.190redaer25(83552(y)-358.36(co))0.43.01892(r)-0,ay e cep c o[illegible] n[illegible] o [illegible] c e eed c of an entity encountered will only in the case that both partners are in contact with each other – if interaction is only one–way, between a subject and the other’s shadow, the shadow will eventually move away, because the subject it is shadowing is still engaged in searching activity. Two–way mutual scanning is the only y n n. Therefore, the solution to the task does not rely on individuals performing the right kind of perceptual discrimination between different momentary sensory patterns, but emerges from the mutual perceptual activity of the experimental subjects that is oriented towards each other.

Interesting hypotheses and further questions can be deduced from these results, for instance, whether such global dynamical processes, in which none of the individual actors can be held responsible for the interactional success, also play a role in more complex conditions, such as Trevarthen’s double monitor experiments. But also within this minimal experimental set–up, there are more questions to be asked. In this paper, we investigate simple simulated robotic agents performing the same task from a dynamical systems perspective. Due to the novelty of the approach we must first detour to explain how such purely synthetic findings can enrich the practice of the experimental psychologist.

stopping once there or cycling around it, etc. The evolutionary search can come up with any of these solutions, while a human designer would only find few of them intuitive. Indeed, it happens frequently that the evolutionary roboticist finds it difficult to understand the evolved behavioural solutions. In these cases, a 'pseudo–empirical' investigation of the agents follows in order to explain their performance: Agents are tested under different psychophysical conditions, internal and external variables are monitored, the structure of the evolved agent control architecture is closely examined or altered, etc.

Typically, the systems that are designed in evolutionary robotics are controlled by continuous-time recurrent neural networks (CTRNNs, (Beer, 1990, 1995)). These neurocontrollers are particularly useful for dynamical models since they allow the specification of multiple timescales, from the very fast to the very slow, including behavioural, learning and developmental timescales in a single neural network (see appendix).

The agents can move along one dimension, i.e., to the left and to the right. This one-dimensional world wraps around. The agents are controlled by CTRNNs. They have one touch sensor that feeds an on/off signal into the network if they touch the other agent or any other object located on the tape. The output activation of the neural network is used to control the left/right movement of the agent. The parameters and architecture of this recurrent network are evolved with a genetic algorithm to maximise the performance of the task which is to locate the partner agent and spend as much time as possible as close to each other as possible while not being trapped by static objects or shadow images. In this simulation, both partners are identical, i.e., just a single population of agents is evolved.

When we first tried to evolve agents to solve the perceptual crossing task, the evolutionary search algorithm was not able to find a satisfactory solution. The behaviour that evolved was for agents to halt when crossing any object encountered on the tape, be it the partner, the fixed object or the shadow of the other. Given the experimental set–up, this is a comparably successful strategy: If agents first encounter each other, or if one agent runs into its waiting partner, it achieves perfect fitness, and these are the majority of possible cases. However, it is neither the behaviour, as in the remaining cases, the agents will not find each other at all, nor is it a very intelligent or adaptive solution and it does not resemble any of the strategies adopted by human subjects, who keep actively exploring. Only when a small time delay between a crossing on the tape and the agent's sensation was included into the model (see appendix), the evolutionary search algorithm came up with an adaptive solution. The trajectories generated by the agents are similar to those generated by some human subjects (Fig. 3 (C)).

An interesting question arises from these unsuccessful trials: Is the oscillat

We use almost the same settings as in the previous model except for the number of sensors which is now increased to six in order to allow for more accurate discrimination of the partner's movements (this would facilitate individual discrimination strategies if they were to be favoured by the artificial evolutionary process). The

these results, an extended version of the experiments is generated, which is first investigated in simulation, leading to refined hypotheses and ideas. These ideas will subsequently be tested in empirical psychological experiments. The typical complaint when confronted with artificial models of the dynamics of psychological process is that of the gross gap in complexity between the model and the modelled situation. This problem is solved in this work by pairing up an empirical experiment and a computer model that both deliberately strive for minimalism, in the spirit of keeping the dynamics of the investigated behaviour tractable. The fact that even such minimal models lead to unintuitive findings speaks for the dynamical complexity of the subject matter and the usefulness of the approach. We argue that such two way interaction between minimal dynamical simulation models and minimal dynamical psychological experiments is likely to be fruitful for a larger class of scientific problems.

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Append ec n c de 3

( ) Cnn r rrnn r n r

A neuron i in a CTRNN is governed by the following continuous-time di erential equation:

$$_i\dot{y}_i = -y_i + \sum_{j=1}^{N} w_{ji} z_j(y_j) + I_i, \quad z_i(x) = 1/(1 + e^{-x-b_i}),$$

where y_i represents the cell potential, z_i is the firing rate, $_i$ is its time constant (modulating the speed of response of the node), b_i is a bias term, and w_{ji} is the strength of the connection from the neuron, j, to i. I_i represents the sensory input, which is given to only sensory neurons. The number of neurons is given by N.

( ) n S n

A generational genetic algorithm with truncation selection ($\frac{1}{3}$) and a real valued $\in$ [0,

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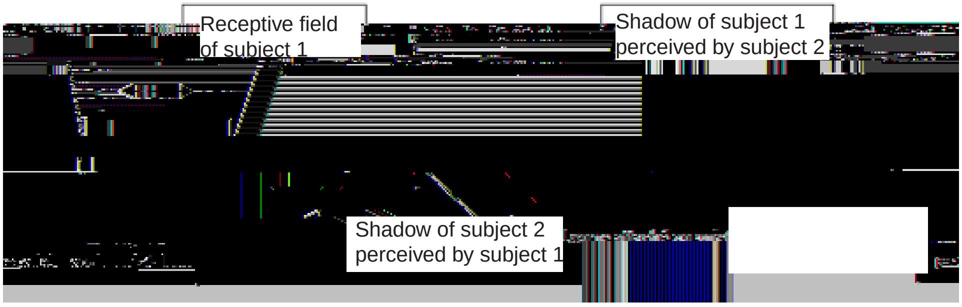
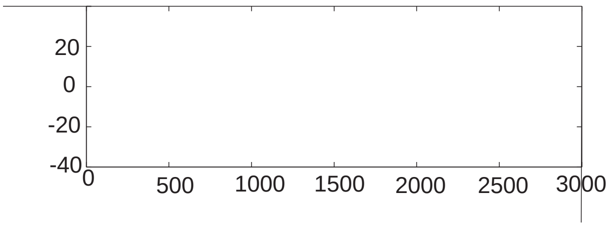

Receptive field
of subject 1
Shadow of subject 1
perceived by subject 2
Shadow of subject 2
perceived by subject 1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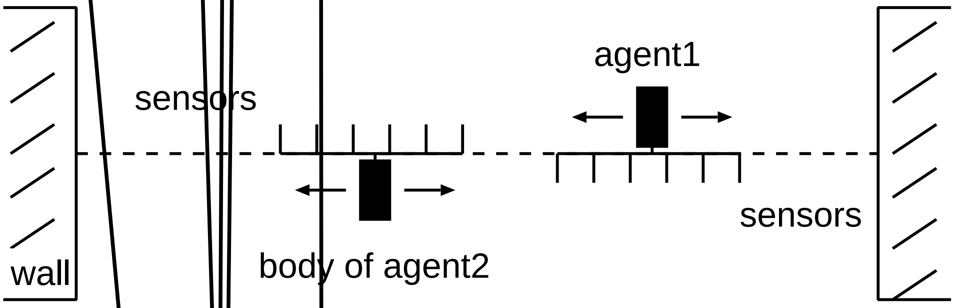
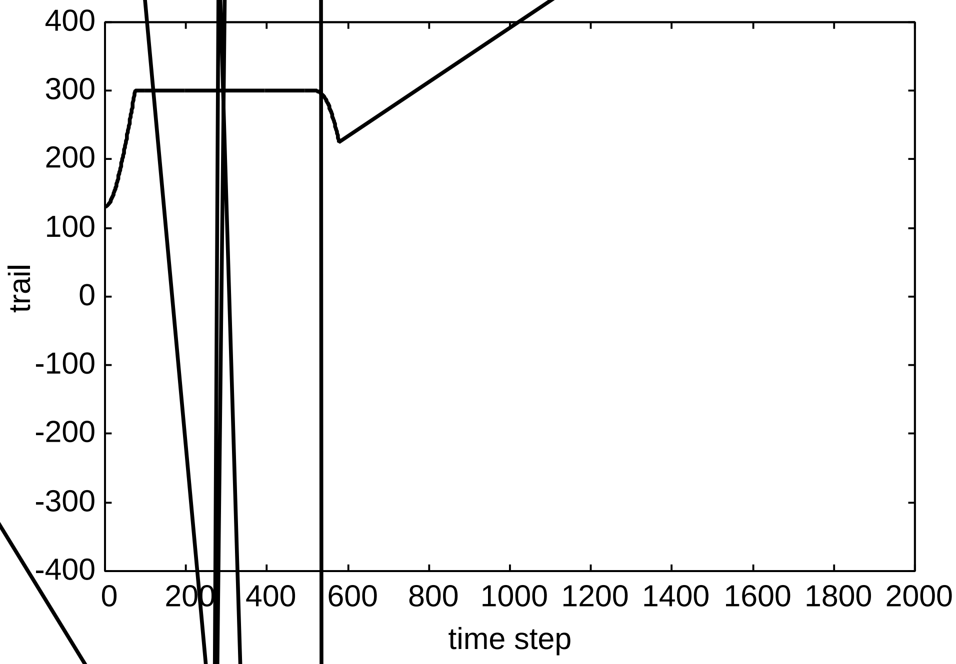

agent1
sensors
sensors
wall
body of agent2

Figure 4.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