Do Complementarities Exist in Agent Interactions?

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Abstract

In social interactions and communications, agents are required to coordinate their own activity patterns to maintain and continue dynamic balanced interactions. These activity patterns consist of dynamically the balanced changes in distance, postures, and positions of agents. There is a clear tendency for social interactions to apply such particular motion changes to exclude irrelevant patterns.

But how these activity patterns correlate with each other and the mechanisms they use in interaction remain a mystery. We use the concepts of action system theory from ecological psychology to formulate these activity patterns and study the complementarity of behavior coordination in agent interactions.

We simulated behavior coordination of agents for the argument of our formulation and found that agents in interaction could correlate their activity patterns complementarily when they orient themselves each other. These initial findins are expected to provide us new possibilities for the analysis of human-robot interaction.

1 Introduction

In the interactional activities of animate objects, many macro and micro actions compose entire behaviors. Macro actions involve smooth, habitual or periodic movements. On the other hand, micro actions include erratic and atypical movements, for example, hesitation. Accordingly, a behavior composed of macro or micro actions exhibits its own order or disorder of activity patterns. To date, a wide variety research in behavior generation and coordination suggests that behaviors in interaction have some coordinative structures(synergetics). For example, these include skillful bodily movements[1][2][3].

Meanwhile, we wonder whether behaviors in social interaction also have such synergetics. From the standpoint of relational design, we want to study behaviors in social interaction to find the coordination mechanism of behavioral changes.

In this paper, by using concepts from ecological psychology, we first formulated environmental and interactional factors for behavior generation. Next, we simulated behavior coordination of agents for the argument of our formulation and found that there is a probability of complementarity between activity patterns of agents in interaction. We believe the results of this work will provide new possibilities for the analysis of human-robot interaction.

2 Relational Design of Behavior

2.1 Relational Properties for Activities

We use the concepts of ecological psychology to discuss behavior generation and coordination. In ecological psychology, behavior is regulated by *affordances* as relational properties of the agent-environment system[4][5][6]. We formulate *affordances* as environmental and interactional factors to study or design agent-environment systems that regulate behavior. In general, a behavior in interaction would involve two kinds of activity: exploratory and performatory activity[4].

Exploratory activity, i.e. the scanning for and use of information, typically does not require the expenditure of a significant amount of force to alter the substances or surfaces of the environment. Adjustments of this activity are typically embodied in low-energy and low-impact movements. In performatory activity, an agent(actor) does use a significant amount of force to alter the substances and surfaces of its environment. For example, it is one thing to see or to smell a piece of food, but it is quite another thing to obtain it and eat it.

We presuppose that the physical properties relating an agent's perception and action are nearly invariant within a period of time. X is defined as the set of environmental states available for perception and action, and S is the set of perceptional states, and A is the set of actions. Let $T(x, a | x \in X, a \in A) = x' \in X$ denote the state transition function and $O(x | x \in X) = s \in S$ denote the perceptional function.

First, if an agent involved in exploratory activity reliably finds or chooses a certain equivalence relation R^e of environmental perception, then S with A will be partitioned into several equivalence classes S_i with A_i^e under R^e, as follows:

$$S = \sum_{i \in M} S_i, \quad A = \bigcup_{i \in M} A_i^e \tag{1}$$

with $S/R^e = \{S_i | \exists u, v \in S_i, u R^e v\}$, $A_i^e = \{a^e \in A | \exists s = O(x \in X) \in S_i, O(T(x, a^e) \in X) \in S/R^e\}$. In this case, S/R^e is called the quotient set of S by R^e, and A_i^e is the set of *perceptional actions* a^e.

Second, if an agent involved in performatory activity reliably finds a certain equivalence relation R^p of actions in the environment, then X with A will be partitioned under R^p, as follows:

$$X = \sum_{j \in N} X_j, \quad A = \bigcup_{j \in N} A_j^p \tag{2}$$

with $X/R^p = \{X_j | \exists u', v' \in X_j, u' R^p v'\}$, $A_j^p = \{a^p \in A | \exists x \in X_j, T(x, a^p) \in X/R^p\}$. In turn, X/R^p is called the quotient set of X by R^p, and A_j^p is the set of *direct actions* a^p. Then, an agent would extract factors from two kinds of relational property *affordances* to regulate both activities. We can describe these two kinds of *affordances* as follows:

$$Af_i^e = S_i \times A_i^e, \quad Af_j^p = X_j \times A_j^p \tag{3}$$

where $i \in M, 0 < M \leq |S| \leq |X|$ and $j \in N, 0 < N \leq |X|$. In addition, the role of equivalence relation R^e or R^p is used here to brush against and aside *affordances*, or, more precisely, to abstract and eliminate changes in the layout of affordances for perception and behavior cycles.

2.2 Triggers for Behavior Coordination

Each activity takes advantage of each corresponding relational property Af_i^e, Af_j^p to generate behavior, since these properties provide templates for the activity patterns in behavior (see Fig.1). If the next set A_{ij}^{ep}, in which several elements of A_i^e and A_j^p can satisfy within the same given period,

$$\begin{aligned} A_{ij}^{ep} = \{\tilde{a} \in A | \exists s = O(\exists x \in X_j) \in S_i, \\ \underline{O(T(x, \tilde{a}) \in X/R^p) \in S/R^e}\} \end{aligned} \tag{4}$$

is $A_{ij}^{ep} \subseteq A_i^e \cup A_j^p$, $A_{ij}^{ep} \cap A_i^e \neq \emptyset$, $A_{ij}^{ep} \cap A_j^p \neq \emptyset$, then both activities would be synchronous or identifiable. In this period, a particular behavior that nests exploratory and performatory activity can share A_{ij}^{ep}.

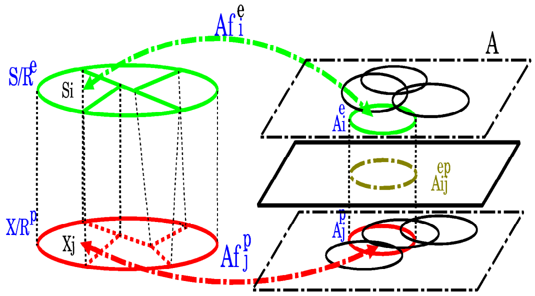

Figure 1: Relational properties *affordances* Af^e, Af^p are respectively for exploratory and performatory activity.

In contrast, the underlined part of eq.(4) can also be modified as below:

1. $O(T(x, a) \in X/R^p) \notin S/R^e$
2. $O(T(x, a) \notin X/R^p) \in S/R^e$
3. $O(T(x, a) \notin X/R^p) \notin S/R^e$

These three cases would provide possibilities for changes in the intentionalities of the behavior. In the first case, a recognized action involves an undistinguishable perceptional state. That is, it needs another suitable equivalence relation, $R^{e'}$, on perceptional states S to distinguish and identify that undistinguishable perceptional state as another kind of perceptional state. In the second case, an unrecognized action involves a distinguishable perceptional state. It needs another suitable equivalence relation, $R^{p'}$, on environmental states X to identify one's own current capacity for direct actions. In a third case, an unrecognized action involves an undistinguishable perceptional state. It needs suitable equivalence relations $R^{e'}$ and $R^{p'}$. In these cases, another suitable exploratory or performatory activity is, or both is required to follow the adjacent behavior. However, the effort to find the suitable one is sometimes successful and sometimes not. In addition, we assume that changes in these cases would promote the breakup or reorganization of behavior.

Furthermore, if an agent has abundant equivalence relations for exploratory or performatory activity, then it is possible that suitable activities would form the coordinative behavior as the dynamic equilibrium process or state. In addition, we assume that the activity patterns of a number of agents in interaction might be complementary if they could share identifiable equivalence relations.

3 Agent-Environment Interaction

3.1 Preparations

We designed identifiable equivalence relations to implement agents in the verification of complementarity between the activity patterns of agents in interaction. We prepared a mobile agent and an experimental environment to analyze the interaction of agents in the environment. The agent as an actor has two wheels to move itself and six distance sensors to detect changes in distances between itself and its surroundings as an informational flow. A radio emitter and a receiver were installed to emit or receive signals in an area of a certain diameter. The designed environment provides the agent a limited range of movement (see Fig.2).

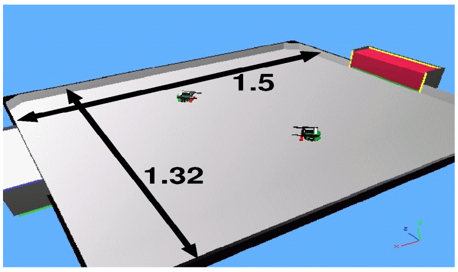

Figure 2: The experimental environment.

3.2 Mutual Interaction among Agents

Two agents have different but constant moving velocity. They both use the same equivalence relation R^{e_1} to distinguish the perceptional states existing when an object is moving in their surroundings, this is done by using the distance sensors. Their other equivalence relation R^{e_2} is used to distinguish perceptional states existing when a signal is produced; this is done by using the radio emitter and receiver.

These equivalence relations could be designed by using the differences of time-series data from the sensory equipment. In addition, the state that affords the informational flow could be defined as the ideal state for the agent. The design criterion to judge an unsuitable state becomes effective, for example, when an agent is surrounded by something. We use these conditions to implement the learning algorithm in an agent in order to generate the variational equivalence relation R^p and regulate action patterns by R^p. In this case, we use the Q-learning method, one of the reinforcement learning methods, not for its usual purpose (i.e. to reach the goal) but for possible behavioral coordination. The following is the update rule of the learned action-value function in Q-learning:

$$Q(s_t, a_t) \leftarrow (1-\alpha)Q(s_t, a_t) + \alpha(E_t + \gamma max_{b \in A} Q(s_{t+\Delta}, b))$$

where Q, E denote the action value and the state value, t is the number of steps, factors $\alpha, \gamma \in [0, 1)$. We assume that the action values correspond to the variational equivalence relation R^p to regulate actions.

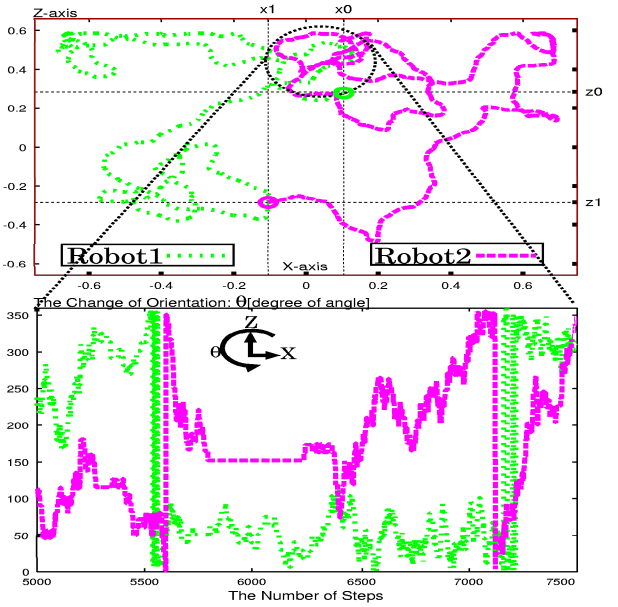

Figure 3: Changes of the trajectory and orientation of agents in interaction. The starting points (x_0, z_0), (x_1, z_1) are respectively for each agent.

In the experiment, the behaviors of two agents in a common environment apparently exhibited irregular and disorganized patterns (see Fig.3). However, Fig.4(a) shows that changes in the orientation of the two agents are in particular branched patterns. Significantly, when they have mutual interaction between 5000 and 7000 steps, they orient their positions and postures to each other. Moreover it appears that their activity patterns in interaction gather in the embodied actions set $A^{e_1 p e_2}_{ijk}$ (see Fig.4(b),(c)). The dashed circles in Fig.4(b) and (c) also show that mutual interaction among the two agents, or coordination of their behavior, are complementary. That is, we could hypothesize that if multiple actors use the same homogeneous informational flows, then their mutual interaction can emerge and have dynamic complementarity.

4 Conclusion

This paper presents formulas of relational properties as environmental and interactional factors for activities, based on concepts from ecological psychology. We used these formulated properties to study behavior processes. As a result, complementarity between activities was found to be one property for developing interaction. However, the work reported here needs to be followed up by further research, such as a comprehensive analysis of human-robot interaction.

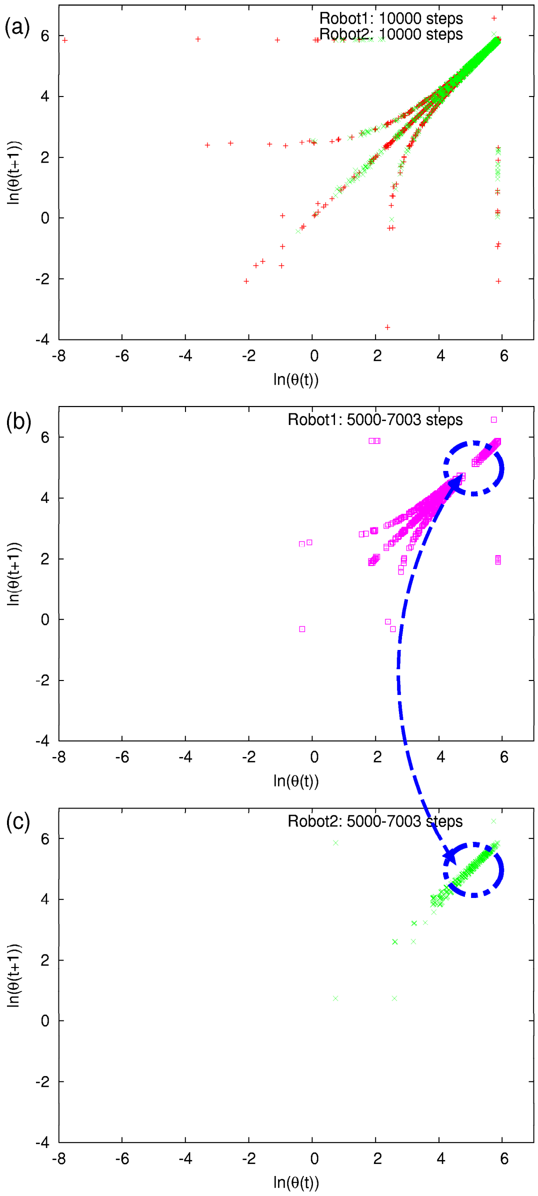

Figure 4: The phase space of $\theta(t), \theta(t+1)$ and t is the number of steps. (a) Changes in orientations of agents during 10^4 steps, show sort of spatio-temporal patterns. (b)(c) Changes in orientations of each agent between 5000 and 7003 steps. Dashed circles in (b), (c) exhibit mutual interaction among agents are complementary.

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References

[1] N. Bernstein, “On dexterity and its development” the japanese edition, Kanekoshobo Press, 2003.

[2] T. Fujinami and T. Yamamoto and M. Abe, “Synchronisation and Differentiation found in skillful bodily movements”, *The 18th Annual Conference of the Japanese Society for Artificial Intelligence 2004*, 3D1-04, 2004.

[3] K. Yamane and Y. Nakamura, “Pin-and-Drag Synergetic Interface for Choreography of Hman Figures”, *Journal of the Robotics Society of Japan*, Vol.20, No.3, pp.335-343 2002.

[4] E.S. Reed, “*Encountering the World - Toward an Ecological Psychology*”, (Oxford University Press., 1996).

[5] T.A. Stoffregen, “Affordances as properties of the animal-environment system”, *Ecological Psychology*, 15(2), 2003, 115-134.

[6] E.C. Goldfield, “Development of infant action systems and exploratory activity: a tribute to Edward S.Reed”, *Ecological Psychology*, 12(4), 2000, 303-318.