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Inverting the Interaction Cycle to Model Embodied Agents

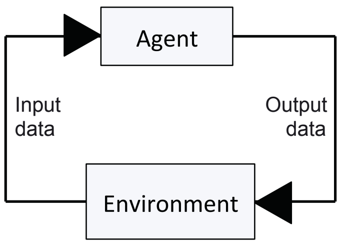
Olivier L. Georgeon[1] and Amélie Cordier[1]
[1]Université de Lyon, CNRS.
Université Lyon 1, LIRIS, UMR5205, F-69622, France.
olivier.georgeon@liris.cnrs.fr, amelie.cordier@liris.cnrs.fr

Abstract
Cognitive architectures should make explicit the conceptual begin and end points of the agent/environment interaction cycle. Most architectures begin with the agent receiving input data representing the environment, and end with the agent sending output data. This paper suggests inverting this cycle: the agent sends output data that specifies an experiment, and receives input data that represents the result of this experiment. This complies with the embodiment paradigm because the input data does not directly represent the environment and does not amount to the agent's perception. We illustrate this in an example and propose an assessment method based upon activity-trace analysis.

Keywords: Embodiment, perception-action, cognitive modeling, intrinsic motivation, activity trace.

1 Introduction

Cognitive architectures and machine-learning models generally represent the interaction between the agent and the environment as a cycle in which the agent alternatively receives *input data* from the environment and sends *output data* to the environment. Figure 1 depicts this cycle.



The agent receives input data (left arrow) from the environment and sends output data (right arrow) to the environment. The cycle rotates indefinitely; the figure does not show when the cycle begins and when it ends.

Figure 1: interaction cycle between an agent (top) and an environment (bottom).

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The model in Figure 1 implies no particular commitment about the nature of the input and output data. Most models, however, make an additional commitment: they arrange the input data so that it *represents* the environment, and they implement the agent's algorithm so that it exploits this assumption. The term *represent* is used here in its etymological sense of "making present again". That is, traditional models use the input data as a *representative* sent to the agent by the environment, as if the input data made the environment's state accessible to the agent, at least partially and possibly blend with noise. Section 2 develops this argument by analyzing symbolic cognitive models (e.g., [1]) and reinforcement learning models as they are typically implemented in Partially Observable Markov Decision Processes (POMDPs, e.g., [2]).

There exist other possibilities than designing input data to represent the environment. A typical alternative has been offered by cybernetic control theory (e.g., [3]) in which the input data was a *perturbation* of a control loop. More recently, some authors have advocated an *inversion of the perception-action cycle* (e.g., [4]). Inverting the interaction cycle allows modeling the input data so that it does not directly represent the state of the environment. Instead, the input data can represent the result of an experiment initiated by the agent. In the same environment's state, different experiments may produce different results; the result itself thus does not represent the environment's state, not even partially or with noise. This paper follows this idea to propose the Experiment-Result Cycle (ERC). Section 3 examines it further.

A key concept of the embodiment paradigm (e.g., [5]) is that the agent is not a passive observer of reality but rather constructs a perception of reality through active interaction ("perception and action arise together, dialectically forming each other", [6] p5). This implies that the model should derive perception as a secondary construct resulting from experience of interaction, rather than considering the input data as the agent's perception. The term *embodiment* means that the agent must be a part of reality for this active interaction to happen.

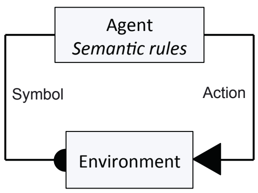
The ERC ensures that the input data is not considered as the agent's perception precisely because the input data does not represent the state of the environment. For this reason, we propose the ERC as a possible starting point to model agents according to the embodiment paradigm.

Since ERC agents do not access the environment's state, the designer cannot program them to seek a particular environment's state as a goal. Therefore, we cannot assess ERC models by measuring their performance in reaching goal states. ERC models thus require another validation paradigm. This requirement has been frequently raised in the literature of embodied robotics (e.g., [7]), intrinsic motivation (e.g., [8]), and developmental learning (e.g., [9]).

We suggest using a validation paradigm similar to that used to assess natural cognitive systems (animals): behavioral analysis (e.g., [10]). This paradigm requires the embodied-artificial-intelligence scientific community to find a consensus on how to qualify *cognitive behaviors*. To contribute to this endeavor, Section 3 gives an initial example of behavioral analysis of a simple ERC algorithm.

2 When does the cycle begin?

Figure 2 illustrates *symbolic cognitive models* (e.g., [1]) by making explicit the conceptual begin and end points of the interaction cycle.



The black circle represents the begin point: a symbol is passed from the environment to the agent. The agent interprets this symbol according to semantic rules, and decides on an action to carry out in the environment. The black triangle represents the end of the cycle when the environment receives the action chosen by the agent.

Figure 2: the symbolic cognitive cycle.