Sensorimotor paradigms for design of movement and social interaction

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Abstract. The human brain has evolved for governing motor activity by transforming sensory patterns to patterns of motor coordination. Movement, as a basic bodily expression of this governing function is shown to underlie higher cognitive processes and social interaction. There are three prevailing concepts of sensorimotor interaction that set up different frameworks for design of artificial movement. This paper focuses on the common coding [14] paradigm of sensorimotor interaction as justified by recent experimental studies on the mirror neuron system. It aims to provide a novel approach to design of movement interactions in an inter-agent[1] setting.

Keywords: Sensorimotor interaction, mirror neurons, design, movement.

1 Introduction

The level of understanding of human behaviour and perception frames the borders for design. Movement and action (action is understood as purposeful movement) are the primary expressions of behaviour. Tracing the evolution of species, movement takes more complex and abstract forms. By humans, movement is grounding cognition, language, and social interaction.

Interaction through movement and its implications for creation of social agents are discussed in an attempt to outline a new design framework. After reviewing the main views on perception and action and the design concepts they can afford, we choose the *common coding paradigm* [14] as a basis for design of movement in inter-agent setting. The common coding is explained in concrete sense with the latest discoveries in neuroscience and experimental psychology. In particular, the discovery of the mirror neuron system in humans [4],[7],[9] have given new dimension of understanding the sensorimotor system and its interaction to a complex environment, including the interactions with another agents.

This paper is organised as follows. In Section 2 the three prevailing paradigms and their implications for design are introduced. Section 3 elaborates on the common coding theory, its biological background and its implications for design of movement

[1] As an agent is understood any object or subject that can express own behaviour, e.g. human, animal, or animat.

and social interaction. Section 4 summarises the main conclusions and suggests a road for further work.

2 Views on perception-action interplay and implications for movement design

The commonly accepted views on perception-action interplay yield different paradigms and settings for accomplishment of a movement. During more than a century of research few major views on the interaction between perception and action have been suggested. They can be divided into three groups, depending on the determining factor in this interaction. Historically first comes the understanding that perception precedes and may provoke an action; a different view suggests that actions determine our perceptions; recently more evidence suggests the perception-action unity.

The Information-processing view on the perception-action interplay postulates that *perception precedes action.* Even though it has been established more than a century ago by Donders [5] it remains to be a widely accepted methodological strategy for decomposing the stream of processing between stimulus presentation and response generation into a number of stages: first, perception is acquired, followed by an internal representations and processing, eventually causing an action. There is not a direct way in which actions and perceptions could interact, but through the environment. This view suggests that to design an embodied movement one has to go trough stages of sensing, processing, and representing in a subsequent manner. Since a direct backward coupling between action and perception is lacking, the embodied design of moving agents is not intrinsically promoted. Figure 1 represents schematically this view.

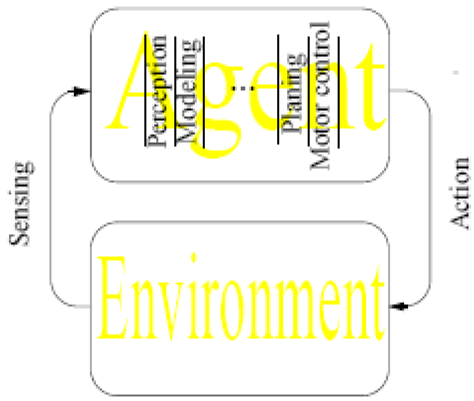

Fig. 1. Information processing view facilitates design of movements, actions, and behaviors as a linear system. The direct feedback link from action to perception is not possible.

On the contrary, Selection view advocates that *actions determine our perceptions*. Attention mechanisms account for various limitations observed in human performance. Thus, they are assumed to enhance or to inhibit the activity in the various streams and at various stages in the flow of information. The basic principle behind this view is that any integrated action requires selection of action-relevant aspects of environmental information, and at the same time ignore or reject the non-relevant aspects. For instance, we can think of our visual system as a gigantic hand that "palpates" the needed part of a visual scene. Gibson [6], Clancey [3], and Shaw and Todd [19] emphasize this relation between action and perception and regard the perception of things as a function of actions they afford. The metaphor of 'affordance' accounts for the direct link between perception and action, but still the action or the affordance for an action remains the determining factor. The selection view is represented in Figure 2.

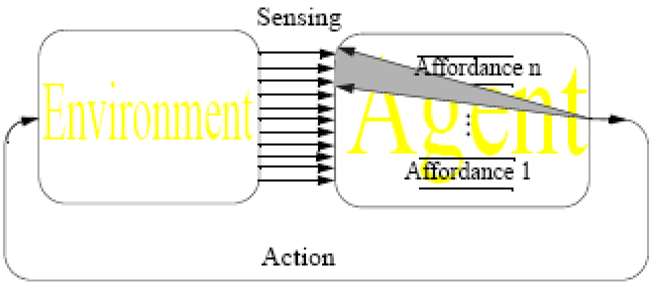

Fig. 2. The selection view suggests that any integrated action requires selection of relevant environmental (sensory) information. This sensory information is enhanced by the "right" perception by a top-down mechanism. Action selection is determined by affordances with different complexity.

The advantages and limitations of this approach are already explicit in its definition: perceiving affordances in the environment means that perception as filtered through the individual capabilities for physical action and through the current goals or intentions. This leads to the advantage to couple perception and action deep down in the sensorimotor control loop, providing an action-oriented interpretation of percepts in real time. In addition, affordances provide on a high granularity level a basis for agent interaction and for learning or adapting context-dependent, goal-directed action.

However, the perception is filtered and restricted through an immediate action; in a real life scenario this filtering can bring to a very distorted and single-sided choice. Besides, the lack of representation (see Figure 2) is not a realistic assumption and certainly can not account for all cases of perception. In addition, although the selection view builds on the existence of a strong link between perception and action, it does not assume a reciprocal unity between perception and action, because it does not go further than taking a "black box" interpretation of the agent.

While the information-processing view was unable to explain perception in many cases related to direct action, the selection view and Gibson's notion of direct perception failed to explain another group of phenomena like memory and imagination that can certainly originate an action by themselves. To address this problem, Neisser proposed an alternative which captures aspects of both approaches [13]. Based on neurological and cognitive studies, he proposes that there are two biological perceptual systems, one for direct perception and one for recognition. The direct perception system evolved earlier and explains Gibsonian phenomena. The recognition system developed later in evolution and uses memory, complex representations, and inference to distinguish instances of objects which have a semantic content. Neisser's view of direct perception and recognition as distinct perceptual systems has important ramifications for design of moving agents. It suggests that affordances will not be suitable for all behaviours. It also can be interpreted as suggesting that traditional model-based techniques are appropriate for recognition-style perception. However, his analysis can be an origin of a hybrid approach that somehow should combine the positive aspects of the two theories. Although more realistic, the approach based on Neisser's view will not bring a compendious approach to design.

An alternative direction is implied in the work of Shepard [20]. He suggests a way toward opening the "black box" in the Gibsonian approach. Shepard argued that, as a result of biological evolution and individual learning, the organism is tuned to resonate to the incoming patterns that correspond to the invariants that are significant for it. These patterns, according to Shepard, have become most deeply internalized (i.e., represented), and even in the complete absence of external information, the system can be excited entirely from within (e.g., while imagining). Thus, unlike Gibson, Shepard makes an explicit reference to internal representations and makes it possible to articulate the notion of resonance with that of motor representations.

The Common coding theory postulates real *parity between perception and action* [14]. Its core assumption is that actions are coded in terms of the perceivable effects (i.e. the distal perceptual events) that they should generate [11][12]. A growing body of behavioural and neurophysiological studies supports this theory. As a first evidence for a direct matching between action perception and action execution came the discovery of 'mirror neurons' in the ventral premotor cortex of the macaque monkey [15][16][17]. Mirror neurons fire both when monkey carries out a goal-directed action and when it observes the same action performed by another individual [18], i.e. the perception and the action are likely coded in the same way, by the same structure. More recently, it was found that a subset of these mirror neurons also respond when the final part of a previously seen action is hidden and can only be inferred [21]. Therefore, the observation of an action activates action representations to the degree that the perceived action and the represented action are similar [12]. Moreover, specific neurons in this region respond to the representation of an action rather than to the action itself. Further reasoning infers that observed, executed, and imagined actions are represented in a common code (Figure 3). Better understanding of this code will give insights not only for the nature of action and perceptual representations, but also gives a very efficient and novel way of designing actions that will not avoid any aspect of the perception, and still rely on a single design concept.

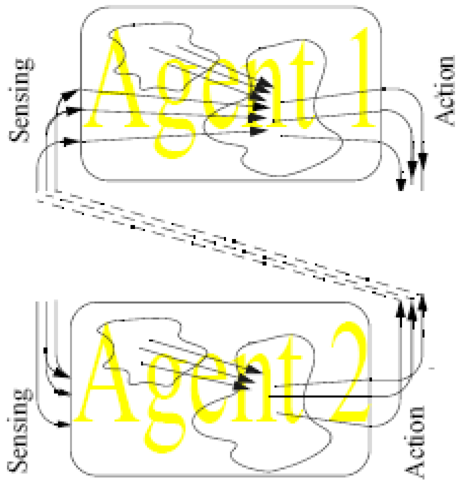

Fig. 3. The common coding theory shows that sensing and action activate the same internal representations. Moreover they can be activated by endogenous factors. If Agent 2 expresses an action the activation as by an own action will take place by the observing Agent 1.

3 From movement to meaning and social interaction

The importance of motor patterns in the development of concept formation has long been elaborated. Not only making sense of the environment, but interacting with it has its roots in sensorimotor learning. The production of purposeful, goal-directed movement pervades all human activity like walking, grasping, typing, sports, dance, etc. Speech is also intrinsically a motor act. On a deeper cognitive level, eye movements, and body language go together as a subtle expression of complex mental processes. Besides the obvious involvements, movement as a part of the sensorimotor process underlies cognition and social interaction.

Indeed, the human brain has evolved for governing motor activity with the basic function to transform sensory patterns into patterns of motor coordination. The reaction to changing environment is the first functionality that is mastered in human development.

By studying conscious motor imagery in humans, it has been shown that it is possible to access the action representation [10]. Motor imagery, which is thought to involve the activation of internal models of action, can be considered a first-person process of the participant "seeing" the execution of own action. A motor image is therefore an equivalent to a prediction for that action. Recently, Voss et al. have shown that internal model prediction occurs even in the absence of movement [22]. Therefore, due to common representation and internal simulations we are able to anticipate the consequences of our own actions, be con conscious of and able to control our mental states.

Since the perception of an action can reflect the behaviour of a conspecific, the common representation and internal simulations are not necessarily directed to our own actions. Mirror neurons, found in ventral premotor cortex of macaque monkeys, are activated both when the monkey executes grasping actions and when it observes someone else (or another monkey) making grasping actions [8]. Following the discovery of mirror neurons in monkeys, there is increasing evidence that a large proportion of the human motor system is activated by the mere observation of an action [17]. In addition, observing an action affects the peripheral motor system in the specific muscles that are used in the action being observed [9].

Observing another person's actions also influences one's own ongoing movements. Recent evidence suggests that observing an action interferes with one's own actions when these are different from the observed actions [1][2].

4 Discussion

The three sensorimotor paradigms provide different possibilities for design of movements. The Information processing paradigm facilitates design of movements, actions, and behaviors as a linear step by step process. The direct feedback link from action to perception is not possible, therefore the embodied, and especially interactive behaviors are difficult to design. The Selection paradigm, based on the notion of affordances makes it possible to implement embodied movements and actions. However, movement interaction and prediction of its own actions are not intrinsic to this paradigm.

The Common coding paradigm that accounts for a realistic unity of the perception -action process is shown to have the highest potential for design. Not only movement but also higher motor cognition behaviours are within its reach, since a system that can predict its own actions can also be controlling them. Moreover, the social interaction patterns can naturally be represented within this paradigm.

Important questions for designing a movement lies in the respective computational role of each brain area that subserves the internal simulations and shared representations between self and others, as well as in a better description of what precise aspects of an action are actually represented. The temporal distribution of these representations is also likely to help understanding various mechanisms that in its nature are acts of motor cognition.

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