Dynamic Models for Intention (Goal-Directedness) Are Required by Truly Intelligent Robots

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Abstract. Intelligent behavior is characterized by flexible and creative pursuit of endogenously defined goals. Intentionality is a key concept by which to link brain dynamics to goal-directed behavior, and to design mechanisms for intentional adaptations by machines. Evidence from vertebrate brain evolution and clinical neurology points to the limbic system as the key forebrain structure that creates the neural activity which formulate goals as images of desired future states. The behavior patterns created by the mesoscopic dynamics of the forebrain take the form of hypothesis testing. Predicted information is sought by use of sense organs. Synaptic connectivity of the brain changes by learning from the consequences of actions taken. Software and hardware systems using coupled nonlinear differential equations with chaotic attractor landscapes simulate these functions in free-roving machines learning to operate in unstructured environments.

1 Introduction

1.1 Neurodynamics of Intentionality in the Process of Observation

The first step in pursuit of an understanding of intentionality is to ask, what happens in brains during an act of observation? This is not a passive receipt of information from the world. It is an intentional action by which an observer directs the sense organs toward a selected aspect of the world and interprets the resulting barrage of sensory stimuli. The concept of intentionality has been used to describe this process in different contexts, since its first proper use by Aquinas 700 years ago. The three salient characteristics of intentionality as it is treated here are (i) intent, (ii) unity, and (iii) wholeness [1]. These three aspects correspond to use of the term in psychology with the meaning of purpose, in medicine with the meaning of mode of healing and integration of the body, and in analytic philosophy with the meaning of the way in which beliefs and thoughts are connected with ("about") objects and events in the world.

(i) Intent is directedness of behavior toward some future state or goal; it comprises the endogenous initiation, construction, and direction of actions into the world. It emerges from brains by what is known as the “action-perception-assimilation cycle” of Maurice Merleau-Ponty and Jean Piaget. Humans and animals select their own goals, plan their own tactics, and choose when to begin, modify, and stop sequences

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of action. Intent is the creative process by which images of future states are constructed, in accordance with which the actions of search, observation, and hypothesis testing are directed. (ii) Unity appears in the combining of input from all sensory modalities into *Gestalts*, the coordination of all parts of the body, both musculoskeletal and autonomic, into adaptive, flexible, and effective movements, and the focused preparation for action that is experienced in consciousness. (iii) Wholeness is the construction of a life history, by which all of experience is sifted, catalogued, and organized in support of future contingencies in the ongoing adaptation to the environment. The aim of this report is to describe the dynamics by which animals prefigure their own goal-directed actions and predict the sensory information they need to perform their actions and achieve their goals, and to sketch briefly the simulation of these processes in simple robots.

1.2 The Limbic System Is the Organ of Intentional Behavior

Brain scientists have known for over a century that the necessary and sufficient part of the vertebrate brain to sustain minimal intentional behavior is the ventral forebrain, including those components that comprise the external shell of the phylogenetically oldest part of the forebrain, the paleocortex, and the deeper lying nuclei with which the cortex is connected. Intentional behavior is severely altered or absent after major damage to the basal forebrain, as manifested most clearly in Alzheimer's disease.

Phylogenetic evidence comes from observing intentional behavior in simpler animals, particularly (for vertebrates} that of salamanders, which have the simplest of the existing vertebrate forebrains [2]. The three parts are sensory (which, also in small mammals, is predominantly olfactory), motor, and associational. The associational part contains the primordial hippocampus with its septal, amygdaloid and striatal nuclei. It is identified in higher vertebrates as the locus of the functions of spatial orientation (the "cognitive map") and of temporal integration in learning (organization of long term and short term memories). These processes are essential, because intentional action takes place into the world, and even the simplest action, such as searching for food or evading predators, requires an animal to know where it is with respect to its world, where its prey or refuge is, and what its spatial and temporal progress is during sequences of attack and escape.

The three parts are schematized in Fig.1. All sensory systems in mammals send their output patterns to the entorhinal cortex, which is the gateway to the hippocampus and also a main target of hippocampal output. Multisensory signals are integrated in transit through the hippocampus and then transmitted back to the entorhinal cortex (the “time loop”) and then to all the sensory cortices (the “reafference loop”), so that within a third of a second of receipt of new information in any sensory area, all sensory areas are apprised and up-dated. The hippocampal and entorhinal outputs also go to the musculoskeletal, autonomic and neuroendocrine motor systems with feedback inside the brain (“control loop”) and through the body (the “proprioceptive loop”). Feedback through the environment to the sensory receptors (the “motor loop”) constitutes the action-perception cycle, and the learning that follows completes the process of assimilation.