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Brain computational primitives

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Abstract
The brain uses computational primitives that are analogous with but qualitatively different from the computational primitives used in electronic computer systems. The primary computational primitives of the brain are described, and their implementation in anatomy and physiology discussed. Combinations and sequences of these primitives implement cognitive tasks. Many of the primitives have also been implemented electronically. The brain is a very effective general learning system, and although an artificial general intelligence system will be required to learn a different range of behaviours from the brain, the computational primitives used by the brain are the best available guide to appropriate primitives for such an AGI system.

1 Introduction

Many computer systems exist that independently control complex combinations of physical equipment in real time. One example is the flight control system on a modern commercial aircraft, that in many situations can fly the airplane for long periods without pilot intervention. There are extensive computer systems that provide ongoing internet services with little human intervention. A complex real time control system must detect conditions in the constantly changing information available to it and associate the detections of different combinations of conditions with the implementations of different behaviours. For example, a flight control system receives information indicating the state of the aircraft and its environment, and detects conditions in this information that indicate the appropriateness of behaviours such as changing the angles of flaps, rudders etc. or the engine power levels.

The hardware that implements such control has the ubiquitous memory/processing architecture. There is a primary separation between hardware that performs instructions (for example, the CPU) and hardware that performs data read/writes (for example, various memories). The two types of information process form the basis for designing the features of the system in a way that can be implemented on the hardware.

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The computational primitives of an electronic system are thus instructions and data read/writes on various levels of complexity. For example, the instruction set of a general purpose CPU includes instructions like *add*, *multiply*, and *branch*. Other instruction sets may be used to control screen displays, such as *plot_point* or *plot_line*. Memory operations are supported by primitives like *fetch_and_store*, *compare_and_swap* etc. All these types of primitives are implemented by different combinations of transistors and other components on CPU, memory, and graphics interface integrated circuits. The software that defines the system features accesses these primitives via the compiler. The set of primitives can vary between different computer systems, and the same group of features could be implemented by different sets, although some sets may implement a given set of features more effectively in terms of factors like execution speed.

The human brain also controls a complex combination of "equipment" in real time. This "equipment" includes the body but also includes the brain itself. However, there is a major difference between a computing system and the brain. In a computing system the conditions, behaviours and associations between them are specified by an external designer, while in the brain they are largely specified heuristically from experience. This difference results in a qualitatively different "hardware" architecture. The two types of information process ubiquitous in the human brain are condition definition/detection and behavioural recommendation [Coward 1990]. There is a primary separation between cortex-like physical structures that perform condition definition/detection processes and subcortical structures that perform behavioural recommendation processes [Coward and Gedeon 2009]. In computing systems the memory/processing architecture is created by design. For brains, natural selection results in a strong tendency towards the cortex/subcortex architecture in all species in which a complex range of behaviours must be learned by experience [Coward 2001; Coward and Gedeon 2009; Coward 2013]. The pressures toward this architecture include the natural selection advantages of a species that can learn a given set of behaviours with fewer resources (like neurons) and of a species that can learn new behaviours without damaging the performance of previously learned behaviours [Coward 2001].

There is a range of "computational" primitives in the brain that implement different information processes of the condition definition/detection and behavioural recommendation types. Although there could be other primitives that could support the learning of a complex combination of behaviours, these brain primitives are a good starting point for the design of artificial general learning systems

2 The Information Architecture of the Brain

As illustrated in figure 1, cortex-like and subcortical structures are both separated into substructures that perform different types of processes of the primary types [Coward 2013]. At the highest level, cortex-like structures define and detect conditions. It is important to note that definition and detection are entangled, there is no detection without definition, and no definition without detection. Behaviourally relevant groups of conditions are called receptive fields, where a receptive field is detected if a significant proportion of the group is detected. The definition of "significant" may involve a complex integration process. To a degree, the behaviours available to the brain are specified in advance. There are muscle movement behaviours that at a detailed level are largely specified by the available muscles. However, the specific combinations and sequences of muscle movements required, for example, by walking or speaking must be defined heuristically.

In a computing system, conditions are unambiguously associated with behavioural commands (i.e. instructions) by the designer. In a complex learning system like the brain, conditions and receptive fields are defined heuristically. Receptive fields therefore change over time. If one receptive field was associated with an unambiguous behavioural command, subsequent changes to the field could mean that when detected later the associated behaviour was inappropriate. For this reason, receptive field detections can only be associated with behavioural recommendations, and to ensure