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A Basis for a Rigorous Cognitive Science: Maintaining Context for Information Exchange between Modules in a Functional Hierarchy

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A functional system acts upon itself and an environment in order to achieve internally specified objectives. A system is defined as functionally complex if four conditions are met. The first is that the system can perform many different behaviours. The second is that the system has multiple potentially conflicting objectives. The third is that a high degree of interaction is required between large volumes of information derived from current and past environmental and internal system conditions, from past behaviours, and from system objectives in order to determine appropriate behaviour at any point in time. The fourth is that limited time is available between when an environmental condition occurs and when a behavioural response must be completed.

By this definition, electronic image processing systems are functionally trivial (although difficult to design). The vast majority of information technology applications are very simple functionally. Functionally complex electronic systems are those which control large physical systems with no human intervention except as users of services provided. Such physical systems include aircraft simulators and telecommunications networks. The corresponding electronic control systems have millions of lines of software code designed by hundreds of engineers. Brains are biological examples of functionally complex systems.

Experience with functionally complex electronic systems demonstrates the need for system architectures which make effective use of resources, allow functional changes without side effects, and permit identification and repair of failure conditions. Analogous needs exist for biological brains. These needs force any system which performs a sufficiently complex combination of functions into a modular hierarchy defined by the requirement that modules on each level are roughly equal and information exchange between modules is minimized as far as possible (Coward 2000; 2001). In addition, careful attention must be paid to maintaining the context for such information exchange. Modules within such a hierarchy will not in general correspond with obvious system features, but can be used to relate high level system functions to detailed operations down to the device level.

Two types of information exchange are possible between modules. An unambiguous information exchange indicates that the currently appropriate system behaviour is within a specified set of possible behaviours with 100% confidence, and can therefore be interpreted as an instruction. A partially ambiguous information exchange indicates that appropriate system behaviour is probably within a specified set of possible behaviours, and can therefore be interpreted as a recommendation (Coward 2001).

The requirement to support unambiguous contexts forces a system into the memory, processing form of the von Neumann (or instruction) architecture ubiquitous in functionally complex electronic systems. However, heuristic definition of functionality (i.e. learning) is impractical with unambiguous information exchange.

The requirement to support meaningful although partially ambiguous contexts forces a system into the clustering, competition form called the recommendation architecture. Heuristic definition of functionality is possible, with clustering defining and detecting information combinations in system inputs and competition associating different sets of combinations with different behaviours. However, the requirement to maintain contexts is a severe constraint on both physical form and device algorithms (Coward 2000; 2001).

An implemented electronic version of a system with the recommendation architecture has demonstrated that learning is possible in such a system, and that learning can proceed with minimal effects on prior learning. There are a wide range of similarities between the structure and phenomenology of the implemented system and that of the mammal brain (Coward 2001).

The cortex with columns and areas resembles the clustering subsystem of the recommendation architecture, and the thalamus, basal ganglia and cerebellum resemble the required competition subsystems. REM sleep resembles the required process to ensure global minimization of information exchange. The phenomenologies of implicit and explicit memory resemble the different types of changes to information recording in clustering and competition (Coward 1999). The memory deficits introduced by damage indicate that the hippocampus manages resource assignment within the cortex (Coward 1990).

It is concluded that natural pressures have forced mammal brains into the recommendation architecture form, and that this architectural form can be used to understand the relationships between cognitive processes and physiology.

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