A theoretical multi-tasking executive function for the information processing model of the human brain

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Abstract

Research into holistic systems thinking needed an explanation or analogy for how the brain shifted from one task to the next. The cognitive psychology model of the human brain as an information processing system uses an executive function to control the transfer of information between short term and long term memory but seems to have little to say about how the executive function works. On the other hand, the multi-tasking operating system of a digital computer when modified provides such an analogy and is described in this paper. The key concept is that digital computer does not perform multiple tasks simultaneously. It performs one task at a time for very short periods of time, switching tasks under the control of the operating system so that it seems to multi-task. The model also suggests mechanisms for why some people can multi-task, and others focus on a single task to the exclusion of other tasks. The paper summarizes the digital computer multi-tasking operating system and then discuses a conceptual theory for multi-tasking in the human brain based on adapting the digital computer multi-tasking operating system in a parallel processing environment. The paper concludes with some observations which can lead to further research.

Keywords: systems thinking, critical thinking, holistic thinking, systems engineering, multi-tasking, cognitive psychology.

Purpose of paper

Holistic systems thinking is described as viewing a system from different perspectives (Kasser and Mackley, 2008). However, the human brain does not seem to be configured for viewing anything from different perspectives at the same time since according to Anderson we can only pay attention to one cognitively demanding task at a time (Anderson, 1995); yet the brain does seem to be able to perform a number of tasks at the same time. The cognitive psychology model of the human brain as an information processing system uses an executive function to control the transfer of information between short term and long term memory and perform other tasks, but the literature seems to have little to say about how the executive function works; see summary in (Miyake, et al., 2000).

The primary goal of this paper is to propose a hypothesis for a way of performing holistic thinking from an engineering perspective using the digital computer as an analogy. The secondary goal is to provide some speculation from different systems thinking perspectives and empirical data for future cooperation between cognitive psychologists and systems engineers to cooperatively develop a conceptual model for the operation of the executive function in the brain as a multi-tasking operating system. Consequently the focus of the paper is on holistic thinking and task switching within the context of the wider set of functions performed by the brain.

While the human brain is not configured for viewing anything from different perspectives at the same time, it can sequence through the different perspectives sequentially. Consequently when averaged over time, the brain is performing holistic systems thinking. This sequence can be considered as being similar to the manner in which a digital computer performs several applications at the same time (multi tasks). The multi-tasking operating system of a digital computer when modified to provide an analogy for multi-tasking in the human brain also suggests mechanisms for why some people can multi-task, and others focus on a single task to the exclusion of other tasks.

A digital computer multi-tasking system

The basic digital computer multi-tasking concept is broadly shown in Figure 1. Several tasks or applications are loaded in memory and represented by Tasks 1, 2, to N. Each Task contains a program that 'thinks' about something and accesses and stores data in memory. The Context Switch is the program that performs the task switching function by transferring the attention of the computer from one task to the next when it receives an interrupt signal. Task switching requires ways to save and restore the state of each task when switching occurs.

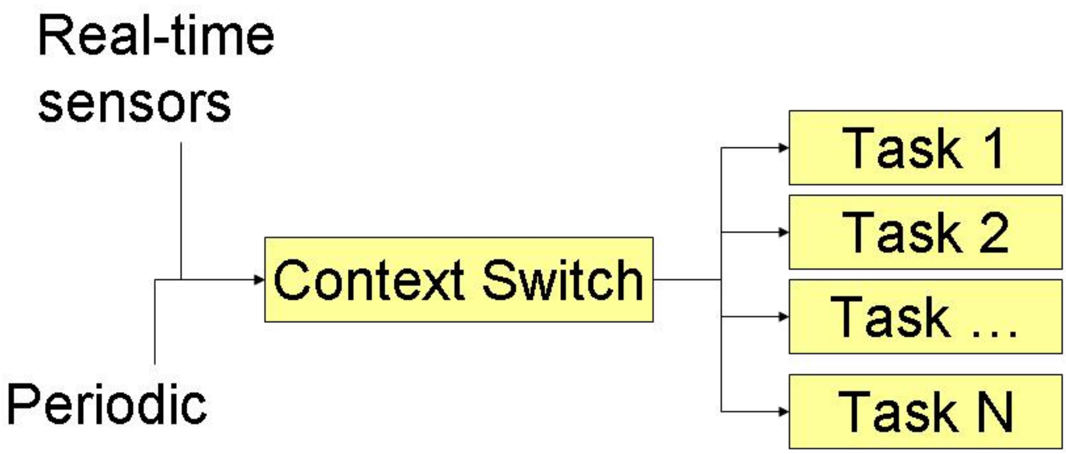

Figure 1 Digital Computer Multi-tasking Architecture

Interrupt processing

The interrupt signal may be generated periodically at fixed periods of time by a hardware signal, by a sensor in response to an event or even within the task when the program recognises the need to terminate the task.

Periodic interrupts

When a periodic interrupt is received the Context Switch responds in the following manner.

1. The state of the current task is saved.
2. The state of the next task in the sequence is retrieved.
3. The new task becomes the current task.
4. The next task is identified. If the current task is the last task, then the next task is the first task.

5. The current task is enabled to continue from where it left off in the previous task sequence cycle.

In most digital computer multi-tasking operating systems based on a periodic interrupt, the number of tasks can be large, and since the time allocated to each task is a fraction of the time available for all the tasks (including the time to save and restore the state of the task between task switches), the more tasks loaded into memory, the slower any one task seems to take[1].

Real-time interrupts

When a real time interrupt is received the Context Switch responds in a slightly different manner as follows.

1. The state of the current task is saved.
2. The state of the task associated with the specific real time interrupt is retrieved.
3. The new task becomes the current task.
4. The next task is identified. If the current task is the last task, then the next task is the first task.
5. The current task is enabled to continue from where it left off in the previous task sequence cycle.

Self-terminating tasks

When a task self terminates, the sequence of activities performed is the same as for a periodic interrupt.

Foreground and background tasks

One arrangement of tasks in a digital computer is to divide tasks between foreground and background tasks. Background tasks are those that are routine autonomic housekeeping activities such as those that monitor the state of the system, diagnostics, etc. Foreground tasks are the applications controlled by the operating system and depend on the context in which the system is deployed.

Parallel processing

The previous multi-tasking description is generally applicable to a single central processing element in a digital computer. An alternative architecture is to use more than one central processing element and split the tasks between them (using a third central processing element). Each central processing element can perform a single task or several tasks in a multi-tasking mode.

Holistic thinking via multi-tasking

Developing an understanding of a system, issue or problem requires an analysis of the parts of the system in the set of thoughts relating to the complete system, thinking about the system in its context and verifying that the relationships between the thoughts are valid; hence holistic thinking seems to be the way to develop an understanding of a system in accordance with (Hitchins, 1992) page 14).

Recognizing that the tight coupling between systems thinking and critical thinking has resulted in a number of [overlapping] definitions of systems thinking, critical thinking and critical systems thinking, holistic thinking (the system) is defined as sum of analysis, systems thinking and critical thinking (the subsystems) with the relationship between systems thinking and critical thinking shown in Figure 2 (Kasser, 2010).

[1] This is why reducing the number of open windows on a PC can seem to speed up the computer.

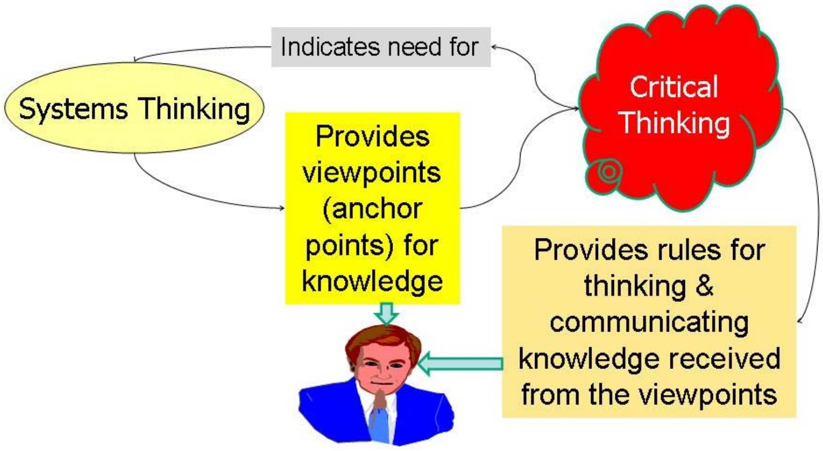

Figure 2 Holistic Thinking

Analysis

Analysis provides a white box approach for viewing a system from internal perspectives to develop an understanding of the functionality of the parts in a closed system configuration.

Systems thinking

Systems thinking is a discipline for seeing wholes (Senge, 1990), and indeed systems thinking is practiced much of the time by systems engineers but in an ad-hoc manner. The literature abounds with:

- publications advocating the use of systems thinking, e.g. (Flood and Jackson, 1991),
- philosophical and academic theories of systems thinking, e.g. (Flood and Jackson, 1991),
- the need to view problems from various perspectives, e.g. (Morgan, 1997).
- one or two publications describing how an understanding of the way things are connected together provides one with a competitive advantage over those who do not share the same understanding (Morgan, 1997; Luzatto, circa 1735),
- descriptions of the application of feedback loops (e.g. casual loops) and the claim that the use of such loops constitutes systems thinking (Senge, 1990), and
- similar descriptions of the application of systems dynamics and the claim that systems dynamics constitutes systems thinking.

Critical thinking

Critical thinking is “a unique kind of purposeful thinking in which the thinker systemically and habitually imposes criteria and intellectual standards upon the thinking, taking charge of the construction of thinking; [continually] guiding the construction of the thinking according to standards; [deliberately] assessing the effectiveness of the thinking according to the purpose, the criteria and the standards” (Paul and Willsen, 1995) page 21).

Application of holistic thinking

The holistic approach to the application of systems thinking was developed from a previous systematic and systemic approach to applying systems thinking (Richmond, 1993). Further research based on Richmond's work produced a set of nine viewpoints called System Thinking Perspectives (STP) (Kasser and Mackley, 2008) which have been used in teaching holistic systems thinking in postgraduate classes and workshops in Japan, Singapore, Taiwan and the UK. The systems thinking element of holistic thinking is a systemic and systematic way of viewing a system from each of the following nine viewpoints.

1. Big picture
2. Operational
3. Functional
4. Structural
5. Generic
6. Continuum
7. Temporal
8. Quantitative
9. Scientific

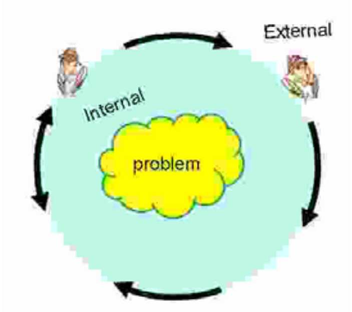

Figure 3 The perspectives perimeter

The first eight perspectives are descriptive, while the scientific perspective is prescriptive.

Systems engineers apply holistic thinking when using causal loops and concept maps to examine relationships and construct models. The descriptive (i.e. operational, functional and generic) perspectives provide parameters, critical thinking provides and verifies the relationships for the casual loops, the quantitative perspective provides the values for the model parameters and the model itself is a hypothesis (scientific perspective).

The perspectives perimeter

Consider the act of thinking about a problem. In general, the thinking process performs a sequence of tasks, each of which views the issue from a different perspective on the perimeter of the circle in the metaphoric representation depicted in Figure 3. Note however, that some minds seem[2]:

- To be fixed at one point on the perimeter and observe the issues from a single fixed perspective. This is akin to Wolcott and Gray's biased jumper (Wolcott and Gray, 2003).
- To only range over a limited part of the perimeter and view the issues from a limited number of perspectives.
- To range over the entire perimeter and view the issues from the set of perspectives but do not seem to do so in a systemic and systematic manner.
- To range over the entire perimeter and view the issues from the set of perspectives and seem to do so in a systemic and systematic manner.

[2] The continuum STP suggests that this might be situational for an individual for various reasons and the same mind in different situations may view problems in different ways according to the list.

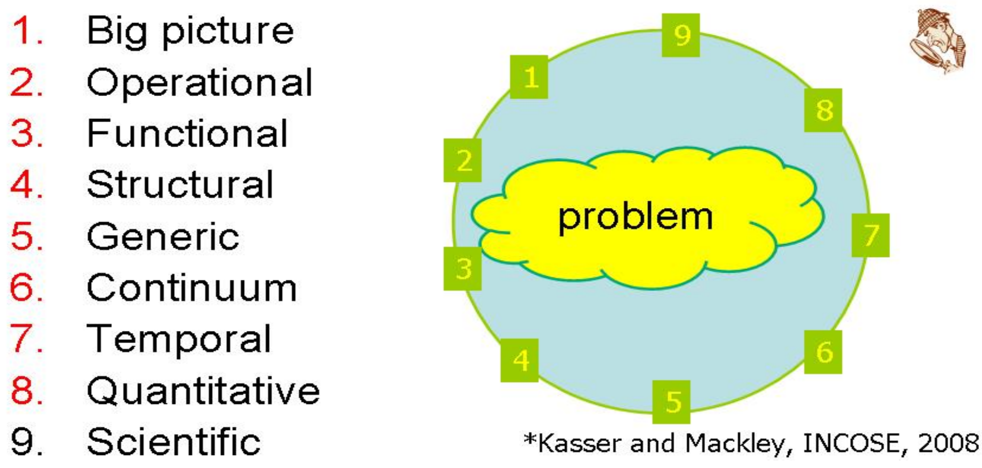

Figure 4 System Thinking Perspective Anchor Points

Since there are no standard stopping points along the perspectives perimeter, each time communications between two parties takes place time is spent ensuring that both parties to the communication are viewing the issue from the same perspective (stopping point on the perspectives perimeter). This situation can be observed by the use of phrases such as “are we on the same page?” and “are we on the same wavelength?” etc. A standard set of perspectives or “anchor points” are needed to facilitate communications. One such set of anchor points is the systems thinking perspectives described above and illustrated in Figure 4.

Holistic thinking as multi-tasking

We can only pay attention to one demanding task at a time (Anderson, 1995). In computer terms the human information processing system, while capable of multi-tasking, can only handle one foreground or conscious task at any particular time. In holistic thinking the mind moves round the perspectives perimeter viewing the system from each of the systems thinking perspectives one perspective at a time. The approach is holistic when considered over a period of time or a number of cycles around the perspectives perimeter. The switching between perspectives may be sequential or may be driven by association of ideas where an idea from one perspective triggers a switch to a different perspective out of sequence in the manner of a self-terminating task. One focused way of switching perspectives is active brainstorming (Kasser, 2009) which uses the (Kipling, 1912) questions (who, what, where, when, which, why and how) to trigger ideas in a proactive manner.

The time spent in each perspective will depend on the attention span. While the digital computer spends a fraction of a second in each task, the attention span of the human brain (time spent on a task) seems to vary. Sometimes tasks are completed before switching to the next task; these are cases where the person is focused on that task to the exclusion of others, and at other times switching takes place before a task is completed.

Multi-tasking in the brain

Multi-tasking covers autonomic and cognitive activities. Autonomic activities can be considered as the background tasks, while cognitive activities can be considered as foreground tasks. Cognitive activities include accessing, processing and storing information. The most widely used cognitive psychology information processing model of the brain based on the work of (Atkinson and Shiffrin, 1968) cited by (Lutz and Huitt, 2003) shown in Figure 5 likens the human mind to an information processing computer. Both ingest information, process it to change its form, store it, retrieve it, and generate responses to inputs (Woolfolk, 1998).. In the multi-tasking model, the inputs from the external sensors also feed the executive as interrupts. Internal sensors for pain also feed interrupts. Some people seem to be able to set the threshold of their pain sensors (to ignore the input) at higher levels than others. From the generic perspective, some people also seem to be able to focus on a single task and set the threshold of other interrupts at higher levels which allow them to ignore the sensor inputs up to a point. Some people can set the threshold so high that they do not respond to any external stimulus and may have to be physically shaken in order to attract their attention to a different task.

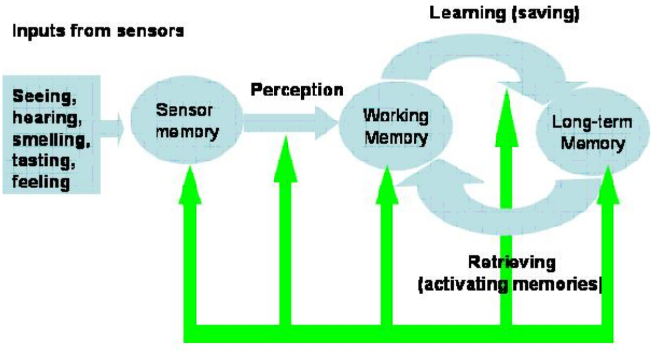

Figure 5 Human Information System

In a computer the number of tasks can be large as stated above. In the human brain, perhaps (Miller, 1956)'s rule of seven plus or minus one limits the number of anchor points on the perspectives perimeter that can be used during holistic thinking.

Observations

This section lists a number of observations to meet the secondary goal of the paper and to provide direction for future research.

- People who can multi-task may have short attention spans, and/or low thresholds on their interrupt circuits.
- Consider left brain and right brain activities as being performed by independent parallel processors. Each side of the brain can perform separate tasks but sometimes both sides of the brain process data from the same inputs. When the left brain and right brain and processes produce complimentary results they reinforce each other. However, when the processes produce contradictory results problems can be seen and might explain some of the observations in (Goleman, 1995).
- Interrupt circuit switching thresholds range along a continuum from low (boredom) to high (very interested).
- Faulty high interrupt thresholds may account for abnormal intellectual abilities which result in people being locked into one cognitive task to the exclusion of others.

Summary

The paper summarized the digital computer multi-tasking operating system and then discussed a conceptual theory for multi-tasking in the human brain based on adapting the digital computer multi-tasking operating system in a parallel processing environment. The paper concluded with some observations which can lead to further research

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