S.M.A.R.T.
Memory and Emotional Subsystems Review on an ATC Software

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Introduction

Human brain is capable of absorbing, encoding, processing, storing and retrieving information. The sensory system detects signals, processes data preattentively, seeks patterns, encodes content, stores relevant information, create meaningful connections between the new and prior knowledge, retrieves information when needed and learns to use it for future use through metacognitive abilities. Throughout this process where raw data is transformed into purposeful information, the outcome is stored in the brain as in a harddisk, while the information that needs to be easily and urgently accessible is stored as in a random access memory of a computer system, ready to operate immmediately. The former is referred to as the long term memory and the latter as the short term memory, also known as the working memory, as it may better emphasize the function of short term memory: an immense, continuous cognitive load in the system.

Working Memory

Evolved from the concept of a unitary short term memory system, working memory refers to a brain system that provides temporary storage and manipulaton of the information necessary for complex tasks such as learning and reasoning (Baddeley, 1992). Most of the names given to working memory over the course of decades of research such as primal memory, elementary memory, immediate memory, short-term memory or working memory have the similar conception; an approach that breaks down the memory system into sections that interact with each other.

In the traditional model of human memory, memory is divided into three structural components; the sensory register, the short-term store, and the long-term store. Incoming sensory information first enters the sensory register, where it resides for a very brief period of time, then decays and is lost (Atkinson & Shiffrin, 1968). Immediate free recall yields items directly retrieved from a temporary short-term memory and items retrieved by retrieval cues from a more durable storage in long-term memory (Ericsson & Kintsch, 1995).

The maximum number of items we transiently store in our working memory is a good predictor of our cognitive abilities (Edin, Fredrik et al, 2003). One of the landmarks of cognitive experimental studies in the world of working memory on this aspect was made by George Miller, where he shared his findings on how accurately people can assign numbers to the magnitudes of various aspects of a stimulus. By introducing the concept of these dual layers of memory, he referred to a grouping mechanism to memorize by chunking information in order to indicate that we have a limited capacity of around seven chunks. In his study, he stated that there is a span of absolute judgment that can distinguish about seven categories and that there is a span of attention that will encompass about six objects at a glance (Miller, 1956). Cowan later on shared his evidence on Miller's magical number on chunk capacity limit, stating that it is possible to combine no more than about four items per chunk and these chunks may form together to form a superchunk of no more than four chunks (Cowan. 2012).

In an attempt to describe a more accurate model of working memory, Baddeley and Hitch introduced another model (1974) as an alternative to Atkinson & Schiffrin's multistore memory model that consisted of a central executive system with two slave systems (a control engineering term), the phonological loop for processing verbal information and visuospatial sketchpad for processing visual information (Baddeley, 2012) to which Baddeley added a third system later on, called the episodic buffer which acts as a buffer for other subsystems of working memory; "a limited capacity system that provides temporary storage of information held in a multimodal code, which is capable of binding information from the subsidiary systems, and from long-term memory, into a unitary episodic representation" (Baddeley, 2000).

Another fundamental approach related to working memory in terms of capacity, defined as the maximum amount of activation available in working memory to support storage and processing (Just & Carpenter, 1992), and its inefficiency is explained in decay theory that deals with the origin of the nature of immediate memory span and why we forget when this span is exceeded. The theory states that when the span is exceeded, we forget because retention becomes dependent on a mechanism less efficient (Brown, 1958).

Working memory is the workbench where new information is coming in all the time through our senses. Metacognitive content such as calculations, confidence levels that need to be applied, emotional states such as anxiety and anger all happen within the working memory and create an enormous amount of cognitive load. This extra load in the central executive system make us prone to cognitive biases and causes us to make more bad decisions.

Apart from capacity and durability, there are also other factors that interfere with our primary tasks which cause volatility, corrupt our flow and disrupt our attention such as mindless engagement -as in daydreaming- or split attention causing factors - as in competing visual tasks and noise as a distraction (and in addition to cognitive load in working memory, another aspect to be taken into consideration is the diminished cognitive capacity such as in people with low literacy and the elderly, however, I will not go into detail due to the scope of the paper).

Emotional Subsystems

There are many emotions that affect the innerworkings of working memory in a positive and negative way. The two fundamental emotions to be considered into account are motivation and anxiety.

Anxiety, derived from the Latin word anxius (troubled mind) is a negative emotional state of agitation or depression with feelings of distress (Spielberger, 2013). Anxiety is assumed to "impair efficient functioning of the goal-directed attentional system and increases the extent to which processing is influenced by the stimulus-driven attentional system. In addition to decreasing attentional control, anxiety increases attention to threat-related stimuli." (Eysenck & Michael W et al, 2007). While a little dose of anxiety may assist in improving productivity by improving attentiveness and awareness of the person, too much of it is harmful to the psychological state and paralyzing as well. Working memory is negatively affected by anxiety reduces available central executive capacity as it involves "cognitive interference by preempting the processing and temporary storage capacity of working memory" (Eysenck & Michael W et al, 2007).

On the other hand, motivation is a positive emotional state that helps in minimizing the aversive effects created by the anxiety state, as anxiety is not an isolated state but an integral aspect of motivated cognition (Luu, Tucker & Derryberry, 1998). It is a process by which we consciously or unconsciously allocate our working memory resources; and motivation positively affects how we choose the memory chunks we have available to us we will activate, a notion that emerges as a synthesis from the research literatures of cognition, motivation, and connectionism (Brooks, D. W. & Shell, 2006).

Motivation may be examined under two distinguishing attitudes; intrinsic and extrinsic motivation. Intrinsic motivation relates to the internal motivation factors, and is an attitude derived from currently available external cues (Wood, 1982), while extrinsic motivation relates to the factors formed by outer factors. For example, for an Air Traffic Control specialist, an internal motivation factor would be to successfully communicate with Airplane A and making sure that plane is going to land safely; an extrinsic motivation would be to assist the other planes on air waiting their turn to contact with the ATC specialist.

"S.M.A.R.T." Design Review:

Air Traffic Control (ATC) is a demanding task with a heavy cognitive load on the working memory. It includes many pressures to the Air Traffic Control Operator (ATCO) during operation and the role of emotions such as anxiety and panic is critical in terms of completing tasks effectively in extreme timeframes. Systematical Modernization of Air Traffic Resources of Turkey (S.M.A.R.T.) is a software used in Antalya Airport in Antalya, Turkey and the design of the system will be reviewed through screenshots taken during real operations.

Fig. 1 Different colors help in prioritizing.

When an ATCO interacts with S.M.A.R.T. in Antalya, they see dozens of airplanes on the screen differentiated by colors; some of which resemble planes approaching, planes departing, planes about to land in a specified route that need full attention and planes moving away that needs less attention (Fig. 1). Sensory detection is active, preattentive processing is operating, the brain continues to compare new information with prior knowledge continuously and metacognitive capabilities such as learning is ongoing.

In ATC, one of the basic principles is that only one ATCO is responsible for communicating with an airplane at a given time, in order to avoid conflicts or confusion in commands between the pilot and the ATC operators. An ATCO is responsible for predetermined altitude levels; if a plane descends or ascends out of scope of an ATCO's predetermined altitude range, another ATCO in charge of that altitude takes over. This is a global practice worldwide. However, Antalya Airport ATC is an exception. In Antalya, ATCOs are not responsible for predetermined altitudes but for predetermined coordinates divided between operators as East or West. So, independent of a plane's altitude, what matters is the coordinates of an airplane at a given time.

Fig 2. In a sudden route change in one plane due to bad weather, two planes (AVR 421 and SHY 338) became dangerously close.

However, when weather conditions are problematic and a plane decides to maneuver to East or West in order to avoid a turbulence, things may easily get out of control. The plane contacts with the ATCO, gets confirmation and changes route. When that plane is out of range of ATCO 1, the color displayed in the system changes as well and ATCO 1 sees it as 'out of responsibility area' while ATCO 2 sees it on their screen as a new object 'within the responsibility area'. It causes an unanticipated cognitive load in ATCO 2; on the other hand, ATCO 1 feels anxious as well, as it is not a screen to be mindlessly engaged for both operators so ATCO 1 feels the need to warn ATCO 2, mostly verbally, shouting in the same room. On the other hand, the software sends no warning signals to ATCO 2 about this new update, not until the two planes seem to be on top of each other as if about to collide (Fig. 2), luckily the altitudes are still different. However a sudden change in altitudes in planes may turn into a catastrophic threat within seconds, so the ATCO 2 inform the pilots to adjust their altitudes until both planes have a safe distance in between. Actually there are supplemental systems that will help in avoiding a collision when two planes are too close, but still, the lack of interaction between S.M.A.R.T. and the operators during this shift creates an extreme load in working memory and causes enormous anxiety during altitude changes in a matter of seconds, especially in novice ATCOs.

Fig 3. A mislabeling issue in the system causes high emotional pressure.

When a plane takes off on a predesignated level, S.M.A.R.T.'s radar system may rarely mislabel that plane's abbreviated name in the system with another departing plane's abbreviated name that is also about to depart in a close distance. If the ATCO is not highly attentive about checking the details of both planes to make sure that they are labeled correctly and if both planes are not following the same route, a normal departure process turns into chaos very quickly (Fig. 3). A plane about to turn east on the way to Russia is mislabeled as another plane about to turn west on the destination to Istanbul, due to the fault in the design.As soon as both planes depart, the one on the left (destination Moscow) will be turning right while the one on the right (destination Istanbul) will be turning left; forming a DNA-spiral-like maneuver on the air and the planes will cause severe threat to each other. Even an experienced ATCO with a higher depth of learning may overlook if not paying full attention at the moment, suffering from fatigue, or just daydreaming; which as a result will cause a situation that will create a lot of anxiety. Moreover, apart from visual warnings on the screen, the system adds alarm sounds as well, which adds more to the pressure, causing a highly increased state of stress.

Another negative aspect of the design is the terminology used within the S.M.A.R.T. system. Although the software is used only within Turkish ATC operators, the abbreviations used within the system are in English. There are many global abbreviations in aviation terminology, however some commands used in this software has no relation with global terminology yet still used in English, such as TOC (Fig 1.) for Transfer of Control. The good news is that in the updated version of the software, only Turkish abbreviations will be used.

One last issue to be taken into account relates to how the minimum safe distance between planes, determined by the size of the vortex behind them, are displayed in the design. Taking into account the vortex that a leading plane leaves in its wake, the distance between the tail of one plane and the nose of the next plane is of high importance. “Because the speed of a plane is very high, the pressure around the wings is low. The change in results in a force pushing the planes together; the force may alter the plane’s flight pattern” (Doshi. Lessem & Mooney, 2000) and a miscalculation may cause highly severe consequences. Due to the fact that domestic planes generally need a 5-mile distance and heavy planes such as an Airbus, require a minimum of 8 miles, it is in the ATC operators’ best interest to make sure the heavy planes are easily visible on the screen, especially in Antalya Airport where the airline traffic is so dense that keeping the distances in minimum is always a matter of efficiency, as any delay creates a domino effect for all the planes. However, the system does not offer the ATC operators a chance to see the heavy planes on the screen easily. In order to adjust the distance settings accordingly, an ATCO has to browse through the detailed infos of each plane which may be skipped easily as the working memory is already operating at full capacity. So, as a recommendation in design, a “blinking H” sign which addresses the heavy planes with a letter would simply help in resolving this issue by minimizing the risks created by the vortex and reducing the anxiety level of the ATC operators concurrently.

Conclusion:

S.M.A.R.T. is an important software system with a vital purpose: hundreds of people’s lives depend on it every minute. Yet, there are some design issues that need to be resolved no matter what, as although the system seems to work accurately most of the time, it’s not a system where satisficing works. Good enough simply won’t cut it as there’s zero tolerance for error in ATC. Thus, any issue resolved in the system will help the ATC operators work more efficiently by reducing their cognitive overload and minimize negative emotions that arise during operation and as a result, decrease anxiety. This software shows that a system may be designed to suit well to the needs of a user, however the importance of working memory and its susceptibility should also be considered at all times in order to create a safer environment for interaction. To sum up, as a designer, we have to strive to make the design more emotionally aware so that the overall interaction between the user and the system is working in harmony and the user is motivated to focus on their main goals throughout the entire experience.

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