Prior Knowledge

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Introduction

Helmholtz's **likelihood principle** states that higher cognitive information is required to make quick sense of the limitless, often ambiguous sensory experiences and information that we receive from our environment (Helmholtz & Fripp, 1876). We actively construct our perception of reality based on past experiences and prior knowledge stored in our memory (Gregory, 1970). For example, understanding difficult handwriting is easier when reading a complete sentence, compared to reading individual, isolated words. The **modal model** of memory proposes three hypothetical memory stores - sensory memory, short-term memory (STM), and long-term memory (LTM) - and that information is transferred between these stores in a linear manner (Atkinson & Shiffrin, 1968). Information detected by the sense organs enters the sensory memory, which stores a fleeting impression of sensory stimuli. If attended to, this information enters the STM and if the information is given meaning by the process of **elaborative rehearsal** (Craik & Lockhart, 1972), it is passed on to the LTM, which has **nearly infinite capacity** and unlimited duration of storage (McLeod, 2017). Physiologically, LTM is stored in different regions throughout the brain and other parts of the nervous system; when neurotransmitters are activated in the brain, a process called *chemotaxis* (Drews, 2005) communicates the message to every part of the body, even muscles, via blood and cerebrospinal fluid. People who have undergone organ transplants have reported emotional reactions and feelings about certain events that they have never experienced before (Goldstein, 2015). If the memory is consciously evoked, it is part of the **explicit** or **declarative memory**. On the other hand, if the memory is related to a procedure or the process of movement of the body (like driving, swimming, writing, etc), it is **implicit memory**. The constructive process of perceiving reality relies on working downward from initial impressions to particular details while retrieving the prior, stored knowledge from LTM – which is highly organized, intricately interconnected, and constantly evolving. This is known as **top-down processing** (Gregory, 1970). Our brain applies what it already knows and is stored, to fill in blanks and anticipate what's next. Prior knowledge enhances the process of acquiring and retaining new conceptual information with the passage of time (Chen et al., 2018). This paper will focus on the theories and models that deal with storage, access, and retrieval of prior knowledge from LTM that allows top-down processing of memory.

Highly Organized

Many theories propose that knowledge is represented in a highly organized network in the LTM, some of which have been discussed below.

Schema Theory

Schema theory states that knowledge is structured in LTM in the form of **schemas** (or schemata), which are abstract, organized, dynamic units of knowledge for a subject or event, accessed to guide current understanding or action (Jean Piaget, 1936). Schemas are hierarchically categorized and intricately interconnected units, becoming more specialized over time- which supports the notion of neuroplasticity (Berlucchi, 2002). Bartlett in 'Remembering' was the first psychologist to write about schemas as an "active organization of past reactions or experiences". His experiments showed that very little of an event is perceived when it actually occurs. It is while we reconstruct that memory that gaps in observation or perception are filled in, with the aid of previous experiences coloured by cultural attitudes and personal habits. This provides expectations and frameworks for action (Bartlett & Kintsch, 1932). On a similar strain, Minsky spoke of **frames** or **framed networks** (Minsky, 1974), which has a major impact on work in artificial intelligence. When entering any room, we retrieve a typical room with its quintessential walls at right angles, a ceiling, and a floor from memory. Some aspects of the frame are fixed, but others contain **terminals**, which are slots that must be filled in by specific instances of data. (Thagard, 1984). This data is sometimes developed over generations; new concepts or schema are developed by altering and combining earlier ideas (Almy & Genishi, 1979). Any organism's behavior is impacted by its biological drive to obtain balance between its schema and the environment (equilibration). Piaget's **process of cognitive development** states that when we are exposed to new information which cannot be easily integrated, it causes cognitive dissonance. The manner and speed with which we organize and alter our existing schema to accommodate the new information determines our 'intelligence' (Jean Piaget, 1936).

In the 1960s and 1970s, most schema research was based on learning procedures because of the key role its organized structure played in comprehension and memory. The **interactive reading model** (Rumelhart, 1975) described an underlying grammar used by the brain to not only process and interpret new stories, but also retain new information. Anderson's **Adaptive Control of Thought-Rational (ACT-R)** formulated a model of cognition which defined the process of **encoding** and using schemas, particularly in mathematics and problem solving (J. R. Anderson, 1983a). Studies showed that people are more likely to remember salient information that was consistent with their schema expectations because of the **congruency subsequent memory effect** (G. Bower, 1972) though false memories also tend to increase as proved by Brewer and Treyens' office experiment (Brewer & Treyens, 1981). Alba and Hasher suggested four encoding processes by which schema might affect memory, starting with **selection** by which attention is focused only towards relevant information for encoding. The second process is **abstraction** that allows meanings of certain stimuli to be stored without syntactic and lexical details. Thirdly, schema allows **interpretation** or understanding of new information by providing the relevant prior knowledge. Lastly, schema provides **integration** that forms "a single, holistic memory representation" from the products of the previous three processes (Alba & Hasher, 1983).

Mental models vs. Concept Maps

Schema theory assumes that every act of comprehension is dependent on one's knowledge of the world (R. C. Anderson et al., 1977) and this knowledge is based on the mental model of the individual. Kenneth Craik postulated the term 'mental model' in his book 'The Nature of Explanation' (N. & Craik, 1943), to denote impermanent **internal representations** of external reality. These models help predict and explain interactions with environment and technology (Norman, 1983). Formation of mental models is influenced by our views, attitudes, and beliefs regarding the world around us, our perception of ourselves, our prior knowledge and capabilities, the tasks we undertake, the problems we deal with, and the strategies we adopt (Norman, 1983). Mental models are incomplete and constantly evolving, may contain errors, misconceptions, and contradictions, and may deliver simplified clarifications of complex phenomena. However, despite the uncertainty about their validity, these mental models are utilized (Johnson-Laird, 1983). These models are situation-dependent and essential for problem-solving, and can be idealized via **concept maps** (Seel, 2003), which are **external representations**. Their output is **concept mapping**, which is used to visualize the relationship between various concepts (Shute & Zapata-Rivera, 2008) in a framework, and "can be created or used by a single person or by small groups" (Weinberger & Mandl, 2003). Aligned to the popular view in cognitive psychology that the mind is structured much like a language, concept maps are used to organize and represent knowledge in units of 'concepts' and 'propositions', which are the building blocks for knowledge in any domain (Ausubel, 1968). Propositions are the most basic units of meaning about two or more concept(s) connected using **linking words or phrases** to form a meaningful statement (that may be true or false) or a **propositional network** (J. R. Anderson, 2010). For example, in the proposition – 'Birds *have* hollow bones'- 'Birds' and 'hollow bones' are concepts and 'have' is the linking word expressing a static relationship between the two concepts in this specific context. Dynamic relationships, on the other hand, describe how the change in one concept affects the other concept, and lead to dynamic propositions, for example ‘Increase in smog *may cause* road accidents.’ Including dynamic propositions result in richer concept maps because they facilitate the skill of searching for patterns and relationships among concepts (J. R. Anderson, 2010).

Scripts and Categorization

Like Rumelhart’s proposition of underlying grammar to understand new stories, Schank and Abelson proposed that all humans developed ‘scripts’ for all the typical events that occur in our lives (Schank & Abelson, 1977). Scripts are highly organized, contain sequential information, and sometimes share stereotypical attributes, for example, events like waiting in line at a restaurant and waiting in line at the post office have shared features (Schank, 1982). This allows individuals to make inferences due to the human cognitive capability of recognizing and categorizing shared features or perceptually distinctive experiential elements of the same class and treating them equivalently (Berlin, 1978) (Murphy & Medin, 1985) (Rosch, 1988). We can draw inferences efficiently based on what kind of category we assign an experience or object to. Research on categorization has focused both on how we form these categories, how we use them to encode and remember our experiences, and how this knowledge is represented. (J. R. Anderson, 2010)

Intricately Interconnected

The long-term memory’s nearly infinite storage capacity requires the knowledge within it to be not only highly organized, but also intricately interconnected so that it can be quickly retrieved or recalled. Information about the categories that we form (as discussed above) are structured and represented in **semantic networks** (Quillan, 1963). These hierarchical networks connect **nodes** of knowledge, both propositional and conceptual, that help us create a more robust understanding and assist deeper, semantic level of processing (Moss et al., 1995). Features shared by each category are associated with that category and features that are true of higher-level categories are also true of lower-level categories (Collins & Quillian, 1969). ACT-R theory (J. R. Anderson et al., 2004), referred to earlier, states that we acquire all our intricate skills due to an innate, neurological, information-processing system that sets humans apart from other creatures. According to this theory, the strength of the nodes of knowledge in our semantic network increases with practice and decays with delay. **Retrieval**, which is considered the key function of memory, is performed by **spreading activation** throughout the semantic network. The level of activation in the network determines the rate and probability of recall – this is the reason we see different levels of responses triggered since this differs individually. Knowledge required to answer questions like “Is a penguin a bird?” is retrieved from semantic networks by activating the two nodes and allowing the activations to spread between them until they meet (Wagemans, 2005). Recognition times or error rate for a particular concept increases as more information or associations about the concept is acquired in the network – this is known as the **fan effect**. This is dependent on the strength and degree to which one of the nodes can connect to the other and the importance of the concept to a person during the retrieval process. Some activations tend to occur more rapidly as a result of **automatic processing**, due to learning, practice, and repetition, which allows us to feel comfortable and familiar with different environments and act without recalling entire procedures. (J. R. Anderson, 1983b)

Any successful act of retrieval requires that sensory information is first selected to be encoded and **elaborately rehearsed** (Craik & Lockhart, 1972), stored in an organized, interconnected manner, and then accessed when required (Melton, 1963). Studies show that if all three stages did not take place, two types of errors may occur: Forgetting and misremembering (false recall, false recognition, or misrecall) (Deese, 1959) (Roediger & McDermott, 1995). We remember events that are **distinctive** (Reed Hunt, 2003) and sometimes, the distinctiveness and strong emotional nature of an event makes it remarkably memorable- the recall and activation of which can be very intense and is termed as **flashbulb memory** (Brown & Kulik, 1977). The “amygdala, in combination with the hippocampus and prefrontal cortex, plays an important role in the retrieval of memories for emotional events” (Buchanan, 2007). Creating vivid images (in our imagination) out of information, even verbal information, it can greatly improve later recall, since this helps activate more connections in our semantic network (G. H. Bower & Reitman, 1972).

Constantly Evolving

Studies show that our neural activity continually reconfigures or ‘drifts’ during repeated trials of learning tasks (Rule et al., 2020). Our long-term memory is constantly evolving as we keep acquiring new experiences, skills, and information from a constantly changing environment. Two processes are used by an individual in its attempt to adapt to the environment in an increasingly complex manner (Jean Piaget, 1936). According to Piaget, when we encounter a new idea, we attempt to equilibrate by either ‘fitting’ it into our existing schema, i.e., **assimilation**, or reshaping our existing schema, i.e., **accommodation**. For example, when a child learns the word for ‘dog’, they start calling all four-legged animals dogs (assimilation). When explained that it is actually a different animal, the schema for dog gets modified to restrict it to only particular four-legged animal. The schema for dog then gets modified to restrict it to only certain four-legged animals (accommodation). Equilibration assists and demonstrates how children must move from one stage of thinking into the next stage as part of their cognitive development (Jean Piaget, 1936). On a similar strain, Norman made distinctions between three modes of learning using the example of learning morse code, **accretion** being the initial learning of the code, **restructuring** referred to recognizing sequences or full words (occurs much less frequently and requires considerable effort), and the gradual increase in translation or transmission speed indicated the process of **tuning** which is the slowest form of learning and accounts for expert performance (Norman, 1982). This model later evolved to include analogical processes, which meant creating a new schema by modelling it on an existing schema, and then modifying it based on further experiences (Rumelhart & Norman, 1976).

Case Study

Elements of Toll Plaza design

Electronic toll plazas and expressways offer a high level of service and see a lot of traffic worldwide. Research has been conducted on traditional, hybrid, and electronic toll plaza designs to evaluate their impact on traffic safety (Abuzwidah & Abdel-Aty, 2018). Results show that familiar drivers had better driving performance in terms of changing lanes and collision involvements compared to unfamiliar drivers (Valdés et al., 2017). In this paper, I will focus on reviewing a few elements of toll plaza design and their intuitiveness in terms of prior knowledge.

Gate barriers (see **Fig 1**): A gate barrier carries a pole which is attached to one static endpoint and is often seen at parking facilities, checkpoints, and toll stations. They are generally used to allow or block vehicles. Magnetic barriers have loop detectors which can sense when a

Fig 1: MHTM Drive (source https://www.magnetic-access.com/en-US/products/barriers/toll/toll.html)

motor vehicle is present and can detect codes, tickets, cards, etc. to permit or block access. To permit access, the pole is lifted till the eligible car passes through, after which it returns to its original position. An experienced user, here, the person driving the car and heading towards the barrier is likely to recognize it from prior knowledge. Barriers usually resemble our schema of a pole, situated at a height which is likely to cause damage to cars if they collide with it. They also anticipate that the lifted pole would rapidly block the way when the vehicle is sensed. If it was designed in a visually different way, say, a kiosk, it is likely to cause confusion and would require users to dedicate attention and resources to figure out how it functions as they would have no recall reference in their semantic network. Automatic processing alert us to the danger of collision if we do not reduce the speed of our car. We rapidly alter and combine our frames of space, speed, and distance to adapt to the environment and adjust our speed to allow the barrier time to lift.

We ensure not to stop very quickly as that may not give enough time to the car behind us to slow down, therefore causing a collision. We automatically, therefore, tend to slow down when we near magnetic drive barriers, learning from prior experiences. To enhance and assist that prior knowledge, we often see ***rumble strips*** (see **Fig 2)** near toll stations to alert the driver of an upcoming intersection.

Fig 2: Rumble strip (source https://en.wikipedia.org/wiki/Rumble_strip#/media/File:North_Luzon_Expressway_Rumble_Strips.jpg)

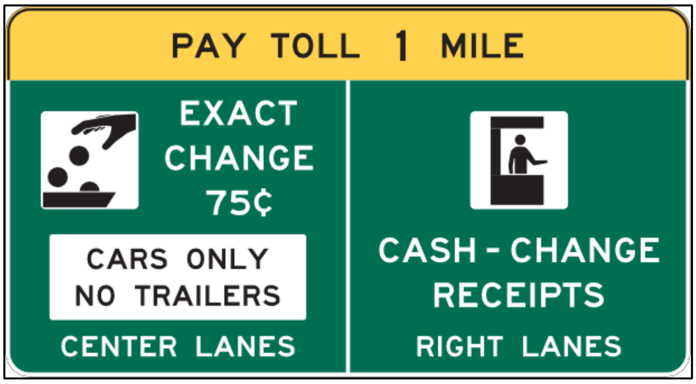

Fig 3: Toll plaza signage (source: https://worksafetci.com/signs/toll-plaza-signs/)

Toll plaza signage **(see Fig 3)** has a lot of impact on driver behavior. Advance placards are placed to inform users of the presence of the tolling facility which activates various concepts in their semantic networks, for example, the need to slow down, to prepare for payment (electronic or otherwise), to prepare for likely traffic ahead. In Fig 3, we see two vector images used which does not ideally serve great purpose in directing drivers. Arrows next to, or below the lane marking would help enhance directional knowledge. There is also cognitive overload in the left pane and the difference of color patterns (white on green background, black on white background, black on yellow background) don’t allow us to form categories easily. Removing the images and retaining a consistent format for the two information points would help users easily accommodate the information.

Conclusion

Long-term memory is easily recalled due to its organized and interconnected nature. Our conscious mind may not be aware of the information stored in its nearly infinite capacity, but this information can be recalled and activated with ease and accuracy, including recollections of events in the distant past which may even help in processing new events. Certain things easily become part of the ever-evolving long-term memory, while others may need continuous practice to be stored for a long time. It also varies from person to person. Long-term memory problems may affect how information is recalled. They may cause an individual to be confused or disoriented when presented with a set of instructions or steps in learning a new material. They may also have difficulty completing simple tasks that require more than two steps, or encounter difficulty computing math or problem-solving. Confusion may arise regarding the order in which syllables are used in a word or phrase, which inhibits an individual's ability of organizing ideas, finding the appropriate word, or communicating their thoughts in a clear manner. This difficulty may affect speech as well as writing skills.

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