In 500 Feet, Turn Right Onto Memory Lane

How Our Brains Create Maps of Our Memories

By Sofia Alonso
We as humans have an incredibly refined understanding of the physical world. Remembering in detail specific landmarks and spaces in our everyday lives comes with very little effort. Evolutionarily speaking, this innate ability was crucial in ensuring our survival during a time where maps had yet to make their debut. It isn’t surprising that our strongest memories are significantly linked to the spatial information associated with its consolidation. Giving physical context to our memories can help to lock them in and improve our ability to retrieve those memories when necessary.

An ancient form of this technique is used by the well-known fictional detective Sherlock Holmes in the form of a “memory palace,” also known as the method of loci. According to myth, the invention of this technique is said to have come from the Greek poet Simonides of Ceos who invented it after attending a banquet that ended terribly. Simonides is said to have stepped outside during this banquet. Upon arriving outside, the banquet hall collapsed in his absence. Simonides was able to identify his fellow banqueters, despite their bodies being crushed and disfigured. He did so by putting a name to each body in relation to where they had been sitting before the hall collapsed. The technique was further adopted by the Greeks and Romans, such as the orator Cicero. During a time where writing was an expensive luxury few had, he would utilize a memory palace to help memorize his speeches (1).

This memory strategy is a mnemonic device that helps to memorize information by positioning a visual cue or item at a specific point along an imaginary journey of your choice. Typically, this journey must be at a familiar location with a well-known route. This could be your house, high school, or a familiar stretch of road whose layout you know how to navigate like the back of your hand. To satisfy the conditions of a memory palace, you would have to create a mental journey through your chosen geographical entity composed of numerous discrete loci. If you are imagining your home, these loci could be your bedroom, staircase, kitchen, backyard, and many other locations specific to your house. To then embed information into your memory palace for later recall, one is advised to travel through the mental journey and commit imagery of the information you would like to memorize to any locus of your choice. When the time comes that you wish to retrieve the information, all you must do is walk through your memory palace and come upon the loci associated with each piece of information, activating it into your memory. Let’s try it out! Here’s
Let’s Go Back in Time!

Henry Molaison, also known as Patient H.M., was a 27-year-old epileptic patient in 1953 when he experienced severe memory impairment following an experimental brain procedure. Surgeons removed a thumb-sized piece of tissue from each side of Molaison’s hippocampal formation and surrounding medial temporal lobe areas of his brain in hopes that it would help relieve the severe seizures he had been suffering for 10 years. Although the seizures subsided following the surgery, Molaison experienced severe memory loss and was not able to form new memories, leaving him with permanent amnesia. This tragic event for Molaison became a significant turning point for the field of neuroscience, letting us know that each cortical region of the brain may be associated with a specific mental function such as learning or memory. Memory was now considered separate from other cognitive functions of the brain and was specifically attributed to the medial temporal lobe, which includes the hippocampus, amygdala, and parahippocampal regions. Research inspired by Patient H.M. focused on replicating similar memory impairments in laboratory animals which led the animals to display memory deficits as well. It was also established that the hippocampus played an important role in declarative memories — memories of facts and events that can be consciously recalled or “declared” in humans (2). Researchers were still left wondering what underlying neuronal mechanisms are involved in storing information as memories.

The term cognitive map — a mental image that provides the layout, or map, of a space — came about when American psychologist Edward Tolman tested the concept of latent learning. At the time it was widely accepted in the field of behaviorism that learning only took place when the individual was conditioned to a specific stimulus or reinforcement. Tolman tested three groups of food-deprived rats and observed their ability to transverse a maze all the way to its end. One group had food rewards at the end of the maze, the second group had none, and the third group had no food for the first ten days, but on the 11th day, food was placed at the maze’s exit. Interestingly, after the 11th day when rats in the third group found the food at the end of the maze, subsequent maze trials immediately showed that the same rats were able to quickly and efficiently find their way out of the maze, similar to the rats who were always fed. Tolman’s experiment showed that the rats developed a cognitive map and learned the layout of the maze despite the lack of any reinforcement, disproving accepted theories of learning at the time (3).

Palace Cells

Some things remained unclear following Tolman’s discovery. O'Keefe and Lynn Nadel tested and proved their belief that a population of neurons exists in the hippocampus that holds the ability to encode the position of the mammal within its spatial environment. These neurons were given the name place cells. Recordings of these place cells in the hippocampus of rats showed that when
the rats would enter a particular location in their environment (cage) place cells specifically associated with that location would fire (4). If we take for example yourself navigating through your kitchen, some place cells will become activated as you hover your hand over your collection of holiday-themed mugs trying to find your favorite mug. Other place cells will fire as you try to navigate your kitchen through the dark attempting to find the refrigerator door handle. Place cells are responsible for our sense of place. Once you have explored your environment and place cells have anchored themselves to particular places, they accumulate and create a mental map of the space. These cells are subject to change, remapping to different landmarks as the location of the subject changes and so does the environment (4). When you walk from your kitchen upstairs to your room, it may be that the place cells that were once firing when you approached your kitchen cabinets are now firing when you come upon your bed.

They discovered that the hippocampus not only has an important role in declarative memory but is also primarily involved in spatial interpretation and navigation. Given that both memory and space appeared to function within the same brain region, researchers were challenged to account for both and better understand how they work together. A linkage between space and memory became apparent in some early studies of place cells where they were able to express past experiences in mice. It was discovered that place cells are not just markers of an animal’s instantaneous location, but they also represent locations in the environment that the animal experiences in the past, present, and future. Mice placed through maze tasks showed place cells that fired when the animals went the wrong direction, or when they made errors trying to navigate out of the arena, showing that these neurons have stored information of these spaces into memory (5). In a separate study, similar place-cell activity in rats persisted through multiple “morphed” environments, exhibiting the brain’s ability to reactivate previous representations of the external world that seem to be retrieved from memories (6).

**Grid Cells**

Given the flexible nature of place cells, researchers were not sure whether they were entirely responsible for the spatial blueprint we use to fabricate how we perceive and experience our surroundings. These uncertainties eventually led to the discovery of grid cells by the wife and husband duo, scientists May-Britt Moser and Edvard Moser, and their students at the Norwegian University of Science and Technology. These types of neurons are located in the entorhinal cortex — the hippocampus’ very talkative, next-door neighbor. The entorhinal cortex is a flood gate for information leaving and entering the hippocampus. Grid cells are specialized cells of the brain that, unlike place cells, do not represent specific locations, rather they internally create a coordinate system that allows us to...
navigate our external world. They do not require sensory information from the environment, such as sounds, textures, and visuals, to form this spatial framework. Each grid cell will fire at various locations that are at a consistent distance from each other, forming a grid-like hexagonal pattern across the space (8). An easy way to picture this is if you position yourself in a small room and imagine the floor is made up of large, hexagon-shaped tiles. Now imagine dividing each one of those hexagons into six equilateral triangles and assigning a specific color to each. A unique grid cell will fire every time you step on a certain colored triangle. Let’s say you move to the corner of the room and step on a red tile, grid cell #1 will fire. Then you move to another red triangle at the other corner of the room and grid cell #1 fires again. Finally, you move to a green triangle in the middle of the room and grid cell #2 fires up. These grids can overlap and can have various orientations or different hexagonal sizes. When you take them all into consideration, they all add up in a way that maps out the exact spatial structure of our world. Specific locations in your home, whether that be the corner of your hallway that you must turn to enter your room or that one creaky step in your staircase, are represented by a special sequence of grid cells. Your brain will understand where your body is positioned in relation to space when multiple grid cells that overlap at a specific location are firing at once, almost like when your GPS tells you your exact location relative to a map. Together place cells and grid cells work somewhat like Google Maps. Place cells establish the presence of landmarks and important locations in your cognitive map. Grid cells are responsible for the coordinate system, fragmenting your environment into latitudinal and longitudinal points that track direction and distance.

It is believed that the grid code which underlies how grid cells communicate structural information of space to your brain, could also be responsible for representing other types of information. There is reason to speculate that grid cells can also represent the structure of conceptual knowledge and abstract thought. Mapping not only our physical world but our internal world as well. It has been hypothesized that we humans can process conceptual information in the same manner that we approach navigating space. It was speculated that the hexagonally symmetric grid-code produced by grid cells during spatial navigation may also be activated during the storage of conceptual knowledge. Timothy Behrens and his team of researchers at the University of Oxford tested this hypothesis by having human subjects navigate two-dimensional knowledge. Subjects were instructed to watch a video where the black outline of a bird continuously morphed as the leg and neck lengths were shortened and elongated. They found in their data the presence of a hexagonal grid code that changed and varied as if the subjects were navigating their way through a “two-dimensional conceptual bird space”
— the two dimensions being the bird’s neck length and leg length. Their results suggest that this code is used in both the navigation of physical space as well as non-spatial conceptual information (9). As of recently, many neuroscientists have sought to propose the idea that the hippocampal-entorhinal region provides a universal geometric code that maps out all types of knowledge — experiences, memories, and ideas — within cognitive spaces in the brain.

**Memories Are Not Forever**

Most memories are not permanent as you may have come to realize yourself. Many of the things we have learned or studied in school do not stick with us forever. Although we have spent a significant amount of effort attempting to store this information long-term, it is impossible to remember everything we have experienced. According to Ebbinghaus’s forgetting curve, most of our memories of learned knowledge will tend to fade over time, unless this knowledge is attended to with repetitive review across a long period of time (10). Despite the effort it might take to store most information into long-term memory, some meaningful memories can be permanently retained. Considering this observation, Kentros and his colleagues investigated the long-term stability of place cell firing fields when paired with attentional demands to specific spatial cues. Mice were trained in a cylindrical arena to locate a goal location while their hippocampal place cells were being recorded. Other mice were allowed to freely roam through the arena with no specific goal location or task to complete. They found that place cell stability, which is when the same place cell can maintain a consistent firing field across multiple exposures to the same environment, is strongest when the mouse was encouraged to pay attention to spatial cues to complete the task at hand. Essentially pointing to the notion that when spatial cues are attributed to memories, whether that be facts or experiences, the retention of the information is strongest and most consistent (11).

Therefore, you may have noticed that most of your episodic memories are the easiest to recall. Episodic memories are those of autobiographical events that we have experienced. These types of memories allow us to “re-experience” the events as if we were actors in a mini movie playing in our heads. They can be engraved in our minds as they are strongly characterized by multiple cues such as location, time, and sensations. Take, for example, a significant event in your life whether that be the death of a loved one or the day you won a grand prize from a contest you decided to randomly enter. If you try to re-experience this moment it would probably not be difficult to see all the details that made up your environment the day you received the news.

The strong association between memory and spatial cues can be attributed to place-cell activity in the hippocampus. The possibility that spatial characteristics of our episodic memories are encoded by our place cells was tested on patients awaiting surgery for their epilepsy. The subjects had electrodes placed in their medial temporal lobes while they were asked to navigate a virtual town and deliver items to one of

![Figure 3. Grid cells will record and track the mouse’s location through an overlapping hexagonal coordinate system. Left image: Singular grid cells firing at locations A, B, and C as the mouse moves through its environment. Right image: Multiple, overlapping grid cells firing along the red dotted path depicting mouse’s movement. Image created with Biorender.com by Sofia Alonso.](image-url)
the stores. The recordings showed that place cells, once active at the locations where each item was delivered, were also activated when the subjects were asked to recall each item. The findings suggest that when attempting to recall an event, place cell activity during this recall will bring into consciousness the spatial context that the event or item took place in (12). Similar to how a memory palace associates imaginary spatial cues that give spatial context with objects or facts. Time is also a crucial element of information regarding experiences and events in our lives that are stored as episodic memory. A study led by Kraus and a team of researchers discovered that grid cell activity in rats running on a treadmill was able to track not only spatial features but temporal features as well. Their findings supported the notion that a common circuitry is present between the computation of spatial mappings in our brain as well as the temporal organization of episodic memories (15).

Now What?

How can we utilize the grid code and use it to answer some of the problems and questions that come up in our everyday lives? Researchers are looking into how the grid code can be applied to social relationships and hierarchies. There is a spatial component to our perception of the social world around us. When we consider social status and hierarchies, sometimes we group certain individuals as having a “higher” or “lower” social standing. A study conducted in 2015 observed the social brain by tracking its hippocampal activity in response to changes in social relationships. The participants were asked to play a computer game where they navigated a virtual world in which they interacted with cartoon characters and worked to increase their social status by finding a new home and job. They were able to find that the hippocampus of the participants navigated the social space of the game in two dimensions, that being affiliation and power (14). Researchers are hoping to utilize the concept of encoding social information into a social cognitive map to examine social deficits present in clinical disorders like autism spectrum disorder (15). Additionally, studying place and grid cells in these new contexts has propelled researchers to study their connection to diseases associated with age. A paper published by Stangl and his colleagues looked into the progressive loss of navigational abilities that come about with old age. They hypothesized that since the entorhinal cortex is predisposed to neurodegeneration during aging and Alzheimer’s disease, grid cell functioning should be significantly reduced in these individuals causing navigational decline. They were able to find exactly that. The older subjects were less successful in keeping track of their position when attempting to navigate a course with curved paths while their vision was impaired. The researchers believe that taking into consideration grid code stability could be a potential early measure.
for Alzheimer’s and other neurodegenerative disorders. Since the spatial grid code system also provides a neuronal basis for non-spatial domains such as conceptual knowledge and memories, broadening our understanding of how this system may be destabilized in the brain could help us to comprehend how our memories and other cognitive domains are affected with time (16).

Coding the Future

Researchers within this specialized field are just beginning to expand on the concept of place and grid cells in a variety of different ways. They speculate that there is a slew of intricacies that may link memory and spatial navigation within our brains, inspiring research that approaches this potential unity from different directions. Many theories and claims on this notion remain unexplored, with some claims being more striking than others. A team of researchers led by Jeff Hawkins are looking to expand our understanding of the grid code beyond memory and the hippocampal-entorhinal region of the brain. They hypothesized that grid-cell-like neurons are present throughout the entirety of the neocortex rather than at just one localized area. Similar to how grid cells in the hippocampal-entorhinal complex can process and store spatial information, the neocortex also utilizes such cells to learn the structure of objects that one touches or looks at, as well as to learn higher-level cognitive tasks. According to Hawkins, if you were to hold a pen in your hand, each sensor patch of your skin, like sections of your hand’s palm or your fingertips, will be associated with grid cells in your neocortex that will process each patch’s location relative to the pen. Your neocortex will add up all the information generated by each sensor patch and create an expansive internal map of the object’s features, helping your brain recognize that the object you are holding is a pen (17). The “neocortex” model has been met with controversy as some researchers believe grid cells may not be present in other areas of the brain beyond the hippocampus and entorhinal cortex. If this model were to be proven true, it could pave the way for the incorporation of a universal grid-code system into the world of artificial intelligence.

And so we ask: Can this universal grid framework help create machines that better mirror the human brain and its abstract qualities? Neuroscientists at University College London and AI researchers at DeepMind may have just launched us in the right direction. Using a deep learning AI technique inspired by brain structures, they were able to train a rat-like computer simulation to keep track of its position as it navigated a virtual maze. Surprisingly, the simulation program created activity fields of hexagonal patterns similar to the hexagonal grid code generated by grid cells in mammals. The simulation was then able to utilize the grid code to learn and navigate its way through the maze. It almost seems impossible to imagine what more we could discover about how we store and navigate knowledge and memories with the help of AI and a universal grid-code. The possibilities seem endless!

Now that you know more about the memory palace and the neuroscience behind this technique, let’s put it to the test! Go back to the memory palace you created and retrace the route you took when placing the ten items on our list. Grab a sheet of paper and jot down the items you see in your route and in the order you come across them. See if you can match your list with the one I provided above. Feel free to continue expanding your memory palace. I’ll leave it up to you and your imagination to “map” out your memories however you see fit!
References


