Part IV

MUSEUM ARCHITECTURE AND THE SENSES

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Navigating the Museum

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SETTING THE SCENE

A visit to a museum is generally a welcome treat. As we experience a museum our brain constructs its own internal museum of the mind to help us navigate, explore, and form the memories we live our lives by. This process is fundamentally guided by the architecture of the space and its influence on our perceptions and expectations. In this chapter we will present recent discoveries of how the brain represents and remembers space and use this understanding to create a starting point for a journey we are beginning; the relation of architecture to neuroscience.

NEURAL REPRESENTATIONS OF SPACE

The world and its underlying material substance and immaterial qualities are composed of a rich and varied assemblage of components, attributes, and interactions. In order to be able to navigate and negotiate the world, human beings are equipped with a wondrous and intricately evolved instrument, the body. This body, being a finely tuned apparatus, relies upon an array of intertwined sensory modalities, each contributing to a unified experience of the world. To form a unified cognitive sense of being and to repeatedly recognize and self-localize in a single world "out there," the brain combines and sequences sensual input in a sensible manner. Immediately aware of connecting to the world through sight, we often forget or perhaps ignore that the world exists not solely as a visible interface and that vision is not the only means we have to make sense of our surroundings.

Beyond vision, hearing, touch, taste, and smell, the brain has a sixth sense. Not extra sensory perception, but *proprioception*, the capacity to keep track of where our limbs are in space. In addition to proprioception, neurons responding to the movement of tiny stones in our inner ear (the otoliths), and hairlike cells tugged and swayed in the fluid of our semi-circular canals allow us to sense our movement relative to the gravitational pull of the earth (see e.g., Jeffery, 2008). This information allows humans to comprehend an environment through internal senses of movement and furnish it with visual and auditory information (when available) to map the space explored. Vision may be a dominant basis for the forming of internal maps of space (cognitive maps), but these maps are by no means complete—they are both filled with and strengthened by the sense of our own movement (see e.g., Massumi, 2002). The two brain systems provide converging information and, to some extent, back each other up.

The first step in understanding how the brain constructs space is to realize how the brain processes information. Our brain is composed of approximately 86 billion neurons (Azevedo et al., 2009). Each neuron sends and receives *action potentials*, which are changes in the cell's electrical charge. For example, cells in our eyes convert light into action potentials which are sent to regions of our brain involved in processing the image. These processing neurons, and indeed all neurons, communicate via action potentials. A cell generating action potentials is described as firing. Neural firing can be prompted by high-level, multimodal combinations of inputs in response to environmental encouragement, such as configuration, sequence, boundaries, features, or topography. Navigating an environment not only requires the processing of immediate sensory information extracted from external or internal stimuli, but also matching these with internal predictions about the world and acting on the output to guide movement (see e.g., O'Keefe and Nadel, 1978). A key brain region responsible for spatial navigation is the *hippocampal formation* (see for review Spiers, 2012 and Figure 14.1).

The hippocampal formation is a set of interconnected brain structures that is essential for memory and that appears highly homogenous across all mammals (see e.g., Andersen et al., 2006). Recent neuroimaging and neuropsychological observations support the assumption that the hippocampal formation is part of a core "default network" required to support episodic memory, navigation, and imagination (Buckner and Carol, 2007). The hippocampal formation, owing to its physical appearance, is named after the Latin word for seahorse and consists of the hippocampus proper, the dentate gyrus, and the subiculum (Laveneux et al., 2007). The hippocampus proper can be divided into three main subdivisions: CA1, CA2, and CA3. CA stands for "Cornu Ammonis," derived from the Egyptian god Amun's symbol, the horns.

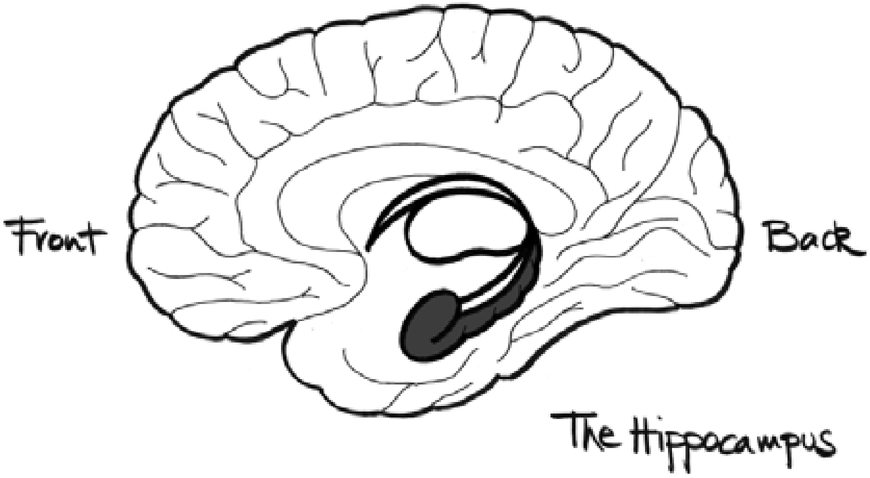

Figure 14.1. The hippocampus is an interconnected structure that lies at the center of the mammalian brain.

Due to the necessity of using invasive technologies to record from individual cells, most modern neuroscience studies hippocampal cells in rodents. After undergoing surgery and having had tetrodes (sets of four electrodes which measure the electrical discharge from individual cells) implanted into its hippocampus, a rat brain can be recorded from by connecting the tetrode to a PC. Few studies have been done on humans, however the results of such rare studies (conducted on epileptic patients who have had tetrodes implanted as part of their therapy) provide evidence that rodent hippocampi behave not dissimilarly to human hippocampi and this allows educated propositions about human space representation (Quiroga et al.; 2005, Ekstrom et al., 2003).

Situated within the mammalian hippocampus there are some of the most intriguing cell types in the brain and one of their functions is to serve navigation and memory abilities. Many of these cells are located in the CA1 and CA3 regions and are dedicated to extracting spatial information from the world, in order to construct internal representations. Cells in the hippocampus have been named due to their spatial properties.

We will first give a brief introduction to these different cells and later revisit some of their properties as we begin our quest to explore their relation to an understanding of architectural experience. Before we begin, we offer a brief reflection. In both neuroscience and architecture there exist discipline-specific distinctions and connotations among the universal terms space, place, object, boundary, and direction. Here we provide a brief summary of properties of the cells involved in processing spatial information and acknowledge that the use of terms derives from neuroscience.

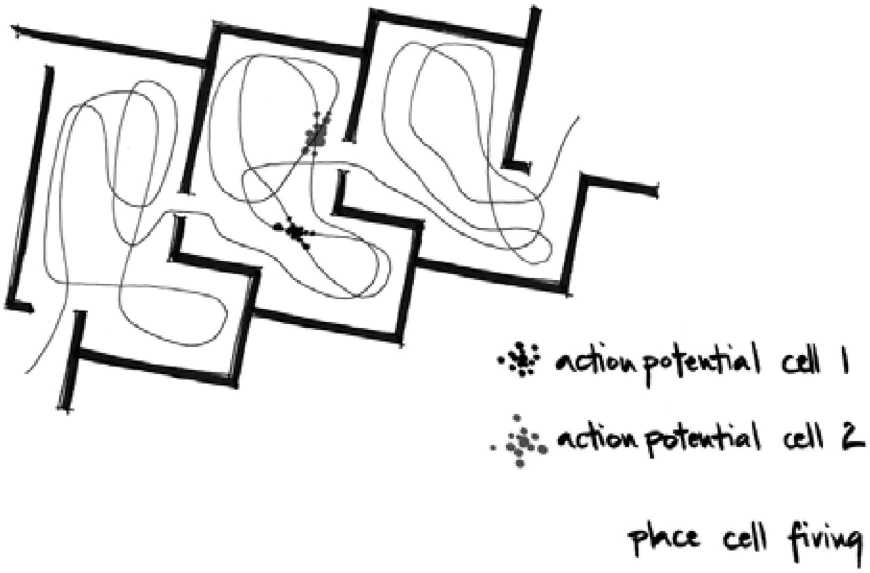

Figure 14.2. Sketch of a movement trajectory through space. Place cell 1 and place cell 2 fire in different locations along the path.

Place Cells

The first spatial cells in the hippocampal formation are *place cells* (O'Keefe and Dostrovsky, 1971). Discovered in 1971 and appropriately named, they fire action potentials only when a particular region of a space is occupied by the animal being recorded from (see Figure 14.2). The specific location in the environment where a place cell fires is known as its *place field* and this field is different for each cell. Each location in every environment is therefore represented by a unique combination of place fields. Each step of your journey to work, each place in your house, indeed every location in the world you have ever encountered is represented in your brain by the unique combination of place cells active. One question that has puzzled scientists for a while is: how do place cells know where to fire action potentials? Recent discoveries of other cells have provided insights.

Grid Cells

Grid cells in the medial entorhinal cortex fire periodically and each cell generates multiple firing fields, which are arranged in a tessellating grid pattern across an environment (Hafting et al., 2005, and Figure 14.3). Grid cells have been thought of as providing something similar to the grid divisions that divide up metric space on a cartographic map. Grid cells send action potentials

Figure 14.3. Sketch of a movement trajectory through space. Grid cell 1 and grid cell 2 fire in different locations, but exhibit the same tessellating pattern.

to place cells (Zhang et al., 2013), allowing place cells to determine how far an animal may have traveled. Several models describe how place cells may determine where to fire based on grid cell activity (see, e.g., Burgess et al., 2007; Solstad et al., 2006).

Boundary/Boundary Vector Cells

Boundary cells (Solstad et al., 2008) and *boundary vector cells* (Lever et al., 2009) are cells in the medial entorhinal cortex and subiculum respectively, which fire along or slightly offset to the boundaries of a space. It is thought that each place cell might receive information from a number of such cells, allowing it to determine how close the animal is to the different borders, thus pinpointing a specific location in space for the place cell to fire (Hartley et al., 2000).

HEAD-DIRECTION CELLS

Grid cells and place cells provide information about locations occupied during travel, but they do not provide information about orientation. This is thought to come from neurons known as *head-direction cells,* which exist in a set of limbic brain regions, including the presubiculum and entorhinal cortex, which have been likened to an internal compass (Taube, 1998). They fire when the head is oriented in a certain direction with respect to the environment. Head-direction cells are modulated by self-motion and by visual information.

Parietal Spatial Cells

The brain does not just form internal representations of orientation and position in the environment; it also constructs estimates of where things are relative to our body and our current viewpoint. Such cells are not found in the hippocampal formation, but in a region highly connected to it, the posterior parietal cortex of the primate brain (see, e.g., Colby and Goldberg, 1999). It has been proposed that these cells provide viewpoint representations of the environment to allow action in the space and that the spatial cells of the hippocampal formation provide the map and compass to tie these views to long-term memory (Byrne et al., 2007).

A VISIT TO THE MUSEUM

Having given a brief overview of the spatial cells in the brain, we now explore how these cells might operate during a journey to a museum and ponder what may be happening in the brain of the visitor as she explores and enjoys the visit.

When going to museums, our goals and expectations are often mixed. We may follow a definite intent, such as wanting to view a specific piece of art, or we may simply wish to spend an afternoon leisurely meandering around soaking up the atmosphere. This behavior, which, for want of a better term, we call spatial, cultural, and social "browsing," is interesting from both a scientific and an architectural viewpoint. It is spatial, but it is not in the first instance spatially goal directed. It is cultural, but it relies inherently on multisensory input rather than being based uniquely in language and conventions, and it is social, as browsers often have a parallel social agenda.

Museum spaces are often described as following a narrative. The implication is that specific sets of linear experiences are created. According to Tony Bennett, display organization and thus the architectural configuration known as *galleria progressiva* emerged after the French Revolution (Sutton, 2000). Often temporary exhibitions, there are however notable examples of permanent gallery spaces that are constructed in this way. Examples include the Picasso Museum in Paris and the Louisiana Museum of Modern Art in Humblebaek, as well as the New York Guggenheim Museum and the New

York Metropolitan Museum, which combine the galleria progressiva with the other prevalent format, the *period room*. A linear approach to museum planning can offer a subtle mixture of common and individual stories to the visitor without relying on symbolic guidance cues such as signposts (Sutton, 2000).

We take it as axiomatic, from an architectural, neuroscientific, and philosophical standpoint, that the visitor through all her senses constructs the visitor experience before, during, and after the visit (e.g., Von Glaserfeld, 1996). However, unlike the radical constructivists, here we take the view that the visitor is exposed to an external physical reality that is more or less the same as the reality being experienced by other visitors at the same time. We propose that it is the intricate neural and mental construction, preconstruction, and reconstruction of sophisticated architectural environments that promotes successful navigation, while additionally eliciting sensual delight.

The past and future are immanently important both to such feelings of wonder and to navigational capacities, and we will now consider what happens in the brain before a visit.

BEFORE THE VISIT

A museum begins not as the visitor arrives at and enters the museum, but indeed as soon as the thought of going enters her stream of consciousness. Having decided to undertake the excursion, imagination and memory take hold of her mind and her brain prepares her for the visit. The experience of a museum gallery is preconditioned by possible prior experience of the gallery, by knowledge of the gallery content, of similar gallery settings and, increasingly, of galleries in digital representation. Even if she has never been to a specific museum, based on media or others' reports, the visitor will have an expectation of the building. Significant buildings often have a key image with which most visitors are familiar. When visitors experience the place the image was taken from, they have a memory to which they refer, regardless of their having been there before or not. Architects have been consciously aware of this since the Renaissance and it is reasonable to say that they design key moments in their buildings on this basis. The British architect Sir James Stirling is reputed to have always aimed to specifically create a place in his buildings where a key image could be taken in photographic portrait format (see, e.g., Stirling and Krier, 1975).

External sources of memory underlying preexperience, such as key images, are of course shared by many visitors, but given the vast range of galleries, settings, and content any individual and personal set of preexperiences is likely to be unique. This is especially the case when we consider that preexperiences are also remembered in the context of a respective state of body and mind and of the sequence of individual life stories. The human ability to imagine the future (as the reconstructing and reconfiguring of past memories into novel assemblages) probably provides essential guidance mechanisms when traversing and browsing a museum (see, e.g., Schacter et al., 2012). Original—often even fantastical—imagination is to the best of our knowledge unique to human beings. The neural basis for constructing and indeed manipulating memories which enable human imagination, however, manifest in similar ways in our mammalian relatives. We speculate that humans are able to project across larger periods in time and space and construct more elaborate novel situations than rodents. Our assumptions are based on scientific facts; for now they remain, of course, suggestions. Despite the apparent and yet to be understood differences, recent research with rodents has revealed a remarkable capacity of their neural network to "pre-play" upcoming trajectories to places in the world (see, e.g., Pfeiffer and Foster, 2013). By pre-play we mean sequential activation of the cells that represent each of the places encountered on a journey in the future. As an example, imagine three place cells. The first represents the entrance to a room, the second a field in the center, and the third a field on the far side of the room. As you pass through the space, each cell fires action potentials as you enter its preferred part of the world (its place field). Intriguingly, in a quarter of a second before you set off across the room, all three cells may fire in sequence 1,2,3, much like a readout of the future path. Rat hippocampi have indeed been observed to fire in a way predictive of flexible future behavior, when trajectories between start and end of a journey are new to the animal (Pfeiffer and Foster, 2013). Extrapolating from rodent data, where pre-play is likely to act as a mechanism that guides foraging and finding, we may contemplate that such "mental time-travel" (Pfeiffer and Foster, 2013) in a prospective museum visitor can serve to generate a depository of possible sequences, which in situ can then inform her browsing behavior.

Hans Ulrich Gumbrecht refers to the future as the "horizon of expectations" (Gumbrecht, 2004), and adopting this piece of imagery nicely sketches how human brains may prepare a collection of likely-to-be-required operations. Having undergone this exercise, behavior which is custom tailored to each idiosyncratic situation will then be able to emerge (Foster and Knierm, 2012). As the following research shows, rest and sleep (offline periods) are especially important to planning. Memory pre-play mechanisms in hippocampal place cells appear to be most active in offline periods, giving rise to meditations about the role dreams play as simulation systems (Schacter et al., 2012). In addition to prefiring immediately before running along a trajectory, place cells in sleeping rats have been shown to briefly fire action potentials in the same order that they would if the animal were running along a familiar path (Wilson and McNaugton,1994). This has been speculated to be, quite literally, the "stuff of dreams" (Ji and Wilson, 2006). After a visit to the museum, it is likely the visitor's hippocampus is very active replaying reruns of the experience. More controversially, recent work has argued the brain may pre-play places yet to be experienced in the future, during sleep (Dragoi and Tonegawa, 2011, 2013). This type of pre-play is thought to arise from a set of preconfigured charts in the hippocampus.

If true, it suggests that the night before the first time a museum is visited, the visitor's brain will start to simulate the next day's visit.

EXPERIENCING THE VISIT

After constructing representations and entertaining conscious and unconscious, material and immaterial forecasts of the museum visit, the visitor can begin to enjoy the unfolding journey through the space and the events that will take place within. In this section we will illustrate a succession of factors that are important both to navigation and perception of space.

The Entrance

Entrance areas to both public and private buildings are universally afforded special consideration. Museum foyers are no different, and as origin points, in our subjective experience, they hold a distinct position. What happens in the hippocampus when a starting point to a journey is established? Observations show that in fact a disproportionate number of place fields are located at common starting points of rats' expeditions into testing environments (Ainge et al., 2007), as well as in "doorways" in a multiregional environment (Spiers et al., 2013). This may relate to the need for an anchor point for each experience, but more research will be required to understand this. Passing through doorways also seems to cause forgetting (Radvansky et al., 2010), and it may be that they set the "frame" for a new learning experience.

Sequence and Configuration

We will now travel to a specific linear museum to explore how the brain might process such a space. The Louisiana Museum is well known for its sophisticated design and exquisite configuration and balance of spaces (see Figure 14.4). The museum as it exists today is an elegant assemblage of interlocked and interconnected pavilions and corridors of varying transparencies.

The architecture of the museum hinges on the primacy of producing flowing visitor movement through the overall exhibition space, ushering patrons from one pavilion to the next. An example of a galleria progressive, the Louisiana's arrangement is vaguely reminiscent of nineteenth-century exhibition design, which drew inspiration from urban spaces such as shopping arcades, market halls, and department stores, as well as conservatory spaces (Bennett, 1995). The aim was to create a relaxed atmosphere which, while putting the visitor on a fixed route, was also conducive to a leisurely mode of walking. The Louisiana pavilions allow visitors to stroll at a speed of their choosing and the multiple access points along the route to the surrounding gardens serve the purpose of decentralizing viewing angles and presenting a steady succession of exit possibilities. The New York Guggenheim uses a similar principle, allowing visitors to sidestep into exhibition rooms and then return to the fixed journey on the sloping ramp.

We can now ask an interesting question. The individual spaces are connected and experienced as a flow of events, but are they part of one grid map, or do grid cells rather fire in a succession of linked submaps? Once again, data extracted from experiments on rodents can give hints and allow

Figure 14.4. Louisiana Museum of Modern Art—Key Plan. Courtesy Louisiana Museum of Modern Art

reflections. In testing environments that are separated into compartments, grid and place cell map representations are veritably separated into submaps (Derdikman et al., 2009; Skaggs and McNaughton, 1996; Spiers et al., 2013). Representations are promptly reset upon entering a new space as neural firing discontinues for one space and restarts for the next. When a similar trajectory in an open field without walls is followed, no map fragmentation is observed (Derdikman et al., 2009), providing evidence for the importance of physical divisions of spaces. The overall mental map of a museum such as the Louisiana, where visitors follow one fluid linear trajectory through a succession of partitioned pavilions, probably consists of a collection of grid cell submaps based on the architectural layout, which divides the route into a succession of highly distinctive rooms and corridors. Perhaps it is the phenomenon of the doorways mentioned above that divides the route by setting a map for each space (Radvansky et al., 2010). Currently we don't know how the brain links these submaps to one another to create what we may call a "chain of submaps." What we do know is that as described above, active place cells encode spatiotemporal sequences of places; additionally, their firing is the hippocampal formation's mode of encoding transitions between events and states, often using current circumstance to predict the next stage (Alvernhe et al., 2008). In order to generate the necessary updating in the map, the hippocampus must keep note of the body's changing position in space by integrating linear and angular self-motion, which are thought to be provided by grid cell firing patterns (see, e.g., McNaughton et al., 2006; Jeffery, 2008).

In the context of a museum such as the Louisiana, we may speculate that the pronounced firing sequence exhibited by place cells transitioning from pavilion to pavilion creates unique "braces" that bind each grid cell submap to its respective neighboring maps. Pondering this, an inference may be that a linear journey that is laced with salient spatial transitions between distinguishably shaped spaces, stimulates the cells in our hippocampal formation in a manner which allows for better encoding and understanding of the space. By "understanding," we mean the capacity to form a coherent internal representation of the environment. The linearization and careful punctuation of the space may lead to a strongly coherent representation. Does a strong coherent representation then produce a better sense of space and place? Representation in a linear fashion is known as linearization in psycholinguistics and, in short, describes a process by which the experience of spatial structures is transformed into a temporal succession. It has been proposed that this process promotes spatial comprehension and sense-making (Wenz, 1997). The sophisticated succession of linearly interwoven spaces at the Louisiana would thus elegantly complement the way human beings make sense of space and process it, by breaking its sequential experience down into a chronology of events. The above would thus suggest that the strong sense of space in this museum is achieved by its coherent linear representation.

Construction

In the context of museums and galleries, sense of space is desired to be a pleasurable experience. We believe that it may be the act of constructing memories of experiences in space that gives pleasure. Here we have described how movement in rats stimulates the cells in their brains and shepherds the construction of representations. The idea that pleasure is elicited by the construction process is speculative and to date there is no scientific knowledge to back this up. Pleasure responses in the brain have been explored; however, links to spatial processing have yet to be identified (see, e.g., Berridge et al., 2009). The architectural speculation we make is based on an argument about the nature of an aesthetically potent environment put forward by Gordon Pask and elaborated by Stephen Gage.

Pask offers us a brief for this environment:

> With all this in view, it is worth considering the properties of aesthetically potent environments, that is, of environments designed to encourage or foster the type of interaction which is (by hypothesis) pleasurable. It is clear that an aesthetically potent environment should have the following attributes:
>
> It must have sufficient variety to provide the potentially controllable novelty required by a man (however, it must not swamp him with variety—if it did, the environment would merely be unintelligible).
>
> It must contain forms that a man can interpret or learn to interpret at various levels of abstraction.
>
> It must provide cues or tacitly stated instructions to guide the learning and abstractive process.
>
> It may, in addition, respond to a man, engage him in conversation and adapt its characteristics to the prevailing mode of discourse. (Pask, 1968)

Gage offers a hypothesis, in *The Wonder of Trivial Machines*, that the pleasure that is experienced occurs as the observer constructs an explanation for herself (Gage, 2006). Currently we still lack the scientific link between emotional feeling related to constructing and understanding a space and the spatial cell responses that map this space.

Orientation and Location

We will now return to the realm of what has been explored and ask a question of which an understanding is beginning to emerge. How is movement integrated into the grid map so that we can orient in a space? How do we know where we are—how do we self-localize?

In essence, self-localization in an environment requires two things. We need to know which environment we are in and then establish our location and direction within it. To do this, the brain connects information from multiple sensory modalities to previous knowledge (Jeffery, 2008). A process known as *path integration* relates contextual information and prominent environmental cues to velocity and angular and linear direction of self-movement to determine the present location and orientation in space (Jeffery, 2008). Head-direction cells relate the position and direction of self to environmental cues. The logical inference is that self-localization on the internal map, or in the case of a succession of spaces the sequence of submaps, is inscribed using movement, direction, and viewing angle. Let us consider an example of a cue the brain may use to extract direction information from grid and place cell interplay. One theory that has been outlined offers an explanation the role boundaries which demarcate spatial extent, such as walls, may play.

The *boundary vector model* proposes that each place cell receives information from several boundary cells, which create vectors for place cells (Hartley et al., 2000). Boundaries that are close to the animal appear to specify the location of boundary place fields, whereas more distant cues provide the additional directional information required to create vectors (Jeffery, 2008). It has further been suggested that grid cell spacing factors into metric computations within which place fields are laid down. Vector information delineating geometry of space alone may often not suffice to recognize individual spaces when shape only slightly or in fact does not provide sufficient information (Anderson and Jeffery, 2003). Contextual information then provides sensory input—such as sound, smell, or color—to the place cells. Why does context information not appear to directly inform place cells? If it were to directly impact place cells and not be filtered through boundary cells, a single place cell's multiple place fields—in multiple environments—could not exhibit independent behavior, but would always perform in an identical manner irrespective of the environment (Anderson and Jeffery, 2003).

Multiple Maps

Each spatial environment exists not only in immediate experience, but in memory and imagination. Immediate experiences at each point in time differ and we therefore propose the existence of a network of multiple stored spatial representations for individual spaces. Furthermore, spaces may undergo changes and thus require alteration to existing map representations (we will explore this toward the end of the chapter). All this implies that each space may be represented by a collection of temporally and sequentially separated maps, depending on circumstance and happenstance. A look at how rodent brains amass map representations and use these flexibly can help build an understanding. In its abundant memory archive, the brain accumulates maps as action patterns and can retrieve these rapidly when needed (Jeffery, 2008). Associative connections allow stored memories to be recalled from incomplete or dated versions of the original input and match these with current experience. This process is known as *pattern completion*. Its counterpart is a function called *pattern separation*, which prevents the mixing up of the memory with other memory events stored in the network. When comparing incoming information with stored representations, brain oscillations have been observed to either immediately retrieve the relevant representation or to flicker between representations, before coming to rest on one (Jezek et al., 2011). Upon imagining, remembering, or experiencing, representations will be recalled and, if necessary, be corrected and updated dynamically to elegantly include new information or exclude outdated information (Gothard et al., 1996). It is thought that it is the path integration mechanism that is updated, and when large aberrations occur, they can be accompanied by a slight delay as the internal system catches up with the external scene. Thinking of a museum visit, we may use this knowledge to reflect upon the following. The visitor, who has enjoyed many an afternoon in a museum and has accumulated a rich collection of maps and moods, knows the space well. She is therefore likely to experience surprise when she encounters novelty or discovers the unsuspected. There is little scientific knowledge about this, but could feelings of delighted surprise be connected to this process of updating and delay?

A multiple or varied map theory receives further support when we consider the following discovery. Changes in geometry, context, or a combination of both alter neural response to a spatial environment (Jeffery, 2008). This process is known as *remapping*. *Rate remapping* alters firing rates and we propose that this can create variations in the intensity of a map. *Global remapping* on the other hand, which is caused by large changes, alters the location of place fields and can also mean changes in size, shape, and firing intensity. As mentioned, we will revisit the remapping phenomenon in the final section when we consider what may happen on a return visit to the museum. Before this, we will consider one last aspect of the actual visit—how the intent of the visit may relate to its experience.

Intent of the Visit

A museum visit can follow a range of intentions. Often, visitors show browsing behavior as they move from one perceptual field to the next. The intent these visitors are following, as they browse the gallery space and its content, is foraging for experience. When rats forage for rewards, neural firing rates change significantly as the intentionality of a journey changes (Wood et al., 2000; Ainge et al., 2007; Ferbinteanu and Shapiro, 2003). Firing rates have been shown to remap depending on the type of a goal or reward sought. The locations of fields remain fixed, and it is believed that rates represent variation in goal-specific encoding and thus the intention inscribed into a place field (Ainge et al., 2007). From an architectural viewpoint, perception is intimately linked to intention; intentionality of the designer who embeds it and the visitor who absorbs it (Holl, 1994). Phenomenal experience in architectural space merges pure sensational perception with the human inclination to conceptualize. Steven Holl writes:

> According to Brentano, physical phenomena engage our "outer perception," while mental phenomena involve our "inner perception." Mental phenomena have real, as well as intentional, existence. Empirically we might be satisfied with a structure as a purely physical-spatial entity but, intellectually and spiritually, we need to understand the motivation behind it. This duality of intention and phenomena is like the interplay between objective and subjective or, more simply, thought and feeling. The challenge for architecture is to stimulate both inner and outer perception; to heighten phenomenal experience while simultaneously expressing meaning; and to develop this duality in response to the particularities of site and circumstance. (Holl, 1994)

Intent in the context of meaning, specifically meaning embedded into architecture that is intellectually stimulating, is, to the best of our knowledge, exclusive to humans. For humans, intent need not always be the seeking and receiving of a specific reward aimed for, but can also mean the extraction of meaning that we discover or uncover along the way. We cannot of course equate this like-for-like to our reward-seeking rodent relatives; however, what can be observed is the highly important aspect of qualitative distinction among goals. Firing rates appear in their differences to reflect distinctions among the unique characteristics of a reward (Ainge et al., 2007). When rewards in goal locations presented in a maze differ (e.g., chocolate milk in one location, vanilla in another), these elicit different firing rate patterns depending on the flavor of the reward aimed for. The differences do not manifest once the reward is retrieved, they persist from start to finish of the journey, indicating that it is the intention motivating the pursuit and not simply the achievement of successful reward retrieval that underlies firing variation (Ainge et al., 2007).

A question still to be answered is if the intent a museum visitor is either following or uncovering is equally marked by idiosyncratic patterns, and which other brain functions these might rely upon.

The Visit Ends

The visitor is now at the end of the visit and we will offer a brief concluding observation, which fits nicely with the starting point, the entrance area. Much like at the beginning of a journey, place fields also tend to cluster around end points (see, e.g., Gothard et al., 1996). Before leaving a museum, humans often recap their visit mentally and it appears that spatial neurons follow suit. When an animal has reached the end of its run, place cells fire in correctly timed yet reverse order and then lay down a large number of place fields at the end (Foster and Wilson, 2006; Diba and Buzsaki, 2007). As we reflect, the brain makes a memory of the space for its memory archive. Recalling Gumbrecht's metaphor of the future as the "horizon of expectations," we have now arrived at the point where the museum visit will become part of our past, our "space of experience" (Gumbrecht, 2004).

AFTER THE VISIT

When the visitor leaves the museum the experience still lingers on her mind. Her brain now gradually consolidates the impressions gained. The process of consolidation refers to the storage and securing of memory traces—the firing patterns that construct each memory—in neural networks. Contemporary neuroscience explains the accumulation of memory information as the strengthening or weakening of synaptic efficacy between cells in brain regions responsible for memory storage. This is referred to as *long-term potentiation* (Bliss and Lømo, 1973) and is the persistent enhancement of signal transmission between two neurons resulting from synchronous activity of these neurons. A stable memory is one that is deeply embedded and can be recalled—reconstructed—over long periods of time and space. Sleep and times of rest allow the brain to consolidate perception and experience in a highly efficient manner and safely tuck them away in its archive. With time the hippocampus is needed less and less to retrieve memories that can be described without need for vivid reexperiencing (see, e.g., Moscovitch et al., 2005). During sleep and rest the hippocampus is thought to broadcast its activity patterns to other brain regions (see, e.g., Diekelmann and Born, 2010). Thus, for our museum visitor, after her trip her hippocampus will probably be updating her internally constructed museum to other areas of her brain for the long-term memory that will serve over decades. She may recall the experience many years later, now drawing on other brain regions to reconstruct the experience.

This brings us back to the beginning of our chapter and the time before the visit, when the brain prepared and planned for the expedition.

A RETURN VISIT

The final part of our story sees the visitor return to the museum for another visit and start the next iteration of experience. Having been to the museum before, she is physically familiar with the space, and her sense of the spaces—and herself in them—allows her to preimagine vividly and in detail what she may subjectively encounter (Schacter et al., 2012). The process of self-localizing and having "felt" a space, through self-motion, creates a strong foundation on which reconstruction and modified or manipulated construction can take place. What, however, happens if changes have been made to the space, and can we identify different responses to different changes?

In a gallery setting change is inevitable. A variety of scenarios is imaginable. The artwork may have been rearranged, in which case the influence of changes on spatial cells is negligible. However, changes to space per se do have an impact. Surface textures in the space may have been altered. Small changes to the geometry of the space may have been made as temporary exhibitions come and go or pieces of art are added or (re)moved and thus necessitate changes to be made to the space that holds them. Finally, the most fundamental of all, spaces may have been redesigned completely, rendering them in essence to be perceived as novel.

Earlier we introduced the phenomenon known as remapping and outlined the differences between rate remapping and global remapping. The question of how cells remap globally from one environment to another or in rate when changes have been made to the same environment has fueled many a scientific experiment. In investigating rate remapping, often the effects of color, shape, or smell are tested and a number of preliminary insights have been gained (Jeffery and Anderson, 2003). As one select point of interest for a revisit of a known space, we will take a look at what may happen when the same environment undergoes contextual or minor geometric alteration, and thus firing rates remap. One recent model proposes the following plausible hypothesis (Jeffery and Anderson, 2003): it may be that rate remapping is informed by a combination of geometry and context. When contextual changes are made, such as changing the color of a wall (Burgess and Hartley, 2002), what happens? First, the geometry provided by walls is assumed to not only demarcate a space, but indeed to underlie the localization of firing fields (O'Keefe and Burgess, 1996). In this role, they lay the foundation for where a firing field is located. The rate at which the cell fires upon entering the firing field is then thought be determined by context, and if this is changed, the rate also changes. In the museum, the visitor may find herself in a space she knows, but the walls have been repainted. Her place cells will fire accordingly. They recognize the space in its geometry and instantly lay down their previously acquired topographic composition of place fields. The change in color, however, promotes new firing rates and elicits a novel experience, in the knowledge that the visitor is in a familiar space; this allows spaces to be both the same and different in hippocampal representations (Fenton, 2007). Anyone familiar with the New York Guggenheim who visited the museum in 2001 or 2002 for the Brazil: Body and Soul exhibition, which was designed by Jean Nouvel and saw the entire interior painted black, will recall vividly the peculiar experience of recognizing the space and immediately orienting within, while at the same time being exposed to a rather different Guggenheim.

What happens when minor changes are not contextual but geometric, for example if a dividing wall is moved within a space to accommodate a new exhibition setup? The overall space remains the same, yet boundary input that localizes firing fields will be altered. In this case, research has shown that those place fields that were initially informed by the wall, which has now been moved, indeed shift or stretch to accommodate the changed geometry (O'Keefe and Burgess, 1996). The walls that remain the same continue to provide input to their respective place fields and these remain fixed. Changes at times can be substantial; however, if the basic spatial layout pertinent to navigation and orientation remains fixed, a visit may thus elicit in the visitor a qualitatively different experience within a well-known space.

In our final scenario, the space has been altered to such an extent that it is now unrecognizable in every way imaginable and previously acquired navigational strategies are rendered useless. The brain will treat it as a new environment and a brand-new map is required. Old representations are discarded and the spiel between architectural space and brain can begin afresh.

WHAT LIES AHEAD

In this chapter we have outlined a brief summary of the neuroscience relevant to an understanding of how the brain constructs internal representations of space. Tentative first steps toward a conversation between architecture and neuroscience have been taken and we hope to continue and develop the discourse. In more than one sense the journey to link these two disciplines is just beginning. At the end of this first introduction, a world of questions awaits and common ground will need to be defined. The limitations and equally affordances of technologies notwithstanding, we have myriad enquiries and ideas that invite further research. An additional limitation, of course, is the difficulty of collecting data from humans. Central to this is the degree to which we can observe the different cells in the hippocampus as they are excited when observers experience architectural spaces in real or virtual representations. Studying humans will no doubt introduce a range of unique complexities, such as sociocultural differences or the fact that human perception is not only guided by our immediate senses, but also by the human need to contextualize and abstract experience. The exploration of neural excitement in relation to architectural stimulation is the departing point for this journey. If technical difficulties can be overcome, however, the results could open up a range of new endeavors valuable to both the architectural and neuroscience communities. A striking challenge is the lack of understanding of how feelings, such as delight and wonder, are processed in the brain and how these interact with the spatial representations we use for memory and navigation.

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