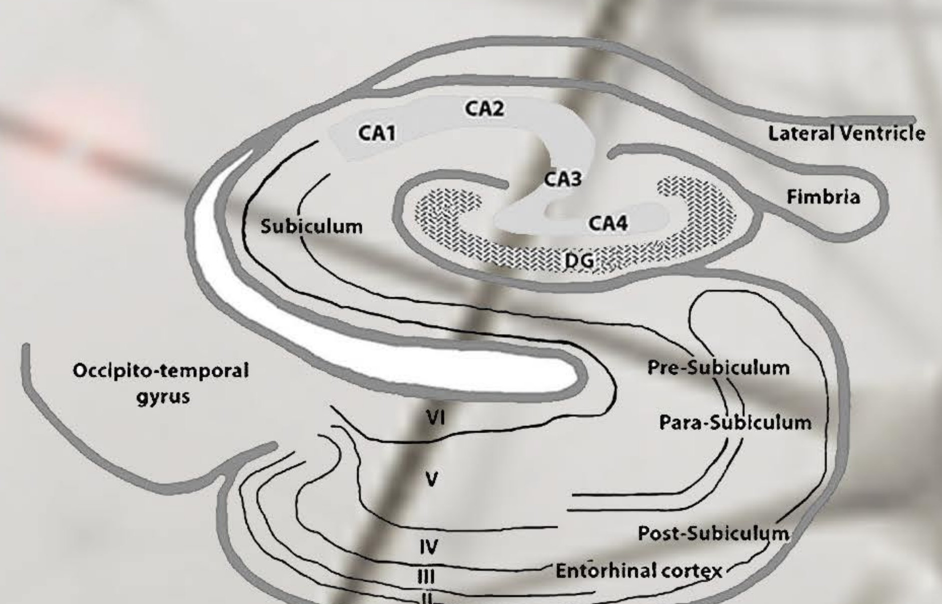
Neural Mechanisms of Place Attachment

Overview

What is the relationship between cognitive mapping as a neural process and place attachment theory?

This thesis examines three neurophysiological mechanisms that impact place attachment processes: movement generated place cell firing, spatial learning, and route replay. Place attachment theory examines people's relationships with space and is used by social scientists, architects, urban planners, and geographers. In its most basic understanding, attachment is developed through experience, stored in long-term memory, and then retrieved for comparison purposes for learning new experiences. If a clear connection can be established between cognitive mapping and place attachment then the neural mechanisms that are active in cognitive mapping can inform place making, design choices, and future research.



Hippocampal Formation

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Physical Movement

Exploring space through physical movement enables the hippocampus to represent the physical environment in the brain through the firing of place cells and the subsequent construction of a cognitive map (O'Keefe & Dostrovsky, 1971). Place cells are neurons that individually fire in response to specific locations in an environment, called the cell's "firing field" or "place field". One initial connection between place attachment theory and cognitive processes is the concept of movement. Phenomenologically, our surroundings gather meaning, developing a sense of place as we move through and explore them (Johnson, 2007). Movement and subsequent place cell activation are strong indicators of the human brain's ability to construct a mental map of one's environment.

Spatial learning

Spatial learning is a complex neural process that serves as the basis for place attachment. There are several contributing factors that inform the place cell as to its location in the environment. Boundaries are fixed physical or representational elements in the environment that define a space and act as an important cue, triggering the firing of border cells and the formation of a structural representation. Grid cells create multiple triangular grids that overlay the environment and are slightly shifted from each other to increase the accuracy of location representation. Path integration is the use of internal, self-motion cues by grid cells to pass along location information to place cells. Place cells then use this path integration information to recall stored firing patterns compared to current firing patterns as the basis for remembering a route travelled. Hippocampal place cells are informed by the firing of border cells, grid cells and head direction cells, resulting in a complex spatial representation of the environment.

There are two contributing factors that help establish a strong place code; the firing rate of the place cells and the temporal code of the theta cycle. The theta cycle is an electrical frequency found in many parts of the brain including the hippocampus and is related to spatial learning and navigation (O'Keefe & Recce, 1993; Buzsáki, 2005). Place cells fire at a slightly higher rate than the theta frequency so that the phase of firing occurs earlier and earlier on the theta wave as the animal moves through the environment. The firing rate of place cells code for the speed of movement through the space while the temporal code represents the animal's location in the place field. The binding of behavioral and sensory information with the animal's location provides a higher resolution map of the environment and may explain the hippocampus's involvement in both spatial and episodic memory (Huxter, Burgess, & O'Keefe, 2003).

Stress plays a dual role in learning processes, both facilitating and impairing learning potential. The location for stress processing is the amygdala, a neurological structure that is both located adjacent to the hippocampus and plays a role in hippocampal learning processes. There are multiple types of stress, each with differing impacts on spatial learning. Some stress is necessary for learning by focusing attention and improving memory of relevant information (Joëls, Pu, Wiegert, Oitzl, & Krugers, 2006). Chronic stress has been shown to actually change the structure of the hippocampus (McLaughlin, Gomez, Baran, & Conrad, 2007), negatively impacting Long Term Potentiation (the probable molecular mechanism behind memory and synaptic plasticity, involved in learning) and spatial memory (Diamond & Rose, 2006). In a remarkable study on environmental enrichment and stress, several scientists have shown that environmental enrichment can protect against the effects of chronic stress before or after the stressful experience (Hutchinson et al., 2012). This study clearly suggests that manipulation of environmental factors can have positive impacts on chronic stress, stress related neuropsychological disorders in adults, and overall brain integrity (Hutchinson et al., 2012).

This dialectical nature of stress has interesting correlations with several theoretical dimensions of place attachment. The nature of places is to provide challenge and security, meeting both the homeostatic and the heterostatic needs of an organism concurrently (Lewicka, 2010). These related theories include mystery vs. coherence (Kaplan, 1979), prospect vs. refuge (Appleton, 1984), and excitement vs. relaxation (Russell, 1988). In each of these theories some level of stress and subsequent release are essential to achieve place attachment.

Stress will focus attention and improve learning and memory if experienced within the time and space of the learning experience (Joëls et al., 2006). These findings have strong implications for place learning and place attachment. While too much stress will inhibit spatial learning, some stress is crucial for place attachment processes, establishing a neural basis for the theoretical dimensions of place that have been suggested by environmental psychologists and researchers.

Route replay

Route replay is the neural mechanism involved in the replay and review of neural activity as it occurred throughout spatial exploration. During awake but inattentive pauses in the route, a laboratory rat will review its path, replaying sequences of neural activity (Foster & Wilson, 2006). The neural mechanism of replay is complex, representing not only recent activity but also never before experienced trajectories that are thought to contribute to the consolidation of long term memory and the learning of cognitive maps (Gupta, 2010). A complementary neural mechanism that occurs when the rat pauses at a choice point in the path allows the animal to sweep possible future paths and non-local information, enabling the evaluation of action outcomes at decision points (Gupta, 2010). The period and space of pause within which the rat replays its movement is a significant event involved in both memory consolidation and decision-making, directly contributing to the construction of a map-like representation of the environment.

Hippocampal Function	Neural Mechanism	Environmental Correlate
Spatial Navigation	Boundary, grid, head direction, and place cells collaborate to create a composite spatial representation and expression of physical location.	Legible boundaries and active exploration of an environment increase place field stability. Strong place fields support spatial learning processes and place attachment.
	Long-term potentiation is implicated as a primary neural mechanism in learning and is enhanced on the peak of the theta rhythm.	Physical movement at the human scale triggers theta, while theta increases learning potential and place attachment. Environments should encourage physical movement and active physical exploration to strengthen place attachment.
Memory Encoding	Route replay is a complex process involving both backward and forward replay; it is also involved in memory consolidation and decision making. Route replay occurs during both sleep and waking, but inattentive pauses in the environment.	Designers should consider the design of environmental choice points and places of pause and their implication in memory formation and spatial learning.
	The hippocampus serves as a comparator of present with stored (past) memories, making sense of current events through a retrieval and association process.	Organized spaces with clear visual or symbolic reference features can facilitate the creation, consolidation, and recall of spatial memories contributing to place attachment processes.

Neural Mechanisms and the Environmental Correlate

Summary:

The goal of this project is to understand the neural mechanisms active in cognitive mapping and how they impact place attachment processes. The three primary mechanisms explored are place cell firing, spatial learning, and route replay. Physical movement and active exploration are critical components in spatial learning and should be an essential element of architectural design. Stress is a fascinating factor that both promotes and impedes learning processes. Recent studies show that Post Traumatic Stress impacts spatial learning (Tempesta, Mazza, Iaria, De Gennaro, & Ferrara, 2011). Further analysis could expose how much stress is beneficial to place attachment and what specific environmental design features would encourage a useful level of stress. Memory formation, consolidation, and retrieval are contributing factors to place attachment processes and can be strengthened in places of pause. Future research could examine which architectural elements create successful places of pause so that spatial learning and place attachment are encouraged during the environmental experience. Another possibility for further research involves the continued exploration of environmental psychology and the neuroscientific basis that supports the development of these psychological theories. Continuing the discussion will advance interdisciplinary collaboration in an effort to create successful designs that promote place attachment through neural processes.

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Hippocampal Formation: http://neuralnetoff.umn.edu/mediawiki/index.php/Hippocampal_Anatomy

Background picture: http://desimad.com/js/neurons-firing