From Neural Space to Physical Space: Giving a "Brain" to a Building

Michael Arbib, Tricia Ngoon, and Eric Janes

Introduction

We explore the integration of two ways in which neuroscience (which we extend to include the study of cognitive science as well as brain mechanisms) may impact architecture.

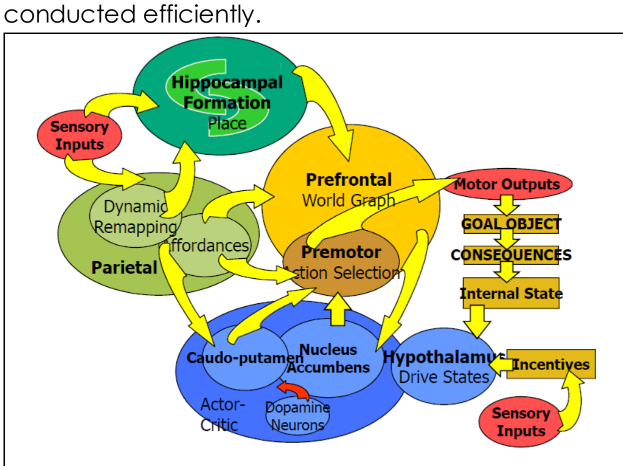
- *Neuromorphic architecture:* Studying neuroethology (the neuroscience of animal behavior) in search of systems whose mechanisms can inform future developments in smart architecture. A key notion is that of "neural space," the network of sensors, effectors, and computations embedded in the building, analyzed in terms of their functionality rather than their placement in 3D space.
- *Neuroscience of the experience of architecture:* Assessing the ways in which different populations of people explore, experience and interact with the built environment, in search of lessons relevant to the design process.

We propose that careful attention to the "neural space" of a building may yield innovative designs that enrich the physical "building space" through constraint satisfaction between the physical and neural dimensions of the building.

Neuroscience of the experience of architecture

A key notion from neuroscience is that a human (or animal) is engaged in a continual cycle of action and perception (APC) with its environment, with sensors providing the input for perception and effectors providing the means to carry out actions – but perception is based in part on the human's current goals and needs as well as memory based on prior experience, with actions serving both to gather more information and to effect changes in the environment. An important feature of the APC is the social interaction of people with each other, as the plans and behavior of each actor change with their perception of the actions and intentions of others. The neuroscience of the experience of architecture applies findings and methods of neuroscience (and cognitive science more generally) to assess the behavior and experience of a person within or in proximity to a building (or architected space) in terms of these concepts, seeking to understand how changes in the building may constrain or enrich that behavior. Conversely, we seek to engage neuroscientists in extending studies from the laboratory to the built environment.

Example: Multi-sensory integration plays a key role in human experience of buildings, but much behavior makes especial use of vision both to locate objects and to navigate despite the possible variations in the placement of obstacles. How does that change when vision is absent? Folska (2012) had blind participants sketch maps of a routine route at the Colorado Center for the Blind. All participants exhibited a preference for relying on touch rather than audition for extracting environmental information. Passini and Proulx (1988) found that the blind made more decisions in navigating complex spaces and required more information access points than those who navigated sighted, but blind participants were still able to navigate novel, complex spaces. This suggests the need to provide diverse tactile cues in designing for the blind. Similar considerations apply to aiding memory formation and recall, both providing means to help blind newcomers to the building orient themselves, and supplementing the resident's working memory of where objects are to be found. We have analyzed this in terms of the TAM-WG model (Guazzelli, Corbacho, Bota, & Arbib, 1998) which explains the integration of a cognitive map with available affordances in locomotion, showing how the unavailability of visual affordances requires a greater density of established "via points" if navigation is to be conducted efficiently.



A schematic of the TAM-WG model. *

Parietal cortex finds affordances for behavior; premotor cortex selects actions for which affordances are currently available.

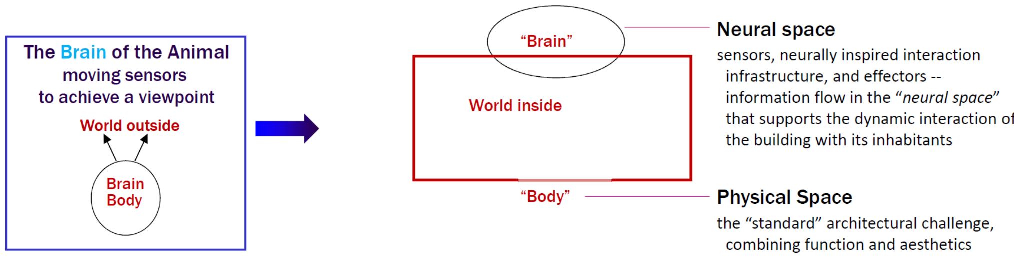
Populations of place cells in the hippocampus function like a distributed GPS: "You are here." But the hippocampus must work with other systems to mediate navigation.

The model adds a Cognitive Map (World Graph) to a hippocampus in modeling the brain.

* An exposition of the model for architects is available on YouTube: https://www.youtube.com/watch?v=iZZIGAYE9Cs

Neuromorphic architecture

Viewing a building as an "inside-out" animal which contains the environment in which it interacts with human occupants, *neuromorphic architecture* proposes that the future evolution of architecture will endow many buildings with appropriate variations on sensors, effectors and *interaction infrastructure* ("brain") studied in neuroethology to support the adaptive interaction of each building with its inhabitants (Arbib, 2012). The "neural space" of a building then provides the abstract network linking the sensors, effectors and "brain" to achieve a key set of functionalities, such as supporting navigation, memory and the performance of key functions.



A Proposal

The design of the interaction infrastructure ("neural space") should lead the design of the physical layout ("building space"), although each will constrain development of the other as design proceeds.

Rather than rooting the initial design stage in large-scale site planning and massing models, we begin with the neural space: What actions is the building to perform to benefit specific occupants in specific ways? What sensors are needed to gather the necessary data? What effectors will implement the actions? How will the interaction infrastructure be designed to link them, using new neuroscience data to develop complex information structures such as that of the TAM-WG model? With an initial design completed for the neural space (where "space" is used here in the abstract sense of elastic relationships, with no prior commitment to placement of its elements in space in the conventional 3D sense), design of the physical layout can proceed, incorporating the placement of the design elements of the neural space in the unfolding integrated design.

A Case Study

The poster at ANFA 2018 will provide a worked-out example, an apartment for a blind resident whose design exemplifies this strategy. We will use the above data on the importance of the tactile sense as a guiding principle for the physical layout, while adding a specific exercise in neuromorphic architecture – the design of the interaction infrastructure ("brain") of the kitchen which integrates sensors and effectors to supplement the resident's working memory of where items are located and the sequencing and timing of a recipe while cooking. Supplementing the blind resident's command of a great deal of verbal and spatial memory, the interactive kitchen uses technological tools and audio cues to offload this memory and assist in cooking tasks. A key point for debate is the extent to which neuroscience can add to the growing impact of artificial intelligence in the design of interactive architectures.

References:

Arbib, M. A. (2012). Brains, machines and buildings: towards a neuromorphic architecture. *Intelligent Buildings International, 4*(3), 147-168, DOI:110.1080/17508975.17502012.17702863.

Folska, C. L. (2012). *In blind sight: Wayfinding in the absence of vision.* Ph.D. Thesis, University of Colorado at Denver,

Guazzelli, A., Corbacho, F. J., Bota, M., & Arbib, M. A. (1998). Affordances, Motivation, and the World Graph Theory. *Adaptive Behavior, 6*, 435-471.

Passini, R., & Proulx, G. (1988). Wayfinding without vision: An experiment with congenitally totally blind people. *Environment and Behavior, 20*(2), 227-252.

Authors:

Michael Arbib. Adjunct Professor of Psychology, UCSD, and Contributing Faculty Member, NewSchool of Architecture and Design, San Diego. arbib@usc.edu

Arbib wrote the book on "Brains, Machines and Mathematics" and is an expert in computational neuroscience and the evolution of the language-ready brain. He pioneered the notion of "neuromorphic architecture" in the sense of designing a building with a "brain." Having served as ANFA vice-president, he is currently coordinator for the ANFA Advisory Council. His UCSD lectures (and other talks) linking neuroscience and architecture are available on YouTube.

Tricia Ngoon. Ph.D. Student in Cognitive Science, UCSD, tngoon@ucsd.edu

Ngoon is a Ph.D. student in Cognitive Science advised by Dr. Scott Klemmer. Her research examines how to support relational thinking and creativity in learning. This paper is based in part on her project in Michael Arbib's 2017 course at UCSD on the interaction between neuroscience and architecture.

Eric Janes. Designer.SanDiego, janeseric@gmail.com

Janes is an architectural designer with a keen interest in the biological reasons behind how we, as humans, experience tectonic space. He believes that design is an evolution of work produced along a meandering path of discovery and learning.