The Cognitive Envelope

Aude Oliva & Santani Teng

Computer Science and Artificial Intelligence Laboratory
Massachusetts Institute of Technology
oliva@mit.edu, santani@mit.edu

Disclaimer: This summary is a section of the following chapter: *Oliva A., Teng S. (2016). The Cognitive Society. In: Handbook of Society and Technology Convergence. W. S. Bainbridge, M. C. Roco (Eds.), Springer, pp. 743-754.*

Summary

The Cognitive Envelope is a framework allowing the mapping of spatiotemporal interactions of technology and cognition, and examining the temporal and spatial scales over which we have cognitive access.

The Cognitive Envelope

Humanity's rate of technological progress is breathtaking: in 1969, the single, prophetic word "login" was the first message ever to travel between two connected computers. By 2020, 50 billion devices will routinely access a vast cloud of near-ubiquitous knowledge and connections (Meunier et al., 2014). Their interactions, at both individual and global levels “will be notable for being invisible” to the human mind. Meanwhile, the field of cognitive science, progressing in intimate parallel with computing technology, has facilitated major advances in our understanding of brains, minds, and their constituent operations.

Given a ubiquity of convergent cognitive technologies that are leveraged to enhance human decision-making, well-being, and public health: How can we think about the implications of a vast range of human-technological interactions in cognitive terms? We address this question within the framework of a *cognitive envelope* to conceptualize some of the consequences of human and artificial cognitive interactions.

Cognition in the broadest sense is both a straightforward and elusive concept. Intuitively we think of cognition as thinking — “the ultimate brain function” (Robbins, 2011). In the context of artificial systems, cognitive computation must be both fast and complex. To speak concretely about the implications of cognitive computation, we propose to sketch a *cognitive envelope* that places the broad concept of cognition within pragmatic dimensions of time and space.

Human thought and action operate on a wide range of time scales: an individual episodic memory, for example, may take fractions of a second to retrieve, seconds to select from among others, minutes to write down, and a lifetime to forget. The concept is not new to cognitive science: In building a case for a universal theory of cognitive architectures, Allen Newell (1990) divided human activity into four "bands" — Biological, Cognitive, Rational, and Social — spanning 12 orders of temporal magnitude between 100 μs and several months. For Newell, the range from about 10 ms to 1 second was key for basic cognitive processes and was thus labeled the Cognitive Band. As Newell himself pointed out, these boundaries were approximate; for our purposes, the bulk of cognitive psychology and neuroscience experiments place critical cognitive processes in this range, up to several seconds.

Cognition has a spatial as well as a temporal scale. This notion is common within the field of embodied cognition, which posits, e.g., that cognition is situated in relevant real-world contexts, optimized for motor action, and sometimes "offloaded" to the environment (Wilson, 2002). It also finds traction in the neuropsychology literature, with evidence of distinct cortical networks supporting different behaviorally relevant realms. For example, space within arm's reach has a different behavioral relevance, and thus likely a different cognitive role, than does space at an unreachable distance (e.g., Previc, 1998). Notably, the various models reviewed by Previc (1998) and others tend to limit space for interaction to a radial distance of a few tens of meters. For our purposes, the intuition to extract from this body of research is that space matters to cognition, and that the interactions for which cognition is most relevant tend to occur on the order of 10^1 m or less.

Many processes, both natural and artificial, operate at short time scales unavailable to conscious perception, i.e., below the cognitive envelope. Represented by the lower left example in (Oliva & Teng, 2016, Fig 1), an artificial robot system comprising a three-fingered hand and high-speed camera can achieve a perfect winning record against a human in repeated games of rock-paper-scissors (Katsuki, Yamakawa & Ishikawa, 2015). The implications of this seemingly innocuous example are profound: the robot can perceive the human player's gesture and react accordingly in less time than it takes the human player to complete her own move. Thus, a game premised upon unpredictable decisions, driven essentially by chance, becomes wholly deterministic. In this way, small interactions between humans and artificial systems take on a fundamentally different character from a perspective inside versus outside the cognitive envelope. Finally, at lower right, sub-perceptual speed of processing can span large distances as well. As part of a research program in neural prostheses at Duke University, a monkey in the United States was able to remotely control a walking robot in Japan using implanted neural electrodes (Cheng et al., 2007). The signals traveling from the monkey's brain reportedly reached the robot, over 11000 km away, 20 ms before arriving at the monkey's own leg. Thus, through this high-speed fiber-optic connection, an artificial motor system on the opposite side of the planet was integrated into the monkey's own cognitive envelope as she controlled the robot using her own motor cortex and visual feedback from a video feed. This demonstration illuminates the possibility that technology can enable cognitive-level operations (in this case, deciding to initiate or stop a motor movement) even across distances otherwise inaccessible to real-time cognitive interaction.

While the Cognitive Envelope framework is illustrated along two salient dimensions, cognitive operations are necessarily complex and likely to exist in a high-dimensional space. Yet a computer performing a billion floating-point operations in one second is not automatically doing the same thing as a human performing a cognitive act in one second. Thus, a third dimension could capture complexity or "cognitive capacity," some measure of not just the time and spatial scales of cognitive processes, but of their sophistication.

Operationalizing cognitive capacity, especially into a meaningful single dimension, is difficult at best. However, intuitively, we should be able to characterize, to some extent, the relationships between artificial systems, biological cognition, and the common principles underlying them. As with the 2-dimensional Cognitive Envelope presented above, a three-dimensional model provides an intuitive representation of the space that cognitive processes inhabit, and that human-technology interactions can traverse.

We can speculate on the possible expressions of cognitive capacity. For example, information such as the time of day, distance to an obstacle, or the number of people in a crowd is difficult to estimate quickly unaided, but does not comprise very different operations from what a human would conduct over a longer time scale. A head-up or other augmented-reality display would therefore present this information into a user's cognitive envelope across time and space, but not capacity. By contrast, humans have many well-documented limits on cognitive capacity: remembering or visually tracking more than a handful of moving items simultaneously will tax a typical person to the point of near-certain errors. Cognitive tasks such as mental rotation or continuous attention, critical to monitoring surveillance, defense, or medical imaging equipment, are also subject to systematic performance limitations. Wearable or prosthetic artificial devices without such limitations could, for example, bring a 20-object tracking capacity, occurring over the same time and space scale as tracking three objects, into a user's cognitive envelope via the capacity axis.

In the next decade, we will likely witness an era where technology will compress or expand time, space and capacity, to bring remote information into our cognitive envelope. Transformations like these are among the most direct embodiments of the oft-heard sayings that "the world is shrinking" or that "life is speeding up." In a not-so-distant society, the technologies mediating these distortions will become increasingly pervasive, and the consequences of leveraging them, positive and negative, must be taken into account.

References

Cheng G, Fitzsimmons NA, Morimoto J, Lebedev MA, Kawato M, Nicolelis MA. Bipedal locomotion with a humanoid robot controlled by cortical ensemble activity. Paper presented at: Annual Meeting of the Society for Neuroscience, 2007 San Diego, California.

Kaufman SB (2013) The Real Neuroscience of Creativity Beautiful Minds http://blogs scientificamerican com/beautiful-minds/the-real-neuroscience-of-creativity/

Katsuki Y, Yamakawa Y, Ishikawa M (2015). High-speed Human/Robot Hand Interaction System. In Proceedings of the Tenth Annual ACM/IEEE International Conference on Human-Robot Interaction Extended Abstracts (ACM) pp. 117–118.

Kelly K (2014) The Three Breakthroughs That Have Finally Unleashed AI on the World. Wired, Oct. 2014

Meunier F, Wood A, Weiss K, Huberty K, Flannery S, Moore J, Hettenbach C, Lu B (2014) The 'Internet of Things' is now: Connecting the real economy. Morgan Stanley Blue Paper, pp. 1–96

Newell A (1990) Unified Theories of Cognition. Harvard University Press, Cambridge MA

Oliva A., Teng S. (2016). The Cognitive Society. In: Handbook of Society and Technology Convergence. W. S. Bainbridge, M. C. Roco (Eds.), Springer, pp. 743-754.

Previc FH (1998) The neuropsychology of 3-D space. Psychol Bull 124:123–164

Robbins TW (2011) Cognition: the ultimate brain function. Neuropsychopharmacology 36:1–2