Agents' Cognition in the Smart City: An Agent Architecture Interaction Assessment Framework

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Abstract

This paper presents an agent architecture interaction assessment framework developed using constructs and measures from architecture [11,12, 18, 26, 27, 28, 35, 46], agent-based modeling [15, 52], human factors [36, 38, 39, 40, 45, 49, 50, 51], systems science & engineering [5, 6, 17, 12], cognitive science [1, 13, 20, 22, 23, 41, 47, 48, 53], neuroscience [19, 20, 37] and evolutionary biology [19, 34, 42]. This work elaborates the ANFA Conference Mission, *"…the range of human experiences that occur in context with elements of architecture, both exterior and interior..."* by expanding the constructs of 'human' to 'agent' and 'elements of architecture' to include all physical and non-physical architectures that function as part of an agent's ecological niche [18]. This reframing of the constructs of and relationships between humans and architecture is useful for modeling and analyzing interactions between humans, other intelligent agents, and their environments, because it puts all agents and environmental elements into one unified representational framework, defining them through a single, consistent, comprehensive schema with shared constructs and measures. This agent-based information processing systems assessment framework is especially useful now, as designers and researchers develop new constructs, methods, and tools for modeling, analyzing, simulating, and designing smart environments (e.g., smart cities, intelligent buildings, interactive environments, augmented cognition, etc.) [3, 4, 26,43]. As part of expanding the sense of what constitutes a 'cognizing agent' and an 'architecture', readers/attendees are introduced to emerging system types, including: complex, interactive architectural systems (CIAS) [1], cyber-physical systems (CPS) [16, 24, 25, 31, 32, 54, 55], socio-technical systems (STS) [14], cyber-social systems (CSS) [30], ultra-large scale systems (ULS) [33], complex, large, integrated, open systems (CLIOS) [10, 29, 44], multi-scale systems (MSS) [21], and the Internet-of-Things-Enabled Smart City Framework [4, 30]. These emerging systems entail increased complexity, a high degree of real-time interactivity between agents (people, buildings, other organisms, hardware, software), and an accelerated rate of adaptation/evolution [26] .

Need

Environmental design is an ethical act because the environments we create challenge and/or affirm people's beliefs and enhance or degrade their sensory perception, cognition, task performance, and well-being. As Winston Churchill noted, "We shape our buildings and afterwards our buildings shape us." [7] This same sentiment, expressed from an extended mind perspective is,

> *"In all this we discern two distinct, but deeply interanimated, ways in which biological cognition leans on cultural and environmental structures. One way involves a developmental loop, in which ways in response to external symbols adds something to the brain's own inner toolkit. The other involves a persisting loop, in which ongoing neural activity becomes geared to the presence of specific external tools and media…..the true power and beauty of the brain's role was that it acted as a mediating factor in a wide variety of complex and iterated processes, which continually looped between brain, body and technological environment, and it is this larger system that solved the problem."* [8]

In summary, by the environments we make, we, *"…make better worlds to think in."* [8] Our environments and tools are extensions of our minds. Architects and environmental researchers and designers should develop design and analysis tools to model and assess the likely beneficial or detrimental impacts of design decisions on human sensory perception, cognition, task performance, and well-being during the design process.

Goal

Environmental designers and researchers should develop constructs, measures, methods, and tools to simulate the likely impact of design decisions on sensory perception, cognition, task performance, and well-being during design, construction, and on an ongoing basis during organizational use. As a first step toward achieving these goals, people and their environments and other tools must be placed in a shared representational framework. If people's sensory perception, cognition, task performance, and well-being cannot be modeled directly in relationships with environmental structures and behaviors, then it is not possible to simulate and analyze how those environmental and tool affordances likely impact sensory perception, cognition, task performance, and well-being.

Context & Challenge

The challenge of developing such a shared representational framework is made more arduous by the current proliferation of complex and interactive systems and software, in our environments and as parts of our daily routines, as well as their rapid paces of evolution. This complexity, interactivity, and the rapid rates of change of these technologies increases the challenge of creating such a shared representational framework while also increasing the need for such a framework. Humans currently innovate and evolve their environments and behavioral routines faster than the concomitant changes to sensory perception, cognition, task performance, and well-being can be integrated into our work processes and cultures. How can we design systems of cognizing and socializing systems so complex that none of the designers or users completely understands what is being designed, what its boundaries are, how best to design it, how best to simulate/test/validate its performance, or how it will impact the sensory perception, cognition, task performance, and well-being of individuals and groups?

Approach

This paper uses agent-based modeling constructs and methods to frame the relationships between human, non-human, physical, and non-physical agents. It presents an agent architecture interaction assessment framework --- a shared representational framework for humans and their environments and tools --- designed to be useful for creating and analyzing models of how environmental design decisions likely impact human sensory perception, cognition, task performance, and well-being.

This approach is useful, especially now, as designers and researchers develop new constructs, methods, and tools for modeling, analyzing, simulating, and designing smart environments (e.g., smart cities, intelligent buildings, interactive environments, augmented cognition, etc.). Emerging system types, including: complex, interactive architectural systems (CIAS), cyber-physical systems (CPS), socio-technical systems (STS), cyber-social systems (CSS), ultra-large-scale systems (ULS), and complex, large, integrated, open systems (CLIOS), expand the sense of what constitutes a 'cognizing agent' and an 'architecture'. These emerging systems entail increased complexity, a high degree of real-time interactivity between agents , and an accelerated rate of adaptation/evolution.

Framework

The *agent architecture interaction assessment framework* treats all forms of processing --- whether physical or non-physical activities, as cognition. In addition, methods for measuring information content and information gain for agents engaged in processes are calculated. [56] Information gain is assessed with respect to overall quantity transformation from beginning of process to end of process, as well as assessment of rate of change, number of dependencies, number of dependents, centrality, and membership in neighborhoods of information. In addition, the stability and fault-tolerance of the information processing between agents are assessed in order to determine the resilience of the information processes enacted by the agents. Lastly, a weighted assessment of information processes per agent in relation to overall system goals is performed in order to validate usefulness of the information process with respect to a purpose. [57] (See Figure 1 and Figure 2)

This toolkit of assessments is performed with respect to four information processing domain constructs adapted from the theory of ecological niche construction in evolutionary biology. An agent's interactions are assessed with respect to the broad categories of ecosystems engineering, modification of selection pressures, ecological inheritance, and adaptation. [34] Through this analysis, it is possible to develop a relative assessment of the information content gain or loss (overall effect) of a design decision on agents' processing as well as a sense of the arduousness of the transition (amount of change needed to achieve a threshold value) per area of focus. This is a first step toward facilitating a cost/benefit analysis of the impact of design decisions on sensory perception, cognition, task performance, and well-being in order to make more useful and healthy decisions about design interventions.

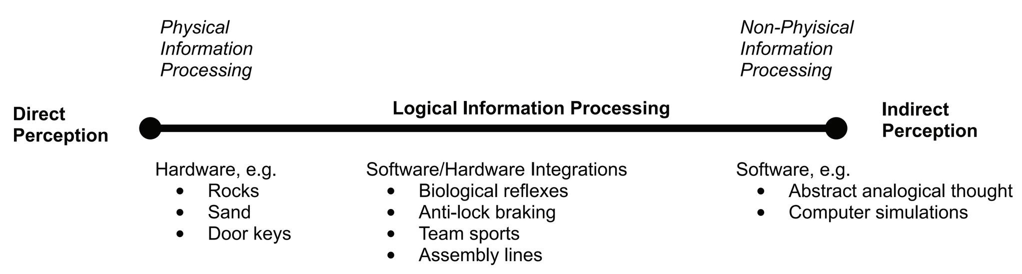

Figure 1: Viewing all physical and non-physical logical information processing as forms of thinking

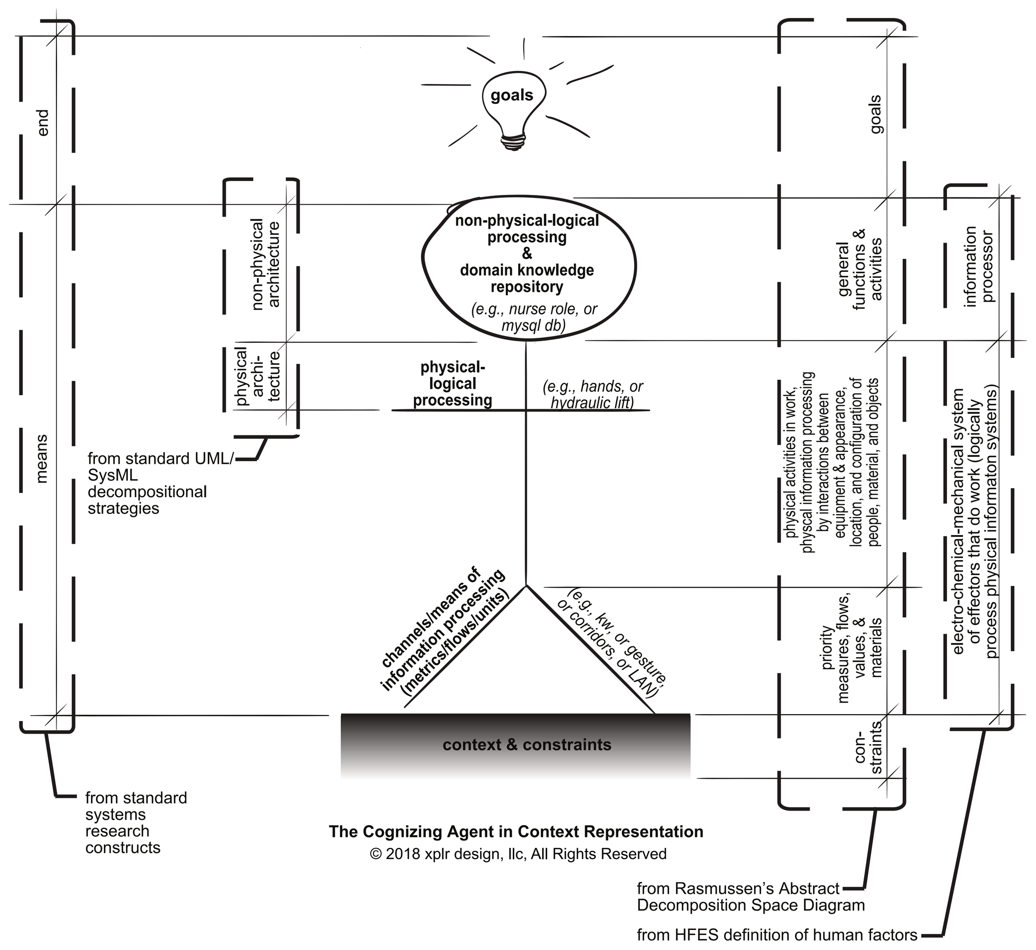

Figure 2: Integrated agent information processing view: Universalizing the Actor Representation --- All processing, physical and non-physical, is logical and is cognition.

Likely Use Cases

Likely use cases entail activities that have well-defined roles performing well-defined tasks through well-defined work processes in well-defined environment and tool ecosystems, including: military, healthcare, some educational environments, and industrial environments. Environments that entail poorly understood roles and tasks and environments would require additional work in order to implement the Agent Architecture Interaction Assessment Framework. This makes this Framework a useful litmus test for use of deep learning for process optimization.

Strengths & Weaknesses

The strengths of the Agent Architecture Interaction Assessment Framework are that it makes visible to the designer the relationships between the environments and tools being designed and the roles, sensory perception, cognition, task performance, and well-being of individuals and groups. The weaknesses of the Agent Architecture Interaction Assessment Framework are that it is labor-intensive and requires adequate access to information about the roles and tasks to be performed in an environment.

Next Steps

The next step is to develop tools based upon this framework and test the efficacy of the tools through case study analyses.

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