Reframing "Intelligence" in Computational Design Environments.

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Abstract

This paper seeks to establish a set of principals that form an understanding of intelligent systems related to design and architecture, through a review of intelligence as it has been understood over the last 60 years since Alan Turing first asked the question "can machines think?"[1] From this review, principals of intelligence can be identified within the neurophysiological and artificial intelligence (AI) communities that provide a foundation for understanding intelligence in computational architecture and design systems. Through critiquing these principals, it is possible to re-frame a productive general theory of intelligent systems that can be applied to specific design processes, while simultaneously distinguishing the goals of design oriented intelligent systems from those goals of general Artificial Intelligence research.

1. Why Critique Intelligence?

How can we begin to evaluate claims of intelligence for computational systems in architecture within the current technological environment?[2] Equally, how do we distinguish between complex, expert, computational and intelligent systems as the discipline moves into an era of open and highly customized software production and application? Clearly a framework of terms is necessary if we are to answer these questions. Similarly a taxonomy of system architectures is also necessary to determine what elements of a system might be considered essential for intelligence.

In architectural terms intelligence is perhaps typically understood along the lines of this definition by Kas Oosterhuis who writes, "Intelligence as I use it here is not seen as human intelligence. It is regarded as emergent behavior coming up from the complex interactions of less complex actuators. It seems to be possible to apply the same definition of intelligence to the functioning of our brains, traffic systems, people gathering, and to the growth and shrinking of cities." [3]

An Intelligent system should be seen as distinct from a system that is simply beyond understanding or computationally complex and based rather on types of computational architectures, and the goals of each type of system. These goals might include optimizing and managing processes or returning partnership capacities within a design team such as generating possible design options or integrating complex information and analysis into the design process. Architects and designers will ultimately use both intelligent and non-intelligent systems within their work. However as our discipline further evolves with technology, the genealogy of the digital is necessarily becoming more complex requiring an equal sophistication in its terminology.

As we interact more and more with design systems beyond our specific understanding, it could be said the site of design moves from the object to the organization, and the need for meta-models to assist designers and architects in understanding how to work with a systems particular architecture becomes both practically and theoretically important.

Without understanding a systems structure, or having a clear definition of its terms, effective communication between various systems structures becomes difficult, as does working with the limits and advantages of the growing numbers of systems that we are currently engaging.

Apart from identifying the foundations for a taxonomy of digital processes, identifying specific properties of an intelligent system in computational design processes is necessary to distinguish the design ambitions of an intelligent system from normative (if not complex) computationally driven work. The large majority of advanced work in architecture today is a result of systems often touted as intelligent, such as parametric modeling, BIM, evolutionary structural optimization (ESO) and so on. Typically however, these processes rely on functions of high level computational power within normative programming architectures displaying processing prowess but few of the hallmarks of intelligence as it is understood in other fields.

Similarly, the introduction of autonomous systems to both design and manufacturing, place a portion of the design and development process in the metaphoric hands of a system that may or may not have been programmed with disciplinary knowledge in mind. As we generate, auto-generate and assign control of aspects of design processes to complex systems, we are assigning part of our design intelligence to a third party whose assumptions and goals are likely to be different to our own.

As such there are many reasons to consider this an important point to determine a framework for intelligent design systems (IDS). Developments in all manner of technological systems and processes as well as our changing relation to software within the design process all contribute to the evolution of customized expert, complex and “intelligent” systems. While complex simulations such as the Earth Simulator project at the Japan Agency for Marine-Earth Science and Technology are not yet intelligent, their capacities for knowledge storage and retrieval, world modelling and behaviour generation might be considered aspects of intelligence which are evolving and converging. It is not difficult to imagine these systems developing rapidly to gain a measure of direct advisory and executive capacities such as those now well advanced in autonomous military weapons and information and battle management systems employed by the military.

All these aspects point to the evolution of a new relationship with technology beyond the simple singular operations of technology use today, in which computational intelligence will partner with us, not as a tool or device, but as a sophisticated set of compounded operations that will advise, guide, inform, suggest and empathize with our simplest tasks as well as our most complex goals as architects, designers and researchers.

Defining Intelligence

Definitions of intelligence vary with every discipline. James S. Albus writes, “Even the definition of intelligence remains a subject of controversy, and so must any theory that attempts to explain what intelligence is, how it originated, or what are the fundamental processes by which it functions.”[4] The intelligence industry is very active across many different disciplines including Neuroanatomy, Neurophysiology, Neuropharmacology, Psychophysics, and Behavioral psychology, not to mention work in Artificial Intelligence Research, Robotics, Computer Science and Computer Integrated Manufacturing.[5] While an exhaustive comparison of intelligence as it is understood across these disciplines is beyond this paper, there are several characteristics of intelligence that are common to many of these disciplines, and illustrate various characteristics of intelligence that may be appropriate to a general model for an intelligent design system.

It is necessary to note intelligence can be understood within the demands of each disciplinary type and is also typlically partitioned into various general levels of intelligence. Albus recognizes these levels as corresponding to *Basic Intelligence* or the ability to Sense the environment, make decisions and control actions, *Higher Intelligence* or the capacity to recognize objects, construct a world model and represent knowledge, and reason and plan for the future, and *Advanced Intelligence* which includes the capacity for perception and understanding, choosing wisely, acting successfully under numerous complex circumstances, and prospering.[6] Generally, a low level intelligence like that of a swarm of bees can be understood as being an implicit intelligence, generated from within the architecture of the (biological) system itself. This accounts for such apparently coordinated intelligence of insects and so on that act on instinct rather than reasoned thought, yet can be said to display intelligent behaviour that increases the survival possibilities of that species. Conversely high level intelligence is generally considered explicit and relies on calling from and reasoning through a knowledge base and knowledge representations or a world model.

Interestingly Turing frames the concept of higher and lower intelligence through the terms *sub-critical* and *super-critical*. *Sub-critical* intelligence in his example is that which would produce one response for every single input, something akin to an instinctual response. A *super-critical* response however would be the generation of multiple thoughts or outcomes, "...a whole theory, consisting of secondary, tertiary and more remote ideas"[7].

In Turning's test of machine intelligence in 1950 the common assumption of anthropocentrism is clearly defined through the device of his "imitation game". Predicated on the idea that if a computer can fool an impartial human into thinking it is a human through responses to questions, then that calculating machine should be considered intelligent. This test while still contentious[8] has motivated and sustained the artificial intelligence communities for decades and continues to provide a cornerstone of intelligence, even while other types of machine and biological intelligence form a substantial part of the research. In this sense, much AI and neurological research is conducted explicitly on the basis of explaining human/biological intelligence in such as way as to instantiate it in machine behaviour.

Manuel De Landa however interrogates the possibility of non-human intelligence as an alternative to this anthropocentrism. In *War in the age of Intelligent Machines*, De Landa for example writes a history of technology from the point of view of machines arguing "technological development may be said to possess its own momentum, for clearly it is not always guided by human needs."[9] In this way, other forms of intelligent systems may be possible to envisage, indeed become necessary to work with, but have until more recently been outside the mainstream of intelligence research.

However intelligence generally is assumed to encompass both biological and machinic/artificial instances and any general theory of intelligence then should encompass both these instantiations. Indeed most discussions of intelligence move easily between biological and artificial or synthetic examples. Albus, a roboticist and control systems expert, ascribes the creation of intelligence precisely to natural selection and the evolution of survival mechanisms within biology while seamlessly employing computational hierarchies, modules and frames to break-down intelligence into replicable applicable computational modules.

Jeff Hawkins and Sandra Blakeslee link intelligence specifically to prediction and memory, insisting that intelligence cannot be measured by behaviour. "Intelligence is measured by the predictive ability of a hierarchical memory, not by human like behaviour." [10] The central or peripheral role of behaviour as an indicator of intelligence is key to design systems yet still controversial as Hawkins' and Blakeslee's claim for example is refuted directly by the understanding in the AI community that intelligence is "that which produces successful behaviour."[11] Turing complicates this further by recognizing that a requirement of intelligence is the return of unexpected results from any interaction with an intelligent calculating machine noting, "It is probably wise to include a random element in a learning machine."[12]

Others such as Pierre Levy define intelligence not through a computational analogy or dependance on behaviour, but through a socio/political lens akin to Marshall McLuhan's concept of a *global brain* and Manuel Castells' formulation of the *Network Society*. In Levy's thinking, "We pass from the Cartesian *cogito* to *cogitamus*. Far from merging individual intelligence into some indistinguishable magma, collective intelligence is a process of growth, differentiation, and the mutual revival of singularities."[13] Intelligence in his case is aligned with an architecture of massive parallel processes creating intelligence through complexity. Levy's assumption is that intelligence is an inevitability of highly interconnected flows of information, foregrounding the anthropocentric aspect of a collective, technologically afforded and shared knowledge base that is part of an anthropological space he identifies as the "knowledge space".[14] Interestingly Levy includes technology as a foundational part of an anthropological definition, while being primarily concerned with the politicization of this knowledge space, linking intelligence to ideology. This allows him to state for example, "Totalitarianism collapsed in the face of new forms of mobile and cooperative labour. It was incapable of collective intelligence."[15] This aspect of intelligence has been developed more recently by Christopher Hight and Chris Perry[16] linking collective intelligence not only to forms of practiced intelligence with roots in the phenomena of emergence and complex information space akin to Oosterhuis definition, but to the political/ideological agenda of Michael Hardt and Antonio Negri's *Empire* and *Multitude*[17].

Yet another version of intelligence is in the sophistication of contemporary highly automated manufacturing systems. According to Andrew Kusiak[18], intelligence in design and manufacturing situations is an awareness of many subsystems and the capacity principally to integrate a multitude of discontinuous inputs. According to Kusiak computational intelligence is an almost everyday part of the manufacturing and design process. Motivating and linking systems such as automated material handling, data storage and retrieval systems, quality management systems, CAD, CAM and CAPP systems, and so on, Kusiak however still defers to an anthropologic model, stating for example "Computational Intelligence…allows automated systems, e.g. robotics, to duplicate such human capabilities as vision and language processing." In this context CI is an integration and protocol interpretation level operation.

For the purposes of initiating this research, Albus' provides the most direct and elaborated exposition in his *Outline for a Theory of Intelligence*, defining intelligence as "the ability of a system to act appropriately in an uncertain environment, where appropriate action is that which increases the probability of success, and success is the achievement of behavioural sub goals that support the system's ultimate goal."[19] Intelligence in these terms includes the integration of a range of essential components including, "behaviour generation, world modelling, sensory processing and value judgment."[20] For the purposes of this brief discussion, Albus' definition will suit as a benchmark to elaborate some elements of intelligent systems from the broader I.S. community that could help define intelligence in a design system.

Considering characteristics of Intelligent Design Systems (IDS)

It is clear that AI and design systems will not overlap completely in their understanding of intelligence, however it is still useful to compare aspects of one system to the other. As an example of some of the differences between IDS and AI systems we might look at the issue of goals. The goals of design as they are understood in this paper are along the lines of creativity and innovation, rather than problem solution. Goals within design and architecture in this sense then are frequently ill-defined and contingent on typically intuitive explorations of a very broad design or problem space, more so in design research. In this sense, one of the characteristic differences of intelligent design systems from Albus's and others definition is the ability to search out and recognize opportunity and innovation, and adjust goals as opportunities present themselves. Within this context, "acting appropriately" is contrary to innovation or generating deviations from normative or stochastically average behaviour. Indeed acting *inappropriately* is more of a goal of design systems, where explorations that redefine a design or problem space are initially highly desirable. Goals in this example are very fuzzy within design with priorities changing depending on circumstances and results. Within AI definitions goals are typically understood as highly determined and from outside the intelligent system, whereas in design, goals could be said to be generated from within it.

From the definitions above, it is possible to begin to isolate a non-exclusive list of characteristics that could be used to formulate a test for intelligence in computational design systems. These might include;

- The ability to respond to an environmental situation
- The ability to deviate from normative or expected behaviour
- Interaction with knowledge identities (databases) from inside and outside the design space
- Internalized feedback and feed-forward loops for error checking and self analysis
- Integration of both hierarchical and horizontal systems architectures
- An exceptionally broad world model i.e. set of assumptions about the world from which to base behavior and value judgments on.
- Capacity to integrate various systems protocols
- Generative of behavior
- Ability to generate and evaluate new system goals
- The ability to apply value-state variables or Value Judgments. "Unless machines have the capacity to make value judgments (i.e. to evaluate costs, risks, and benefits, to decide which course of action, and what expected results, are good, and which are bad) machines can never be intelligent or autonomous."[21]

Conclusion

As computational systems evolve from expert tools to fulfill both advisory and executive roles within generative design practice,[22] a critical understanding of what defines intelligence in computational design systems is particularly pressing. Oosterhuis' definition is typical of the application of the term intelligence within current architectural discourse, equating intelligence with emergence, or other forms of recognizable pattern or behavior as a consequence of complex interactions or calculations. In this form, intelligence is often ascribed to any system displaying complexity beyond human comprehension yet in a general model of intelligent design systems we should be critical of assigning intelligence to phenomena we do not understand. Like Levy's Collective Intelligence, Oosterhuis' swarm intelligence operates at best at a low level when assessed through current AI definitions as it lacks attributes of higher or advanced intelligence such as reference to world models, value judgments and so on, and demonstrates the need for a more sophisticated approach to an evolving and maturing digital genealogy.

Through comparison of several key properties of intelligence from AI and Neurophysiological research, benchmarks can be created to assess whether an IDS is indeed intelligent or not. Using these characteristics it will also be possible to begin to sketch out a schema of levels of intelligence and various systems architecture. Without this taxonomy, meaningfully communicating across the vast array of systems currently in use will become more difficult.

The anthropomorphic measure of intelligence is also far less of issue in computational design systems than within most AI applications, and IDS are dependant on new paradigms of intelligence in order to evolve. While most researchers agree that when artificial intelligence or intelligent systems do come along they won't be in any recognizable or expected form[23], basic issues such as the inference of intelligence through behaviour or pattern generation remain controversial. Since these basic assumptions remain unclear, it is timely to ask how we might begin to develop a theory of design in the age of intelligent systems. As the design work flow moves from image to information based models, and as architects further develop working processes with the abstractions of script, algorithm and real-time data flows, the need for a common framework to distinguish and evaluate evolving forms of computational processes and partnerships will become only more urgent.

Endnotes

1 See Turing A, *Computing Machinery and Intelligence*, Mind, 59, 1950 pp 433-460 http://www.abelard.org/turpap/turpap.htm (accessed 11.01.08)
2 For a general overview of digital design and manufacturing systems see Kolarevic B (ed.), *Architecture in the Digital Age. Design and Manufacturing*, London: Spon Press, 2003.
3 See Oosterhuis K, "A new kind of Building", in Graafland A, and Kavanaugh L J, (eds.) *Crossover. Architecture Urbanism Technology*, Rotterdam: 010 Publishers, 2006, p243
4 See Albus J, "Outline for a Theory of Intelligence" in IEEE Transactions on Systems, Man and Cybernetics, vol 21, No.3, May/June, 1991 pp473-509
5 Paraphrased from Albus J, "Outline for a Theory of Intelligence" in IEEE Transactions on Systems, Man and Cybernetics, vol 21, No.3, May/June, 1991 pp473
6 See Albus J, "Outline for a Theory of Intelligence" in IEEE Transactions on Systems, Man and Cybernetics, vol 21, No.3, May/June, 1991, p474
7 See Turing A, *Computing Machinery and Intelligence*, Mind, 59, 1950 pp 433-460 http://www.abelard.org/turpap/turpap.htm (accessed 11.01.08)
8 See John Searle's Chinese Room Argument (1980) directly contests Turing's assumptions of the relationship between mind and intelligence and remains controversial.
9 See De Landa M, *War in the Age of Intelligent Machines*, New York: Zone Books, 2000, p3
10 See Hawkins J, Blakeslee S, *On Intelligence*, New York: Times Books, 2004, p210
11 See Albus J, "Outline for a Theory of Intelligence" in IEEE Transactions on Systems, Man and Cybernetics, vol 21, No.3, May/June, 1991, p473
12 See Turing A, *Computing Machinery and Intelligence*, Mind, 59, 1950 pp 433-460 http://www.abelard.org/turpap/turpap.htm (accessed 11.01.08)
13 See Levy P, *Collective Intelligence*, Cam. Mass: Perseus books, 1997, p17

14 See Levy P, *Collective Intelligence*, Cam. Mass: Perseus books, 1997, p5
For levy, an anthropological space is “a system of proximity (space) unique to the world of humanity (anthropological), and thus dependant on human technologies, significations, language, culture, conventions, representations, and emotions.”

15 See Levy P, *Collective Intelligence*, Cam. Mass: Perseus books, 1997, p3

16 See Hight C, Perry C, (eds.) *Collective Intelligence in Design*, AD Vol 76, No. 5, New York: Wiley Press, 2007

17 See Hardt M, Negri A, *Empire*, Boston: Harvard University Press, 2000 and Hardt M, Negri A, *Multitude*, New York: The penguin Press, 2004

18 See Kusiak A, *Computational Intelligence in Design and Manufacturing*, (New York: John Wiley and Sons, 2000

19 See Albus J, “Outline for a Theory of Intelligence” in IEEE Transactions on Systems, Man and Cybernetics, vol 21, No.3, May/June, 1991, p474

20 See Albus J, “A Theory of Intelligent Machine Systems” in *Intelligent Robots and Systems ’91. ‘Intelligence for mechanical Systems, Proceedings IROS ’91*. IEEE/RSJ International Workshop, vol1, 1991, pp3-9

21 See Albus J, “Outline for a Theory of Intelligence” in IEEE Transactions on Systems, Man and Cybernetics, vol 21, No.3, May/June, 1991, p502

22 Burke A, “After BitTorrent: Darknets to Native Data” in Hight C, Perry C, (eds.) *Collective Intelligence in Design*, AD Vol 76, No. 5, New York: Wiley Press, 2007

23 See Hawkins J, Blakeslee S, *On Intelligence*, New York: Times Books, 2004, p207