

## The Prospects for Creating Conscious Machines

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While there have been discussions of computers reaching human levels of intelligence ([1], [2]), we should not over-simplify the issue of building intelligent or conscious machines. We should also not conflate intelligence and consciousness. Many computational problems may involve trade-offs of intelligence and consciousness. The largest current computer is the 212,992 processor IBM BlueGene (74 terabytes memory and 596 teraflops peak speed). It could probably simulate  $10^{13}$  synapses [3], while humans have about  $10^{15}$ . There are many unknowns, however, related to wiring diagrams, software, hardware, algorithms, learning, sensory input, and motor-control output. A machine that combines intelligence and consciousness cannot just be an isolated computer. It will need to be a complex *system of systems* and be capable of learning and understanding real world situations. The key, however, is emergent behavior development through a variety of algorithmic techniques including: genetic algorithms, machine learning, cognitive architectures and connectionist methods. Humans will not be capable of completely specifying and programming the entire system; learning and emergent behavior [4] will be a stringent requirement for development.

Conscious machines will need to be embedded in the real world with significant input/output capabilities and the ability to learn from people and experience. They will also need to be able to use context to modulate the expression of learning. The human sensory systems use hundreds of millions of cells, and there are roughly 600 muscles in the human body. The fascinating robotic vehicles in the DARPA Urban Challenge have very few sensor systems (e.g. lasers, cameras, and radar) and very few motor-control output channels. They also required complex software and teams of engineers. Cognitive architectures (e.g. Soar, SS-RICS, and ACT/R), have been implemented on mobile robots ([5], [6]), but these too are not very capable yet. Biological systems and computers can be compared in terms of in terms of memory and speed, but these are only two of the requirements for an intelligent machine.

Evolution is basically an optimization program, and the human brain has been evolving for at least 4 million years. Genetic algorithms and evolutionary techniques can be used to simulate human evolution; however, duplicating the conditions that led to the evolution of the human brain would be difficult, if not impossible. Symbolic A.I. will not lead to machines capable of duplicating human behavior. Connectionists and subsumptive architectures will not, by themselves, lead to the development of human-level intelligence nor the functional characteristics that define consciousness. Rule-based systems and cognitive architectures require humans to program the rules, and this process is not scalable to billions of rules (a.k.a. the Frame problem). The machines will need to rely on hybrid systems and emergent behavior; and they will need to be carefully taught and "mothered" by teams of engineers and scientists. In conclusion, human-level intelligence and consciousness might be possible as an emergent property of a massively parallel learning machine using a hybrid system of algorithms, architectures, and computational mechanisms.

1. Kurzweil, R., *The Age of Spiritual Machines: When Computers Exceed Human Intelligence* 2000: Penguin.
2. Moravec, H., *Robot: Mere Machine to Transcendent Mind*. 1998: Oxford University Press.
3. Long, L.N. and A. Gupta, *Biologically-Inspired Spiking Neural Networks with Hebbian Learning for Vision Processing*, in *46th AIAA Aerospace Sciences Meeting*. 2008, AIAA: Reno, NV.
4. Koch, C., *The Quest for Consciousness: A Neurobiological Approach*. 2004: Roberts and Company.
5. Hanford, S.D., O. Janrathitkarn, and L.N. Long. *Control of a Six-Legged Mobile Robot Using the Soar Cognitive Architecture*. in *46th AIAA Aerospace Sciences Meeting, AIAA Paper No. 2008-0878*. 2008. Reno, NV.
6. Avery, E., T.D. Kelley, and D. Davani, *Using Cognitive Architectures to Improve Robot Control: Integrating Production Systems, Semantic Networks, and Sub-Symbolic Processing*, in *15th Annual Conference on Behavioral Representation in Modeling and Simulation (BRIMS)*. 2006: Baltimore, MD.

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- We believe there will eventually be human-created conscious machines
- These will be complex “systems of systems” capable of learning and sensing, and understanding real world situations
- The key is emergent behavior development through a variety of algorithmic techniques (genetic algorithms, machine learning, cognitive architectures, and connectionist methods) and parallel computer/software systems.
- Humans will not be capable of completely specifying and programming the entire system; learning and emergent behavior will be a stringent requirement for development
- Need to differentiate between mechanisms needed to create consciousness and mechanisms required to maintain consciousness
- Systems, algorithms, and software must be scalable to human levels of performance:
  - Traditional AI is not scalable
  - Cognitive architectures are not scalable
  - Some Neural Networks are scalable

Important to distinguish between *Consciousness* and *Intelligence* :

### Consciousness:

“A State of Awareness” including:

- **Subjectivity:** Our own ideas, moods, and sensations are experienced directly; unlike those of other people.
- **Unity:** All sensor modalities melded into one experience
- **Intentionality:** experiences have meaning beyond the current moment

Arises from physical properties of the brain. (Kandel, et al, *Principles of Neuroscience*, 2000)

### Intelligence:

“A very general mental capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience.” (Gottfredson, *Intelligence*, 1997)

### Emergent Behavior:

“An emergent property of a system is one that is causally explained by the behavior of the elements of the system; but it is not a property of any individual elements and it cannot be explained simply as a summation of the properties of those elements.” (Searle, 1997)

Many current large engineering and software systems exhibit emergent properties. (Long, *CrossTalk Journal*, 2008).

### Consciousness and Emergent Behavior:

“... consciousness emerges from neuronal features of the brain.”  
(Koch, *The Quest for Consciousness*, 2004)

“Human consciousness ... can best be understood as ... virtual machine implemented in the parallel architecture ...” (Dennett, *Consciousness Explained*, 1991)

“Consciousness ... we can think of it as an emergent property.”  
(Searle, 1997)

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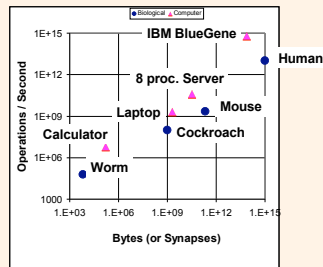
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## Computers alone will not produce Conscious Machines

## Systems are Needed, Not Just Computers

### The GOOD News:

Computer Systems are Close to Speed and Memory of Human Brain

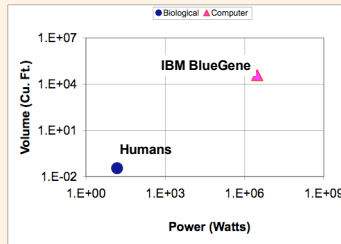
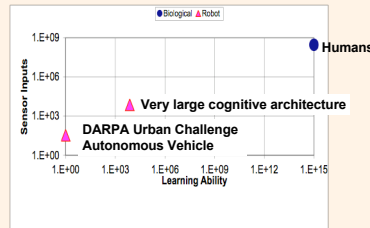


• But there are many other issues:

- Power
- Size
- Learning
- Sensory input
- Motor-control output
- Wiring diagrams
- etc.

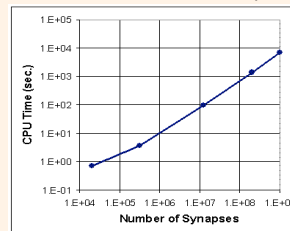
### The BAD News:

Computer Systems Require Enormous Power and Volume; and Robots have far less than Human Levels of Sensory Input and Learning

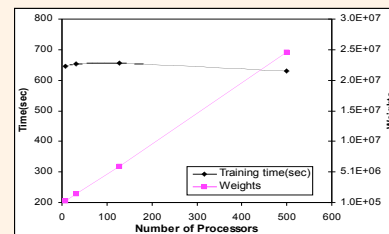


### Neural Networks

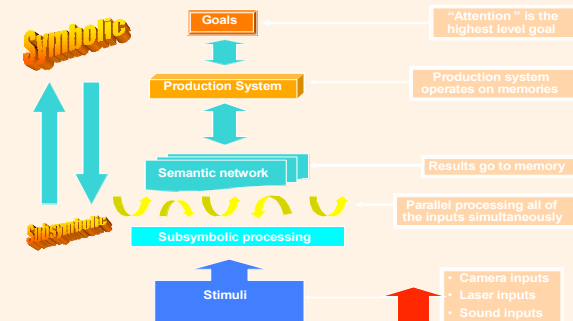
Scalable, Low Power, and can Learn (unsupervised or supervised). Will be many years, however, before these alone can produce consciousness. Laptop is on order of Cockroach. (Long and Gupta, AIAA Paper 2008-0885, 2008)



NN's can be Perfectly Scalable on Parallel Computers (Long and Gupta, JACIC, 2008)



Symbolic and Subsymbolic Robotic Intelligence Control System (SS-RICS) (Avery, Kelley, and Davani, BRIMS Conference, 2006)



In the near term, we will need hybrid systems: symbolic and sub-symbolic. We believe consciousness will result as an emergent behavior if there is adequate sensor input, processing power, and learning. Current robotic systems are many orders of magnitude from human abilities.

Very Similar to Dennett's (*Consciousness Explained*, 1991) idea of consciousness:

"Human consciousness is itself a huge complex of memes that can best be understood as the operation of a "von Neumannesque" virtual machine implemented in the parallel architecture of a brain that was not designed for any such activities."