

# Light in neural systems

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December 8, 2018

## Abstract

## 1 Introduction

Light is excellent for communication. If we are going to signal to extraterrestrial civilizations, it will almost certainly be with electromagnetic radiation. On our own planet, fiber optic links carry by far the most information across continents and between data centers. An important question in modern computing is: what is the shortest distance over which photonic communication is sufficiently advantageous and practical to merit displacement of electronic interconnects? Optical links between racks in data centers are becoming common. Major companies are investing seriously in photonics in the package. Monolithic optical links between processor and memory fabricated in a 45-nm CMOS node with no in-line changes have been demonstrated [2], with integration in 32-nm technology looking promising as well [1]. A primary challenge affecting further chip-scale electronic-photonic integration is the continued difficulty of achieving a light source implemented on silicon that is robust, efficient, and economical.

In parallel with the hardware considerations affecting optoelectronic integration are questions related to the future of computer architecture. A prominent theme emerging since clock speed leveled off in 2003 [ ] is parallelism. Computation is increasingly distributed among more processor cores. Many-core architectures continue to expand into complex on-chip networks (OCNs), in some cases resulting in highly distributed, brain-inspired systems [ ]. As compute grows more distributed, communication demands more from interconnect networks. The demand for energy efficient communication bandwidth has been a major driver of on-chip photonics.

The major drivers for brain-inspired computers fall on a spectrum: energy and algorithmic efficiency for deployable applications (Internet of things, self-driving cars, mobile devices) reside on one side of the spectrum, and artificial general intelligence (AGI) resides on the other. Knowledge gained from neuroscience informs us that systems with general intelligence will benefit from very large numbers of computational elements as well as extreme communication between them. It is our perspective that hardware incorporating light for communication between electronic computational elements combined with an architecture of distributed optoelectronic spiking neurons will provide tremendous potential for AGI. Considerations

pertinent to the realization of such a technology are the subject of this article.

## 2 Guided by neuroscience and VLSI

To guide the design of hardware for AGI, we must simultaneously consider the principles of neural information and principles of fabrication for very-large-scale integration. Regarding the principles of neural information, we know that computation in the brain makes efficient use of space and time by leveraging fractal scaling. [recap of general principles]

Based on these considerations, we expect a hardware platform capable of AGI to display at least six traits:

1. Plasticity mechanisms (excitation, inhibition, stdp, meta, homeostatic)
2. Dendritic nonlinearities (sequence detection and integration)
3. Spiking neuronal dynamics
4. Massive connectivity to enable short path lengths across big networks
5. The ability to efficiently use space from the scale of a single synapse up to systems limited by light-speed communication, and the ability to efficiently use time with network oscillations across a wide range of frequencies
6. Energy consumption and power density low enough to enable scaling to systems of this size

Regarding the fabrication of large systems, we assume success developing AGI is most likely if the infrastructure developed for digital computing with silicon electronics can be utilized. This leads us to at least five traits that hardware must display if extreme scalability is to be achieved:

1. Most likely based on performing lithography on silicon wafers
2. Patterning should not require features smaller than 193 nm lithography can achieve

3. Materials that are rare, volatile, or incompatible with conventional processing should be avoided
4. It is unlikely with any artificial technology that a human-level intelligence will fit on a single wafer. Straightforward assembly into multi-wafer modules should be achievable
5. For very large systems with photonic connectivity, the ability to leverage fiber optic technology will likely be highly advantageous

## References

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