VLSI neuromimetic artefacts

Brain-like computing on Silicon

Giacomo Indiveri

Institute of Neuroinformatics
UZH | ETH Zurich

Zurich, January 2007

Natural Computation

The Honeybee

The brain of the worker honeybee occupies a volume of around $1mm^3$ and weighs about 1mg. The total number of neurons in the brain is estimated to be 950,000

- Flies acrobatically
- Recognizes patterns
- Navigates
- Forages
- Communicates

Natural Computation

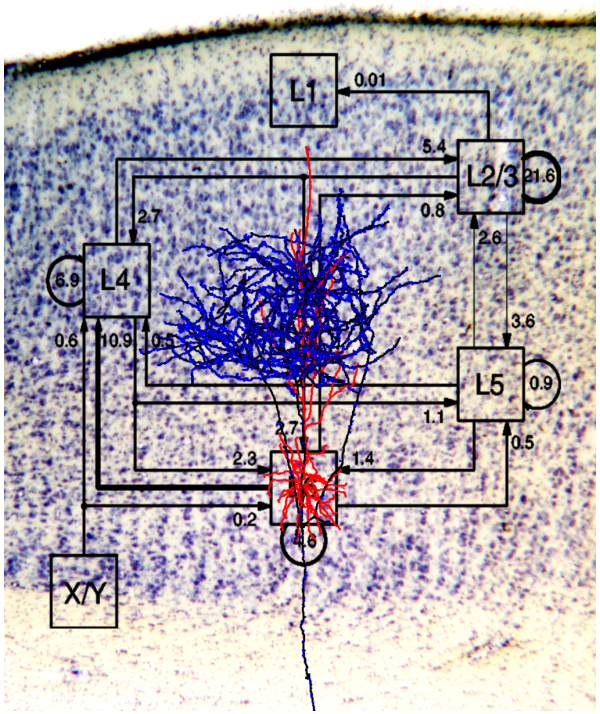
The Honeybee

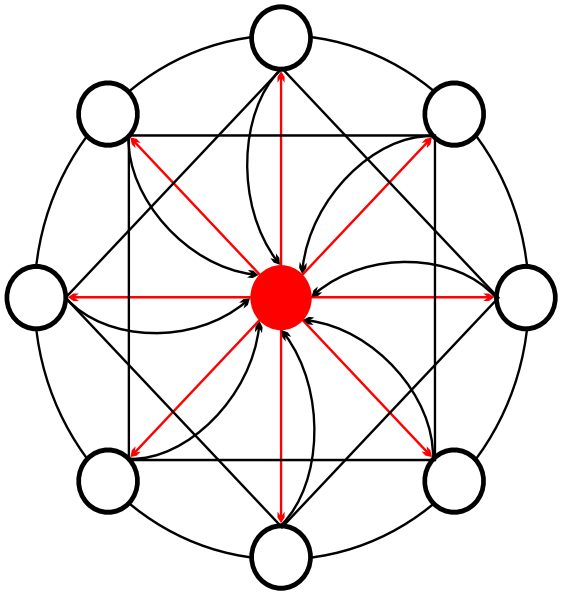
Energy consumption: 10^{-15} J/op, at least 10^6 more efficient than digital silicon

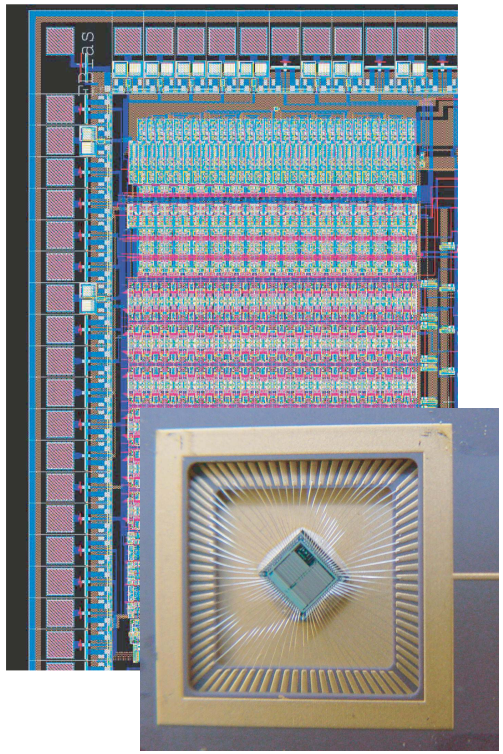
The brain of the worker honeybee occupies a volume of around $1mm^3$ and weighs about 1mg. The total number of neurons in the brain is estimated to be 950,000

- Flies acrobatically
- Recognizes patterns
- Navigates
- Forages
- Communicates

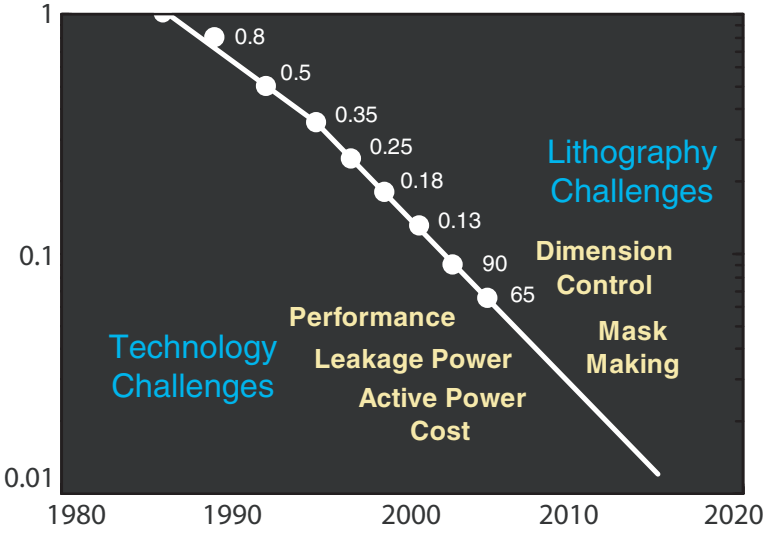
Neocortex → Neural computation → Silicon

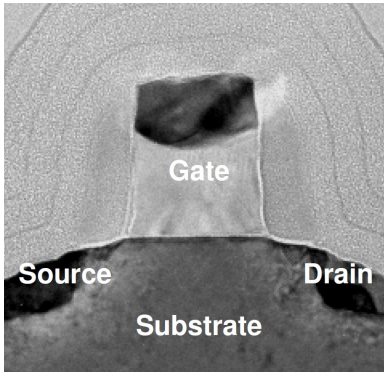






VLSI technology





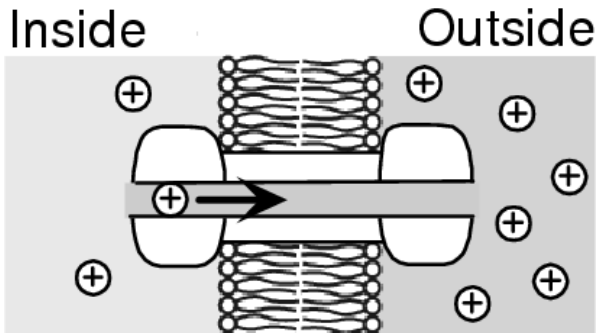
www.intel.com

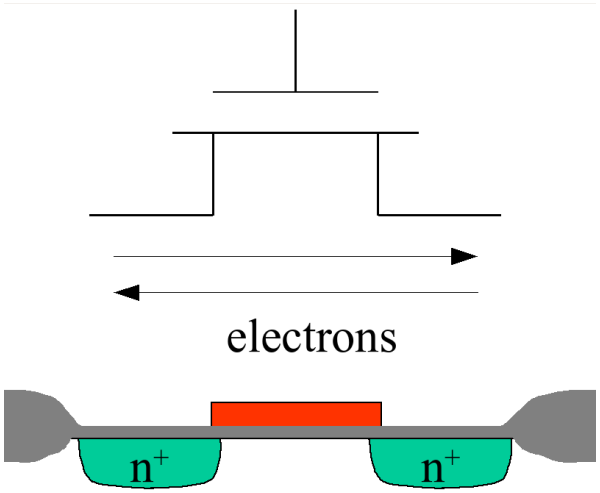
- Technological progress has rapidly increased the number of transistors that can be included on a single chip.
- Most current computing architectures are based on clocked, digital processing units with a low degree of parallelism
- IT community is struggling to find alternative design and computing paradigms to overcome these limits (e.g. INTEL multi-core CPUs, or IBM CELL processor).

Neuro-IT Roadmap v2.0

Neuromorphic VLSI systems

An attractive alternative computing paradigm

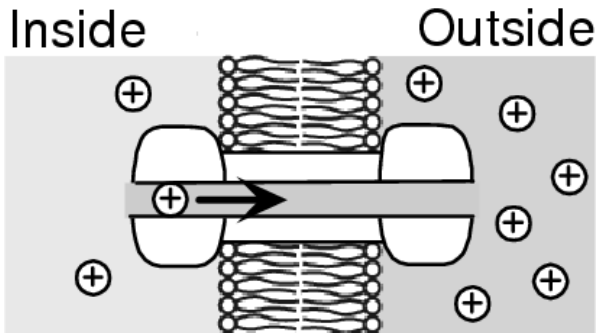


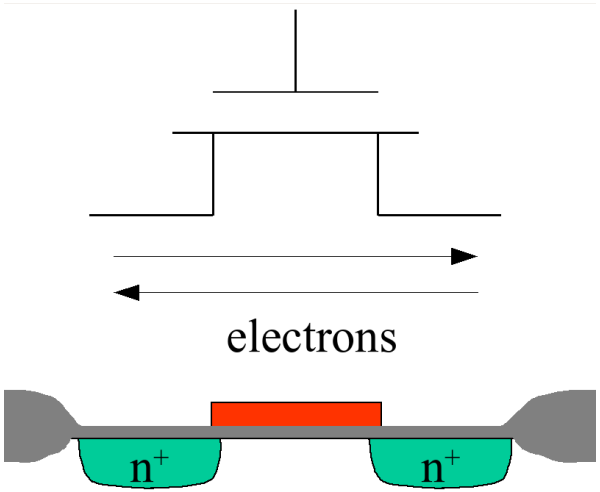


Exploit the physics of silicon to reproduce the *bio*-physics of neural systems.

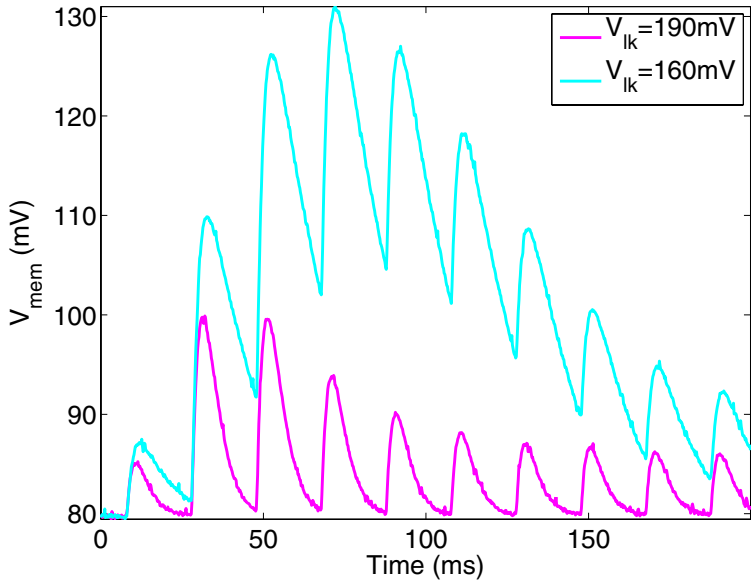
Neuromorphic VLSI systems

An attractive alternative computing paradigm



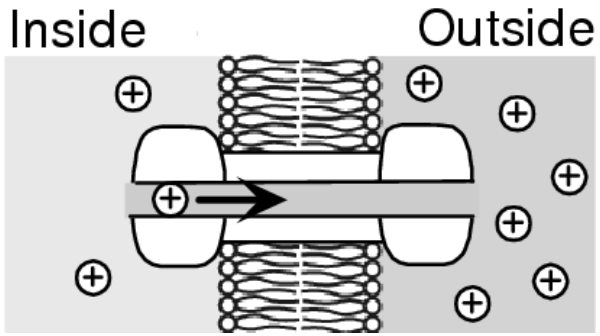


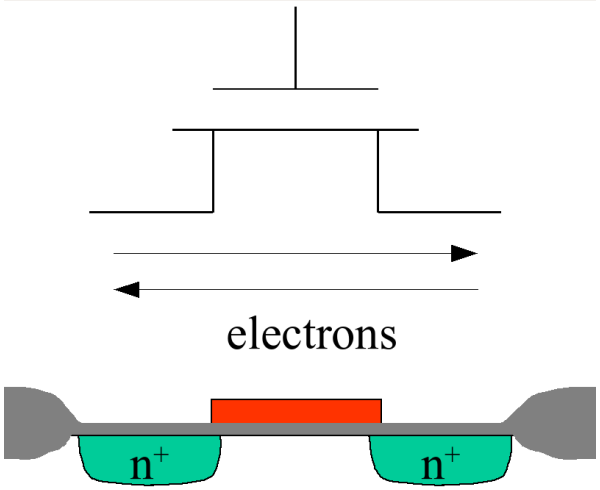
Exploit the physics of silicon to reproduce the *bio*-physics of neural systems.



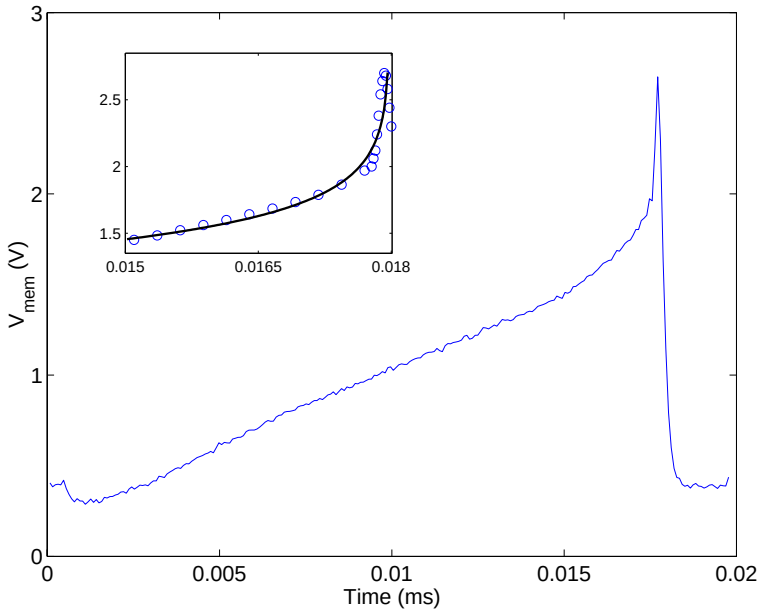
Neuromorphic VLSI systems

An attractive alternative computing paradigm



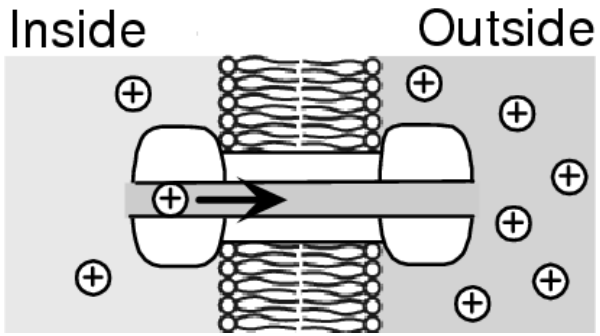


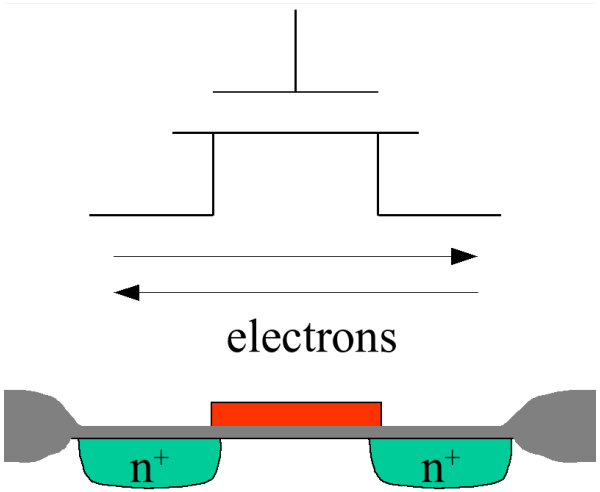
Exploit the physics of silicon to reproduce the *bio*-physics of neural systems.



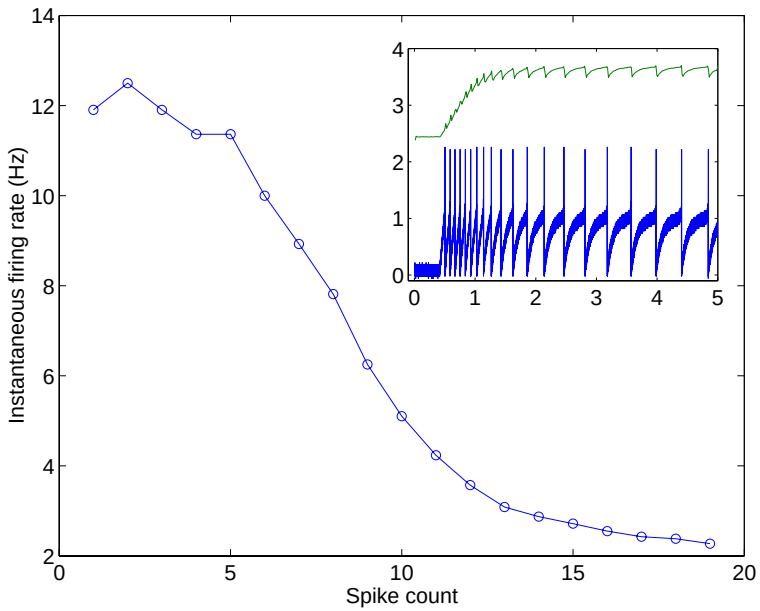
Neuromorphic VLSI systems

An attractive alternative computing paradigm



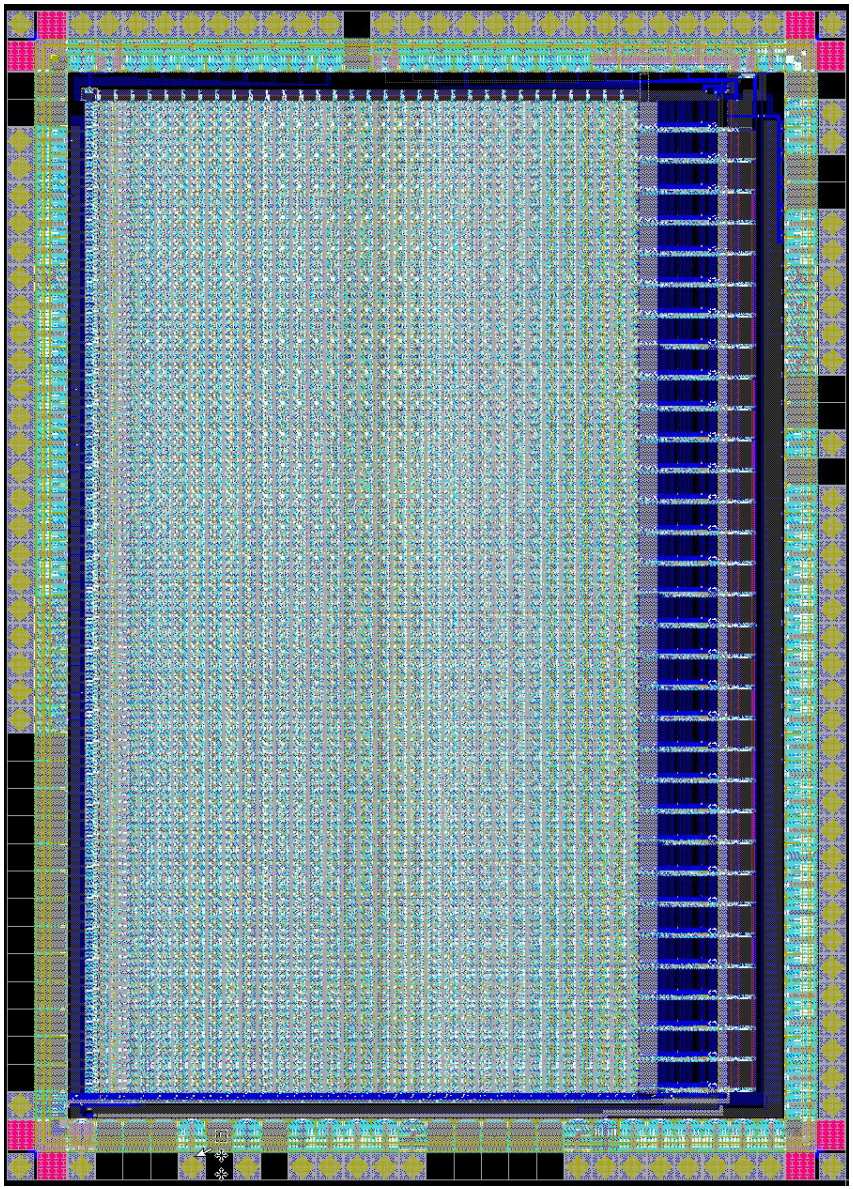


Exploit the physics of silicon to reproduce the *bio*-physics of neural systems.



Neuromorphic VLSI systems

An attractive alternative computing paradigm

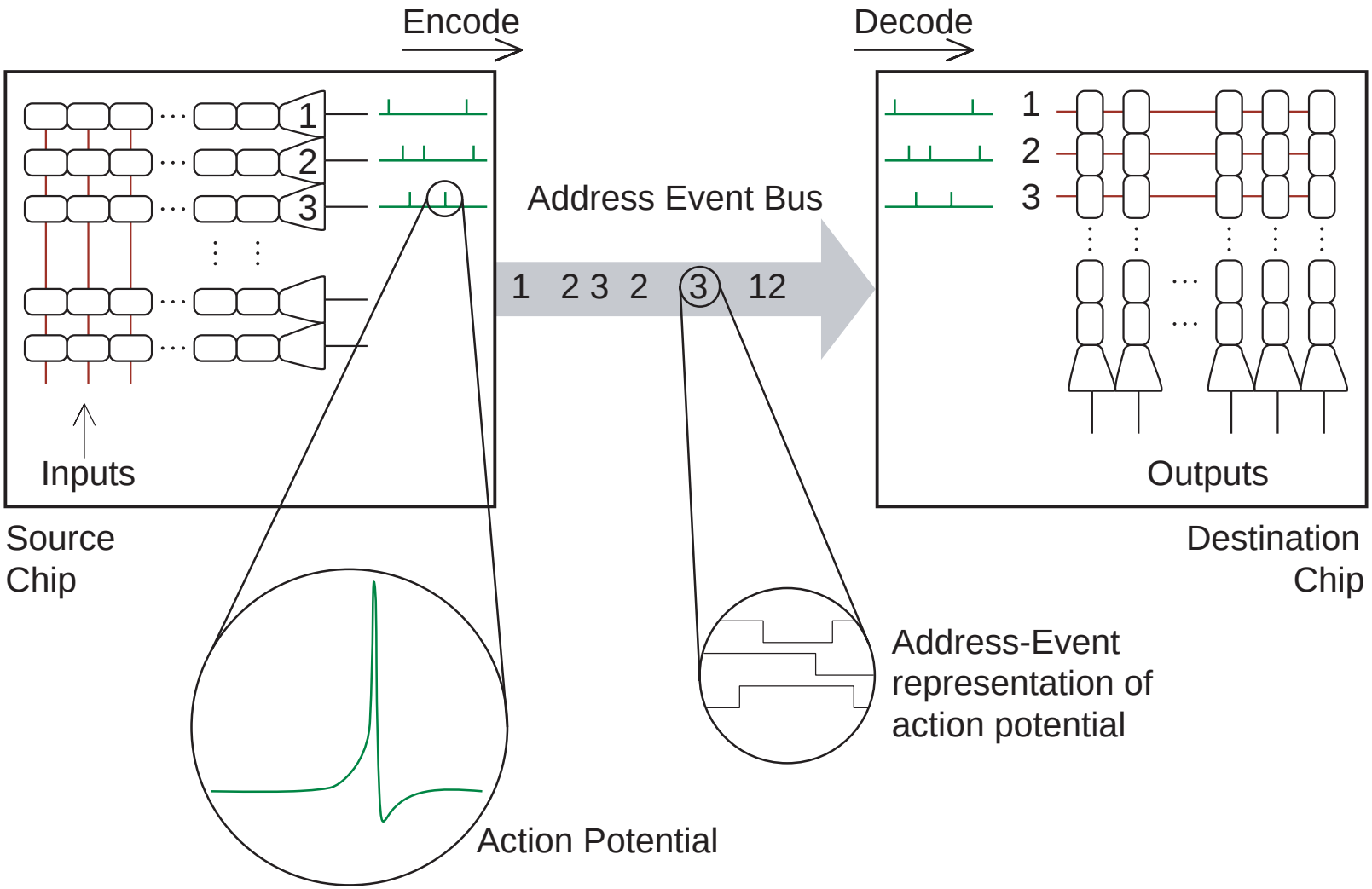


Exploit the physics of silicon to reproduce the *bio*-physics of neural systems.

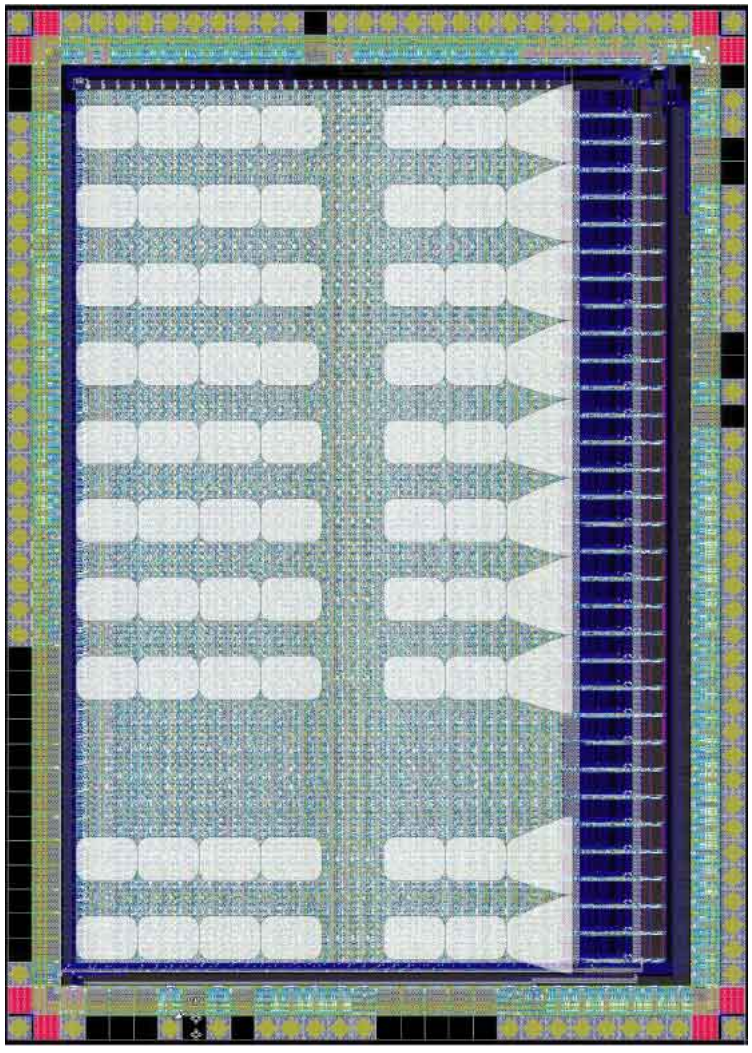
- Standard CMOS Technology
- Process independent
- Massively parallel
- Mismatch “insensitive”
- Fault tolerant
- Compact
- Low-power
- Asynchronous

Address Event Representation

Best of both (digital & analog) worlds

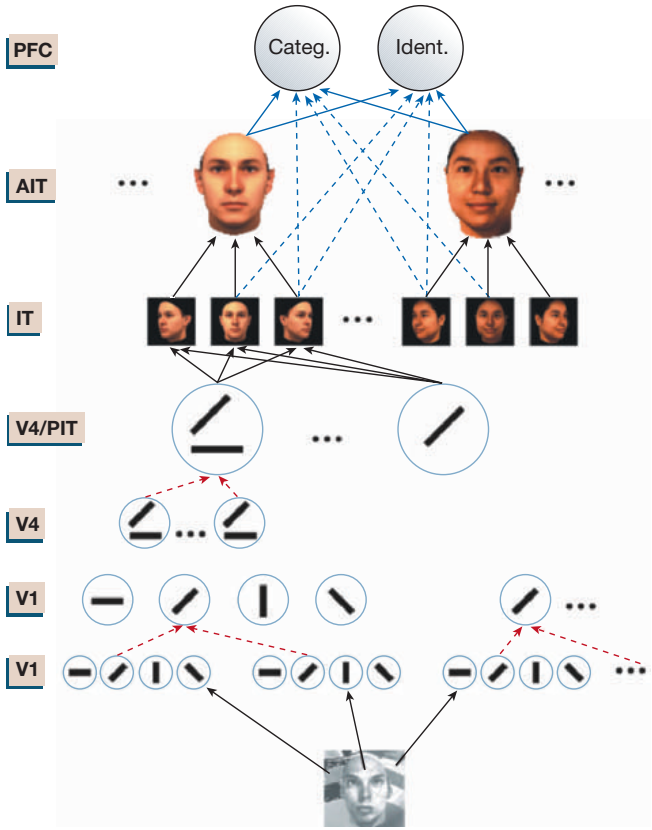


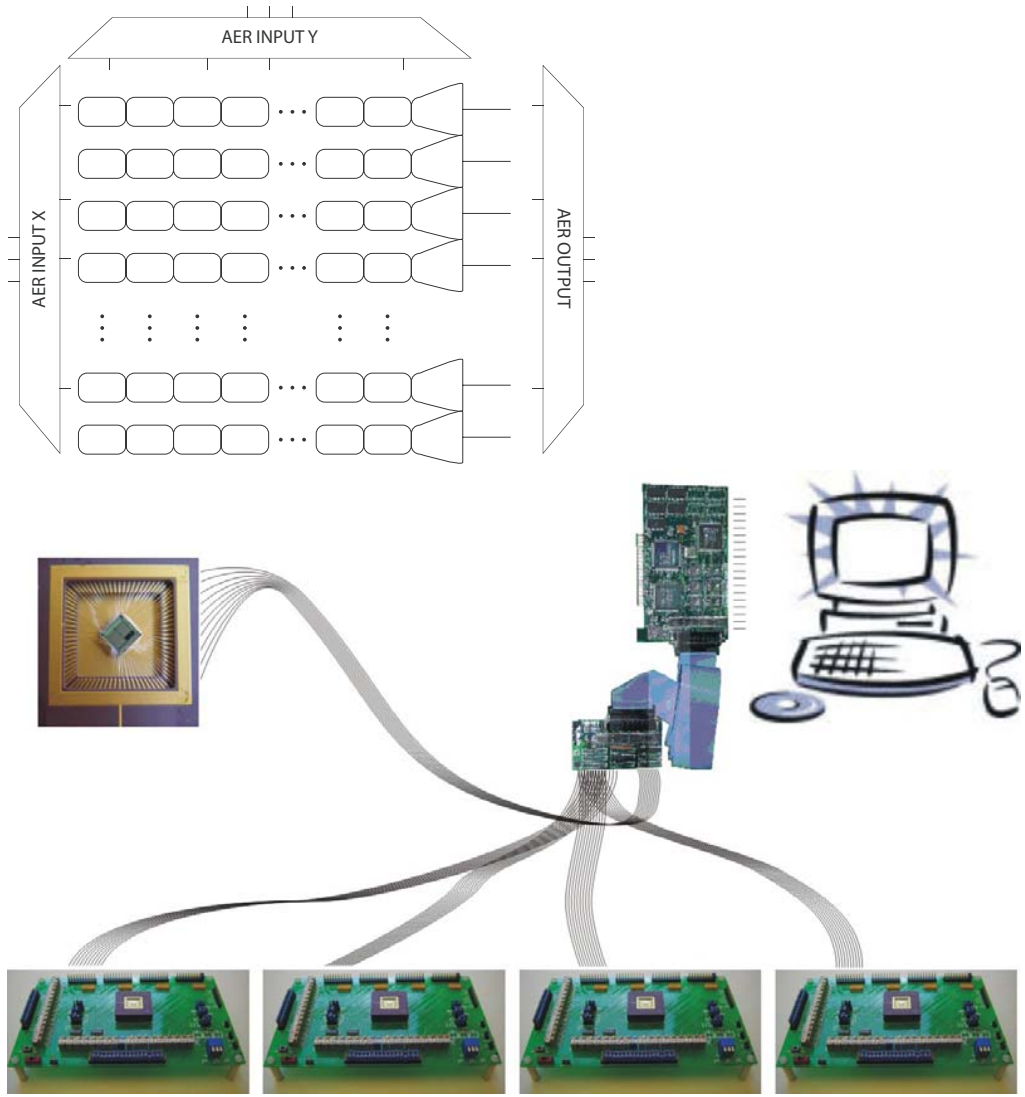
AER neural chips



- Activity in “core” is sparse
- Currents are integrated in parallel
- Synapses are the site of memory and computation:
  - Implement “elaborate” temporal dynamics
  - Implement “elaborate” plasticity mechanisms
- Neurons generate and transmit “spikes” on an asynchronous digital bus.

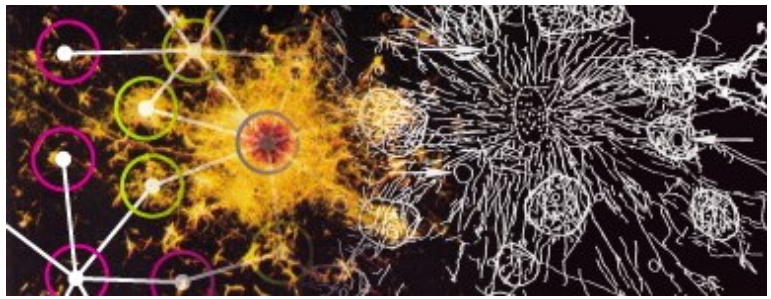
Hierarchical or multi-layer networks

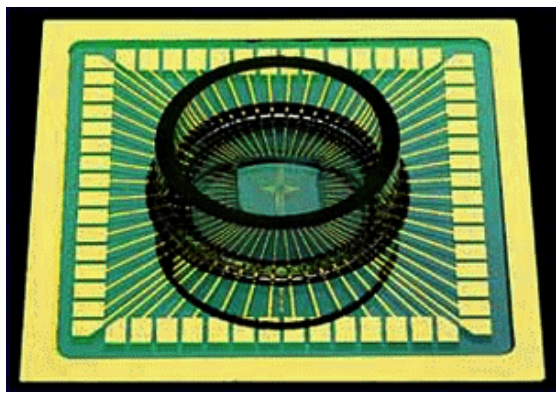




Potential Impact

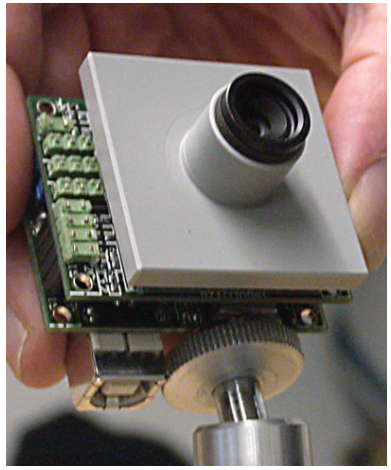
- Neuroscience
  - Theoretical models
  - Interfacing technology
- Robotics and Embedded Systems
  - AER, data-driven sensory input devices
  - Modular, reconfigurable AER signal processing
- Parallel Computation
  - Spike-based computation
  - Programming of massively parallel systems





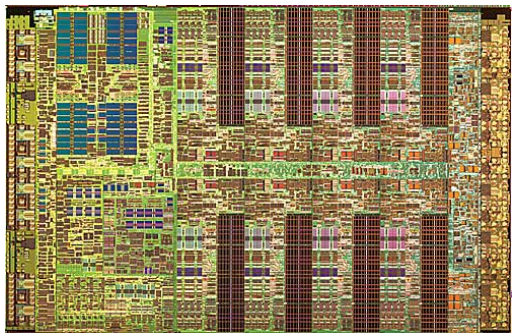
Potential Impact

- Neuroscience
  - Theoretical models
  - Interfacing technology
- Robotics and Embedded Systems
  - AER, data-driven sensory input devices
  - Modular, reconfigurable AER signal processing
- Parallel Computation
  - Spike-based computation
  - Programming of massively parallel systems



Potential Impact

- Neuroscience
  - Theoretical models
  - Interfacing technology
- Robotics and Embedded Systems
  - AER, data-driven sensory input devices
  - Modular, reconfigurable AER signal processing
- Parallel Computation
  - Spike-based computation
  - Programming of massively parallel systems



The ball is rolling

Past EU-Funded projects on AER systems

- ALAVLSI
- CAVIAR

These were the first important AER-oriented coordinated endeavors in the European context. ALAVLSI and CAVIAR developed complementary strategies for developing challenging hardware implementations of AER-based neural processing systems.

Integrated Projects (FP6 Bio-I^3 Proactive Initiative)

- CILIA: Customized Intelligent Life-Inspired Arrays
- DAISY: Neocortical Daisy Architectures and Graphical Models for context-dependent Processing
- FACETS: Fast Analog Computing with Emergent Transient States in Neural Architecture

Room to grow...

Bio-inspired hardware

In the short term, it is unlikely that such architectures will outperform conventional solutions, except perhaps on the sensory periphery. But they could be the first step towards new high performance computing strategies and provide new insights into the working of the brain.
[. . .]
Brain-like computing on silicon will be useful in a broad range of applications, from real time control devices for robots to implantable devices such as artificial cochleas and artificial retinas, to large scale simulation (e.g. of the brain).

Neuro-IT Roadmap v2.0