VLSI Neuromorphic Systems
Brain-like computing on Silicon

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The honeybee energy consumption is 10^{-15} J/op, at least 10^6 more efficient than digital silicon (20 watts vs. 10^6 watts).

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

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

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Neocortex → Neural computation → Silicon
Technological progress has rapidly increased the number of transistors that can be included on a single chip.

Future scaled CMOS systems will have increasing problems with device inhomogeneities and fault-tolerance.

IT community is struggling to find alternative design and computing paradigms to overcome these challenges (e.g. INTEL multi-core CPUs, or IBM CELL processor).
Neuromorphic VLSI systems
An attractive alternative computing paradigm

Exploit the physics of silicon to reproduce the *bio*-physics of neural systems.
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- Standard CMOS Technology
- Process independent
- Massively parallel
- Mismatch insensitive
- Fault tolerant
- Compact
- Low-power
- Asynchronous
Biomimetic neural chips
An attractive alternative computing paradigm

- Time constants are biologically plausible
- Currents are integrated in parallel
- Activity in “core” is sparse
- Synapses are the site of memory and computation
- Neurons generate and transmit “spikes” in an asynchronous (non-clocked) fashion.
Address Event Representation

Best of both (digital & analog) worlds
Hierarchical or multi-layer networks

The basic problem with these models is, of course, generalization: a look-up table cannot deal with new events, such as viewing a face. Logothetis et al. trained monkeys to perform an object recognition task with isolated views of novel three-dimensional objects. The tuning of the neurons in anterior inferotemporal cortex shows specificity for a certain object view or lighting condition.

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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
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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
Bio-IT initiatives in FP7

State-of-the-art
- Neuronal coding and computing
- Oscillations and attention
- Biomimetic artefacts
- Biohybrid artefacts

Cooperation Issues
- Within EU (NiSIS, Once-CS)
- With the OECD International Neuroinformatics Coordinating Facility (INCF)
- With the US
- With China

Fruitful discussion session

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