Neuromorphic Technology Developments in FET

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Exploitation of Neuromorphic Computing Technologies
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Neuromorphic Computing vs. Neuromorphic Engineering

**The origins**

Neuromorphic computing

- Conventional hardware VLSI technology.
- Large-scale high performance computing platforms.
- **Simulation** of simplified neuron models.

Neuromorphic engineering

- Subthreshold analog and asynchronous digital.
- Basic research deeply rooted in biology.
- **Emulation** of neural computing primitives.

Carver Mead

Misha Mahowald
Channel current-voltage relationships

![Channel current-voltage relationships diagram]

- **Ids (A)**
- **Vgs (V)**

**subthreshold**

**above threshold**

Diagram showing the channel current-voltage relationships with log-log scale for Ids and Vgs.
Channel current-voltage relationships

**FIGURE 4.6** Exponential current–voltage characteristic of voltage-dependent channels. At high voltages, the fraction of channels that are open approaches unity, causing a saturation of the curves. (Source: [Hodgkin et al., 1952b, p. 464].)
Ultra-low power neuromorphic cognitive systems

6M CMOS 0.18 µm process
43.79 mm² area
4 × 256 neurons
4 × 64 k synapses
276 µA@1.3 V, @all 30 Hz

Radical paradigm shift: brain-like computing architectures

- Radically different from von Neumann architectures.
- Parallel nodes with memory and computation co-localized.
- Event-based passive circuits, driven by input data
- Fault-tolerant, robust computation through adaptation and learning

[Indiveri et al. 2015, “Neuromorphic Architectures for Spiking Deep Neural Networks”]
Ultra-low power neuromorphic cognitive systems

1 mg weight
1 mm$^3$ volume
960’000 neurons
$10^{-15}$ J/spike

Existence proof: bees target model

- Massively parallel distributed computation
- Slow, noisy and variable processing elements
- Real-time interaction with the environment
- Complex spatio-temporal pattern recognition
- Foraging, navigation, language, and social behavior

We have the technology to implement such components.
We need the understanding (i.e. basic, exploratory research).
FET long-term “pro-active” support

- **SENSEMAKER** A Multi-sensory, Task-specific, Adaptable perception System (2001 - FP5 - K. Meier)
- **SPIKEFORCE** Real-time Spiking Networks for Robot Control (2002 - FP5 - B. Barbour)
- **CAVIAR** Convolution AER vision architecture for real-time (2002, FP5 - B. Linares-Barranco)
- **NEUROBIT** A bioartificial brain with an artificial body: training a cultured neural tissue to support the purposive behavior of an artificial body (2002 - FP5 - S. Martinoia, S. Renaud)
- **ALAVLSI** Attend-to-learn and learn-to-attend with neuromorphic, analogue VLSI (2002, FP5 - J. Braun, R. Douglas, G. Indiveri)
- **DAISY** Neocortical Daisy Architectures and Graphical Models for context-dependent Processing (2005, FP6, - H. Kennedy)
- **FACETS** Fast Analog Computing with Emergent Transient States in Neural Architectures (2005, FP6, - K. Meier)
- **eMorph** EventDriven Morphological Computation for Embodied Systems (2009, FP7, C. Bartolozzi)
- **BrainScales** Brain-inspired multiscale computation in neuromorphic hybrid systems (2011, FP7, K. Meier)
## EU sustained support

### Flagship
- **HBP** The Human Brain Project
  - Neuromorphic Computing Platform
  - Neurorobotics Platform

### ERC (lighthouse projects)
- **CDAC** The role of consciousness in adaptive behavior: A combined empirical, computational and robot based approach (2014, ERC-2013-ADG, P. Verschure)
- **PROJESTOR** PROJECTED MEMRISTOR: A nanoscale device for cognitive computing (2016, ERC-2015-CoG, A. Sebastian)
- **NeuroP, NeuroPsense, NeuroAgents** Neuromorphic Electronic Agents: from sensory processing to autonomous cognitive behavior (2017, ERC-2016-COG, G. Indiveri)

Thanks to this support **EU is at the forefront of this research**
FET required synergistic “pro-active” efforts

To maintain leadership in this domain there are still many important open questions that need urgent investigation.

Flagship project and ERC light-house projects alone are not enough.
FET required synergistic “pro-active” efforts

To maintain leadership in this domain there are still many important open questions that need urgent investigation.

There is a need for **many** small scale thematic exploratory projects.
Thank you for your attention

Horizon2020

Swiss National Science Foundation

Institute of Neuroinformatics
The CapoCaccia Cognitive Neuromorphic Engineering Workshop

- Interdisciplinary, international, inter EU-US project
- Morning lectures, afternoon hands-on work-groups
- Active and lively discussions (no powerpoint)
- Concrete results, establishment of long-term collaborations
- Neuromorphic computing, robotics, and fundamental neuroscience

http://capocaccia.iniforum.ch/

Alghero, Sardinia, Italy. April 24 - May 6, 2017
Neuromorphic synapse circuits
emulating synaptic dynamics

\[
\tau \frac{d}{dt} I_{syn} + I_{syn} = \frac{I_{thr} I_w}{I_\tau}
\]

[Bartolozzi and Indiveri, 2007]
Neuromorphic silicon neurons
emulating the biophysics of spiking behavior

\[ \tau \frac{d}{dt} I_{\text{mem}} + I_{\text{mem}} \approx \frac{I_{\text{th}} I_{\text{in}}}{I_{\tau}} - I_{g} + f(I_{\text{mem}}) \]

\[ \tau_{\text{ahp}} \frac{d}{dt} I_{g} + I_{g} = \frac{I_{\text{thr}} I_{\text{ahp}}}{I_{\tau_{\text{ahp}}}} \]

[Chicca et al., 2014]
A highly interdisciplinary approach

- Study **fundamental neuroscience**, principles of neuro-physiology, neuro-anatomy, computer science, theory of computation, electrical engineering, microelectronics, physics, . . .

- Exploit the physics of silicon to reproduce the *bio*-physics of neural systems, using **subthreshold analog VLSI circuits**.

- Develop distributed multi-core neuromorphic spiking systems using **asynchronous digital VLSI circuits**.

- Build compact **intelligent agents** able to interact autonomously with the environment in real–time.