SenseMaker

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Project Objectives

- To design and implement an intelligent computational system, drawing inspiration from biological principles of sensory receptor and nervous system function
- To conceive and implement electronic architectures that can merge sensory information from different modalities into a unified perceptual representation of the environment
- To explore a better understanding of information processing and function in the adult brain
- To achieve a higher level of communication between computer scientists, engineering, physics, psychology, and biological researchers
Overview of Project

Integration of neuroscience and engineering models
Cross-modal integration: The Two-Ring Problem

<table>
<thead>
<tr>
<th>Code</th>
<th>Modality</th>
<th>Qualia</th>
<th>Level</th>
<th>Acquisition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>space</td>
<td>orientation</td>
<td>global</td>
<td>parallel</td>
</tr>
<tr>
<td>2</td>
<td>time</td>
<td>texture</td>
<td>local</td>
<td>sequential</td>
</tr>
<tr>
<td>3</td>
<td>motor</td>
<td>direction/motion</td>
<td>local</td>
<td>sequential</td>
</tr>
</tbody>
</table>
Solving the Two-Ring Problem with the SenseMaker System
Psychophysical Investigation of the ‘Two-ring’ problem

Apparatus: Virtual Tactile Display (VTD); developed by UHEI partners

Results: Categorical perception of visual and tactile texture continua

Stimuli: Visual and tactile continua

<table>
<thead>
<tr>
<th>Visual</th>
<th>Tactile</th>
</tr>
</thead>
<tbody>
<tr>
<td>0% vertical</td>
<td>100% vertical</td>
</tr>
<tr>
<td>50% vertical</td>
<td>50% vertical</td>
</tr>
<tr>
<td>100% vertical</td>
<td>0% vertical</td>
</tr>
</tbody>
</table>

% responses “disk w/ horizontal texture in front”

% of vertical texture in overlap area
Silicon IC Neural Units

Custom circuits are developed to compute in real-time HH-like neuron and kinetic synapses models (analog design mode - Bipolar and MOS transistors - photograph: area of the die 4mmx3mm, 2k devices)

Oscilloscope hardcopies:
- Upper plot: membrane voltage output
- Lower plot: input stimulation voltage (inv. prop. to the stim. current)

Regular Spiking (RS) neuron

Fast Spiking (FS) neuron
**SMU2 : FPNN Architecture**

- A fully populated backplane has been produced.
- Network tests are under way.
- 16 Local PowerPC CPUs are running embedded Linux, total memory of up to 16 Gbytes.
- FPNN ASIC interface on network module is working.
- Universal high-level software framework is available since July 2003 to configure and operate the SMU1, SMU2 and the later SMU3 system.
- First experiments with SMU2 are in the preparation phase.

**The SMU2 system.** One crate provides:

- 16 network modules
- 4096 binary neurons
- 524288 analog synapses

Largest full-custom hardware neural network ever build.
SMU3 chip - Implementing low-level biological principles in VLSI

- technology: UMC 0.18µm, 6 metal, 1 poly
- 384 to 768 neurons, about 100000 synapses
- neuron model: modified integrate-and-fire with conductance based synapses
- fully analog network core
- time scale factor $10^{-5}$: 10 ns chip-time equals 1 ms in real-time
- short-term synaptic depression and facilitation: analog on-chip
- spike-time-dependent-plasticity: on-chip (analog measurement with digital weight adjustment)
- operation in the SMU2 system framework
- independently programmable model parameters (at least $E_l$, $E_x$, $E_i$, $V_t$, $V_r$, $g_m$, $t_{ref}$, $t_s$)
Design environment for Spiking Neurons and STDP on FPGAs

- Modular System
- Extendable
- Flexible
- Rapid Prototyping
- Numerous I/O Options
- Standalone
- Embedded System Solution

MATLAB Environment

- Simulink
- Xilinx Blockset
- SenseMaker SNN Blockset

Library

- Simulink Blockset
- Xilinx Blockset
- SenseMaker SNN Blockset

System Generator

Abstract SNN models

Bitstream

Xilinx Integrated Software Environment (ISE)
- Synthesis compiler
- VHDL Simulator
- FPGA Place & Route

FPGA Hardware

BenNuey PC104 Platform
Example implementation of a module of the SenseMaker system - Matlab
Achievements

- Established a paradigm for comparing human and machine performance in merging of sensory codes
- Established task-dependent principles for higher level processing
- Developed an analog-digital simulator to translate biological model in ASIC representation
- Development of large scale spiking neural network, incorporating STDP learning, in analog ASIC