



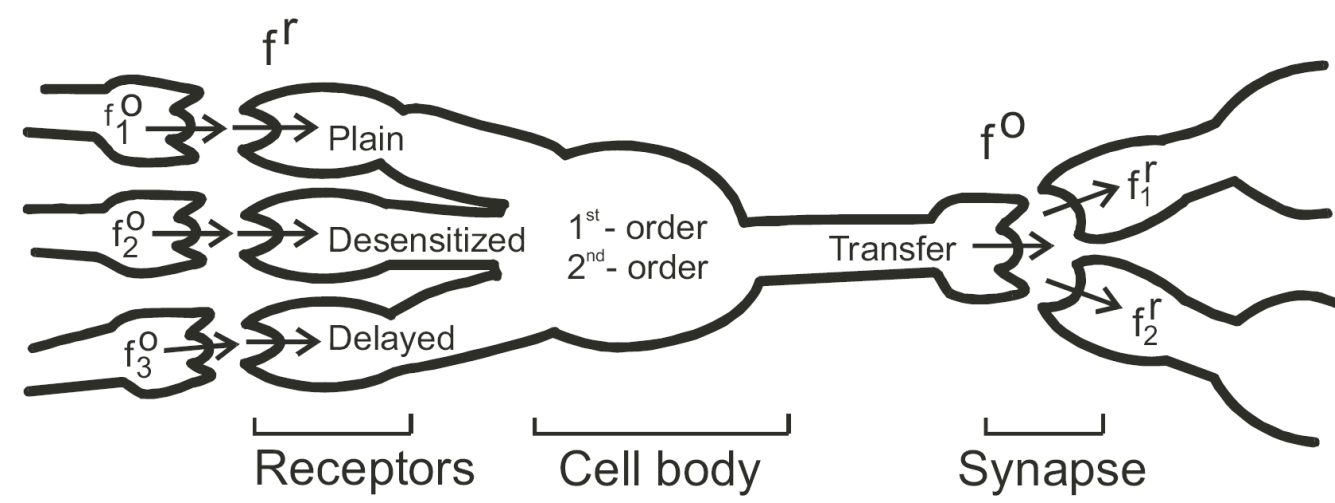
Real-time emulation of a mammalian retina model on emulated digital CNN architecture

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Model Backgrounds: Abstract Neuron



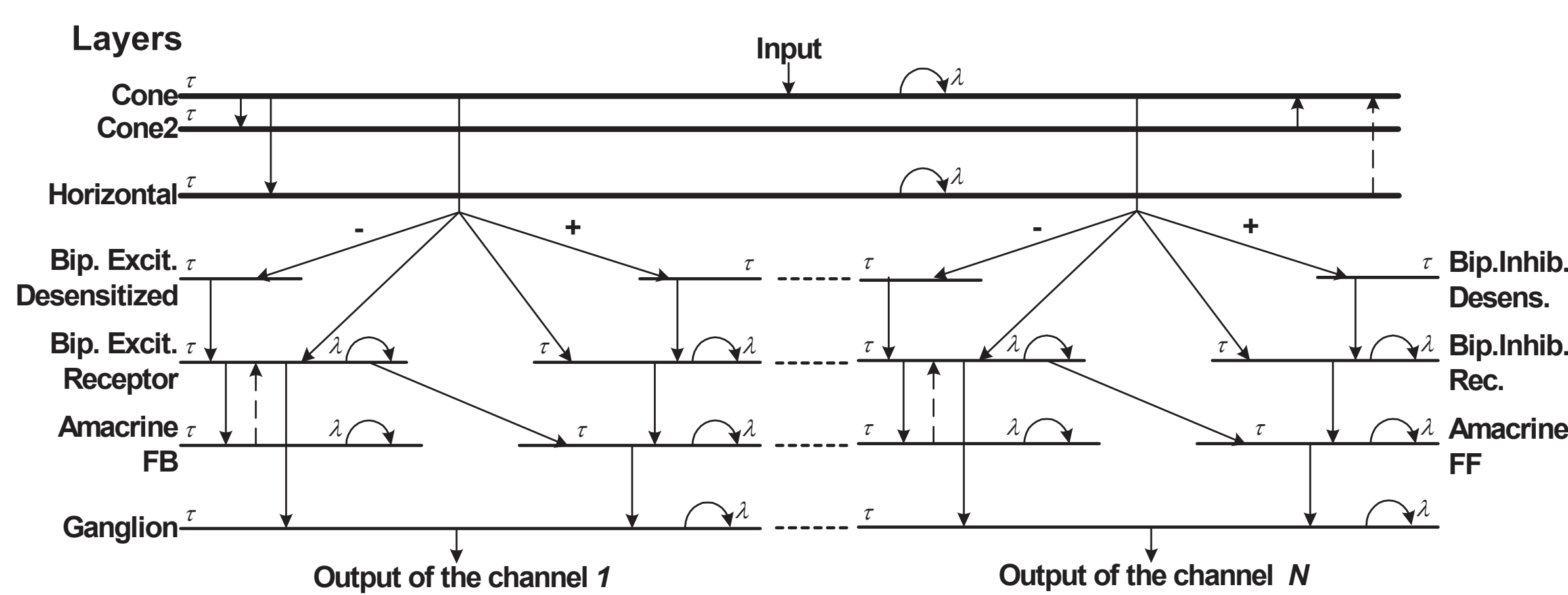
CNN computing paradigm owing to its natural cell-based structure provides a suitable analytical framework to construct bio-inspired models. The basic building blocks are the abstract neurons (cells) organized into 2D CNN layers.

Field Programmable Gate Array (FPGA)

- Xilinx Virtex-6 SXT FPGA
- 476,160 Configurable Logic Blocks (CLB)
 - 2016 25x18bit DSP MAC
 - 38Mbit on-chip BRAM
 - PCI-Express v.2.0 Endpoint
 - Tri-mode Gigabit Ethernet MAC
- Performance
- 100GMACS (25bit integer)
 - 380GFLOPS (Single-precision)
 - 130GFLOPS (Double-precision)



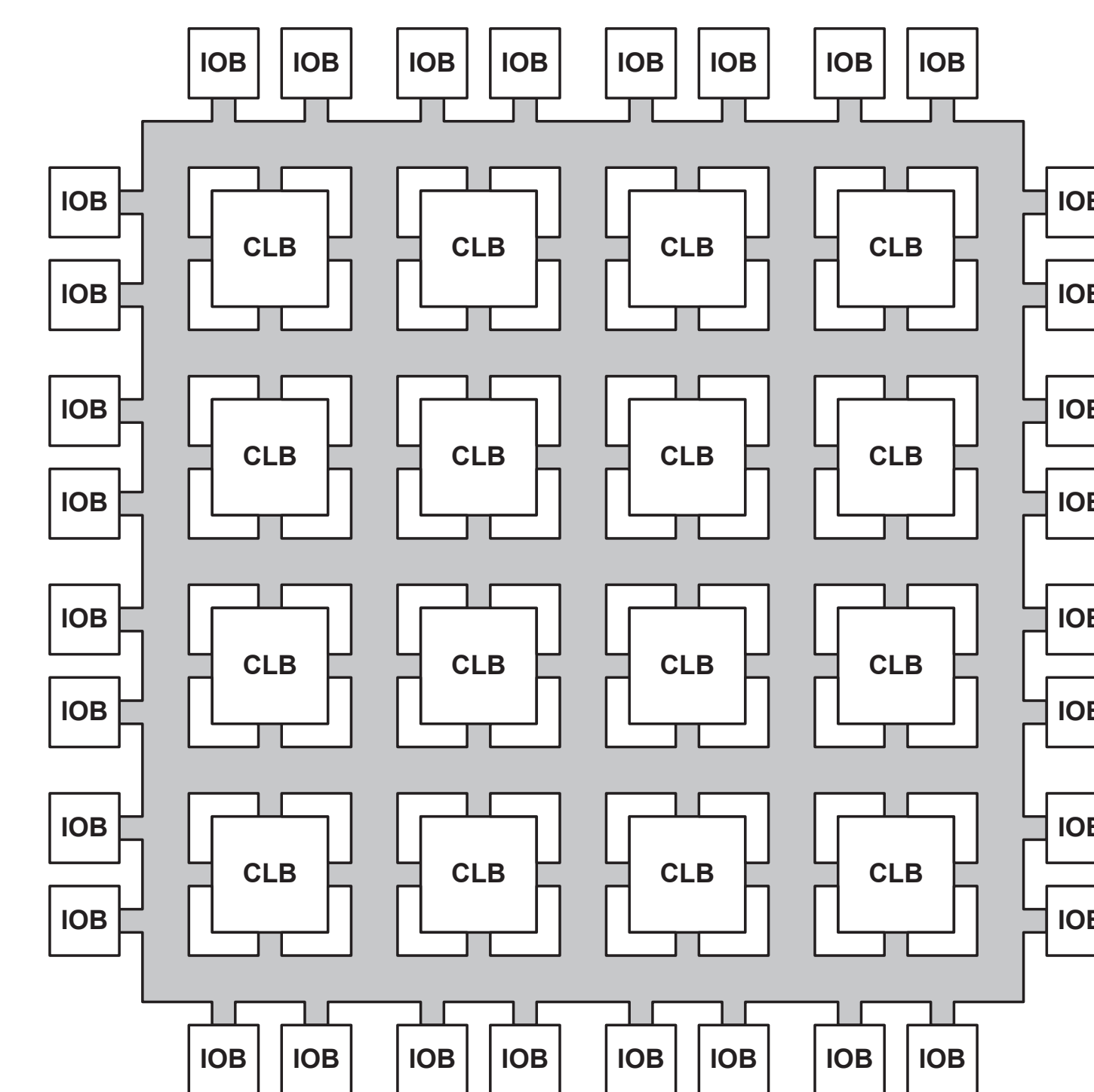
General neuromorphic structure of the light-adapted, N-channel mammalian retina model



The complex model is decomposed into multi-layer CNN structure and is implemented on a reconfigurable computing device. Each channel consists 10 layers with different:

- τ timing constants and
- λ coupling parameters

FPGA Architecture



Governing equations

Derived from the original equations of Bálya et al. Describes the dynamics of

- 1st/2nd order abstract neuron (cell body)
- receptors and synapses (interconnections)
- output transfer functions

$$\tau_n^i \dot{x}_n^i = -x_n^i + \sum_{kl \in S_n} C_{n,kl}^i x_{n,kl}^i + \sum_{\forall m \in Sy1} \sum_{kl \in S_m} f_{nm}^r (G_{nm,kl}^i x_m^j) + \sum_{\forall m \in Sy2} x_{nm}^r + \sum_{\forall m \in Sy3} (x_{nm}^r - r_{nm}^d) - s x_n^j$$

$$\tau_n^j \dot{x}_n^j = -x_n^j + x_n^i$$

1st / 2nd order Cell dynamics

$$y_n^i = f_n^i(x_n^i)$$

Synapses

$$C_n^i = \lambda \begin{bmatrix} 1 & 2 & 1 \\ 2 & -12 & 2 \\ 1 & 2 & 1 \end{bmatrix}$$

Diffusion type template

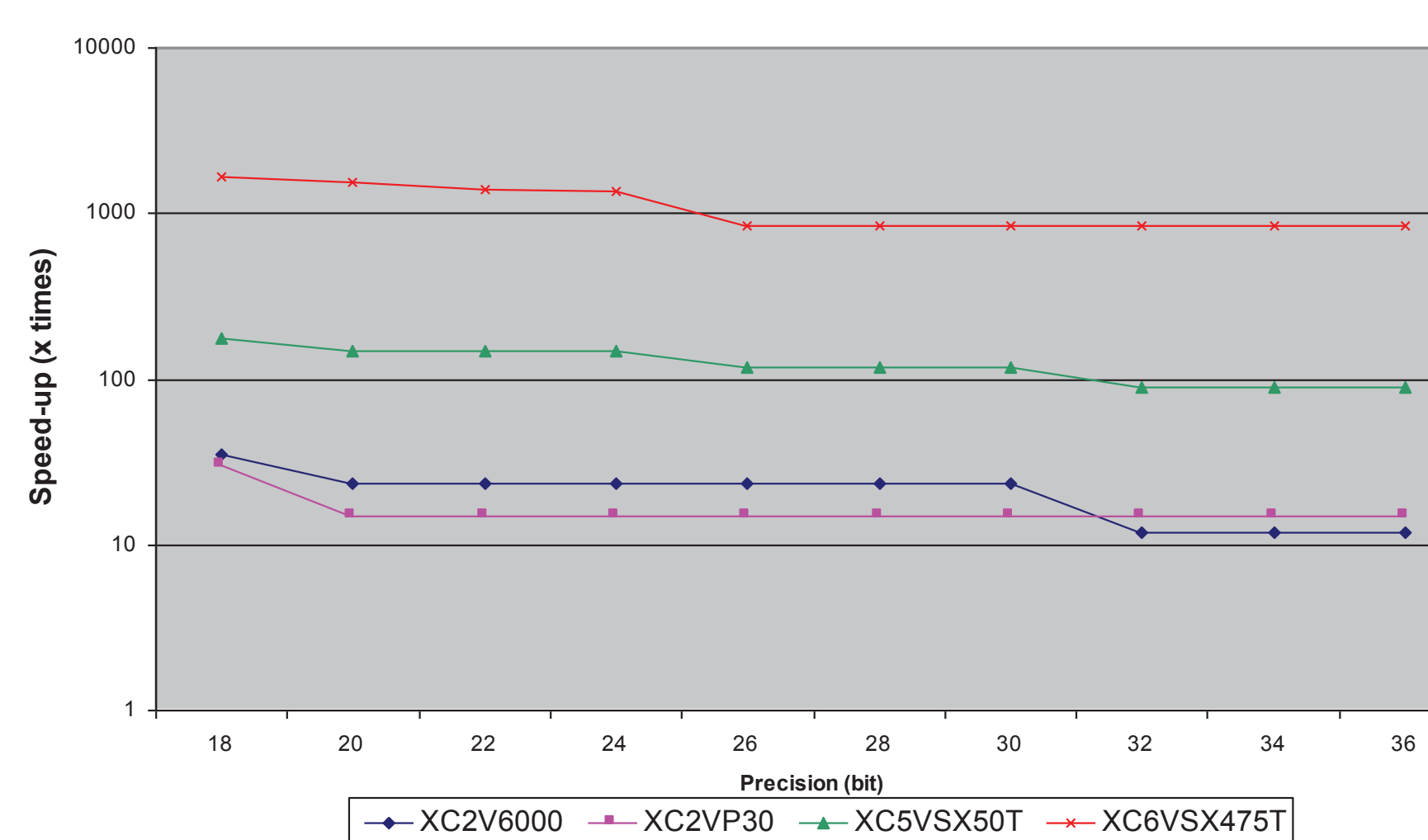
$$G_{nm,ij}^i = \frac{1}{\sum_{k,l} G_{nm}^i(k,l)} e^{-\frac{\sqrt{k^2+l^2}}{\sigma}}$$

$$G_{nm}^i = \begin{bmatrix} G_{-1,-1}^i & G_{-1,0}^i & G_{-1,1}^i \\ G_{0,-1}^i & G_{0,0}^i & G_{0,1}^i \\ G_{1,-1}^i & G_{1,0}^i & G_{1,1}^i \end{bmatrix}$$

Gaussian distribution and template

- Spatial discretization on a regular square (Receptive Field calculus)
- Temporal discretization (forward Euler formula)
- Solution on FPGA processors is motivated by Cellular Neural Networks

Implementation on Xilinx Virtex FPGAs

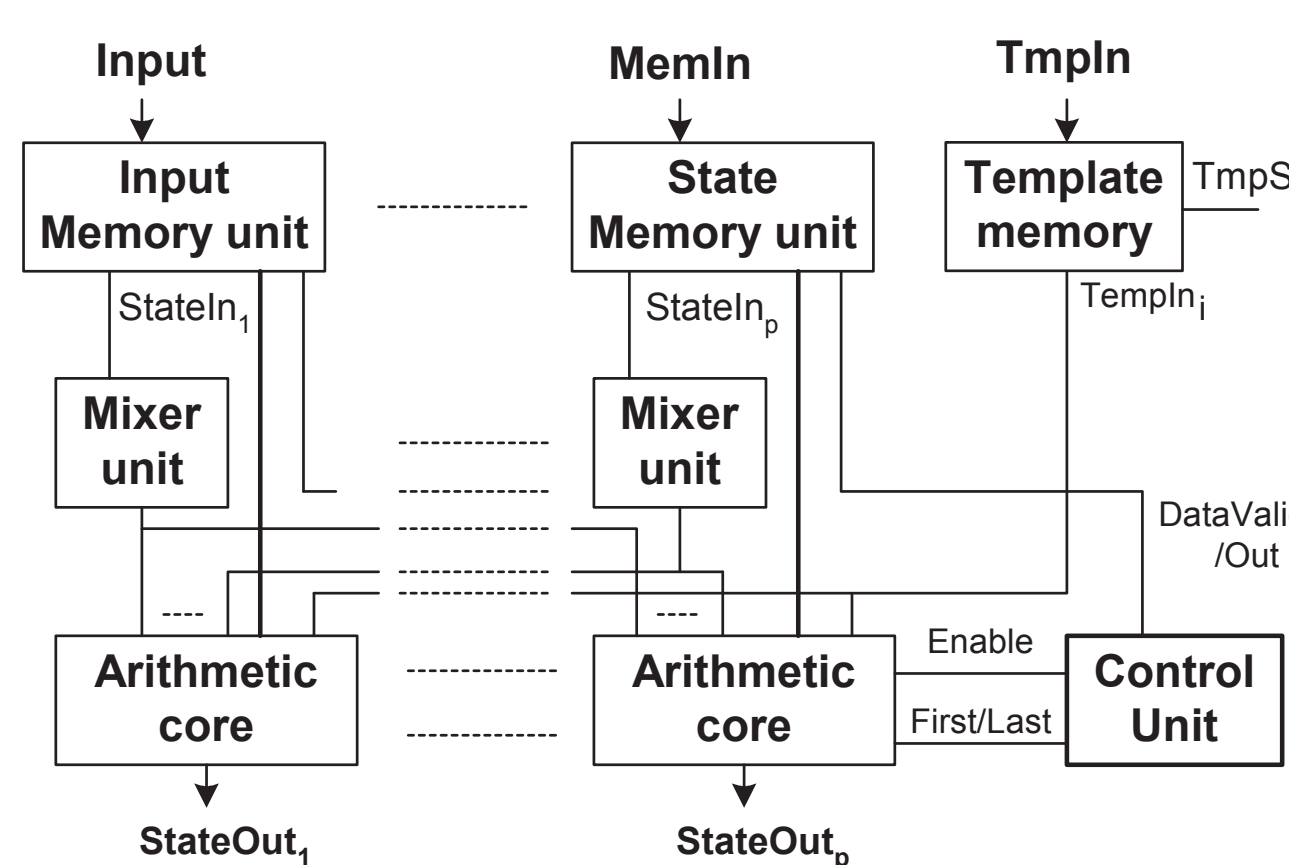


- Xilinx Virtex FPGAs
- Specialized re-configurable hardware accelerators
 - High Level Hardware Description
 - Rapid prototyping

- Performance improvement *
- Virtex-II/Pro: at least 15-times using the qualitatively correct 20-22 bit precision
 - Virtex-5 SXT: 147-times at 20-22 bit precision
 - Virtex-6 SXT: 1412-times at 20-22 bit precision

*Compared to an Intel Core2Duo E8400 microprocessor, and image size is 64x64.

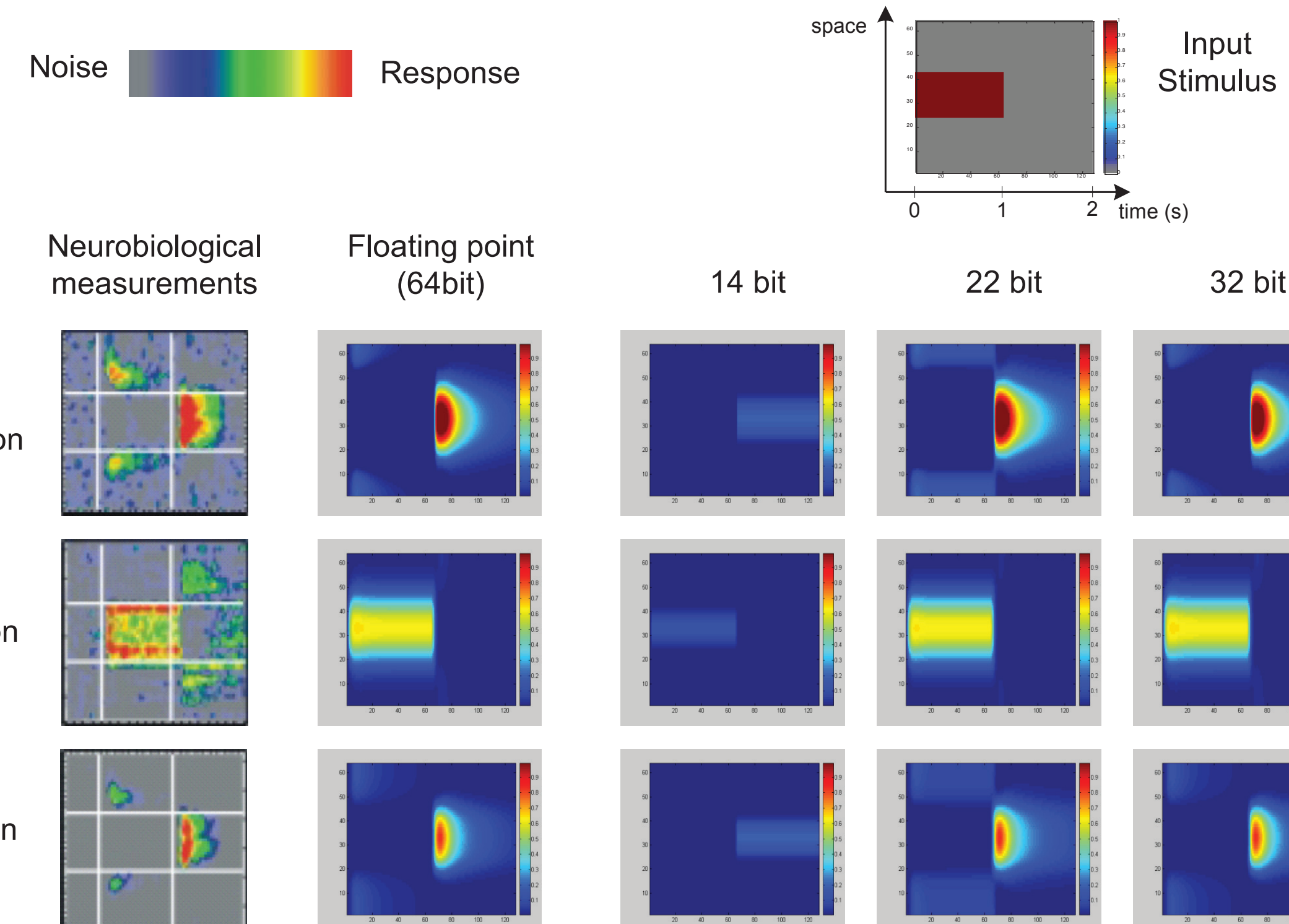
FALCON: Configurable Emulated-Digital CNN-UM architecture on FPGA



Modular structure: number of layers and processors elements, arrangement of processor units, size and number of templates can be adjusted. Bit widths of state-, constant- and template values are configurable.

Additional details: Zs. Vörösházi, Z. Nagy, P. Szolgay "FPGA-Based Real Time, Multi-channel Emulated-Digital Retina Model Implementation", Hindawi, EURASIP Journal on Advances in Signal Processing, Vol. 2009, Issue: CNN Technology for Spatiotemporal Signal Processing, doi:10.1155/2009/749838

Accuracy of solution



Accuracy of solution at different bit widths (in case of OFFBrisk-Linear channel type) compared to the results of neurobiological measurements. The simple test input is a commonly used flashed square stimulus. The time runs horizontally while space is on the vertical axes. The examined time period is 2 seconds, the flashing white stimulus is "turned-on" for 1 second.

