BIOMORF HYPERACUITY IN TIME AND ”FUNCTION IN LAYOUT” VLSI DESIGN

The barn owl’s direction sensitive auditory processing path implemented in a CNN-based Time-to-Digital Converter integrated circuit

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Time-to-Digital Converter (TDC) is basically performing an Analog to Digital Conversion. However, the continuous-valued input is not expressed by a voltage or current, but a delay. The analog input information is represented by the timing of an electrical signal. This is quantized, and logic information is given on the output. Subject of the present PhD research work is the development of a Time-to-Digital Converter, that is based on a hyperacuity core function. The circuit receives rising edge transitions on two input pins, and the timing order and amount of delay between these two signals is coded in a binary number as a result. One highlight of this design is that the internal conversion process is done by manipulation of the delays and timing conditions of propagating pulses. We call this the "Delay Domain Computing" style. In fact the timing is the native input format for the TDC circuitry, and this is kept throughout the whole processing path, until final conversion into digital. Using Cellular Nonlinear Network (CNN) structure for implementation is found to be excellent, because of the propagation delays present in all electronic circuits allows only local interaction. CNN is by definition a computing model based on local connectivity, and regular grid-like architecture.

The main operation principle was inspired by the neurobiology research around the Barn Owl. There have been considerable activity around the so called „Hyperacuity” phenomenon. This is a well known mechanism in neurobiology. Almost every sensory modality (visual, auditory, tactile) shows some Hyperacuity behaviour. The key feature of Hyperacuity is that it yields higher selectivity in the perception, than the accuracy of the individual cells. The secret is in the sensory arrays: elementary receivers are broadly tuned, so their sensitive fields are overlapping. The redundancy is then serves as a basis for resolution enhancement in the brain. Barn Owl has became the most popular animal for studies concerning Hyperacuity mechanism. This is because of the excellent sound localisation skill of this small bird: It can catch a mouse even in total darkness, relying on acoustic signals only. The anatomy behind this is already discovered, revealing a strictly regular neuron structure that is directly applicable to CNN.

The purpose of the research were twofold: Firstly, it showed that it is possible to practically realize a competitive solution for Time-to-Digital Conversion with the help of the CNN paradigm. Secondly, it demonstrated how the CNN paradigm can be generalized to include the invented „Delay Domain Computing” method. The Time-to-Digital Converter circuit that was developed is able to measure delays ranging 1.9 nanosecond, (-850 .. +850 ps) with 6 bit resolution. The smallest detectable delay is 30 picosecond, this is the conversion unit. The circuit contains 64 x 64 CNN cells on a 1,59mm^2 sized silicon die. It was manufactured using a 0.35μm CMOS process.