

A Fully Pipelined Streaming Dataflow LeNet-5 in Hand Written VHDL, a Reference Baseline for Compiler Generated FPGA Inference

Author:

Thalles Menezes Moreira

Dataflow compilers translate quantized neural networks into FPGA hardware automatically, removing the need for register transfer level expertise. What that automation costs in efficiency is rarely measured, because published comparisons seldom include a carefully hand written implementation of the same network on the same device. Without such a reference point, claims about compiler generated dataflow quality remain difficult to evaluate.

This work implements LeNet-5 as a fully pipelined streaming accelerator in pure VHDL, establishes its functional correctness stage by stage, and characterises it so that it can serve as a controlled reference against compiler generated dataflow on an identical quantized model.

A raster pixel stream feeds a padding generator that injects border pixels in the buffer, so downstream stages never observe padding. On the window generator side dilation, kernel size, stride, and channel parallelization are all parametrizable values that will influence on the convolution input. The window generator exposes the resulting five by five tap set to a parallel multiply accumulate array, followed by bias, activation, and pooling. Each stage carries a self checking testbench comparing streamed hardware output cycle by cycle against a bit accurate quantized PyTorch reference, requiring exact match rather than statistical similarity. Behavioural and post synthesis simulation are performed in Vivado, targeting devices available on the OTUS FPGA cluster at PC2.

Making buffer depth, window validity, and row transition framing explicit rather than inferred yields register transfer level code suitable for both FPGA deployment and later physical design, and provides a defensible reference against which compiler generated dataflow can be judged. The verified streaming primitives carry forward directly into a sparsity aware processing tile written in the same style.