# A Novel Design of Adaptive and Hierarchical Convolutional Neural Networks using Partial Reconfiguration on FPGA

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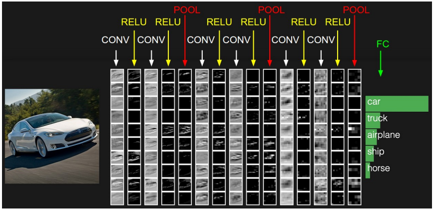
# Convolutional Neural Networks

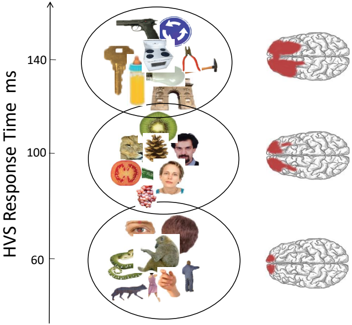
- Convolutional Neural Networks (CNNs)-based methods have become popular in image classification
- Deeper models such as ResNet (152 layers) [He'16] can provide high recognition accuracy
- However, complex models are not suitable for embedded system with confined computing resources
  - Power and performance constraints




http://cs231n.github.io/convolutional-networks

# Adaptive Model

- Human vision system (HVS) has two stages for visual classification [Ritchie'2015]:
  - A shallow primary stage
  - A decision layer to pick a further processing pathway
- A feedback model can be designed to determine the exit from the CNN model



## Adaptive CNNs

- Compressing the structure of CNN models ([Han'2016], [Iandola'2016])
  - Network pruning
- Cascaded classification [Li'2015]
- Branchy-Net: early exit from the model based on the entropy of model output [Teerapittayanon'2016]
- Skip-Net: skip intermediate convolution layers based on the gate decision [Wang'2018]

## CNN acceleration using FPGA

- FINN: A framework for the binarized neural networks (Umuroglu'2017)
- xDNN: Mapping CNNs to Xilinx FPGAs (Sequential) (2018)
- OpenVino: optimize and mapping CNNs to Intel FPGAs (Sequential) (2018)

# Adaptive And Hierarchical CNNs

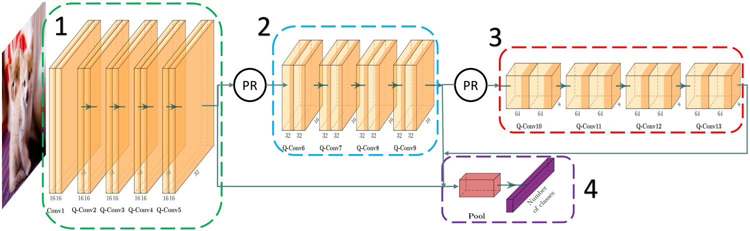
- Start the next convolution as soon as having enough input
  - Connect layers using internal streams
  - Batch processing used for a stream
  - Lower latency
- Quantized CNN model has been used to improve the performance

# Adaptive And Hierarchical CNNs

- Large models cannot fit in the target chip
- Partial reconfiguration utilized to run the whole model
- Shallow part which is a light-weight CNN model
- A decision layer which evaluates shallow part's performance and makes a decision
- A deep part which is a deep CNN with a high inference accuracy

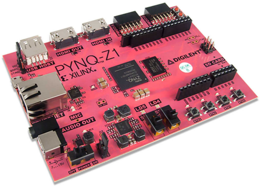
# Implementation on FPGA

- FPGAs are suitable candidates for the low power design of CNN inference
- The adaptive feedback decides to classify the image or apply the next stack of convolutional layers based on the output confidence
- Partial reconfiguration has been used on FPGA to switch between models
  - Dynamic: feature extractor
  - Fixed: data loader, decoder



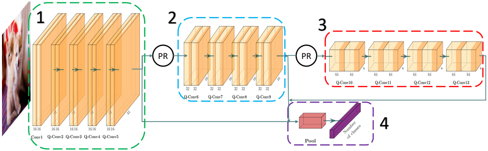
# Device Setup

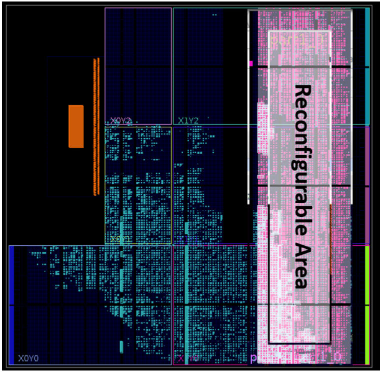
- PYNQ-Z1 board
  - Xilinx Zynq-7000 ZC7020
  - Dual-core ARM A9 processor
- ResNet-18 CNN model
  - Parameters precision: 1-bit weight and 5-bit activation data
- Dataset
  - CIFAR-10
  - CIFA-100
  - SVHN




# Implementation of FPGA

- Layout of the reconfigurable design
- Images are loaded to IP cores using DMA
- Available resources on the Pynq board in comparison with the used resources by the convolution parts




| | Part 1 | Part 2 | Part 3 | Part 4 | Total |
|---|---|---|---|---|---|
| **BRAM** | 81 | 91 | 96 | 31 | 280 |
| **DSP** | 120 | 96 | 96 | 24 | 220 |
| **FF** | 15672 | 16647 | 34069 | 9908 | 106400 |

# Results

- Performance evaluation on the different parts of the design

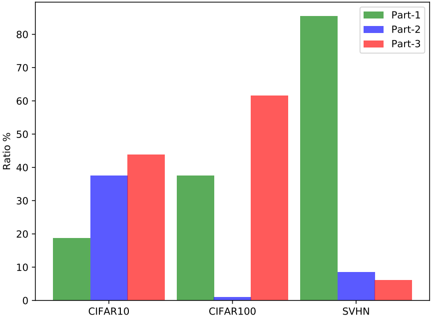
| Bitstream | FPGA Config Time | FPGA Execution Time | CPU Execution Time | FLOPS |
|---|---|---|---|---|
| **Part 1** | 38-42 ms | 2 ms | 98 ms | 10.24M |
| **Part 2** | 38-42 ms | 2 ms | 57 ms | 8.6M |
| **Part 3** | 38-42 ms | 2 ms | 49 ms | 8.5M |

- Top-1 accuracy of the HLS optimized IP cores

| | CIFAR10 | CIFAR100 | | SVHN |
|---|---|---|---|---|
| | | Top1 | Top5 | |
| **Part 1** | 70.95 | 42.26 | 72.14 | 80.35 |
| **Part 2** | 80.57 | 52.23 | 80.25 | 91.24 |
| **Part 3** | 86.27 | 56.60 | 83.46 | 94.62 |

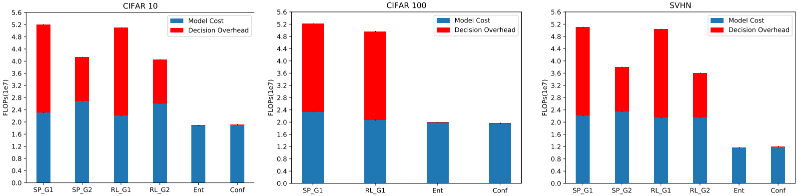
# Results

- The stop ratio for each part of CIFAR-10, CIFAR-100, and SVHN dataset has been shown
- The base model accuracy is preserved
- Switching between IP cores is costly
- By batch processing, the switching cost will be eliminated



# Performance Comparison

- Computation reduction for different methods: Entropy (Ent), Confidence (Conf), SkipNet+SP (SP), SkipNet+HRL+SP (RL)
- Reducing the computation costs by≈30%,≈27%and≈57% on the CIFAR-10, CIFAR-100, and SVHN data using confidence



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# Question