EIE: Efficient Inference Engine on Compressed Deep Neural Network

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Presented by Sihang Liu

Slides mostly from Han's presentation

Background: Hardwares for Deep Neural Network

CPU

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CPU

GPU

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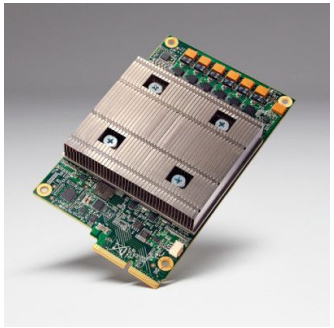
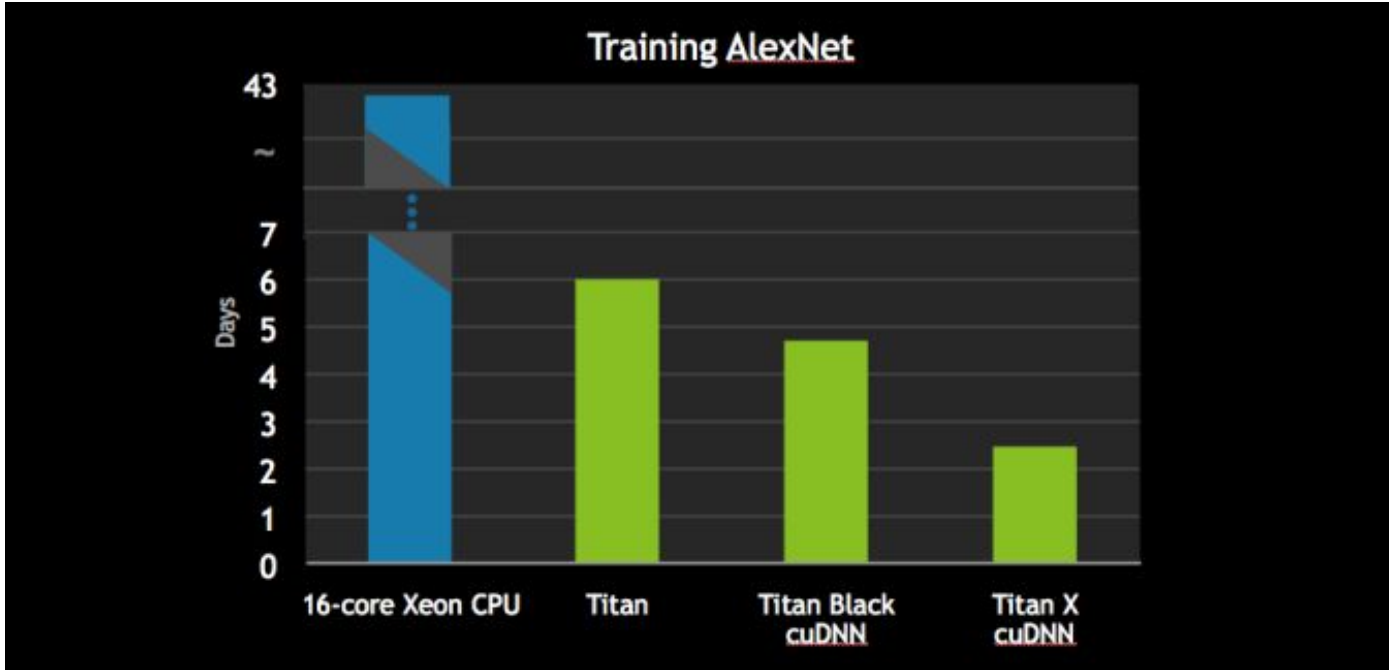
CPU

GPU



Tensor Processing Unit (TPU)

Background: Speedup from GPU



Source: nvidia.com

Deep Learning on Mobile

Phones

Drones

Robots

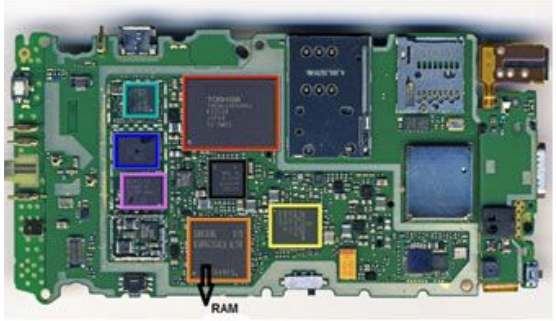
Glasses

Self Driving Cars

Battery Constrained!

Difficulty?

Model Size!

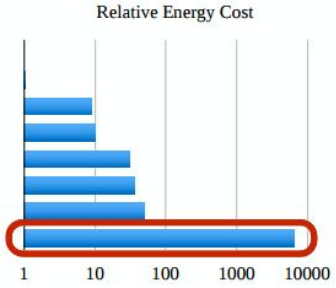


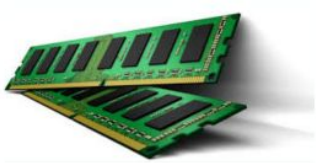
Motherboard of a smart phone

Difficulty?

Model Size!

Operation	Energy [pJ]	Relative Cost
32 bit int ADD	0.1	1
32 bit float ADD	0.9	9
32 bit Register File	1	10
32 bit int MULT	3.1	31
32 bit float MULT	3.7	37
32 bit SRAM Cache	5	50
32 bit DRAM Memory	**640**	**6400**



1  = 100 ✕ +

Deep Compression

Problem: DNN model too large

Solution: Deep Compression

Smaller Size

90% zeros in weights
4-bit weight

Accuracy

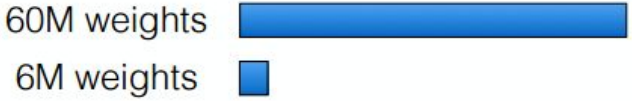
No loss of accuracy /
Improved accuracy

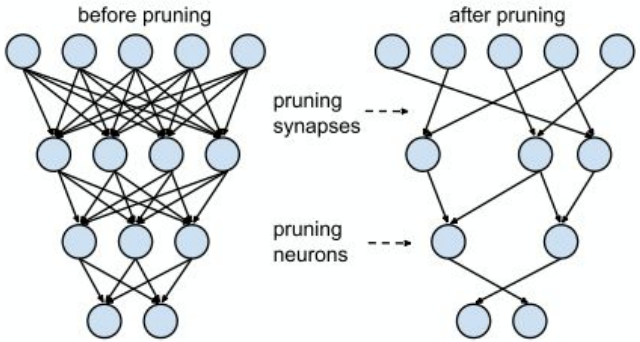
On-chip

State-of-the-art DNN
fit on-chip SRAM

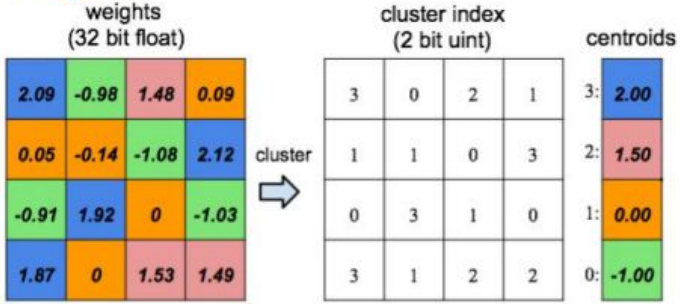
Deep Compression (cont.)

- **Network Pruning [1]**: 10x fewer weights



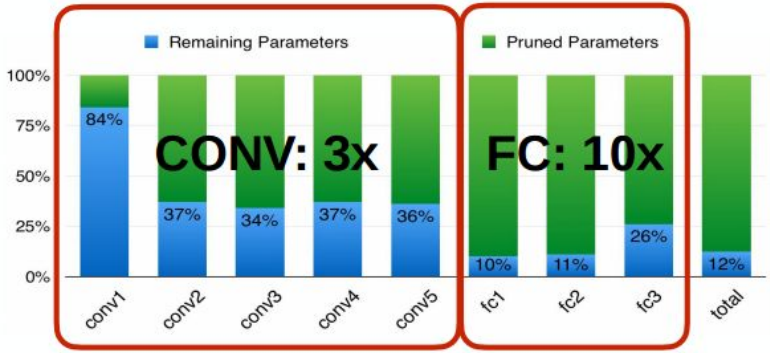


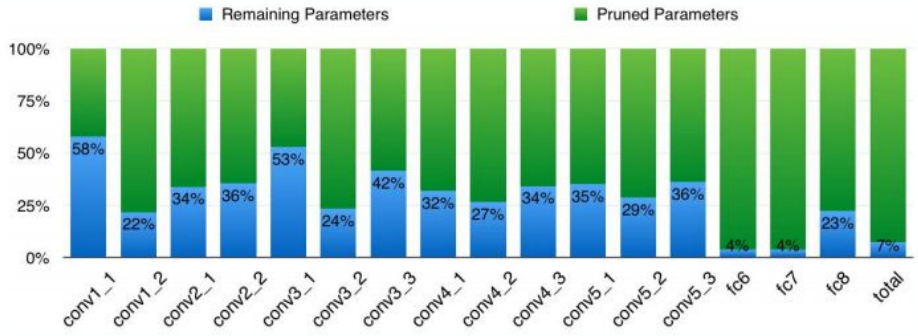
- **Weight Sharing [2]**: only 4-bits per remaining weight



[1]. Han et al. NIPS 2015
[2]. Han et al. ICLR 2016, best paper award

Pruning AlexNet & VGGNet





AlexNet

Layer	Weights	FLOP	Act%	Weights%	FLOP%
conv1	35K	211M	88%	84%	84%
conv2	307K	448M	52%	38%	33%
conv3	885K	299M	37%	35%	18%
conv4	663K	224M	40%	37%	14%
conv5	442K	150M	34%	37%	14%
fc1	38M	75M	36%	9%	3%
fc2	17M	34M	40%	9%	3%
fc3	4M	8M	100%	25%	10%
Total	61M	1.5B	54%	**11%**	**30%**

VGG-16

Layer	Weights	FLOP	Act%	Weights%	FLOP%
conv1_1	2K	0.2B	53%	58%	58%
conv1_2	37K	3.7B	89%	22%	12%
conv2_1	74K	1.8B	80%	34%	30%
conv2_2	148K	3.7B	81%	36%	29%
conv3_1	295K	1.8B	68%	53%	43%
conv3_2	590K	3.7B	70%	24%	16%
conv3_3	590K	3.7B	64%	42%	29%
conv4_1	1M	1.8B	51%	32%	21%
conv4_2	2M	3.7B	45%	27%	14%
conv4_3	2M	3.7B	34%	34%	15%
conv5_1	2M	925M	32%	35%	12%
conv5_2	2M	925M	29%	29%	9%
conv5_3	2M	925M	19%	36%	11%
fc6	103M	206M	38%	4%	1%
fc7	17M	34M	42%	4%	2%
fc8	4M	8M	100%	23%	9%
total	138M	30.9B	64%	**7.5%**	**21%**

Deep Compression (cont.)

Network	Original Size	Compressed Size	Compression Ratio	Original Accuracy	Compressed Accuracy
AlexNet	240MB	6.9MB	**35x**	80.27%	80.30%
VGGNet	550MB	11.3MB	**49x**	88.68%	89.09%
GoogleNet	28MB	2.8MB	**10x**	88.90%	88.92%
SqueezeNet	4.8MB	0.47MB	**10x**	80.32%	80.35%

- No loss of accuracy
- 120X less energy

Accelerator for Compressed Sparse Neural Network

Problem: Irregular Computation Pattern

Solution: EIE accelerator

Sparse Matrix

90% *static* sparsity in the weights,
10x less computation,
5x less memory footprint

Sparse Vector

70% *dynamic* sparsity in the activation
3x less computation

Weight Sharing

4bits weights
8x less memory footprint

Fully fits in SRAM

120x less energy than DRAM

Distributed Storage and Processing

logically

$$\vec{a}\ \begin{pmatrix} 0 & \boldsymbol{a_1} & 0 & a_3 \end{pmatrix}$$

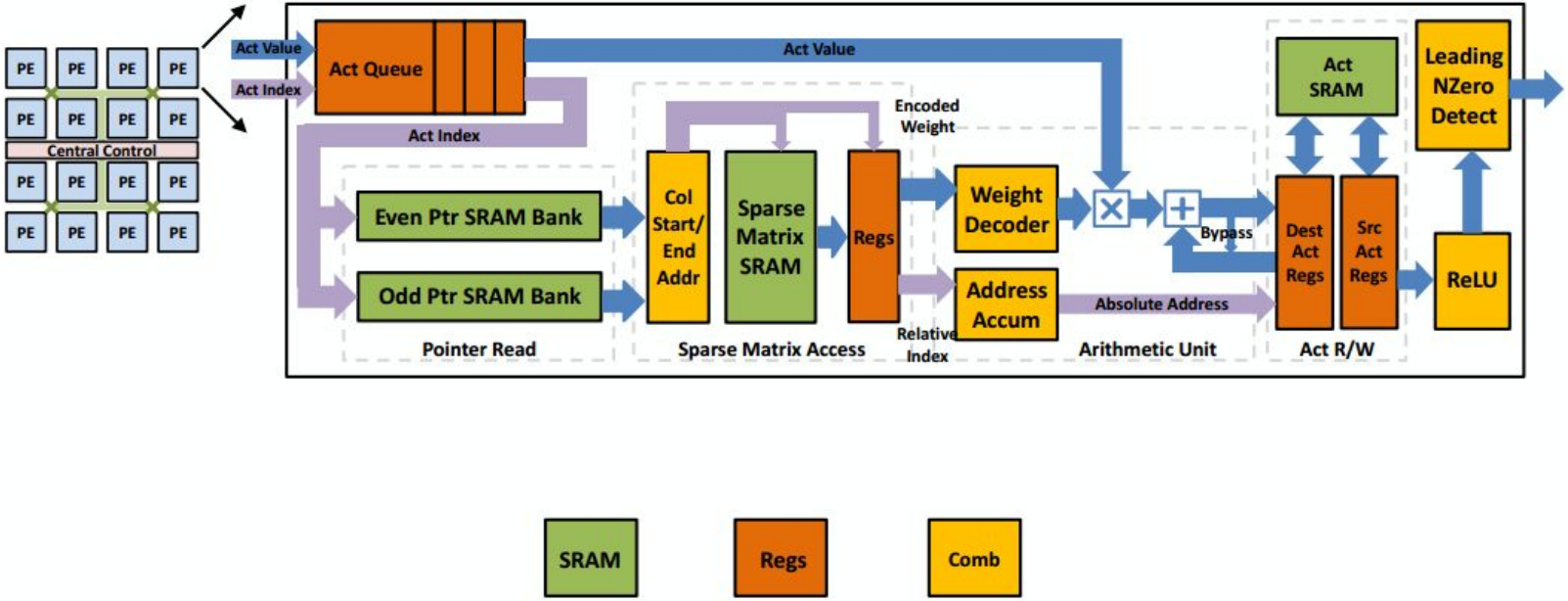
$$\times$$

$$\begin{array}{c} PE0 \\ PE1 \\ PE2 \\ PE3 \\ \\ \\ \\ \\ \end{array} \begin{pmatrix} w_{0,0} & \boldsymbol{w_{0,1}} & 0 & w_{0,3} \\ 0 & \boldsymbol{0} & w_{1,2} & 0 \\ 0 & \boldsymbol{w_{2,1}} & 0 & w_{2,3} \\ 0 & \boldsymbol{0} & 0 & 0 \\ 0 & \boldsymbol{0} & w_{4,2} & w_{4,3} \\ w_{5,0} & \boldsymbol{0} & 0 & 0 \\ 0 & \boldsymbol{0} & 0 & w_{6,3} \\ 0 & \boldsymbol{w_{7,1}} & 0 & 0 \end{pmatrix} = \begin{pmatrix} b_0 \\ b_1 \\ -b_2 \\ b_3 \\ -b_4 \\ b_5 \\ b_6 \\ -b_7 \end{pmatrix} \overset{ReLU}{\Rightarrow} \overset{\vec{b}}{\begin{pmatrix} b_0 \\ b_1 \\ 0 \\ b_3 \\ 0 \\ b_5 \\ b_6 \\ 0 \end{pmatrix}}$$

physically

Virtual Weight	$W_{0,0}$	$W_{0,1}$	$W_{4,2}$	$W_{0,3}$	$W_{4,3}$
Relative Index	0	1	2	0	0
Column Pointer	0	1	2	3	

PE Architecture

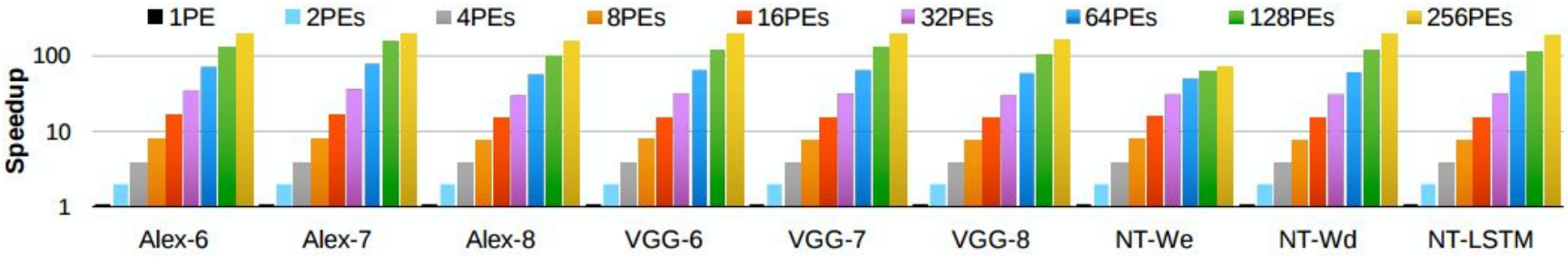


Benchmark

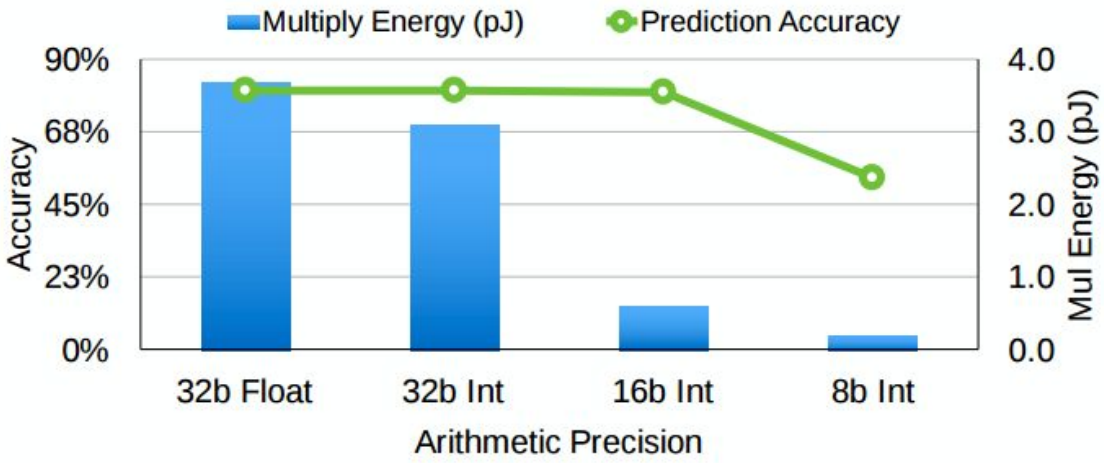
- CPU: Intel Core-i7 5930k
- GPU: NVIDIA Titan X
- Mobile GPU: NVIDIA Jetson TK1

Layer	Size	Weight Density	Activation Density	FLOP %	Description
AlexNet-6	4096 × 9216	9%	35.1%	3%	AlexNet for image classification
AlexNet-7	4096 × 4096	9%	35.3%	3%	
AlexNet-8	1000 × 4096	25%	37.5%	10%	
VGG-6	4096 × 25088	4%	18.3%	1%	VGG-16 for image classification
VGG-7	4096 × 4096	4%	37.5%	2%	
VGG-8	1000 × 4096	23%	41.1%	9%	
NeuralTalk-We	600 × 4096	10%	100%	10%	RNN and LSTM for image caption
NeuralTalk-Wd	8791 × 600	11%	100%	11%	
NeuralTalk-LSTM	2400 × 1201	10%	100%	11%	

Scalability



Prediction Accuracy



Comparison: Throughput