Caffe con Troll:

Shallow Ideas to Speed Up **Deep** Learning

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github.com/HazyResearch/CaffeConTroll

Outline

Motivation

- CPU / GPU gap?

4 Shallow ideas for ***FLOP-proportional scheduling***

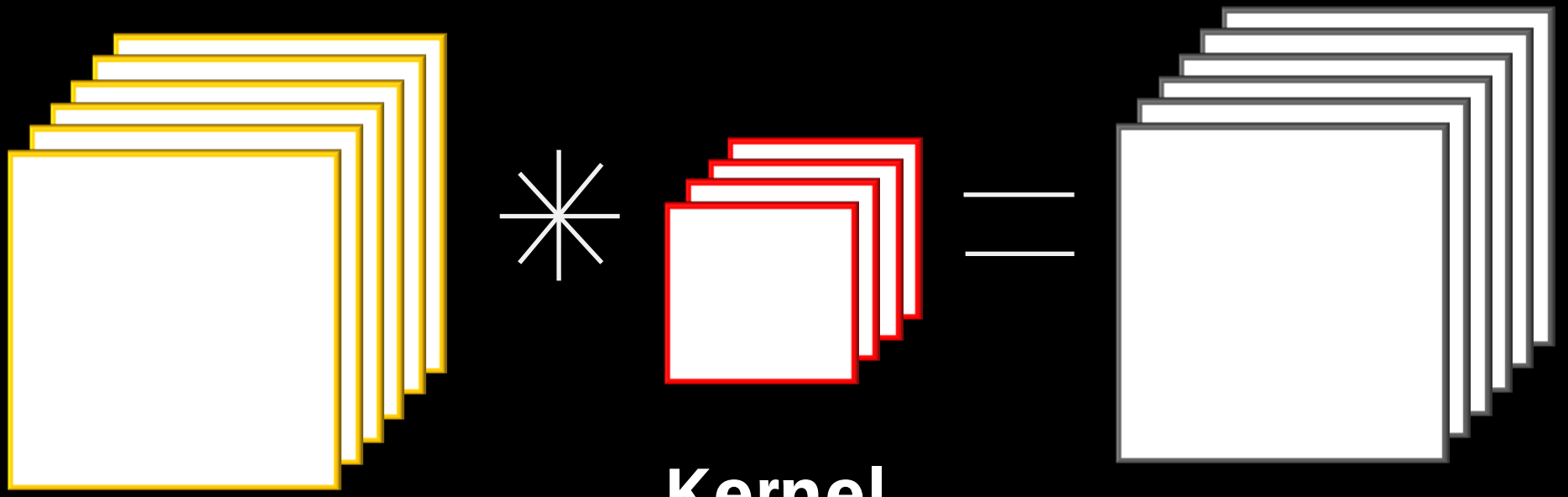
- Order of magnitude speedup on CPU
  - Close CPU / GPU gap
  - Operate all devices proportional to their FLOPS
- *Lets us use CPUs + GPUs together!*

What's next

- New optimizations

Convolutional Neural Nets

- 70-90% of time spent doing **Convolutions**



Input Images

Kernel (Convolution Weights)

Output Images

Convolutional Neural Nets

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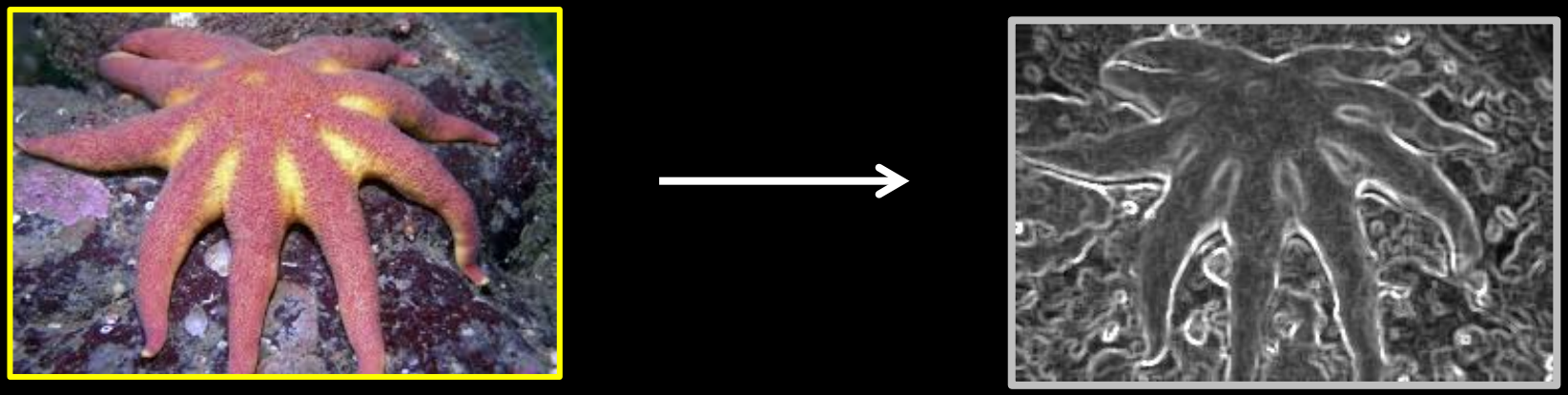

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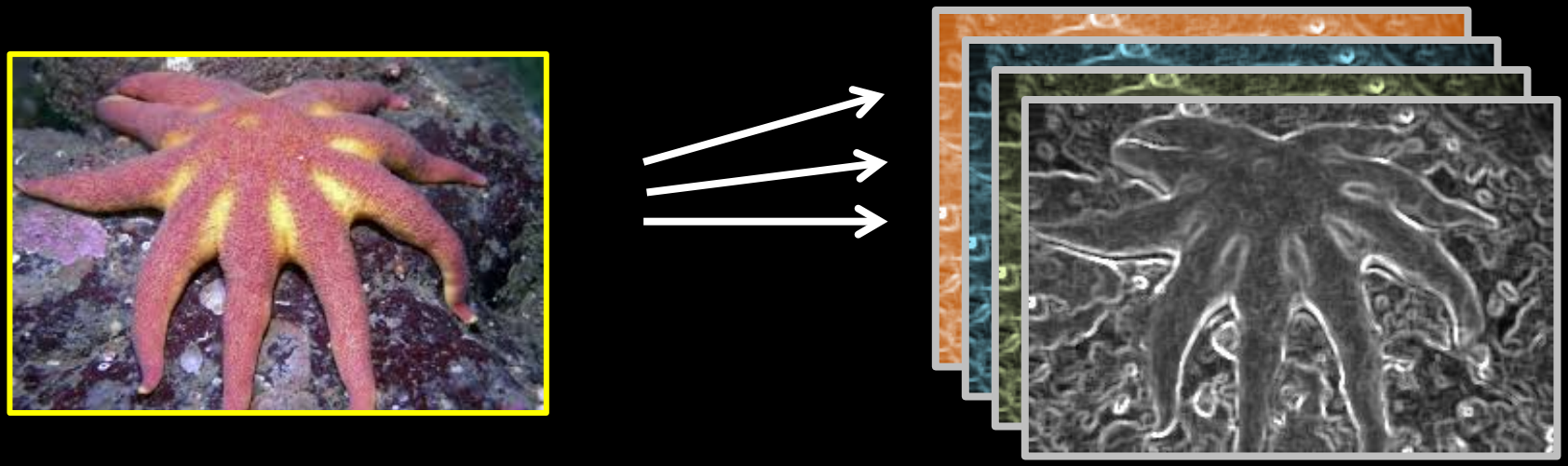

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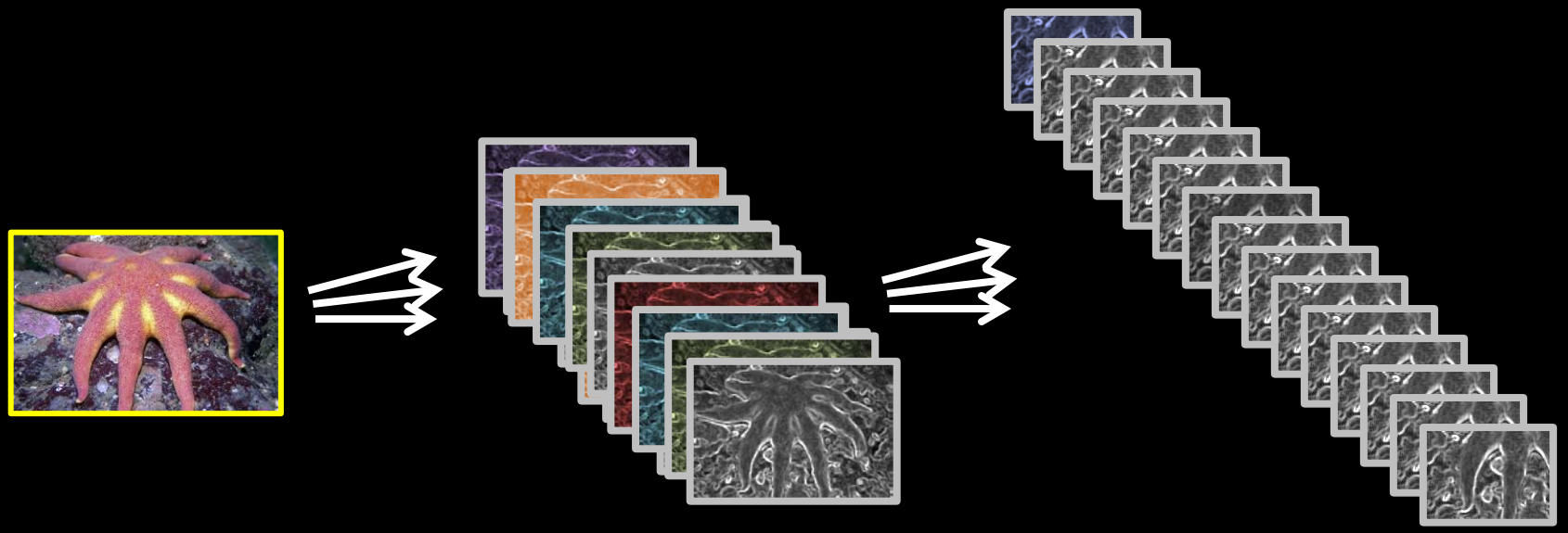
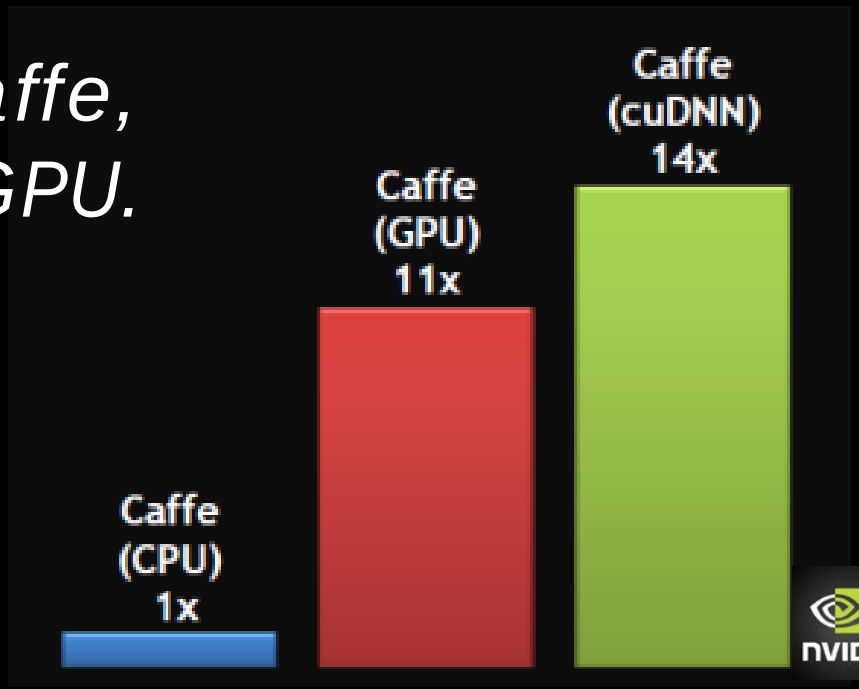


CPU or GPU?

Existing software, e.g., Caffe, 10x slower on CPU than GPU.



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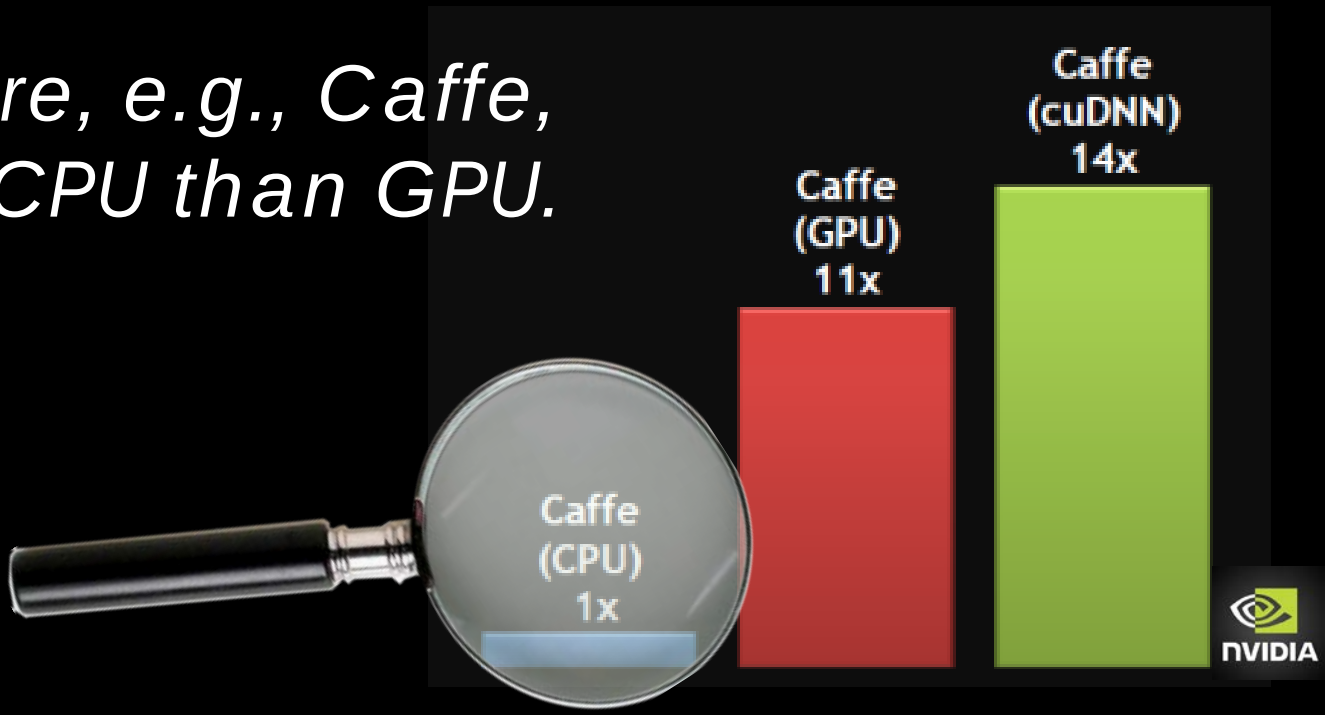

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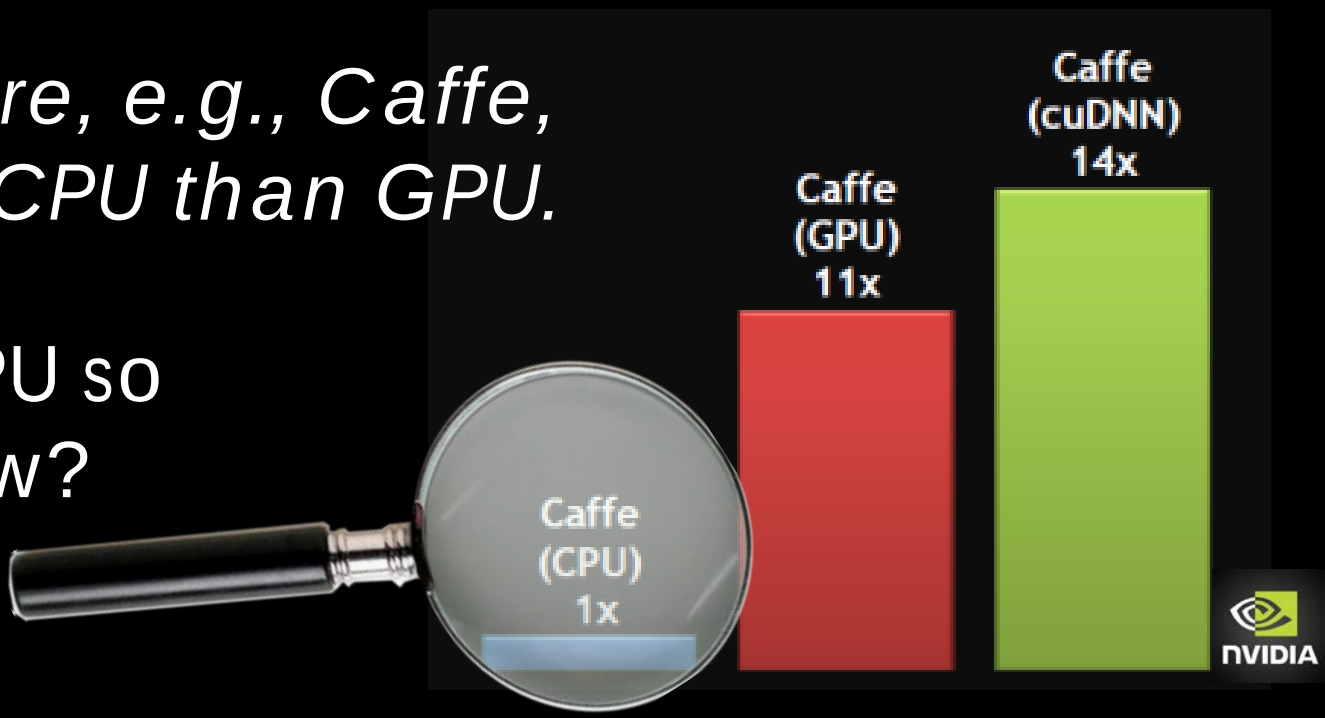
Why is the CPU so Relatively slow?



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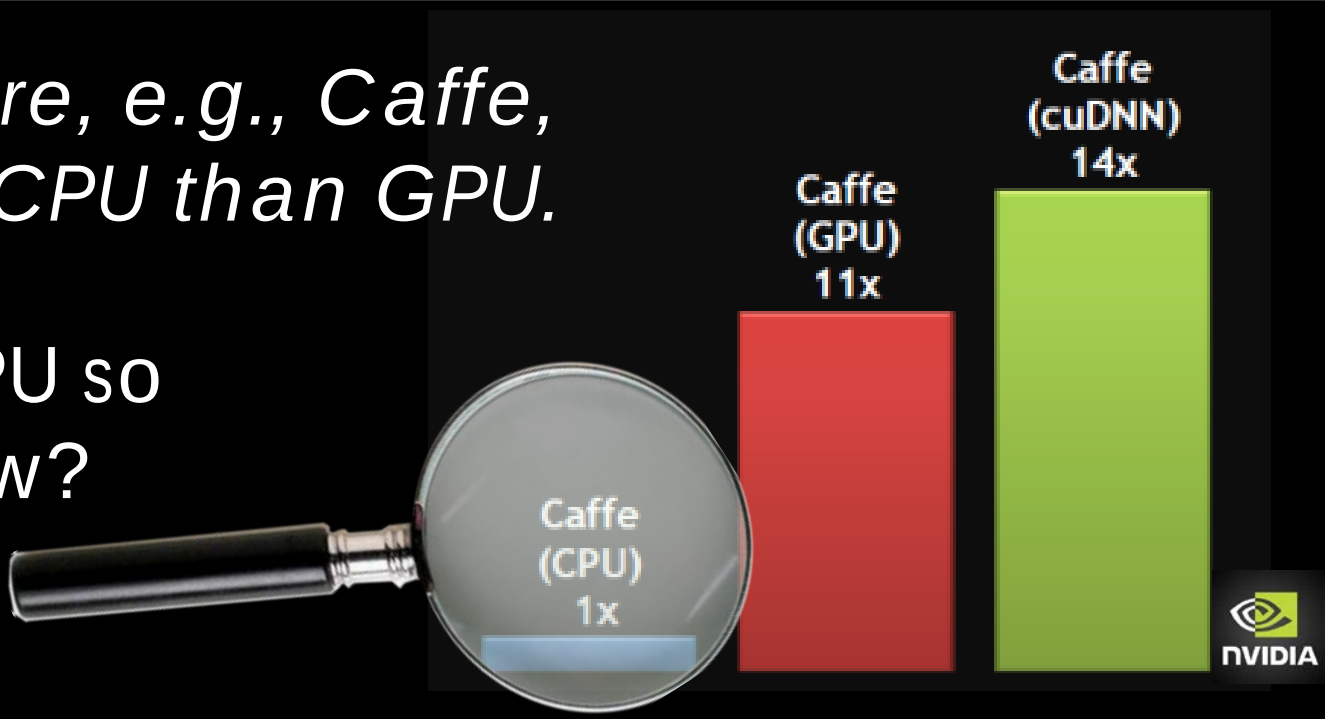

EC2: c4.4xlarge

8 cores@2.90GHz

0.7TFlops

EC2: g2.2xlarge

1.5K cores@800MHz

1.2TFlops

Not a 10x gap? Can we close this?

CPU or GPU?

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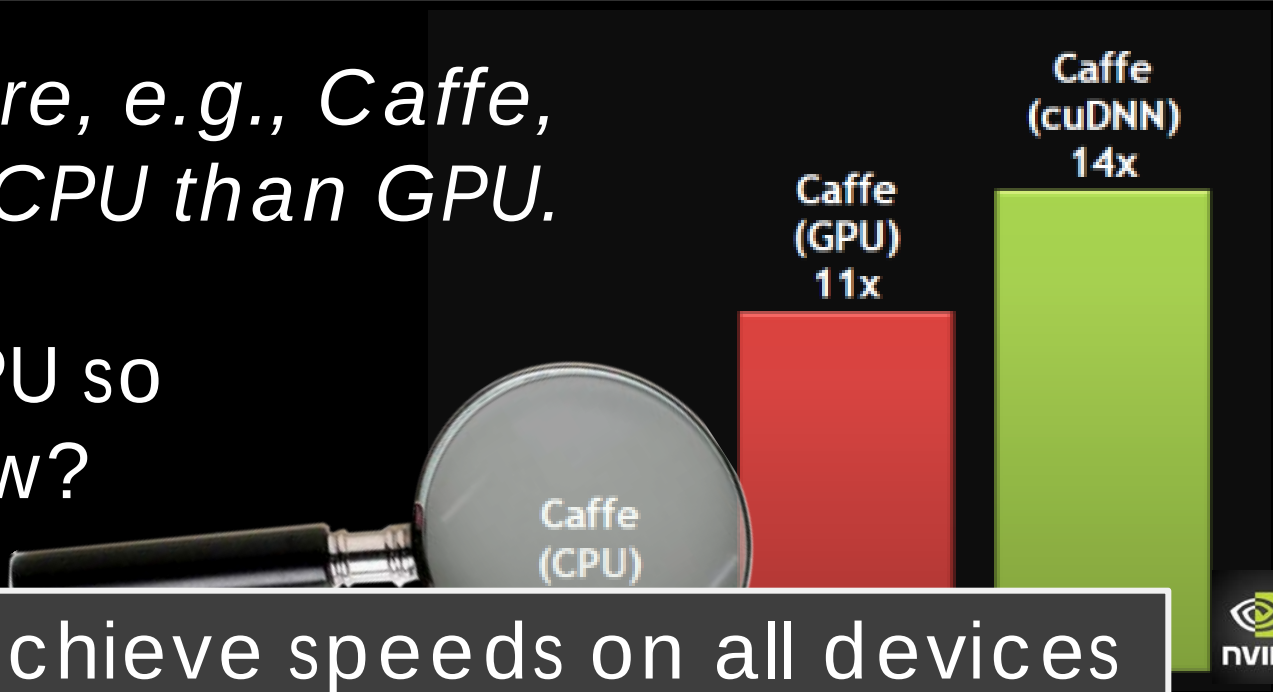


Goal: Achieve speeds on all devices proportional to their FLOPS

➔ Then use CPU + GPU together!

0.7TFlops

1.2TFlops

Not a 10x gap? Can we close this?

github.com/HazyResearch/CaffeConTroll

4 shallow ideas
described in 4 pages

4 Simple Ideas

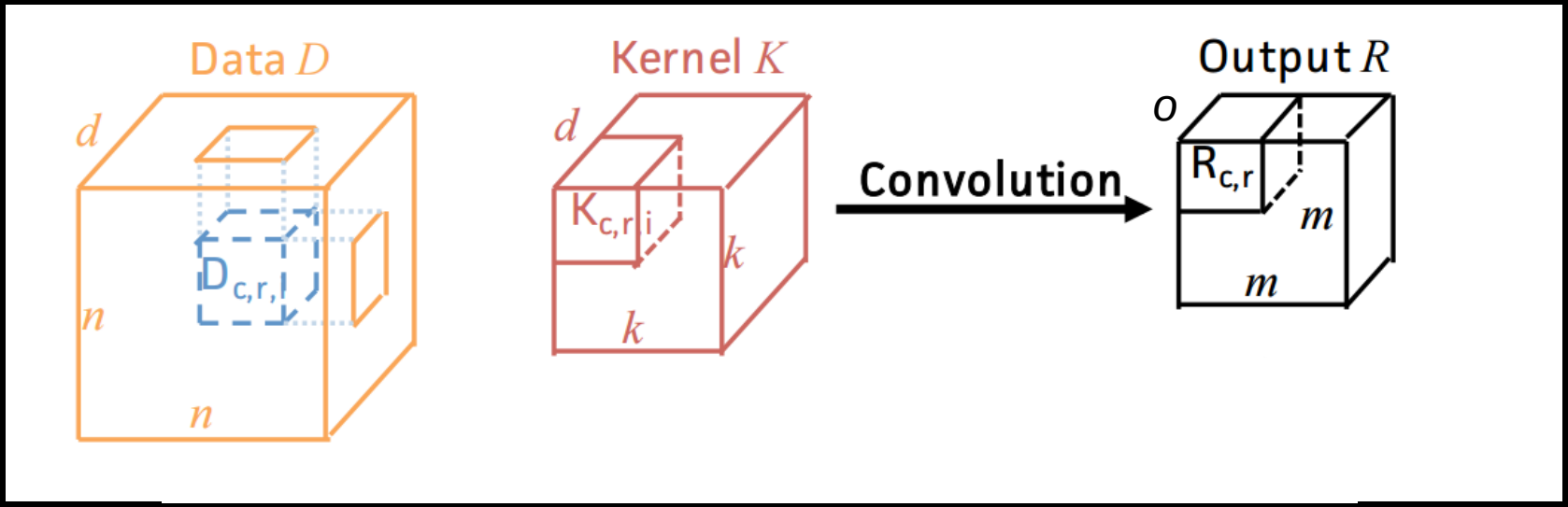
1. Understanding “Lowering”

2. Fusion of Lowering and GEMM

3. Parallel Batching, Blocking, SIMD

4. FLOP-Proportional Scheduling
   → Use both CPU + GPU for further speedups

Lowering: Tensors to Matrix Multiply



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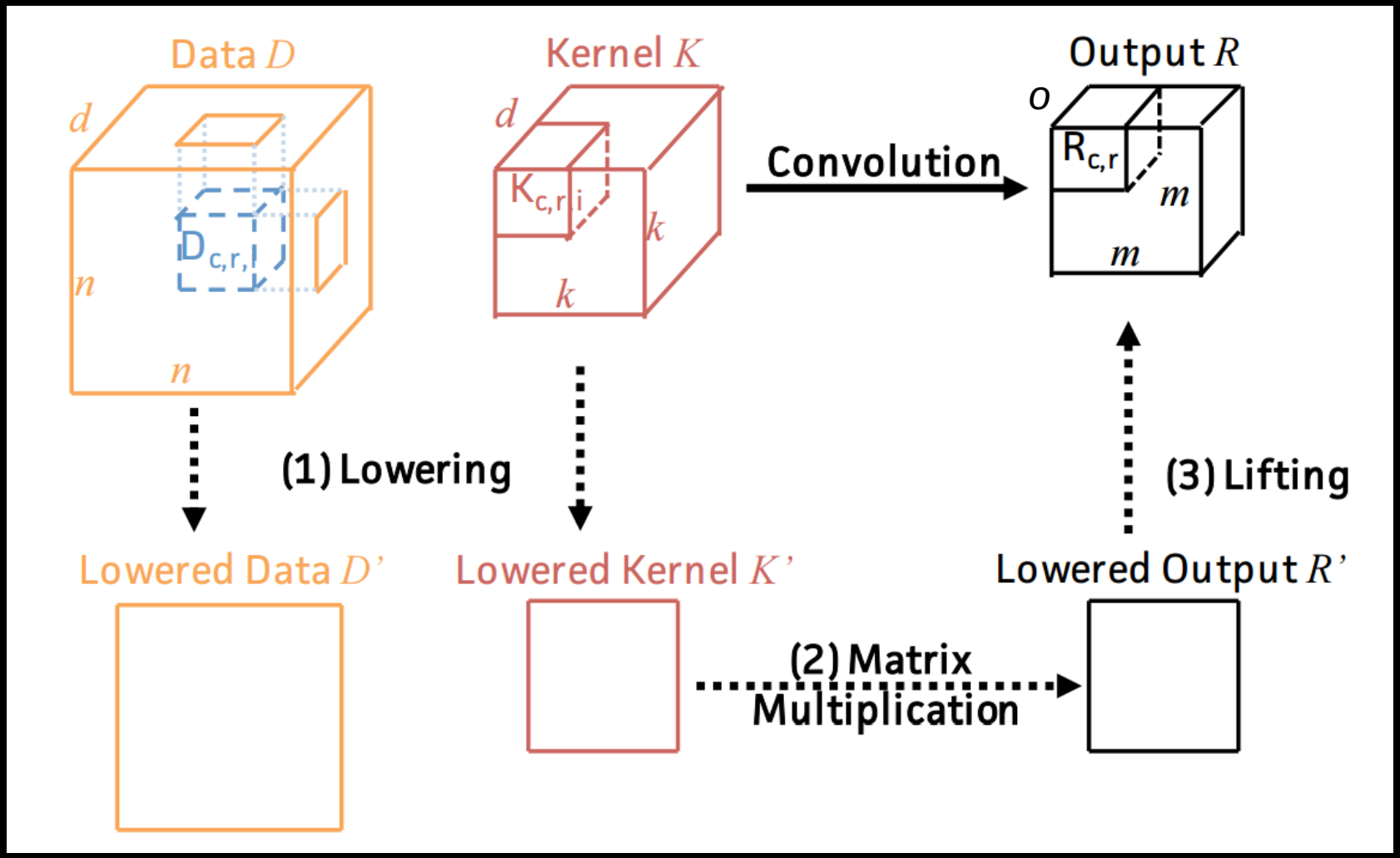

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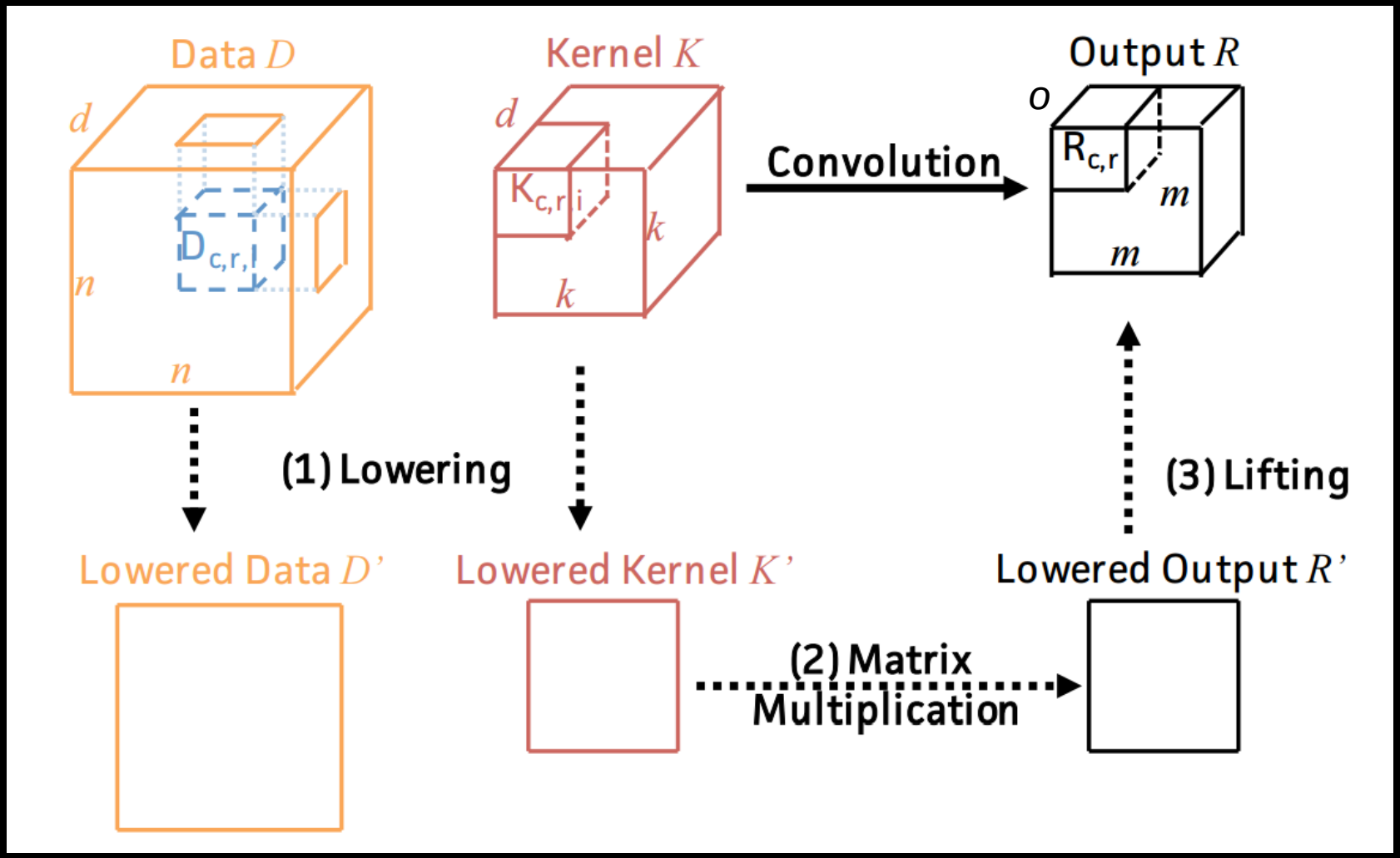
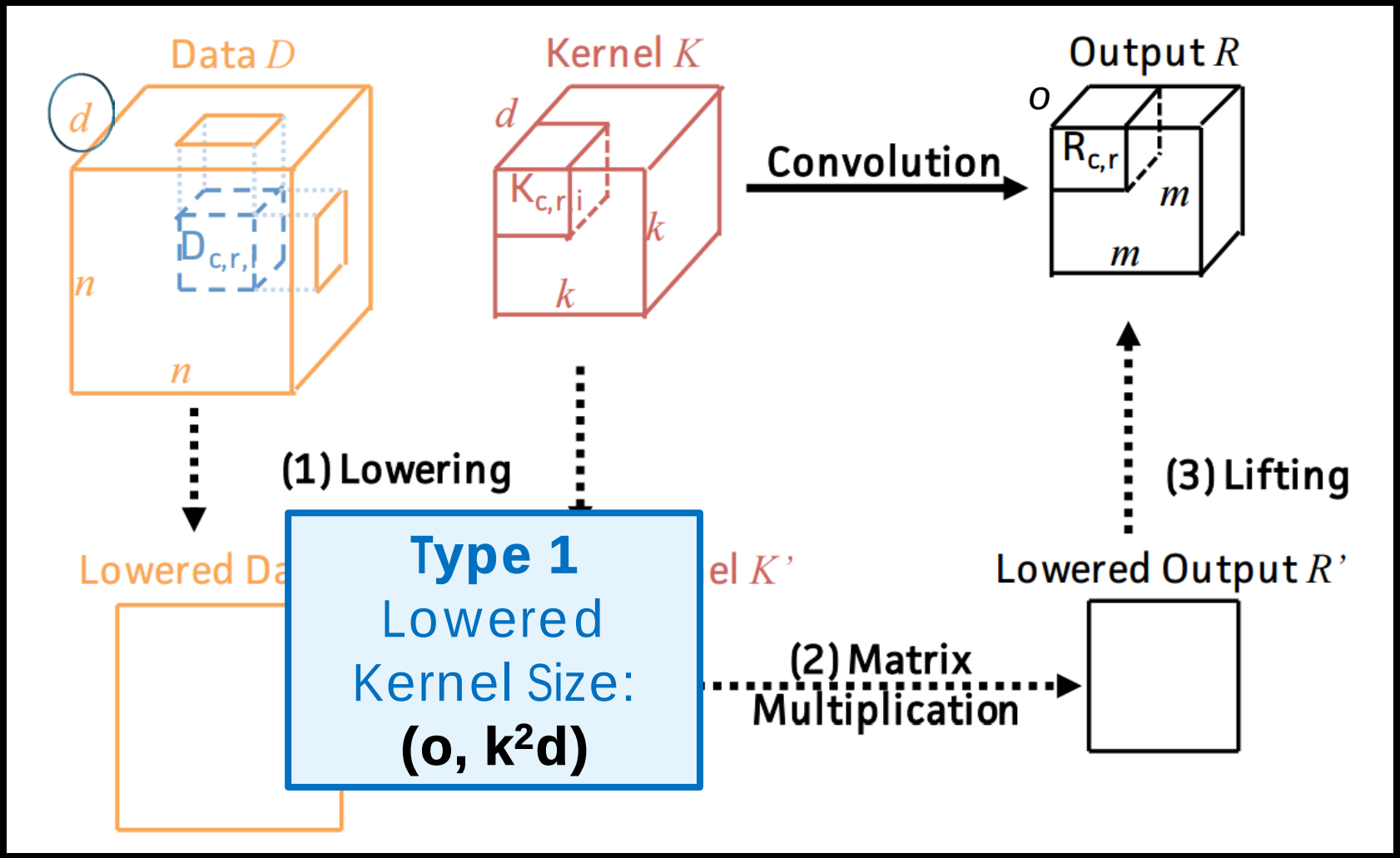


Shallow Idea 1. ***3 ways:*** *Replicate on lowering, Replicate lifting, or a little of both.*

Lowering: Tensors to Matrix Multiply



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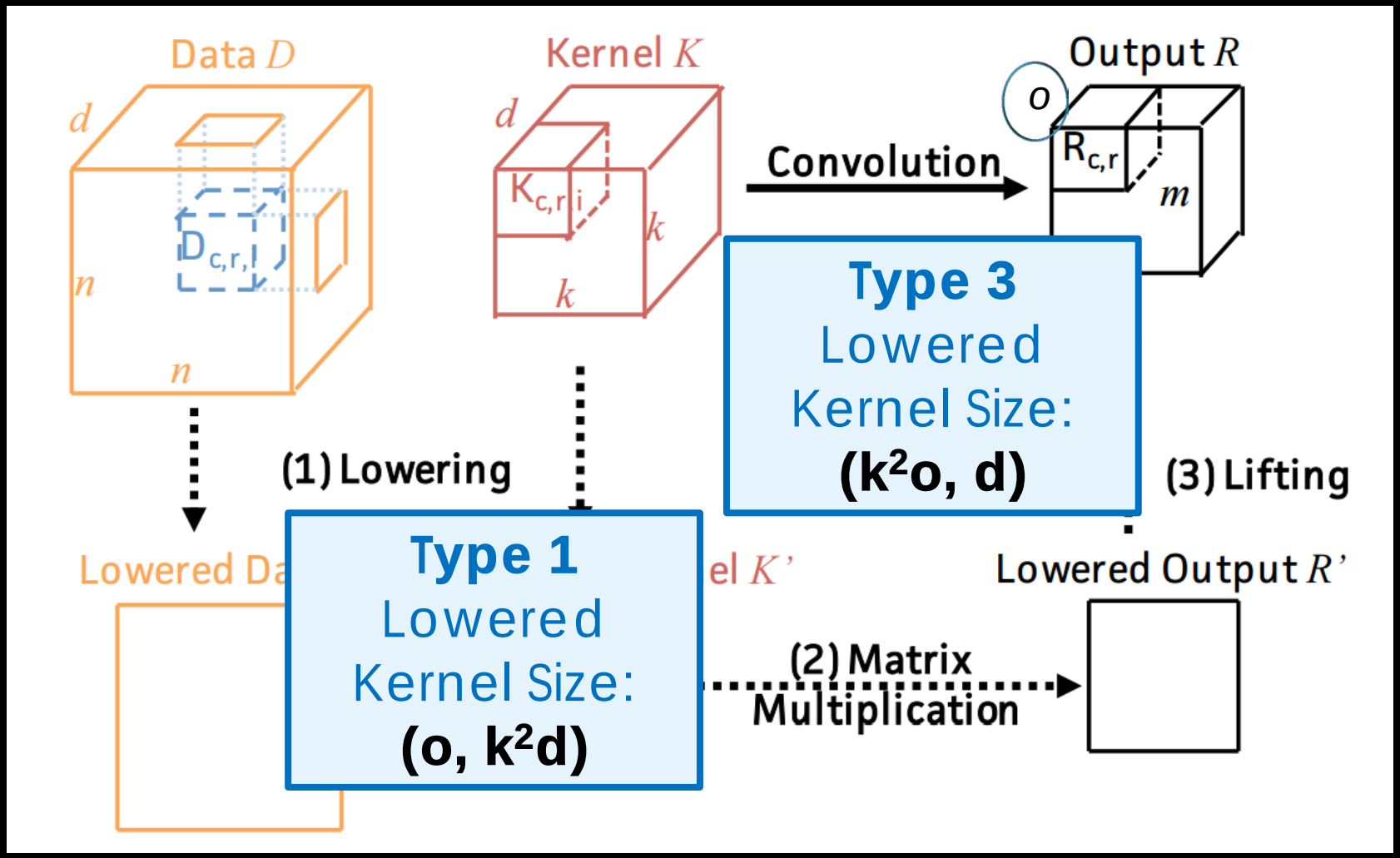

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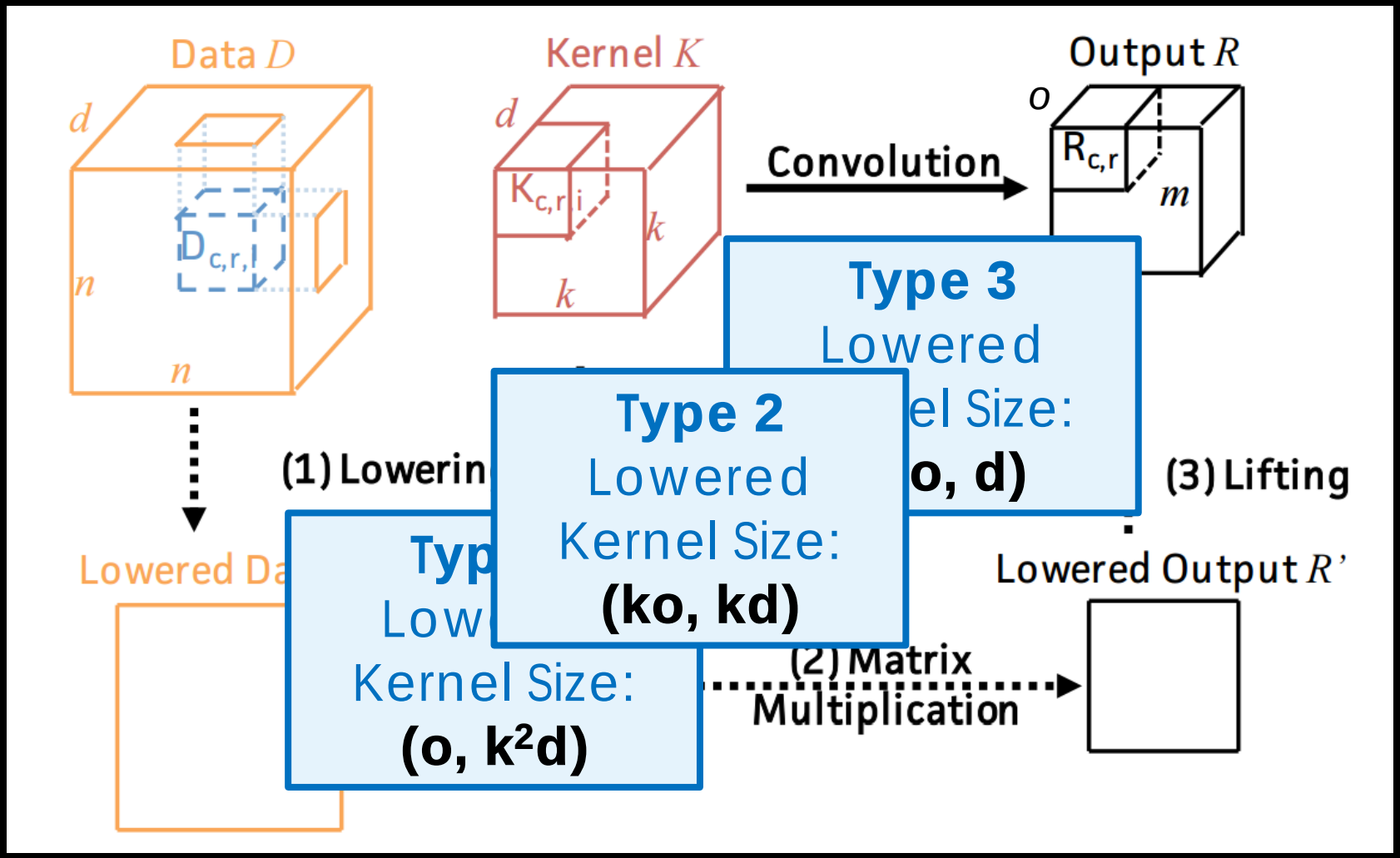
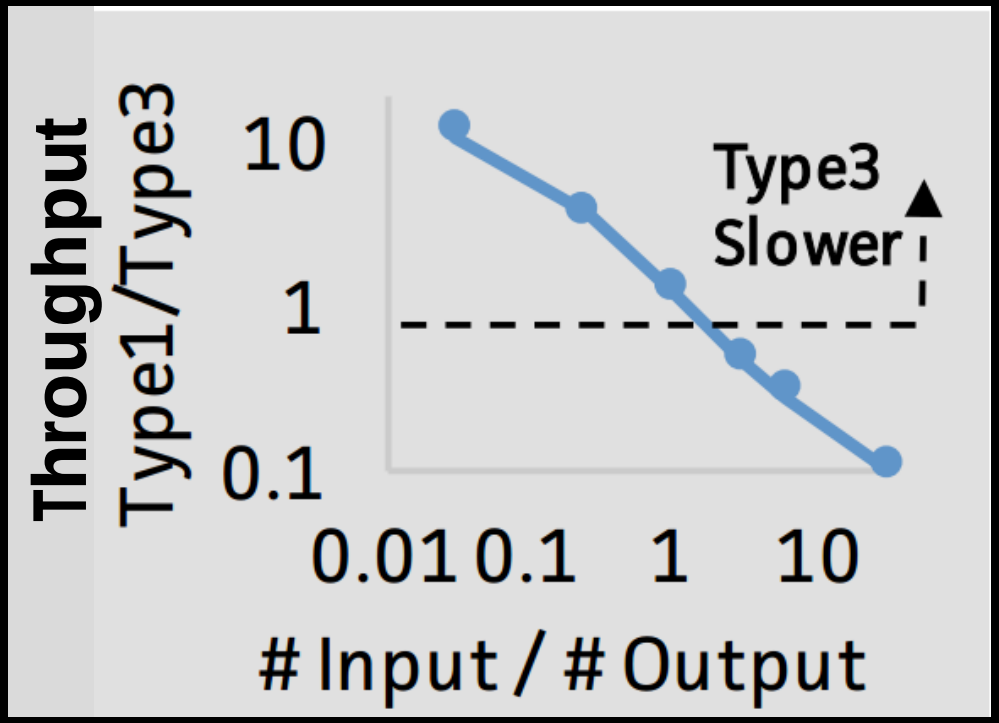


Shallow Idea 1. ***3 ways:*** *Replicate on lowering, Replicate lifting, or a little of both.*

3 Types of Lowering

Replicating Input (Type 1) is faster than replicating output (Type 3) when

#Input Channels < #Output Channels



Most conv layers *increase* depth

Replicating **Input** is usually fastest

3 Types of Lowering

Replicating Input (Type 1) is faster than replicating output (Type 3) when

#Input Channels < #Output Channels

Shallow idea 2:

Preliminary results also show 60% speedup by fusing lowering and GEMM

CPU Speedup: Batching

If the amount of data in GEMM call is too small, BLAS is not at peak FLOPS.

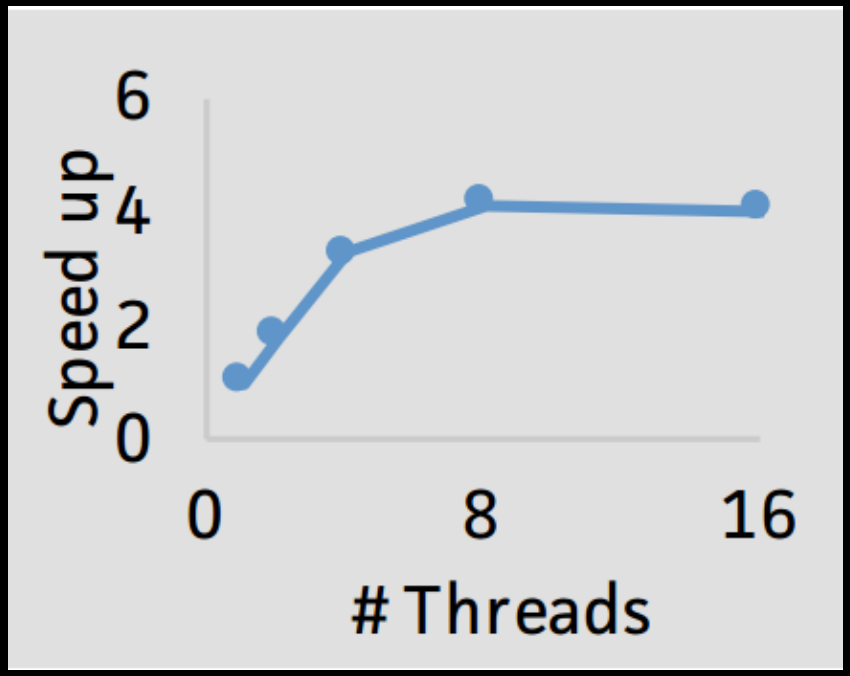
***Shallow idea 3**: Batch more data to give a chance to effectively **block** in GEMM ("fill" the L2 and L3 of all cores), and lower batches in parallel*

➔ *Not always possible to batch on GPU*

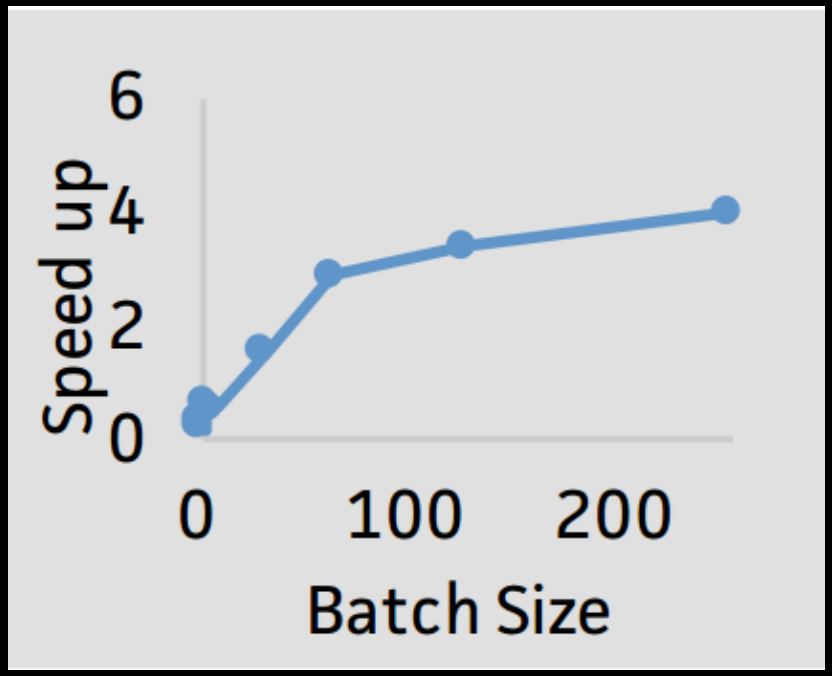
CPU Speedup: Batching

If the amount of data is small, BLAS is not CPU bound.

Effect on more threads and batch size on CPU GEMM kernel:



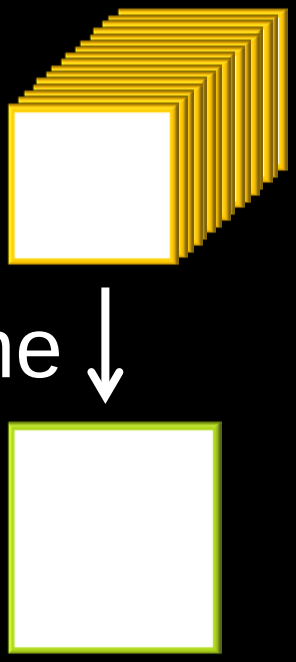
Batch size 256



8 Threads

CPU Speedup: Parallel Batch Partitions

Batching -- Caffe



Lowering

- 1 image at a time

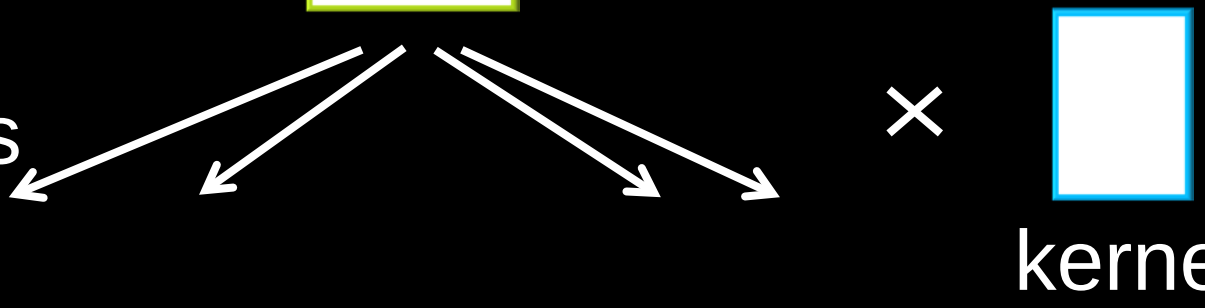
Batching -- Caffe

Lowering

- 1 image at a time

GEMM

- All cores



Batching -- Caffe

Lowering

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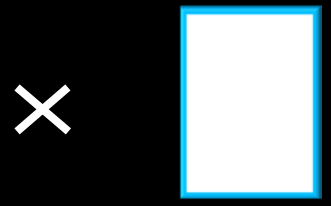
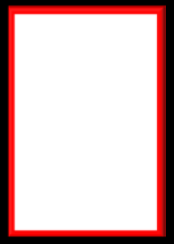
GEMM

- All cores



kernel

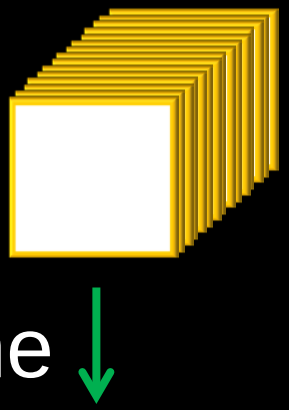
Output



Batching -- Caffe

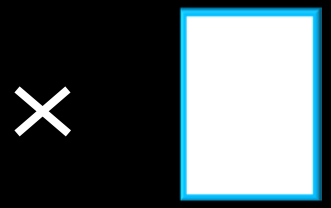
Lowering

- 1 image at a time



GEMM

- All cores



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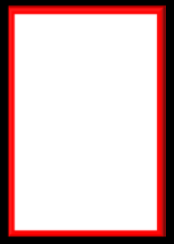

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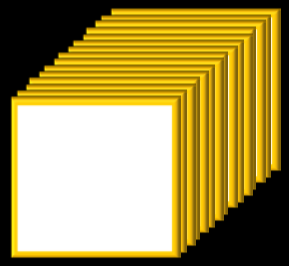

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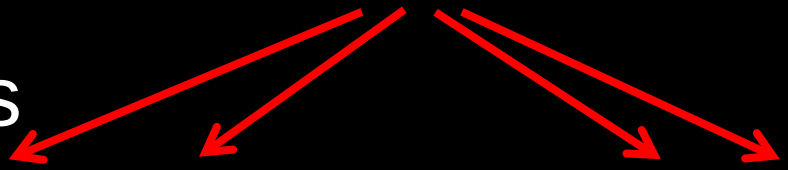

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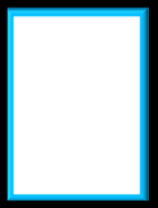

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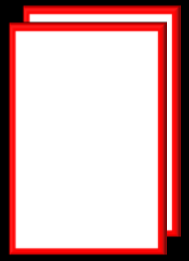

Batching -- Caffe

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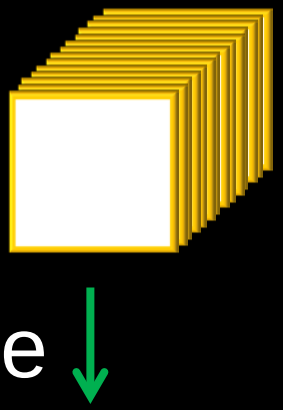
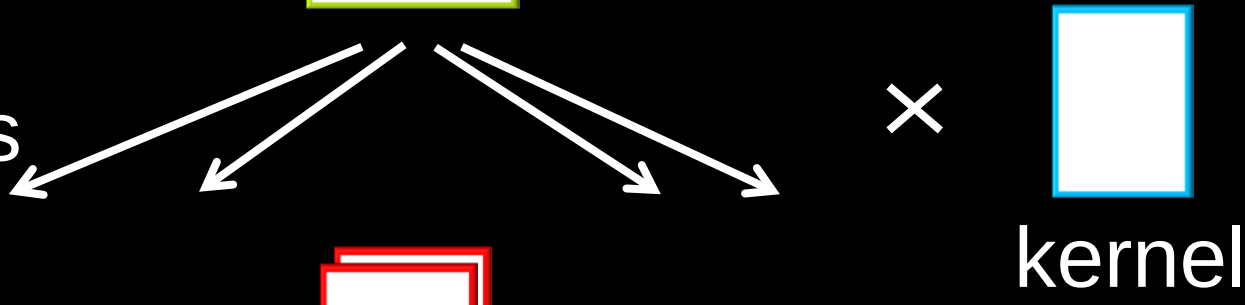


GEMM

- All cores



Output

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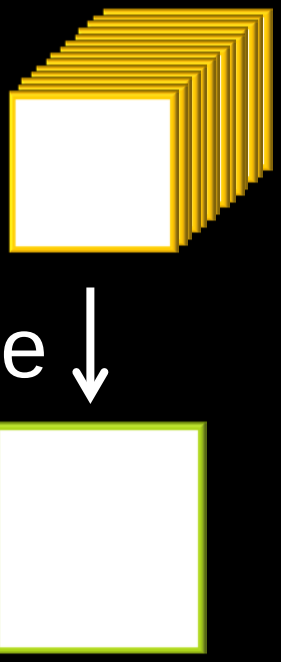

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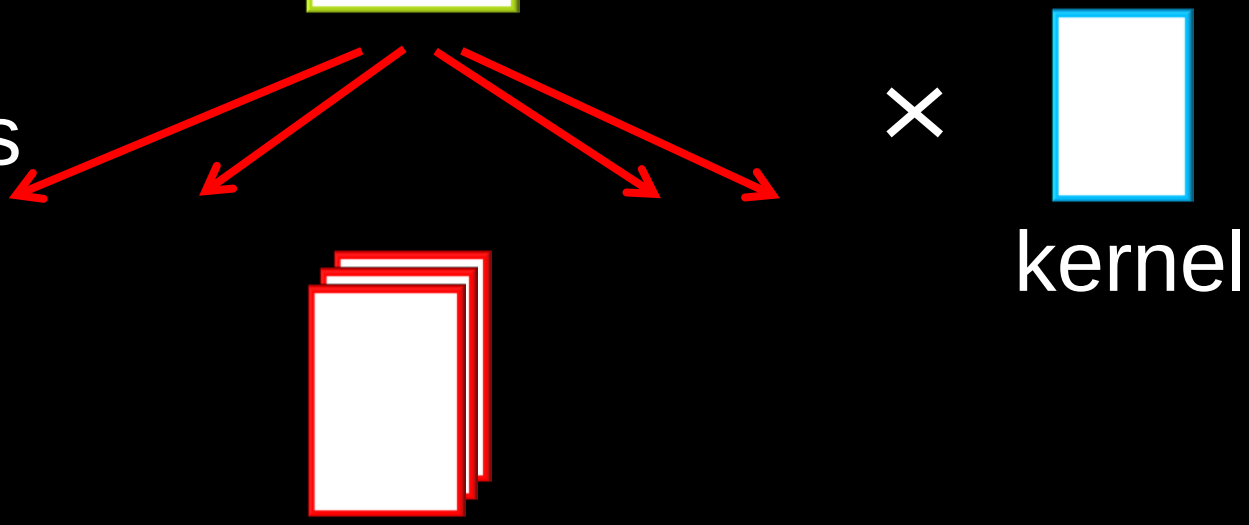

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Lowering

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GEMM

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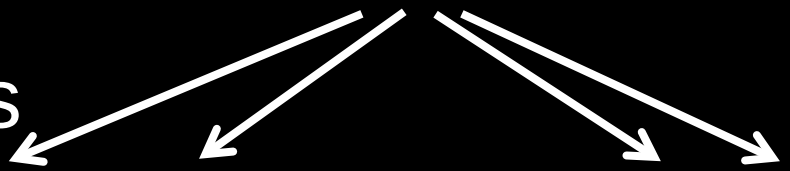
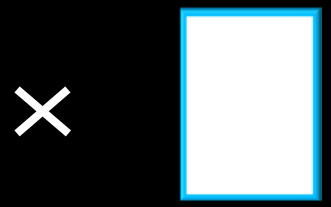
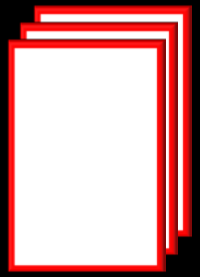




kernel

Output



Batching -- Caffe

Lowering

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GEMM

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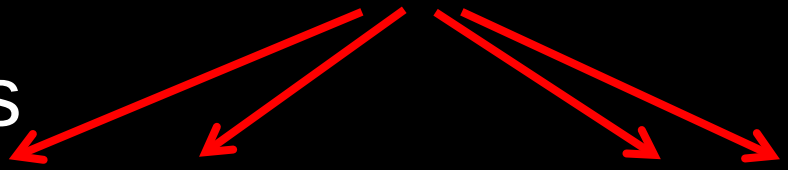

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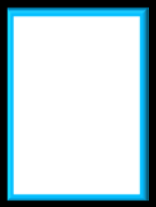

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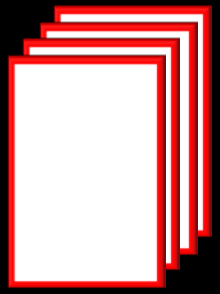
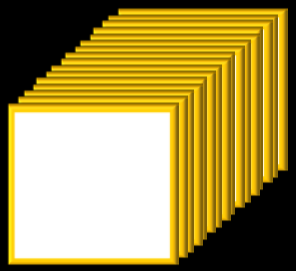
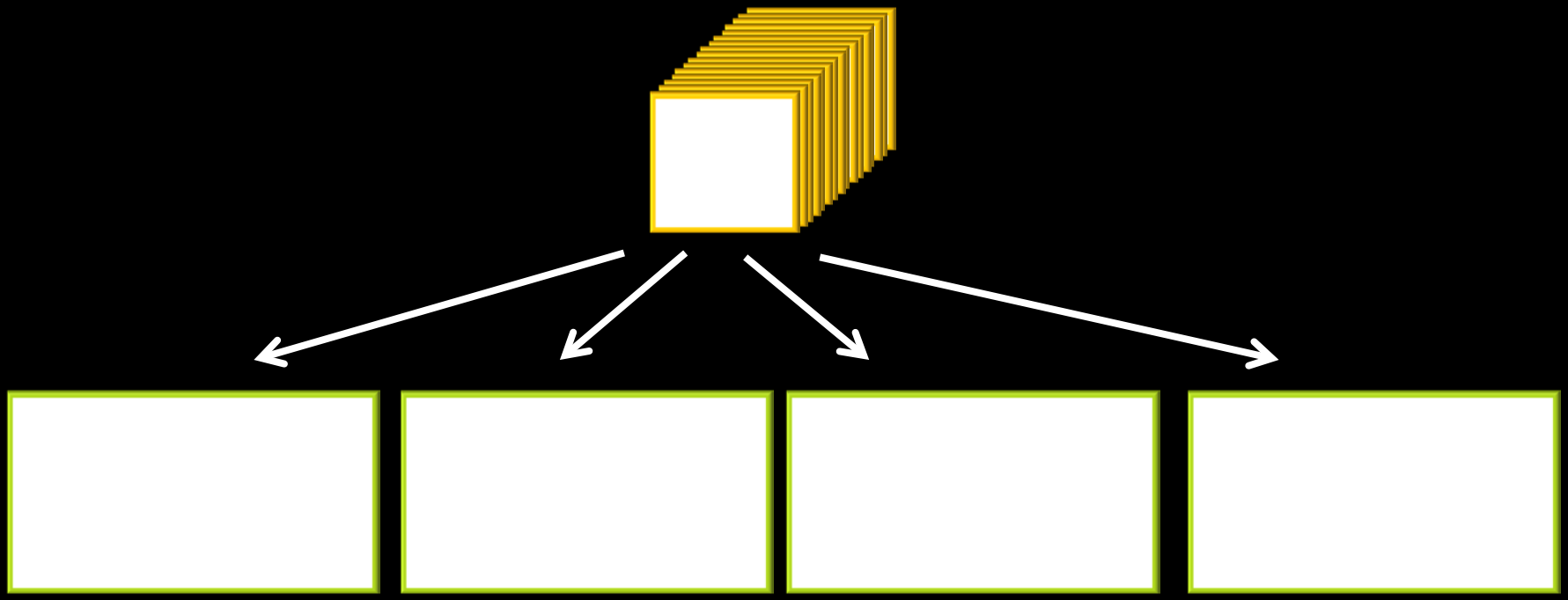


Batching -- CcT



Batching -- CcT



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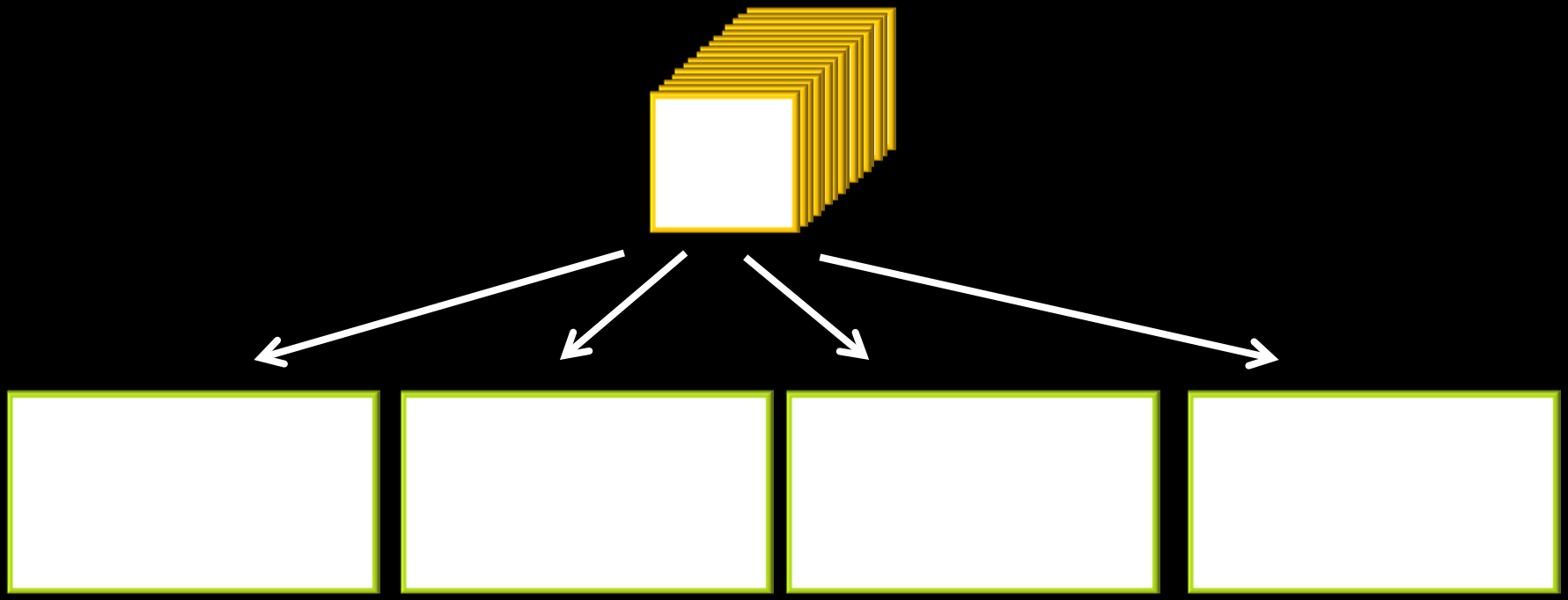
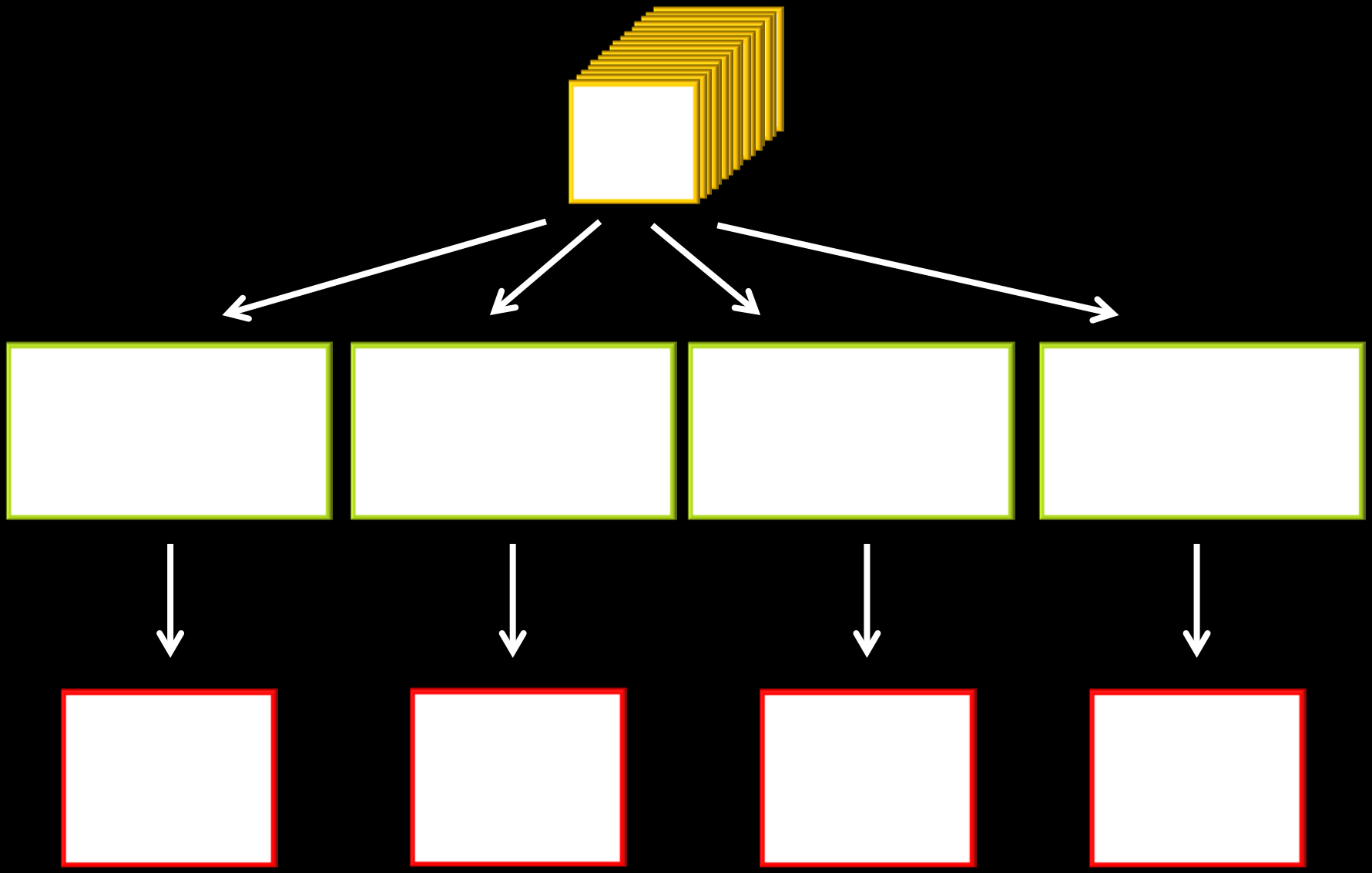


- **Partition** data and lower in parallel
- Use **batching** within each partition
  - All matrices are larger, enabling blocking optimizations and making GEMM CPU bound

Batching -- CcT



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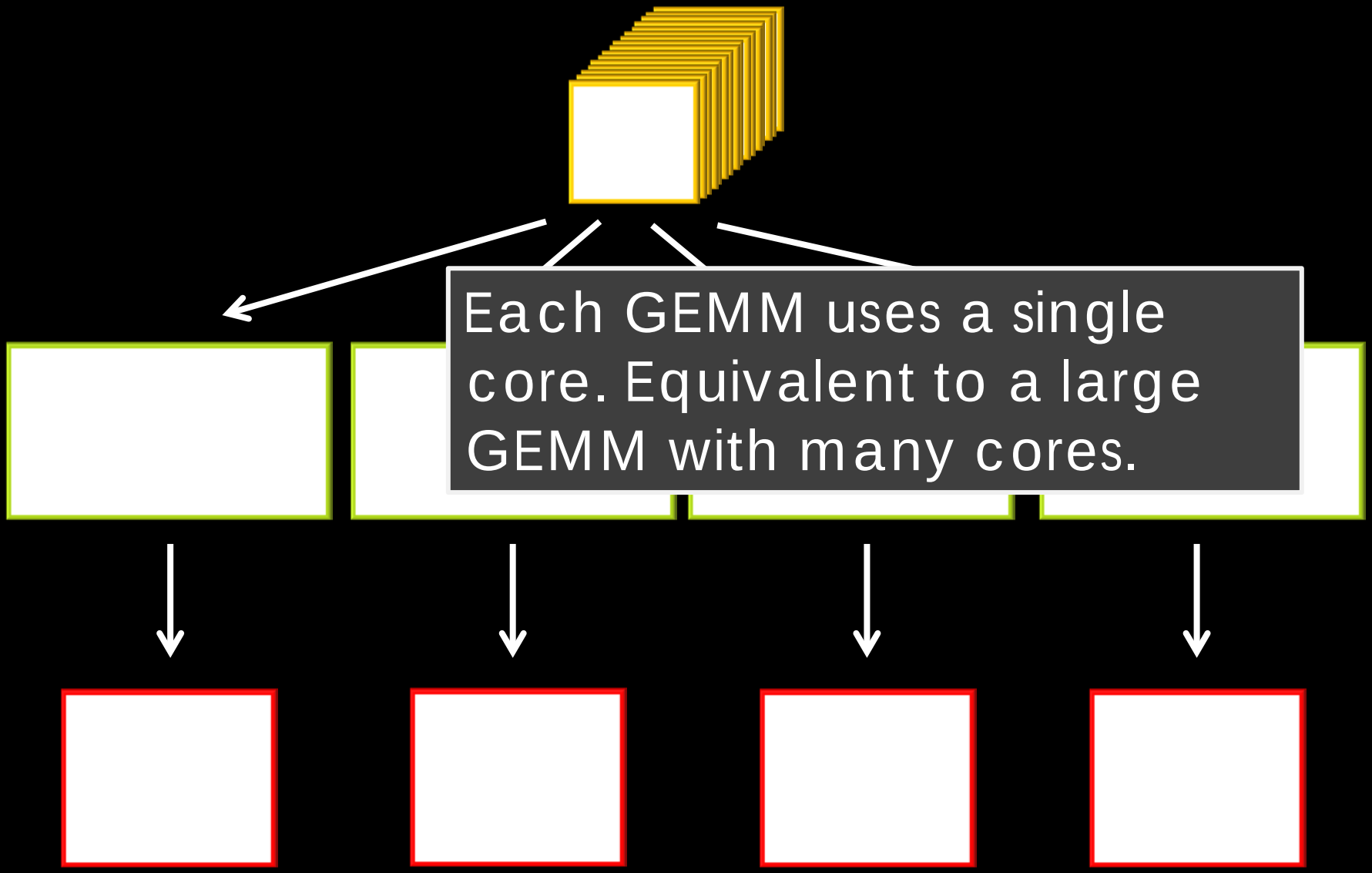

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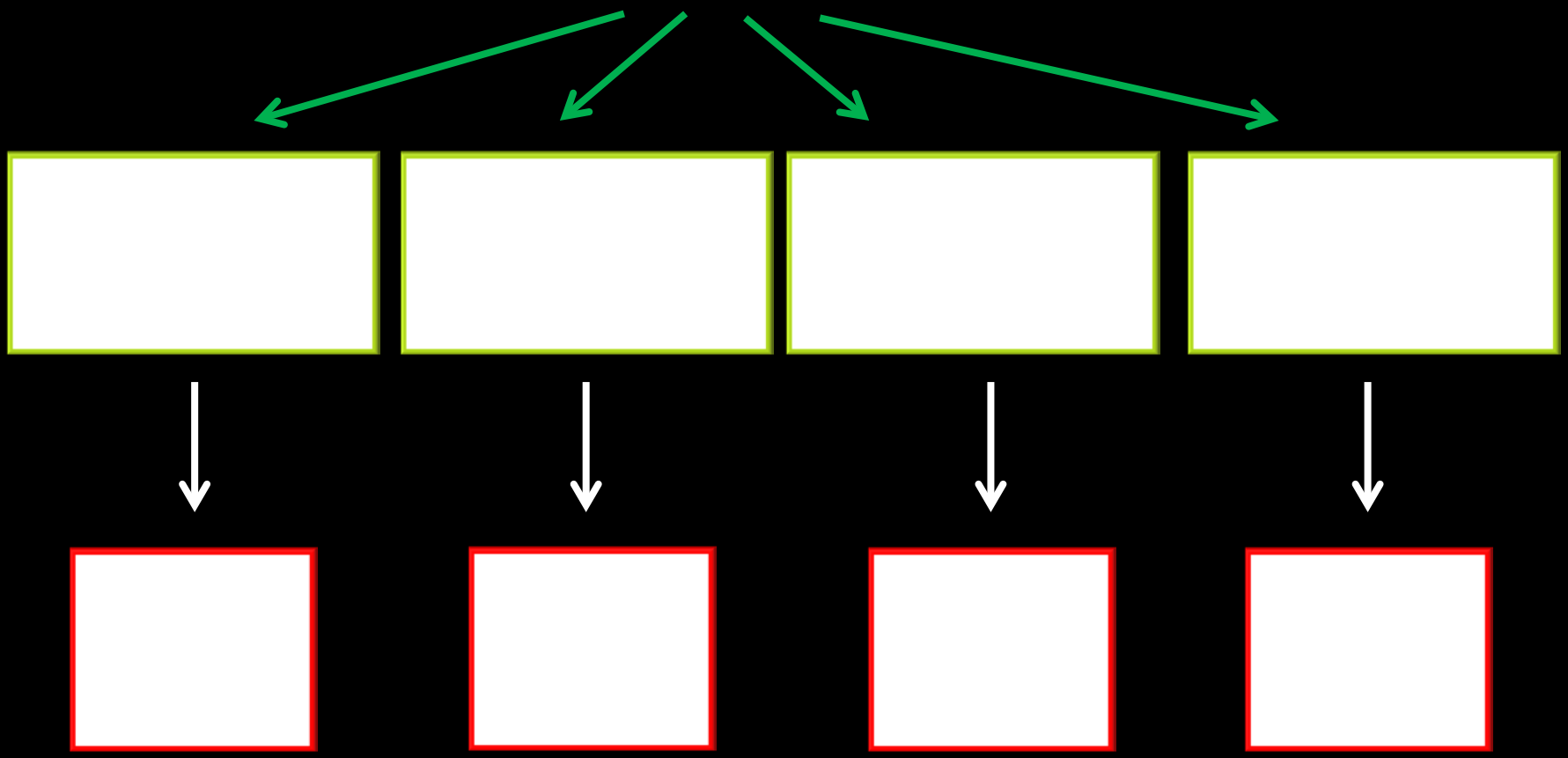

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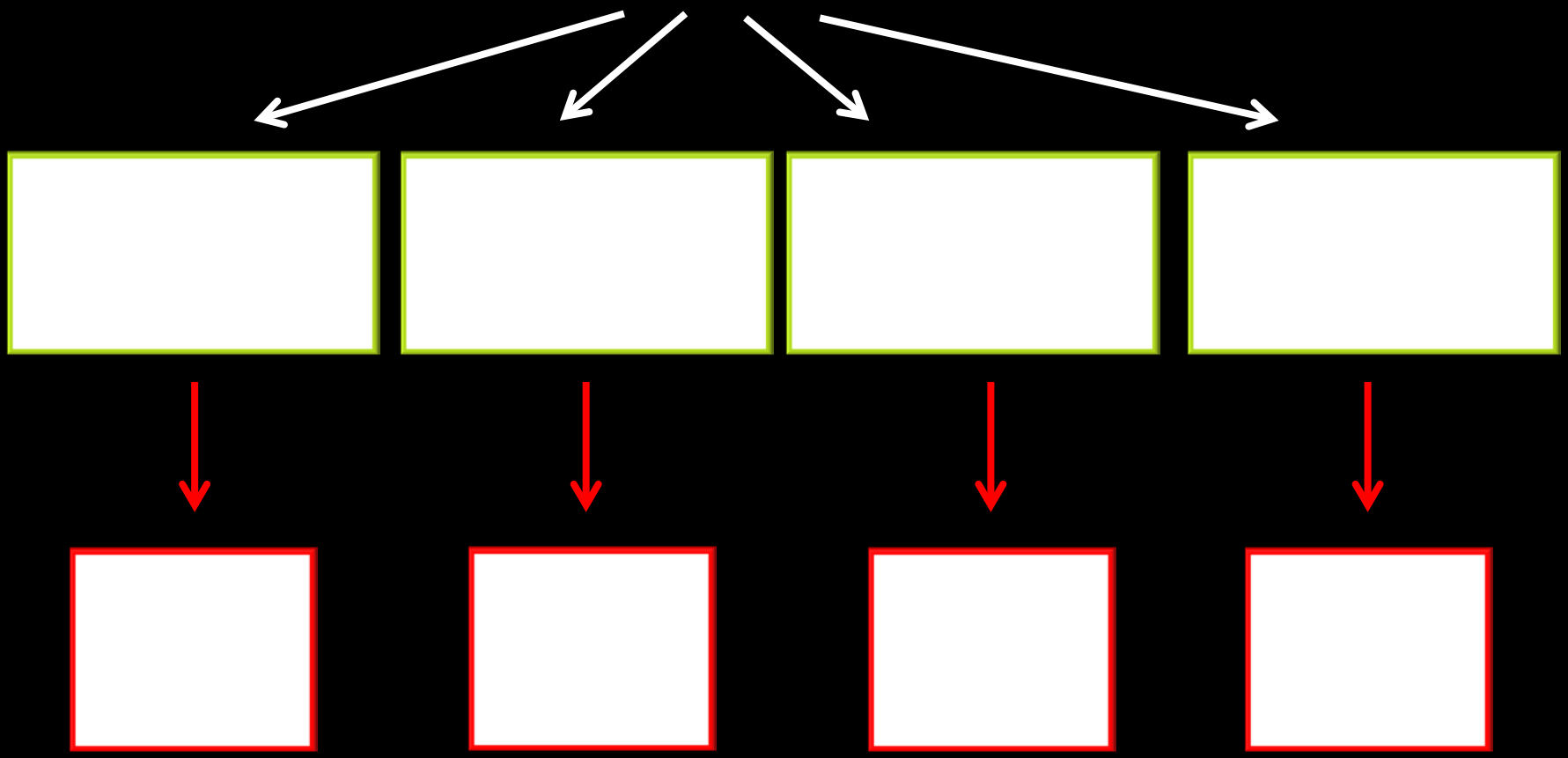
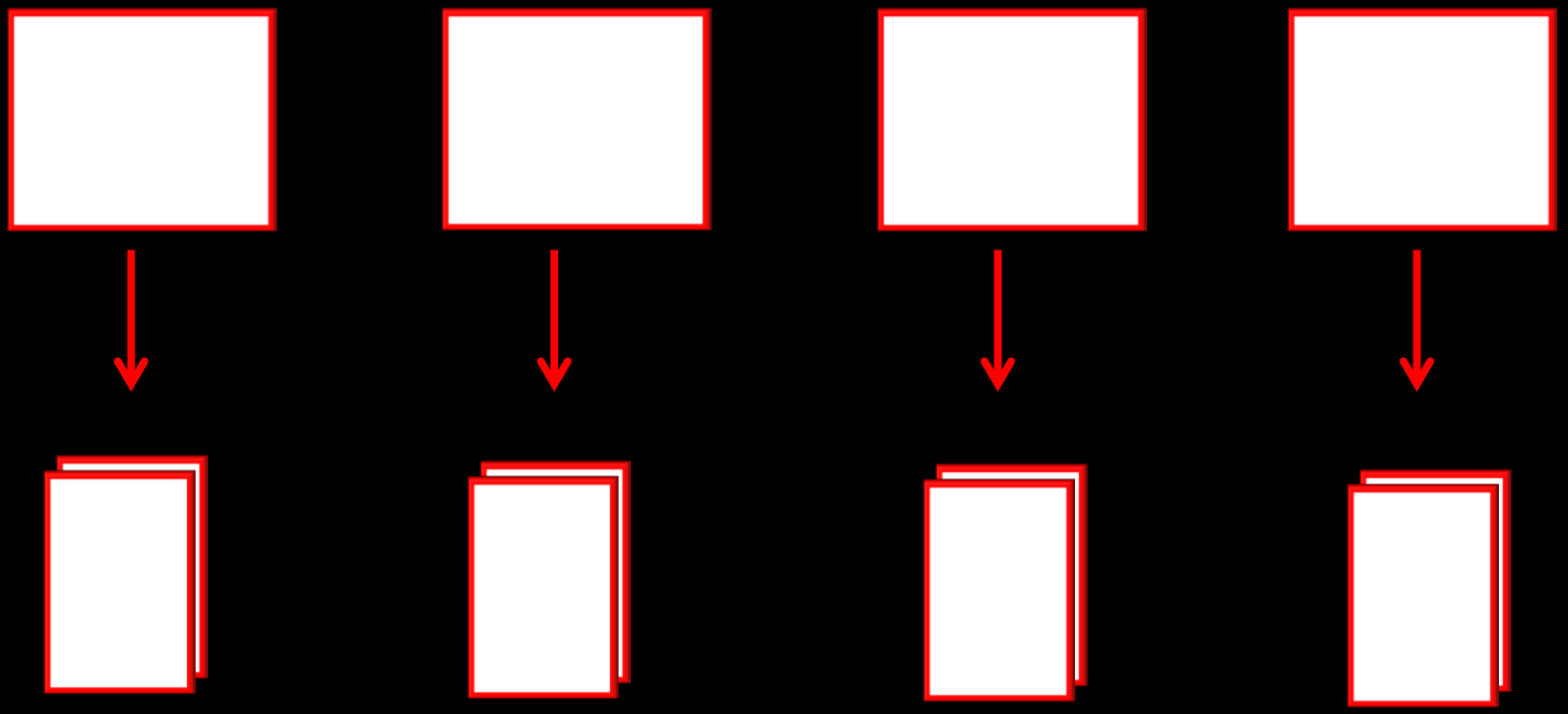
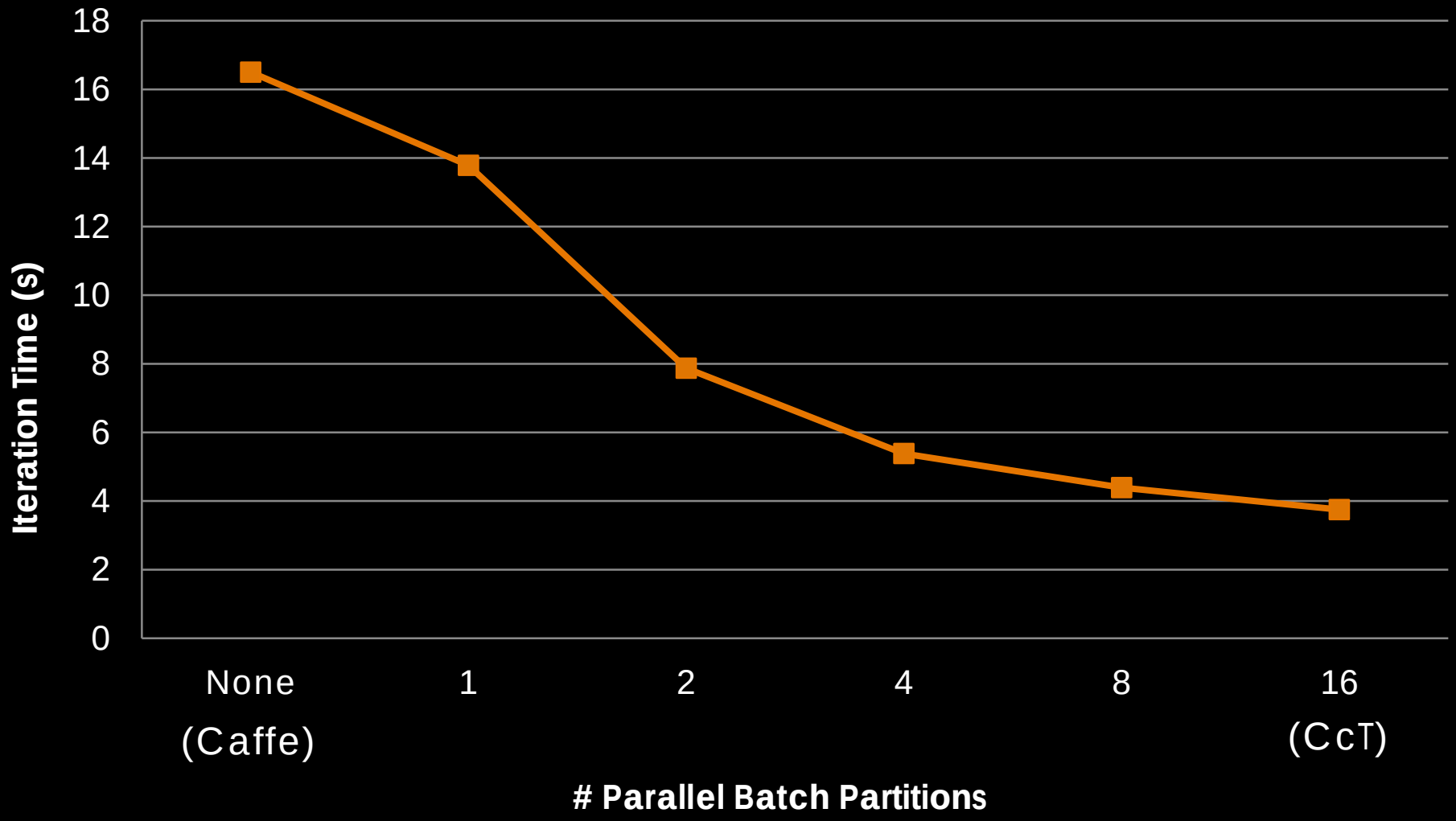


Batching -- CcT

Final step to remap the output



CPU Batching Speedup (full AlexNet)



EC2 c4.4xlarge instance ($0.68/hour), end-to-end *"AlexNet", batch size 256*

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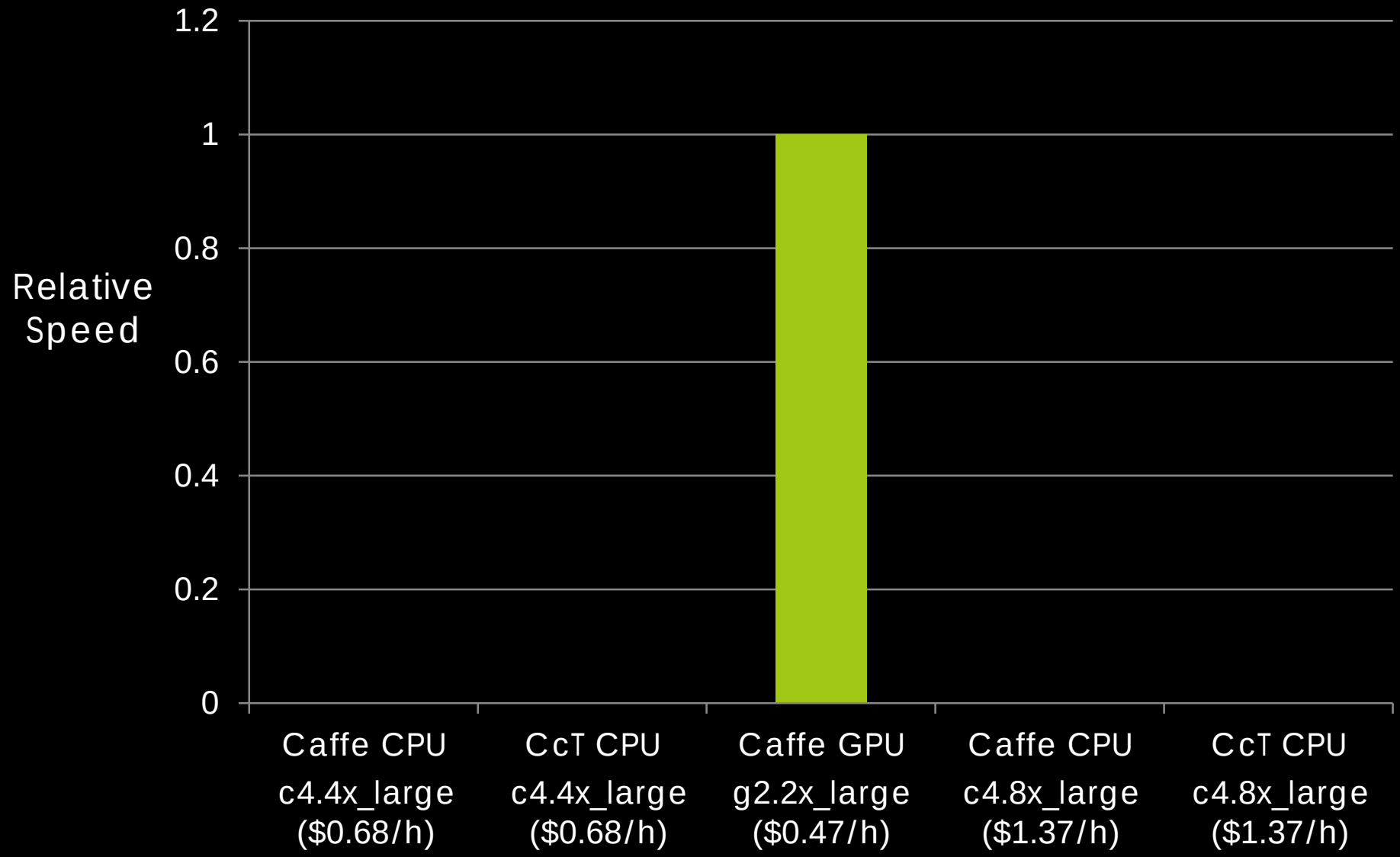

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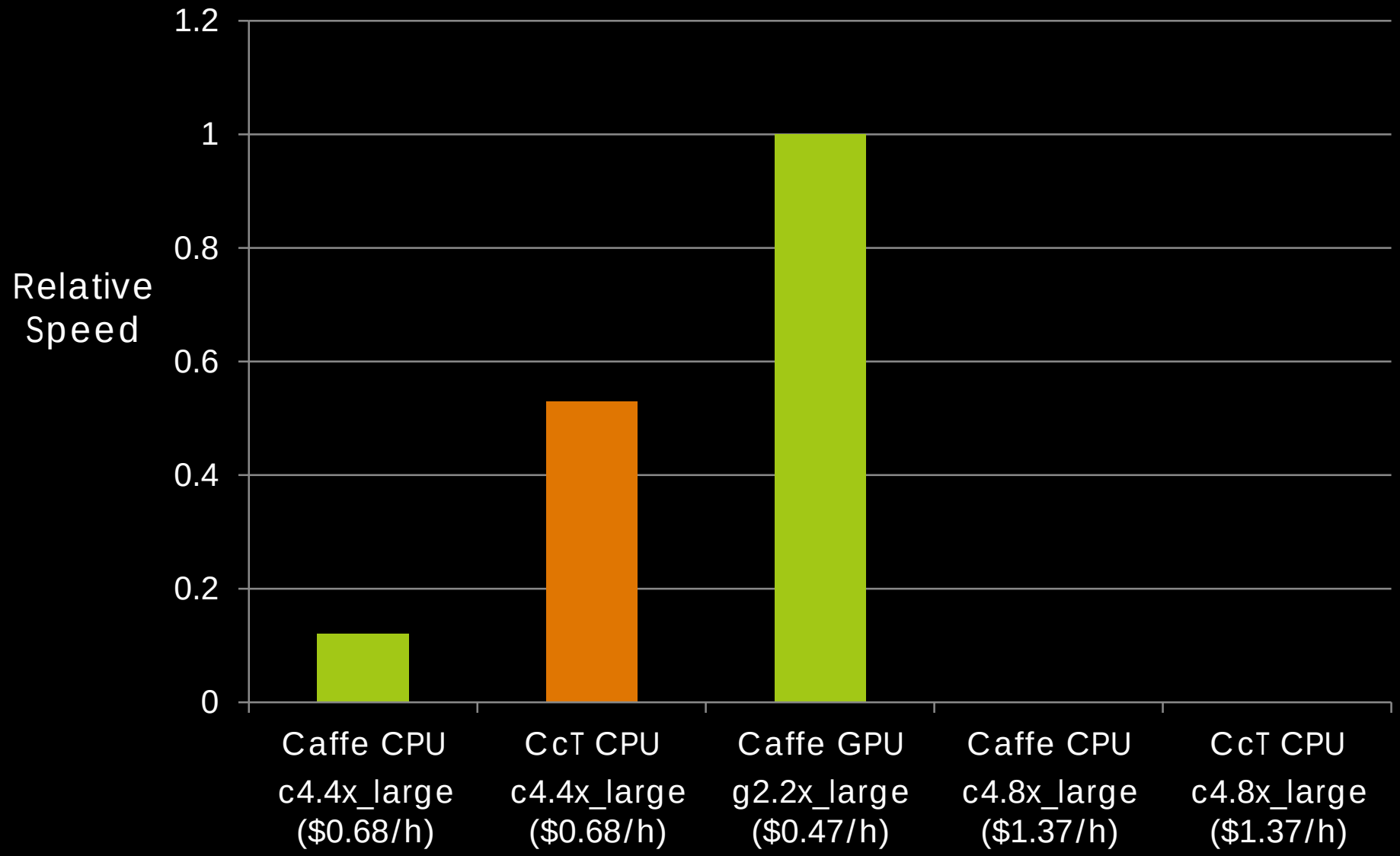
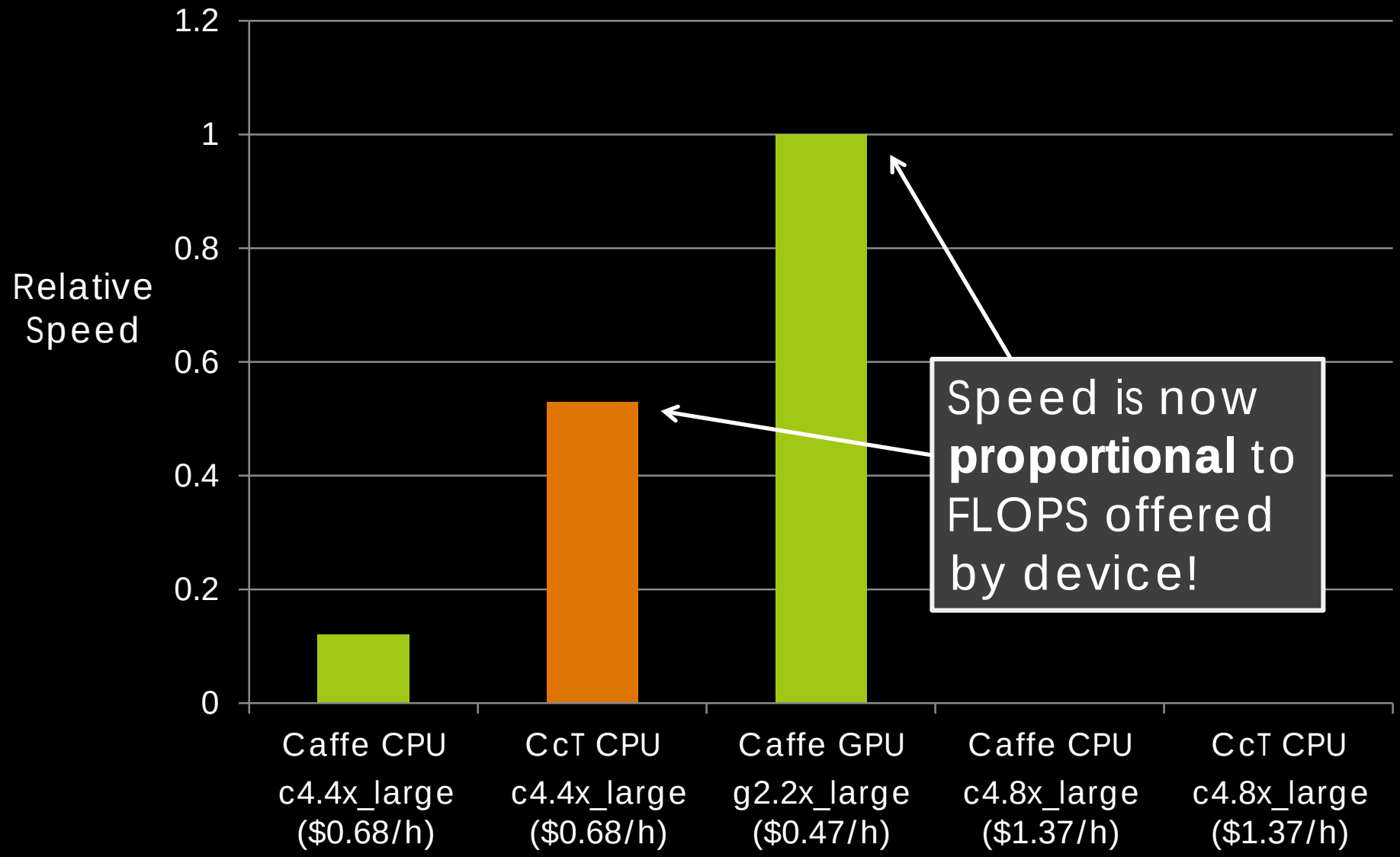
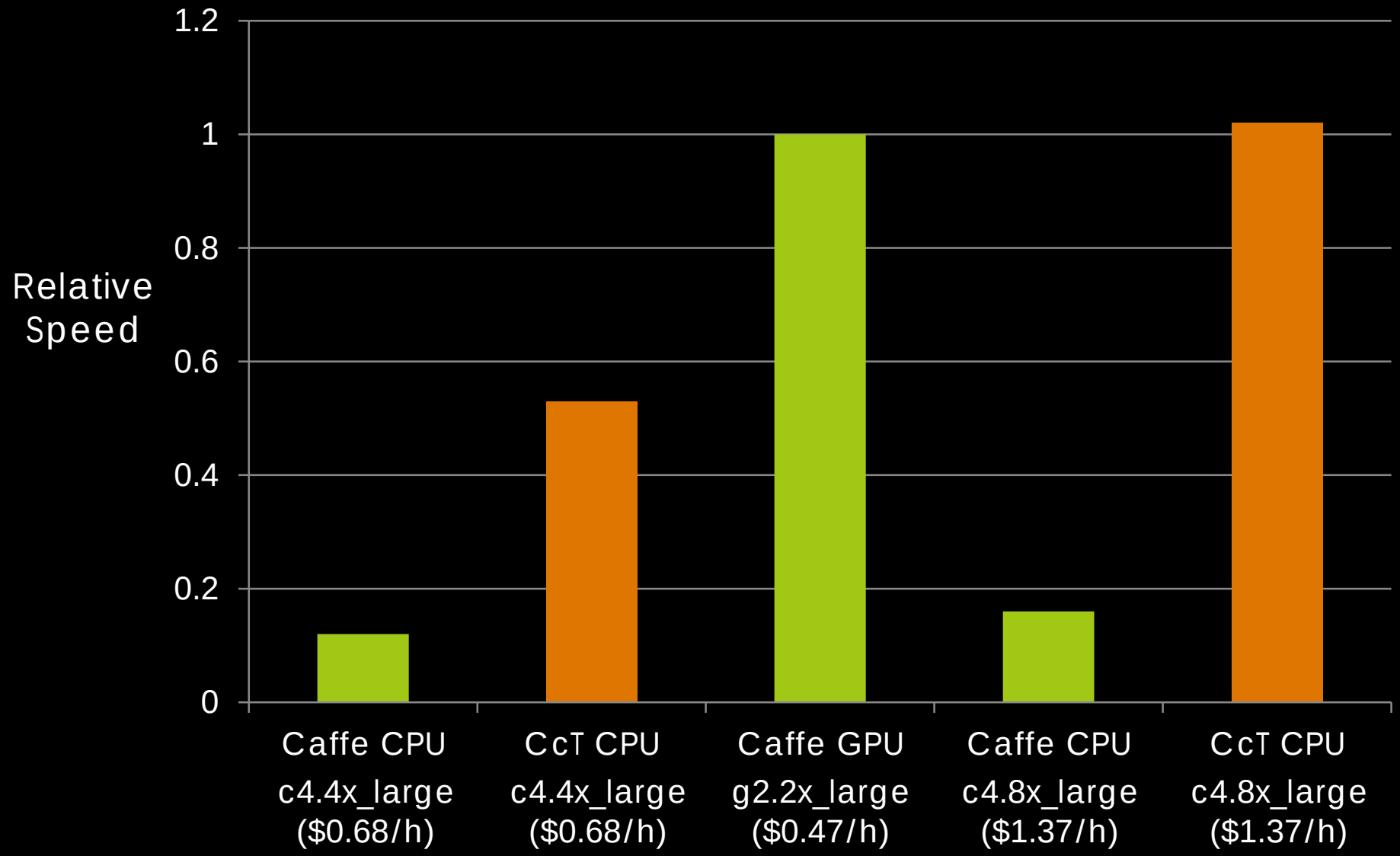


CPU Batching Speedup (full AlexNet)

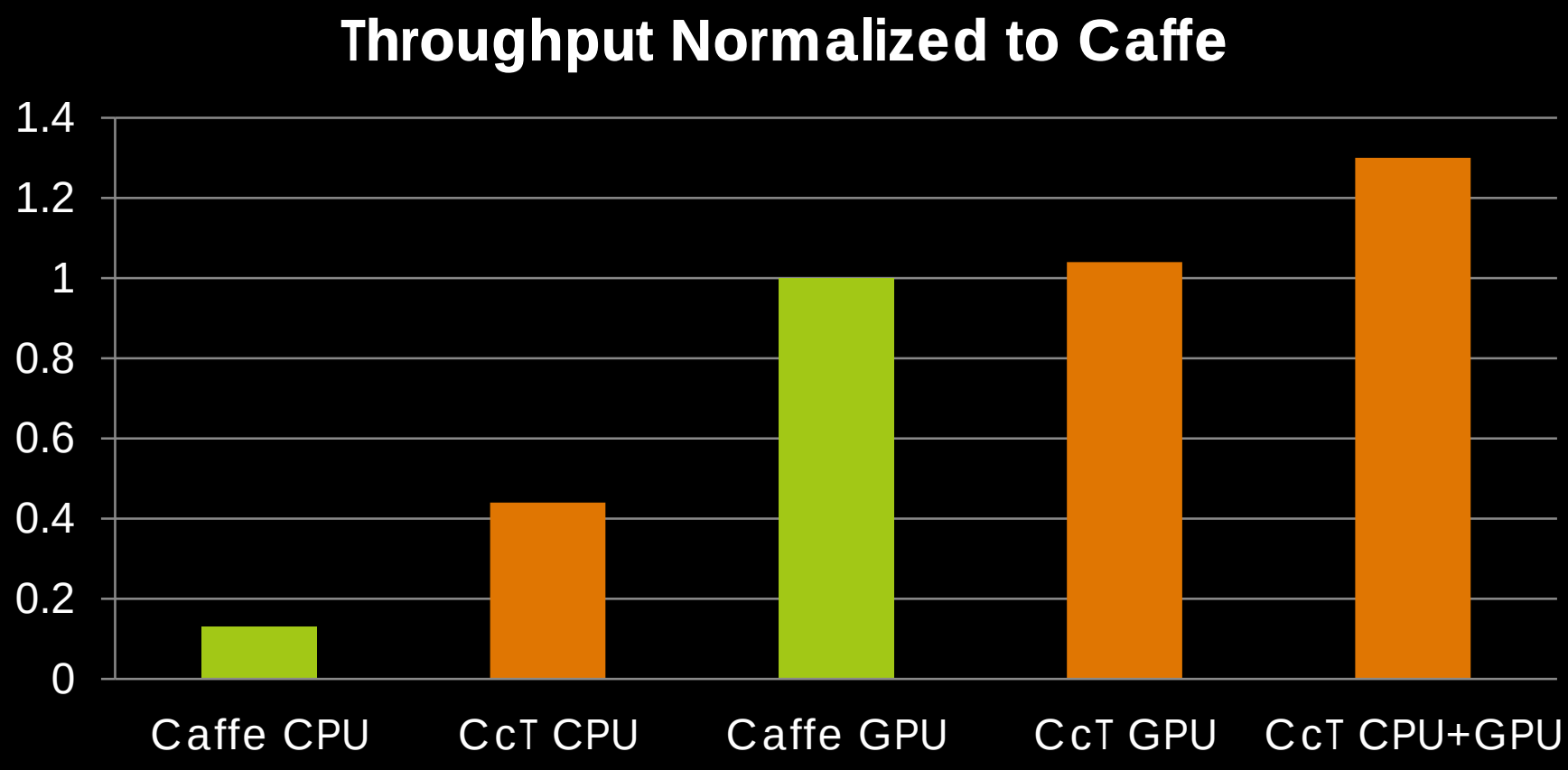


CPU Batching Speedup (full AlexNet)



CPU + GPU (Data Parallel)

Shallow idea 4: *FLOP Proportional Scheduling.*

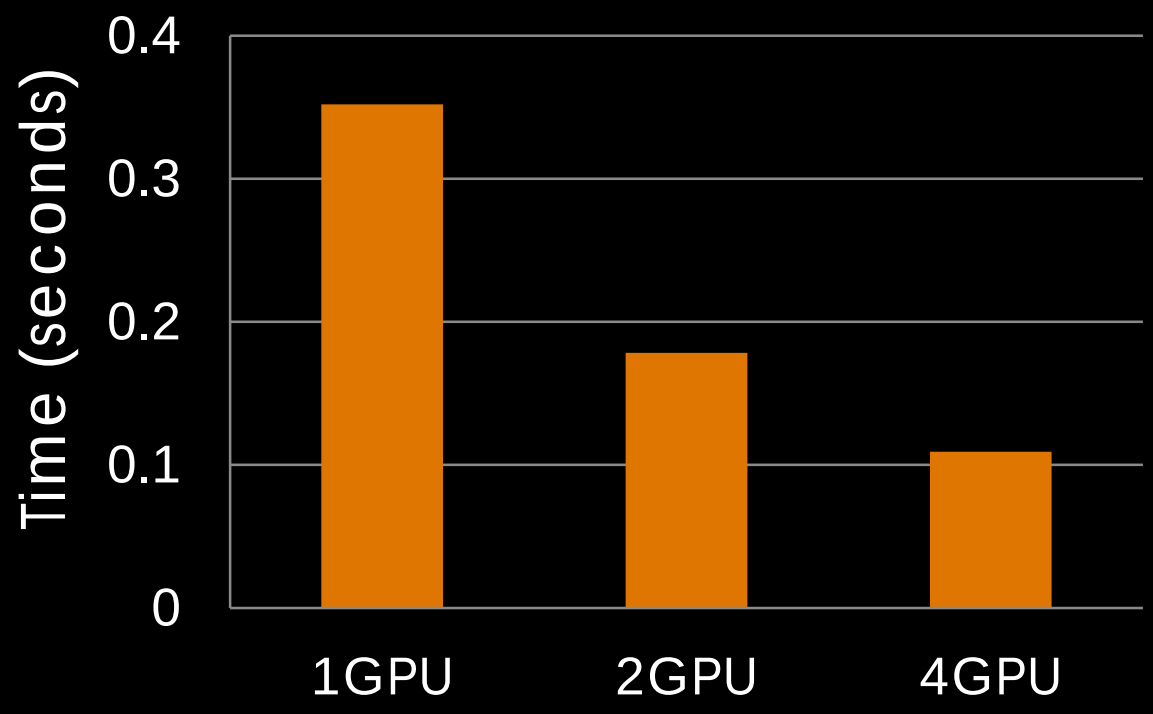


Run on EC2 g2.2xlarge instance ($0.47/hour) *for Layer 1 of popular "AlexNet"*

Multiple GPUs and Multiple Machines.

Flop Proportional Scheduling allows us to distribute the computation in a device-agnostic way.

AlexNet Conv1 Layer



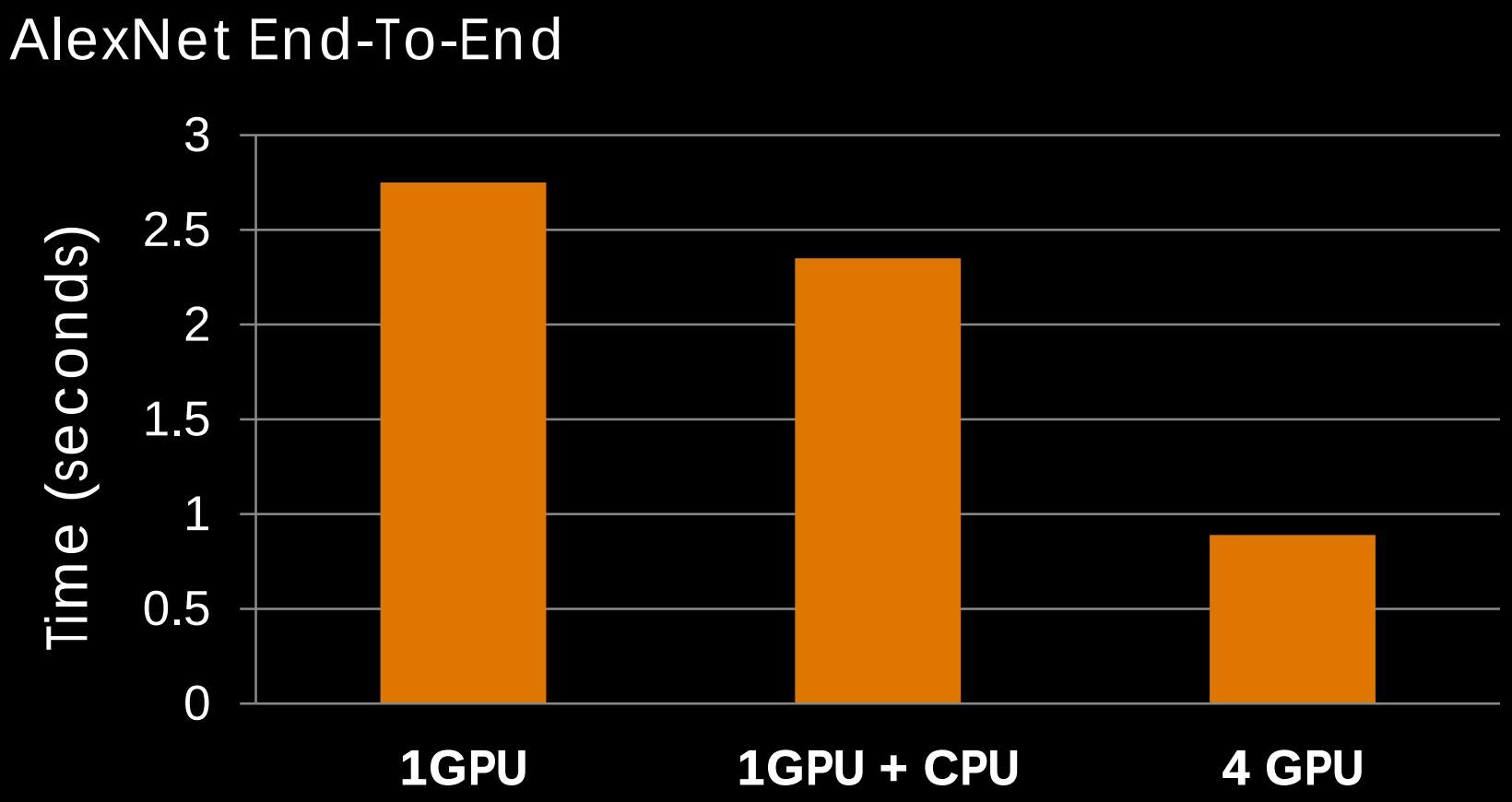
We have applied CcT to a single ***4-GPU EC2 instance*** *(announced last month!)*

Next we are working on a cluster of these instances!

Run on EC2 g2.8xlarge instance

Multiple GPUs and Multiple Machines.

Flop Proportional Scheduling allows us to distribute the computation in a device-agnostic way.



Run on EC2 g2.8xlarge instance

Trying CcT

- VMs (EC2 + Azure) available with CcT installed
- What's next?
  - Multiple Machines
  - New optimizations

github.com/HazyResearch/CaffeConTroll

Summary

- CPU + GPU can work together!
  - Close CPU gap
  - Operate both near peak FLOPS
- FLOP proportional scheduling
  - Next: Scale to distributed setting
- Questions?

github.com/HazyResearch/CaffeConTroll