Memory Bound Computing

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Goals

- Recognize when your computation is memory bounded, not CPU-bounded

- Learn techniques that helps you getting more performance for memory-bound problems

- Learn to use existing packages for tackling these problems

Let's Start with Some Exercises

Within the computing machine, clone the repo at:

https://github.com/FrancescAlted/MemoryBoundComputations

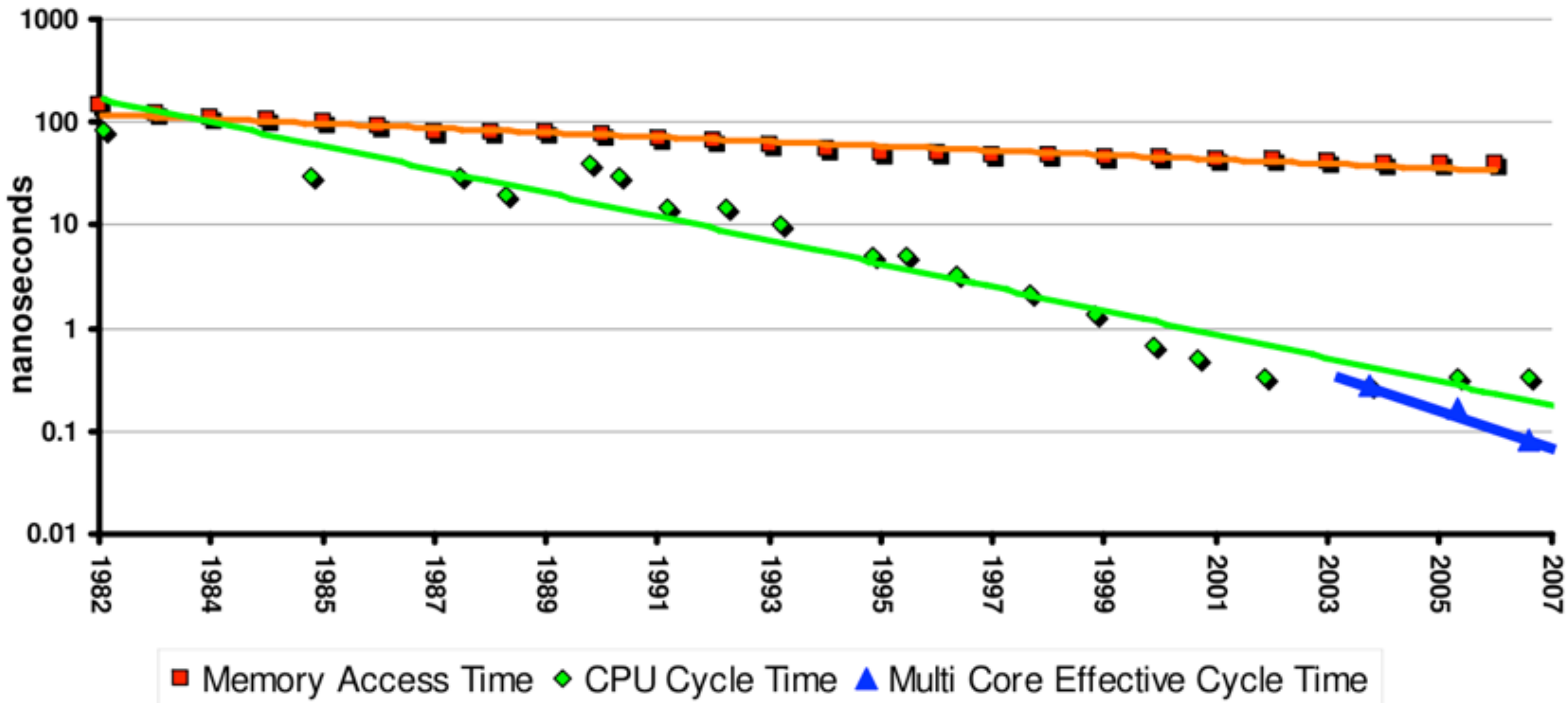
and start doing exercises 0 to 3 (inclusive)

"Across the industry, today's chips are largely able to execute code faster than we can feed them with instructions and data."

– Richard Sites, after his article "It's The Memory, Stupid!", Microprocessor Report, 10(10), 1996

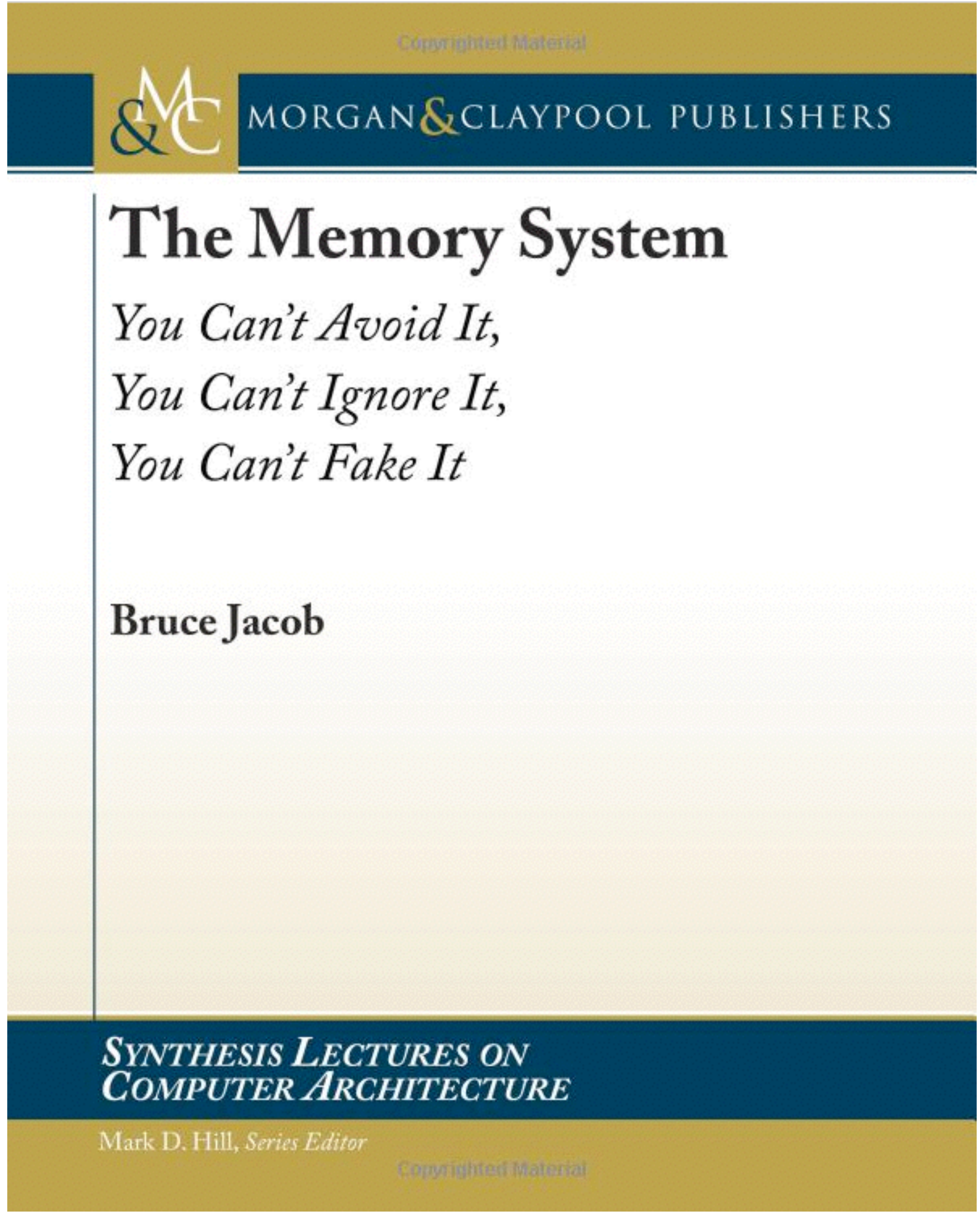
The Starving CPU Problem

Memory Access Time vs CPU Cycle Time



The gap is wide and still opening!

Book in 2009



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The Memory System
You Can't Avoid It,
You Can't Ignore It,
You Can't Fake It
Bruce Jacob
SYNTHESIS LECTURES ON
COMPUTER ARCHITECTURE
Mark D. Hill, Series Editor
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The Status of CPU Starvation in 2016

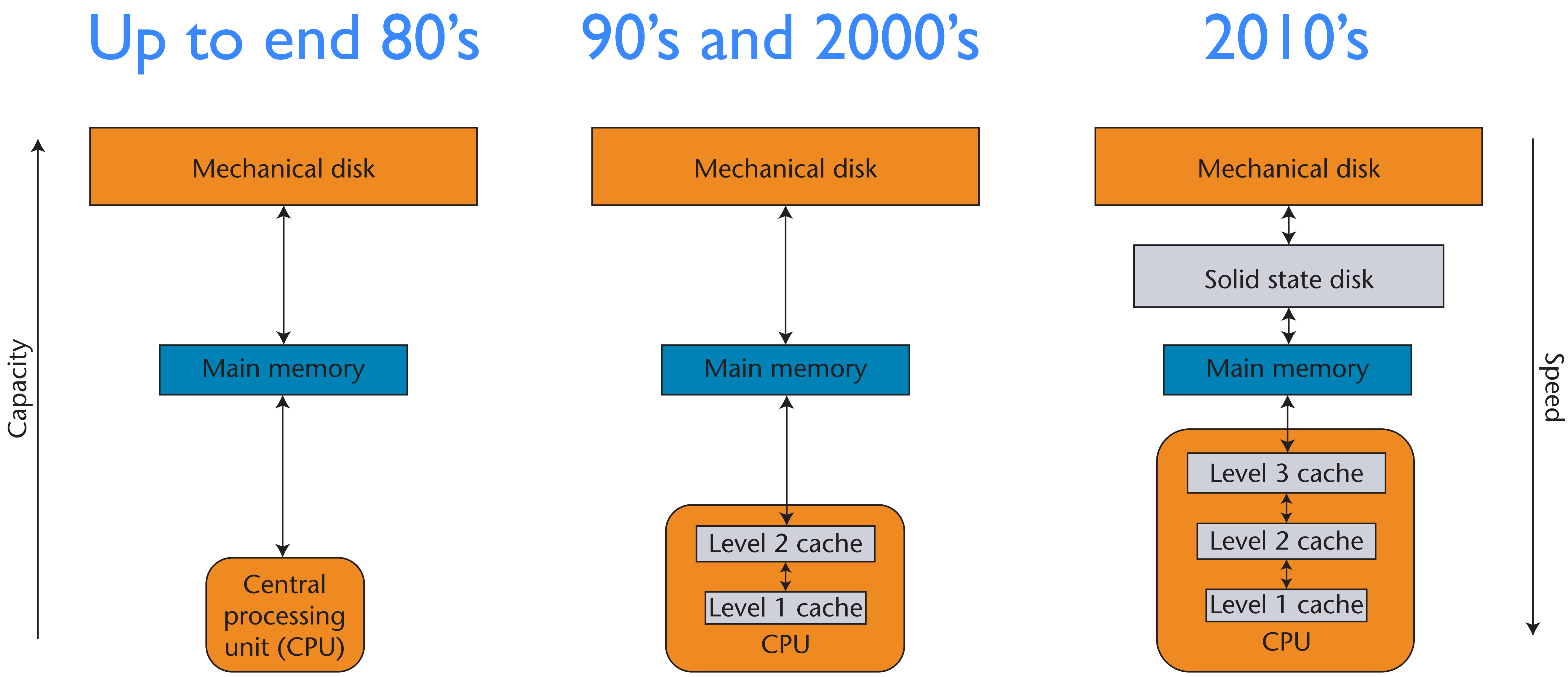
- Memory latency is much slower (between 250x and 1000x) than processors.

- Memory bandwidth is improving at a better rate than memory latency, but it is also slower than processors (between 30x and 100x).

CPU Caches to the Rescue

- CPU cache latency and throughput are much better than memory
- However: the faster they run the smaller they must be (because of heat dissipation problems)

Computer Architecture Evolution



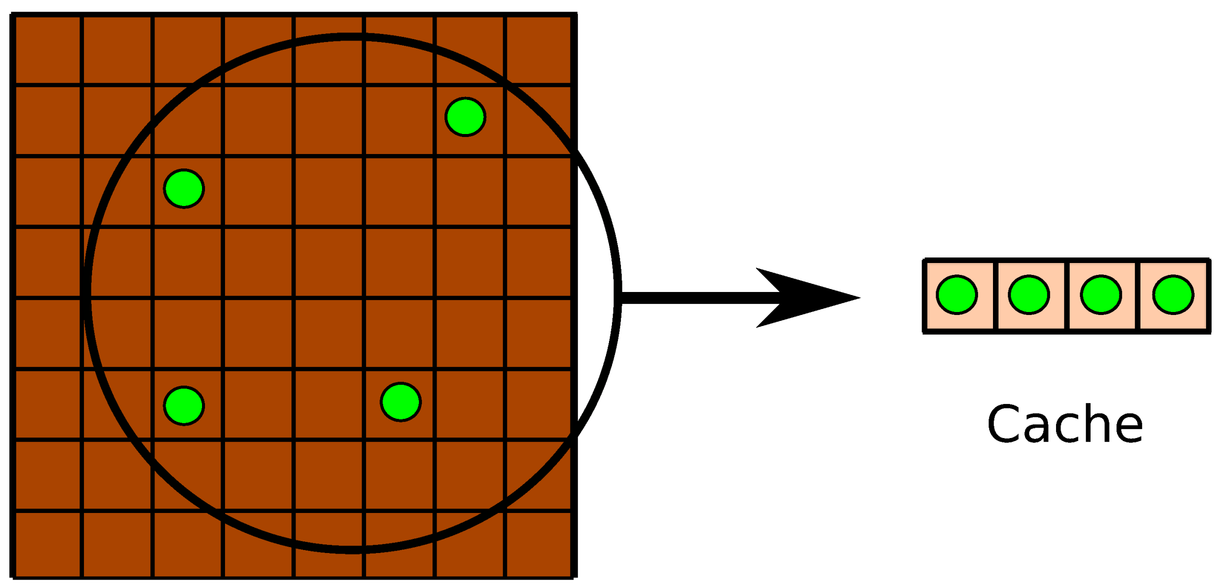
When CPU Caches Are Effective?

Mainly in a couple of scenarios:

- Time locality: when the dataset is reused
- Spatial locality: when the dataset is accessed sequentially

Time Locality

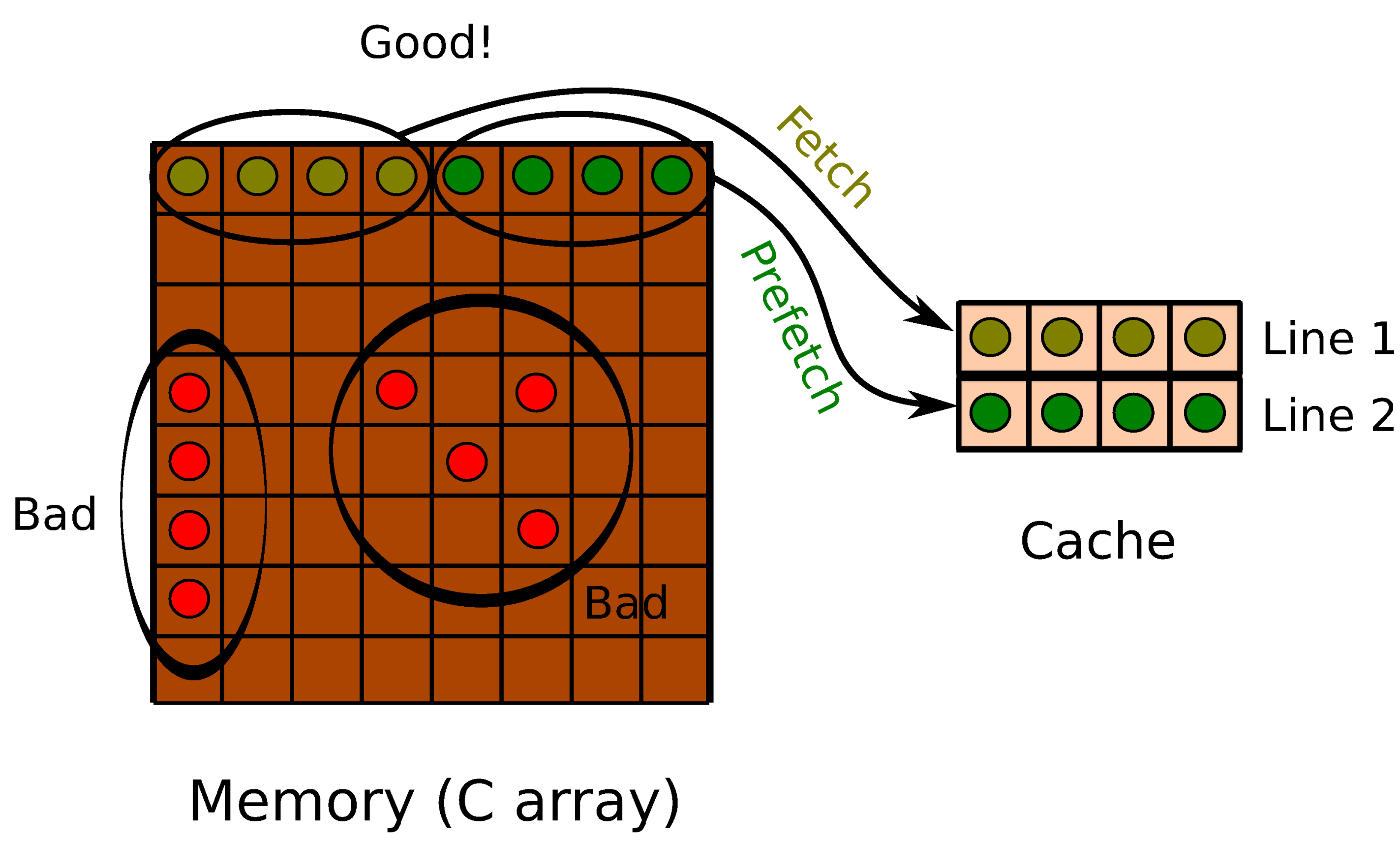
Parts of the dataset are reused



Memory (C array)

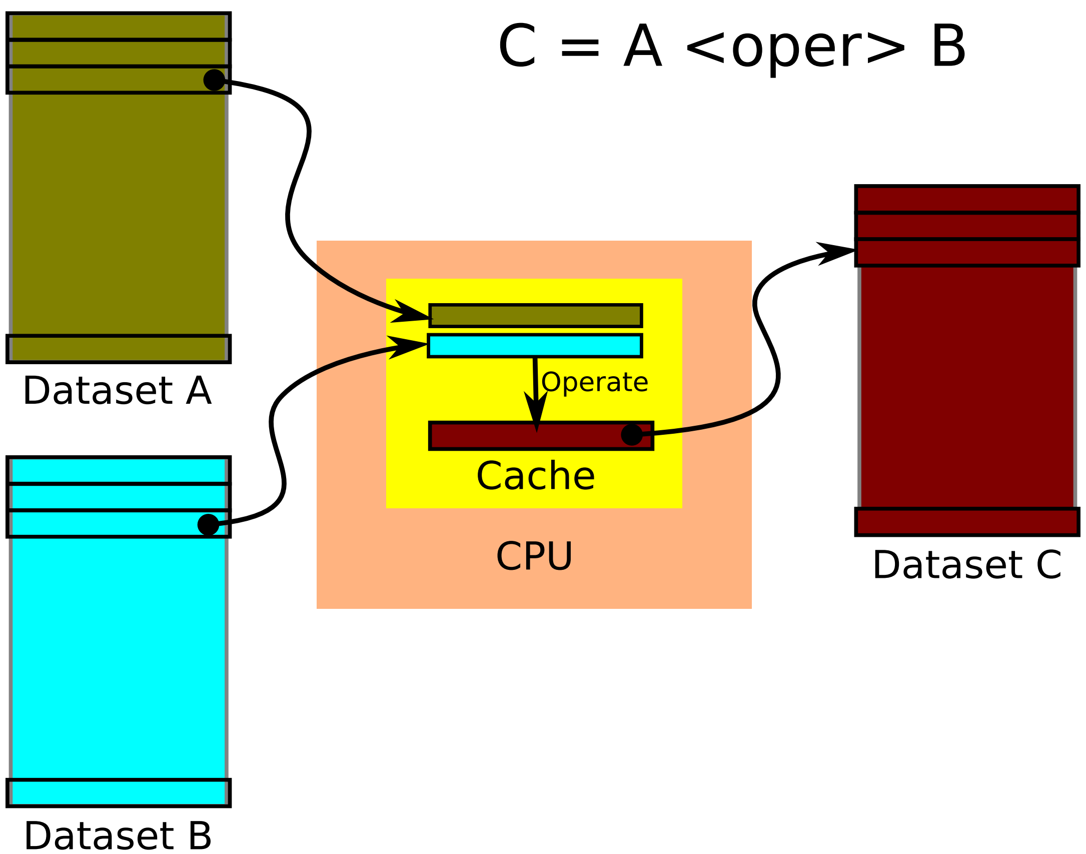
Spatial Locality

Dataset is accessed sequentially



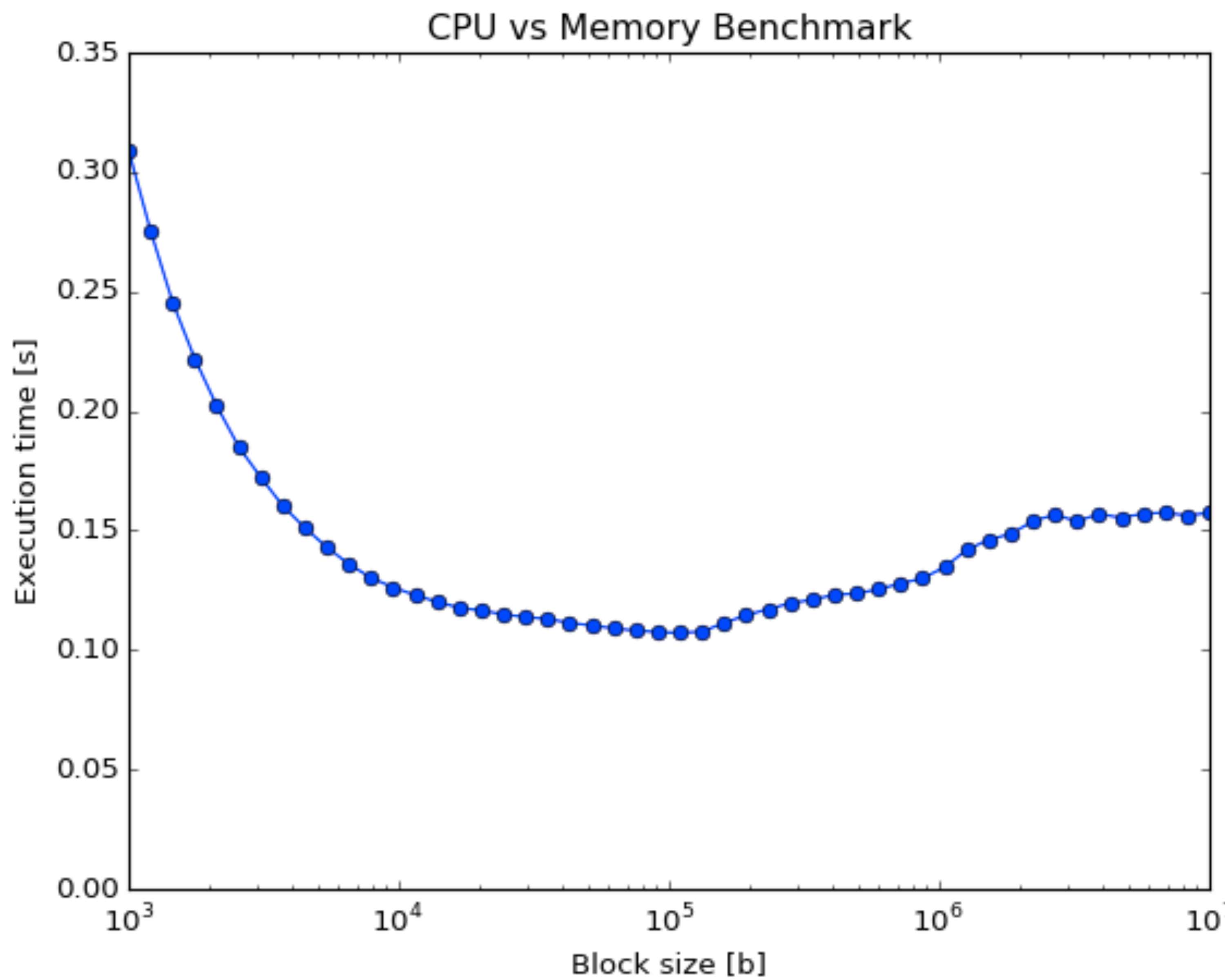
The Blocking Technique

When accessing disk or memory, get a contiguous block that fits in CPU cache, operate upon it and reuse it as much as possible.



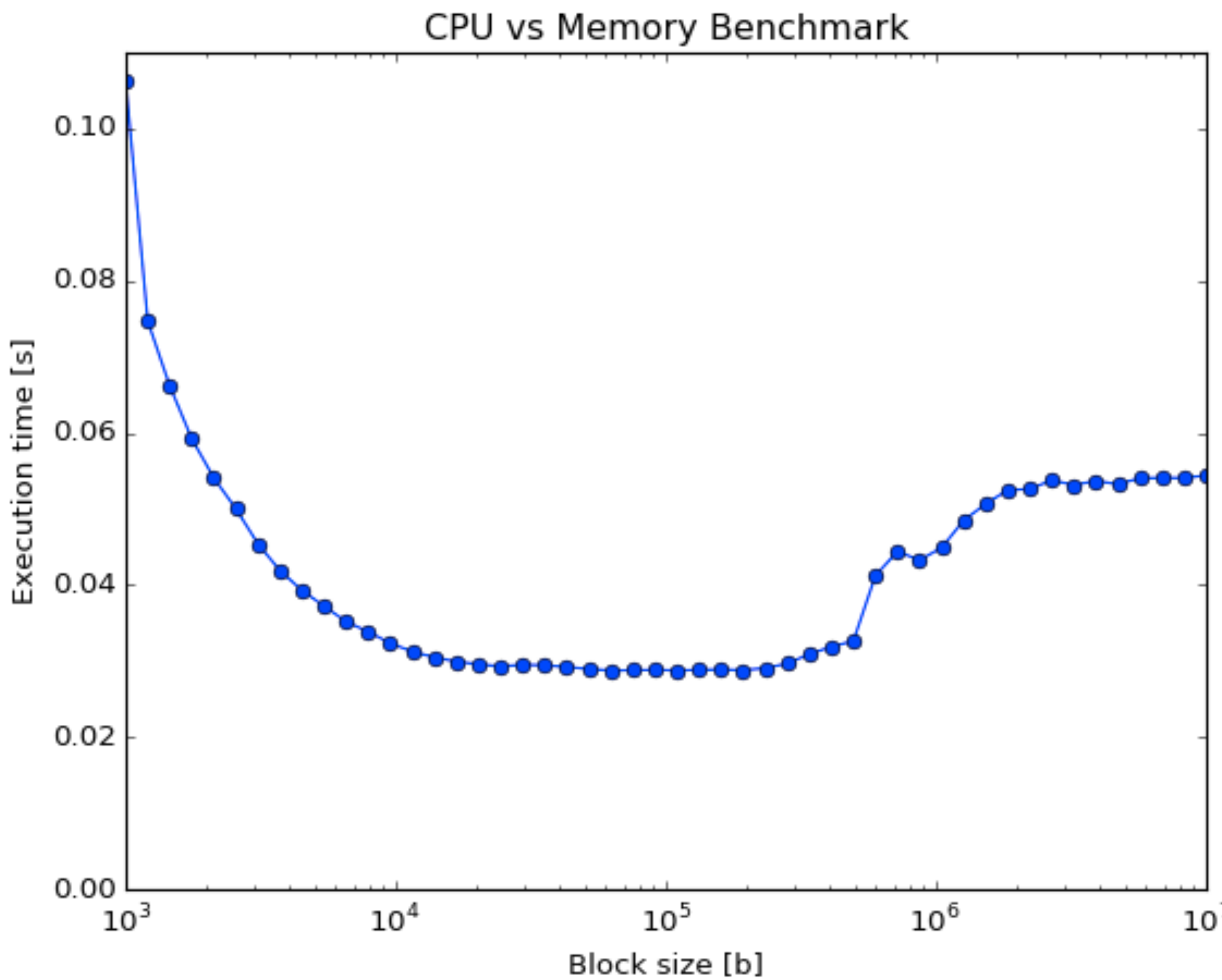
Use this extensively to leverage spatial and temporal localities

The Blocking Technique in Action (Exercise 0)



CPU: Intel Xeon E312xx @ 2.00GHz (Sandy Bridge)

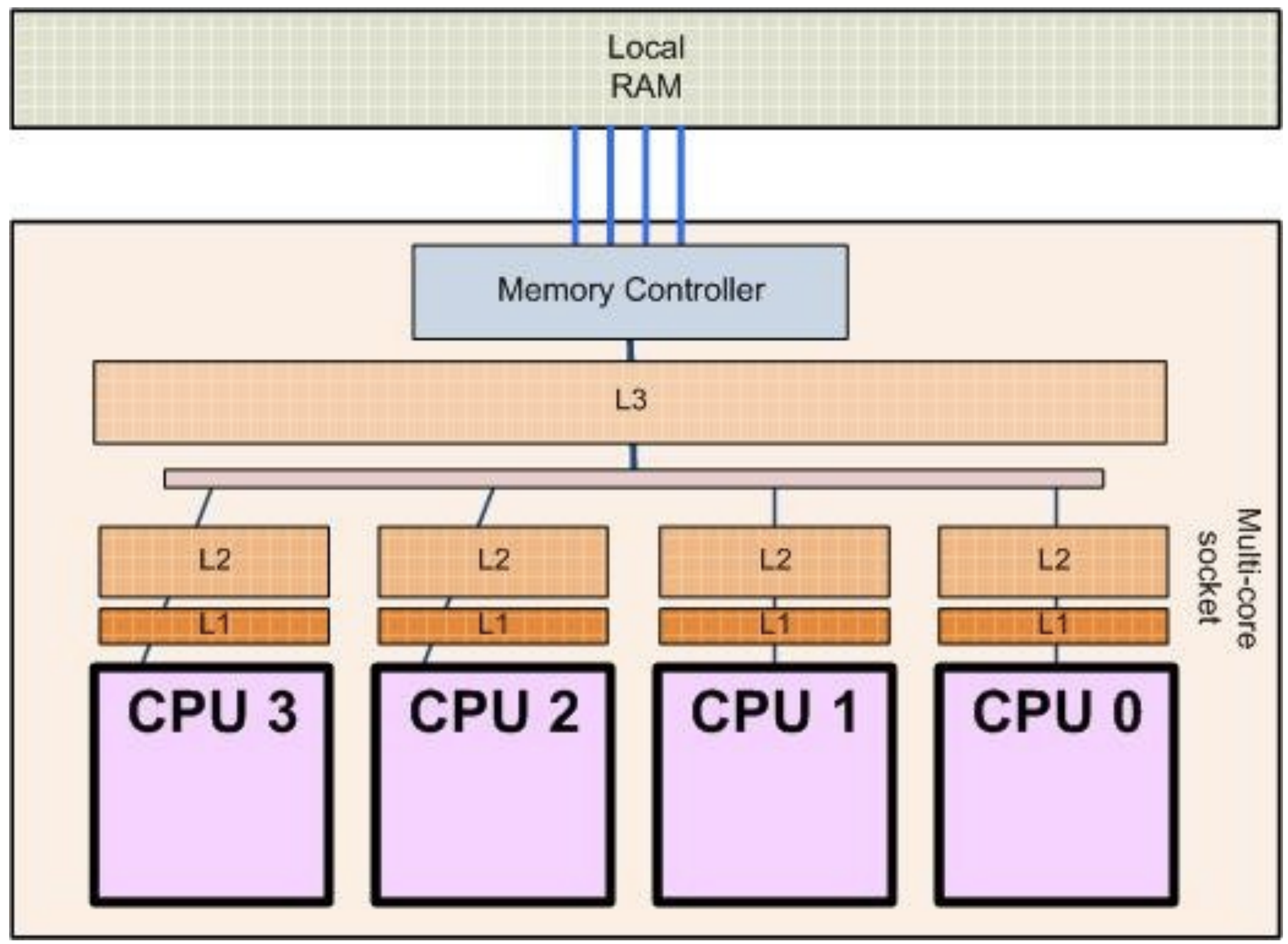
The Blocking Technique in Action (Exercise 0)



CPU: Intel Xeon(R) CPU E3-1245 v5 @ 3.50GHz (Skylake)

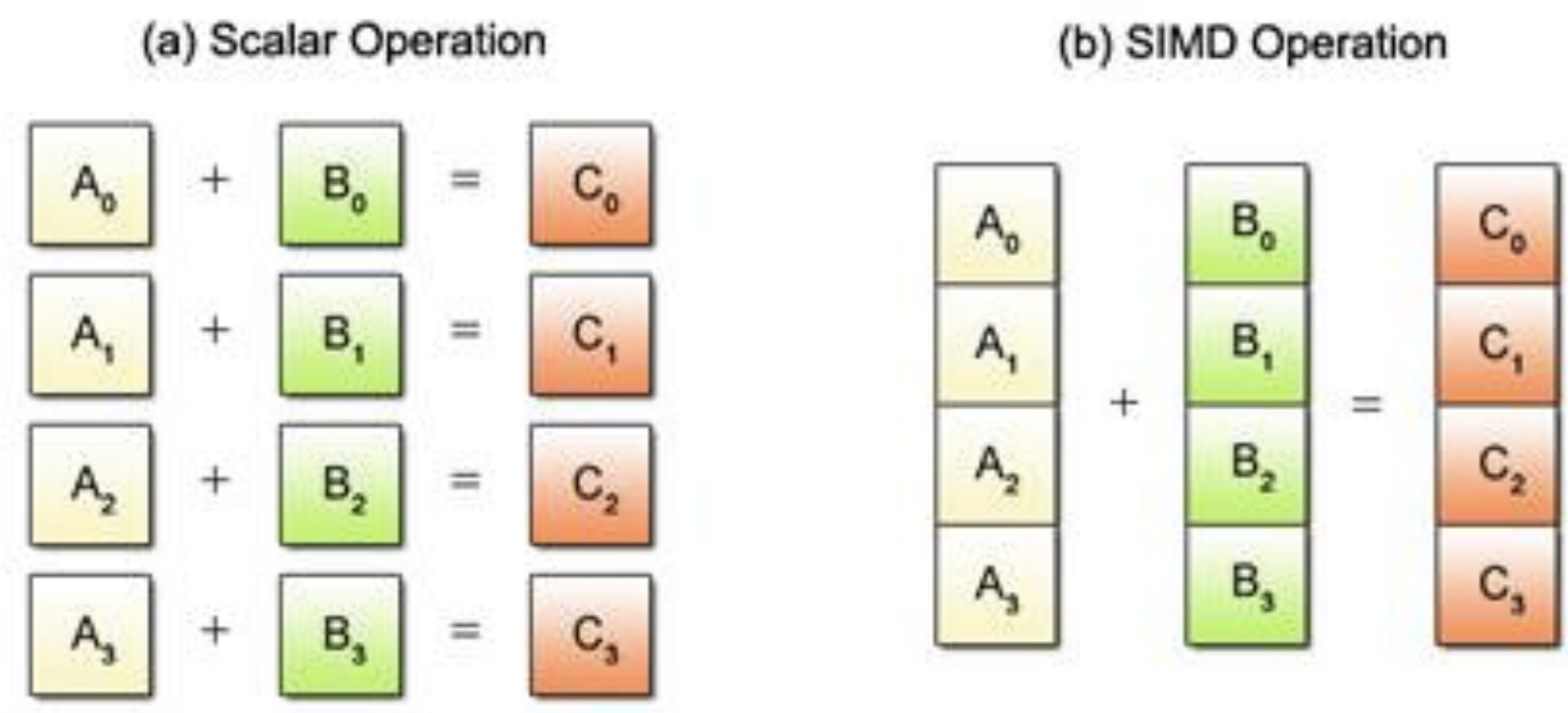
Trends in Computer Architecture

We Are In A Multicore Age



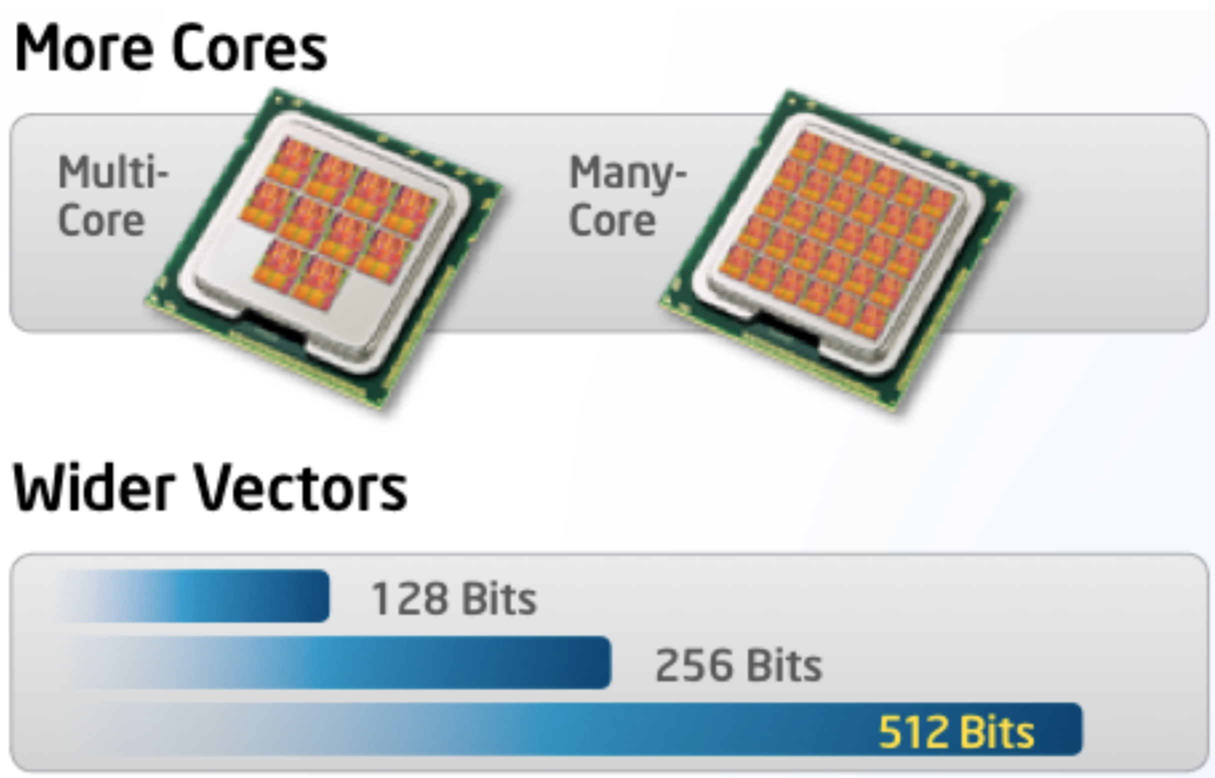
- This requires special programming measures to leverage all its potential: threads, multiprocessing

SIMD: Single Instruction, Multiple Data

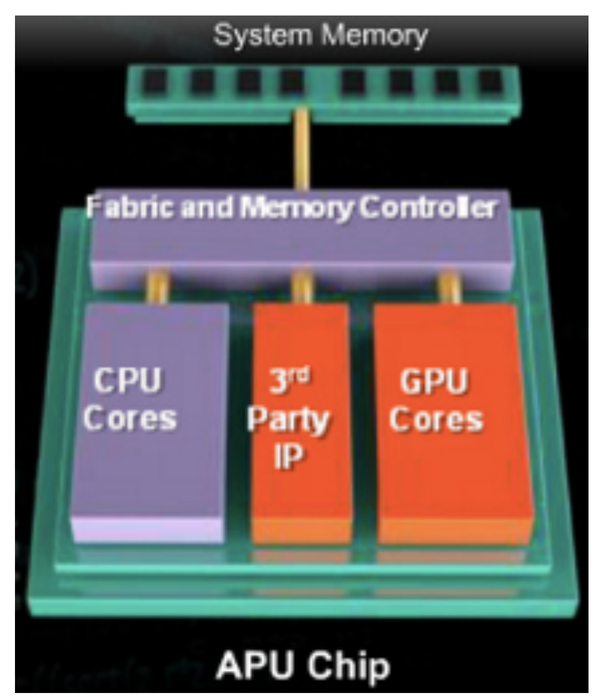


More operations in the same CPU clock

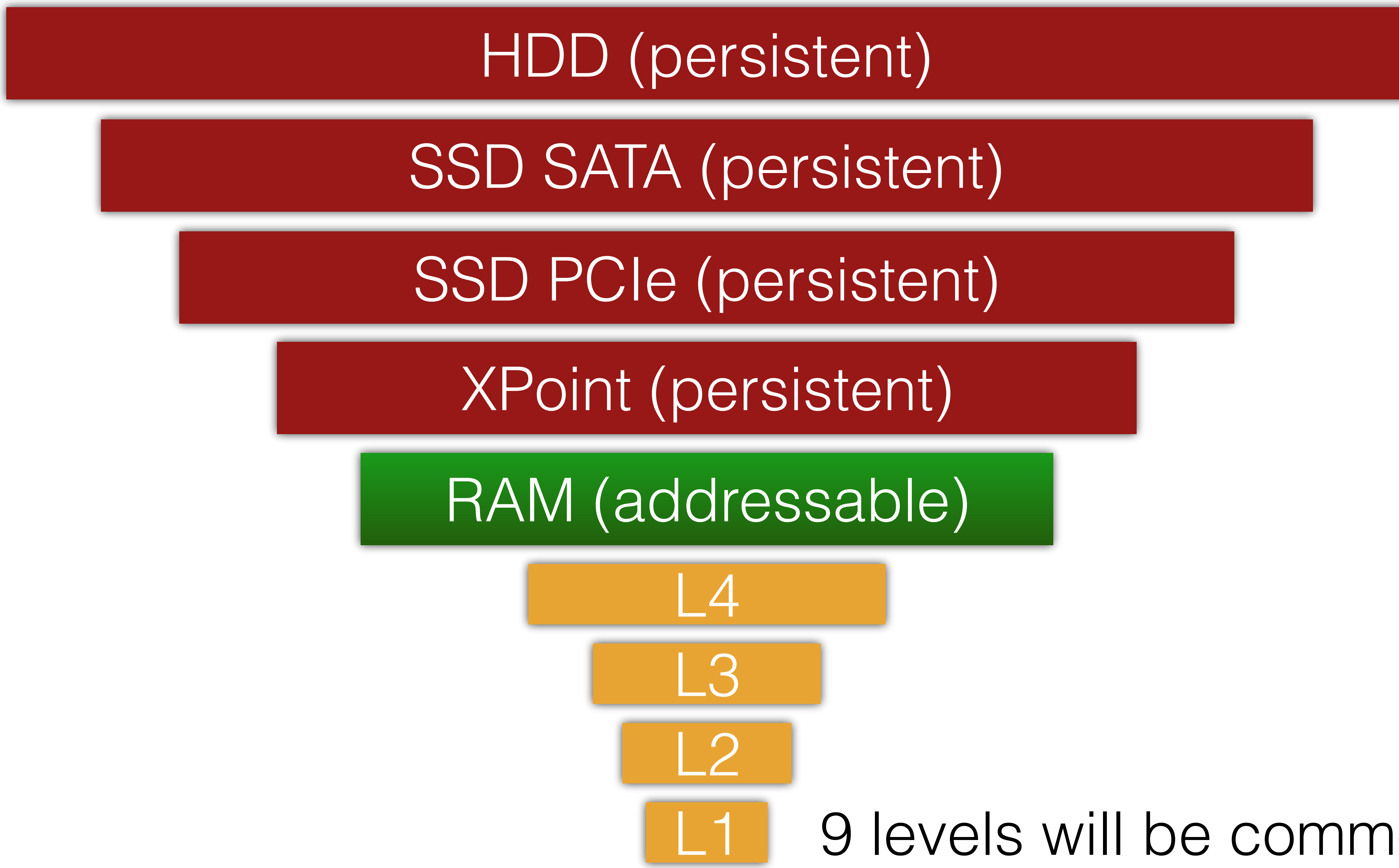
Forthcoming Trends in CPU



CPU+GPU Integration



Hierarchy of Memory
By 2018 (Educated Guess)



9 levels will be common!

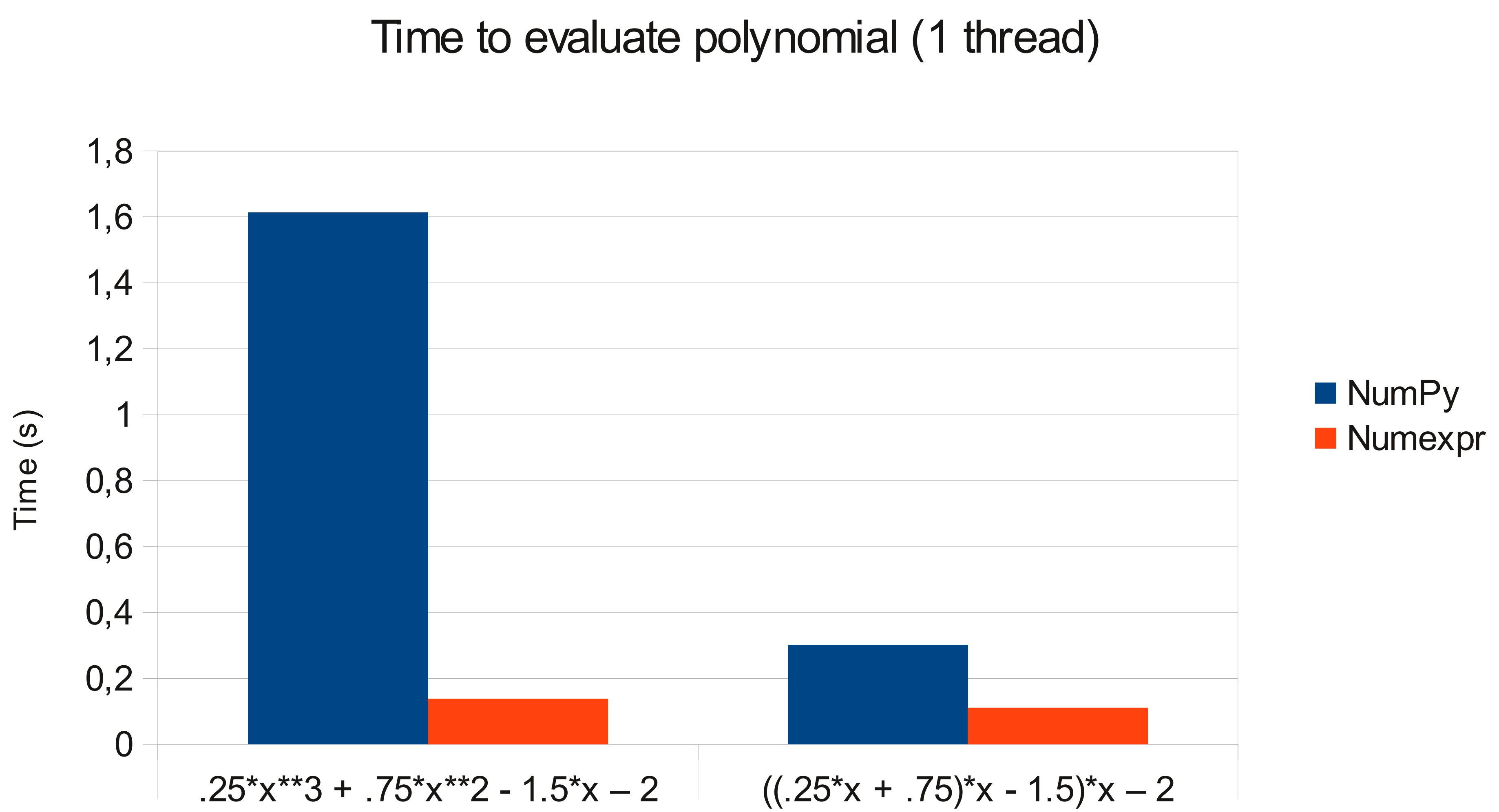
numexpr

- It is a computational engine for NumPy that makes a sensible use of the memory hierarchy for better performance

- It can use multi-core (via multi-threading) and SIMD (via Intel's MKL) for better CPU usage.

- PyTables, pandas and bcolz (among others) can all leverage numexpr automatically if installed

Computing with numexpr



Power Expansion

Numexpr expands expression:

`0.25*x**3 + 0.75*x**2 + 1.5*x - 2`

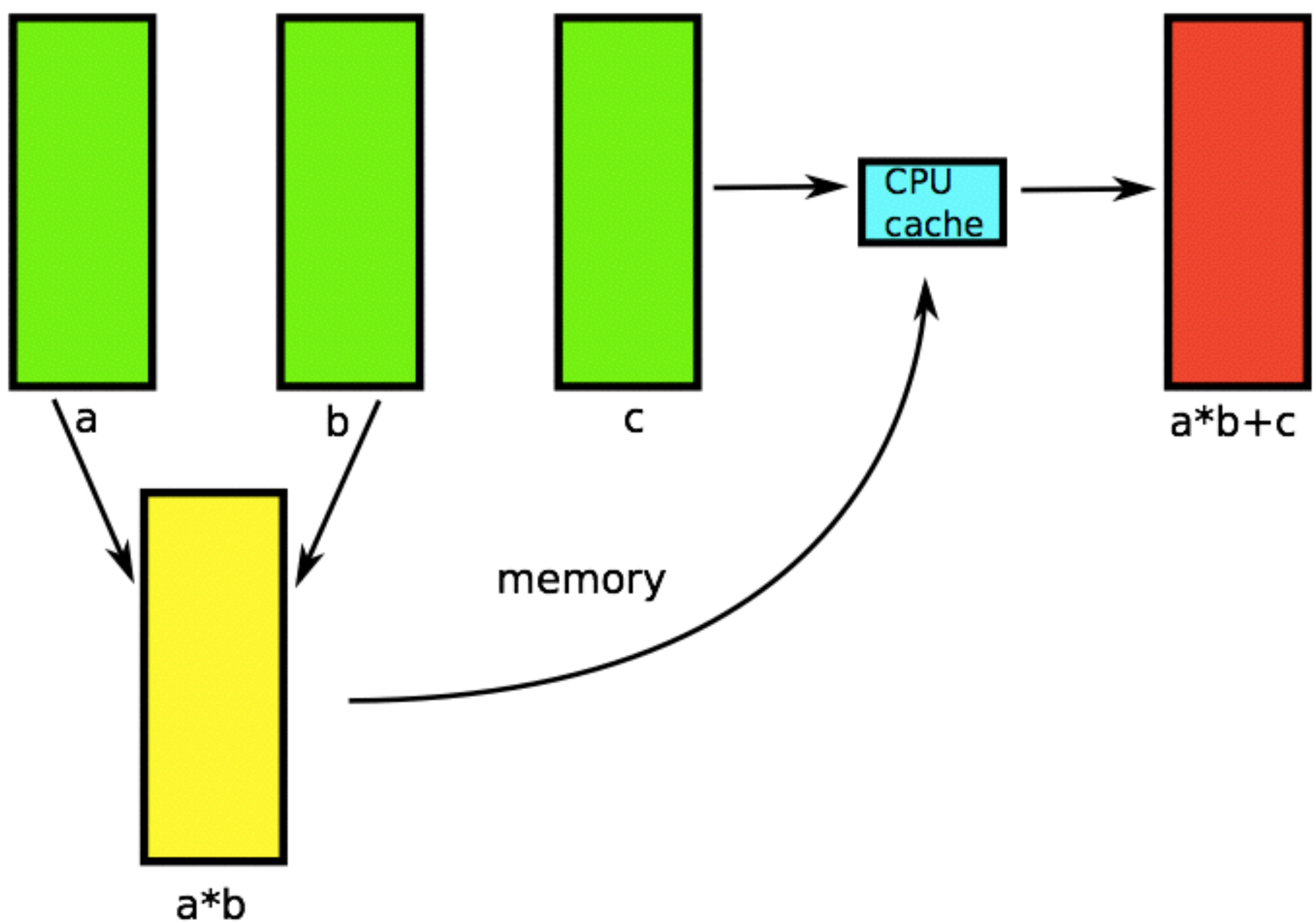
to:

`0.25*x*x*x + 0.75*x*x + 1.5*x - 2`

so, no need to use the expensive **`pow()`**

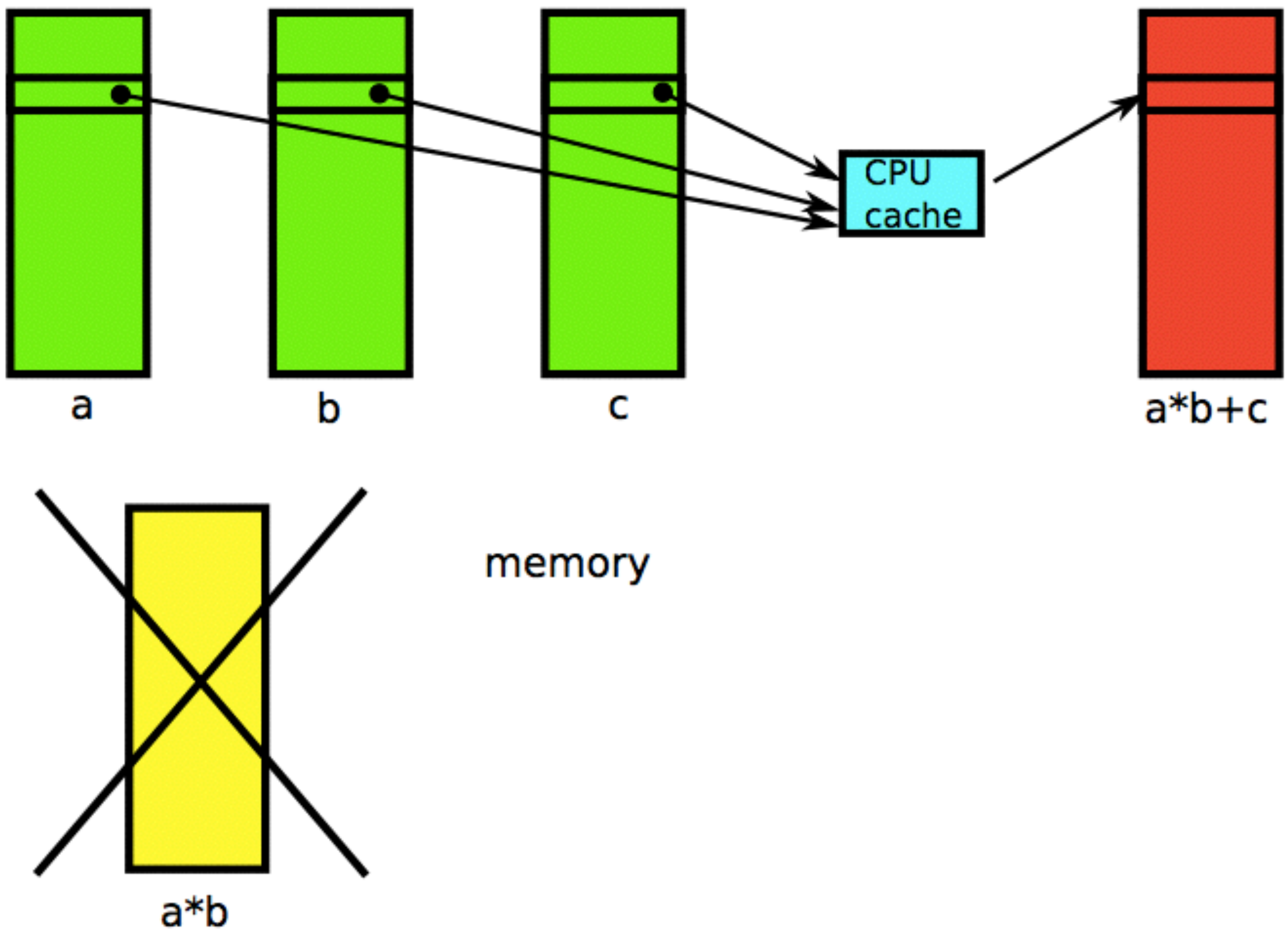
Computing with NumPy

Temporaries go to memory

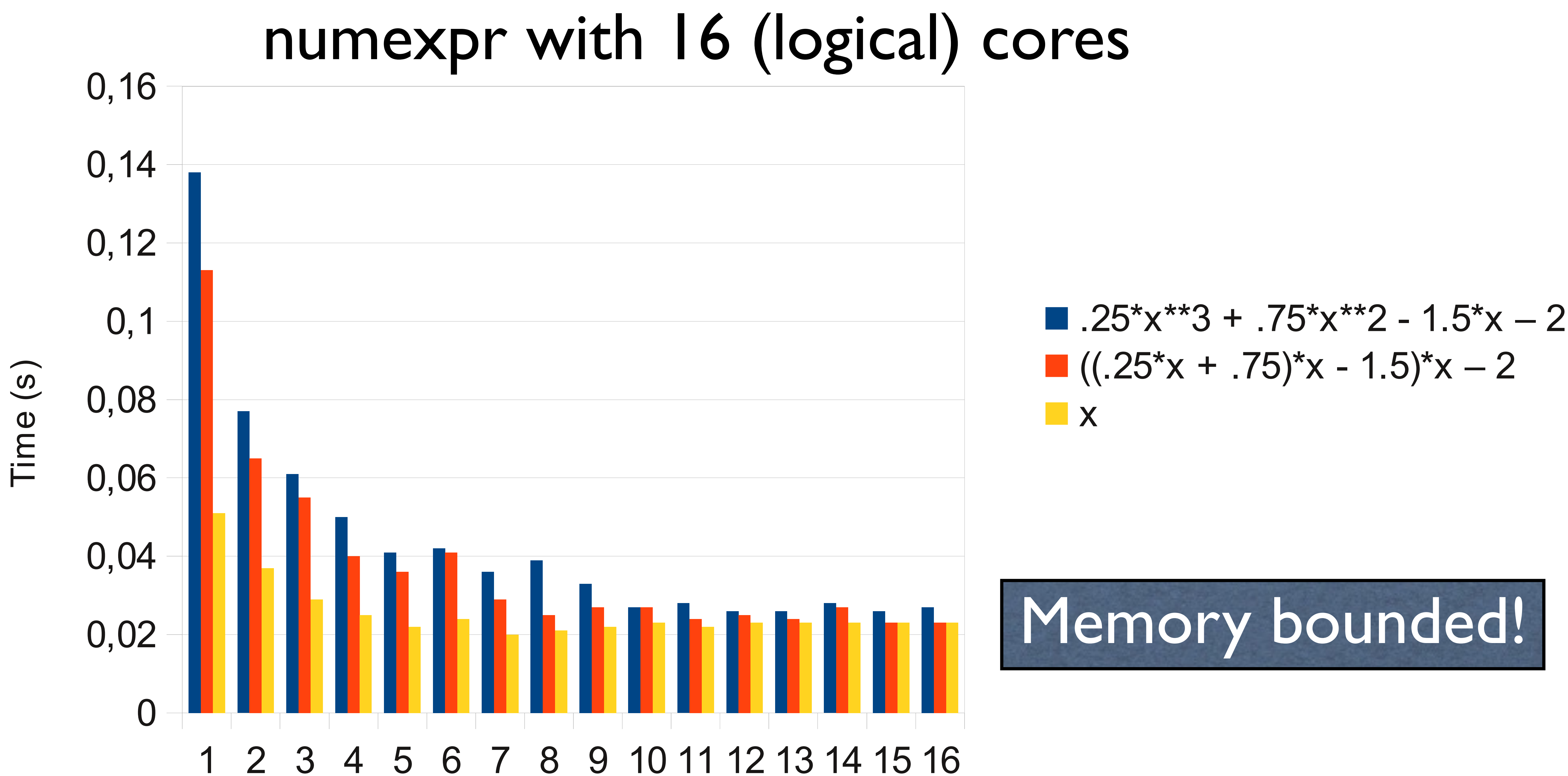


Computing with numexpr

Temporaries stay in cache

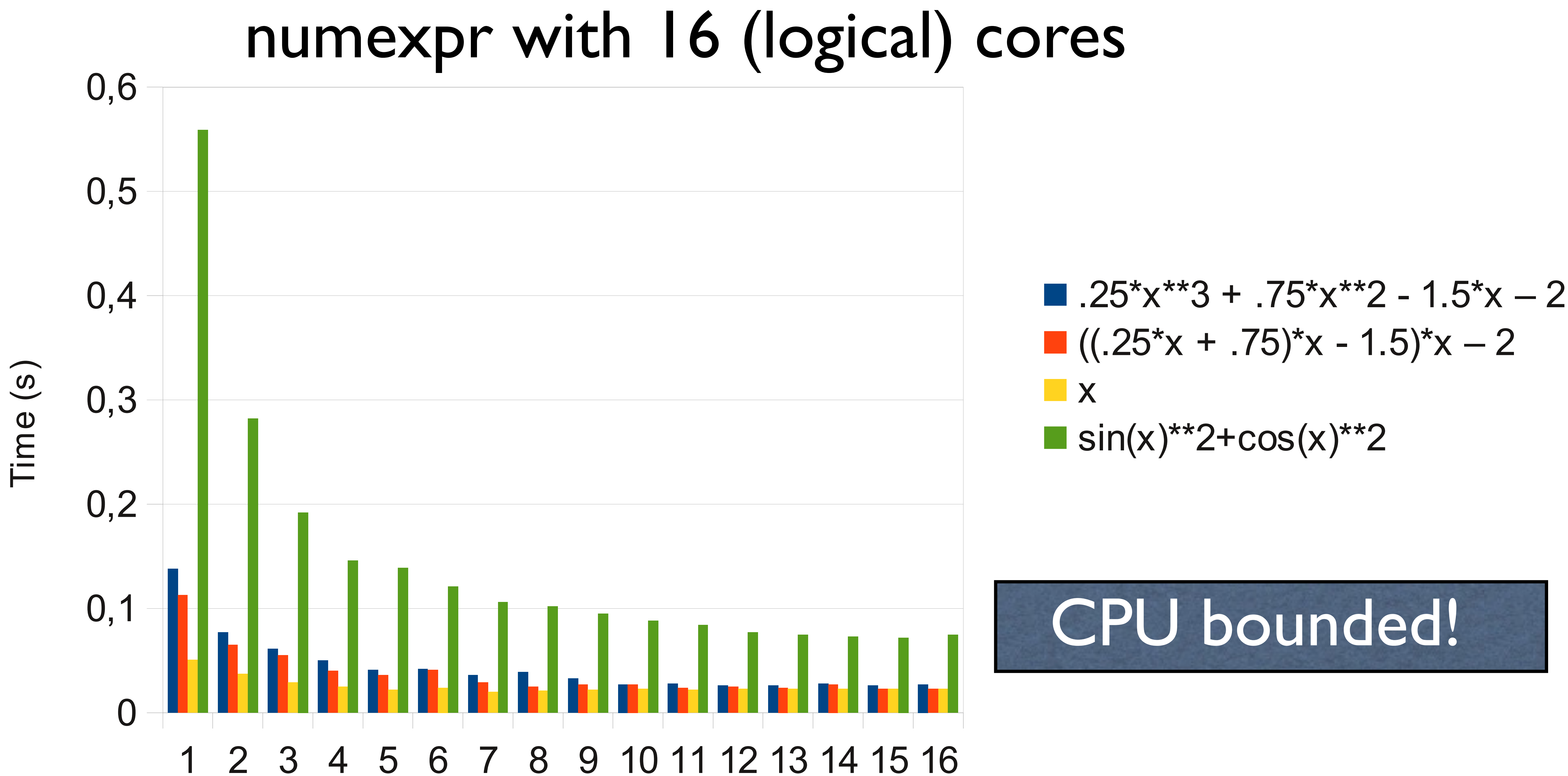


numexpr Allows Multithreading for Free



Memory bounded!

Transcendental Functions



CPU bounded!

Multithreaded numexpr and Beyond: Numba

Numexpr Limitations

- Numexpr only implements element-wise operations, i.e. ‘`a*b`’ is evaluated as:

```
for i in range(N):

    c[i] = a[i] * b[i]
```

- In particular, it cannot deal with things like:

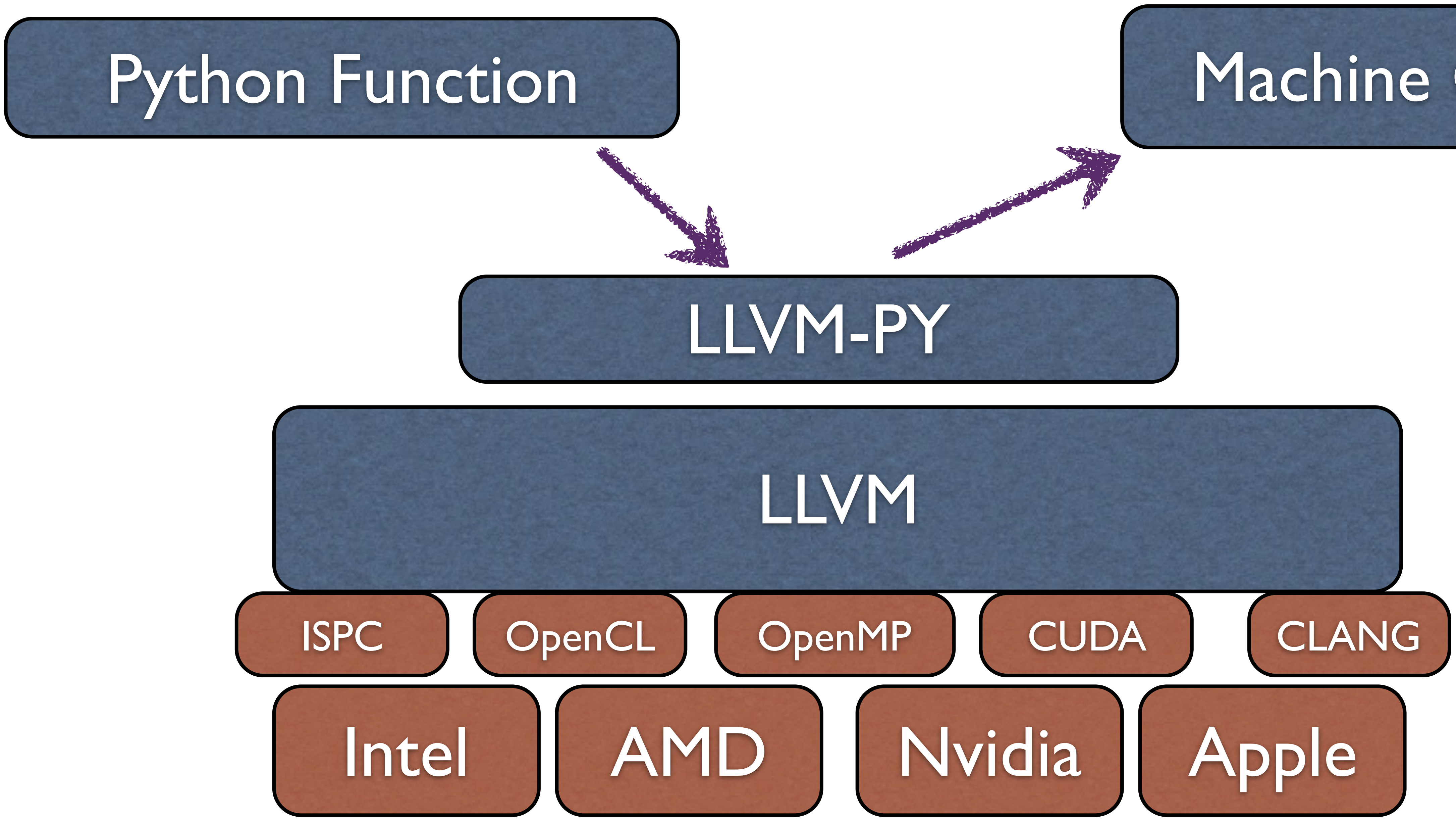
```
for i in range(N):

    c[i] = a[i-1] + a[i] * b[i]
```

Numba: Overcoming numexpr Limitations

- Numba is a JIT that can translate a subset of the Python language into machine code
- It uses LLVM infrastructure behind the scenes
- Can achieve similar or better performance than numexpr, but with more flexibility

How Numba works



Take-away Messages

- When you have to optimize, have in mind the starving CPU problem.
- Do not always try to parallelize blindly. Give optimization a try first.
- Use proper tools when you need speed. Using one single tool for everything is not going to work well.

Eskerrik Asko!