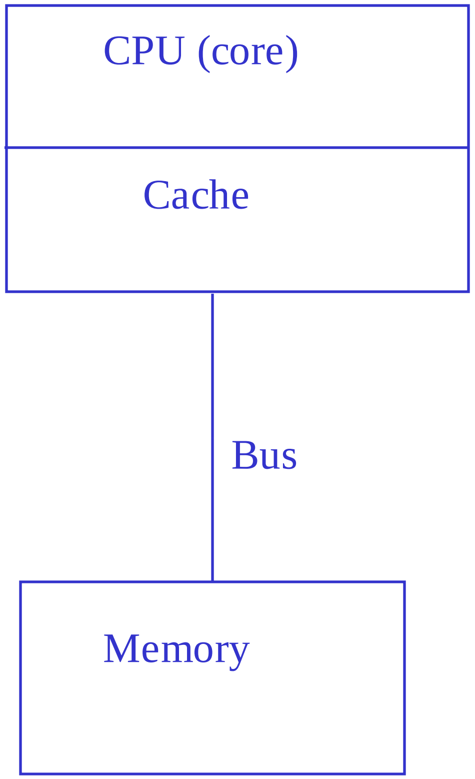
Parallel Scientific Programming

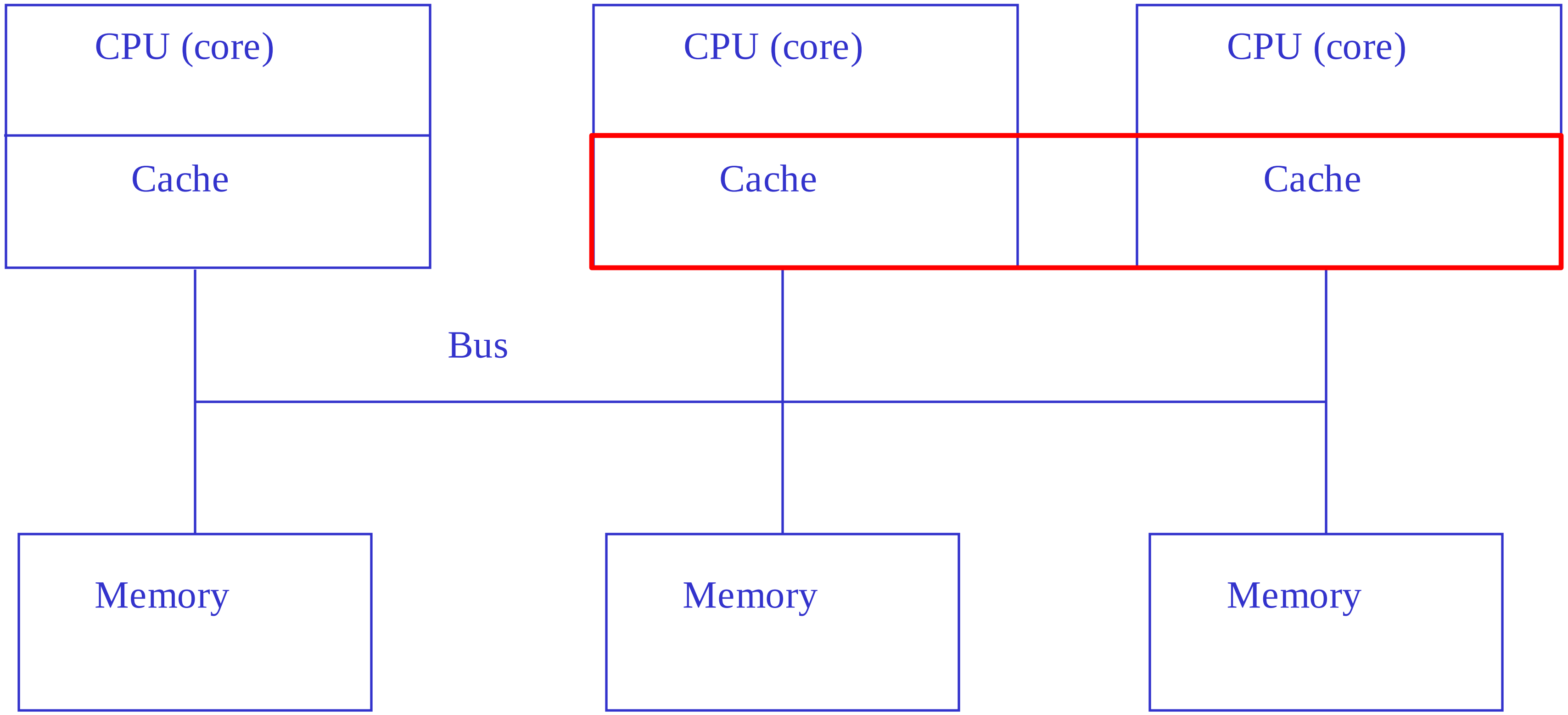
- Definitions
  - Speedup: T_s/T_p, where T_s is the sequential time and T_p is the time when using *p* cores
    - If the speedup is *p*, it is called *linear speedup* (sometimes “perfect speedup”, but linear speedup is preferred)
    - Typically, speedup is less than *p*---but it can be larger than *p* because of memory hierarchy effects
  - Efficiency: Speedup/*p*
    - Intuition: how well am I using my *p* cores?

“Superlinear” Speedup?



Sequential Computer

“Superlinear” Speedup?



Strictly more cache is available when more cores are used

Can result in fewer cache misses when using more cores

Same argument can hold for any level of the memory hierarchy

Parallel Scientific Programming

- Definitions, continued
  - *Amdahl's law*: if T_s is sequential time, then:
    - $T_p \approx T_s * (1-f) + (T_s / p) * f$, where:
      - f is the fraction of the program that is parallelizable, and
      - p is the number of cores

Parallel Scientific Programming

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      - the parallelizable part scales linearly

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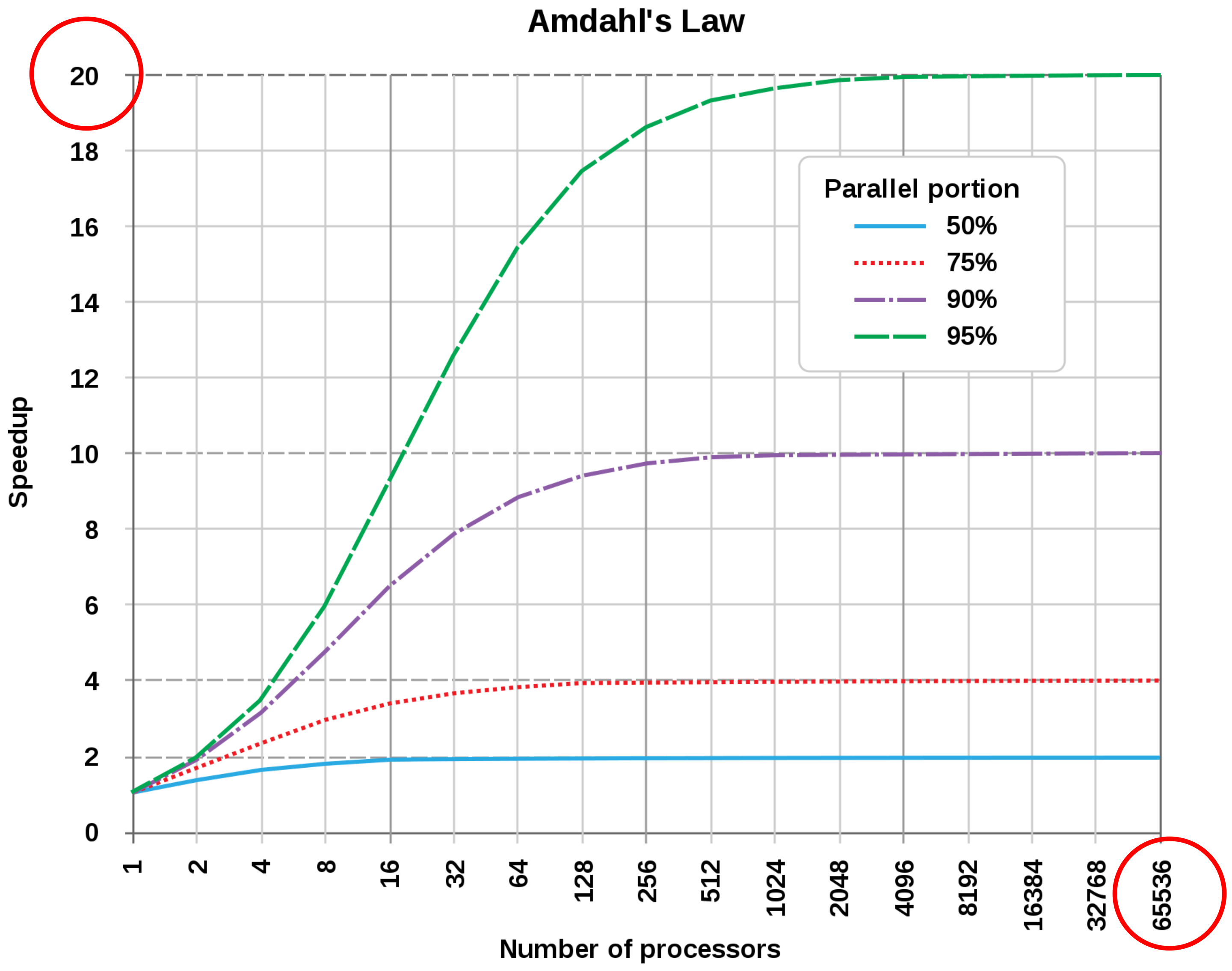
    - $T_p \approx T_s * (1-f) + (T_s / p) * f$, where:
      - f is the fraction of the program that is parallelizable, and
      - p is the number of cores
    - Intuition:
      - the non-parallelizable portion doesn't speed up at all
      - the parallelizable part scales linearly
    - This "formula" isn't true in general; one might, for example, have load imbalance in a parallelizable portion
      - also ignored are overheads including process/thread creation, communication, synchronization

Typical use of Amdahl's Law: Determining an upper bound on speedup

- Starting from $T_p \approx T_s * (1-f) + (T_s / p) * f$
  - Let $p \rightarrow \infty$
  - Then, $T_p = T_s * (1-f)$
- Suppose program takes 50 seconds sequentially, but of that 50 seconds:
  - 5 seconds is initialization that can't be parallelized
  - 5 seconds is finalization that also can't be parallelized
- Then the **maximum speedup** possible is 5!
  - Even if there are an arbitrarily large number of cores!
  - Lesson: try to avoid sequential portions of code



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Different parallel programming styles

- Iterative: SPMD (e.g., Jacobi iteration)
- Recursive: adaptive quadrature
- Task parallel: independent portions of programs
- Bag of tasks: typically used in implementation of recursive parallel programs, but also can be used for iterative

Data Parallel Algorithms

- Execute identical code on different parts of a data structure
  - Usually we mean "SPMD algorithms", which stands for Single Program Multiple Data
  - Data Parallel implies barrier after every instruction (arose from programming SIMD architectures; recall SIMD is Single Instruction Multiple Data)
  - SPMD allows barriers at arbitrary points (arose from MIMD architectures)
    - It is a relaxation of SIMD

Finding the sum of an array in parallel (SPMD program)

Note: Incorrect!

```
int sum[n], a[n]  // Array *a* initialized to arbitrary values
co i := 0 to n-1
  int d = 1
  sum[i] = a[i]
  while (d < n) {
       if (i – d >= 0)
         sum[i] = sum[i-d] + sum[i]
       d = d * 2
  }
oc
```

Why is this program incorrect?

Finding the sum of an array in parallel (SPMD program)

```
int sum[n], old[n], a[n]  // Array a initialized to arbitrary values
co i := 0 to n-1
  int d = 1
  sum[i] = a[i]
  while (d < n) {
      old[i] = sum[i]  ←———— Using extra storage is a common trick
      barrier  ←———————————— Why?
      if (i – d >= 0)
         sum[i] = old[i-d] + sum[i]
      barrier  ←———————————— Why?
      d = d * 2
   }
oc
```

This program is correct.