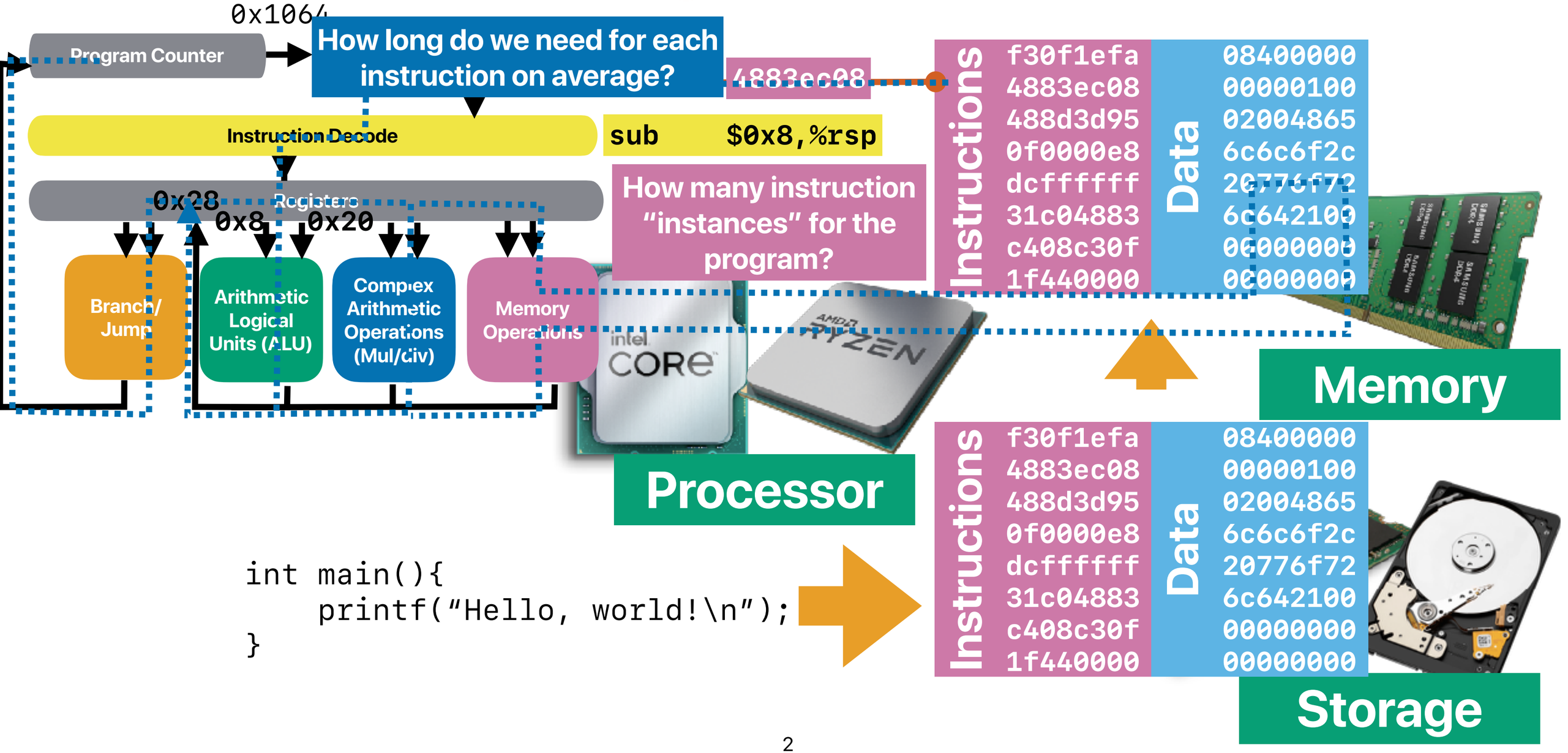
Performance (1): What does "perfect" mean?

Hung-Wei Tseng

Execution time of a program in the von Neumann model




```
int main(){
    printf("Hello, world!\n");
}
```

Recap: Classic CPU Performance Equation (ET of a program)

How many instruction "instances" for the program? × How long do we need for each instruction on average?

$$Execution\ Time = \frac{Instructions}{Program} \times \frac{Cycles}{Instruction} \times \frac{Seconds}{Cycle}$$

C Code

```
int init_data(int64_t *data, int
data_size) {
    register unsigned int i = 0;
    for(i = 0; i < data_size; i++)
{
       s+=data[i];
    }
    return s;
}

int main(int argc, char **argv) {
    int *data = malloc(8000000000);
    init_data(data, 1000000000)
    return 0;
}
```

1000000000x

x86 instructions

```
init_data:
.LFB16:
    endbr64
    testl    %esi, %esi
    jle .L2
    leal     -1(%rsi), %ecx
    xorq     %rax, %rax
.L3:
    movslq   (%rdi), %rdx
    addq     $4, %rdi
    addq     %rdx, %rax
    cmpq     %rcx, %rdi
    jne      .L3
.L2:
    xorlq    %rax, %rax
    ret
```

←memory inst.

←branch inst.

If data memory access instructions takes 5 cycles, branch 2 cycles, others take only 1 cycle, CPU freq. = 4 GHz

$$CPI_{average} = 20\% \times 5 + 20\% \times 2 + 60\% \times 1) = 2$$

$$ET = (5 \times 10^9) \times 2 \times \frac{1}{4 \times 10^9}\ sec = 2.5\ sec$$

Recap: What matters to the classical CPU performance equation?

$$Performance = \frac{1}{Execution\ Time}$$

$$Execution\ Time = \frac{Instructions}{Program} \times \frac{Cycles}{Instruction} \times \frac{Seconds}{Cycle}$$

$$ET = IC \times CPI \times CT$$

- IC (Instruction Count)
  - ISA, Compiler, algorithm, programming language, **programmer**
- CPI (Cycles Per Instruction)
  - Machine Implementation, microarchitecture, compiler, application, algorithm, programming language, **programmer**
- Cycle Time (Seconds Per Cycle)
  - Process Technology, microarchitecture, **programmer**

Takeaways: What is and what affects “performance”?

- Latency is the most fundamental performance metric — Instruction count, cycles per instruction, cycle time define the latency of execution on CPUs
- Different programming languages can generate machine operations with different orders of magnitude performance — programmers need to make wise choice of that!
- Programmers can control all three factors in the classic performance equation when composing the program
- Compiler optimization does not always help
  - Compiler optimizes code based on some assumptions that may not be true on all computers
  - Programmers’ can write code in a way facilitating optimizations!
- Complexity does not provide good assessment on real machines due to the idealized assumptions

Outline

- What does better mean?
- Amdahl's Law and its implications

Quantitive Analysis of “Better”

Speedup of Y over X

- Consider the same program on the following two machines, X and Y. By how much Y is faster than X?

	Clock Rate	Dynamic Instruction Count	Percentage of Type-A	CPI of Type-A	Percentage of Type-B	CPI of Type-B	Percentage of Type-C	CPI of Type-C
Machine X	4 GHz	5000000000	20%	5	20%	2	60%	1
Machine Y	6 GHz	5000000000	20%	7	20%	2	60%	1

A. 0.2
B. 0.25
C. 0.8
D. 1.25
E. No changes

Speedup

- The relative performance between two machines, X and Y. Y is n times faster than X

$$n = \frac{Execution\ Time_X}{Execution\ Time_Y}$$

- The speedup of Y over X

$$Speedup = \frac{Execution\ Time_X}{Execution\ Time_Y}$$

Speedup of Y over X

- Consider the same program on the following two machines, X and Y. By how much Y is faster than X?

	Clock Rate	Dynamic Instruction	Percentage of Type-A	CPI of Type-A	Percentage of Type-B	CPI of Type-B	Percentage of Type-C	CPI of Type-C
Machine X	4 GHz	5000000000	20%	5	20%	2	60%	1
Machine Y	6 GHz	5000000000	20%	7	20%	2	60%	1

A. 0.2
B. 0.25
C. 0.8
D. 1.25
E. No changes

$$ET_X = (5 \times 10^9) \times (20\% \times 5 + 20\% \times 2 + 60\% \times 1) \times \frac{1}{4 \times 10^9}\ sec = 2.5\ sec$$

$$ET_Y = (5 \times 10^9) \times (20\% \times 7 + 20\% \times 2 + 60\% \times 1) \times \frac{1}{6 \times 10^9}\ secs = 2\ secs$$

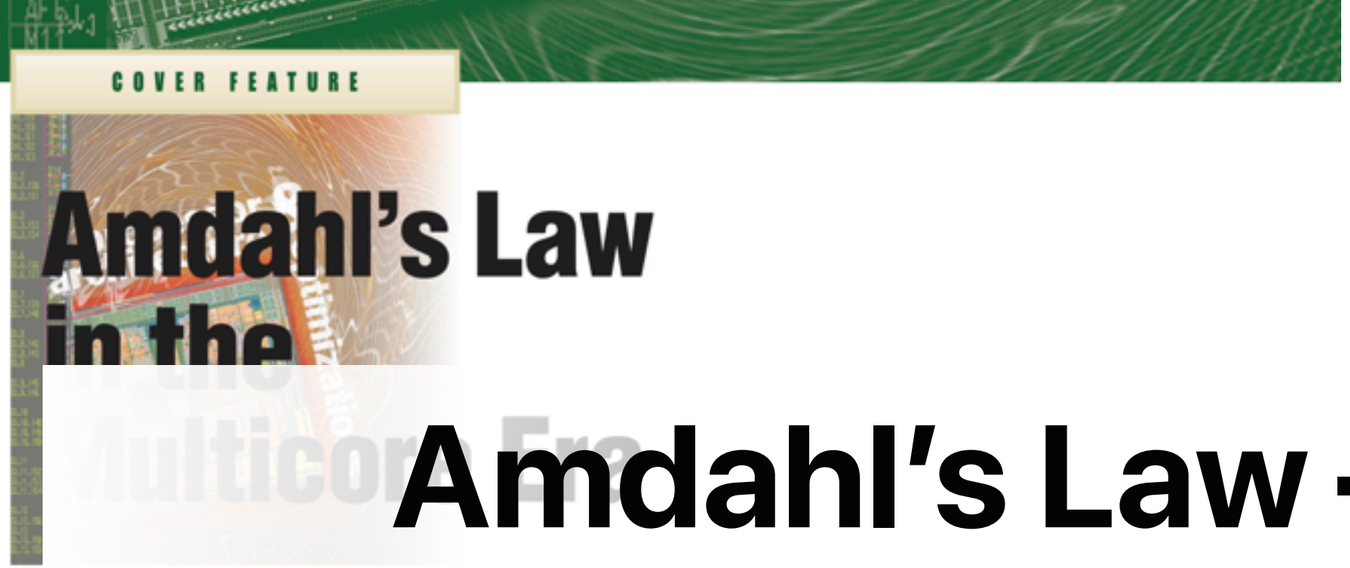
$$Speedup = \frac{Execution\ Time_X}{Execution\ Time_Y}$$

$$= \frac{2.5}{2} = 1.25$$

Takeaways: What is and what affects “performance”?

- The only definition of Y is Speedup times faster than X —

$$Speedup = \frac{Execution\ Time_X}{Execution\ Time_Y}$$



Amdahl's Law — and It's Implication in the Multicore Era

Augmenting Amdahl's law with a corollary for multicore hardware makes it relevant to future generations of chips with multiple processor cores. Obtaining optimal multicore performance will require further research in both extracting more parallelism and making sequential cores faster.

Mark D. Hill, University of Wisconsin-Madison
Michael R. Marty, Google

In IEEE Computer, vol. 41, no. 7

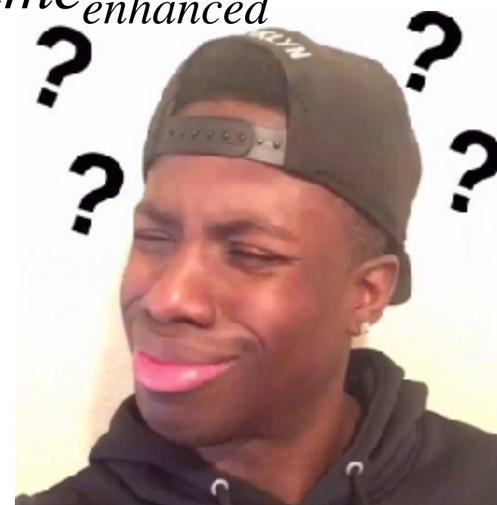
Amdahl's Law

$$Speedup_{enhanced}(f, s) = \frac{1}{(1 - f) + \frac{f}{s}}$$

f — The fraction of time in the original program

s — The speedup we can achieve on f

$$Speedup_{enhanced} = \frac{Execution\ Time_{baseline}}{Execution\ Time_{enhanced}}$$



Amdahl's Law

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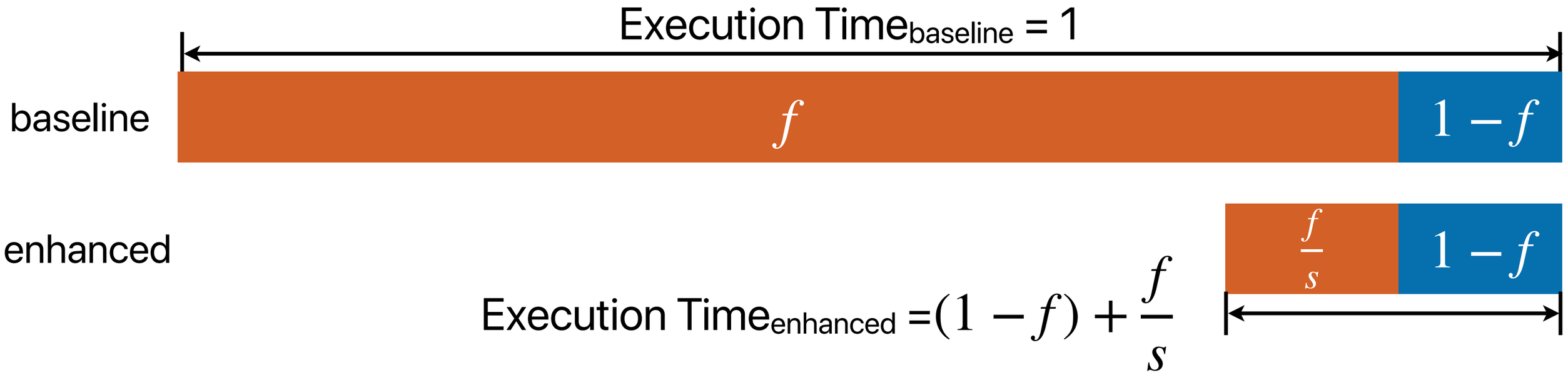

$$Speedup_{enhanced} = \frac{Execution\ Time_{baseline}}{Execution\ Time_{enhanced}} = \frac{1}{(1 - f) + \frac{f}{s}}$$

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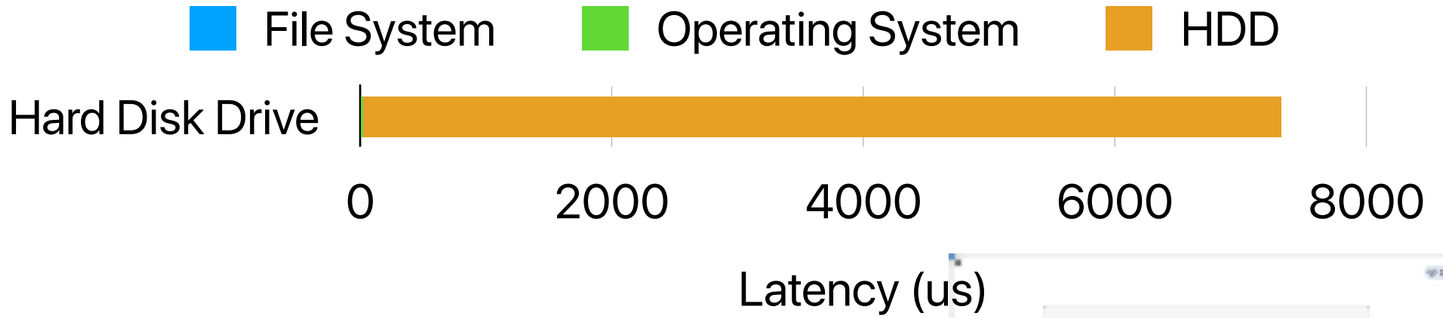
Practicing Amdahl's Law

- Final Fantasy XV spends lots of time loading a map — within which period that 95% of the time on the accessing the H.D.D., the rest in the operating system, file system and the I/O protocol. If we replace the H.D.D. with a flash drive, which provides 100x faster access time. By how much can we speed up the map loading process?
  - A. ~7x
  - B. ~10x
  - C. ~17x
  - D. ~29x
  - E. ~100x



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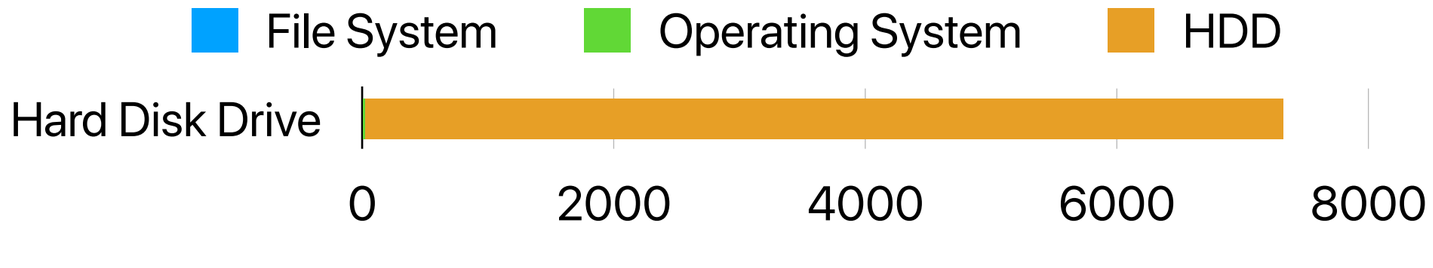
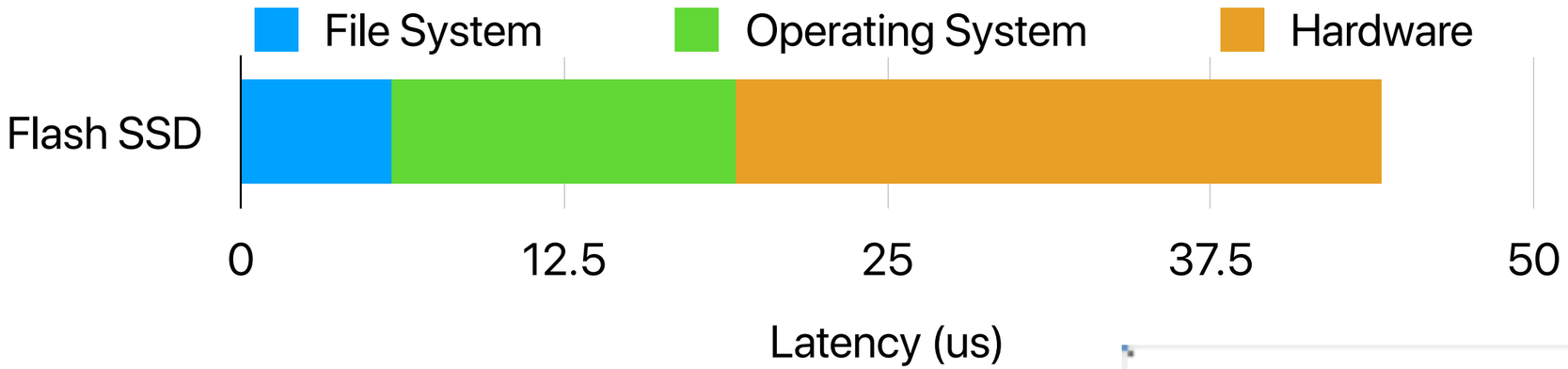


$$Speedup_{enhanced}(95\,\%, 100) = \frac{1}{(1 - 95\%) + \frac{95\,\%}{100}} = 16.81\times$$

Speedup further!

- With the latest flash memory technologies, the system spends 16% of time on accessing the flash, and the software overhead is now 84%. If your company ask you and your team to invent a new memory technology that replaces flash to achieve 2x speedup on loading maps, how much faster the new technology needs to be?

A. ~5x
B. ~10x
C. ~20x
D. ~100x
E. None of the above



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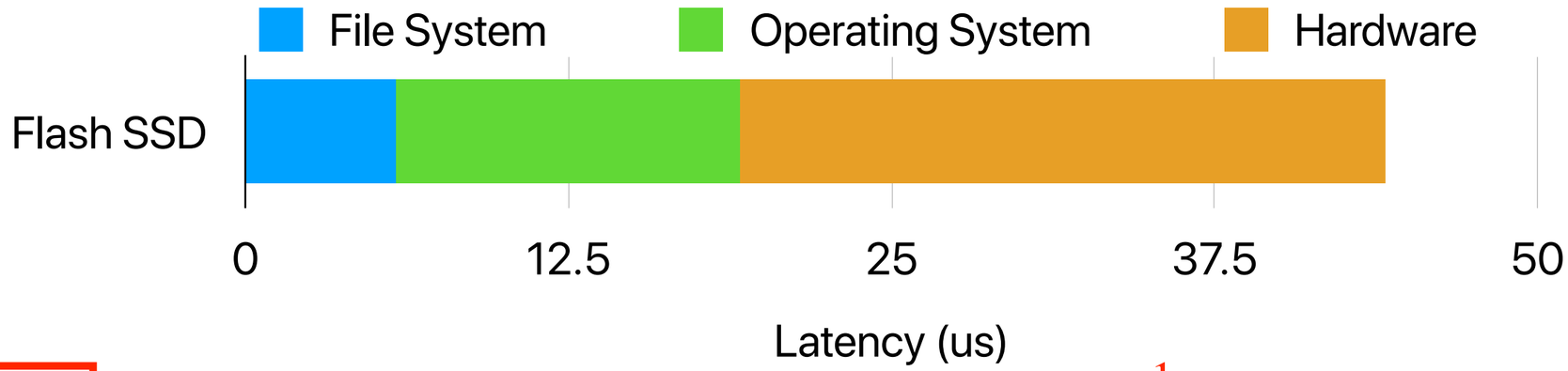

$$Speedup_{enhanced}(16\,\%, x) = \frac{1}{(1 - 16\%) + \frac{16\,\%}{x}} = 2$$

$$x = 0.47$$

Does this make sense?

Amdahl's Law Corollary #1

- The maximum speedup is bounded by

$$Speedup_{max}(f, \infty) = \frac{1}{(1-f) + \frac{f}{\infty}}$$

$$Speedup_{max}(f, \infty) = \frac{1}{(1-f)}$$

Speedup further!

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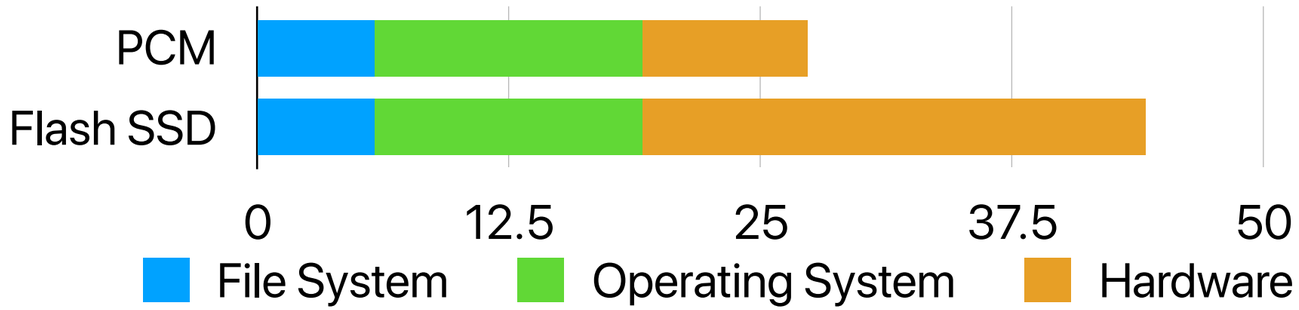
E. None of the above



$$Speedup_{max}(16\,\%\,, \infty) = \frac{1}{(1 - 16\%)} = 1.19$$

2x is not possible

WINDOWS 10 P
(Lower is better)

Optane hyb

1TB WD Bla

1TB Samsung EVO 9

PCWorld

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NEWS

Intel kills the remnants of Optane memory

The speed-boosting storage tech was already on the ropes.

By Michael Crider
Staff Writer, PCWorld | JUL 29, 2022 6:59 AM PDT

You spent a lot of money but can only get 20% performance gain!

Image: Intel

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Practicing Amdahl's Law (2)

- After applying an SSD, Final Fantasy XV now spends 16% in accessing SSD, the rest in the operating system, file system and the I/O protocol. Which of the following proposals would give as the largest performance gain?
  A. Replacing the CPU to speed up the rest by 2x
  B. Replacing the CPU to speed up the rest by 1.2x and replacing the SSD to speed up the SSD part by 100x
  C. Replacing the CPU to speed up the rest by 1.5x and replacing the SSD to speed up the SSD part by 20x
  D. Replacing the SSD to speed up the SSD part by 200x
  E. They are about the same

Amdahl's Law on Multiple Optimizations

- We can apply Amdahl's law for multiple optimizations
- These optimizations must be dis-joint!
  - If optimization #1 and optimization #2 are dis-joint:

$$Speedup_{enhanced}(f_{Opt1}, f_{Opt2}, s_{Opt1}, s_{Opt2}) = \frac{1}{(1 - f_{Opt1} - f_{Opt2}) + \frac{f\_Opt1}{s\_Opt1} + \frac{f\_Opt2}{s\_Opt2}}$$

  - If optimization #1 and optimization #2 are not dis-joint:

$$Speedup_{enhanced}(f_{OnlyOpt1}, f_{OnlyOpt2}, f_{BothOpt1Opt2}, s_{OnlyOpt1}, s_{OnlyOpt2}, s_{BothOpt1Opt2}) = \frac{1}{(1 - f_{OnlyOpt1} - f_{OnlyOpt2} - f_{BothOpt1Opt2}) + + \frac{f\_BothOpt1Opt2}{s\_BothOpt1Opt2} + \frac{f\_OnlyOpt1}{s\_OnlyOpt1} + \frac{f\_OnlyOpt2}{s\_OnlyOpt2}}$$

Practicing Amdahl's Law (2)

- After applying an SSD, Final Fantasy XV now spends 16% in accessing SSD, the rest in the operating system, file system and the I/O protocol. Which of the following proposals would give as the largest performance gain?

$$Speedup_{enhanced}(84\%, 16\%, 2, 1) = \frac{1}{(1-16\%) + \frac{84\%}{2}} = 1.72\times$$

  A. Replacing the CPU to speed up the rest by 2x
  B. Replacing the CPU to speed up the rest by 1.2x and replacing the SSD to speed up the SSD part by 100x

$$Speedup_{enhanced}(84\%, 16\%, 1.2, 100) = \frac{1}{(1-84\%-16\%) + \frac{84\%}{1.2} + \frac{16\%}{100}} = 1.43\times$$

  C. Replacing the CPU to speed up the rest by 1.5x and replacing the SSD to speed up the SSD part by 20x

$$Speedup_{enhanced}(84\%, 16\%, 1.5, 20) = \frac{1}{(1-84\%-16\%) + \frac{84\%}{1.5} + \frac{16\%}{20}} = 1.76\times$$

  D. Replacing the SSD to speed up the SSD part by 200x

$$Speedup_{enhanced}(84\%, 16\%, 1, 200) = \frac{1}{(1-16\%) + \frac{16\%}{200}} = 1.19\times$$

  E. They are about the same

If we don't touch the 84% part, it's hard to speedup!

Corollary #2 — make the common case fast!

- When f is small, optimizations will have little effect.
- Common == **most time consuming** not necessarily the most frequent
- The uncommon case doesn’t make much difference
- The common case can change based on inputs, compiler options, optimizations you’ve applied, etc.

Extension from — Corollary #1 on Multiple Optimizations

- If we can pick just one thing to work on/optimize

$$Speedup_{max}(f_1, \infty) = \frac{1}{(1 - f_1)}$$
$$Speedup_{max}(f_2, \infty) = \frac{1}{(1 - f_2)}$$
$$Speedup_{max}(f_3, \infty) = \frac{1}{(1 - f_3)}$$
$$Speedup_{max}(f_4, \infty) = \frac{1}{(1 - f_4)}$$

The biggest f_x would lead to the largest $Speedup_{max}$!

Takeaways: find the right thing to do

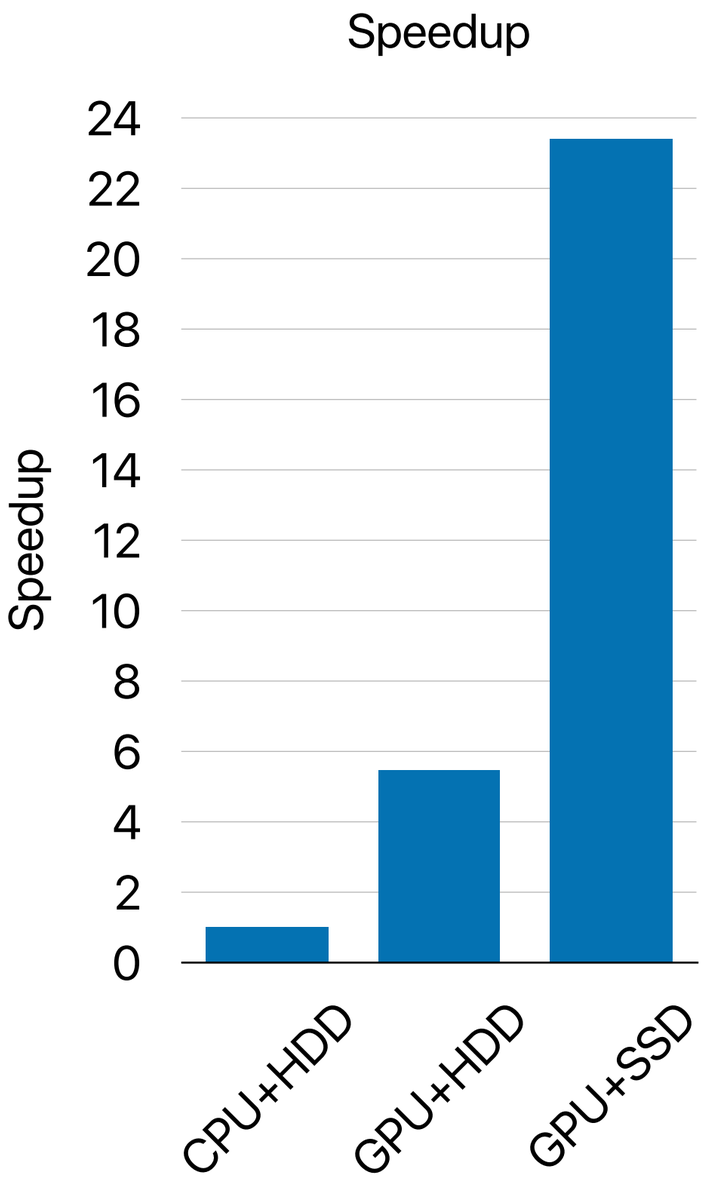
- Definition of "Speedup of Y over X" or say Y is n times faster than X: $speedup_{Y\_over\_X} = n = \frac{Execution\ Time_X}{Execution\ Time_Y}$
- Amdahl's Law — $Speedup_{enhanced}(f, s) = \frac{1}{(1-f) + \frac{f}{s}}$ $Speedup_{max}(f, \infty) = \frac{1}{(1-f)}$
  - Corollary 1 — each optimization has an upper bound
  - Corollary 2 — make the common case (the most time consuming case) fast!

$$Speedup_{max}(f_1, \infty) = \frac{1}{(1-f_1)}$$
$$Speedup_{max}(f_2, \infty) = \frac{1}{(1-f_2)}$$
$$Speedup_{max}(f_3, \infty) = \frac{1}{(1-f_3)}$$
$$Speedup_{max}(f_4, \infty) = \frac{1}{(1-f_4)}$$

Identify the most time consuming part

- Use perf
  - perf record command
  - perf report —stdio
- Use prof
  - Compile your program with -pg flag
  - Run the program
    - It will generate a gmon.out
    - gprof your_program gmon.out > your_program.prof
  - It will give you the profiled result in your_program.prof
- Or insert timestamps

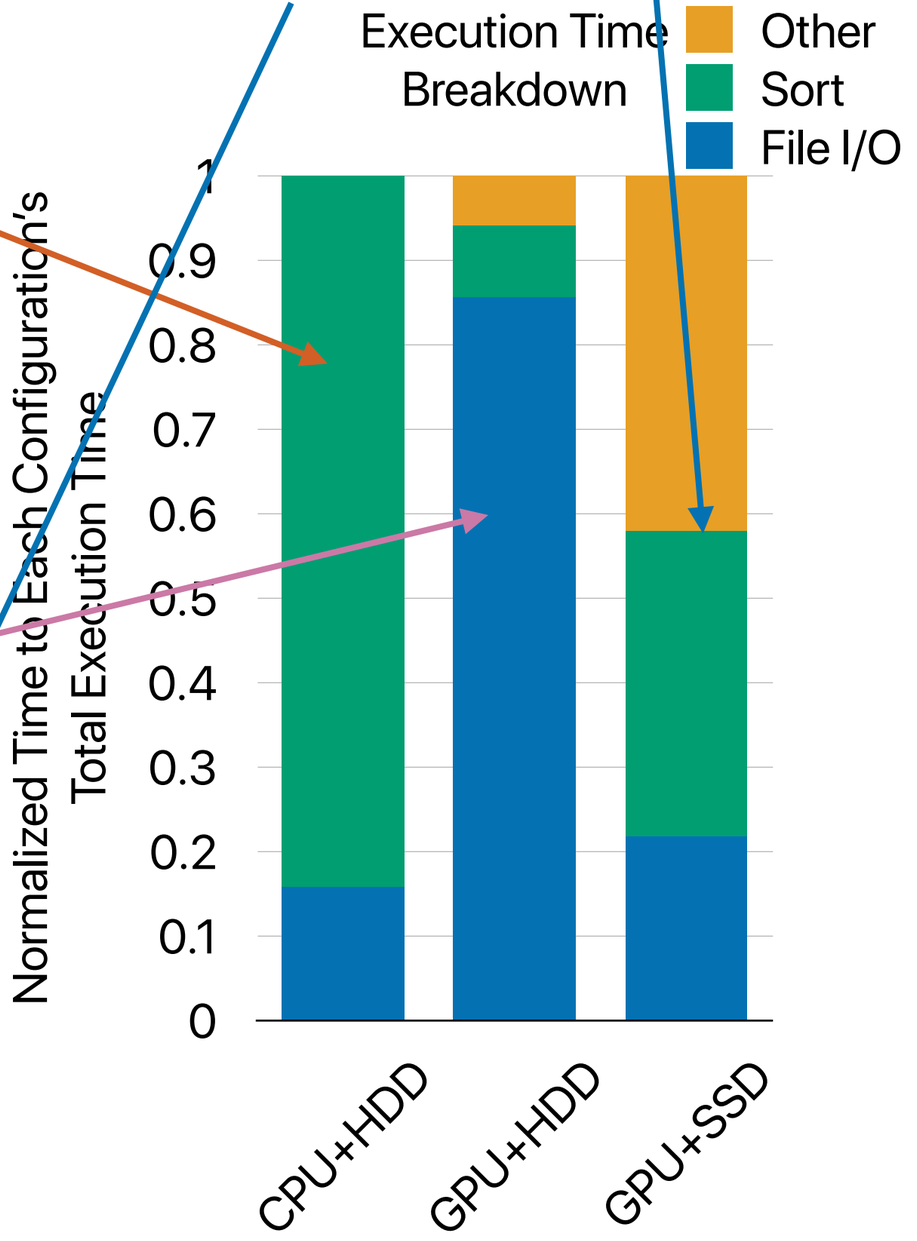
Demo — sort



Sort was the most significant

File I/O is now more critical to performance

Something else (e.g., data movement) matters more



Corollary #3: optimization has a moving target

- With optimization, the common becomes uncommon.
- An uncommon case will (hopefully) become the new common case.
- Now you have a new target for optimization — You have to revisit "Amdahl's Law" every time you applied some optimization

Takeaways: find the right thing to do

- Definition of "Speedup of Y over X" or say Y is n times faster than X: $speedup_{Y\_over\_X} = n = \frac{Execution\ Time_X}{Execution\ Time_Y}$
- Amdahl's Law — $Speedup_{enhanced}(f, s) = \frac{1}{(1-f) + \frac{f}{s}}$ $Speedup_{max}(f, \infty) = \frac{1}{(1-f)}$
  - Corollary 1 — each optimization has an upper bound
  - Corollary 2 — make the common case (the most time consuming case) fast!
  - Corollary 3 — Optimization has a moving target

$Speedup_{max}(f_1, \infty) = \frac{1}{(1-f_1)}$
$Speedup_{max}(f_2, \infty) = \frac{1}{(1-f_2)}$
$Speedup_{max}(f_3, \infty) = \frac{1}{(1-f_3)}$
$Speedup_{max}(f_4, \infty) = \frac{1}{(1-f_4)}$

Amdahl's Law on Multicore Architectures

- Symmetric multicore processor with n cores (if we assume the processor performance scales perfectly)

$$Speedup_{parallel}(f_{parallelizable}, n) = \frac{1}{(1 - f_{parallelizable}) + \frac{f\_parallelizable}{n}}$$

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Amdahl's Law on Multicore Architectures

- Regarding Amdahl's Law on multicore architectures, how many of the following statements is/are correct?
  - ① If we have unlimited parallelism, the performance of executing each parallel partition does not matter as long as the performance slowdown in each piece is bounded
  - ② With unlimited amount of parallel hardware units, single-core performance does not matter anymore
  - ③ With unlimited amount of parallel hardware units, the maximum speedup will be bounded by the fraction of parallel parts
  - ④ With unlimited amount of parallel hardware units, the effect of scheduling and data exchange overhead is minor

  A. 0
  B. 1
  C. 2
  D. 3
  E. 4

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  A. 0
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  E. 4

Amdahl's Law on Multicore Architectures

- Regarding Amdahl's Law on multicore architectures, how many of the following statements is/are correct?

$$Speedup_{parallel}(f_{parallelizable}, \infty) = \frac{1}{(1 - f_{parallelizable}) + \frac{f\_parallelizable \times Speedup(<1)}{\infty}}$$

  ① If we have unlimited parallelism, the performance of executing each parallel partition does not matter as long as the performance slowdown in each piece is bounded

  ② With unlimited amount of parallel hardware units, single-core performance does not matter anymore

$$Speedup_{parallel}(f_{parallelizable}, \infty) = \frac{1}{(1 - f_{parallelizable})}$$

speedup is determined by 1-f

  ③ With unlimited amount of parallel hardware units, the maximum speedup will be bounded by the fraction of parallel parts

  ④ With unlimited amount of parallel hardware units, the effect of scheduling and data exchange overhead is minor

  A. 0
  B. 1
  C. 2
  D. 3
  E. 4

Demo — merge sort v.s. bitonic sort on GPUs

Merge Sort

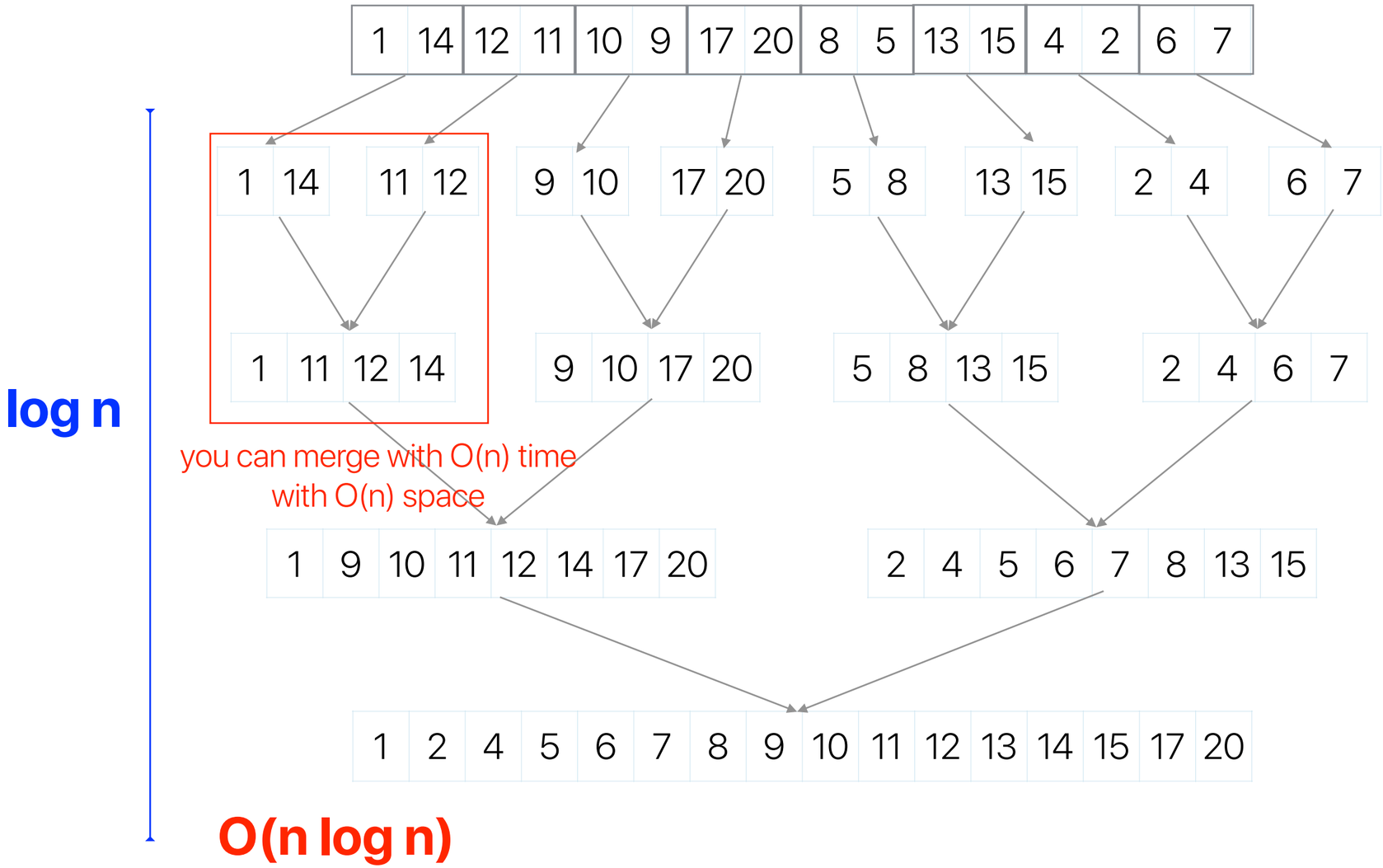
$O(nlog_2n)$

Bitonic Sort

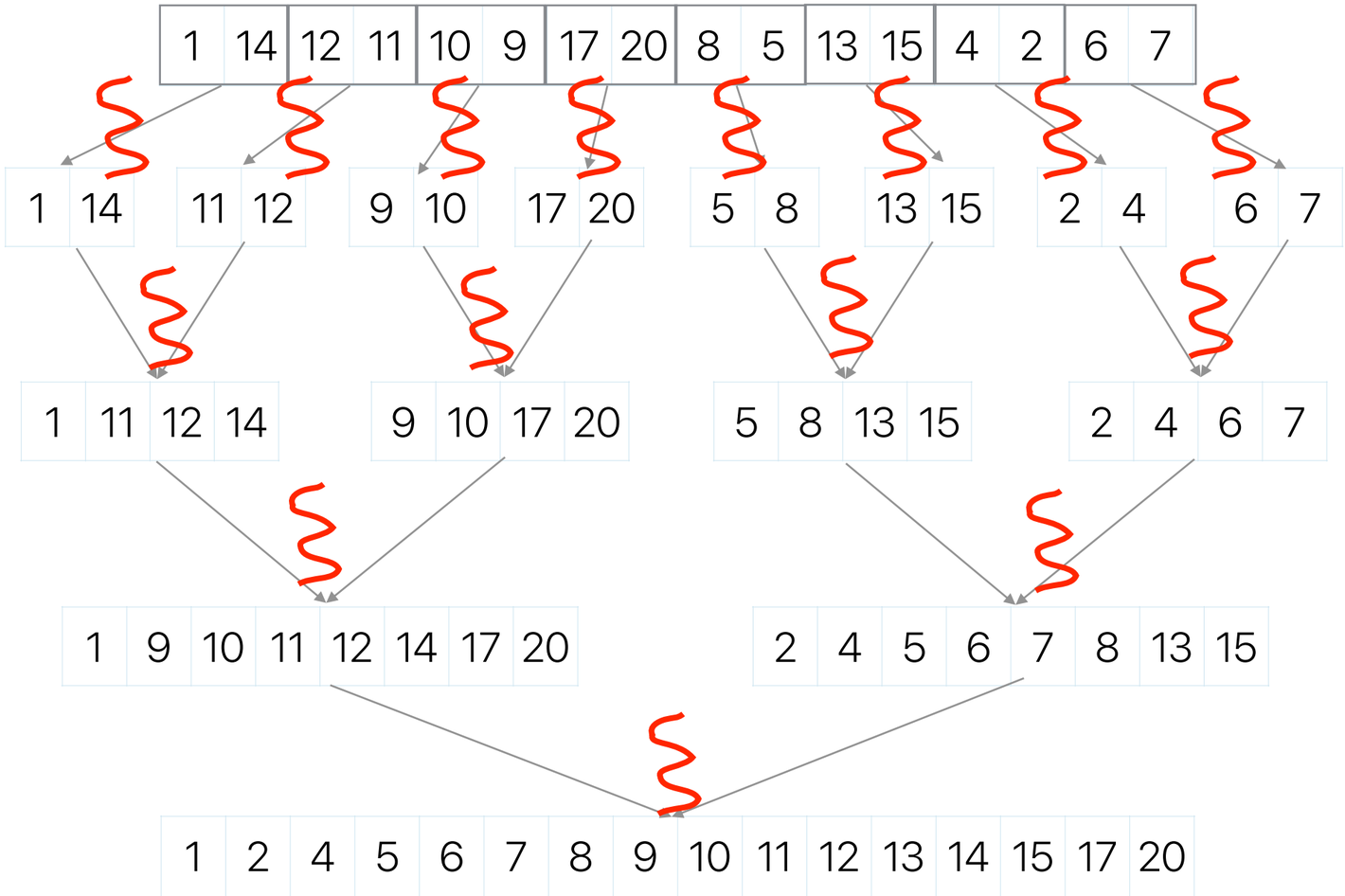
$O(nlog_2^2n)$

```
void BitonicSort() {

    int i,j,k;

    for (k=2; k<=N; k=2*k) {
        for (j=k>>1; j>0; j=j>>1) {
            for (i=0; i<N; i++) {
                int ij=i^j;
                if ((ij)>i) {
                    if ((i&k)==0 && a[i] > a[ij])
                        exchange(i,ij);
                    if ((i&k)!=0 && a[i] < a[ij])
                        exchange(i,ij);
                }
            }
        }
    }
}
```

Merge sort


1 14 12 11 10 9 17 20 8 5 13 15 4 2 6 7
1 14 11 12 9 10 17 20 5 8 13 15 2 4 6 7
1 11 12 14 9 10 17 20 5 8 13 15 2 4 6 7
you can merge with O(n) time
with O(n) space
1 9 10 11 12 14 17 20 2 4 5 6 7 8 13 15
1 2 4 5 6 7 8 9 10 11 12 13 14 15 17 20
log n
O(n log n)

Parallel merge sort



What's the speedup of merge sort using Amdahl's Law

The degree of parallelism is $1, 2, 4, \ldots, \frac{n}{2}$

at step $1, 2, 3, \ldots, log_2(n)$

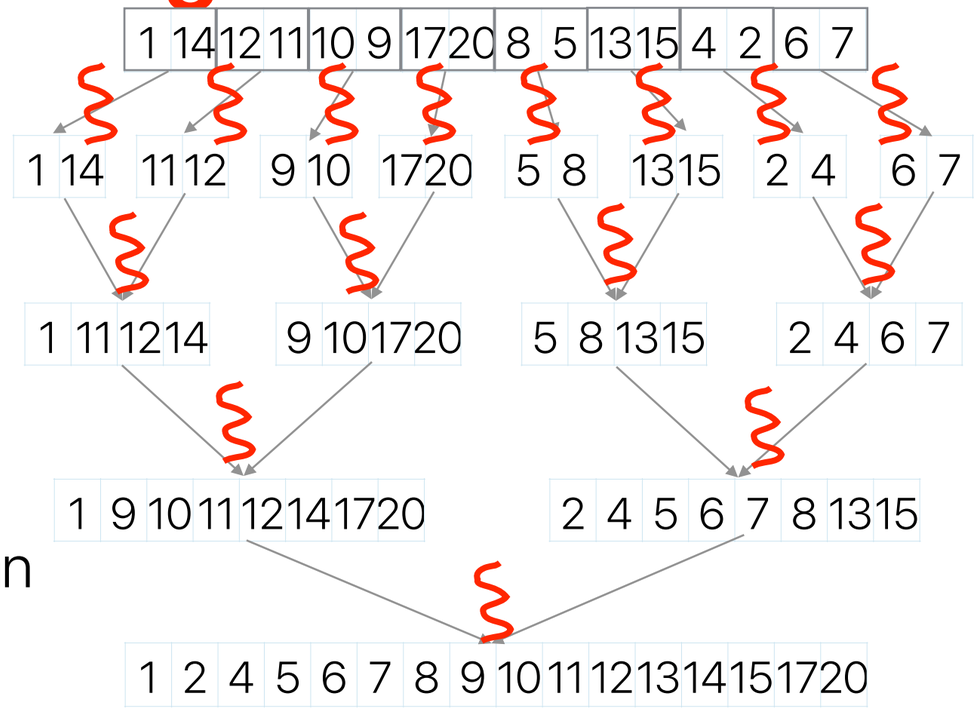
The ideal speedup of each step is $1, 2, 4, \ldots, \frac{n}{2}$ or say

$1, 2, 4, \ldots, 2^{log_2(n)-1}$ if we have **unlimited** parallelism

if we assume equal amount of time in each step in the baseline,

each step is going to take $\frac{1}{lg(n)}$ portion of time in the baseline, an

the first $\frac{1}{lg(n)}$ is not parallelizable (i.e., $(1-x) = \frac{1}{lg(n)}$)

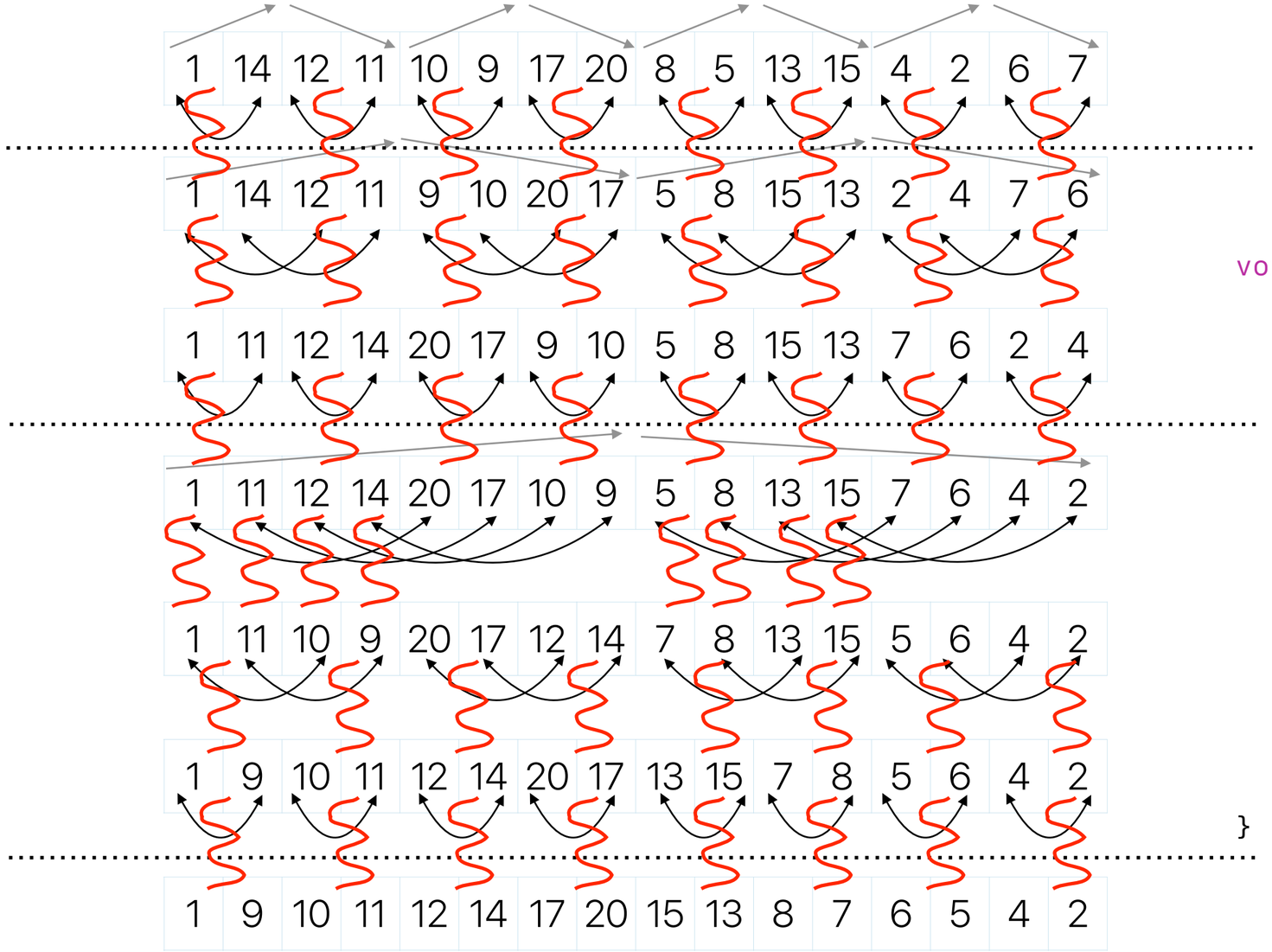


So the Amdahl's Law's evaluation will become

$$\frac{1}{\frac{1}{lg(n)} + \frac{1}{lg(n)\times 2} + \frac{1}{lg(n)\times 4} + \ldots + \frac{1}{lg(n)\times 2^{lg(n)-1}}} = \frac{1}{\frac{1}{lg(n)}(1 + \frac{1}{2} + \frac{1}{4} + \ldots + \frac{1}{2^{lg(n)-1}})}$$

$$= \frac{1}{\frac{1}{lg(n)}(1 + 1 - \frac{1}{2^{lg(n)-1}})} = \frac{1}{\frac{2}{lg(n)}} = \frac{lg(n)}{2}$$

Bitonic sort

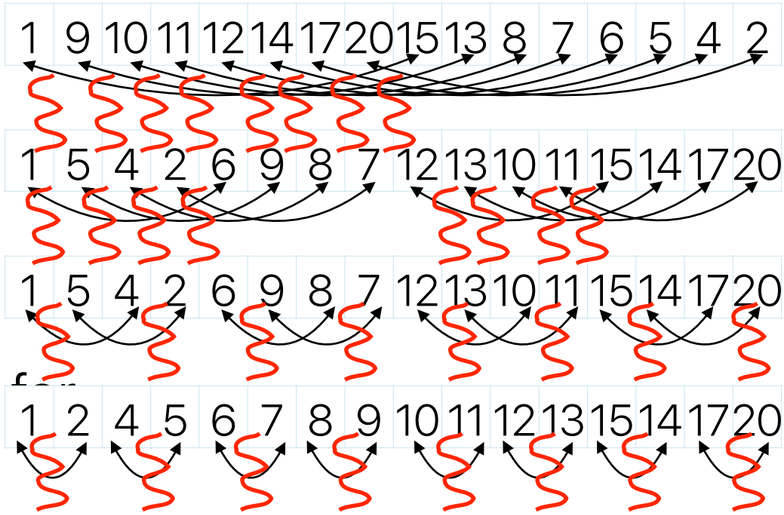



```
void BitonicSort() {

    int i,j,k;

    for (k=2; k<=N; k=2*k) {
        for (j=k>>1; j>0; j=j>>1) {
            for (i=0; i<N; i++) {
                int ij=i^j;
                if ((ij)>i) {
                    if ((i&k)==0 && a[i] > a[ij])
                        exchange(i,ij);
                    if ((i&k)!=0 && a[i] < a[ij])
                        exchange(i,ij);
                }
            }
        }
    }
}
```

What's the speedup of bitonic sort using Amdahl's Law

The degree of parallelism is always $\frac{n}{2}$

at step $1,\ 2,\ 3,\ \ldots,\ log_2^2(n)$



The ideal speedup of each step is $\frac{n}{2}$ if we have **unlimited** parallelism & for each step of bitonic sort. However, bitonic sort will have lg(n)x more steps than merge sort.

If the baseline is merge sort — the speedup of using bitonic sort is

$$\frac{1}{\frac{1 \times lg(n)}{\frac{n}{2}}} = \frac{n}{2lg(n)} > \frac{lg(n)}{2}$$

What if we have only p processors?

For **bitonic sort**,The degree of parallelism is always $\frac{n}{2}$

at step $1,\ 2,\ 3,\ \ldots,\ log_2^2(n)$, but we have only p processors...

The theoretical speedup of each step is $max(\frac{n}{2}, p) = p$ since n is very likely to

be larger than **p** & assume equal amount of time in each step in the baseline

So the Amdahl's Law's evaluation will become $\frac{1}{\frac{p}{lg(n)}} = \frac{p}{lg(n)} = \frac{1024}{30} = 34.1333333$

What about merge sort? $= \frac{1}{\frac{1}{lg(n)}(1 + \frac{1}{2} + \frac{1}{4} + \ldots + \frac{1}{p})}$

What if p=1024, n=1M=2^{30}? $= \frac{1}{\frac{1}{30}(1 + \frac{1}{2} + \frac{1}{4} + \ldots + \frac{1}{1024} + 20 \times \frac{1}{30})} = 14.862119$

Corollary #4

$$Speedup_{parallel}(f_{parallelizable}, \infty) = \frac{1}{(1 - f_{parallelizable}) + \frac{f\_parallelizable}{\infty}}$$

$$Speedup_{parallel}(f_{parallelizable}, \infty) = \frac{1}{(1 - f_{parallelizable})}$$

- If we can build a processor with unlimited parallelism
  - The algorithm complexity becomes less important as long as the algorithm can utilize all parallelism
  - That's why bitonic sort or MapReduce works!
- **The future trend of software/application design is seeking for more parallelism rather than lower the computational complexity**

Takeaways: find the right thing to do

- Definition of "Speedup of Y over X" or say Y is n times faster than X: $speedup_{Y\_over\_X} = n = \frac{Execution\ Time_X}{Execution\ Time_Y}$
- Amdahl's Law — $Speedup_{enhanced}(f, s) = \frac{1}{(1-f) + \frac{f}{s}}$ $Speedup_{max}(f, \infty) = \frac{1}{(1-f)}$
  - Corollary 1 — each optimization has an upper bound
  - Corollary 2 — make the common case (the most time consuming case) fast!
  - Corollary 3 — Optimization has a moving target
  - Corollary 4 — Exploiting more parallelism from a program is the key to performance gain in modern architectures

$Speedup_{max}(f_1, \infty) = \frac{1}{(1-f_1)}$
$Speedup_{max}(f_2, \infty) = \frac{1}{(1-f_2)}$
$Speedup_{max}(f_3, \infty) = \frac{1}{(1-f_3)}$
$Speedup_{max}(f_4, \infty) = \frac{1}{(1-f_4)}$

$Speedup_{parallel}(f_{parallelizable}, \infty) = \frac{1}{(1-f_{parallelizable})}$

Is it the end of computational complexity?

Corollary #5

$$Speedup_{parallel}(f_{parallelizable}, \infty) = \frac{1}{(1 - f_{parallelizable}) + \frac{f\_parallelizable}{\infty}}$$

$$Speedup_{parallel}(f_{parallelizable}, \infty) = \frac{1}{(1 - f_{parallelizable})}$$

- Single-core performance still matters
  - It will eventually dominate the performance
  - If we cannot improve single-core performance further, finding more "parallelizable" parts is more important
  - Algorithm complexity still gives some "insights" regarding the growth of execution time in the same algorithm, though still not accurate

Takeaways: find the right thing to do

- Definition of "Speedup of Y over X" or say Y is n times faster than X: $speedup_{Y\_over\_X} = n = \frac{Execution\ Time_X}{Execution\ Time_Y}$
- Amdahl's Law — $Speedup_{enhanced}(f, s) = \frac{1}{(1-f) + \frac{f}{s}}$ $Speedup_{max}(f, \infty) = \frac{1}{(1-f)}$
  - Corollary 1 — each optimization has an upper bound
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  - Corollary 3 — Optimization has a moving target
  - Corollary 4 — Exploiting more parallelism from a program is the key to performance gain in modern architectures
  - Corollary 5 — Single-core performance still matters

$Speedup_{max}(f_1, \infty) = \frac{1}{(1-f_1)}$
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$Speedup_{max}(f_4, \infty) = \frac{1}{(1-f_4)}$

$Speedup_{parallel}(f_{parallelizable}, \infty) = \frac{1}{(1-f_{parallelizable})}$

$Speedup_{parallel}(f_{parallelizable}, \infty) = \frac{1}{(1-f_{parallelizable})}$

Announcement

- Programming assignment 1 **due this midnight** & Assignment 1 **released**
  - We cannot help you at the last minute — please start early
  - Watch before you start https://youtu.be/m7OoY8y_Isk
  - Please always make sure you follow the exact steps in the readme and the notebook
  - Submit to the right item on Gradescope
- Reading quiz due next Tuesday before the lecture
  - We will drop two of your least performing reading quizzes
  - Once you closed, you cannot restart
- Check our website for slides/quiz links, Gradescope to submit assignments, discord for discussions
- Check your grades at https://www.escalab.org/my_grades
  - If you don't have any grade, you need to make sure your gradescope account is associated with your UCRNetID@ucr.edu
  - You have to submit a course agreement to receive scores
- Youtube channel for lecture recordings: https://www.youtube.com/c/ProfUsagi/playlists

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