Memory & Caches I

CSE 351 Winter 2024

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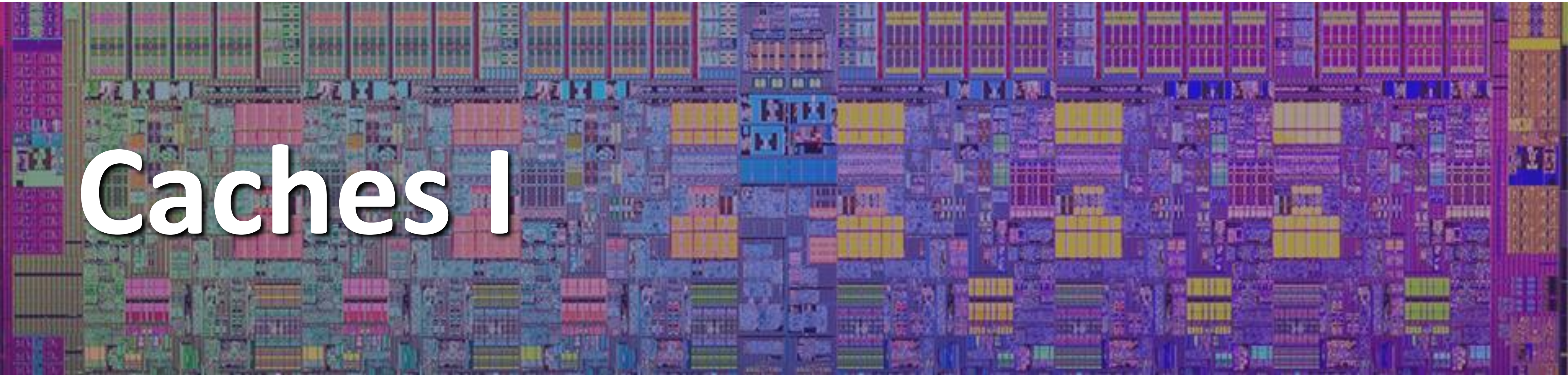
Relevant Course Information

- HW14 due Monday, HW15 due Wednesday
- Lab 3 due next Friday (2/16)
  - Make sure to look at HW14 before starting
- Midterm starts tomorrow (2/8-10)
  - Only private posts on Ed Discussion
  - Staff cannot help you study during the exam window – only point you to resources and clarify the questions
  - We will post clarifications and corrections about the exam on Ed as we go



Caches I

Lesson Summary (1/3)

- IEC prefixes are unambiguously powers of 2:

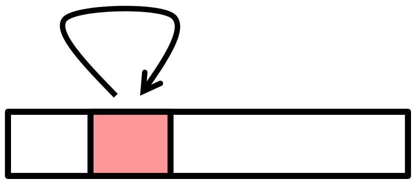
SIZE PREFIXES (10^x for Disk, Communication; 2^x for Memory)

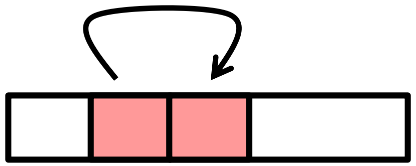
SI Size	Prefix	Symbol	IEC Size	Prefix	Symbol
10^3	Kilo-	K	2^{10}	Kibi-	Ki
10^6	Mega-	M	2^{20}	Mebi-	Mi
10^9	Giga-	G	2^{30}	Gibi-	Gi
10^{12}	Tera-	T	2^{40}	Tebi-	Ti
10^{15}	Peta-	P	2^{50}	Pebi-	Pi
10^{18}	Exa-	E	2^{60}	Exbi-	Ei
10^{21}	Zetta-	Z	2^{70}	Zebi-	Zi
10^{24}	Yotta-	Y	2^{80}	Yobi-	Yi

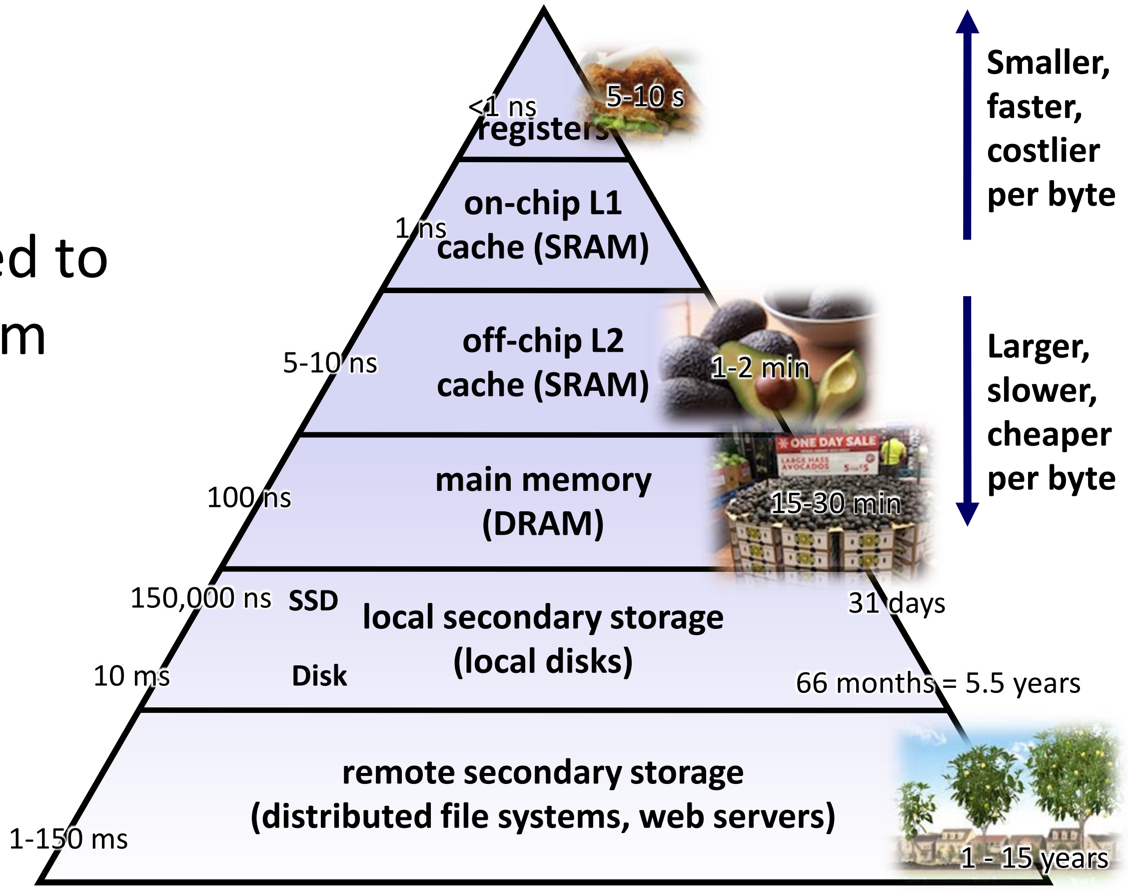
$$2^{XY}\ \text{"things"} = \left[\begin{array}{l} Y = 0 \rightarrow 1 \\ Y = 1 \rightarrow 2 \\ Y = 2 \rightarrow 4 \\ Y = 3 \rightarrow 8 \\ Y = 4 \rightarrow 16 \\ Y = 5 \rightarrow 32 \\ Y = 6 \rightarrow 64 \\ Y = 7 \rightarrow 128 \\ Y = 8 \rightarrow 256 \\ Y = 9 \rightarrow 512 \end{array}\right] + \left[\begin{array}{l} X = 0 \rightarrow \\ X = 1 \rightarrow \text{Kibi-} \\ X = 2 \rightarrow \text{Mebi-} \\ X = 3 \rightarrow \text{Gibi-} \\ X = 4 \rightarrow \text{Tebi-} \\ X = 5 \rightarrow \text{Pebi-} \\ X = 6 \rightarrow \text{Exbi-} \\ X = 7 \rightarrow \text{Zebi-} \\ X = 8 \rightarrow \text{Yobi-} \end{array}\right] + \text{"things"}$$

Lesson Summary (2/3)

- Memory Hierarchy
  - Successively higher levels contain "most used" data from lower levels
  - Caches are intermediate storage levels used to optimize data transfers between any system elements with different characteristics
  - Exploits *temporal and spatial locality*:





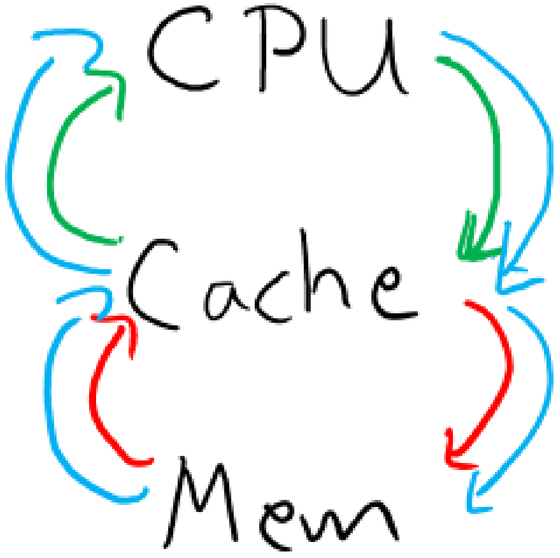


Lesson Summary (3/3)

- Cache Performance
  - Ideal case: found in cache (***cache hit***), return requested data immediately
  - Bad case: not found in cache (***cache miss***), search in next level
    - Bring entire ***cache block*** containing requested data into this cache once found
  - **Average Memory Access Time** (AMAT) = HT + MR × MP
    - Hurt by Miss Rate and Miss Penalty

Hit takes HT

Miss takes HT + MP



Lesson Q&A

- Learning Objectives:
  - Describe the memory hierarchy and explain the relationship between cost, size, and access speed of its layers.
  - Analyze how changes [to cache parameters and policies] affect performance metrics such as AMAT

- What lingering questions do you have from the lesson?
  - Chat with your neighbors about the lesson for a few minutes to come up with questions

Caches I – Practice

Polling Questions (1/2)

- Convert the following to or from IEC:
  - 512 Ki-books
  - 2^{27} caches

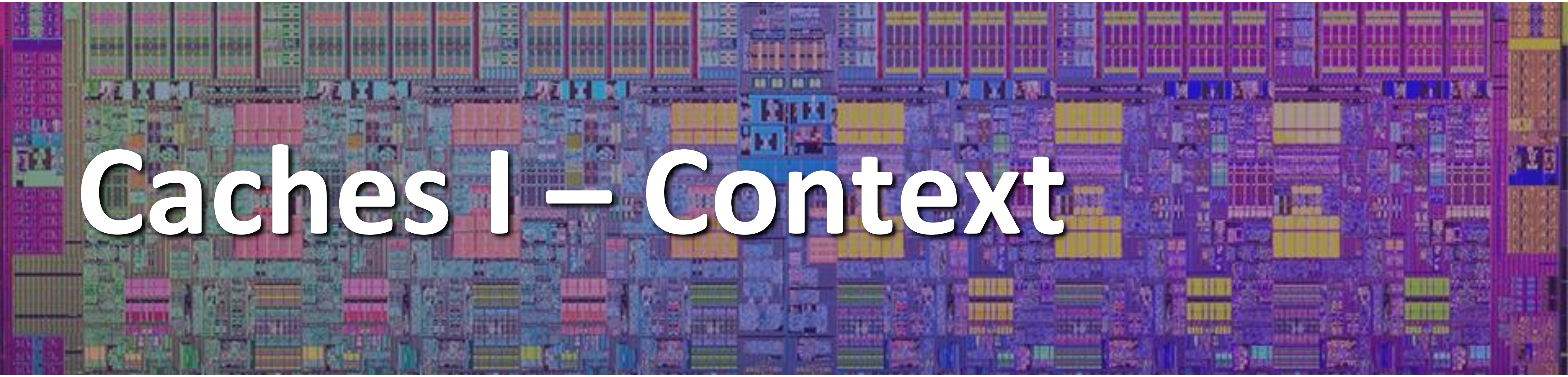
- Compute the average memory access time (AMAT) for the following system properties:
  - Hit time of 1 ns
  - Miss rate of 1%
  - Miss penalty of 100 ns

Polling Questions (2/2)

- **Processor specs:** 200 ps clock, MP of 50 clock cycles, MR of 0.02 misses/instruction, and HT of 1 clock cycle

  AMAT =

- Which improvement would be best?
  - **A.** **190 ps clock**
  - **B.** **Miss penalty of 40 clock cycles**
  - **C.** **MR of 0.015 misses/instruction**



Caches I – Context

AMAT, Revisited

- *Average Memory Access Time* (AMAT): average time to access memory considering both hits and misses

  AMAT = Hit time + Miss rate × Miss penalty

  (abbreviated AMAT = HT + MR × MP)

- We called this a *cache performance* ***metric***
  - This isn't the only metric we could have used!

Metrics in Computing

- Generally, folks care most about performance
  - Energy-efficiency is more important now since the plateau in 2004/2005
  - This is why we have so many specialized chips nowadays

- Really, this is just **efficiency** – making efficient use of the resources that we have
  - Performance: cycles/instruction, seconds/program
  - Energy efficiency: performance/watt
  - Memory: bytes/program, bytes/data structure

Metrics

- What do we do with metrics?
  - We tend to optimize along them!
  - Especially when jobs/funding depend on better performance along some metric
    - See all of Intel under “Moore’s Law”
- Sometimes, strange incentives emerge
  - “Minimize the number of bugs on our dashboard”
    - Does it count if we make the bugs invisible?
  - “Make this faster for our demo in a week”
    - Shortcuts might hurt performance at scale
  - “Minimize our average memory access time”
    - What if we add *more* memory accesses that we know will hit?

Metrics and Success

- Success is *defined along metrics*
  - This affects how we measure and optimize

- Let's say that we choose **performance/program** or **performance/program set** (*i.e.*, benchmarks):
  1. Measure existing performance
  2. Come up with a bunch of optimizations that would improve performance
  3. Select a few to build into the "next version"

Metrics and Success

- Success is *defined along metrics*
  - This affects how we measure and optimize

- Let's say that we choose **profit/year** or **stock price**:
  - Success means earning more profit than last year
  - Improvement or optimizations might include:
    - Reduce expenses, cut staff
    - Sell more things or fancier things (*e.g.*, in-app purchases)
    - Make people pay monthly for things they could get for free
    - Increase advertising revenue:

The New York Times

Whistle-Blower Says Facebook 'Chooses Profits Over Safety'

Frances Haugen, a Facebook product manager who left the company in May, revealed that she had provided internal documents to journalists and others.

Metrics and Success

- Success is *defined along metrics*
  - This affects how we measure and optimize

- Let's say that we choose **minoritized participation in computing**:
  - What does success/participation mean (and dangers)?
    - Women? BIPOC? All minoritized lumped together?
      - Might optimize for one group at the expense of others
    - Taking intro? Passing intro? Getting a degree? Getting a job?
      - Says nothing about retention or participation/decision-making level

Design Considerations

- Regardless of what we build, the way that we define success shapes the systems we build
  - Choose your metrics carefully
  - There's more to choose from than performance (*e.g.*, usability, access, simplicity, agency)

- Metrics are a "heading" (in the navigational sense)
  - Best to reevaluate from time to time in case you're off course or your destination changes

Discussion Questions

- Discuss the following question(s) in groups of 3-4 students
  - I will call on a few groups afterwards so please be prepared to share out
  - Be respectful of others' opinions and experiences

- Let's say your (main) metric for college is to get a 4.0 overall GPA.
  - What are some potential unintended consequences of this metric?
  - What are some other potential metrics you could use for college?

Group Work Time

- During this time, you are encouraged to work on the following:
  1) If desired, continue your discussion
  2) Work on the homework problems
  3) Work on the lab (if applicable)

- Resources:
  - You can revisit the lesson material
  - Work together in groups and help each other out
  - Course staff will circle around to provide support