CSE332: Data Abstractions

Lecture 8: Memory Hierarchy

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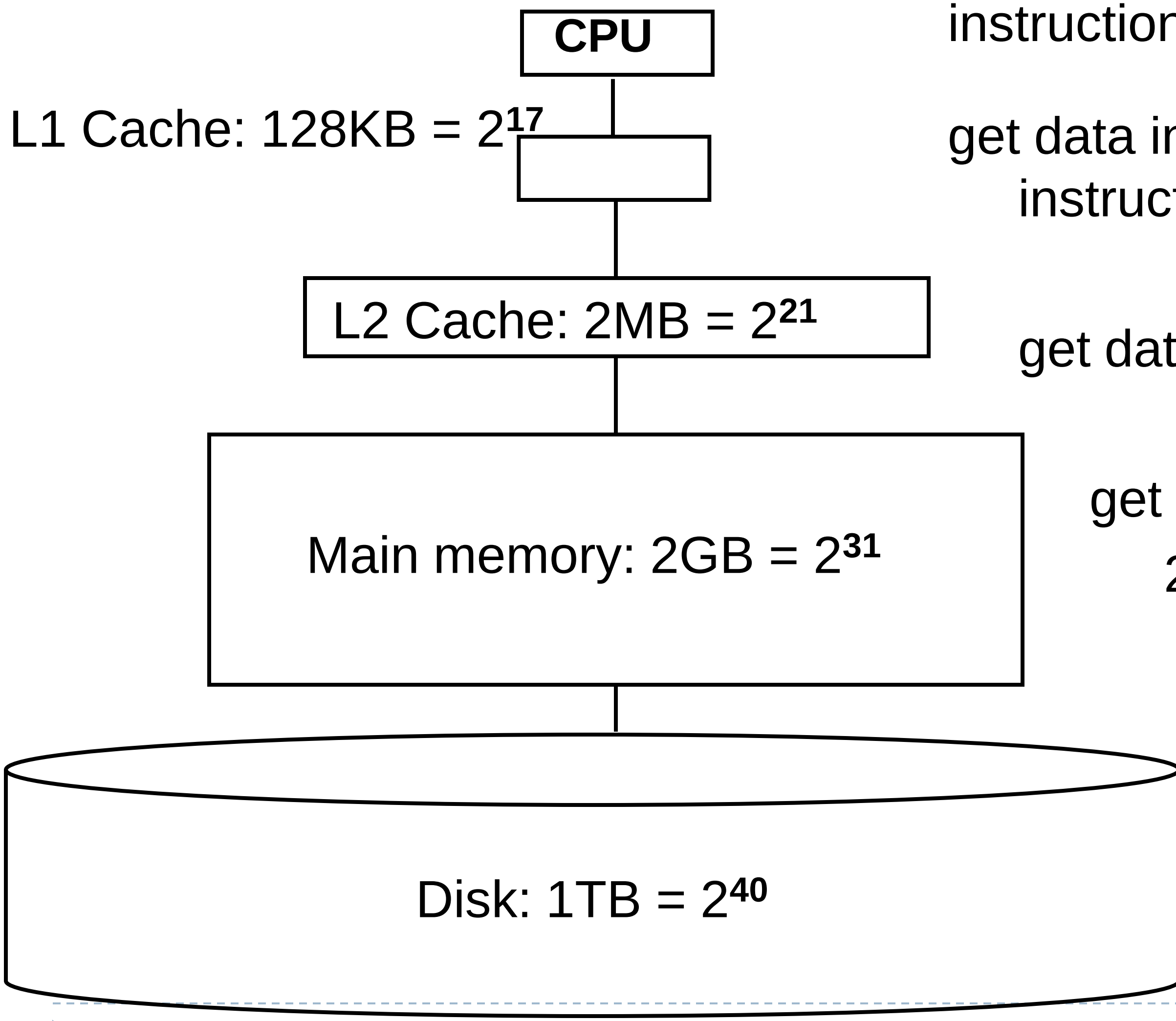
Now what?

- We have a data structure for the dictionary ADT that has worst-case $O($`log` $n)$ behavior
  - One of several interesting/fantastic balanced-tree approaches
- We are about to learn another balanced-tree approach: B Trees
- First, to motivate why B trees are better for really large dictionaries (say, over 1GB = 2^{30} bytes), need to understand some ***memory-hierarchy basics***
  - Don't always assume "every memory access has an unimportant *O(1)* cost"
  - Learn more in CSE351/333/471 (and CSE378), focus here on relevance to data structures and efficiency

A typical hierarchy

"Every desktop/laptop/server is different" but here is a plausible configuration these days



instructions (e.g., addition): 2^{30}/sec

get data in L1: 2^{29}/sec = 2 instructions

get data in L2: 2^{25}/sec = 30 inst

get data in main memory: 2^{22}/sec = 250 inst

get data from "new place" on disk:

2^{7}/sec =8,000,000 inst

"streamed": 2^{18}/sec

Morals

It is much faster to do: Than:

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5 million arithmetic ops	1 disk access
2500 L2 cache accesses	1 disk access
400 main memory accesses	1 disk access

Why are computers built this way?

- Physical realities (speed of light, closeness to CPU)
- Cost (price per byte of different technologies)
- Disks get much bigger not much faster
  - Spinning at 7200 RPM accounts for much of the slowness and unlikely to spin faster in the future
- Speedup at higher levels makes lower levels *relatively slower*
- Later in the course: more than 1 CPU!

“Fuggedaboutit”, usually

The hardware automatically moves data into the caches from main memory for you

- Replacing items already there
- So algorithms much faster if “data fits in cache” (often does)

Disk accesses are done by software (e.g., ask operating system to open a file or database to access some data)

So most code “just runs” but sometimes it’s worth designing algorithms / data structures with knowledge of memory hierarchy

- And when you do, you often need to know one more thing…

Block/line size

- Moving data up the memory hierarchy is slow because of *latency* (think distance-to-travel)
  - Since we're making the trip anyway, may as well carpool
    - Get a block of data in the same time it would take to get a byte
  - What to send? How about nearby memory:
    - It's easy (close by)
    - And likely to be asked for soon (spatial locality)
- Side note: Once in cache, may as well keep it around for awhile; accessed once, a value is more likely to be accessed again in the near future (more likely than some random other value): temporal locality

Block/line size

- The amount of data moved from disk into memory is called the “block” size or the “(disk) page” size
  - Not under program control
- The amount of data moved from memory into cache is called the “line” size
  - As in “cache line”
  - Not under program control
- Not under our control, but good to be aware of

Connection to data structures

- An array benefits more than a linked list from block moves
  - Language (e.g., Java) implementation can put the linked list nodes anywhere, whereas array is typically contiguous memory
  - Arrays benefit more from spatial locality
- Note: “array” doesn’t mean “good”
  - Sufficiently large array won’t fit in one block
  - Binary heaps “make big jumps” to percolate (different block)

BSTs?

- Since looking things up in balanced binary search trees is $O(\texttt{log}\ n)$, even for $n = 2^{39}$ (512GB) we don't have to worry about minutes or hours
- Still, number of disk accesses matters
  - AVL tree could have height of, say, 55
  - Which, based on our proof, is a lot of nodes
  - Most of the nodes will be on disk: the tree is shallow, but it is still many gigabytes big so the *tree* cannot fit in memory
    - Even if memory holds the first 25 nodes on our path, we still need 30 disk accesses

Note about numbers; moral

- All the numbers in this lecture are “ballpark” “back of the envelope” figures

- Even if they are off by, say, a factor of 5, the moral is the same: If your data structure is mostly on disk, you want to minimize disk accesses

- A better data structure in this setting would exploit the block size to avoid disk accesses…