CSE 373

OCTOBER 23RD – MEMORY AND HARDWARE
MEMORY ANALYSIS

• Similar to runtime analysis
MEMORY ANALYSIS

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  • Consider the worst case
MEMORY ANALYSIS

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  • Rather than counting the number of operations, we count the amount of memory needed
MEMORY ANALYSIS

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  • Rather than counting the number of operations, we count the amount of memory needed
  • During the operation, when does the algorithm need to “keep track” of the most number of things?
MEMORY ANALYSIS

- Breadth first search
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  • At what point does the Queue have the *most* amount stored in it?
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  • This is the memory we need to consider
  • At what point does the Queue have the most amount stored in it?
  • When the tree is at its widest – how many nodes is that?
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  • **N/2**: half the nodes of a tree are leaves
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MEMORY ANALYSIS

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  • AVL Insert? Yes, we need to keep track of the path from the insertion to the root
HARDWARE CONSTRAINTS

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  • This isn’t always true!
  • At any given time, some memory might be cheaper and easier to access than others
  • Memory can’t always be accessed easily
  • Sometimes the OS lies, and says an object is “in memory” when it’s actually on the disk
HARDWARE CONSTRAINTS

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  • Sometimes there isn’t enough available, and so memory that hasn’t been used in a while gets pushed to the disk
• Memory that is frequently accessed goes to the cache, which is even faster than RAM
The Memory Mountain

Pentium III Xeon
550 MHz
16 KB on-chip L1 d-cache
16 KB on-chip L1 i-cache
512 KB off-chip unified L2 cache

Slopes of Spatial Locality

Ridges of Temporal Locality

read throughput (MB/s)

stride (words)

working set size (bytes)

mem

L1

L2

s1, s3, s5, s7, s9, s11, s13, s15

8m, 2m, 512k, 128k, 32k, 8k, 2k
LOCALITY AND PAGES

• So, the OS does two smart things
  • Spatial locality – if you use memory index Ox371347AB, you are likely to need Ox371347AC – bring both into cache
  • These are called pages, and they are usually around 4kb
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  - Spatial locality – if you use memory index 0x371347AB, you are likely to need 0x371347AC – bring both into cache
  - These are called pages, and they are usually around 4kb
  - All of the processes on your computer have access to pages in memory.
LOCALITY AND PAGES

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  - So if you allocate 100Bytes of data, you overallocate to 4kb!
  - But you can use that 4kb if you need more
LOCALITY AND PAGES

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LOCALITY AND PAGES

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  • Memory recently accessed is likely to be accessed again
  • Bring recently used data into faster memory
• Types of memory (by speed)
  • Register
  • L1, L2, L3
  • Memory
  • Disk
  • The interwebs (the cloud)
LOCALITY AND PAGES

• The OS is always processing this information and deciding which is the best
  • This is why arrays are faster in practice, they are always next to each other in memory
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  • Each new node in a tree may not even be in the same page in memory!!
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  • This is why arrays are faster in practice, they are always next to each other in memory
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• Important to consider when designing and explaining design problems.
COST OF MEMORY ACCESSES

- Registers (128B): Instantaneous access
- L2 Cache (128KB): 0.5 nanoseconds
- L3 Cache (2MB): 7 nanoseconds
- Main Memory (32 GB): 100 nanoseconds
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PROCESS MEMORY

• How does an individual process use memory?
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• Many different demands
  • Global variables
  • Call stack
  • Allocated variables
  • Process code
PROCESS MEMORY

- **Stack**: Writable; not executable. Managed "automatically" (by compiler).
- **Dynamic Data (Heap)**: Writable; not executable. Managed by programmer.
- **Static Data**: Writable; not executable. Initialized when process starts.
- **Literals**: Read-only; not executable. Initialized when process starts.
- **Instructions**: Read-only; executable. Initialized when process starts.
PROCESS MEMORY

• These different demands are not next to each other in memory—little locality benefit
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• Each call to new allocates wherever there is space in the heap (memory allocator)
  • Even if two elements are created one after another, there is no guarantee that they’ll both be in the same page
  • This is especially true for java
  • How important is caching?
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  - This is much, much worse
LARGE AVL

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  • Between 0 and 50!
  • This is the difference between nanoseconds and almost half a second!
  • If lots data is stored on the disk, O(log n) finds don’t happen in practice
PROBLEMS

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PROBLEMS

• Why is AVL so bad on disk?
  • Each piece of data is its own node
  • Each call of `new` may not place objects next to each other
  • Has large height, for the number of elements?
SOLUTIONS

• What changes might we want to make to an AVL to make it better for disk?
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SOLUTIONS

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  • Still want to keep log n height
  • Allocate more objects closer together
  • Have a higher branching factor so that data you want is at a lower depth
  • Take advantage of page sizes