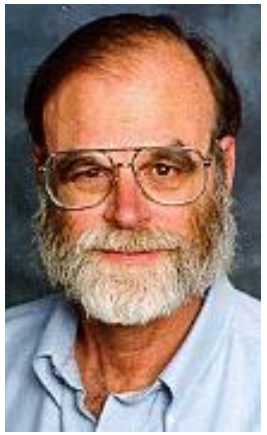
W13 - Virtual Memory (Part1)

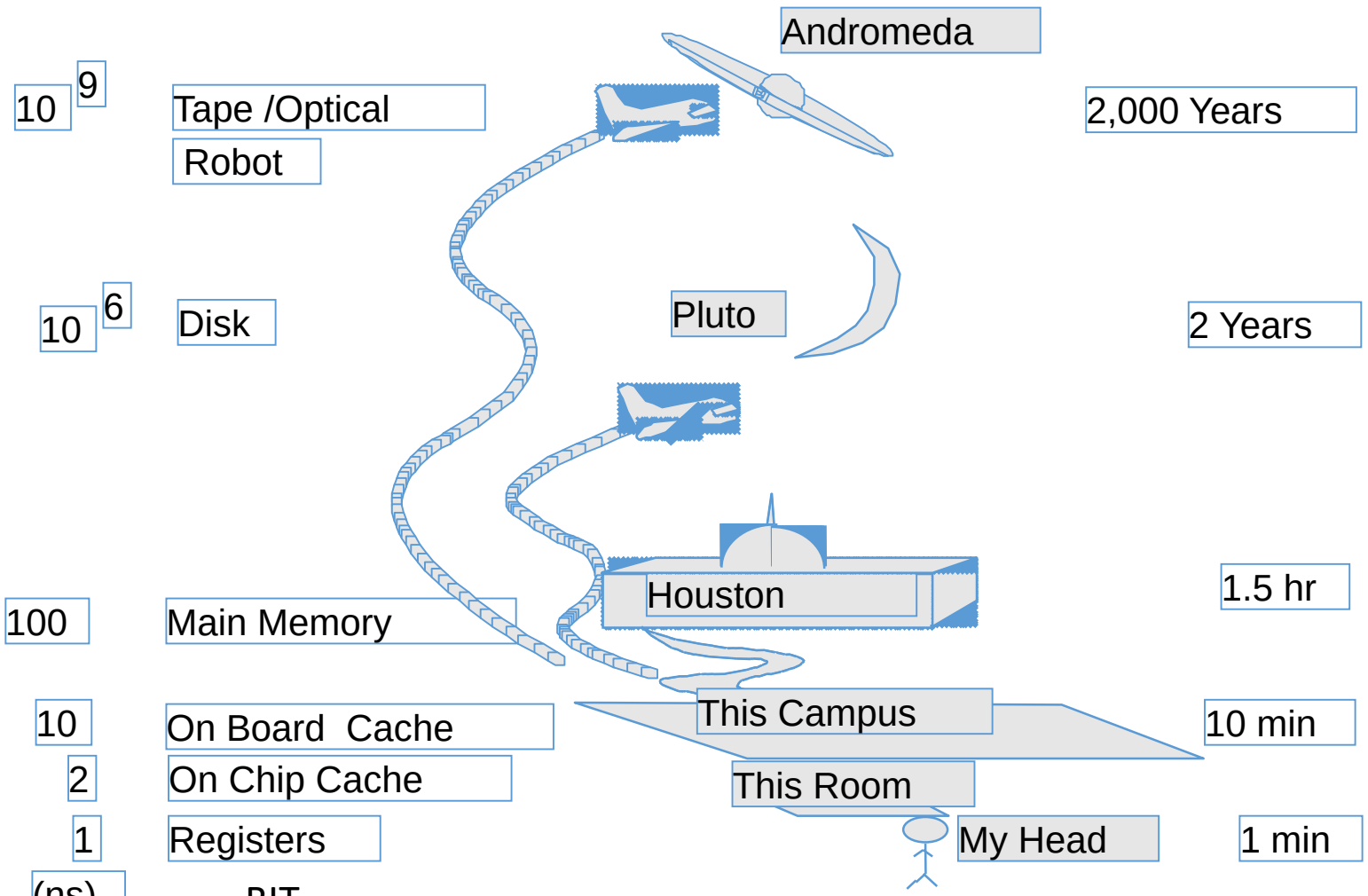
Acknowledgment

- The material for this topic is primarily assembled from four sources:
  - OSPP Textbook, Anderson and Dahlin, Chapter 8, http://ospp.cs.washington.edu/slides.html
  - Computer Systems: A Programmer's Perspective, 3/E, Bryant and O'Hallaron, Chapter 9, http://www.cs.cmu.edu/afs/cs/academic/class/15213-f15/www/schedule.html
  - High Performance Computer Architecture, Milos Prvulovic, http://www.cc.gatech.edu/~milos/Teaching/CS6290F07/
  - Select slide material of my presentation on Virtual Memory to Intel Colleagues, Jan 1995 (no link ☺)
- The slide material is attributed to the sources (templates). Minor changes to source slides are made where necessary for further explanation

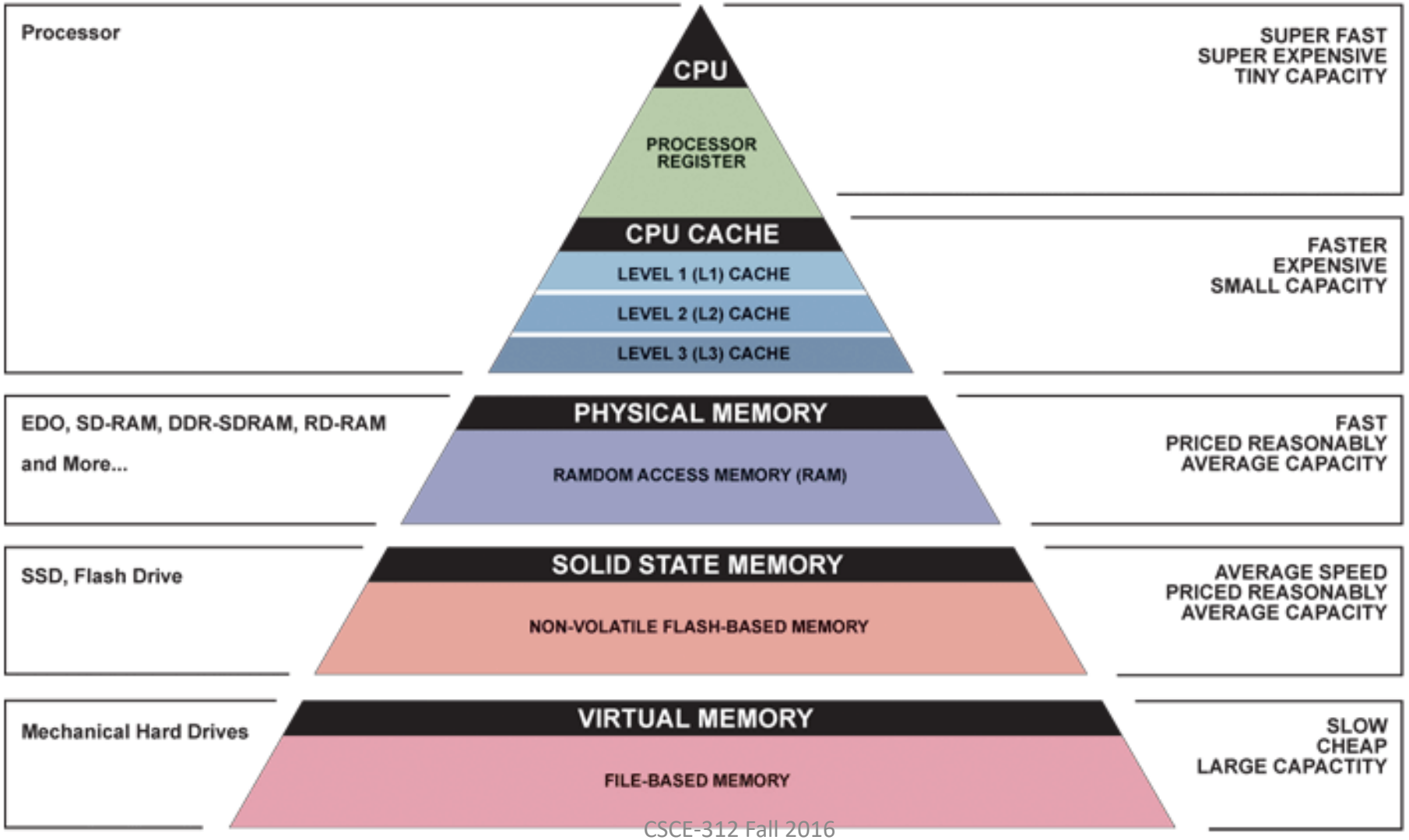
Jim Gray's Storage Latency Analogy: How Far Away is the Data?



Jim Gray
Turing Award



Memory Hierarchy – A case for Locality



Overall Perspective

- Imagine how much memory a 64-bit machine is capable of addressing
  - 'Yuuge' amount of 16 Exa-Bytes!! (1 EB is 2^60)
- Physical memory in most computing devices is of the order of few Giga-Bytes (2^30) at best
- Even the hard-drive (permanent) storage space on the best of computing devices is of the order of Tera-Bytes (2^40)
- Yet, each program (process) in most computer architectures is given complete flexibility to the entire address space!!
- This gives rise to a few interesting questions

- If my disk capacity is 1 TB (2^40) but the address space is 16 EB what happens to unused space?
- Who manages which process gets assigned where in memory?
- Who decides what goes in physical memory and what stays on the disk?
- Who decides how we make space in memory to bring in new content from disk?
- Etc.

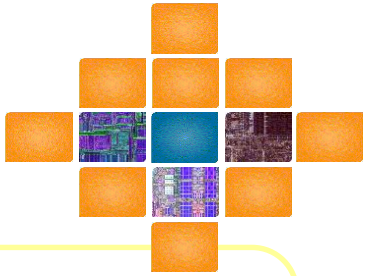
A Snippet from Windows-10 System Information

- We will de-mystify some of this information

Drive	C:
Description	Local Fixed Disk
Compressed	No
File System	NTFS
Size	217.44 GB (233,475,928,064 bytes)
Free Space	131.59 GB (141,290,381,312 bytes)
Volume Name	
Volume Serial ...	D65BA838

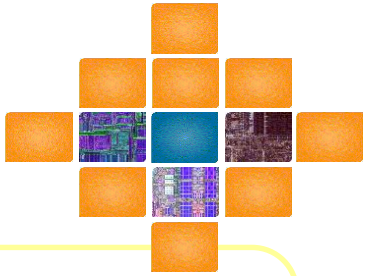
Installed Physical Memory (RAM)	8.00 GB
Total Physical Memory	7.89 GB
Available Physical Memory	3.02 GB
Total Virtual Memory	11.1 GB
Available Virtual Memory	3.13 GB
Page File Space	3.25 GB
Page File	C:\pagefile.sys

Views of Memory



- Real machines have limited amounts of memory
  - 640KB? A few GB?
  - (This laptop = 8GB)
- Programmer doesn't want to be bothered
  - Do you think, "oh, this computer only has 128MB so I'll write my code this way…"
  - What happens if you run on a different machine?
- Virtual Memory
  - Programmer is given the illusion that he has entire address space afforded by the machine architecture to himself!

CPU (Processor) View



- At some point, the CPU is going to have to load-from/store-to memory… all it knows is the real, A.K.A. ***physical*** memory
  - … which unfortunately
    is often < 8GB
  - … almost never 8GB *per process*
  - … and is never 16EB *per process*
- *It is usually less than what programs can access*

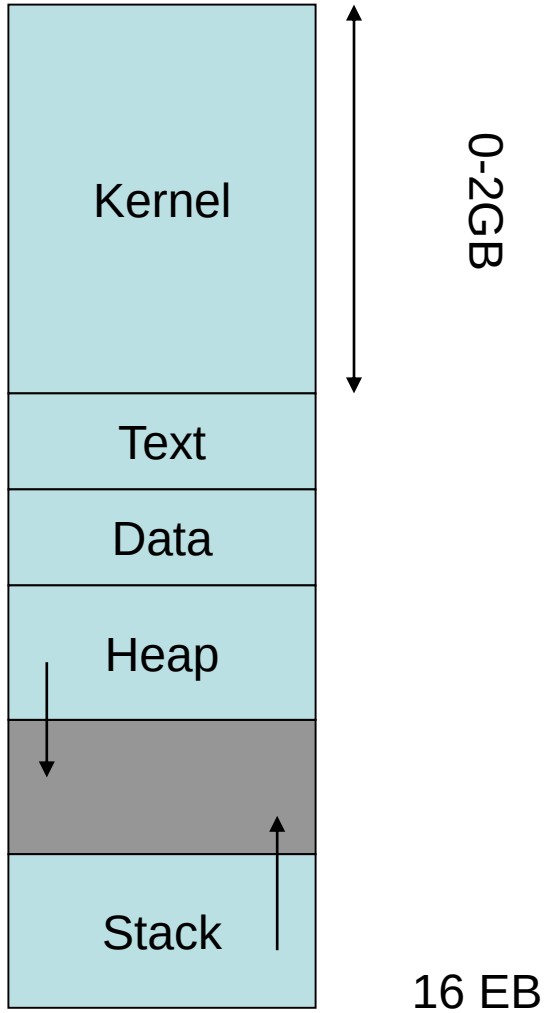
Addresses

  - *1:1 mapping to bytes/words in physical memory*

Programmer's View

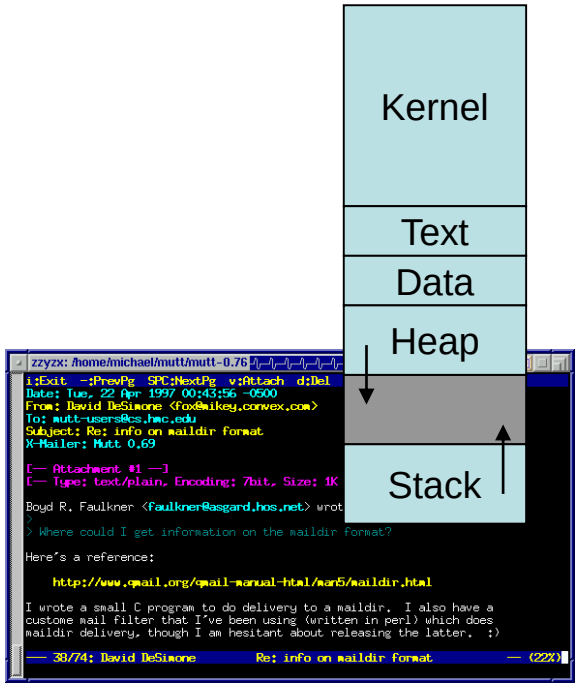
- Example 64-bit memory
  - When programming, you don't care about how much *real* memory there is
  - Even if you use a lot, memory can always be pushed to the disk

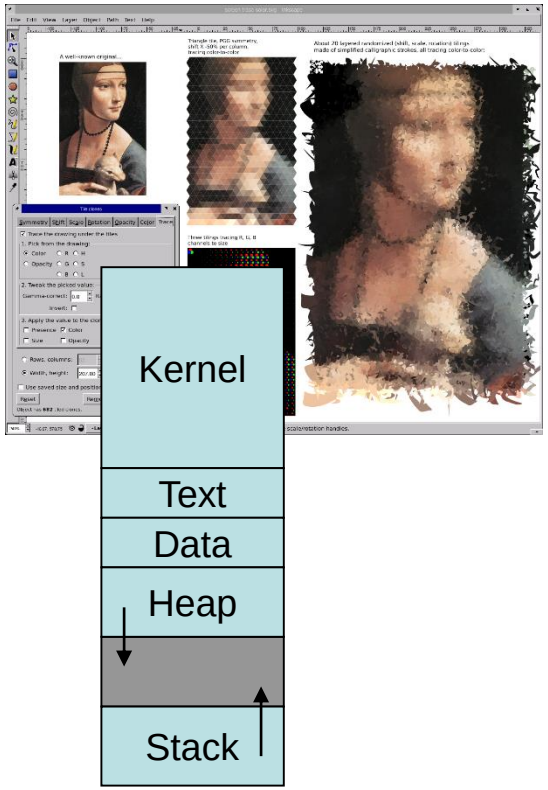
AKA Virtual Addresses

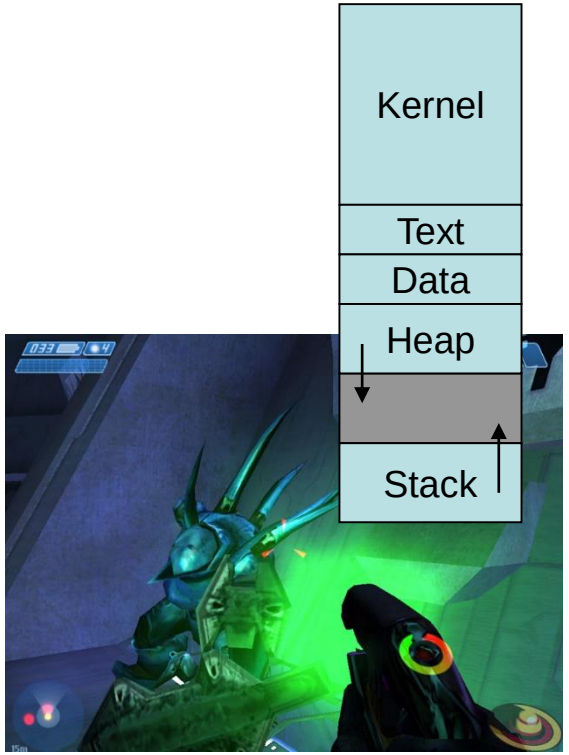


Programmer's View

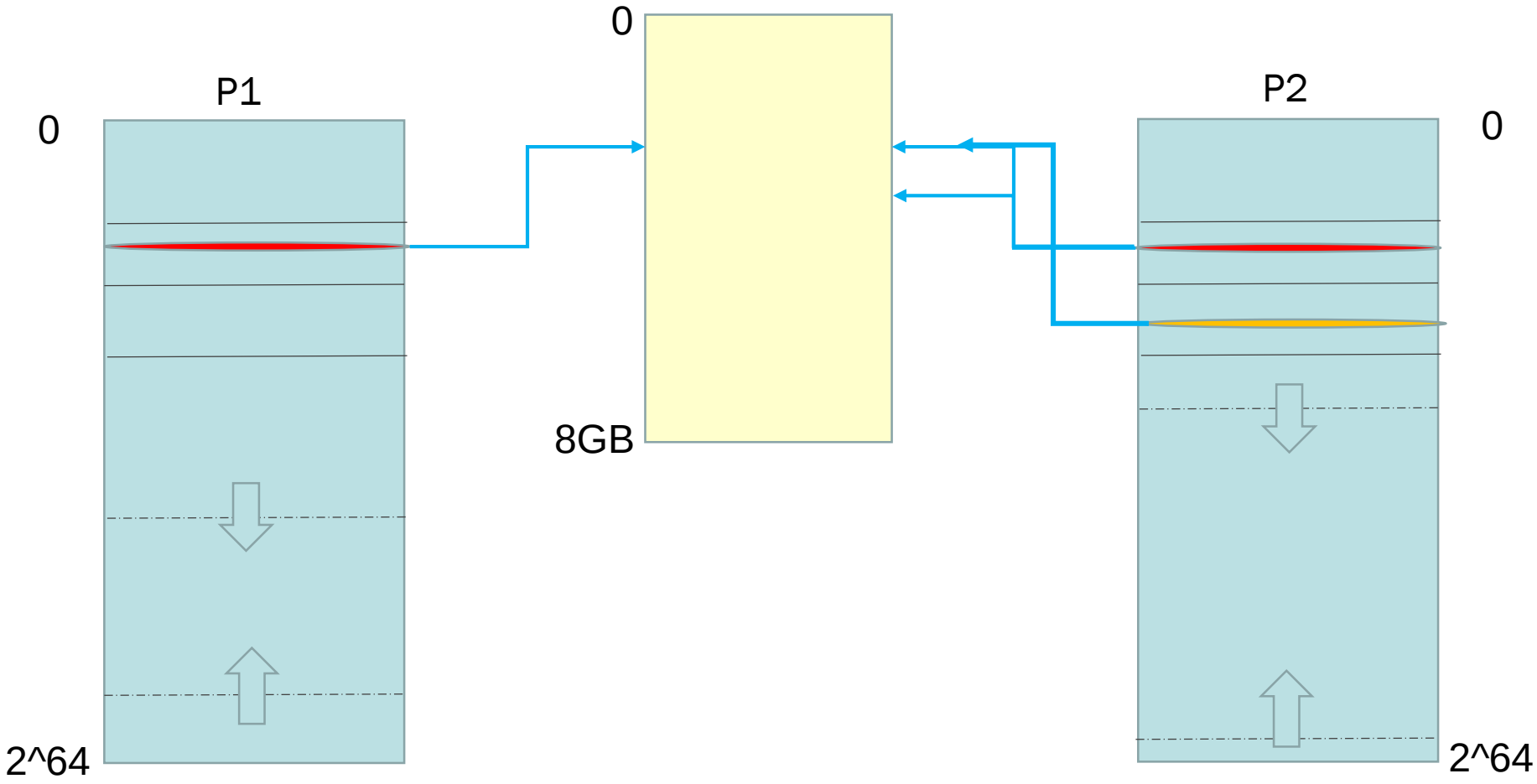
- Really "Program's View"
- Each program/process gets its own 16 EB space!!





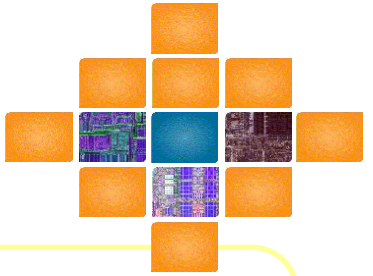


Virtual Memory (Program's View)



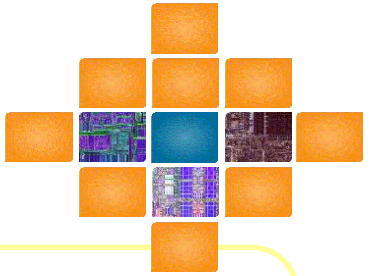
- How do we reconcile the various possibilities of mapping shown above?

Virtual Memory Quiz

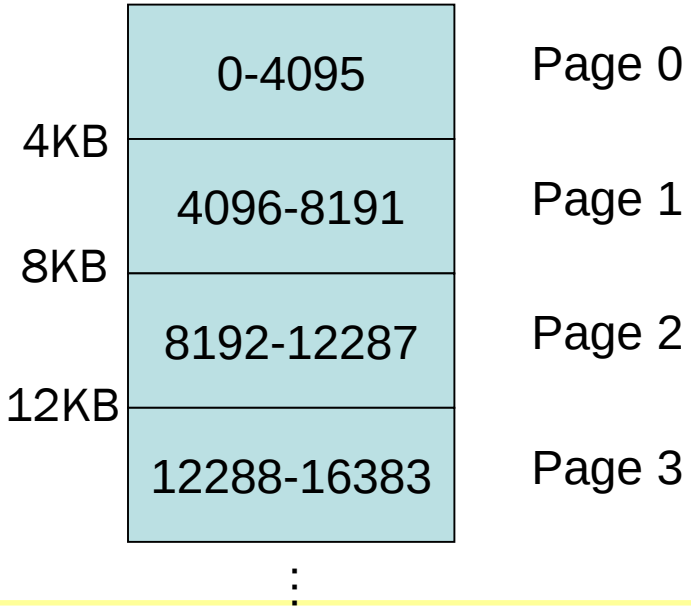


- A computer has 16 active applications each with a 32-Bit address space (4GB). What does the system actually have? Mark all correct answers:
  - Two 2GB memory modules
  - Four 4GB memory modules
  - Eight 8GB memory modules
  - One 2GB memory module

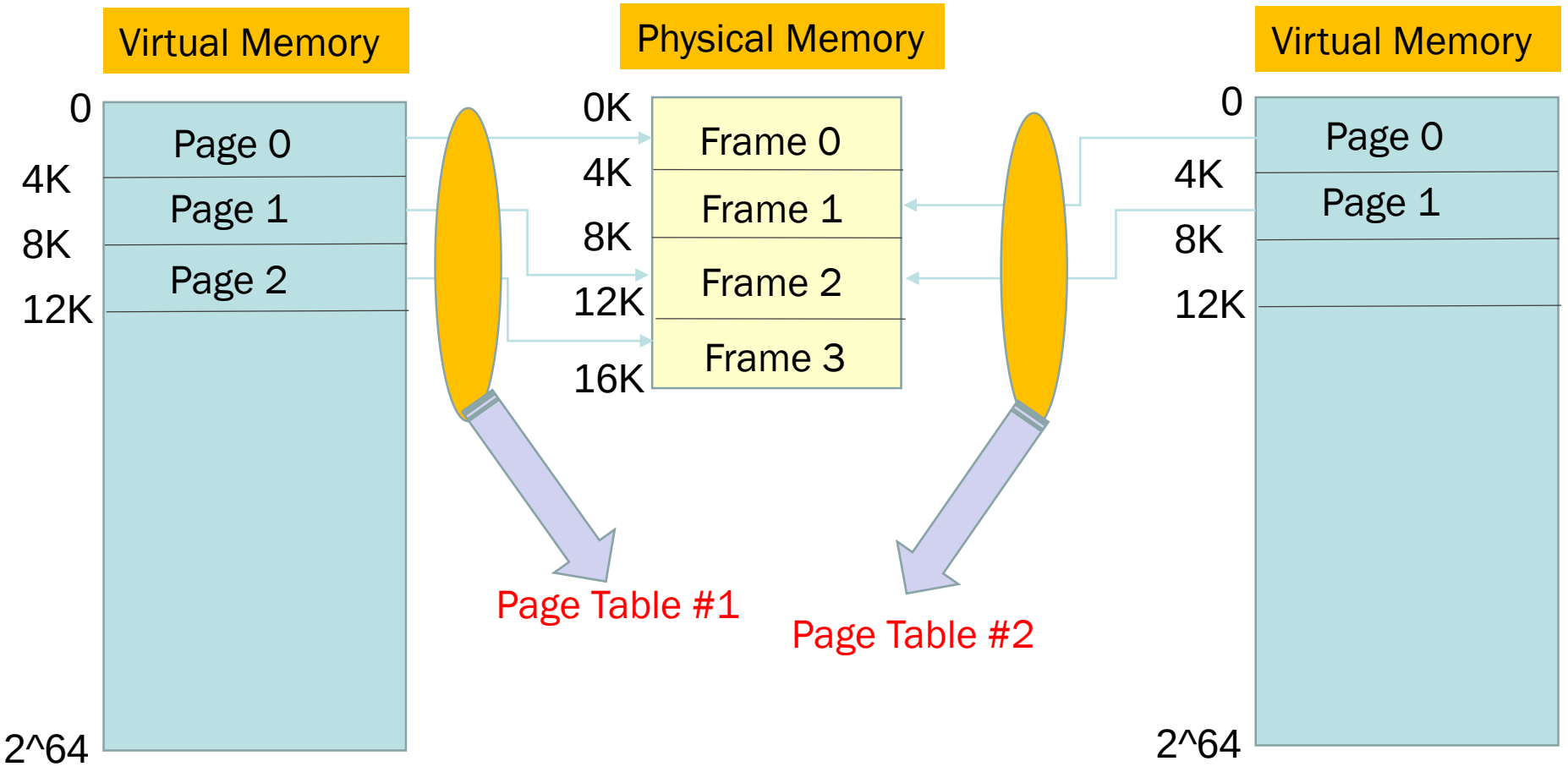
Pages



- Virtual Memory is divided into *pages*, which are nothing more than fixed sized and aligned regions of memory
  - Typical size: 4KB/page (but not always)
  - Pages on disk (akin to Memory Block) become Frames (akin to Cache Line) in memory

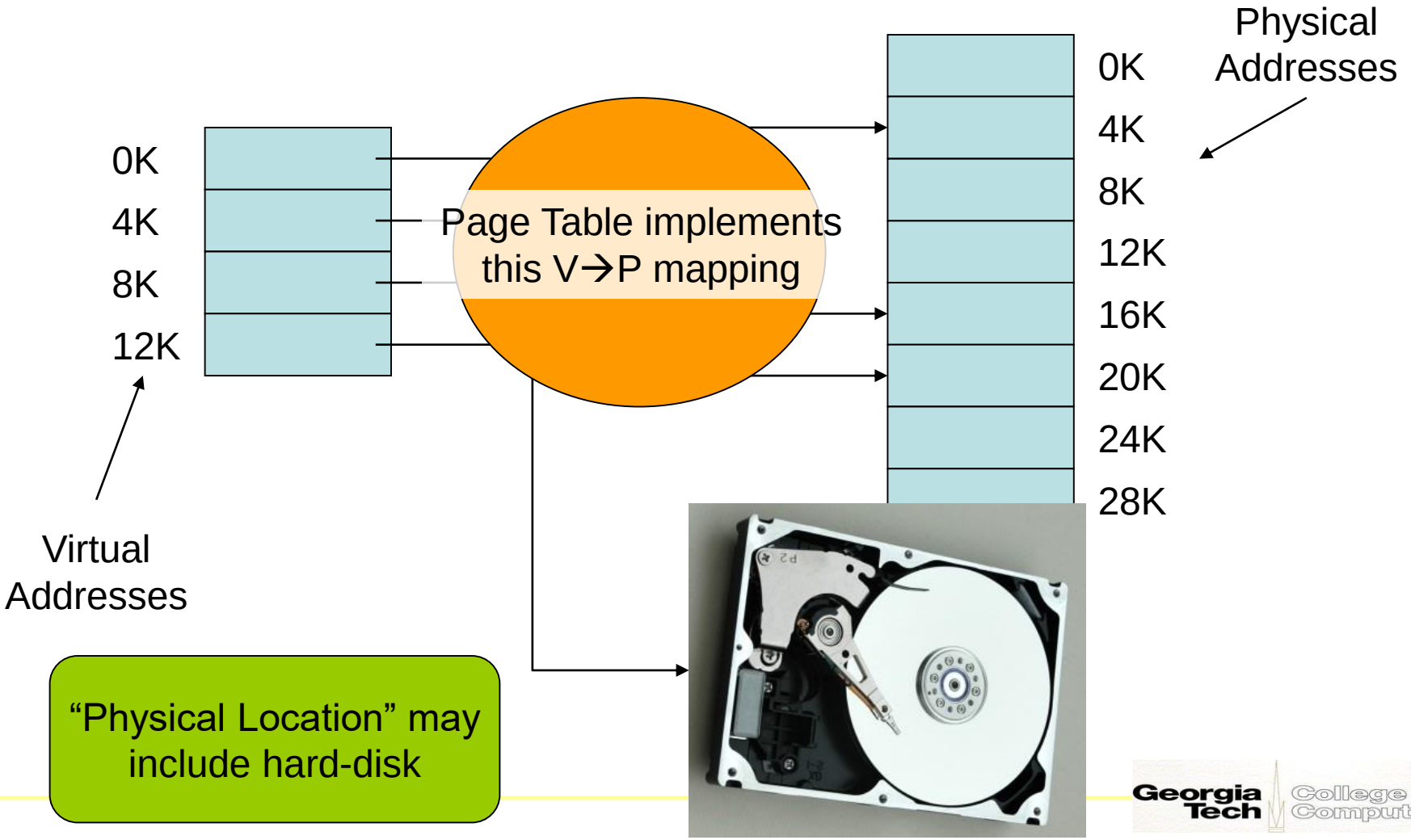


Mapping Virtual → Physical Memory

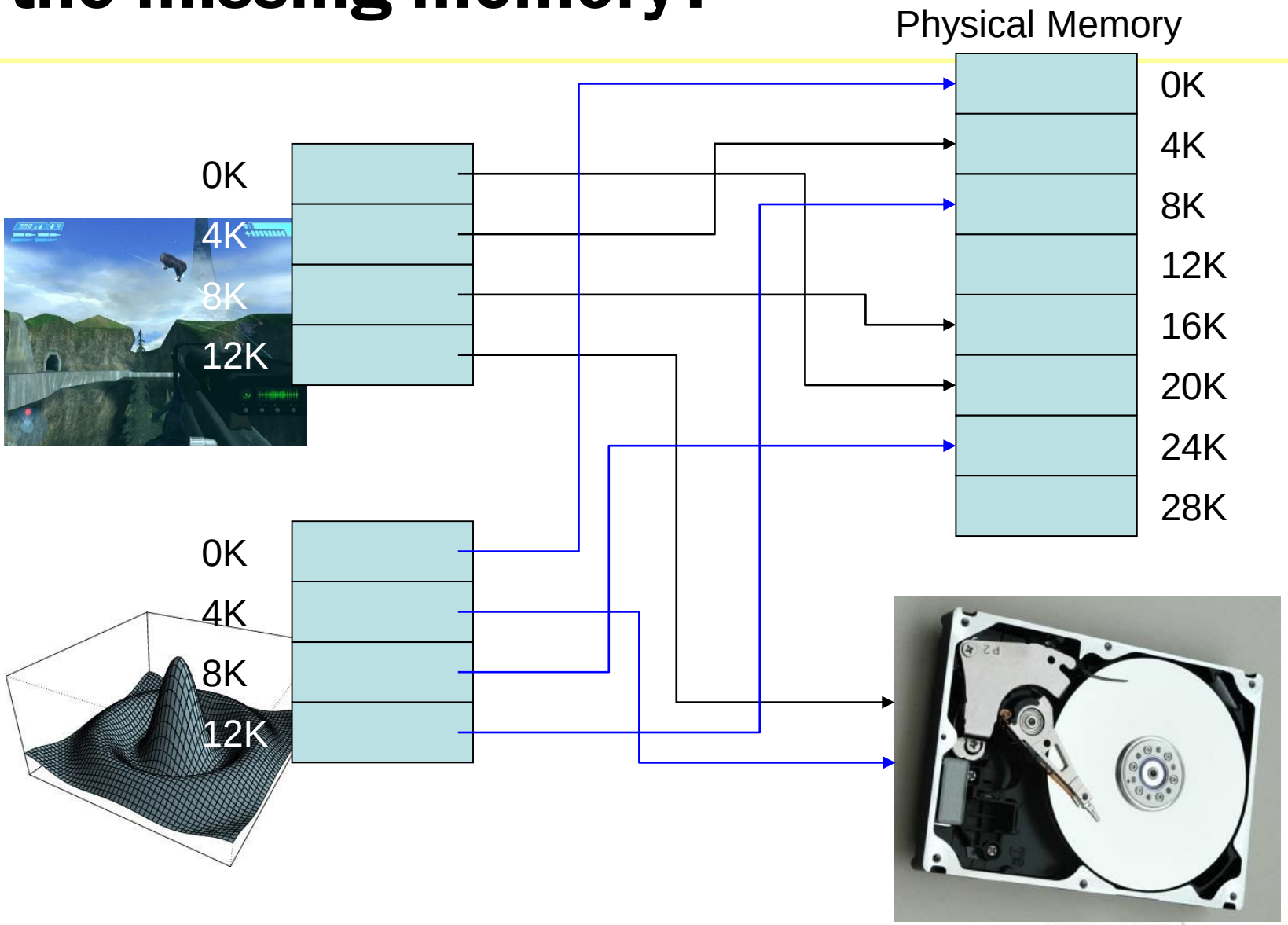


Page Table

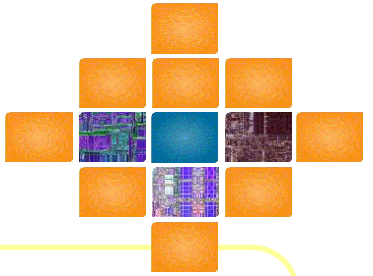
- Map from virtual addresses to physical locations



Where is the missing memory?

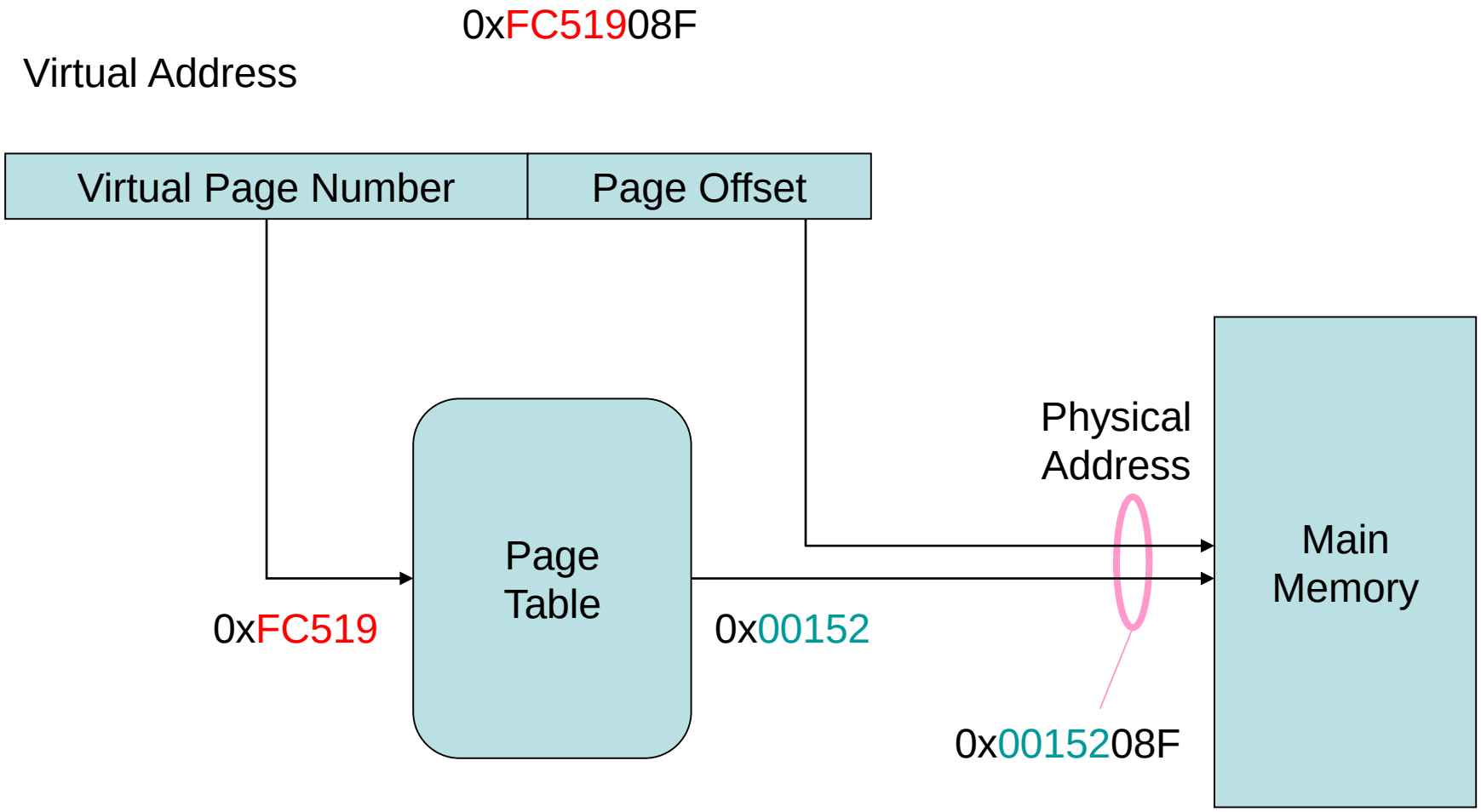


Page Size Quiz

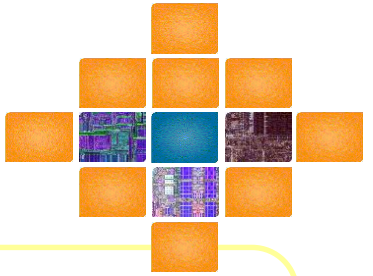


- Physical Memory is 2GB
- Virtual Memory is 4GB
- Page Size is 4KB
  - Question 1: How many page frames are there?
  - Question 2: How many entries are there in each page table?

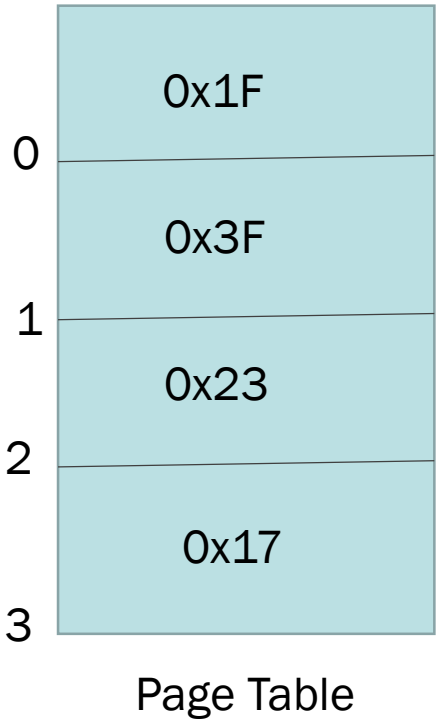
Need for Translation (Virtual to Physical)



Address Translation Quiz



- Suppose we have a process with only 4 page table entries
- 20-Bit physical address space
- 16-Bit virtual address space



Page Table

What are the translated physical addresses from the following virtual addresses:

0xF0F0

0x001F

What's Next?

- ❑ The enormity of single-level page table for today's 64-bit machines! Practical considerations and solutions
- ❑Choosing Page Sizes
- ❑Timing of Page Hits and Page Faults and what can be done to improve access times
- ❑Handling Page Faults
- ❑Virtual Memory as a tool for Memory Management and Protection

Template