Announcements/Reminders

- Lab 3 due today
- Exam 2 is 1 week from Friday
- Lab 4, HW 4 solutions and HW 5 are available from the web page

Quiz

Who Said: "Operating Systems are Destined to be Free"?

What did he mean?

What was he arguing for?

Quiz

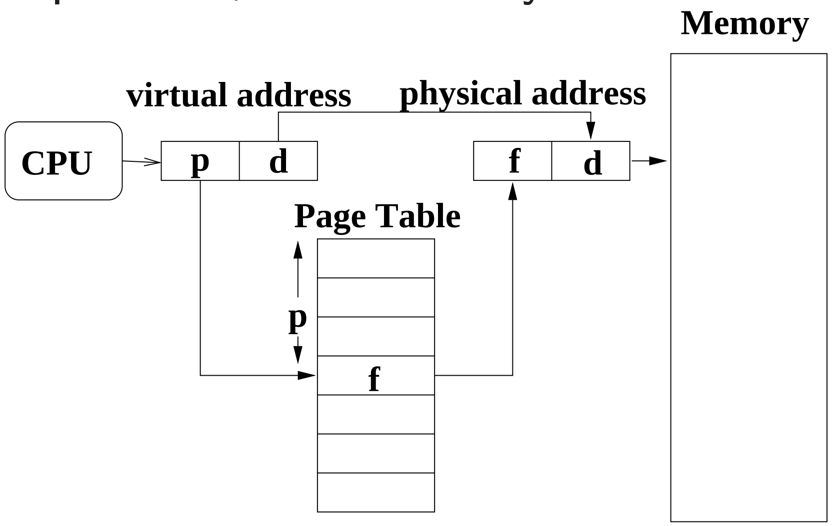
Who Said: “Operating Systems are Destined to be Free”?

Neal Stephenson in: “In the Beginning was the Command Line.”

also wrote: Snow Crash and Cryptonomicon

So Far: Paging

- Process generates virtual addresses from 0 to Max.
- OS divides the process onto pages; manages a page table for every process; and manages the pages in memory.
- Hardware maps from virtual addresses to physical addresses.
- Sharing of pages is possible, but not very useful as implemented. Why?



Today: Segmentation

Segments take the user's view of the program.

- User views the program in logical *segments*, e.g., code, global variables, stack, heap (dynamic data structures), not a single linear array of bytes.
- New idea: the compiler generates references that identify the segment and the offset in the segment, e.g., a code segment with offset = 399
- Thus processes use virtual addresses that include both the segment and segment offset.

⇒ Segments make it easier for the call stack and heap to grow dynamically. Why?

⇒ Segments make both sharing and protection easier. Why?

Today: Segmentation

⇒ Segments make it easier for the call stack and heap to grow dynamically. Why?

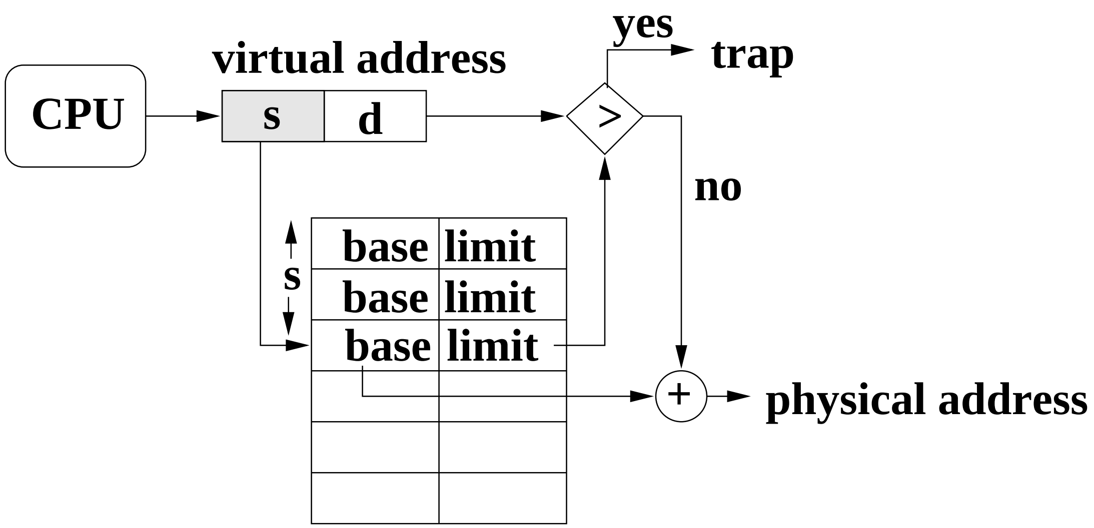
- Without segmentation, the stack and the heap grow toward each other.
- With segmentation, each segment is managed separately, so if the stack or the heap grows, the OS can increase the segment size.

⇒ Segments make both sharing and protection easier. Why?

- The OS manages these logical units separately (instead of managing a fixed-size page).

Implementing Segmentation

- Segment table: each entry contains a base address in memory, length of segment, and protection information (can this segment be shared, read, modified, etc.).
- Hardware support: multiple base/limit registers.
- How is this different than a TLB?



Implementing Segmentation

- Compiler needs to generate virtual addresses whose higher-order bits are a segment number.
- Segmentation can be combined with a dynamic or static relocation system,
  - Each segment is allocated a contiguous piece of physical memory.
  - External fragmentation can be a problem again
- Similar memory mapping algorithm as paging. We need something like the TLB if programs can have lots of segments

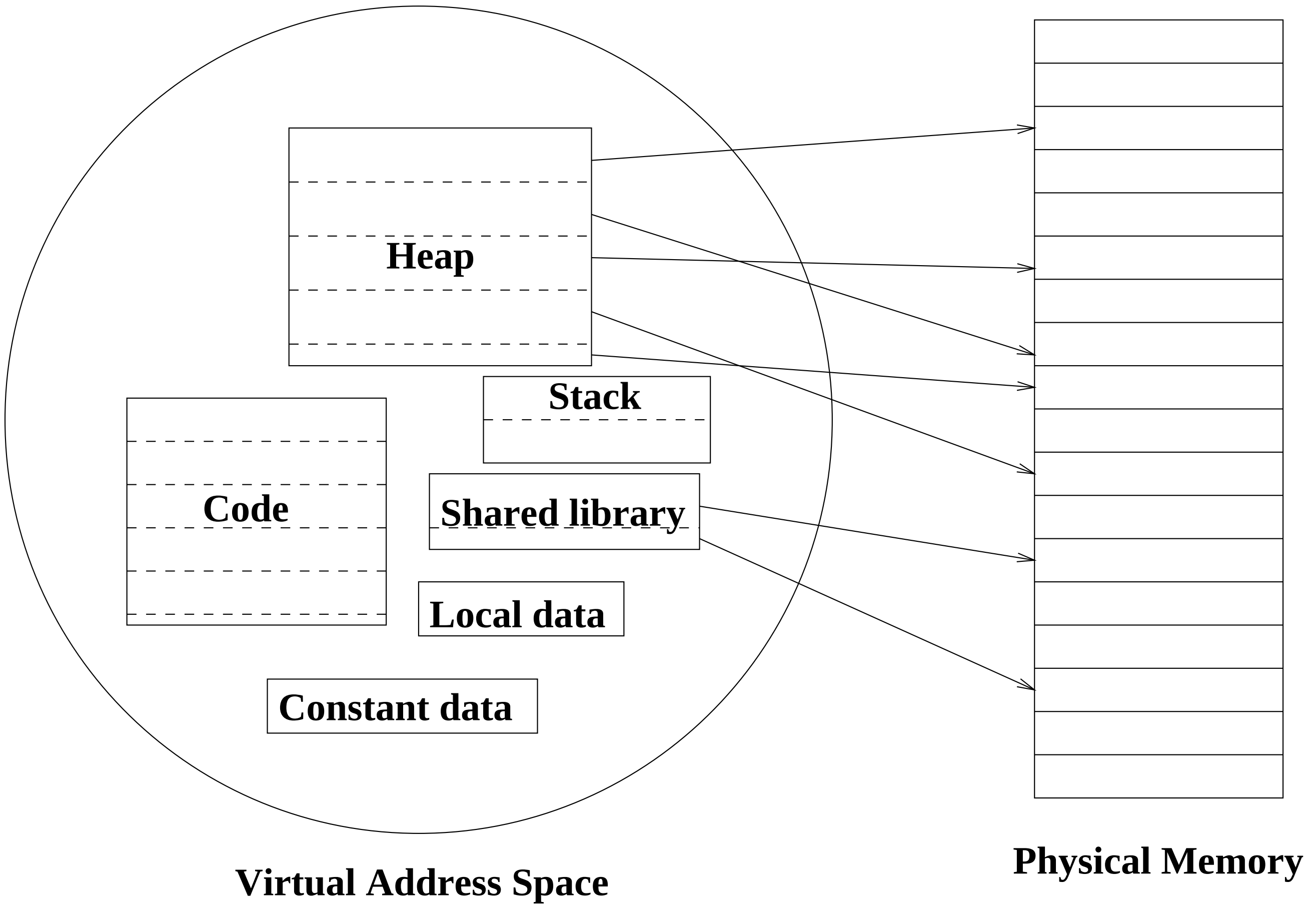
Let's combine the ease of sharing we get from segments with efficient memory utilization we get from pages.

Combining Segments and Paging

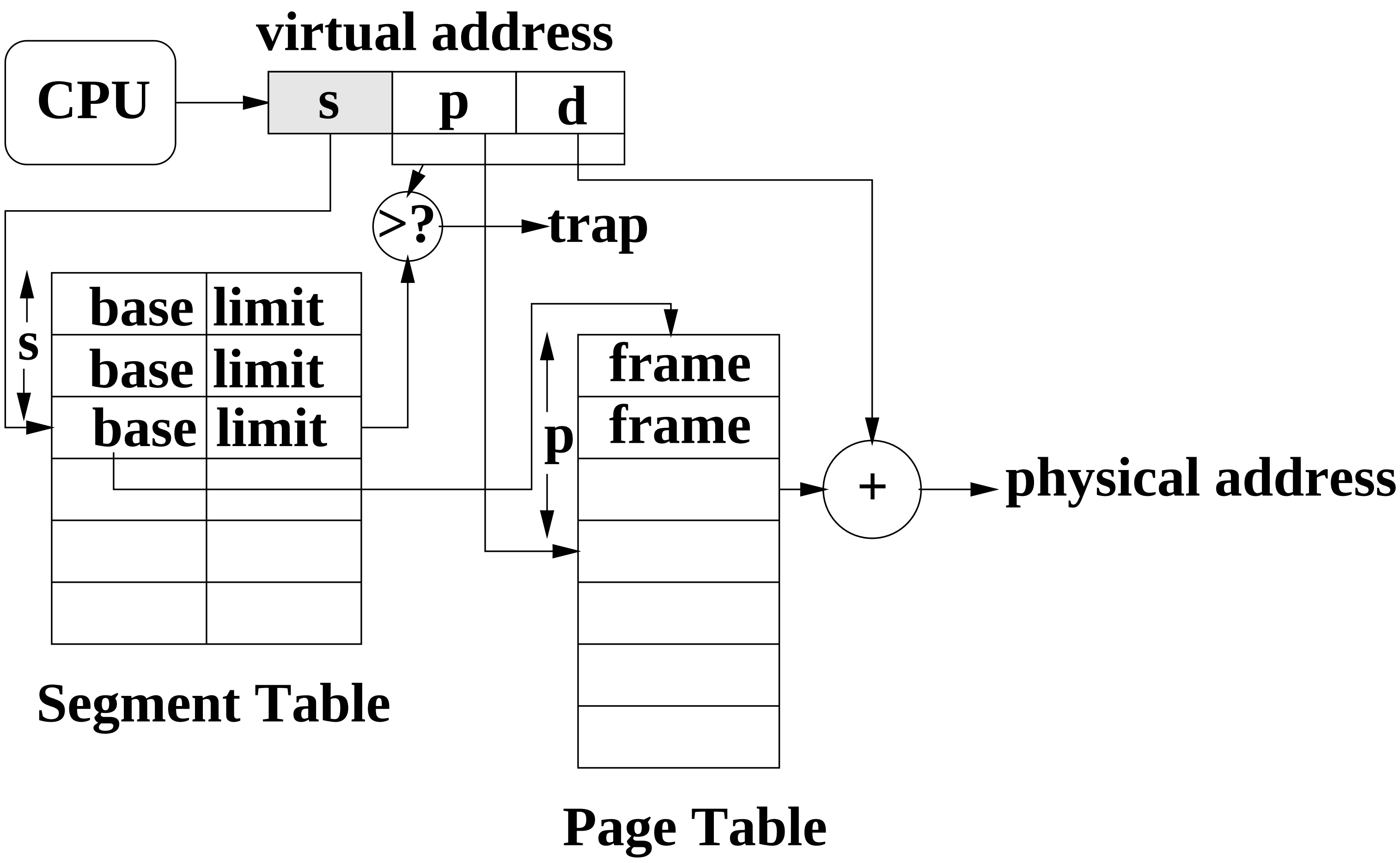
- Treat virtual address space as a collection of segments (logical units) of arbitrary sizes.
- Treat physical memory as a sequence of fixed size page frames.
- Segments are typically larger than page frames,

$\Rightarrow$ Map a logical segment onto multiple page frames by paging the segments

Combining Segments and Paging



Addresses in a Segmented Paging System



Addresses in a Segmented Paging System

- A virtual address becomes a segment number, a page within that segment, and an offset within the page.
- The segment number indexes into the segment table which yields the base address of the page table for that segment.
- Check the remainder of the address (page number and offset) against the limit of the segment.
- Use the page number to index the page table. The entry is the frame. (The rest of this is just like paging.)
- Add the frame and the offset to get the physical address.

Addresses in a Segmented Paging System: Example

- Given a memory size of 256 addressable words,
- a page table indexing 8 pages,
- a page size of 32 words, and
- 8 logical segments

1. How many bits is a physical address?
2. How many bits for the segment number, page table, and offset?
3. How many bits is a virtual address?
4. How many segment table entries do we need?

Addresses in a Segmented Paging System: Example

- Given a memory size of 256 addressable words,
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1. How many bits is a physical address? 8 bits
2. How many bits for the segment number, page table, and offset? 3 3 5
3. How many bits is a virtual address? 11 bits
4. How many segment table entries do we need? 8

Sharing Pages and Segments

- Share individual pages by copying page table entries.
- Share whole segments by sharing segment table entries, which is the same as sharing the page table for that segment.
- Need protection bits to specify and enforce read/write permission.
  - When would segments containing code be shared?
  - When would segments containing data be shared?

Sharing Pages and Segments

- When would segments containing code be shared?
  - Read-only sharing of common applications or common libraries.

- When would segments containing data be shared?
  - Read-only sharing of constant data used by an application.
  - Read-write sharing of heap data used by multiple threads within a process.

Sharing Pages and Segments: Implementation Issues

- Where are the segment table and page tables stored?
  1. Store segment tables in a small number of associative registers; page tables are in main memory with a TLB
     (faster but limits the number of segments a program can have)
  2. Both the segment tables and page tables can be in main memory with the segment index and page index combined & used in the TLB lookup
     (slower but no restrictions on the number of segments per program)

- Protection and valid bits can go either on the segment or the page table entries

- **Note:** Just like recursion, we can do multiple levels of paging and segmentation when the tables get too big.

Segmented Paging: Costs and Benefits

- **Benefits:** faster process start times, faster process growth, memory sharing between processes.
- **Costs:** somewhat slower context switches, slower address translation.
- Pure paging system $\Rightarrow$(virtual address space)/(page size) entries in page table. How many entries in a segmented paging system?
- What is the performance of address translation of segmented paging compared to contiguous allocation with relocation? Compared to pure paging?
- How does fragmentation of segmented paging compare with contiguous allocation? With pure paging?

Segmented Paging: Costs and Benefits

- How many entries in a segmented paging system?

  There are as many page tables as there are segments. The total number of page table entries for a process is $<=$ the number required in a pure paging scheme.

- What is the performance of address translation of segmented paging compared to contiguous allocation with relocation? Compared to pure paging?

  - Slower than contiguous allocation since need to index through segment table AND page table. If TLB miss, much slower.
  - Slower than pure paging because index through segment table. But: normally done in hardware, so not a big problem

Segmented Paging: Costs and Benefits

- How does fragmentation of segmented paging compare with contiguous allocation? With pure paging?
  - No external fragmentation, so no need for compaction.
  - Internal fragmentation: 1/2 page per segment on average, so worse than pure paging.

Putting it All Together: A Historical View

- **Relocation** using Base and Limit registers
  - simple, but inflexible
- **Segmentation:**
  - compiler's view presented to OS
  - segment tables tend to be small
  - memory allocation is expensive and complicated (first fit, worst fit, best fit).
  - compaction is needed to resolve external fragmentation.

Putting it all together

- **Paging:**
  - simplifies memory allocation since any page can be allocated to any frame
  - page tables can be very large (especially when virtual address space is large and pages are small)

- **Segmentation & Paging**
  - only need to allocate as many page table entries as we need (large virtual address spaces are not a problem).
  - easy memory allocation, any frame can be used
  - sharing at either the page or segment level
  - increased internal fragmentation over paging
  - two lookups per memory reference

Next Time

- Friday: Exam Review and start Virtual Memory
- Wednesday: Discussion (hw 3/4 and Memory Management)
- Next Friday: Exam 2
- Following Monday: Virtual Memory and Demand Paging (Chapter 10)