Slide 1

Administrivia

- Reminders:
  - Homework 2 final deadline class time today. Turn in at end of class, pick up sample solution. Programs on Web later today.
  - Homework 3 due today by 5pm. Solutions available tomorrow.
  - Review session Wednesday at 5pm (tentative — will confirm by e-mail after 11:20am section).

Slide 2

Minute Essay From Last Lecture

- What if anything did you find difficult about the programming part of the homework? What if anything did you find interesting/useful about it?

  Almost half mentioned rusty programming skills.

  The point of the first problem (together with the first written question) was to provide some exposure to system calls in a real-world context. (Also you probably have a different view now of `bash`?)

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Slide 3

Multiprogramming with Fixed/Variable Partitions — Recap

- Comparing the two schemes:
  - Both based on idea that each process's memory is one contiguous block — simple, works well with the simple base/limit MMU described earlier.
  - Admissions scheduling required with fixed partitions, probably a good idea with variable partitions.
  - Complexity versus flexibility, memory use.
- Either could be adequate for a simple batch system.
- But . . .
  - Can we somehow have more jobs/processes "in the system" than we have memory for? Could be useful if processes sometimes wait a long time.
  - Can we do something so processes can acquire more memory memory as they run?

Slide 4

Aside — Memory Management Within Processes

- What if we don't know before the program starts how much memory it will want? with very old languages, maybe not an issue, but with more modern ones it is.

  I.e., we might want to manage memory within a process's address space.
- Typical scheme involves
  - Fixed-size allocation for code and perhaps static data.
  - Two variable-size pieces ("heap" and "stack") for dynamically allocated data.

Slide 5

Swapping

- Idea — move processes into / out of main memory (when not in main memory, save on disk).

  (Aside — can we run a program directly from disk?)
- Addresses both questions from previous slide; could also provide a way to "fix" fragmentation.
- Implies another level of scheduling (what to swap in/out).
- Makes non-dynamic solutions to relocation problem unfeasible; MMU-based solution still works, though, and for memory protection.
- Consider tradeoffs again — complexity versus flexibility, efficient use of memory.

Slide 6

Simple Memory Management — Recap

- Contiguous-allocation schemes are simple to understand, implement.
- But they're not very flexible — process's memory must be contiguous, swapping is all-or-nothing.
- Can we do better? yes, by relaxing one or both of those requirements — "paging".

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Paging

- Idea — divide both address spaces and memory into fixed-size blocks ("pages" and "page frames"), allow non-contiguous allocation.
- Consider tradeoffs yet again — complexity versus flexibility, efficient use of memory.

Slide 8

Paging — Mapping Program to Physical Addresses

- One consequence — mapping from program addresses to physical addresses is much more complicated.
- How? "page table" for each process maps pages of address space to page frames; use this to calculate physical address from program address.

  (Are there page sizes for which this is easier?)
- As with base/limit scheme, makes more sense to implement this in MMU. (Notice again interaction between hardware design and o/s design.)
- Could let page table size vary, but easier to make them all the same (i.e., each process has the same size address space), have a bit to indicate valid/invalid for each entry. Attempt to access page with invalid bit — "page fault".

Paging and Memory Protection, Page Sizes

- This scheme also provides memory protection. (How?)
- We could also use it to allow processes to share memory. (How?)
- How big to make pages? compare extreme cases (really big, really small).

Slide 9

Paging and Virtual Memory

- Idea — extend this scheme to provide “virtual memory” — keep some pages on disk. Allows us to pretend we have more memory than we really do.
- Compare to swapping.

Slide 10

Paging — Recap

- Recall idea — divide address space and physical memory into fixed-size blocks. Details follow from this basic idea. More complex, but more flexible.
- Things to look at more:
  - Getting acceptable performance.
  - Dealing with large address spaces.
  - Details of using this idea to provide virtual memory.

Slide 11

Performance / Large Address Spaces

- Even with good choice of page size, serious performance implications — page table can still be big, and every memory reference involves page-table access — how to make this feasible/fast?
- Consider several options — compare access time, cost, context-switch time:
  - Keep page table for current process in registers.
  - Keep whole page table in main memory, pointed to by special register.
  - Use multilevel page tables. (More about this later.)
  - Use inverted page tables (one entry per page frame). (More about this later.)
- If page tables are in memory, performance improves with “translation lookaside buffer” (TLB) — special-purpose cache.

Slide 12

Minute Essay

- Reminder — turn in homework.
- Given a page size of 64K (2^{16}), 64-bit addresses, and 4G (2^{32}) of main memory, at least how much space is required for a page table?