Announcements

- **Project #4**
  - Should have all of the virtual -> mapping working this week
  - Should have the user program running from 0x8000 0000 by early next week

- **Reading Chapter 12**
FIFO Example (3 frames)

- Reference string: 1,2,3,4,1,2,5,1,2,3,4,5
  - access 1 - (1) fault
  - access 2 - (1,2) fault
  - access 3 - (1,2,3) fault
  - access 4 - (2,3,4) fault, replacement
  - access 1 - (3,4,1) fault, replacement
  - access 2 - (4,1,2) fault, replacement
  - access 5 - (1,2,5) fault, replacement
  - access 1 - (1,2,5)
  - access 2 - (1,2,5)
  - access 3 - (2,5,3) fault, replacement
  - access 4 - (5,3,4) fault, replacement
  - access 5 - (5,3,4)

- 9 page faults
FIFO Example (4 frames)

- Reference string: 1,2,3,4,1,2,5,1,2,3,4,5
  - access 1 - (1) fault
  - access 2 - (1,2) fault
  - access 3- (1,2,3) fault
  - access 4 - (1,2,3,4) fault, replacement
  - access 1 - (1,2,3,4)
  - access 2 - (1,2,3,4)
  - access 5 - (2,3,4,5) fault, replacement
  - access 1 - (3,4,5,1) fault, replacement
  - access 2 - (4,5,1,2) fault, replacement
  - access 3 - (5,1,2,3) fault, replacement
  - access 4 - (1,2,3,4) fault, replacement
  - access 5 - (2,3,4,5) fault, replacement
- 10 Page faults
Thrashing

- **Virtual memory is not “free”**
  - can allocate so much virtual memory that the system spends all its time getting pages
  - the situation is called thrashing
  - need to select one or more processes to swap out

- **Swapping**
  - write all of the memory of a process out to disk
  - don’t run the process for a period of time
  - part of medium term scheduling

- **How do we know when we are thrashing?**
  - check CPU utilization?
  - check paging rate?
  - Answer: need to look at both
    - low CPU utilization plus high paging rate --> thrashing
Working Sets and Page Replacement

- Programs usually display reference locality
  - temporal locality
    - repeated access to the same memory location
  - spatial locality
    - consecutive memory locations access nearby memory locations
  - memory hierarchy design relies heavily on locality reference
    - sequence of nested storage media

- Working set
  - set of pages referenced in the last delta references

![Diagram showing Working Set Size vs. Memory Access Speed]

**Small**
- Very Fast

**Large**
- Very Slow
Preventing Thrashing

- Need to ensure that we can keep the working set in memory
  - if the working sets of the processes in memory exceed total page frames, then we need to swap a process out
- How do we compute the working set?
  - can approximate it using a reference bit
Improving Heap Locality

- **Malloc (or new) don’t ensure locality among requests**
  - Two calls to malloc could get memory on different cache lines, pages, etc.

- **Option 1:**
  - Malloc a large chunk of memory and parcel it out yourself

- **Option 2:**
  - Add a “near” hint parameter to malloc
  - Indicates that memory should be allocated near the target location
    - It’s only a performance hint, and malloc can ignore it
    - Allows locality improvement without major changes
Implementation Issues

- **How big should a page be?**
  - want to trade cost of fault vs. fragmentation
    - cost of fault is: trap + seek + latency + transfer
  - Does the OS page size have to equal the HW page size?
    - no, just needs to be a multiple of it

- **How does I/O relate to paging**
  - if we request I/O for a process, need to lock the page
    - if not, the I/O device can overwrite the page

- **Can the kernel be paged?**
  - most of it can be.
  - what about the code for the page fault handler?
File Abstraction

- **What is a file?**
  - a named collection of information stored on secondary storage

- **Properties of a file**
  - non-volatile
  - can read, write, or update it
  - has metadata to describe attributes of the file

- **File Attributes**
  - name: a way to describe the file
  - type: some information about what is stored in the file
  - location: how to find the file on disk
  - size: number of bytes
  - protection: access control
    - may be different for read, write, execute, append, etc.
  - time: access, modification, creation
  - version: how many times has the file changed