Chapter 9
Virtual Memory

Images from Silberschatz
Virtual Memory

- Processes do not need to be completely in memory to execute
  - data
  - code
  - data set can be larger than physical memory

- Demand Paging
Process View

- Big Virtual Memory space
- Only allocated needed pages
- Empty pages are ignored

![Memory Space Diagram]

Empty Until Needed
Sharing Memory

- stack
- shared library
- heap
- data
- code
- stack
- shared library
- heap
- data
- code
- shared pages
Demand Paging

- Load pages as they are needed
  - lazy swapping (pager)
  - less I/O (up front)
  - less memory used at once
  - faster response
  - more processes fit into memory
  - mark pages as in memory or not (similar to valid/invalid)
New Page Table

logical memory

page table

valid-invalid bit

frame

physical memory
Hardware Support

- Accessing an out-of-memory page causes a page fault trap
- OS handles this and brings the page into memory
- Also must check for invalid address

- Pure Demand Paging
  - Locality of reference
- Page fault may occur anywhere in an instruction
  - may backup and rerun something
Page Fault!
Copy-on-Write

• When do processes share pages?

• Only copy (create a new page) when one process writes to a shared page
  – faster

• vfork()/exec()
Page Replacement

- Remove page from physical memory to make room
  - swap out a process/frame

- Two I/O operations
  - out then in
  - time consuming
  - page may still be on disk
  - dirty bit!
Algorithms

- Goal: Few page faults
- Frame Allocation

- Page Replacement
FIFO

- First In, First Out
- Ref String: 1, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5
- Belady's Anomaly:
  - more frames, more faults

```
1  1  4  5
2  2  1  3  9 page faults
3  3  2  4
________________
1  1  5  4
2  2  1  5  10 page faults
3  3  2
4  4  3
```
Optimal Replacement Algo

• “Replace the page that will not be used for the longest period of time”

• Problems with this?
Approximate Optimal

- **LRU**

- **LRU-Approximate**
  - reference bit
  - may be also FIFO (second chance)

- **LRU-Additional-Reference-Bits**
  - many (8?) bits

- **Enhanced Second Chance**
  - referenced, modified bits
Counting Algorithms

• Count references per page
  – rarely used in real world

• Least Frequently Used

• Most Frequently Used
Global vs Local

- Global replacement

- Local replacement
Thrashing

- Furiously swapping pages in and out
- Problems?

- CPU utilization is low, so OS adds more processes
  - more frames are used

- Poor data layout in your application