CSE 3221.3
Operating System Fundamentals

No. 10

Virtual Memory

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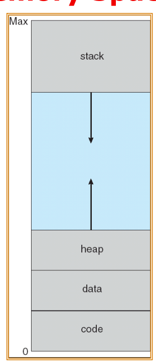
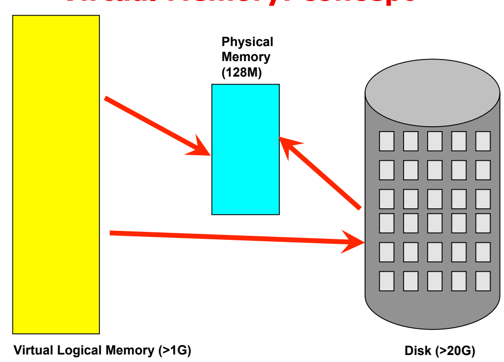
Background

- Memory-management methods normally requires the entire process to be in memory before the process can execute.
- Better not to load the whole process in memory for execution:
  - Programs often have code to handle unusual error conditions.
  - Arrays, lists, and tables are often allocated more memory than they actually need.
  - Certain options and features of a program may be used rarely.
  - Even all codes are needed, they may not all be needed at the same time.
- Our goal: partially load a process.
  - No longer be constrained by the amount of physical memory.
  - Each process takes less memory → CPU utilization and throughput up.
  - Less I/O to load program → run faster.
- Overlay and dynamic loading can ease the restriction, but require extra work from programmers.

Logical Memory Space (review)



Virtual Memory: concept



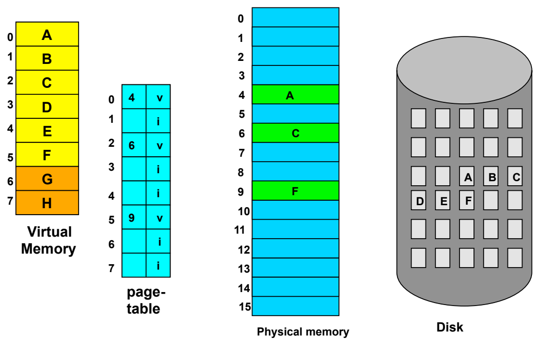
Virtual Memory

- **Virtual memory can be implemented via:**
  - **Demand paging**
  - **Demand segmentation**
    - **Hard since segments have variable size**

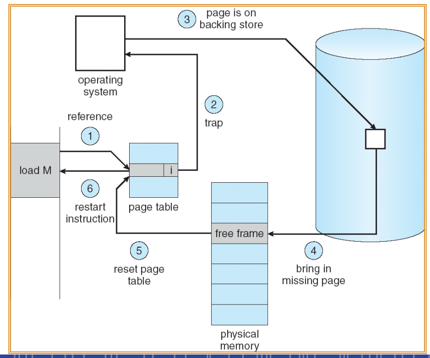
Demand Paging(1)

- **Demand paging:**
  - **A paging system with a lazy page swapper.**
  - **A lazy swapper: never swap a page into memory unless the page will be used.**
- **In demand paging:**
  - **When a process is executed,**
  - **The pager guess which pages are needed. (optional)**
  - **The pager brings only these necessary pages into memory. (optional)**
  - **When referring a page not in a memory, the pager bring it in as needed and possibly replace an old page when no more free space.**
- **Hardware support: to distinguish those pages in memory and those pages in disk.**
  - **Use valid-invalid bit.**

An example: Demand Paging



Handle a page fault



Handle a Page Fault

The interrupt service routine to handle page fault in virtual memory:

- Check an internal table to see if the reference was a valid or invalid memory access.
- If invalid, terminate the process; If valid, this page is on disk. Need page it into memory.
- Find a free frame from the free-frame list. (if no free frame, need replace an old page)
- Schedule a disk operation to read the desired page into the newly allocated frame.
- When the disk read is complete, modify the internal table and page table to set the bit as valid to indicate this page is now in memory.
- Restart the instruction that was interrupted. The process can now access the page as though it had always been in memory

Handle a Page Fault (more details)

- Trap to the OS
- Save the user registers and process status.
- Determine the interrupt was a page fault.
- Determine the location of the page on the disk.
- Find a free frame from the free-frame list.
  - If no free frame, page replacement.
- Issue a read from the disk to the free frame:
  - Wait in a queue for the disk until serviced.
  - Wait for the disk seek and latency time.
  - Begin the transfer of the page to the free frame.
- While waiting, allocate the CPU to other process.
- Interrupt from the disk (I/O completed).
- Save the registers and process state for other running process.
- Determine the interrupt was from the disk.

Handle a Page Fault (more details) (cont'd)

- …
- Correct the page table and other tables to show the desired page is now in memory.
- Wake up the original waiting process.
- Wait for the CPU to be allocated to this process again.
- Restore the user registers and process state and new page table.
- Resume the interrupted instruction.

Pure Demand Paging vs. Pre-paging

- **Pure Demand Paging:**
  - **Never bring a page into memory until it is referred.**
  - **Start executing a process with no pages in memory**
  - **OS set instruction pointer to the first instruction**
  - **Once run, it causes a page fault to load the first page**
  - **Faulting as necessary until every page is in memory**
- **Pre-paging:**
  - **To prevent high page-fault rate at the beginning.**
  - **Try to bring more pages at once based on prediction.**

Some Architecture Concerns in demand paging

- Straightforward in most cases:

ADD A,B,C →

1. Fetch and decode ADD
2. Fetch A
3. Fetch B
4. Add A and B
5. Store the sum to C

- But some instructions which may modify something are not easy to handle:
  - IBM 360/370: MVC (move 256 bytes)
  - PDP-11: auto-decrement or auto-increment addressing mode

    mov (R2)++, --(R3)

Performance of Demand Paging

- To service a page fault is very time-consuming:
  - Service the page-fault interrupt.
  - Read in the page.
  - Restart the process.
- Effective access time for a demand-paged system:

Effective Access Time = (1-p) * ma + p * page fault time

- One example: memory access 100 nanosecond
  page fault 25 millisecond

Effective Access Time = 100 + 24,999,900 * p

If **p**=1/1000, **EAT** = 25 microsecond (slow down a factor of 250)
If requiring only 10% slow down, **p**<4/10,000,000 (one out of 2.5 million)

- How to achieve low page fault rate??

Handling Swap Space on Disk

- **For fast speed:**
  - **Use swap space, not file system.**
  - **Swap space: in larger blocks, no file lookup and indirect allocation.**
  - **Copying an entire file image into swap space at process startup and then perform demand paging from the swap space.**
  - **Or first load pages from file system, then write to swap space.**

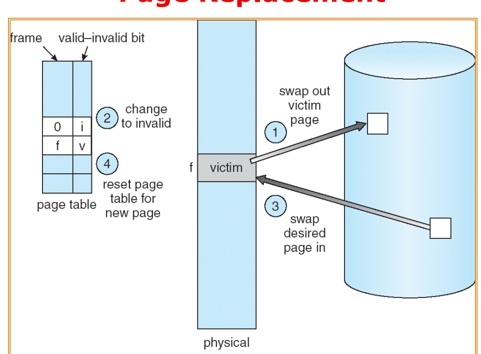
Page Replacement(1)

- **In demand paging, when increasing multiprogramming level, it is possible to run out of all free frames.**
- **How about if a page fault occurs when no free frame is available?**
  - **Stop the process.**
  - **Swap out another process to free some frames.**
  - **Page replacement:**
    - **Replacing in page level.**

Page Replacement(2)

- **If no frame is free, find one frame that is not currently being used and free it.**
  - **Write the page into swap space and change page-table to indicate that this page is no longer in memory.**
  - **Use the freed frame to hold the page for which the process faulted.**
- **Use a page-replacement algorithm to select a victim frame.**
- **In this case, two disk accesses are required (one write one read).**

Page Replacement

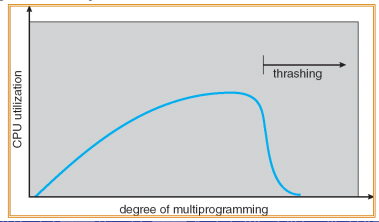


Page Replacement(3)

- Use a *modify bit (dirty bit)* to reduce overhead:
  - Each frame has a modify bit associated in hardware.
  - Any write in page will set this bit by hardware.
  - In page replacement, if the bit is not set, no need to write back to disk.
- For read-only pages, always no need to write back.
- With page replacement, we can run a large program in a small memory.
- Two important issues:
  - Page-replacement algorithm: how to select the frame to be replaced?
  - Frame-allocation algorithm: how many frames to allocate to each process?

Thrashing

- Thrashing: a process is spending a significant time in paging.
- Thrashing results in severe performance problem. The process is spending more time in paging than executing.
- Cause of thrashing:
  - The process is not allocated enough frames to hold all the pages currently in active use.



Locality Model of Programs

- A locality is a set of pages that are currently in an active use by process.
- A process moves from locality to locality.
- A program is generally composed of several different localities.
- The localities are defined by the program structure and its data structures.
- Locality model is the basic principle for caching as well as demand paging.
  - We only need a small number of frames to hold all pages in the current locality in order to avoid further page faults.

Other Considerations in demand-paging

- Program structure: a careful selection of data structure and programming structure
  - To increase locality and hence lower the page-fault rate.
  - To reduce total number of memory access.
  - To reduce total number of pages touched.
- Also compiler and loader can improve.
- Example: Array `A[1024][1024]` of integer
  - Each row is stored in one page
  - Program 1

```
for j = 1 to 1024 do
   for i = 1 to 1024 do
         A[i][j] = 0;
```

  1024 x 1024 page faults

  - Program 2

```
for i = 1 to 1024 do
   for j = 1 to 1024 do
         A[i][j] = 0;
```

  1024 page faults