Virtual Memory

CS 537 - Introduction to Operating Systems

Multiprogramming

- Modern systems keep more than one program in memory at a time
- Often, all these programs together require more memory than what is available
- What to do?
  - use a part of disk and make it look like memory
  - this is called virtual memory

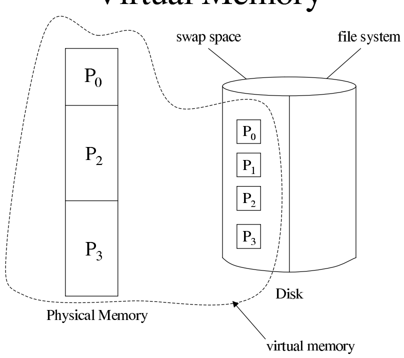
Disk vs. Memory

- Memory characteristics
  - fast - typically 100 ns per access
  - small - hundreds of megabytes
  - random access of any byte
- Disk characteristics
  - very slow - several milliseconds per access
  - large - tens of gigabytes
  - random access of any block (512 bytes)

Virtual Memory

- Basic concept
  - keep frequently used process data in physical memory
  - keep the rest of a processes address space on disk
  - if a piece of infrequently used data is needed, bring it in from disk
- Before any data can be used, it must be in physical memory

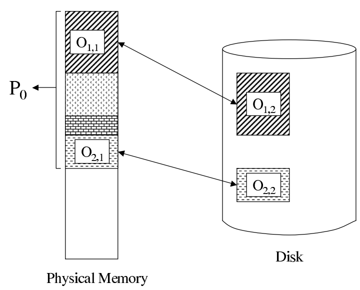
Virtual Memory



Overlays

- User controls what info is on disk, and what is in memory
- To access info kept on disk
  - save some portion of current memory to disk
  - bring in desired info to memory
- Very difficult to implement
- Becomes very system dependant
  - what if more memory becomes available?
  - what if less is available?

Overlays



Paging

- This is the way it done today
- User thinks virtual memory is one large array of real memory
- Let special hardware and the OS keep up this illusion
- Basic idea
  - user enters address from virtual space
    - usually 32 or 64 bits (2^{32} or 2^{64} addressable bytes)
  - hardware and OS map this virtual address to physical address

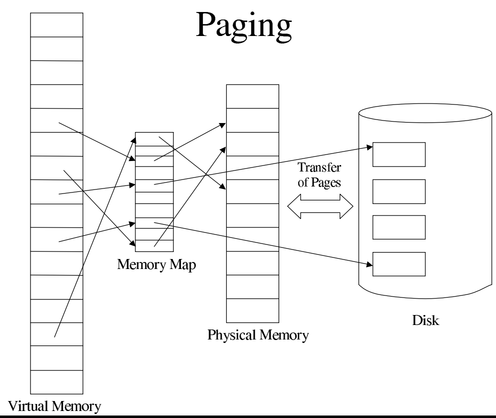
Paging

- Break physical memory into frames
- Break virtual memory into pages
- Page size must be multiple of frame size
  - for simplicity, we'll assume the same size
- When an address is accessed
  - find out which page it is
  - if not in memory, bring it in
  - now grab the data

Memory Map

- Two solutions to almost every problem in computer science
  - indirection
  - caching
- The memory map is a form of indirection
- Call this memory map the *page table*

Paging



Page Table

- Keep a record of every page in virtual memory
- Record actual location of page in this table
  - frame in memory
- Also record some other information in table
  - valid or invalid (in memory or not)
  - protection bits (read/write/executable)

Page Table Entry

- Assume 32 bit addressing
- Entry in table will be 32 bits plus a few extra
  - 32 bits are address in memory
  - extra bits are valid/invalid and protection bits
- If entry is valid, the address is the starting location of the page in main memory
- Index of entry is the page number

Page Table

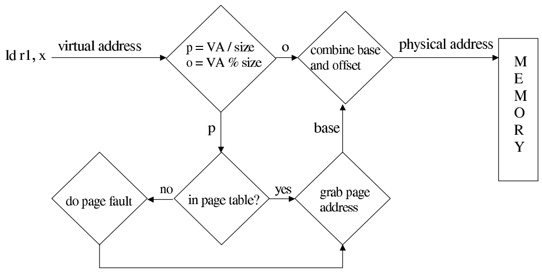
- Assume the page size is 100

Page Number	Location of start of page (disk or memory)	X	W	V
0	1000	1	0	1
1	300	0	1	1
2	100	0	1	0
3	1500	1	0	1
4	400	0	0	0
5	900	0	1	1
6	2000	0	0	0
	32	1	1	1

Calculating Physical Address

- User supplies a virtual address
  - high order bits are the page number
  - low order bits are the offset into the page
- Go to appropriate index in page table
- Examine valid bit
  - if valid, grab starting address of page from table
  - if not, generate a *page fault*, bring it into memory, set page table entry, grab starting address
    - OS uses another table to find location on disk
  - now combine the page table entry and offset to calculate the true physical address

Calculating Physical Address



Calculating Physical Address

	page number	offset
user instruction: st r1, x →	5	33

- check index 5 in page table:
  - it is valid and writeable
  - base = 900
- now calculate physical address:
  - PA = base + offset = 900 + 33 = 933

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	page number	offset
user instruction: st r1, y →	2	75

- check index 2 in page table:
  - it is not valid
  - invoke page fault handler and load page into memory
  - assume following is now true: base = 1400
- now calculate physical address:
  - PA = base + offset = 1400 + 75 = 1475

Virtual Address

- Make all pages a power of 2 in size
  - and make them a multiple of 512 (disk blocks)
- A virtual address consists of 32 bits
  - 64 bits in some systems
- Assume a page size of 4K
  - need 12 bits for the offset (2^{12} = 4K)
  - that leaves 20 bits for the page number
  - our system can hold 1M (2^{20}) of 4K pages
    - 4 GB

Virtual Address

- Given the following virtual address:

page number	offset
0000000000000110011	000000011010

page number = 51
offset in page = 26 bytes

- How many pages would there be with
  - 16 K pages
  - 1 K pages

Locality of Reference

- Important concept in computer science
- spatial locality
  - if an address x is accessed, high probability that address x+1 will also be referenced
- temporal locality
  - if an address x is accessed at time t, high probability it will be accessed again in t+δ where δ is small

Page Size

- Proper page size depends on the program reference behavior
- Too small a page size
  - too much overhead
  - does not consider locality of reference
- Too large a page size
  - waste memory with data that will never be used
    - holding space that another process could use
  - assumes too much locality of reference