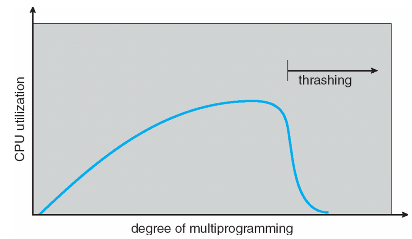
Last Class: Memory management

- Page replacement algorithms - make paging work well.
  - Random, FIFO, MIN, LRU
  - Approximations to LRU: Second chance
  - Multiprogramming considerations

Multiprogramming and Thrashing



- **Thrashing:** the memory is over-committed and pages are continuously tossed out while they are still in use
  - memory access times approach disk access times since many memory references cause page faults
  - Results in a serious and very noticeable loss of performance.
- What can we do in a multiprogrammed environment to limit thrashing?

Replacement Policies for Multiprogramming

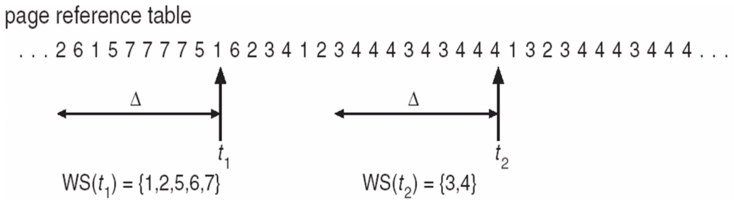
- **Proportional allocation:** allocate more page frames to large processes.
  - alloc = s/S * m
- **Global replacement:** put all pages from all processes in one pool so that the physical memory associated with a process can grow
  - **Advantages:** Flexible, adjusts to divergent process needs
  - **Disadvantages:** Thrashing might become even more likely (Why?)

Replacement Policies for Multiprogramming

- **Per-process replacement:** Each process has its own pool of pages.
- Run only groups of processes that fit in memory, and kick out the rest.
- How do we figure out how many pages a process needs, i.e., its working set size?
  - Informally, the working set is the set of pages the process is using right now
  - More formally, it is the set of all pages that a process referenced in the past T seconds
- How does the OS pick T?
  - 1 page fault = 10msec
  - 10msec = 2 million instructions

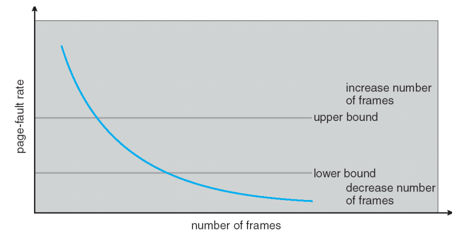
  => T needs to be a whole lot bigger than 2 million instructions.
  - What happens if T is too small? too big?

Working Set Determination



Per-process Replacement

- Working sets are expensive to compute => track page fault frequency of each process instead
  - If the page fault frequency > some threshold, give it more page frames.
  - If the page fault frequency < a second threshold, take away some page frames
- **Goal:** the system-wide mean time between page faults should be equal to the time it takes to handle a page fault.
  - May need to suspend a process until overall memory demands decrease.



Page-fault Frequency Scheme

- **Advantages:** Thrashing is less likely as process only competes with itself. More consistent performance independent of system load.
- **Disadvantages:** The OS has to figure out how many pages to give each process and if the working set size grows dynamically adjust its allocation.

Kernel Memory Allocators

- Buddy allocator
  - Allocate memory in size of 2^n
  - Can lead to internal fragmentation
- Slab allocator
  - Group objects of same size in a "slab"
  - Object cache points to one or more slabs
  - Separate cache for each kernel data structure (e.g., PCB)
  - Used in solaris, linux

Page Sizes

- Reasons for small pages:
  - More effective memory use.
  - Higher degree of multiprogramming possible.
- Reasons for large pages:
  - Smaller page tables
  - Amortizes disk overheads over a larger page
  - Fewer page faults (for processes that exhibit locality of references)
- Page sizes are growing because:
  - Physical memory is cheap. As a result, page tables could get huge with small pages. Also, internal fragmentation is less of a concern with abundant memory.
  - CPU speed is increasing faster than disk speed. As a result, page faults result in a larger slow down than they used to. Reducing the number of page faults is critical to performance.

Today: File System Functionality

Remember the high-level view of the OS as a translator from the user abstraction to the hardware reality.

User Abstraction		Hardware Resource
Processes/Threads		CPU
Address Space	<= OS =>	Memory
Files		Disk

File System Abstraction

Applications Daemons Servers Shell

Programmer Interface

Open() Close() Read() Write()
Link() Rename()

Device Indepedent Interface

Sectors Tracks
Seek() ReadBlock() WriteBlock()

Device Interface

Hardware
Disk

User Requirements on Data

- **Persistence:** data stays around between jobs, power cycles, crashes
- **Speed:** can get to data quickly
- **Size:** can store lots of data
- **Sharing/Protection:** users can share data where appropriate or keep it private when appropriate
- **Ease of Use:** user can easily find, examine, modify, etc. data

Hardware/OS Features

- Hardware provides:
  - **Persistence:** Disks provide non-volatile memory
  - **Speed:** Speed gained through random access
  - **Size:** Disks keep getting bigger (typical disk on a PC=500GB - 1TB)
- OS provides:
  - **Persistence:** redundancy allows recovery from some additional failures
  - **Sharing/Protection:** Unix provides read, write, execute privileges for files
  - **Ease of Use**
    - Associating names with chunks of data (files)
    - Organize large collections of files into directories
    - Transparent mapping of the user's concept of files and directories onto locations on disks
    - Search facility in file systems (SpotLight in Mac OS X)

Files

- **File:** Logical unit of storage on a storage device
  - Formally, named collection of related information recorded on secondary storage
  - **Example:** reader.cc, a.out
- Files can contain programs (source, binary) or data
- Files can be structured or unstructured
  - Unix implements files as a series of bytes (unstructured)
  - IBM mainframes implements files as a series of records or objects (structured)
- File attributes: name, type, location, size, protection, creation time

User Interface to the File System

Common file operations (system calls)

Data operations:

Create()	Open()	Read()
Delete()	Close()	Write()
		Seek()

Naming operations:

HardLink()

SoftLink()

Rename()

Attributes (owner, protection,...):

SetAttribute()

GetAttribute()

OS File Data Structures

1. Open file table - shared by all processes with an open file.
   - open count
   - file attributes, including ownership, protection information, access times, ...
   - location(s) of file on disk
   - pointers to location(s) of file in memory

2. Per-process file table - for each file,
   - pointer to entry in the open file table
   - current position in file (offset)
   - mode in which the process will access the file (r, w, rw)
   - pointers to file buffer

File Operations: Creating a File

- **Create(name)**
  - Allocate disk space (check disk quotas, permissions, etc.)
  - Create a file descriptor for the file including name, location on disk, and all file attributes.
  - Add the file descriptor to the directory that contains the file.
  - Optional file attribute: file type (Word file, executable, etc.)
    - **Advantages:** better error detection, specialized default operations (double-clicking on a file knows what application to start), enables storage layout optimizations
    - **Disadvantages:** makes the file system and OS more complicated, less flexible for user.
    - Unix opts for simplicity (no file types), Macintosh/Windows opt for user-friendliness

File Operations: Deleting a File

- **Delete(name)**
  - Find the directory containing the file.
  - Free the disk blocks used by the file.
  - Remove the file descriptor from the directory.
  - Refcounts and hardlinks?

File Operations: Open and Close

- **fileId = Open(name, mode)**
  - Check if the file is already open by another process. If not,
    - Find the file.
    - Copy the file descriptor into the system-wide open file table.
  - Check the protection of the file against the requested mode. If not ok, abort
  - Increment the open count.
  - Create an entry in the process's file table pointing to the entry in the system-wide file table. Initialize the current file pointer to the start of the file.
- **Close(fileId)**
  - Remove the entry for the file in the process's file table.
  - Decrement the open count in the system-wide file table.
  - If the open count == 0, remove the entry in the system-wide file table.

OS File Operations: Reading a File

- **Read(fileID, from, size, bufAddress)** - random access
  - OS reads "size" bytes from file position "from" into "bufAddress"

```
for (i = from; i < from + size; i++)
    bufAddress[i - from] = file[i];
```

- **Read(fileID, size, bufAddress)** - sequential access
  - OS reads "size" bytes from current file position, fp, into "bufAddress" and increments current file position by size

```
for (i = 0; i < size; i++)
    bufAddress[i] = file[fp + i];
fp += size;
```

OS File Operations

- **Write** is similar to reads, but copies from the buffer to the file.
- **Seek** just updates fp.
- **Memory mapping** a file
  - Map a part of the portion virtual address space to a file
  - Read/write to that portion of memory \implies OS reads/writes from corresponding location in the file
  - File accesses are greatly simplified (no read/write call are necessary)

File Access Methods

- Common file access patterns from the programmer's perspective
  - **Sequential:** data processed in order, a byte or record at a time.
    - Most programs use this method
    - **Example:** compiler reading a source file.
  - **Keyed:** address a block based on a key value.
    - **Example:** database search, hash table, dictionary

- Common file access patterns from the OS perspective:
  - **Sequential:** keep a pointer to the next byte in the file. Update the pointer on each read/write.
  - **Random:** address any block in the file directly given its offset within the file.

Naming and Directories

- Need a method of getting back to files that are left on disk.
- OS uses numbers for each files
  – Users prefer textual names to refer to files.
  – **Directory:** OS data structure to map names to file descriptors
- Naming strategies
  – **Single-Level Directory:** One name space for the entire disk, every name is unique.
    1. Use a special area of disk to hold the directory.
    2. Directory contains <name, index> pairs.
    3. If one user uses a name, no one else can.
    4. Some early computers used this strategy. Early personal computers also used this strategy because their disks were very small.
  – **Two Level Directory:** each user has a separate directory, but all of each user's files must still have unique names

Naming Strategies (continued)

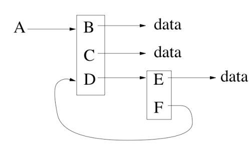
- Multilevel Directories - tree structured name space (Unix, and all other modern operating systems).
  1. Store directories on disk, just like files except the file descriptor for directories has a special flag bit.
  2. User programs read directories just like any other file, but only special system calls can write directories.
  3. Each directory contains <name, fileDesc> pairs in no particular order. The file referred to by a name may be another directory.
  4. There is one special root directory. *Example:* How do we look up name: /usr/local/bin/netscape

Referential naming

- Hard links (Unix: *ln* command)
  - A hard link adds a second connection to a file
  - *Example:* creating a hard link from B to A

Initially:	A → file #100
After "*ln* A B":	A → file #100
	B → file #100

  - OS maintains reference counts, so it will only delete a file after the last link to it has been deleted.
  - *Problem:* user can create circular links with directories and then the OS can never delete the disk space.
  - *Solution:* No hard links to directories



Referential Naming

- Soft links (Unix: *ln -s* command)
  - A soft link only makes a symbolic pointer from one file to another.
  - *Example:* creating a soft link from B to A

Initially:	A → file #100
After "*ln* A B":	A → file #100
	B → A

  - removing B does not affect A
  - removing A leaves the name B in the directory, but its contents no longer exists
  - *Problem:* circular links can cause infinite loops (e.g., trying to list all the files in a directory and its subdirectories)
  - *Solution:* limit number of links traversed.

Directory Operations

- Search for a file: locate an entry for a file
- Create a file: add a directory listing
- Delete a file: remove directory listing
- List a directory: list all files (*ls* command in UNIX)
- Rename a file
- Traverse the file system

Protection

- The OS must allow users to control sharing of their files => control access to files
- Grant or deny access to file operations depending on protection information
- **Access lists and groups** (Windows NT)
  - Keep an access list for each file with user name and type of access
  - Lists can become large and tedious to maintain
- **Access control bits** (UNIX)
  - Three categories of users (owner, group, world)
  - Three types of access privileges (read, write, execute)
  - Maintain a bit for each combination (111101000 = rwxr-x---)