Memory Allocation

Allocation of Page Frames

- Scenario
  - Several physical pages allocated to processes A, B, and C. Process B page faults.
  - Which page should be replaced?
- Allocating memory across processes?
  - Does every process get the same fraction of memory?
  - Different fractions?
  - Should we completely swap some processes out of memory?

Allocation of Page Frames

- Each process needs minimum number of pages
  - Want to make sure that all processes that are loaded into memory can make forward progress
  - Example: IBM 370 – 6 pages to handle SS MOVE instruction:
    - instruction is 6 bytes, might span 2 pages
    - 2 pages to handle from
    - 2 pages to handle to

Fixed Allocation

- Allocate a minimum number of frames per process
- Consider minimum requirements, e.g. on previous slide
  - One page from the current executed instruction
  - Most instructions require two operands
  - Include an extra page for paging out and one for paging in

Equal Allocation

- Allocate an equal number of frames per job
  - Example
    - 100 frames
    - 5 processes
    - Each process gets 20 frames
- Issues
  - But jobs use memory unequally
  - High priority jobs have same number of page frames and low priority jobs
  - Degree of multiprogramming might vary

Proportional Allocation

- Allocate a number of frames per job proportional to job size
  - How do you determine job size
    - Run command parameters ?
    - Dynamically?
- Priority Allocation
  - May want to give high priority process more memory than low priority process
  - Use a proportional allocation scheme using priorities instead of size

Allocation of Page Frames

- Possible Replacement Scopes
  - Local replacement
    - Each process selects from only its own set of allocated frames
    - Process slowed down even if other less used pages of memory are available
  - Global replacement
    - Process selects replacement frame from set of all frames
    - One process can take a frame from another
    - Process may not be able to control its page fault rate.

Local Replacement: Per Process

- Each process has separate pool of pages
  - Fixed number of pages (e.g., Digital VMS)
  - Fixed fraction of physical memory (1/P)
  - Proportional to size of allocated address space
- Page fault in one process only replaces pages of that process
  - Perform replacement (e.g., LRU) over only those pages
- Advantage
  - No interference across processes
- Disadvantage
  - Potentially inefficient allocation of memory
  - How to handle sharing of pages?

Local Replacement: Per User

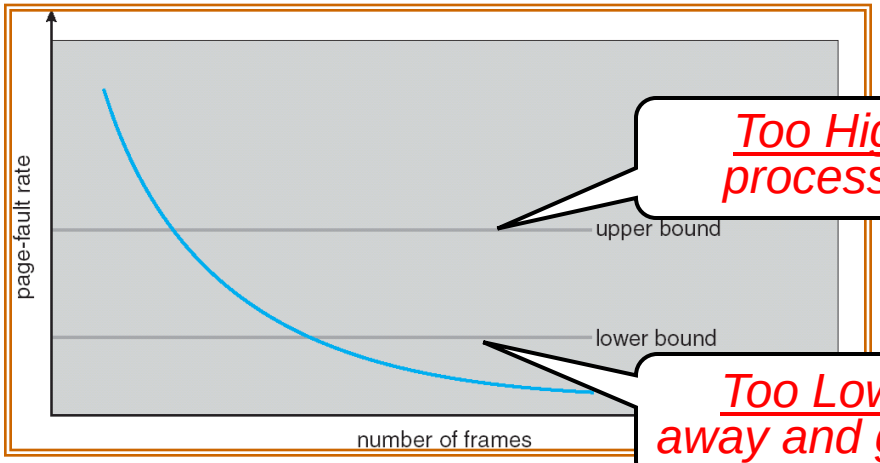
- Each user has separate pool of pages
- Advantage
  - Fair across different users
- Disadvantage
  - Inefficient allocation

Global Replacement

- Pages from all processes lumped into single replacement pool
  - Example: Run clock over all page frames
- Each process competes with other processes for frames
- Advantages
  - Flexibility of allocation
  - Minimize total number of page faults
- Disadvantages
  - One memory-intensive process can hog memory, hurt all processes

Page Fault Frequency Allocation

- Can we reduce Capacity misses by dynamically changing the number of pages/application?



- Establish "acceptable" page-fault rate
  - If actual rate too low, process loses frame
  - If actual rate too high, process gains frame
- Question: What if we just don't have enough memory

Overcommitting Memory

- When does the Virtual Memory illusion break?
- Example
  - Set of processes frequently references 33 important pages
  - Physical memory can fit 32 pages
- What happens?
  - Process A references page not in physical memory
  - OS runs another process B
  - OS replaces some page in memory with page for A
  - How long can B run before it page faults?
    - Cycle continues...

Overcommitting Memory

- If a process does not have enough pages, the page-fault rate is very high
  - Low CPU utilization.
  - OS thinks that it needs to increase the degree of multiprogramming
  - Another process is added to the system.
  - System throughput plunges…
- System is reading and writing pages instead of executing useful instructions
  - Average memory access time = disk access time
  - Memory appears as slow as disk, instead of disk appearing as fast as memory

Thrashing

- If a process does not have enough frames, the page-fault rate is very high
  - Low CPU utilization
- Thrashing
  - A process is busy swapping pages in and out
  - In other words, a process is spending more time paging than executing

Thrashing

- Example
  - Process has 3 frames allocated to it (use LRU)
  - Reference string is 123412341234… - 4th access onwards all cause page faults
- Cannot be fixed with better replacement policies
  - Do not indicate that a page must be kept in memory
  - Only show which pages are better than others to replace

Thrashing

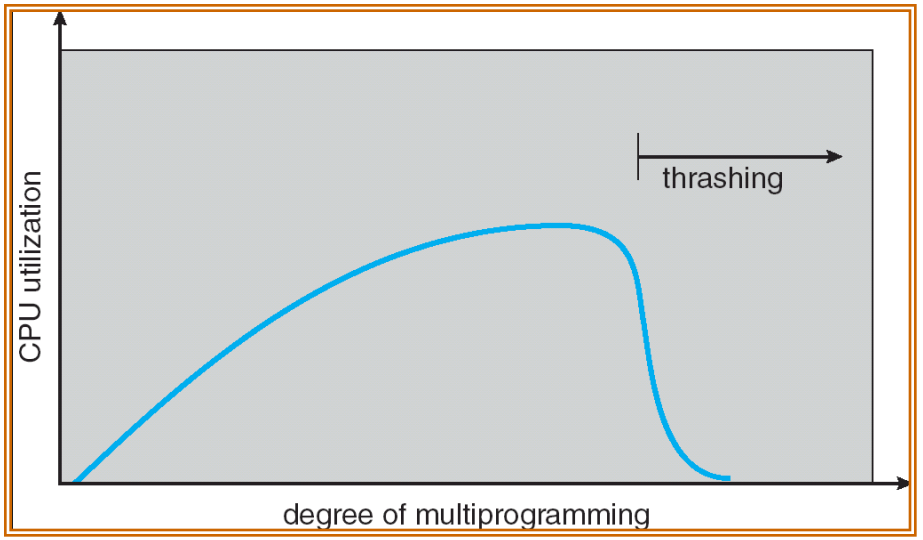
- Student's analogy to thrashing: Too many courses
  - Drop a course
- OS solution: Admission control
  - Determine how much memory each process needs
  - Long-term scheduling policy
    - Run only those processes whose memory requirements can be satisfied
  - What if memory needs of one process are too large????

Why Thrashing?

- Computations have locality
  - Set of pages that are actively used together
- As the number of page frames decreases
  - There are not enough available page frames to contain the locality of the process
- Processes start faulting heavily
  - Pages that are read in, are used and immediately paged out

Thrashing

- Page fault rate goes up
  - Processes get suspended for page out to disk
- The system may start new jobs
  - Reduces number of available page frames
  - Increases page faults
- System throughput plunges!



Working Set

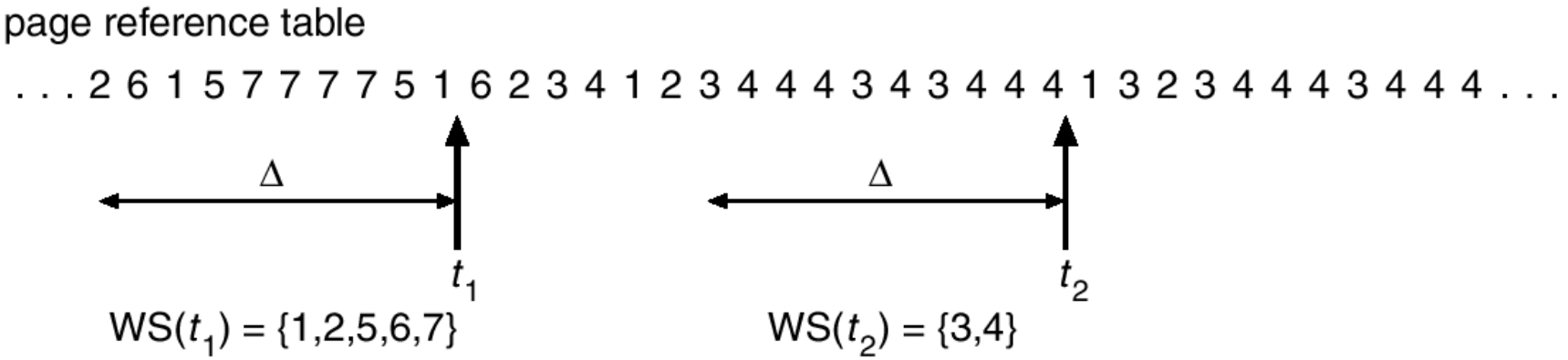
- Question
  - How much memory does a process need to keep the most recent computation in memory with very few page faults?
- How can we determine this?
  - Determine the working set of a process
  - The principle of locality
    - A program clusters its access to data and text temporally
    - A recently accessed page is more likely to be accessed again

Working Set (1968, Denning)

- Need
  - Set of pages process needs to avoid thrashing
  - Requires knowing the future
- Working set
  - Pages referenced by process in last T seconds of execution
  - Approximates locality

Working Set (1968, Denning)

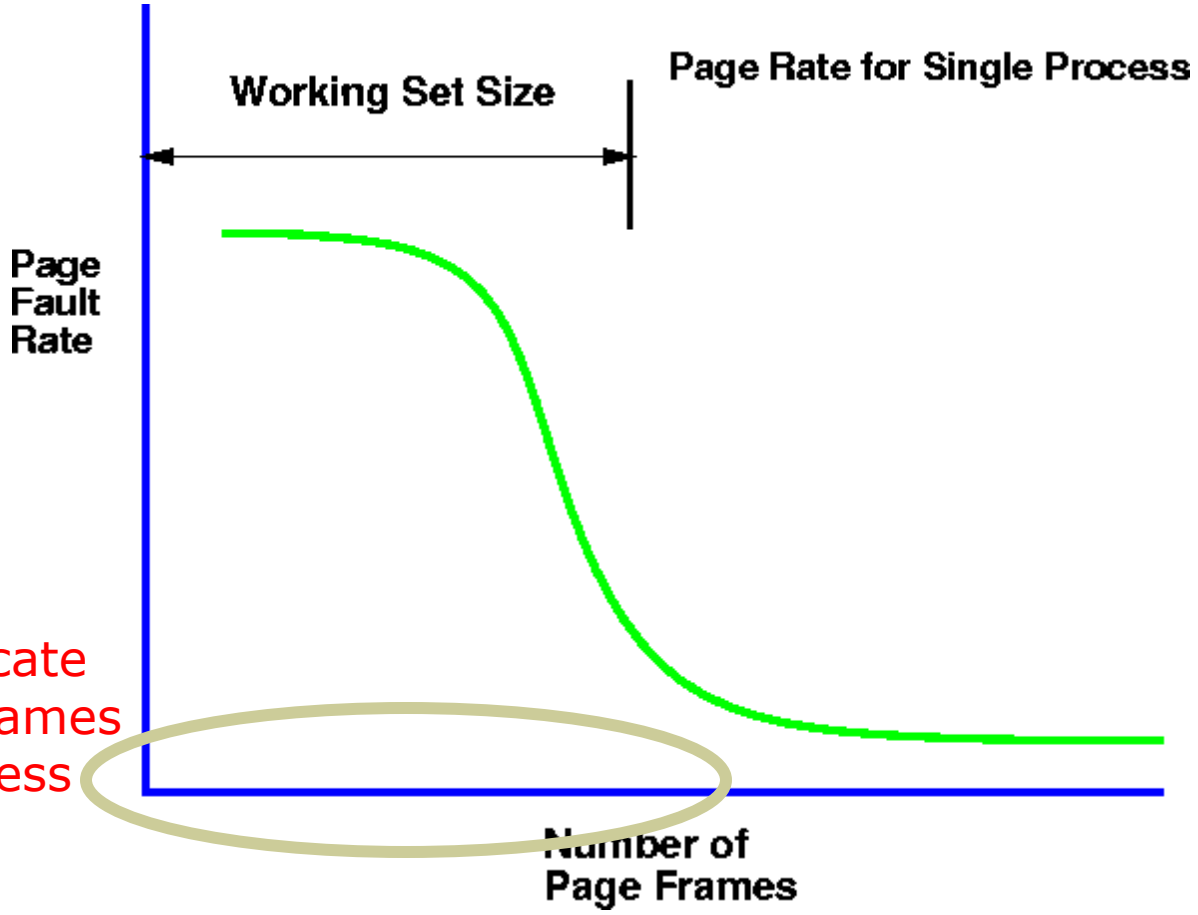
- $\Delta \equiv$ working-set window $\equiv$ fixed number of page references
  - Example: 10,000 instruction
- Working set of P_i = pages referenced in most recent Δ



Working Set (1968, Denning)

- Using working set sizes
  - Cache partitioning
    - Give each app enough space for WS
  - Page replacement
    - Preferentially discard non-WS pages
  - Scheduling
    - Process not executed unless WS in memory

Working Set Size

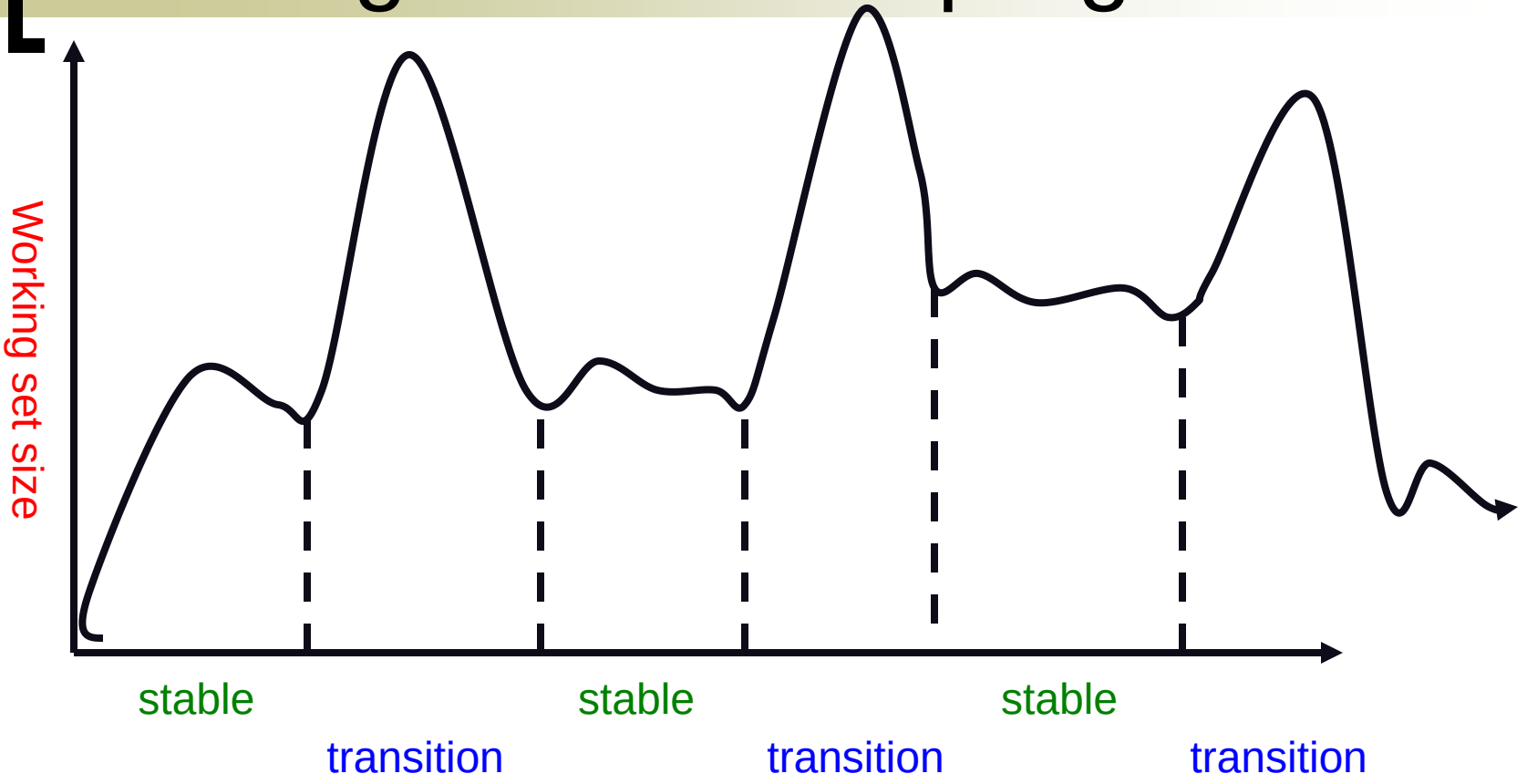


At least allocate this many frames for this process

Working Set Size

- Choosing T
  - T too small
    - Will not encompass entire locality
  - T too large
    - Will encompass several localities
  - T = ∞
    - Will encompass entire program

Working sets of real programs



- Typical programs have phases

Working Set in Action to Prevent Thrashing

- Algorithm
  - If number free page frames > working set of some suspended $process_i$
    - Activate $process_i$ and map in its working set
  - If working set size of some $process_k$ increases and no page frame is free
    - Suspend $process_k$ and release all its pages
- Tracking the working set
  - Moving window over reference string
  - Approximate with Interval timer + a reference bit

Working Set Implementation

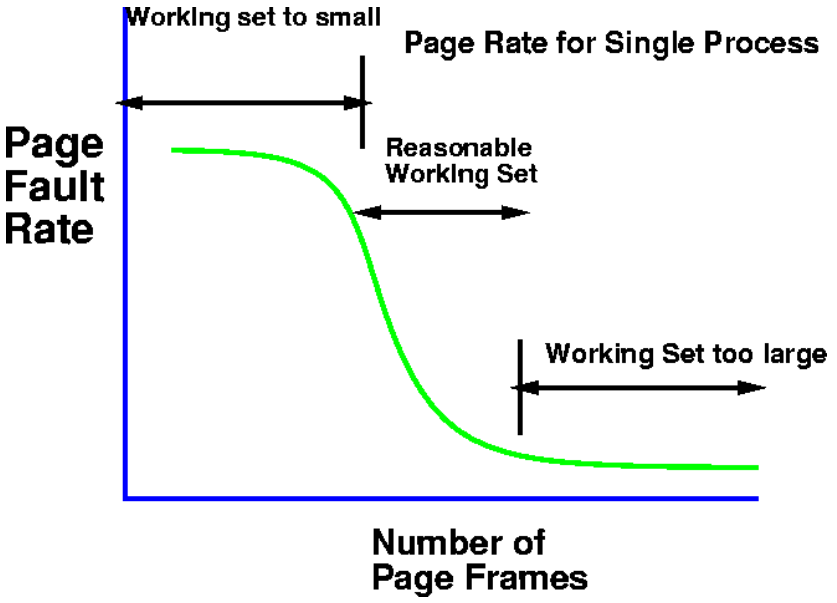
- Example: T = 10,000
  - Timer interrupts after every 5000 time units
    - Copy and set the values of all reference bits to 0
  - Keep in memory 2 bits for each page
    - Indicates if page was used within last 10,000 to 15,000 references
  - If one of the bits in memory = 1
    - Page in working set
- Not completely accurate - cannot tell where reference occurred.
  - Improvement - 10 bits and interrupt every 1000 time units

Page Fault Frequency Working Set

- Approximation of pure working set
- Assumption
  - If the working set is correct
    - Not many page faults
- Approach
  - Control thrashing by establishing acceptable page-fault rate

Page Fault Frequency Working Set

- Algorithm
  - If page fault rate increases beyond assumed knee of curve
    - Increase number of page frames available to process
  - If page fault rate decreases below foot of knee of curve
    - Decrease number of page frames available to process



Page Size Considerations

- Small pages
  - Large page tables
  - Minimizes internal fragmentation
  - Good for locality of reference (~256)
  - Page tables are larger
  - Disk-seek time dominates transfer time (It takes the same time to read a large page as a small page)
- Large pages
  - Significant amounts of a page may not be referenced
  - Enables more data per seek
- Real systems (can be reconfigured)
  - Windows: default 8KB
  - Linux: default 4 KB