Memory Management

MFT Process Scheduling

- When process enters system, goes into a process queue
- Scheduler takes memory requirements of process, sizes of available regions
  - When a region of the right size becomes available, process moved into it
  - Process then goes on ready queue
  - When it finishes, memory region freed, new process brought in

MFT Memory Allocation

- Need to classify processes based on memory needs
  - User specifies maximum size
  - System can (try to) determine it automatically
- Methods take number of queues, region size, swapping, and scheduling algorithm into account

Methods: Multiple Queues

- Each memory region has its own associate queue, and process goes into queue of smallest region it will fit into
- Example:
  - System has 100K, 200K, and larger regions
  - 98K, 170K processes go into queues associated with 100K, 200K regions

Methods: Single Queues

- All processes go into 1 queue, and when scheduler selects next process to run, it waits for the partition to become available
- Example: 100K, 200K regions have their own queues
  - 98K process goes into queue associated with 100K region
  - 170K process goes into queue associated with 200K region
  - If 1MB partition became available, *neither* process would be put in it as they are not on its queue

Methods: Single Queue

- All processes go into 1 queue, and when scheduler selects next process to run, it waits for the partition to become available
- Example:
  - Each process has an associated region with it (use same as before)
  - 98K process enters queue, then 175K process enters queue
  - 200K region becomes free
  - As next process in ready queue goes into 100K region, not 200K region, it does not run until 100K region becomes free
  - Key point: 200K region remains empty until 100K region becomes free and 98K process moved into it

Methods: Single Queue

- All processes go into 1 queue, and scheduler goes down ready queue and picks next process that would fit into an associated region
- Example:
  - Each process has an associated region with it (use same as before)
  - 98K process enters queue, then 175K process enters queue
  - 200K region becomes free
  - Scheduler *skips* over 98K process (as that fits into 100K region)
  - Scheduler picks 175K process to run in 200K region
- Scheduler selects next process that fits into free partition *even of higher priority processes are ahead of it but are too large to run*

Methods: Single Queue

- All processes go into 1 queue, and scheduler goes down ready queue and picks next process that would fit into any free region
- Example:
  - 98K process enters queue, then 175K process enters queue
  - 200K region becomes free
  - Scheduler puts 98K process into 200K region as it is the first region that is free and that 98K job will fit

Methods: Single Queue + Swapping

- Swap processes based on which region they are in
- Example: 3 regions, and all jobs associated with a region scheduled using round robin
  - Quantum expires
  - Memory manager begins swapping out process in the region and swapping in another process associated with that region
  - CPU scheduler gives quantum to process in another region
- Memory manager *must* be able to swap processes fast enough so there are always processes in memory ready to execute when CPU is rescheduled

Methods: Single Queue + Swapping

- When high priority process comes in and a lower priority process is using the region where it would normally go, swap out lower priority process for the higher one
- When higher priority process done, swap lower priority process in
  - Called *roll-out/roll-in*
- Which region does a swapped process return to?
  - Static relocation: process *must* return to its original partition
  - Dynamic relocation: process can return to some other partition

Problems

- Process needs more memory than region has
  - MFT gives process fixed amount of memory
- How is this handled?
  - Terminate process
  - Return control to process with an error indication that request cannot be satisfied
  - Swap out process until a large enough region becomes available
    - Works *only* if using dynamic relocation

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Problems

- System has 100K available
- Almost all process are 20K, but one is 80K and only runs for ten minutes a day
- Then in best case, you can run 3 processes at a time, and you waste 60K (20K process in an 80K partition)
- So make the regions vary in size!

Preface to What Follows

- In MFT, address translation is static; that is, it is set when the program is loaded into memory
- Moving the program requires recalculating the relocation addresses
- Alternative: relocate addresses during execution
- This uses special hardware

Dynamic Relocation

- As each memory reference occurs, transform those that refer to main memory
  - As noted earlier, deals with sequence of memory references *only*
- Use base and limit (bounds) registers
- In hardware:
  - Check the memory reference does not exceed value in limit register; if it does, give error
  - Add contents of base register to memory reference
  - Access the transformed address

Address Translation

- Transformation of a virtual address into a physical one
- With this, address spaces can be moved *during* execution
  - And that's *dynamic relocation*
- Note: limit register may contain physical address of end of address space
  - If so, reverse the order of checking and adding
  - Equivalent to earlier method

Hardware Requirements

- Base and limit registers
- Privileged instructions to store values in them
  - *Must* be privileged!
- Provided by a Memory Management Unit (MMU)
  - Now the MMU does a lot more; the basic idea is the above, though
- Processor status word (PSW) needs to indicate whether system is in privileged mode
  - Usually this is a set of bits
  - Sometimes PSW is called Processor Status Longword (PSL)

Hardware Requirements

- CPU must generate exceptions (aka traps, interrupts) when a process references memory outside its address space
  - Stop process execution
  - Jump to address indicated by interrupt/trap table
    - Each exception has address of routine to jump to

Operating System Requirements

- Operating system must track where in memory processes are, and what memory is not in use
  - Called a *free list*
- Allocate space to processes to be used as address space
  - Search the free list for chunk of memory of appropriate size
- Reclaim memory from terminated process
  - Put it onto free list so other processes can use it

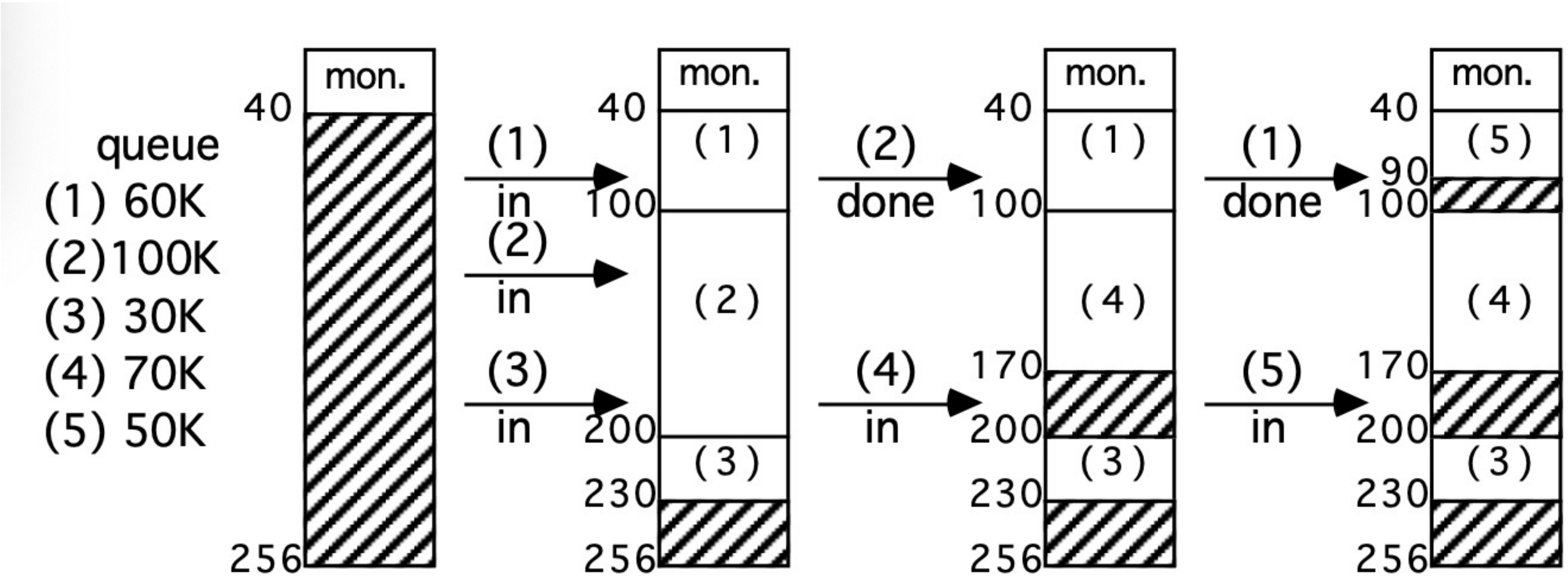
Operating System Requirements

- Save and restore base and bounds registers during context switch
  - When execution switches from one process to another
  - Saved values put into area associated with single process
    - Usually Process Control Block (PCB), a collection of information about a process
- Handle exceptions
  - Functions to be called when exception occurs
  - Example: when bounds register exceeded, throw an exception, causing execution to transfer to function associated with attempt to access memory outside address space
  - Unless altered by process, exception handlers usually (but not always) terminate process

MVT

- Multiple Contiguous Variable Partition Allocation (MVT)
- Like MFT, but partition size varies dynamically
- Operating system tracks which parts of memory are in use
  - Free parts of memory often called *holes*
  - Done in a number of ways, such as bit maps, linked lists, skip lists, etc.

Example



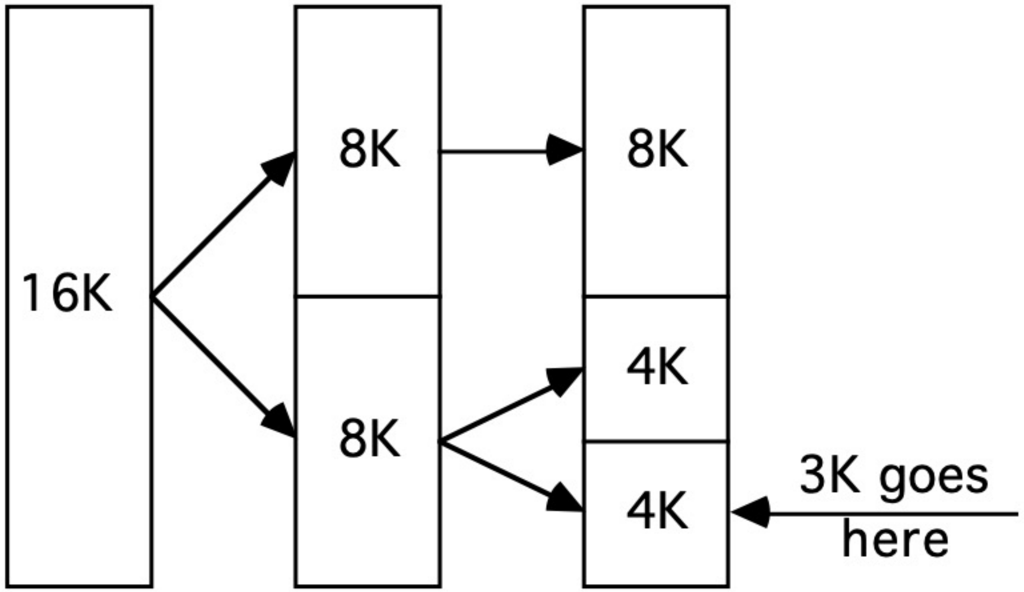
- Processes placed in holes; if hole is too big, it is split and unused portion goes back onto free list
- At process termination, add its memory to free list

Memory Allocation Schemes

- *Best fit*: holes listed in order of increasing size
  - Process is put into the smallest hole it fits
- *Worst fit*: holes listed in order of decreasing size
  - Process is put into the first hole in the list
- *First fit*: holes listed in order of increasing base address
  - Process is put into the first hole it fits
- *Next fit*: like first- fit, except the search for a hole the job fits begins where the last one left off.
- (5) buddy system deals with memory in sizes of 2i for i < k. There is a separate list for each size of hole. Put the job into a hole of the closest power of 2; if it takes up under half, return the unused half to the free list.

Memory Allocation Schemes

- *Buddy system*: Memory kept in sizes of 2^i for $i < k$
  - Separate list for each size of hole
  - Process put into hole of the closest power of 2
    - If it takes up under half, return unused half to the free list
- Example: memory of 16K, process requires 3K of memory
  - So needs to go into a 4K chunk



Process Scheduling

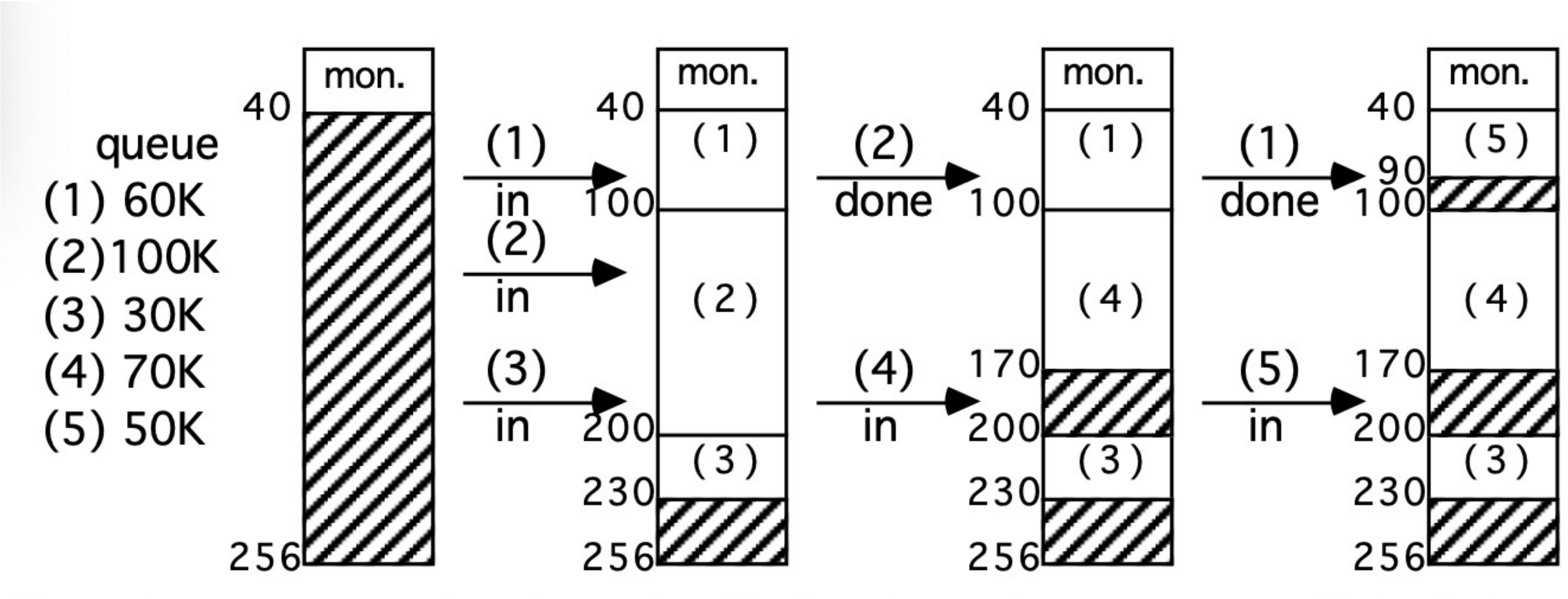
- Scheduler keeps list of available block sizes, queue of processes waiting for memory
- Order jobs according to scheduling algorithm
- Allocate memory until not enough for next process
- Two approaches:
  - Skip to next process in queue that can fit into available memory
  - Wait until enough memory available for next process

Fragmentation

- Internal fragmentation: wasted space in partition
  - With MVT, little to no internal fragmentation
- External fragmentation: wasted space between partition
  - With MVT, much external fragmentation

Fragmentation

- Example: process 5 can run simultaneously with 1, 3, 4 were the two holes combined (56K); but they were not, so 56K of fragmentation



Compaction

- Moving contents of memory about in order to combine holes
- Example: in above, move 3’s memory in third figure to 1710K
  - Combines holes in 170K-200K and 230K-256K to get 1 hole in 200K-256K
  - Now 5 can run
- Need dynamic relocation
  - Copy contents of process memory
  - Update base register appropriately

Compaction Schemes

- Move all processes to one end of memory
  - Can get expensive in time
- Move enough processes to get needed amount of contiguous memory
- Example: CDC 6600 Scope Operating System kept 8 processes in main memory at a time
  - Used compaction on process termination
  - Kept 1 hole at bottom of main memory

Reducing External Fragmentation

- Reduce average process memory size
- Break memory in 2 parts, one for instructions, one for data
- Example: PDP-11 had 2 base/bounds register pairs
  - High order bit of each indicated which half of memory (high or low) the pair refers to
  - Instructions, read-only data go into high half of memory
  - Variables, etc. go into low half of memory

More on Memory Fragmentation

- Process needs *w* words of memory
- Partition has *p* words
- Internal fragmentation exists when $w – p > 0$
  - i.e., memory internal to partition not being used
- Externakl fragmentation exists when $w – p < 0$
  - i.e., partition unused and available but is too small for any waiting process

Memory Fragmentation Example

- 22K of memory available
- Divided into partitions of sizes 4K, 4K, 4K, 10K
- In queue: 7K, 3K, 6K process memory requirements
  - 7K process goes into 10K partition; 3K internal fragmentation
  - 3K process goes into 4K partition; 1K internal fragmentation
  - 6K process waits
  - 2 4K partitions unused, so 8K external fragmentation
- Total fragmentation: 8K external, 4K internal, so 12K total
- Over 50% of memory in fragments!

Memory Fragmentation Example

- 22K of memory available
- Divided into partitions of sizes 4K, 8K, 10K
- In queue: 7K, 3K, 6K process memory requirements
  - 7K process goes into 8K partition; 1K internal fragmentation
  - 3K process goes into 4K partition; 1K internal fragmentation
  - 6K process goes into 10K partition; 4K internal fragmentation
  - all partitions used, so no external fragmentation
- Total fragmentation: 0K external, 6K internal, so 6K total
- Only 27% of memory in fragments