Selected VM Algorithms From FreeBSD

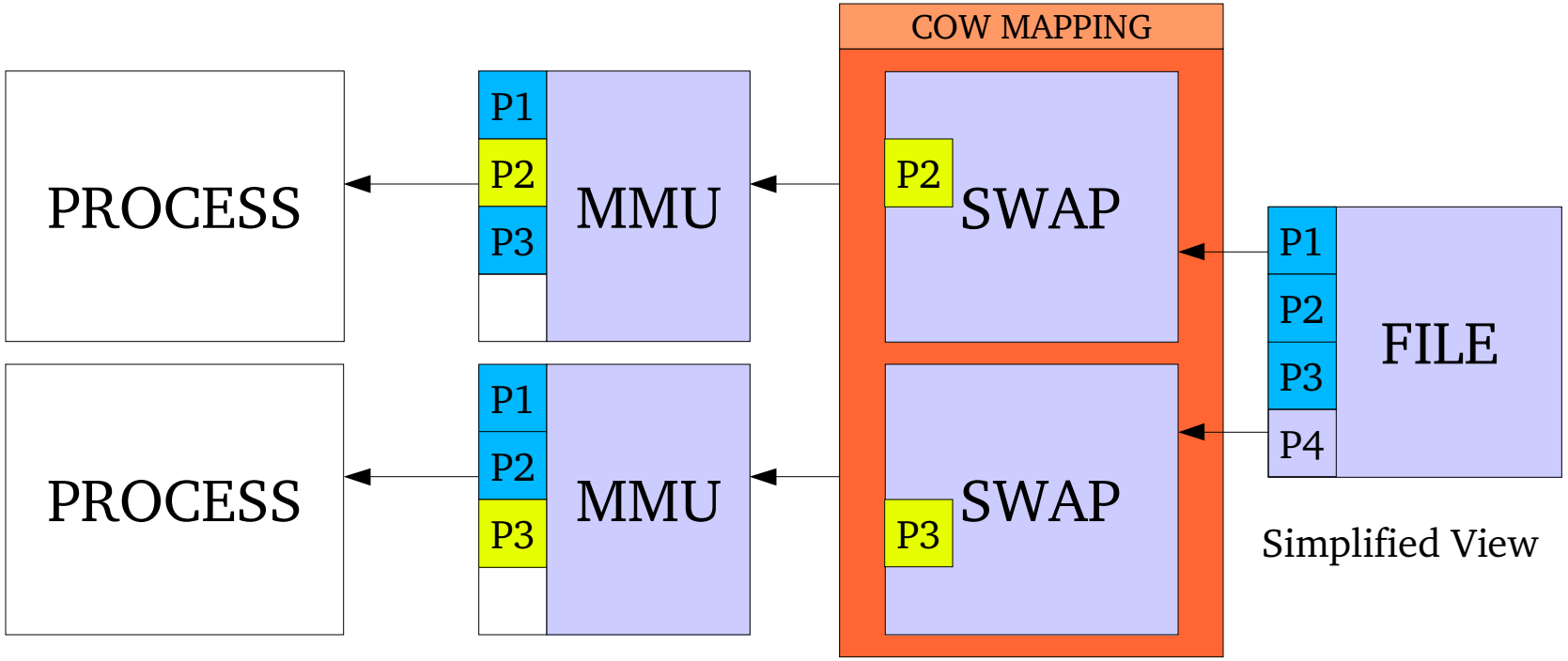
Matthew Dillon
FreeBSD Project

The FreeBSD VM System – What is Memory Anyway?

- Anonymous Memory (Allocations, backed by SWAP)
- File-Backed Memory (Program Binary, mmap())
- SysV Shared Memory
- ZAPHOD's Memory (well, ok, really ZFOD memory = zero-fill-on-demand)
- Device Memory (e.g. Like a Video Frame Buffer)

- SHARED mapping verses PRIVATE (copy-on-write) mapping

Memory Structure is Managed by VM Objects

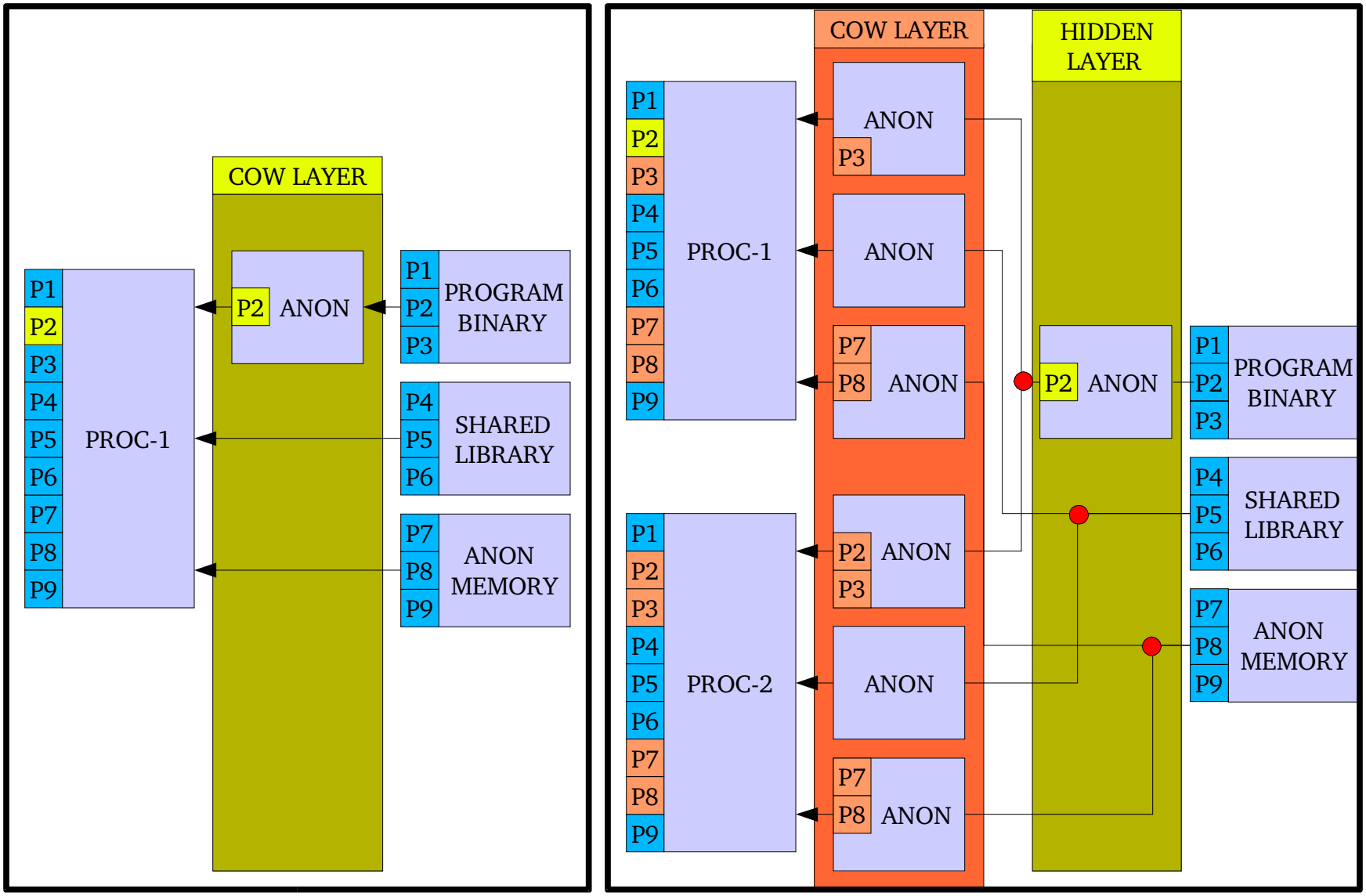


Simplified View

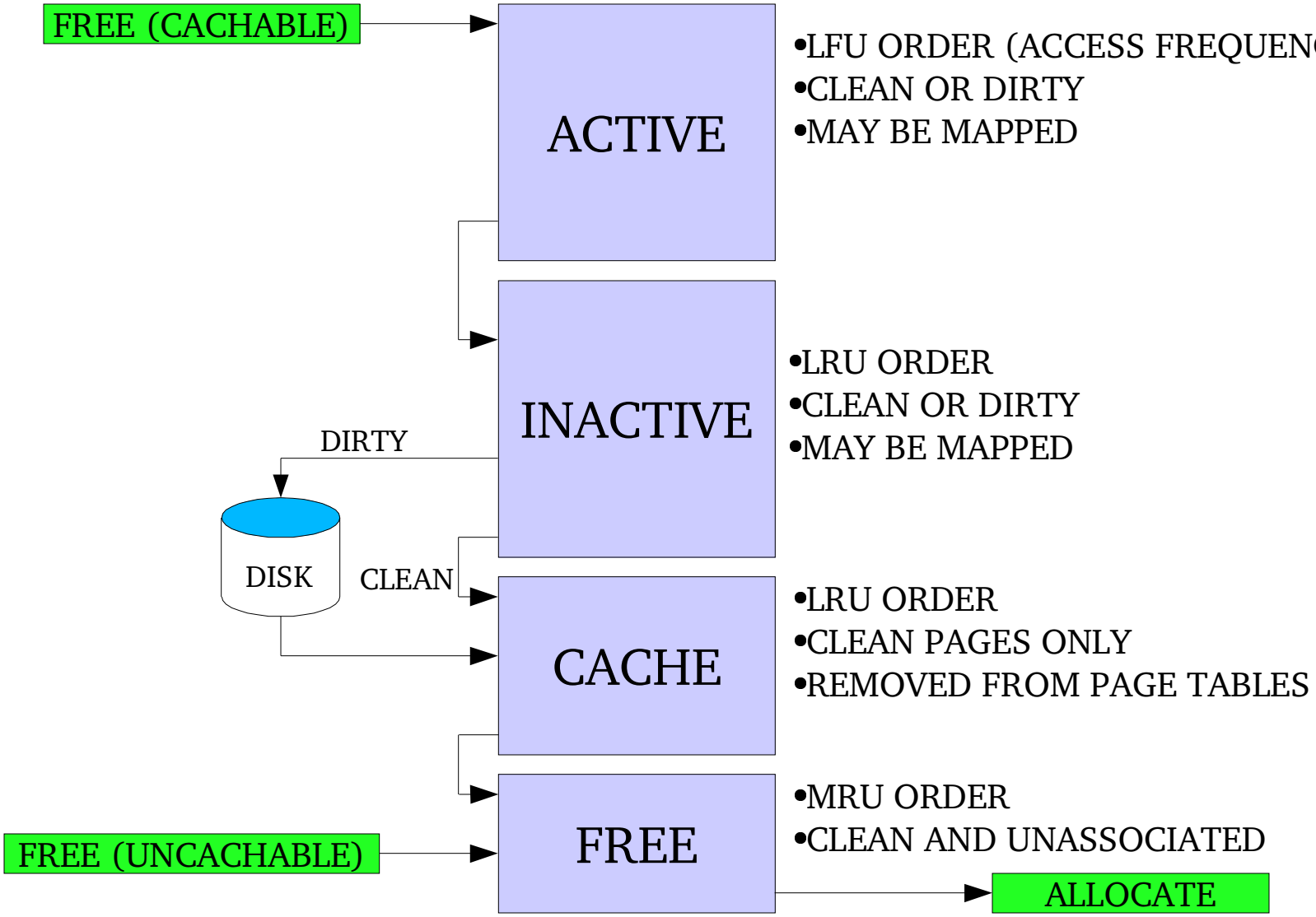
VM Object Stacking can get Complex

BEFORE FORK

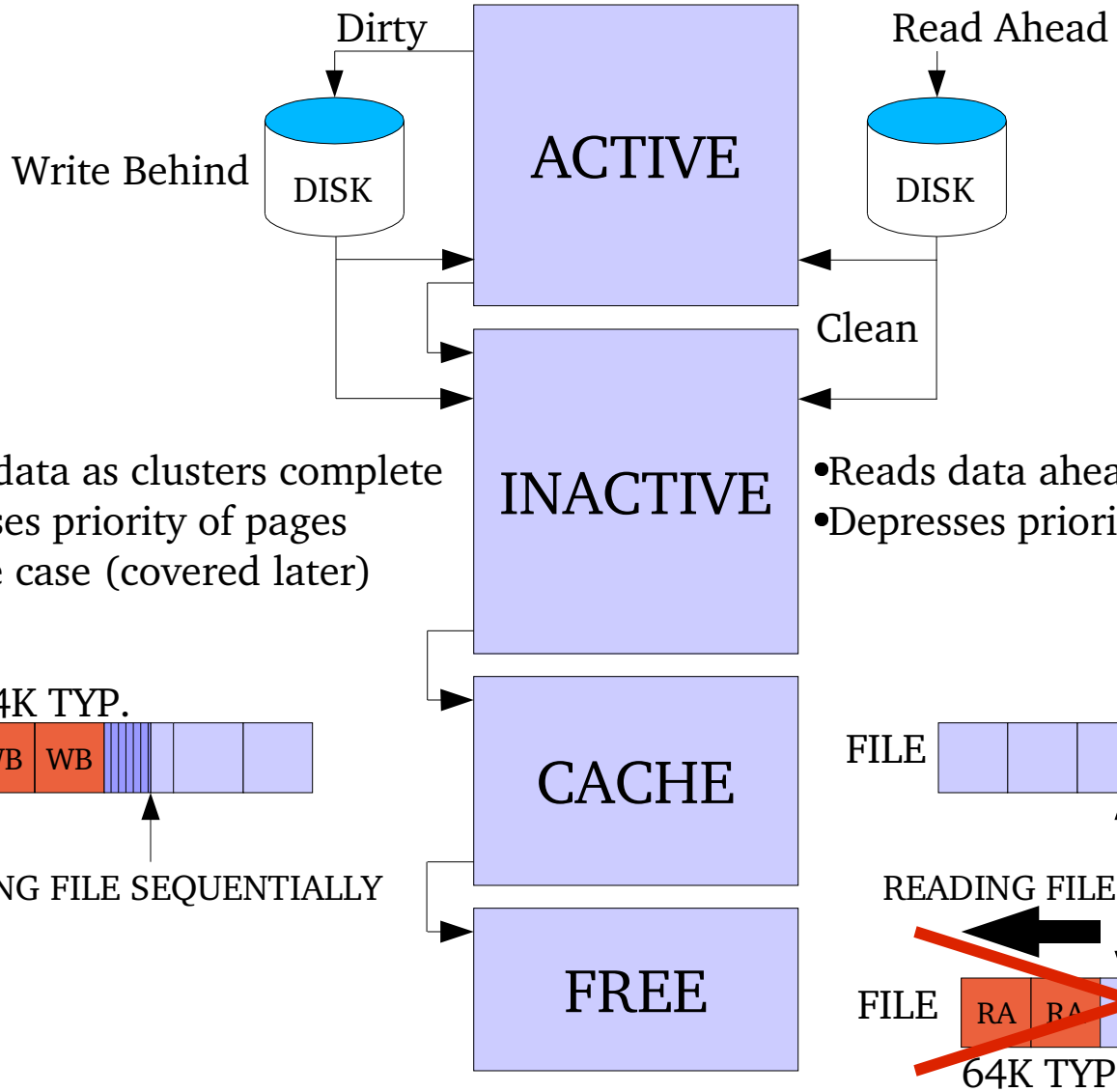
AFTER FORK



Managing Pages of Memory – VM Page Queues



Sequential Heuristics

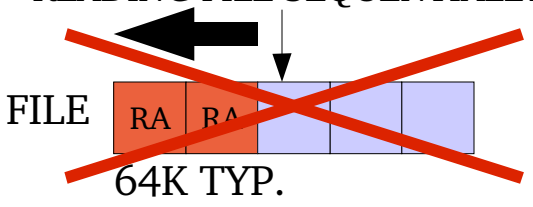


- Writes data as clusters complete
- Depresses priority of pages
- Rewrite case (covered later)

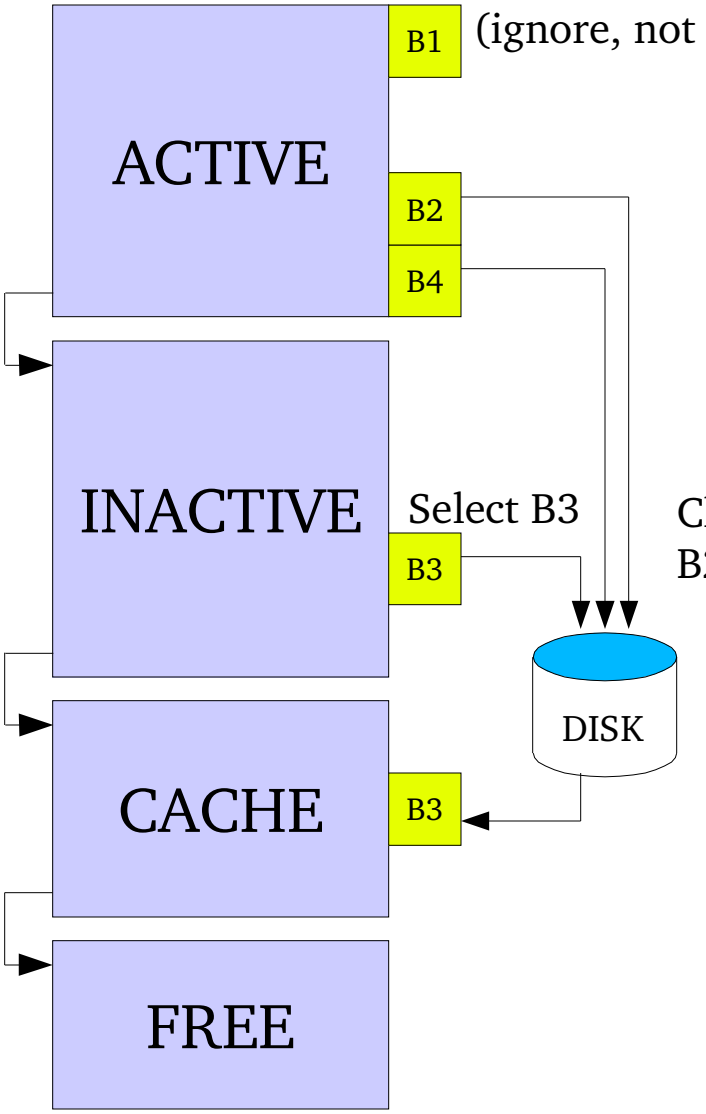
- Reads data ahead of request
- Depresses priority of RA pages

WRITING FILE SEQUENTIALLY

READING FILE SEQUENTIALLY



Write Clustering by the Pageout Daemon



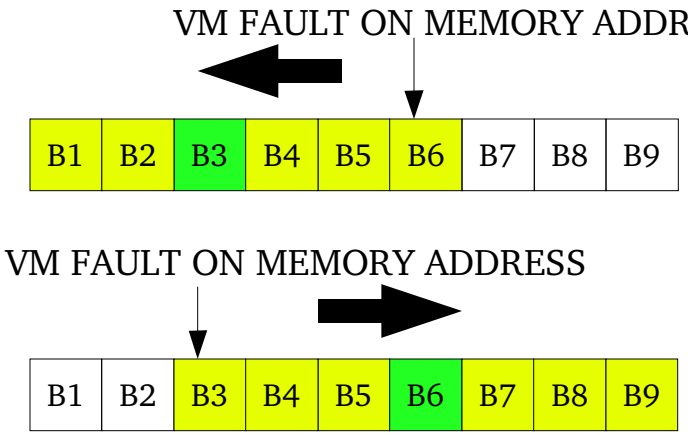
(ignore, not close to deactivation)

- Activated when we decide to clean a dirty page
- Locates other nearby dirty pages (logical)
- Must be in a state similar to the original page
- Must also be physically contiguous
- Works when writing to SWAP or to a FILE

Clustering adds
B2 and B4

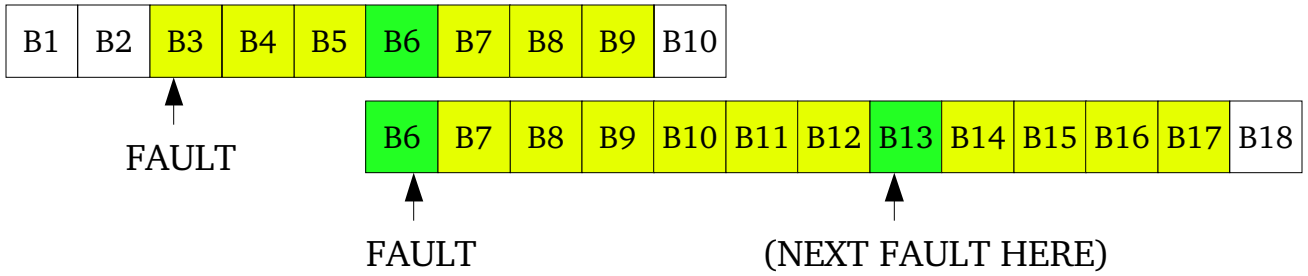
DIRTY PAGES IN VM OBJECT

Read Clustering by the VM Fault handler

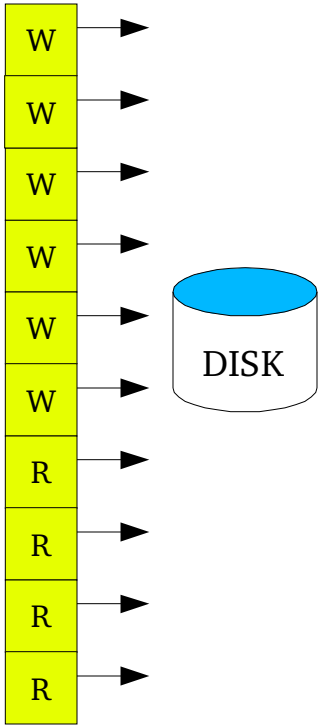


- Uses an unmapped page to trigger read-ahead
- Reads data ahead of request
- Detects if memory is being accessed backwards
- Depresses priority of RA pages
- Works when reading from a FILE or SWAP

- B3-B9 are read
- B6 is unmapped from the process (but remains in the VM Page cache)
- If a fault is taken on B6, an asynchronous read is issued for B10-B17, B13 is unmapped
- If a fault is taken on B6, the VM fault handler is able to return immediately
- Greatly improved performance, processing overhead of program overlaps I/O
- Intentional faults (e.g. B6) are used to detect direction



Running Write I/O Limit



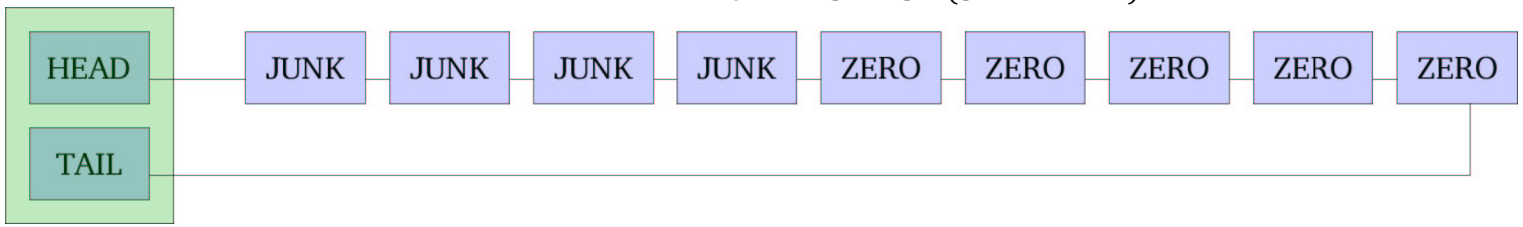
- Writes are almost always asynchronous (pageout, update)
- Reads are typically synchronous or semi-synchronous
- Tags create an issue with traditional I/O queueing and sorting
- IDE W/write-caching turned on has a similar problem
- Pace disk writes to reduce read latency
- Reserve most tags for read operations (not yet in FreeBSD)
- Priority Scheduler for I/O (not yet in FreeBSD)

vfs.lorunningspace=524288
vfs.hirunningspace=1048576

Optimizing Zero-Fill Faults

- Uses idle CPU cycles and hysteresis to pre-zero free pages
- Uses Most-Recently-Used ordering for VM page free queue
- Pulls pages off the head or tail based on need for a cleared page
- Zeros the page manually if no cleared pages available
- Some kernel facilities are able to return cleared pages to the free list

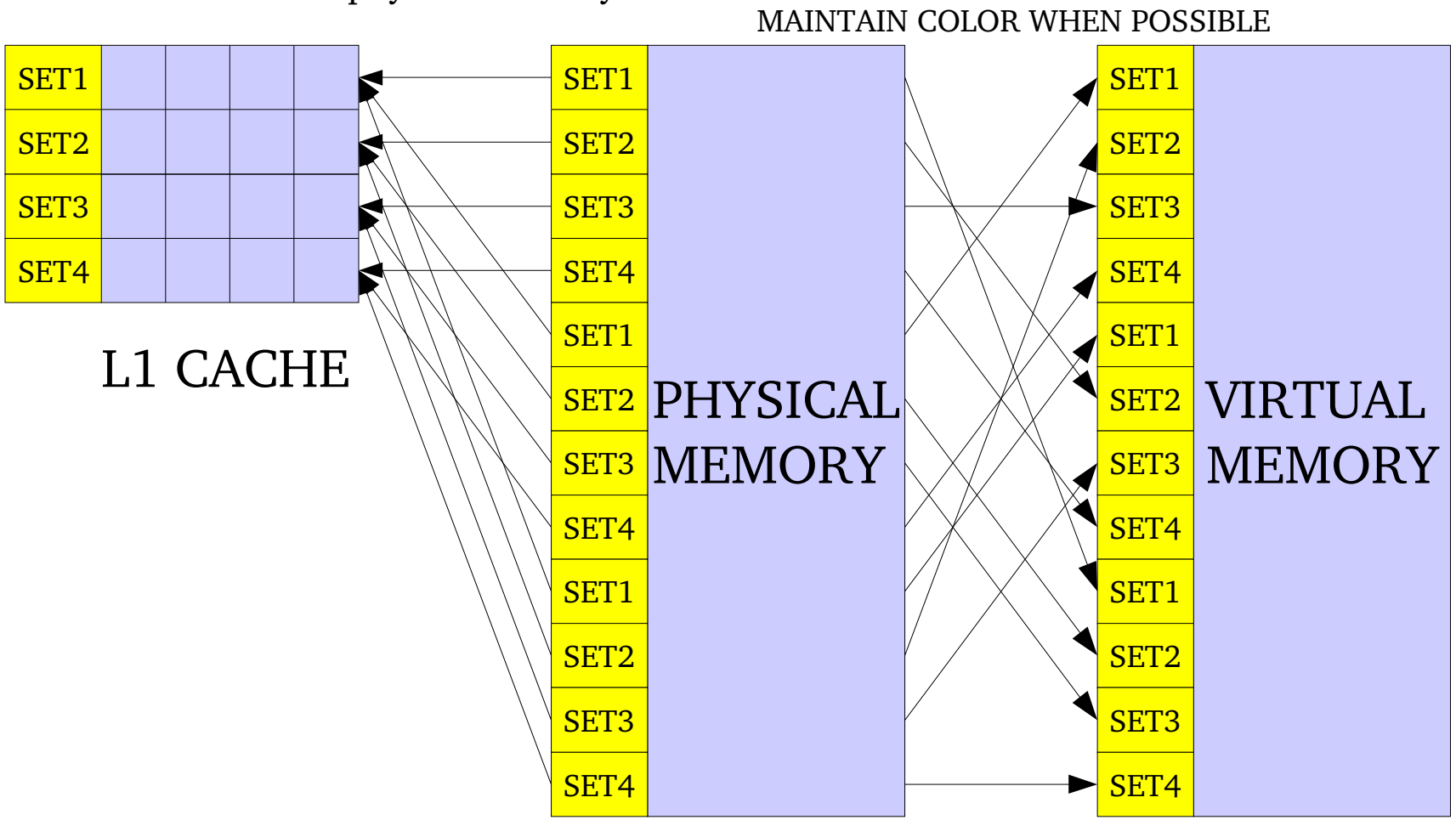
FREE PAGE LIST (SIMPLIFIED)



- Actually multiple lists, indexed by cache color (next slide)

Cache Color

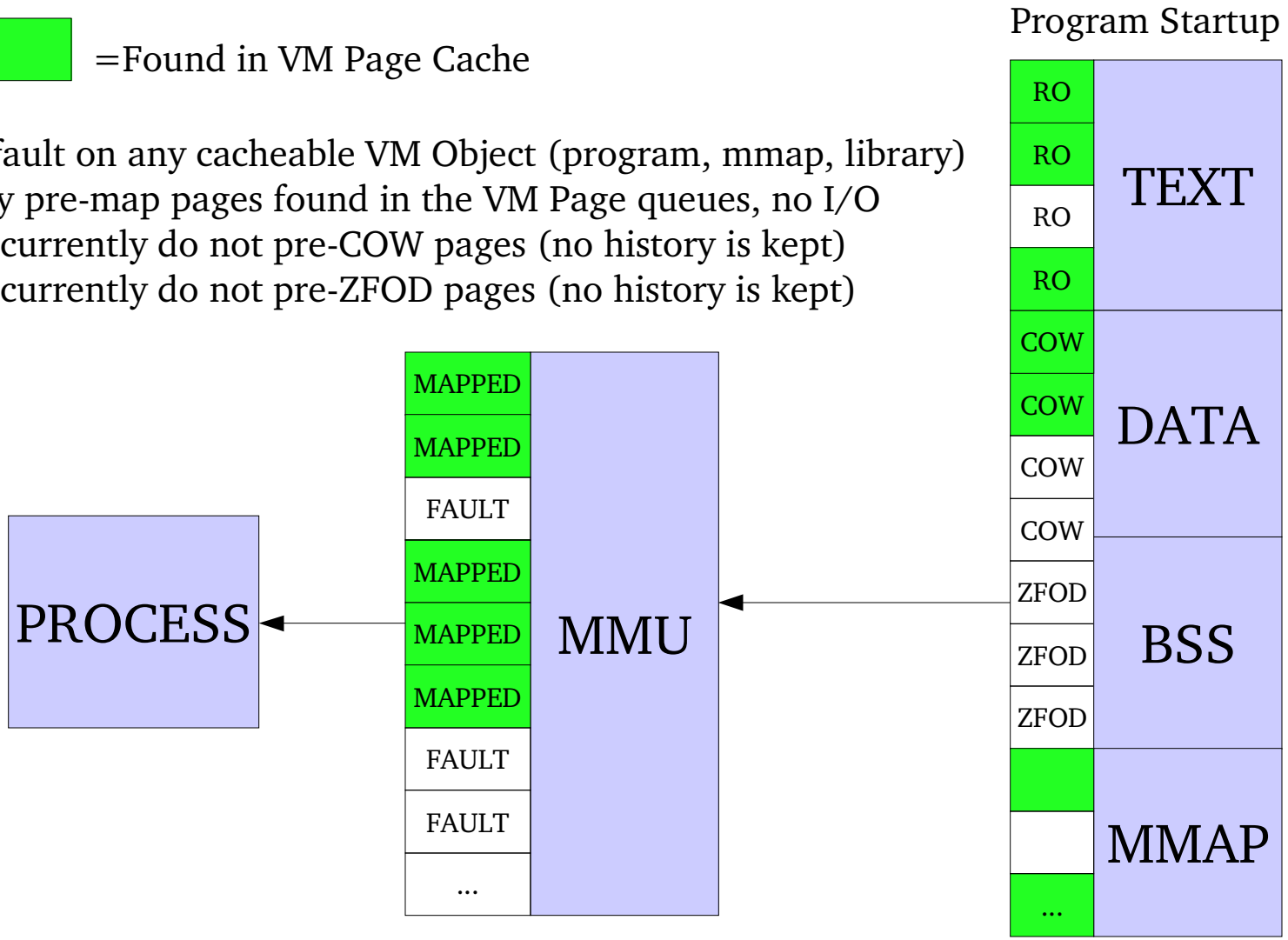
- Make Linear addresses of VM have the same cache behavior as linear addresses of physical memory.



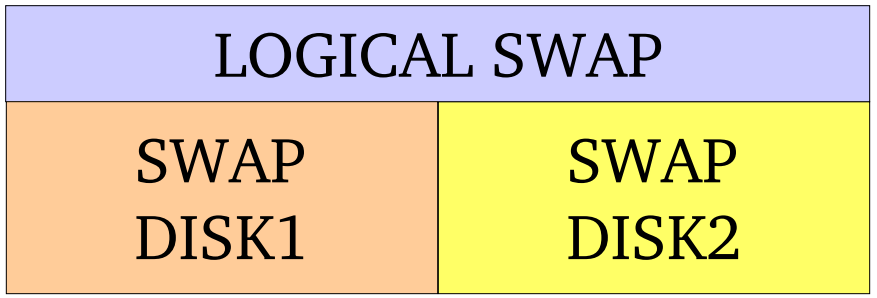
Prefaulting Pages to Improve Performance

=Found in VM Page Cache

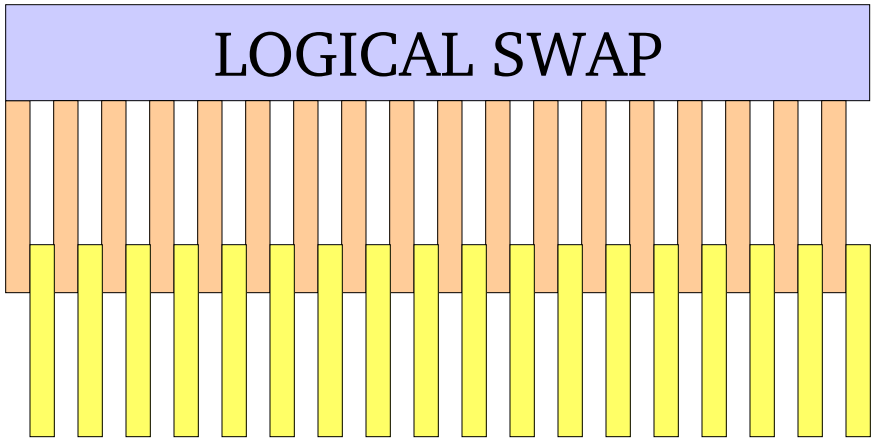
- Prefault on any cacheable VM Object (program, mmap, library)
- Only pre-map pages found in the VM Page queues, no I/O
- We currently do not pre-COW pages (no history is kept)
- We currently do not pre-ZFOD pages (no history is kept)



Interleaved SWAP



Non-Interleaved SWAP



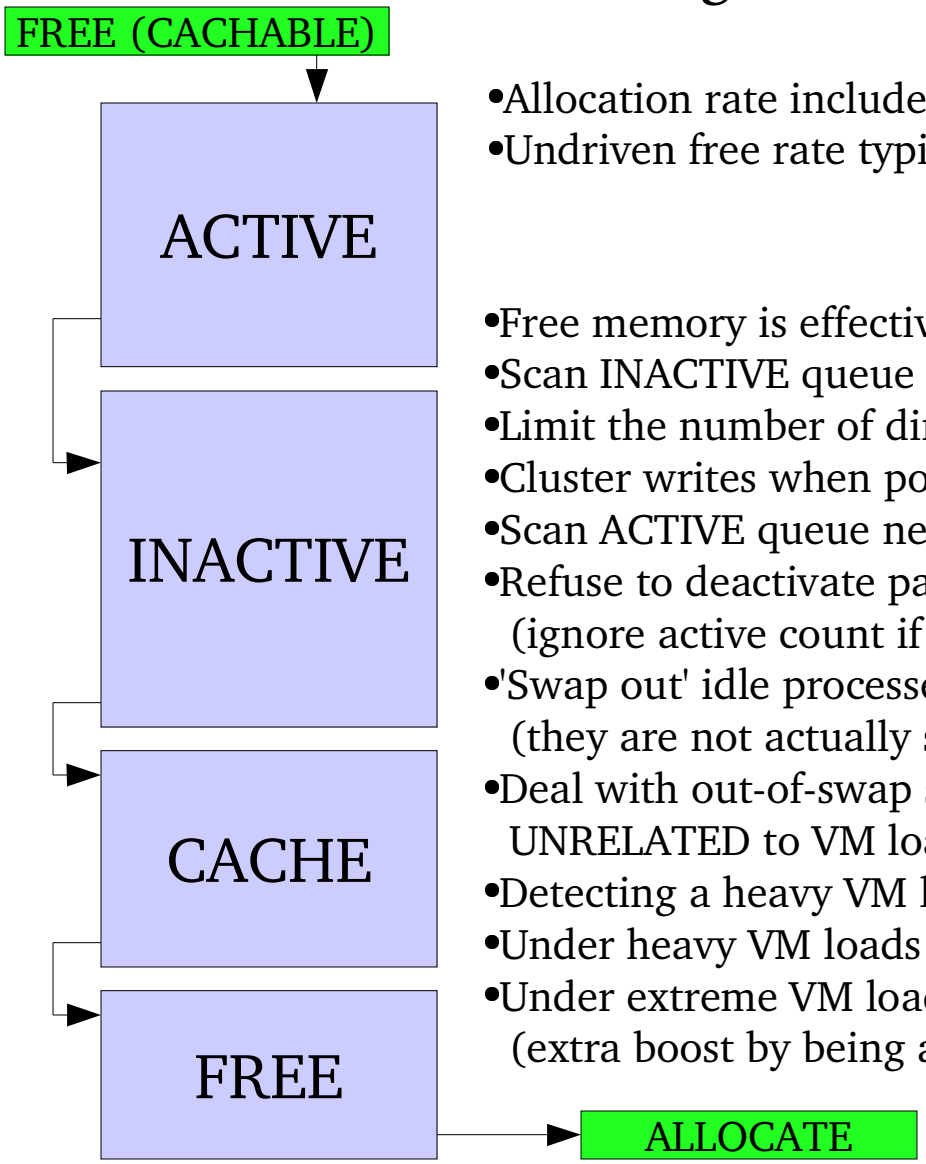
Interleaved SWAP

SWAP DISK 1

SWAP DISK 2

16-page chunks

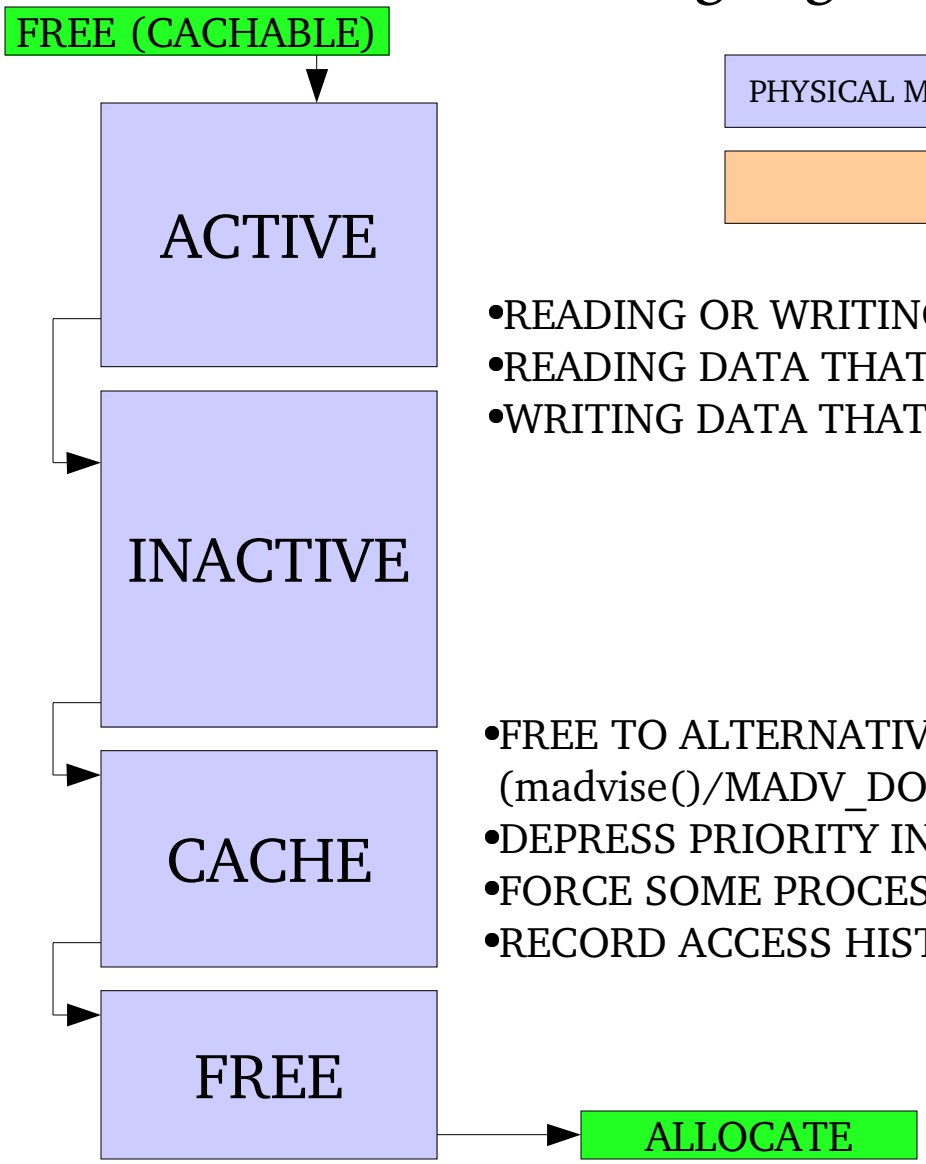
Scaling to the VM Load



- Allocation rate includes pageins, but not a good indicator of load
- Undriven free rate typically due to program exits

- Free memory is effectively CACHE+FREE
- Scan INACTIVE queue first, INACTIVE->CACHE
- Limit the number of dirty pages Laundered
- Cluster writes when possible
- Scan ACTIVE queue next, deactivating pages, ACTIVE->INACTIVE
- Refuse to deactivate pages with a non-zero active count
  (ignore active count if object not referenced, revert to LRU)
- 'Swap out' idle processes only by depressing their paging priority
  (they are not actually swapped out synchronously)
- Deal with out-of-swap situations. Out-of-swap situations are
  UNRELATED to VM load.
- Detecting a heavy VM load: check CACHE+FREE at end of pass
- Under heavy VM loads enforce 'memoryuse' resource limit
- Under extreme VM loads, force runnable processes to go idle
  (extra boost by being able to free pagetable pages)

Where Caching Algorithms Break Down



PHYSICAL MEMORY (256M)

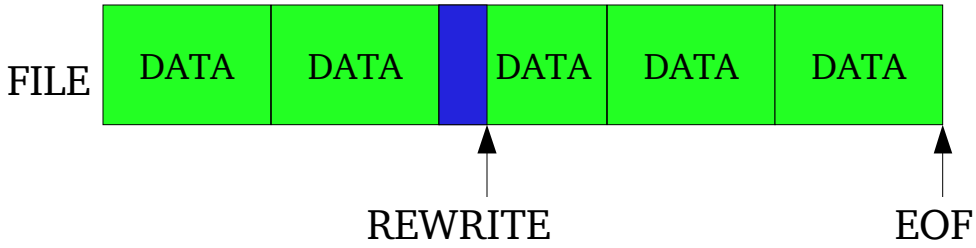
HUGE FILE (512M)

- READING OR WRITING A HUGE FILE (> PHYSICAL MEMORY)
- READING DATA THAT WILL NOT BE READ AGAIN SOON
- WRITING DATA THAT WILL NOT BE READ AGAIN SOON

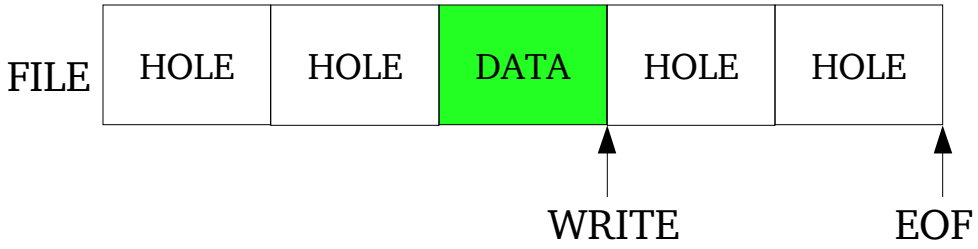
2000 PROCESSES (OOPS!)

- FREE TO ALTERNATIVE LOCATION IN VM PAGE QUEUES (madvise()/MADV_DONTNEED)
- DEPRESS PRIORITY IN ACTIVE QUEUE (DEPRESS-BEHIND)
- FORCE SOME PROCESSES TO GO IDLE FOR A PERIOD OF TIME
- RECORD ACCESS HISTORY OF OBJECT

Where Caching Algorithms Break Down



- Small-block file rewrite case (mismatched filesystem block size)
- Sequential Heuristic can help



- Filesystem fragmentation messes up read and write clustering
- Always write out the 'file' representing a new virtual disk