22. Swaping: Policies

Operating System: Three Easy Pieces

Beyond Physical Memory: Policies

- Memory pressure forces the OS to start paging out pages to make room for actively-used pages.
- Deciding which page to evict is encapsulated within the replacement policy of the OS.

Cache Management

- Goal in picking a replacement policy for this cache is to minimize the number of cache misses.
- The number of cache hits and misses let us calculate the *average memory access time(AMAT).*

$$AMAT = (P_{Hit} * T_M) + (P_{Miss} * T_D)$$

Arguement	Meaning
T_M	The cost of accessing memory
T_D	The cost of accessing disk
P_{Hit}	The probability of finding the data item in the cache(a hit)
P_{Miss}	The probability of not finding the data in the cache(a miss)

The Optimal Replacement Policy

- Leads to the fewest number of misses overall
  - Replaces the page that will be accessed furthest in the future
  - Resulting in the fewest-possible cache misses
- Serve only as a comparison point, to know how close we are to perfect

Tracing the Optimal Policy

Reference Row

0 1 2 0 1 3 0 3 1 2 1

Access	Hit/Miss?	Evict	Resulting Cache State
0	Miss		0
1	Miss		0,1
2	Miss		0,1,2
0	Hit		0,1,2
1	Hit		0,1,2
3	Miss	2	0,1,3
0	Hit		0,1,3
3	Hit		0,1,3
1	Hit		0,1,3
2	Miss	3	0,1,2
1	Hit		0,1,2

Compulsory
Capacity
~~Conflict~~

Hit rate is $\frac{Hits}{Hits+Misses} = \mathbf{54.6\%}$

Future is not known.

A Simple Policy: FIFO

- Pages were placed in a queue when they enter the system.
- When a replacement occurs, the page on the tail of the queue(the "**First-in**" pages) is evicted.
  - It is simple to implement, but can't determine the importance of blocks.

Tracing the FIFIO Policy

Reference Row

0 1 2 0 1 3 0 3 1 2 1

Access	Hit/Miss?	Evict	Resulting Cache State
0	Miss		0
1	Miss		0,1
2	Miss		0,1,2
0	Hit		0,1,2
1	Hit		0,1,2
3	Miss	0	1,2,3
0	Miss	1	2,3,0
3	Hit		2,3,0
1	Miss		3,0,1
2	Miss	3	0,1,2
1	Hit		0,1,2

Hit rate is $\frac{Hits}{Hits+Misses} = \mathbf{36.4}\%$

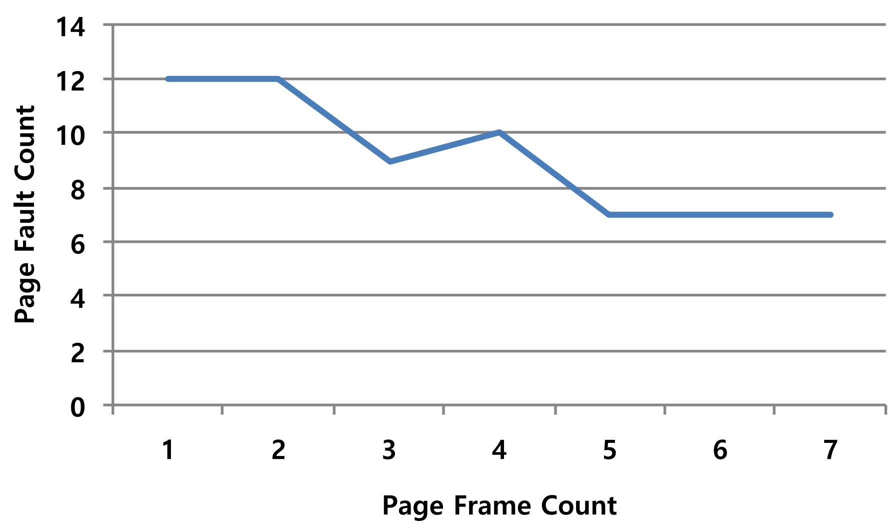
Even though page 0 had been accessed a number of times, FIFO still kicks it out.

BELADY'S ANOMALY

- We would expect the cache hit rate to increase when the cache gets larger. But in this case, with FIFO, it gets worse.

Reference Row

1 2 3 4 1 2 5 1 2 3 4 5



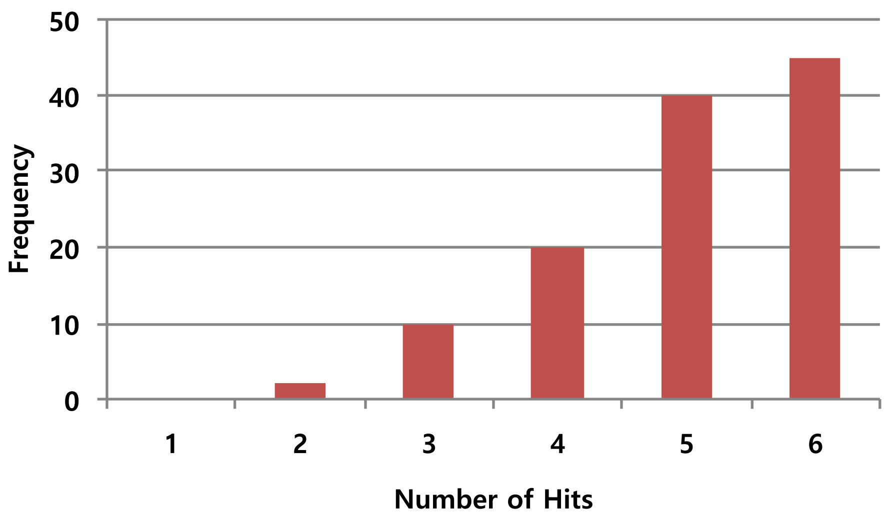
Another Simple Policy: Random

- Picks a random page to replace under memory pressure.
  - It doesn't really try to be too intelligent in picking which blocks to evict.
  - Random does depends entirely upon how lucky Random gets in its choice.

Access	Hit/Miss?	Evict	Resulting Cache State
0	Miss		0
1	Miss		0,1
2	Miss		0,1,2
0	Hit		0,1,2
1	Hit		0,1,2
3	Miss	0	1,2,3
0	Miss	1	2,3,0
3	Hit		2,3,0
1	Miss	3	2,0,1
2	Hit		2,0,1
1	Hit		2,0,1

Random Performance

- Sometimes, Random is as good as optimal, achieving 6 hits on the example trace (10.000 trials, i.e. seeds).



Random Performance over 10,000 Trials

Using History

- Lean on the past and use **history**.
  - Two type of historical information.

Historical Information	Meaning	Algorithms
recency	The more recently a page has been accessed, the more likely it will be accessed again	LRU
frequency	If a page has been accessed many times, It should not be replaced as it clearly has some value	LFU

Using History : LRU

- Replaces the least-recently-used page.

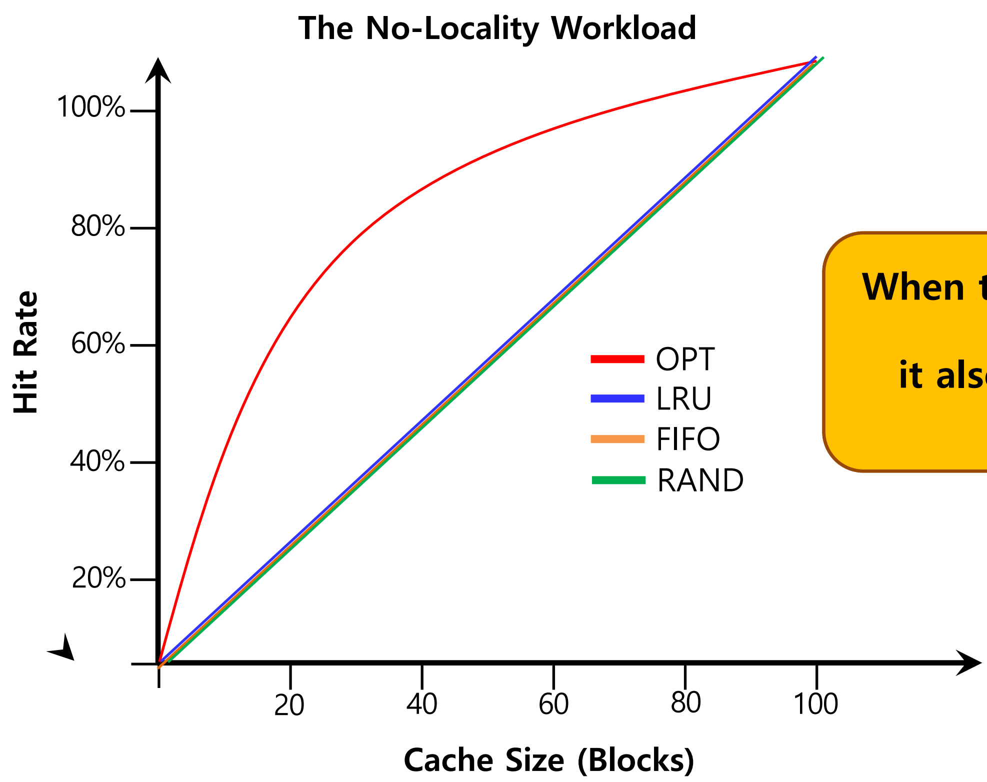
Reference Row

0 1 2 0 1 3 0 3 1 2 1

Access	Hit/Miss?	Evict	Resulting Cache State
0	Miss		0
1	Miss		0,1
2	Miss		0,1,2
0	Hit		1,2,0
1	Hit		2,0,1
3	Miss	2	0,1,3
0	Hit		1,3,0
3	Hit		1,0,3
1	Hit		0,3,1
2	Miss	0	3,1,2
1	Hit		3,2,1

Workload Example : The No-Locality Workload

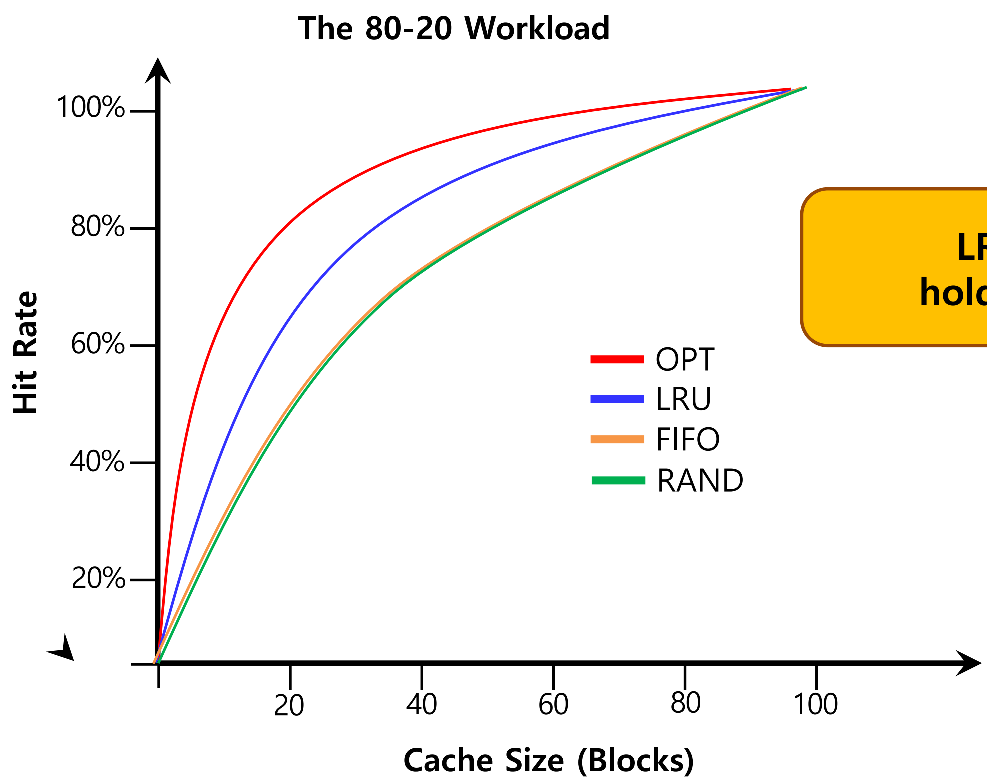
- Each reference is to a random page within the set of accessed pages.
  - Workload accesses 100 unique pages over time.
  - Choosing the next page to refer to at random



When the cache is large enough to fit the entire workload, it also doesn't matter which policy you use.

Workload Example : The 80-20 Workload

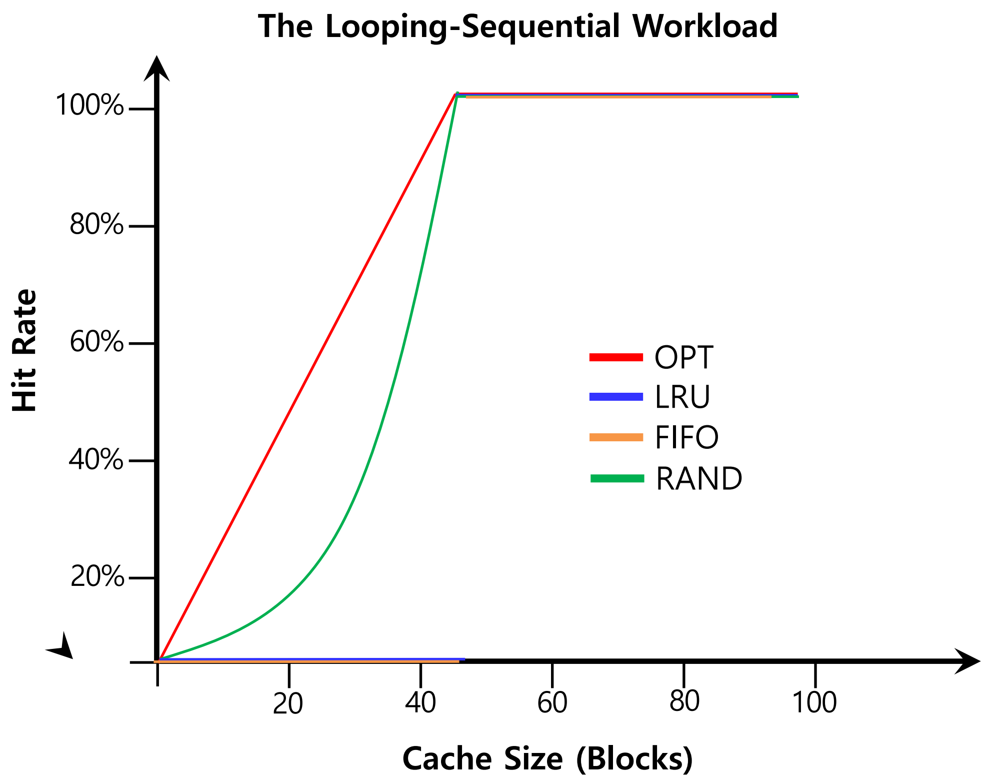
- Exhibits locality: 80% of the references are made to 20% of the pages
- The remaining 20% of the references are made to the remaining 80% of the pages.



LRU is more likely to hold onto the hot pages.

Workload Example : The Looping Sequential

- Refer to 50 pages in sequence.
  - Starting at 0, then 1, … up to page 49, and then we Loop, repeating those accesses, for total of 10,000 accesses to 50 unique pages.



Implementing Historical Algorithms

- To keep track of which pages have been least-and-recently used, the system has to do some accounting work on **every memory reference.**
  - Add a little bit of hardware support.

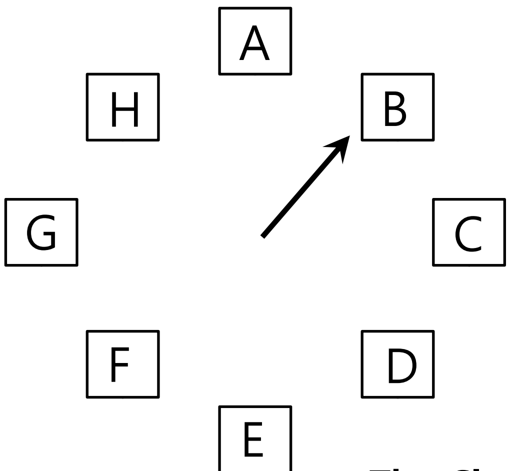
- Full LRU support could be overwhelming
  - A 2GB process with 4KB-size pages, has 512K pages: LRU is unsustainable
    - Computational effort of updating accesses and replacing pages
    - Costly TLB accesses, memory overhead, etc…

Approximating LRU

- Relax requirements of hardware support, in the form of a **use bit**
  - Whenever a page is referenced, the use bit is set by hardware to 1.
  - Hardware never clears the bit, though; that is the responsibility of the OS
- Clock Algorithm
  - All pages of the system arranges in a circular list.
  - A clock hand points to some particular page to begin with.
- Any algorithm that clears the "use" bit periodically might suffice

Clock Algorithm

- The algorithm continues until it finds a use bit that is set to 0.



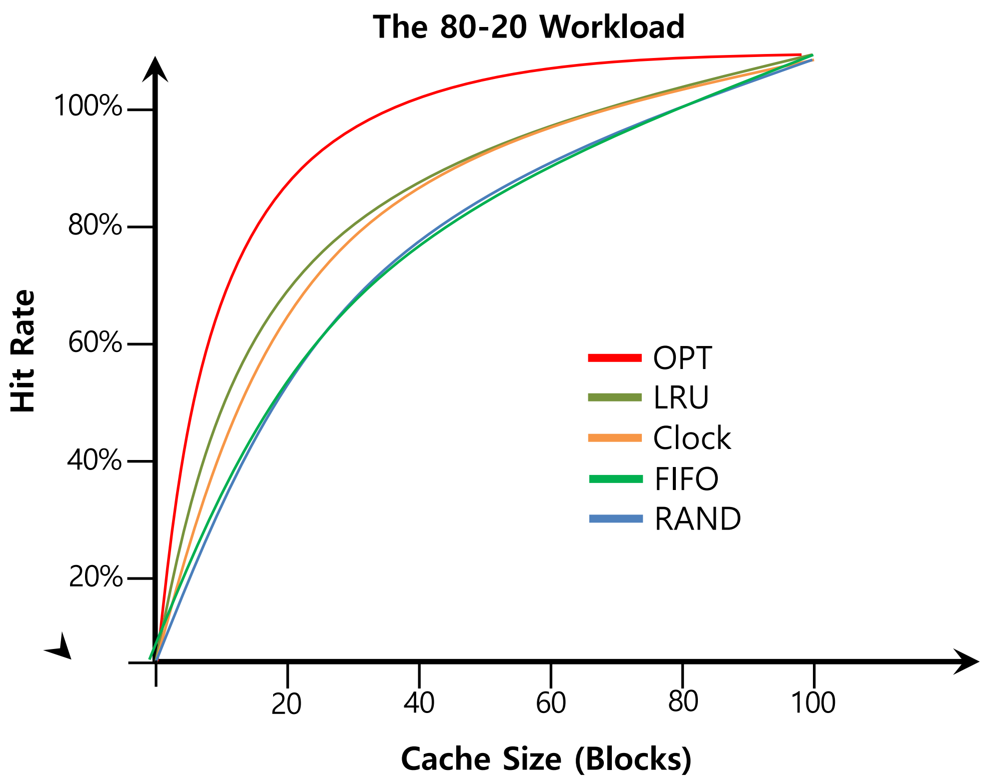
Use bit	Meaning
0	Evict the page
1	Clear **Use bit** and advance hand

The Clock page replacement algorithm

When swap daemon kicks-in, the page the hand is pointing to is inspected. The action taken depends on the Use bit

Workload with Clock Algorithm

- Clock algorithm doesn’t do as well as perfect LRU, it does better then approach that don’t consider history at all.



Considering Dirty Pages (in the clock algorithm)

- Save I/O activity of possible
  - Silent evictions are preferred over non-silent (i.e. avoid OUT disk operations)

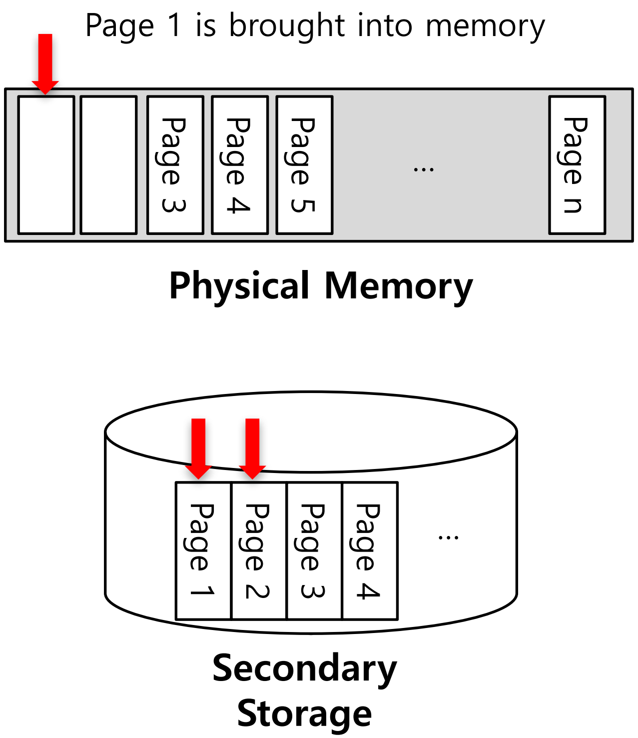
- The hardware include a **modified bit** (a.k.a **dirty bit**)
  - Page has been **modified** and is thus **dirty**, it must be written back to disk to evict it.
  - Page has not been modified, the eviction is free.

Page Selection Policy

- The OS has to decide when to bring a page into memory.
- Presents the OS with some different options.

Prefetching

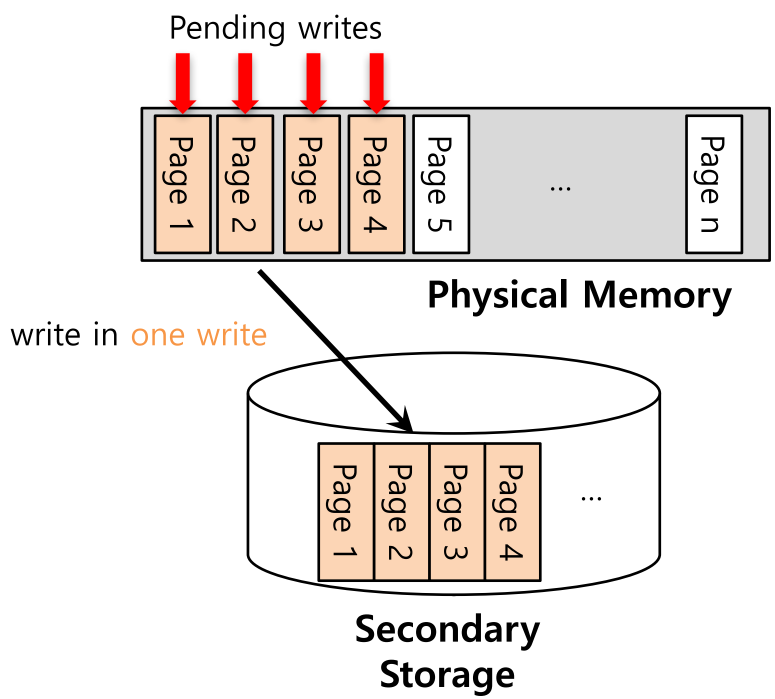
- The OS guess that a page is about to be used, and thus bring it in ahead of time.



Page 2 likely soon be accessed and thus should be brought into memory too

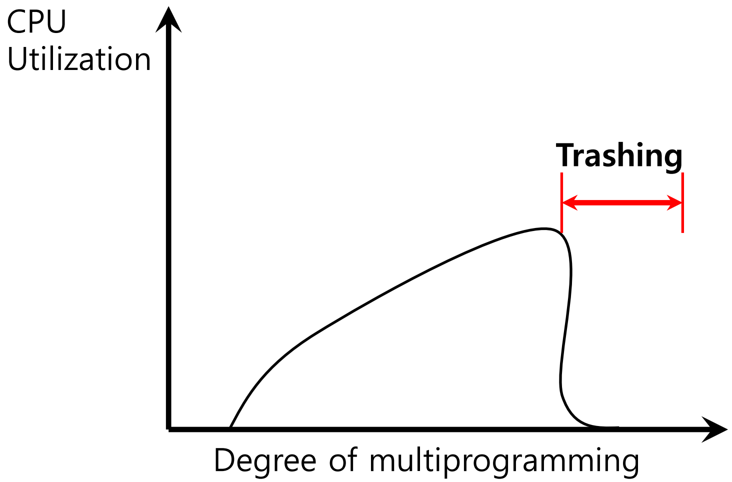
Clustering, Grouping

- Collect a number of pending writes together in memory and write them to disk in one write.
  - Perform a **single large write** more efficiently than **many small ones**.



Thrashing

- Memory is oversubscribed and the memory demands of the set of running processes exceeds the available physical memory.
  - Decide not to run a subset of processes.
  - Reduced set of processes working sets fit in memory.
  - Linux take : OOM (out-of-memory killer)



- Disclaimer: Disclaimer: This lecture slide set is used in AOS course at University of Cantabria by V.Puente. Was initially developed for Operating System course in Computer Science Dept. at Hanyang University. This lecture slide set is for OSTEP book written by Remzi and Andrea Arpaci-Dusseau (at University of Wisconsin)