Operating Systems

22. Swapping: Policies

Goal of Cache Management

- to minimize the number of cache misses.
- 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

- Lead to the fewest number of misses overall.
  - Replace the page that will be accessed furthest in the future.
  - Result 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

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 FIFO 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 $\frac{Hits}{Hits+Misses} = \mathbf{36.4\%}$

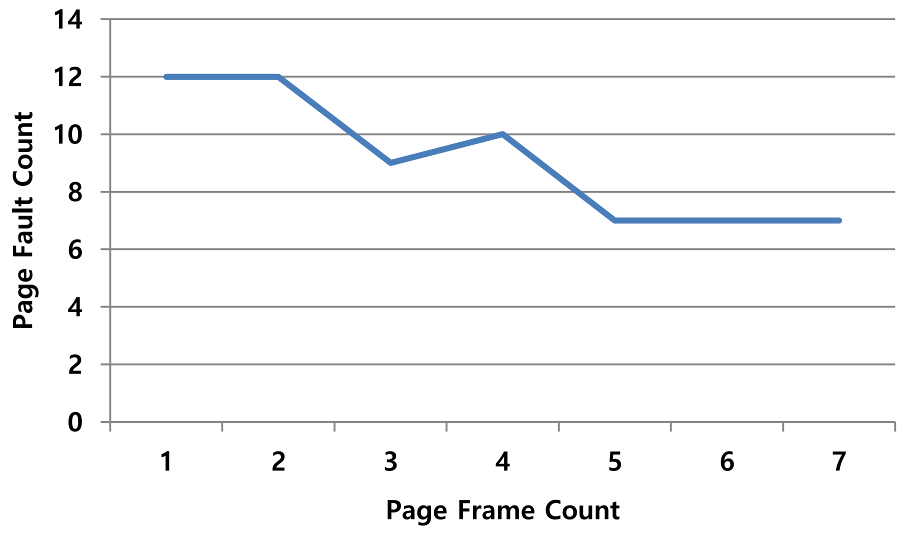
Even though page 0 had been accessed a number of times, FIFO still kicks it out.

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



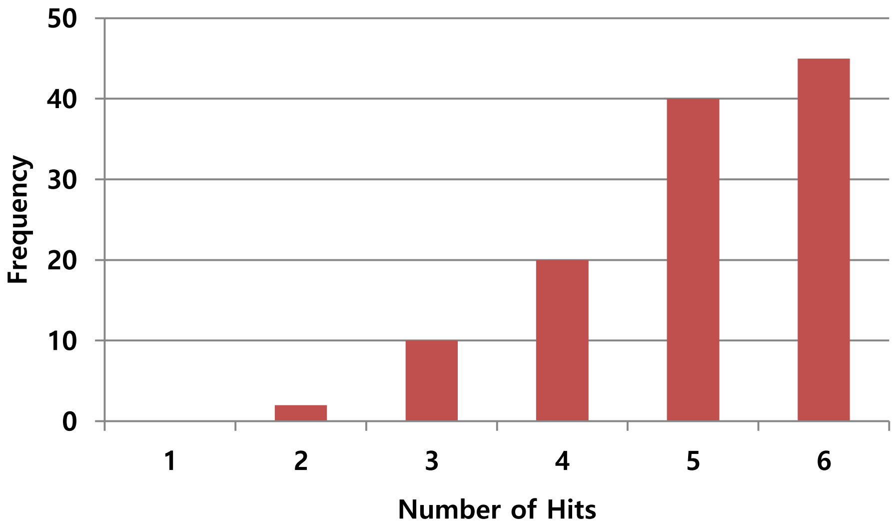
Another Simple Policy: Random

- 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.



Random Performance over 10,000 Trials

Using History

- Learn 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 replcaed as it clearly has some value	LFU

Using History : LRU

- Replace the least-recently-used page.

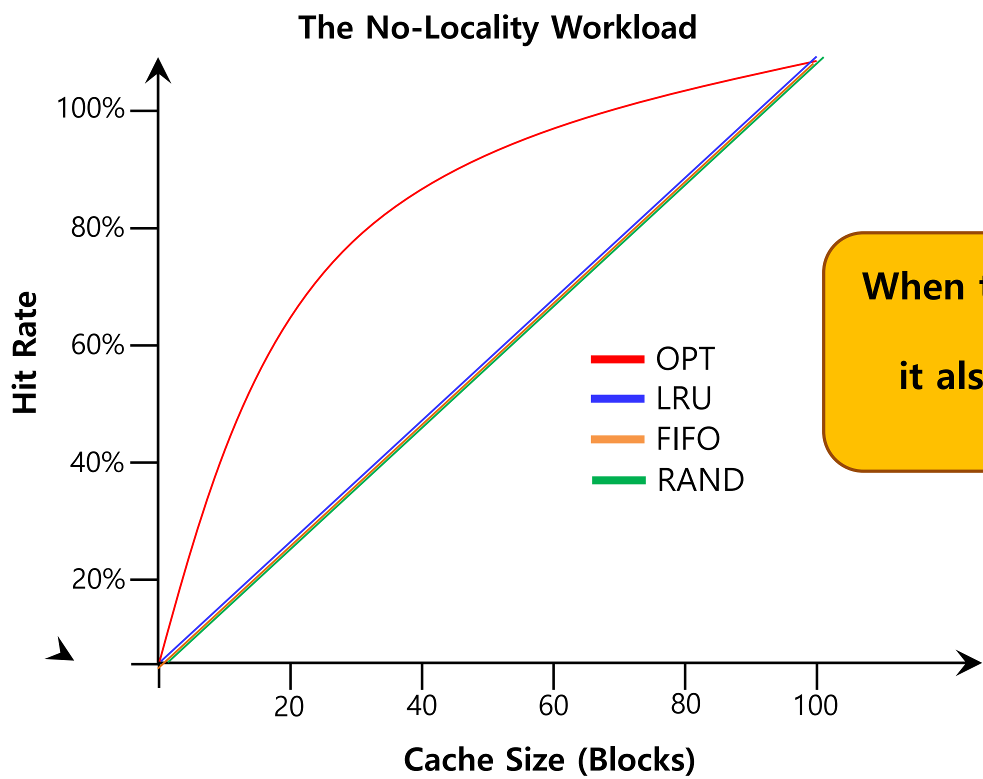
Reference Row

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

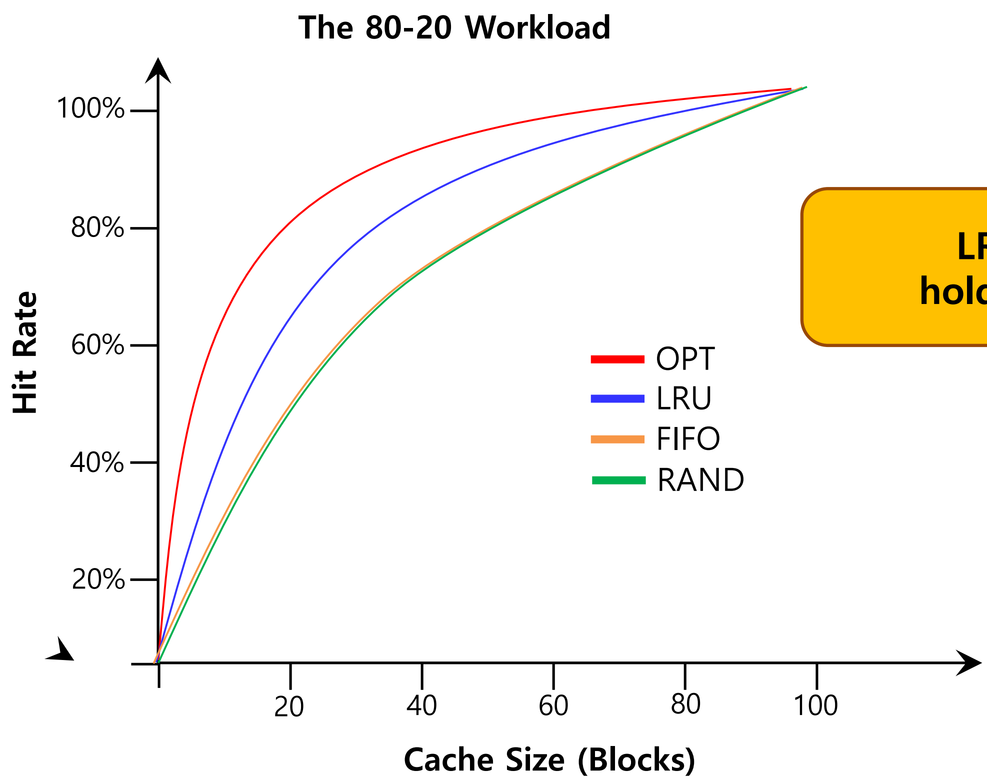
- Each reference is to a random page within the set of accessed pages.
  - Workload accesses 100 unique pages over time.
  - Choosing the next page to refer to at random



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

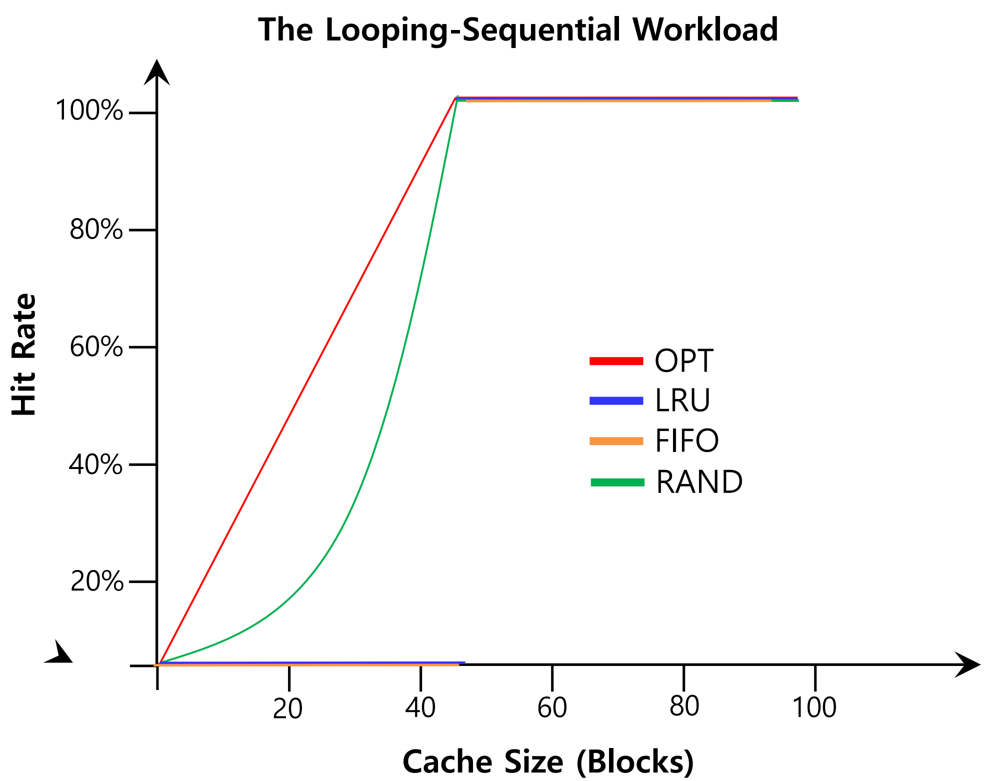
- Exhibits locality: 80% of the reference are made to 20% of the page
- The remaining 20% of the reference are made to the remaining 80% of the pages.



LRU is more likely to hold onto the hot pages.

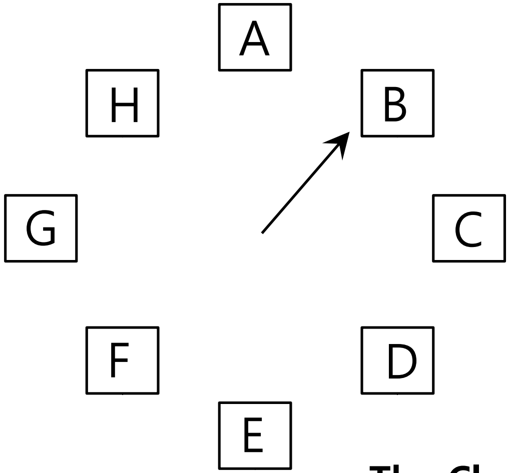
Workload Example : The Looping Sequential

- 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.



Approximating LRU: Clock Algorithm

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

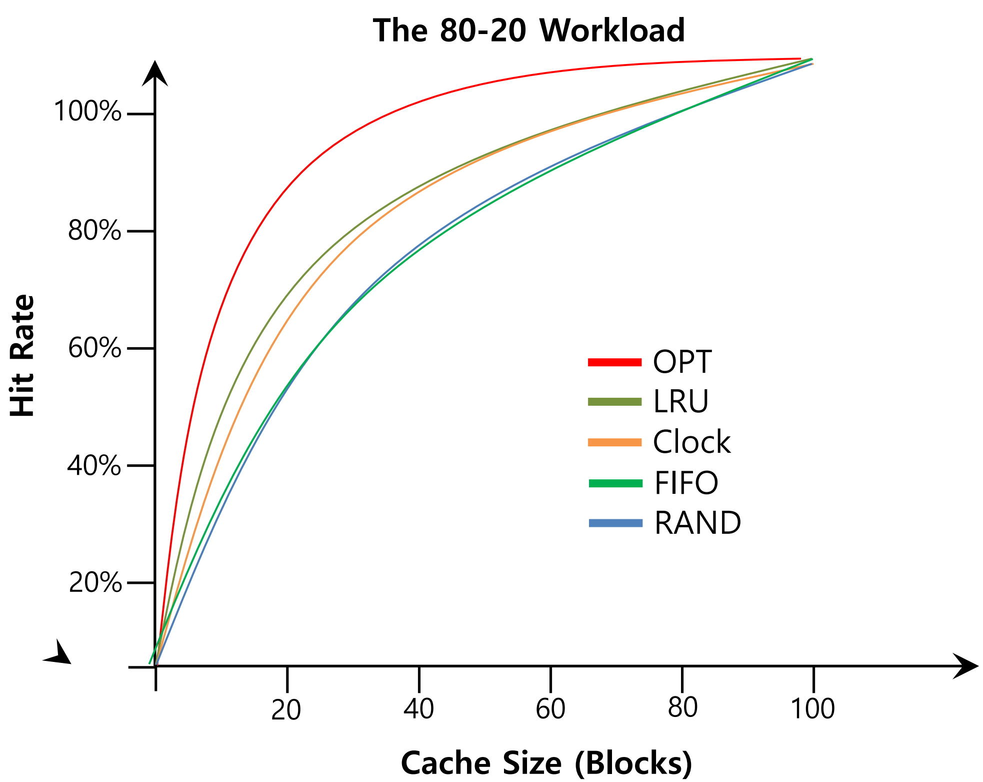


Use bit	Meaning
0	Evict the page
1	Clear **Use bit** and advance hand

The Clock page replacement algorithm

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.

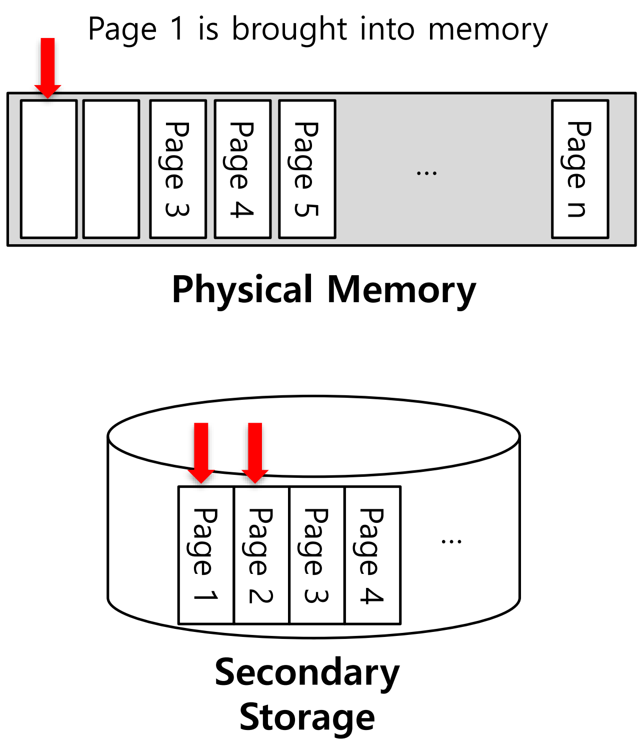


Considering Dirty Pages

- The hardware includes 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.

Prefetching

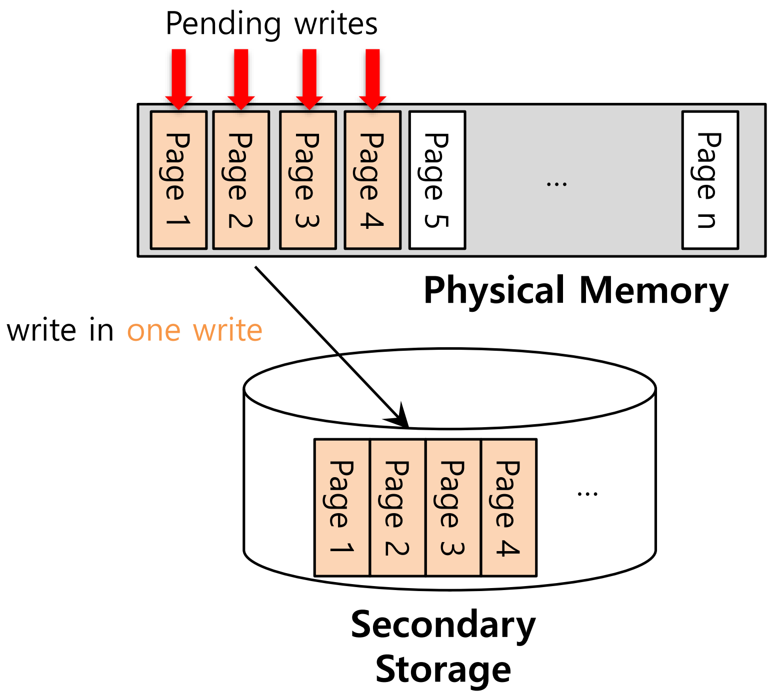
- The OS guesses that a page is about to be used, and thus bring it in ahead of time.



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

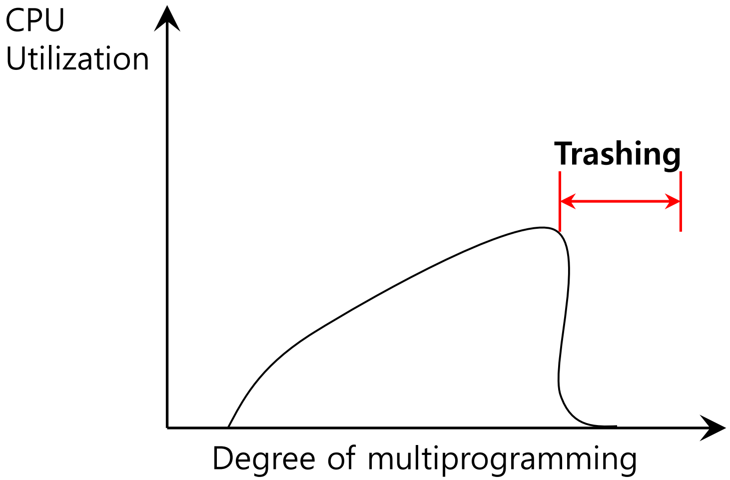
Clustering, Grouping

- 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.



Summary

- Swapping: use part of disk as memory
- LRU, LFU, RANDOM, FIFO
- Approximation to LRU: Clock
- Making the disk IO in larger unit
  - Clustering
  - Grouping
  - prefetching