Locality of Reference

In view of the previous slide, it makes sense to design programs so that data is read from and written to disk in relatively large chunks… but there is more.

Spatial Locality of Reference

In many cases, if a program accesses one part of a file, there is a high probability that the program will access nearby parts of the file in the near future.

Moral: grab a larger chunk than you immediately need.

Temporal Locality of Reference

In many cases, if a program accesses one part of a file, there is a high probability that the program will access the same part of the file again in the near future.

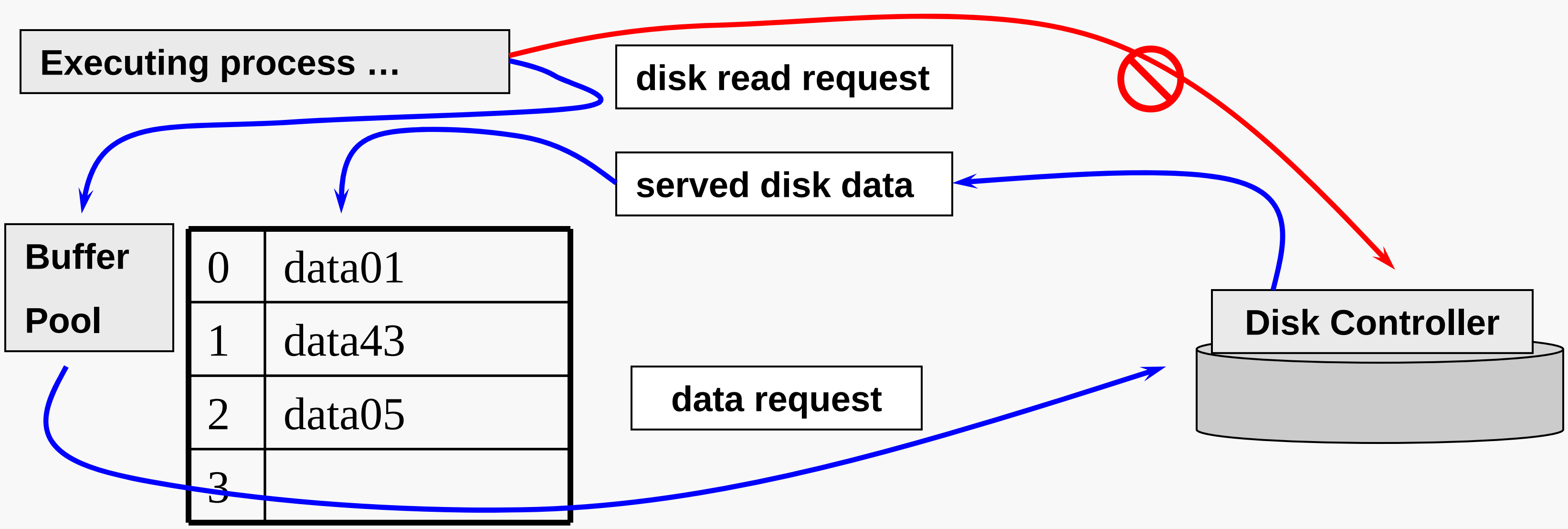
Moral: once you've grabbed a chunk, keep it around.

Buffer Pools

buffer pool — a series of buffers (memory locations) used by a program to cache disk data

A program that does much disk I/O can often improve its performance by employing a buffer pool to take advantage of locality of reference.

Basically, the buffer pool is just a collection of data chunks. The program reads and writes data in buffer-sized chunks, storing newly-read data chunks into the pool, replacing currently stored chunks as necessary.



Replacement Strategies

The buffer pool must be organized physically and logically.

The physical organization is generally an ordered list of some sort.

The logical organization depends upon how the buffer pool deals with the issue of replacement — if a new data chunk must be added to the pool and all the buffers are currently full, one of the current elements must be replaced.

If the replaced element has been modified, it (usually) must be written back to disk or the changes will be lost. Thus, some replacement strategies may include a consideration of which buffer elements have been modified in choosing one to replace.

Some common buffer replacement strategies:

- FIFO (first-in is first-out) organize buffers as a queue
- LFU (least frequently used) replace the least-accessed buffer
- LRU (least recently used) replace the longest-idle buffer

FIFO Replacement

Logically the buffer pool is treated as a queue:

```
   655:   655   miss
   289:   655   289   miss
   586:   655   289   586   miss
   289:   655   289   586   hit
   694:   655   289   586   694   miss
   586:   655   289   586   694   hit
   655:   655   289   586   694   hit
   138:   655   289   586   694   138   miss
   289:   655   289   586   694   138   hit
   694:   655   289   586   694   138   hit
   289:   655   289   586   694   138   hit
   694:   655   289   586   694   138   hit
   851:   289   586   694   138   851   miss
   586:   289   586   694   138   851   hit
   330:   586   694   138   851   330   miss
   289:   694   138   851   330   289   miss
   694:   694   138   851   330   289   hit
   331:   138   851   330   289   331   miss
   289:   138   851   330   289   331   hit
   694:   851   330   289   331   694   miss
Number of accesses:   20
Number of hits:       10
Number of misses:     10
Hit rate:             50.00
```

Takes no notice of the access pattern exhibited by the program. Consider what would happen with the sequence:

655

289

655

393

655

127

655

781

. . .

LFU Replacement

For LFU we must maintain an access count for each element of the buffer pool. It is also useful to keep the elements sorted by that count.

```
  655:  (655, 1)   miss
  289:  (655, 1)  (289, 1)   miss
  586:  (655, 1)  (289, 1)  (586, 1)   miss
  289:  (289, 2)  (655, 1)  (586, 1)   hit
  694:  (289, 2)  (655, 1)  (586, 1)  (694, 1)   miss
  586:  (289, 2)  (586, 2)  (655, 1)  (694, 1)   hit
  655:  (289, 2)  (586, 2)  (655, 2)  (694, 1)   hit
  138:  (289, 2)  (586, 2)  (655, 2)  (694, 1)  (138, 1
  289:  (289, 3)  (586, 2)  (655, 2)  (694, 1)  (138, 1
  694:  (289, 3)  (586, 2)  (655, 2)  (694, 2)  (138, 1
  289:  (289, 4)  (586, 2)  (655, 2)  (694, 2)  (138, 1
  694:  (289, 4)  (694, 3)  (586, 2)  (655, 2)  (138, 1
  851:  (289, 4)  (694, 3)  (586, 2)  (655, 2)  (851, 1
  586:  (289, 4)  (694, 3)  (586, 3)  (655, 2)  (851, 1
  330:  (289, 4)  (694, 3)  (586, 3)  (655, 2)  (330, 1
  289:  (289, 5)  (694, 3)  (586, 3)  (655, 2)  (330, 1
  694:  (289, 5)  (694, 4)  (586, 3)  (655, 2)  (330, 1
  331:  (289, 5)  (694, 4)  (586, 3)  (655, 2)  (331, 1
  289:  (289, 6)  (694, 4)  (586, 3)  (655, 2)  (331, 1
  694:  (289, 6)  (694, 5)  (586, 3)  (655, 2)  (331, 1
Number of accesses:  20
Number of hits:      12
Number of misses:    8
Hit rate:            60.00
```

Aside from cost of storing and maintaining counter values, and searching for least value, consider the sequence:

655 (500 times)

289 (500 times)

100

101

102

103

. . .

LRU Replacement

With LRU, we may use a simple list structure. On an access, we move the targeted element to the front of the list. That puts the least recently used element at the tail of the list.

```
  655:  655  miss
  289:  289  655  miss
  586:  586  289  655  miss
  289:  289  586  655  hit
  694:  694  289  586  655  miss
  586:  586  694  289  655  hit
  655:  655  586  694  289  hit
  138:  138  655  586  694  289  miss
  289:  289  138  655  586  694  hit
  694:  694  289  138  655  586  hit
  289:  289  694  138  655  586  hit
  694:  694  289  138  655  586  hit
  851:  851  694  289  138  655  miss
  586:  586  851  694  289  138  miss
  330:  330  586  851  694  289  miss
  289:  289  330  586  851  694  hit
  694:  694  289  330  586  851  hit
  331:  331  694  289  330  586  miss
  289:  289  331  694  330  586  hit
  694:  694  289  331  330  586  hit
Number of accesses:  20
Number of hits:      11
Number of misses:    9
Hit rate:            55.00
```

Consider what would happen with the sequence:

655

289

655

301

302

303

304

289

. . .

Measuring Performance

The performance of a replacement strategy is commonly measured by its *fault rate*, i.e., the percentage of requests that require a new element to be loaded into the pool.

Some observations:

- faults will occur unless the pool contains the entire collection of data objects that are needed (the *working set*)
- which data objects are needed tends to change over time as the program runs, so the working set varies over time
- if the buffer pool is too small, it may be impossible to keep the current working set resident (in the buffer pool)
- if the buffer pool is too large, the program will waste memory

Comparison

None of these replacement strategies, or any other feasible one, is best in all cases.

All are used with some frequency.

Intuitively, LRU and LFU make more sense than FIFO.

The performance you get is determined by the access pattern exhibited by the running program, and that is often impossible to predict.

Belady's optimal replacement strategy:

replace the element whose next access lies furthest in the future

Sometimes stated as "replace the element with the maximal forward distance".

Requires knowing the future, and so is impossible to implement.

Does suggest considering predictive strategies.

Buffer Pool Design

There are some general properties a good buffer pool will have:

- the buffer size and number of buffers should be client-configurable
- the buffer pool may deal only in "raw bytes"; i.e., not know anything at all about the internals of the data record format used by the client code

  OR

  the buffer pool may deal in interpreted data records, parsed from the file and transformed into an object
- if records are fixed-length then each buffer should hold an integer number of records; for variable-length records, things are more complex and it is often necessary for buffers to allow some internal fragmentation
- empirically, a program using a buffer pool is considered to be achieving good performance if less than 10% of the record references require loading a new record into the buffer pool