Anticipatory scheduling: a disk scheduling framework to overcome deceptive idleness in synchronous I/O

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Anticipatory Disk Scheduling

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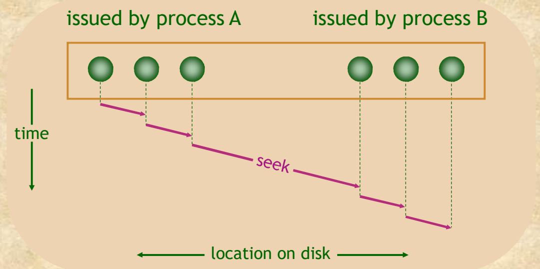
Disk schedulers

Reorder available disk requests for
- performance by seek optimization,
- proportional resource allocation, etc.

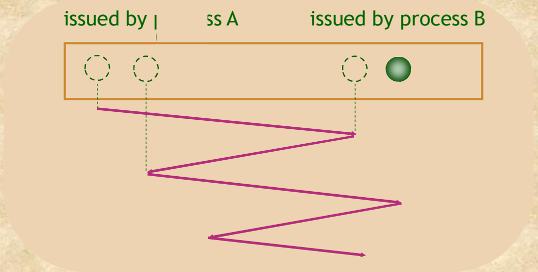
Any policy needs multiple outstanding requests to make good decisions!

With enough requests…



E.g., Throughput = 21 MB/s (IBM Deskstar disk)

With synchronous I/O…



E.g., Throughput = 5 MB/s

Deceptive idleness

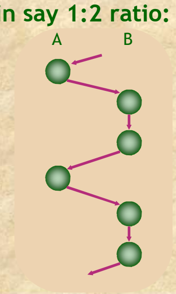
Process A is about to issue next request.

but

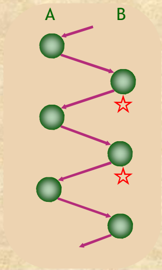
Scheduler hastily assumes that process A has no further requests!

Proportional scheduler

Allocate disk service in say 1:2 ratio:



Deceptive idleness causes 1:1 allocation:



Prefetch

Overlaps computation with I/O.

Side-effect:
avoids deceptive idleness!

- Application-driven
- Kernel-driven

Prefetch

- Application driven – e.g. aio_read()

aio

- aio_read()Start an asynchronous read operation
- aio_write()Start an asynchronous write operation
- lio_listio()Start a list of asynchronous I/O operations
- aio_suspend()Wait for completion of one or more asynchronous I/O operations
- aio_error()Retrieve the error status of an asynchronous I/O operation
- aio_return()Retrieve the return status of an asynchronous I/O operation and free any associated system resources
- aio_cancel()Request cancellation of a pending asynchronous I/O operation
- aio_fsync()Request synchronization of the media image of a file to which asynchronous operations have been addressed

Aio usage patterns

Blocking

```
aio_read()
aio_read()
aio_read()
aio_read()
aio_read()
aio_read()
aio_suspend()
```

Polling

```
aio_read()
aio_read()
aio_read()
aio_read()
aio_read()
aio_read()
do {
    aio_error()
} until (completed)
```

Aio usage patterns

Signals

```
aio_read()
aio_read()
aio_read()
aio_read()
aio_read()
aio_read()
.
other()
stuff()
.
```

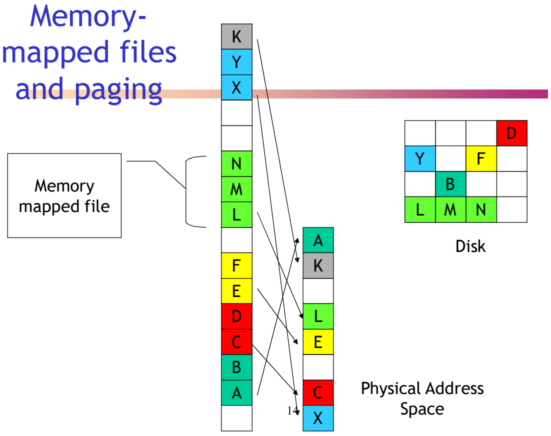
Signal handler

```
process_data()
```

Prefetch

- Application driven - e.g. aio_read()
  - Application need to know their future
  - Cumbersome programming model
  - Existing apps need re-writing
  - aio_read() optional
  - May be less efficient than mmap

Memory-mapped files and paging



Prefetch

- Kernel driven
  - Less capable of knowing the future
  - Access patterns difficult to predict, even with locality
  - Cost of misprediction can be high
  - Medium files too small to trigger sequential access detection

Anticipatory scheduling

Key idea: Sometimes wait for process whose request was last serviced.

Keeps disk idle for short intervals.

But with informed decisions, this:

- Improves throughput
- Achieves desired proportions

When, How, How Long

- When should we or shouldn't we delay disk requests?
- How long do we delay disk requests, if we do delay?
- How do we make an informed decision?
  - What metrics might be helpful?

Cost-benefit analysis

Balance expected benefits of waiting against cost of keeping disk idle.

Tradeoffs sensitive to scheduling policy

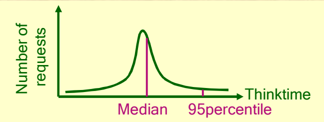
e.g., 1. seek optimizing scheduler

2. proportional scheduler

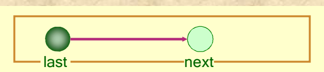
Statistics

For each process, measure:

1. Expected median and 95percentile thinktime



2. Expected positioning time



Cost-benefit analysis for seek optimizing scheduler

best := best available request chosen by scheduler

next := expected forthcoming request from process whose request was last serviced

Benefit =
best.positioning_time — next.positioning_time

Cost = next.median_thinktime

Waiting_duration =
(Benefit > Cost) ? next.95percentile_thinktime : 0

Proportional scheduler

Costs and benefits are different.

e.g., proportional scheduler:

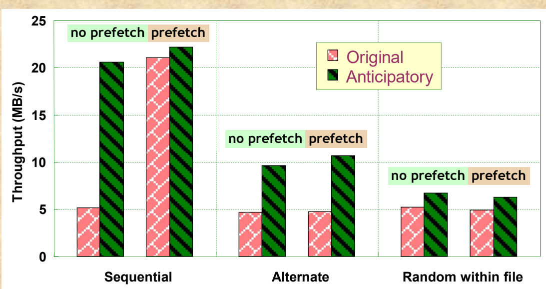
Wait for process whose request was last serviced,
1. if it has received less than its allocation, and
2. if it has thinktime below a threshold (e.g., 3ms)

Waiting_duration = next.95percentile_thinktime

Experiments

- FreeBSD-4.3 patch + kernel module (1500 lines of C code)
- 7200 rpm IDE disk (IBM Deskstar)
- Also in the paper: 15000 rpm SCSI disk (Seagate Cheetah)

Microbenchmark



Real workloads

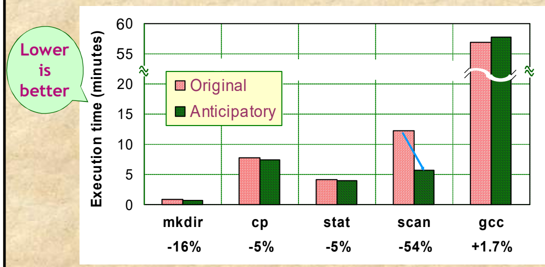
What's the impact on real applications and benchmarks?

Andrew benchmark
Apache web server (large working set)
Database benchmark

- Disk-intensive
- Prefetching enabled

Andrew filesystem benchmark

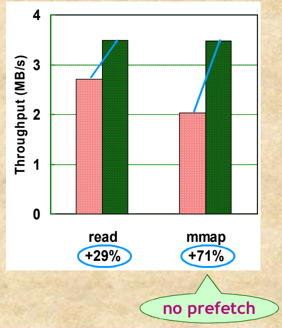
2 (or more) concurrent clients



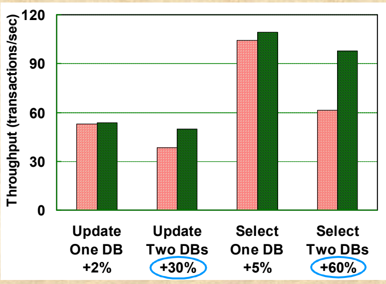
Overall 8% performance improvement

Apache web server

- CS.Berkeley trace
- Large working set
- 48 web clients



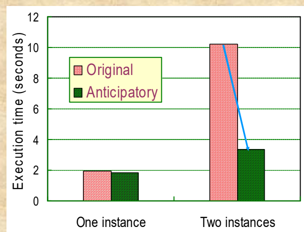
Database benchmark



- MySQL DB
- Two clients
- One or two databases on same disk

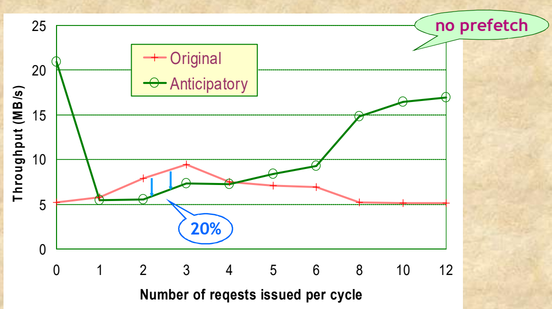
Backup

GnuLD

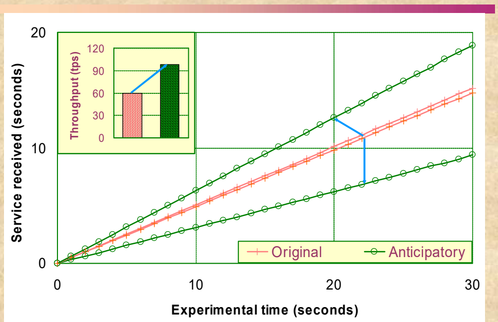


Concurrent: 68% execution time reduction

Intelligent adversary



Proportional scheduler



Database benchmark: two databases, select queries

Conclusion

Anticipatory scheduling:

- overcomes deceptive idleness
- achieves significant performance improvement on real applications
- achieves desired proportions
- and is easy to implement!

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http://www.cs.rice.edu/~ssiyer/r/antsched/