Reducing Disk I/O Performance Sensitivity for Large Numbers of Sequential Streams

George Panagiotakis, Michail D. Flouris and Angelos Bilas

Foundation for Research & Technology - Hellas (FORTH-ICS)

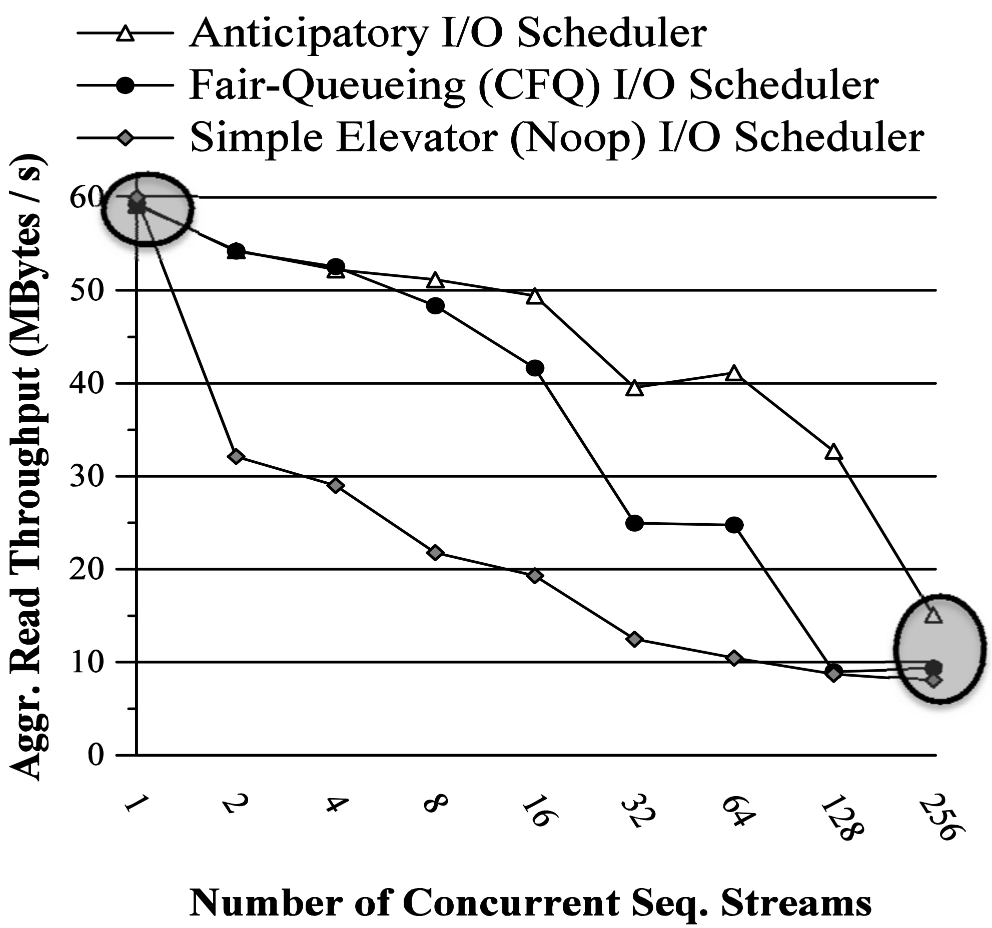
ICDCS 2009

Motivation

- Media servers, scientific data applications
  - Write-once, read-many workloads
  - Large sequential files: Media (HD video), Scientific data
  - Parallel retrieval of sequential I/O streams from disks
- Sequential access: simple & efficient for disks
- Challenge
  - Maintain max read throughput while scaling to large number of I/O streams per disk
- Disk capacity increase ➔ less spindles per stream
  - 2TByte disk holds 440 full-size DVD movies

Linux I/O Schedulers

1 stream:
60MB/sec



Iozone on Ext3: Reading Sequential Files, 4KB Block

256 streams:
10-15MB/sec

Parallel reading of sequential streams on 1 SATA disk

Traditional Solutions

- Caching & aggressive/static prefetching
- Efficient I/O schedulers
  - Anticipatory, Fair-queuing
- Work well
  - Small number of streams
  - Prefetching buffers fit in memory
- However
  - Various workloads need large number of streams
  - Storage controllers: many disks and limited memory

Other Solutions

- SSDs: expensive & low capacity
  - Behavior with high performance workloads not well understood
  - Used as a prefetching buffer?
- Data placement not practical solution
  - Predict which streams read together?
  - Stream playout short-lived vs. time to reorganize data

Overview

- Motivation
- Related work & contributions
- Disk & controller-level prefetching
- Our approach
- Evaluation
- Conclusions

Related Work

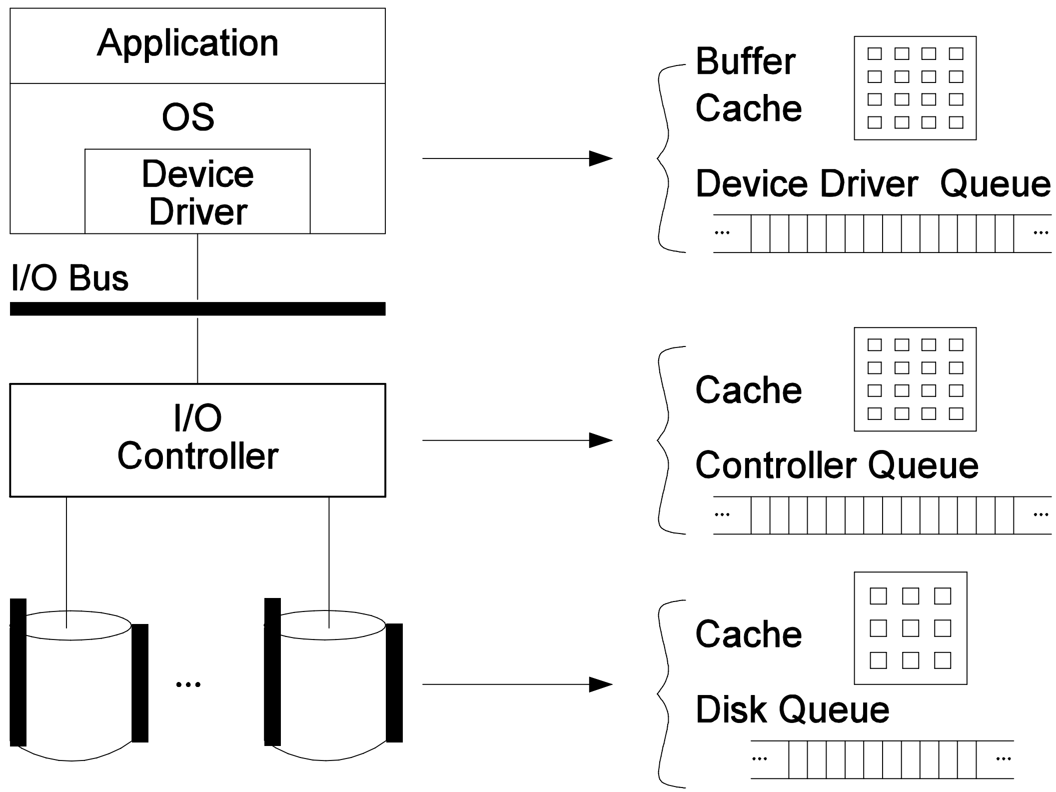
- Modeling & optimizing disks
  - [Ganger95], [Jacobson & Wilkes 91], [Ruemmler & Wilkes 94], [Shriver 97], [Varki et al. 04], [Zhu & Hu 02]
- I/O performance & scheduling optimizations
  - [Bachmat02], [Iyer & Druschel 01], [Kim et al. 06], [Mokbel et al.04], [Shenoy & Vin 98], [Wijayaratne & Reddy 01], [Hsu & Smith 04], [Carrera & Bianchini 02], [Coloma et al. 05], [Yu et al. 06]
- Prefetching
  - [Shriver et al. 99], [Cao et al. 95], [Kimbrel & Karlin 00], [Li et al. 07], [Patterson et al. 95], [Ding et al. 07]
- Storage caching (non-sequential workloads)
  - [Chen et al. 03], [Dahlin et al. 94], [Johnson & Shasha 94], [Zhou et al. 02]
- I/O for multimedia applications
  - [Chen et al. 94], [Dey-Sircar et al. 94], [Rangan & Vin 91], [Reddy & Wyllie 94], [Dan et al. 95]

Contributions

- Analysis of the problem
- Solution at the host level
  - Up to 4x higher throughput with 100 streams / disk
  - Improved disk utilization with limited memory
- Our approach relies on
  - Identifying & separating sequential streams
  - Buffering & coalescing small requests in host memory
  - Notion of working set for servicing multiple I/O streams
- Validation through
  - Disksim simulation and real system experiments
  - Multiple disk & controller configurations

I/O Path

- I/O path components that perform caching & queuing
- Caches become smaller towards bottom



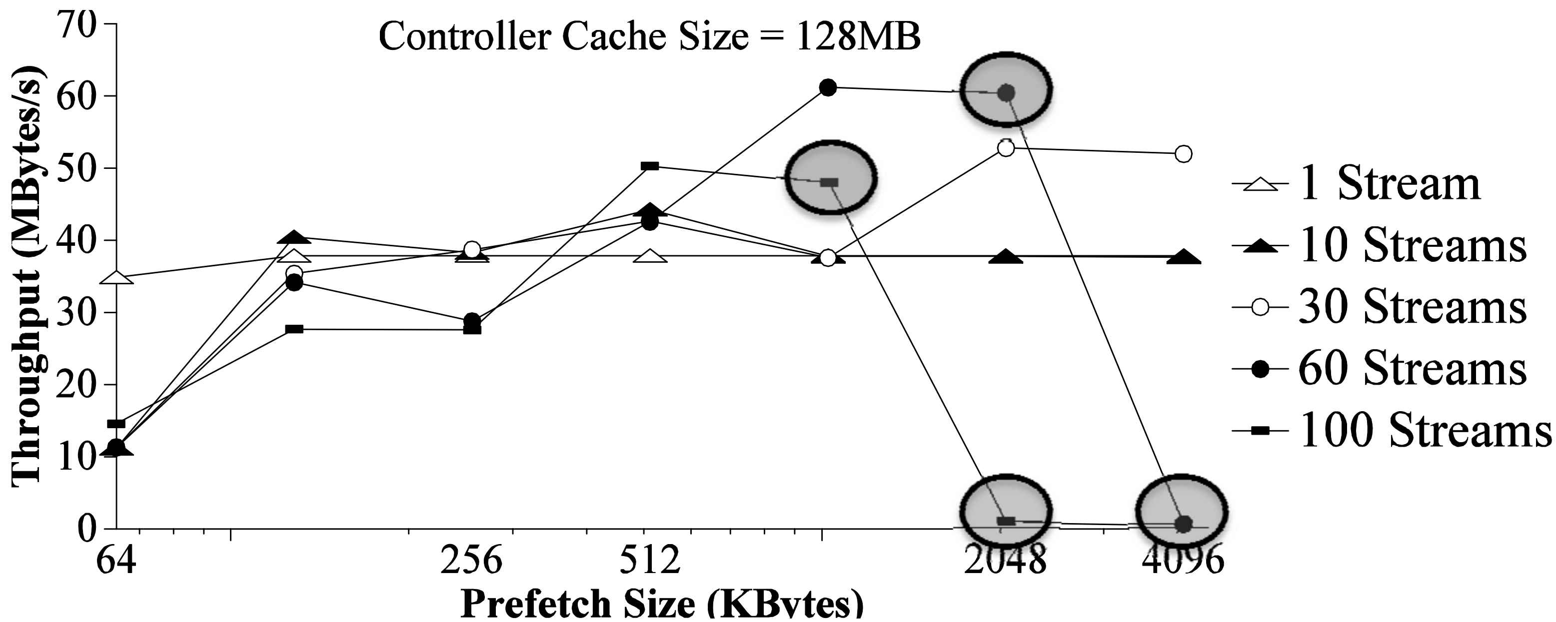
- Disk cache: limited size, divided into fixed segments

Disk-level Prefetching

- Achieved by
  - Increasing application request size
  - Increasing disk segment size to prefetch full segments
- Measurements with Disksim and microbenchmarks
- Larger request sizes improve throughput,
  if there is enough disk cache for all I/O streams
- When number of streams x req. size > cache size throughput degrades dramatically
- Increasing disk cache size and prefetching improves throughput for large number of streams
- However, disk cache size fixed by manufacturer

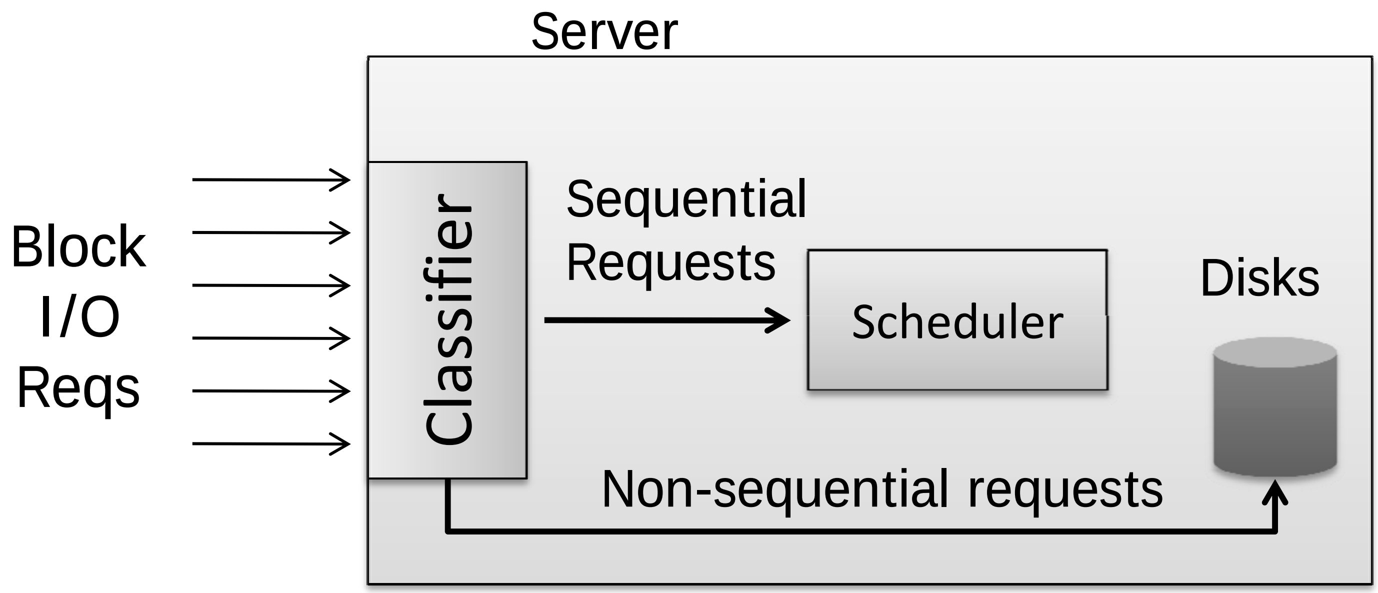
Controller-level Prefetching

- Prefetching at controller-level is effective when there is enough memory for all streams



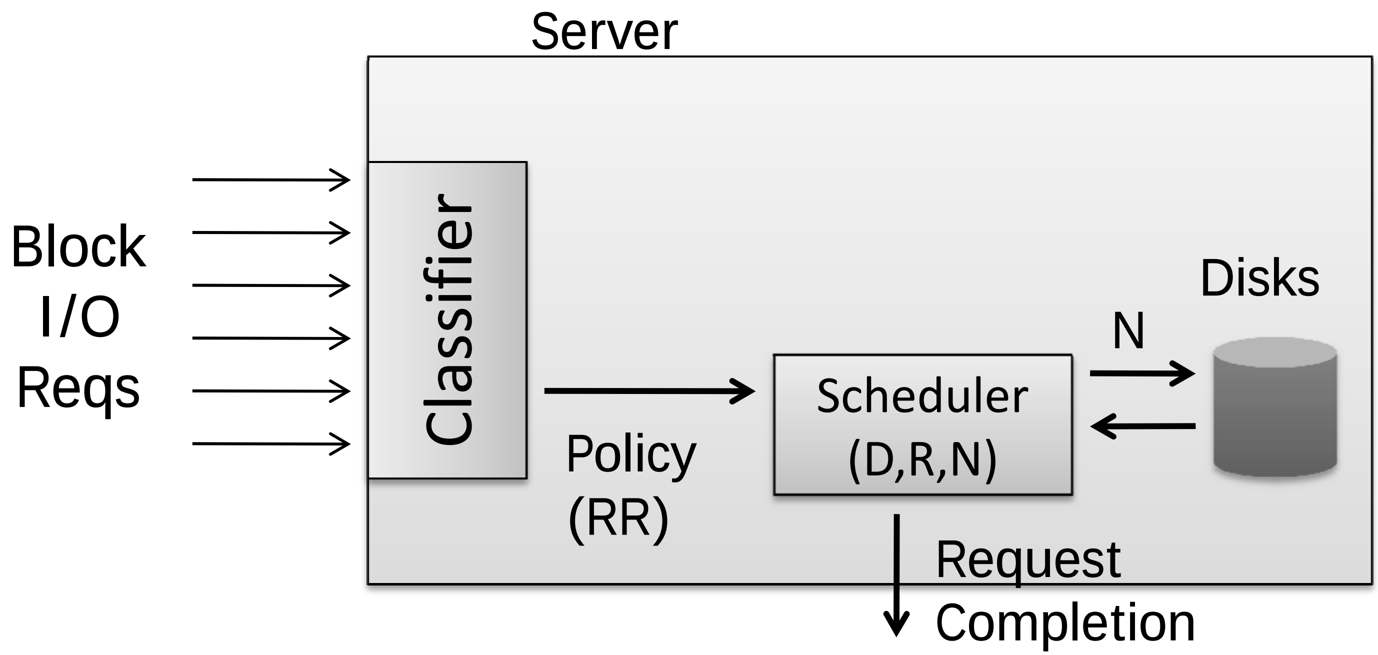
- Not a solution, because one controller may have 4-16 disks and should handle thousands of streams (need GBytes of memory)

Host-level Approach



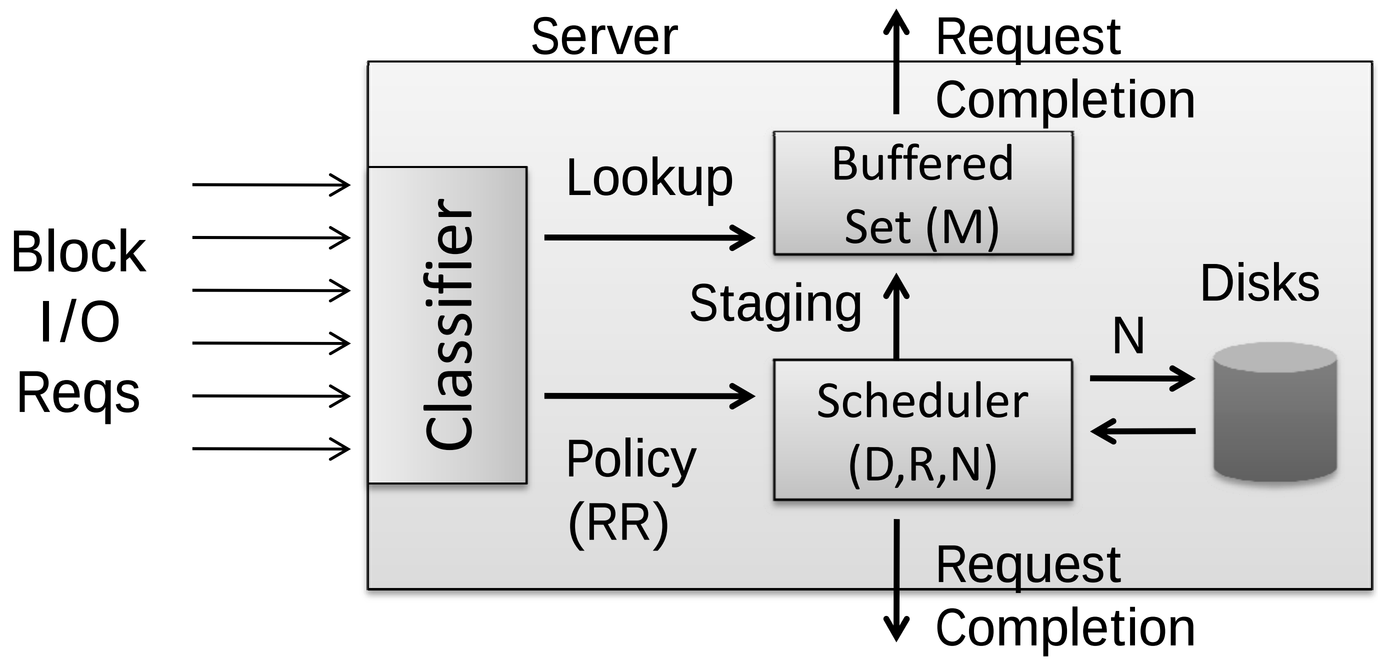
- Block-level operation, file system agnostic
- System receives block I/O requests
- Classifier detects sequential requests using bitmap
- Non-sequential requests sent directly to disks
- Requests in sequential streams sent to scheduler

Scheduling



- Dispatch Set (D): stream set currently in scheduler issues I/O
- Read-ahead size (R): size of requests actually issued to disks
- Streams remain in D until having issued N disk requests
- Replacement policy for streams in D: Round-Robin
- Disk req completion ➔ scheduler completes block I/O request

Staging prefetched data



- Streams removed from D staged in buffered set, until prefetched data are used by new requests or timeout expires
- Classifier looks up req. data in buffered set, completes req. if found
- Overall memory space (M): size of buffered set & dispatch set (D)
- At all times $M \geq D \times R \times N$
- Periodically garbage collect inactive/non-seq streams

Implementation

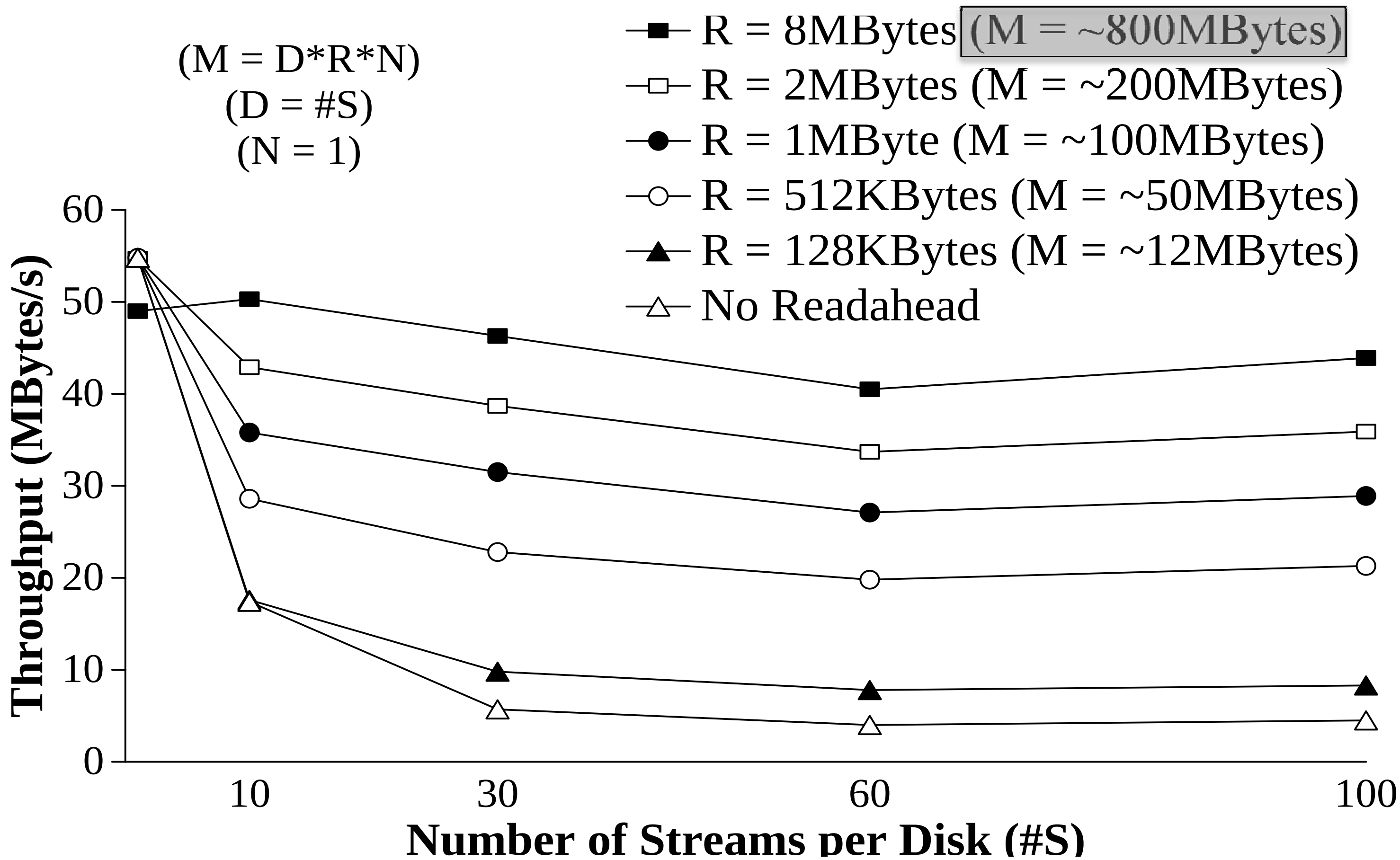
- Implemented on Linux
- User-space I/O server & stream generators
- Using asynchronous I/O, not threads
- Direct I/O to bypass kernel buffer cache

Evaluation Setup

- One storage node
  - Dual Opteron machine, 1GB memory
  - Broadcom RAID controller for 8 SATA disks
  - WD 7200rpm SATA disks (55-60 Mbytes/sec)
- Multiple client nodes
  - Necessary to saturate 8 disks
  - Issues many seq. stream requests over 1 GigE link
  - Data are not transferred over the network

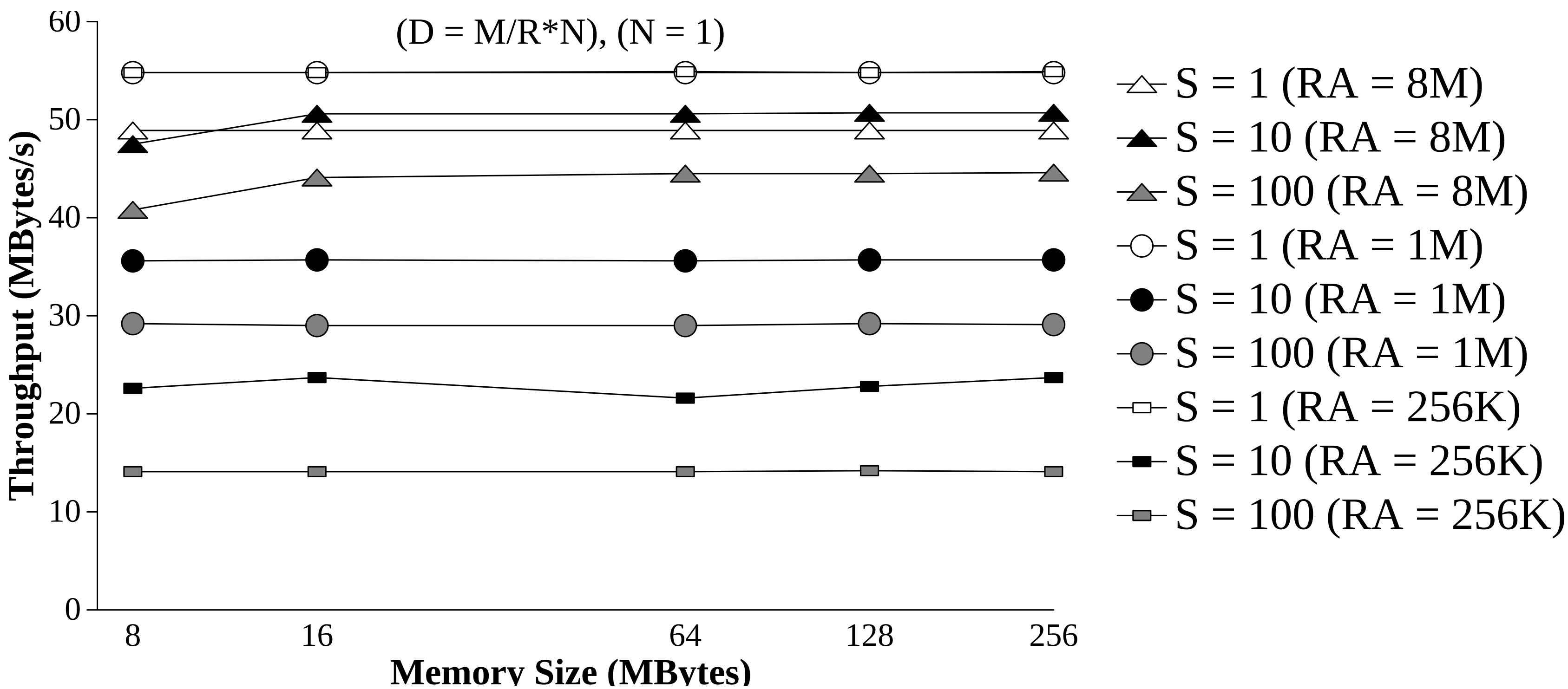
Read-ahead (R)

- S: number of input streams
- M = S ✕ R ✕ N and S = D (fits in dispatch set)
- Substantial amount of memory required



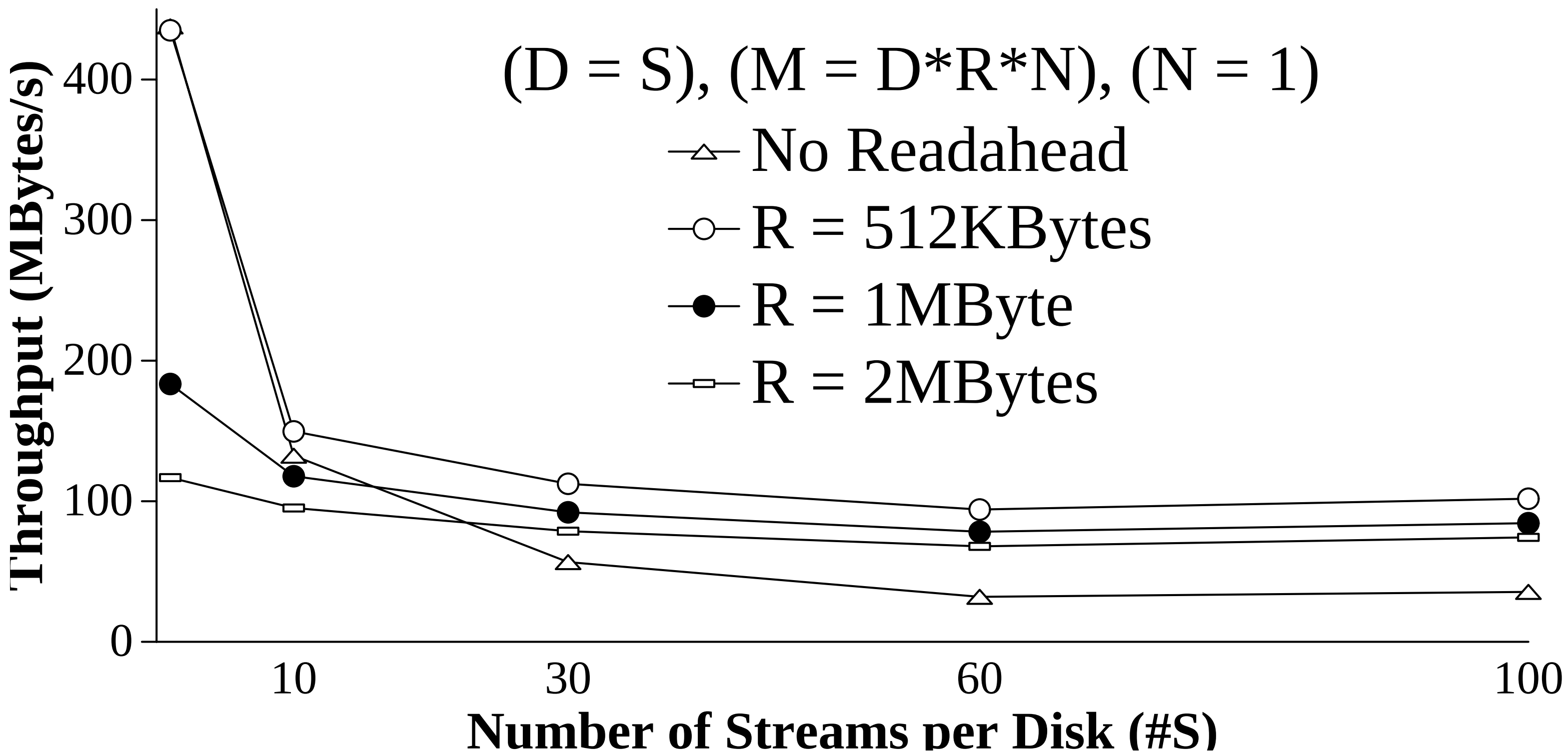
Memory Size

- Interested in many streams that need much memory
- Fixed R value: increasing S ➔ lower throughput
- Increased R important for high throughput



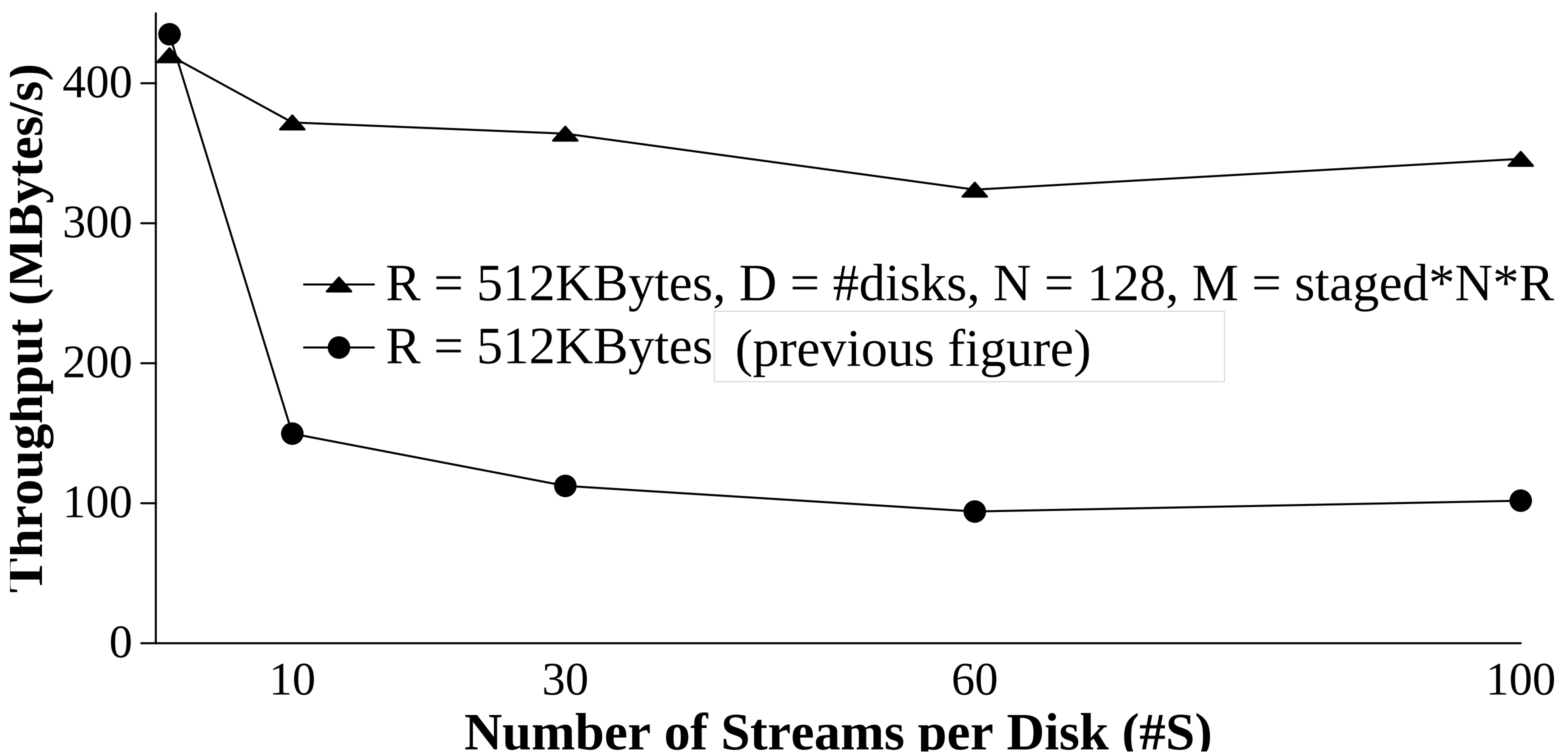
Multiple disks

- Throughput for 8 disks as S per disk increases
- Throughput drops regardless of read-ahead value R
- Bottleneck: controller due to buffer management
- Need to separate dispatched from staged streams



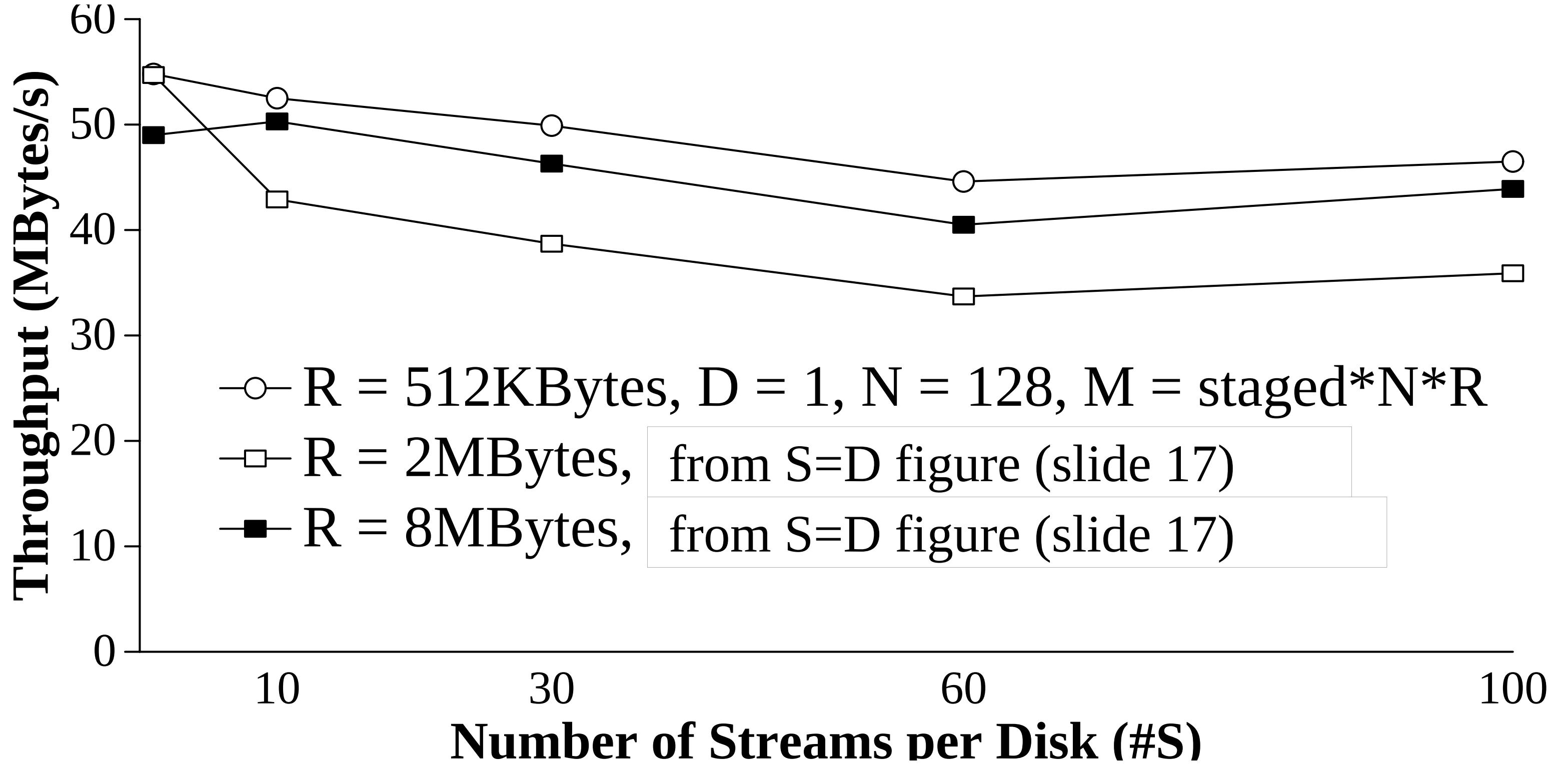
Dispatched vs. staged

- 8 disk setup with dispatched < staged streams
- Better behavior with small amount of memory because of lower buffer management overhead
- Potential for high utilization by tuning R, D, N and M



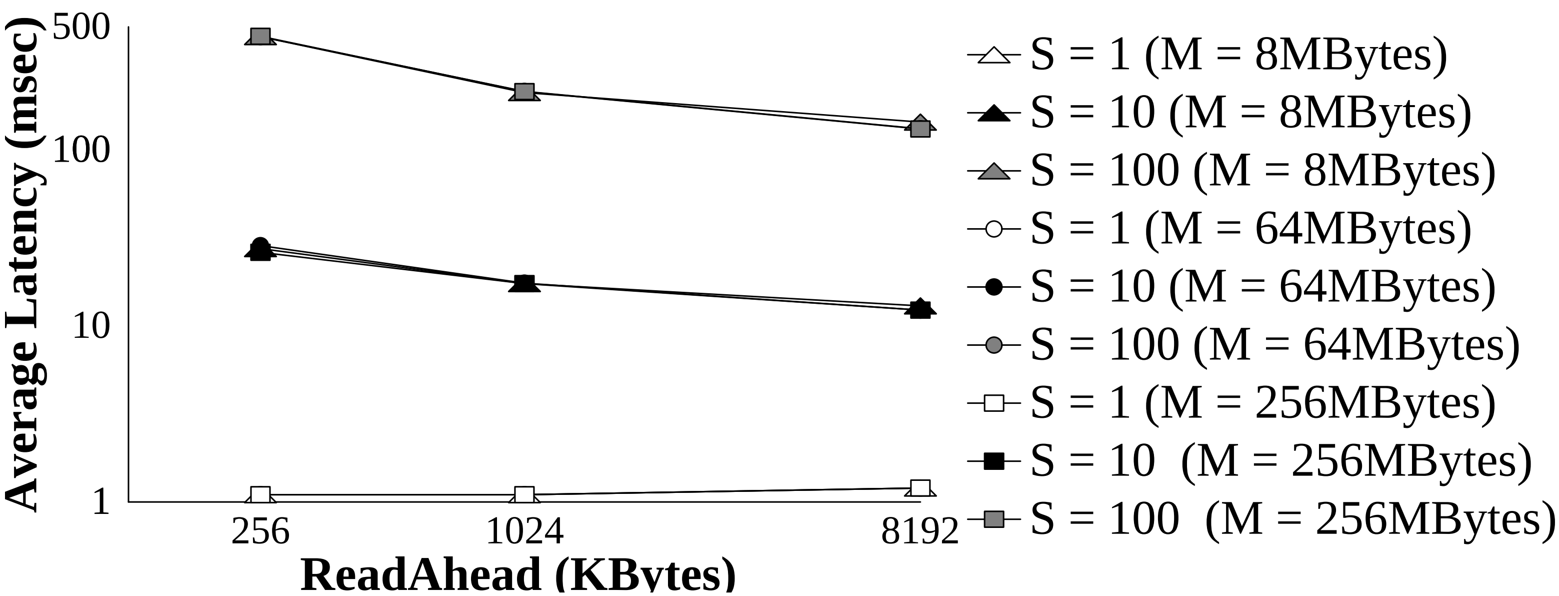
Single-disk Throughput

- 1 disk with dispatched < staged streams
- Better behavior with small amount of memory compared to S = D case (fits in dispatch set)



Response Time

- Mainly interested in improving disk utilization
- Increasing S ➔ high impact on response time
- Increasing R improves response time
- Average request response time not very different among streams because of round-robin policy



Conclusions

- Analyze performance of many seq. I/O streams on disk
- Examine the effect of I/O subsystem parameters
- Find certain parameters can improve performance
- Propose solution at host level that
  - Identifies structures needed & parameterizes each
  - Allows setting these parameters (D, R, N, M) independently
- Implement & measure solution on real system
  - Up to 4x higher throughput with 100 streams / disk
  - Makes the I/O subsystem insensitive to number of streams
  - Approach works with limited memory
  - Response time affected by no of streams, not read-ahead

Thank you!

Questions?

"Reducing Disk I/O Performance Sensitivity for Large Numbers of Sequential Streams"

George Panagiotakis, Michail Flouris & Angelos Bilas

Foundation for Research & Technology - Hellas

FORTH-ICS
Institute of Computer Science

http://www.ics.forth.gr/carv/scalable