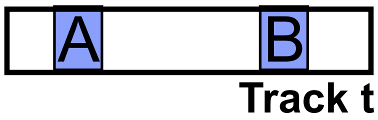
STOW: Spatially and Temporally Optimized Write Caching Algorithm

Binny S. Gill, Michael Ko, Biplob Debnath, Wendy Belluomini
IBM Almaden Research Center, University of Minnesota

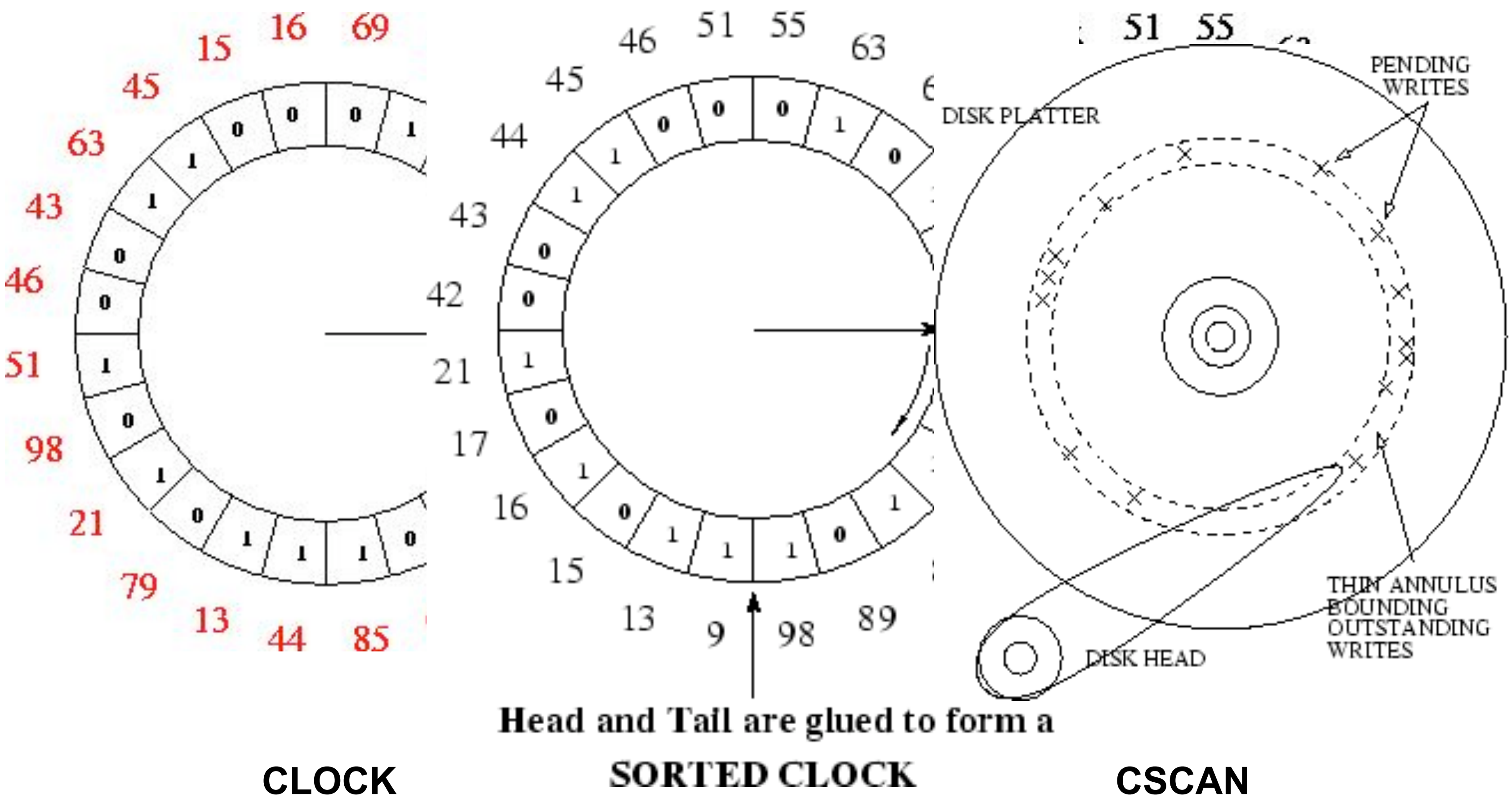
Prior Art: Write Cache Algorithms

- An eviction problem (like read caches)
- Goal: Keep the disk heads busy for the least time
- Some exploit temporal locality
  - To reduce number of destages
  - LRU, CLOCK, FBR, LRU-2, 2Q, LRFU, LIRS, MQ, ARC, CAR
- Some exploit spatial locality
  - Apply temporal locality rules to larger units
  - Tracks (multiple pages), stripes (multiple tracks)



- Some create spatial locality via reordering
  - To reduce the average cost of destages
  - SSTF, SATF, SCAN, CSCAN, LOOK, VSCAN, GSTF, WSTF
- Some do all of the above: WOW (earlier work)

WOW Algorithm



CLOCK

WOW

CSCAN

Is there more to it?

The 5 properties a good write cache serving disks needs to have:

- **Harness temporal locality**
- **Create spatial locality**

Destage Order

- **Maintain free space**
- **Distribute the write load uniformly over time**

Destage Rate

- **Also serve read hits**

Bonus

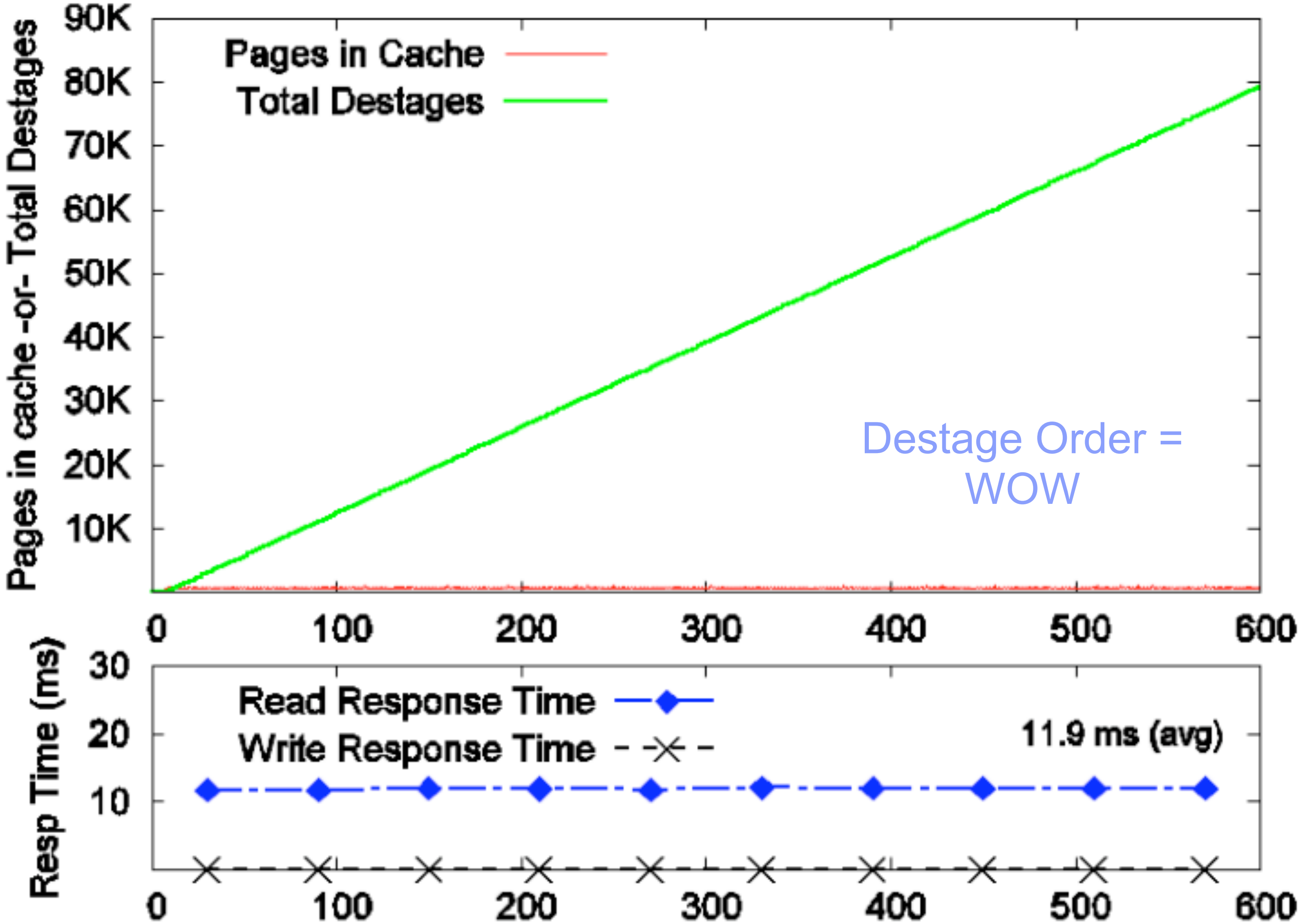
What about the Destage Rate?

- **Most cache research revolves around the *eviction* or *destage order* problem**
- ***Destage rate* is under-studied, but surprisingly is extremely important for performance**
- **If you can tame the destage rate, there is another gold mine beyond the benefits of WOW**
- **We had to invent a new destage order (STOW) to control the destage rate**
- **STOW becomes the first write caching algorithm to explicitly allow a good destage order <u>and</u> a good destage rate = a powerful combination**

Write Cache Tutorial: How to get it wrong?

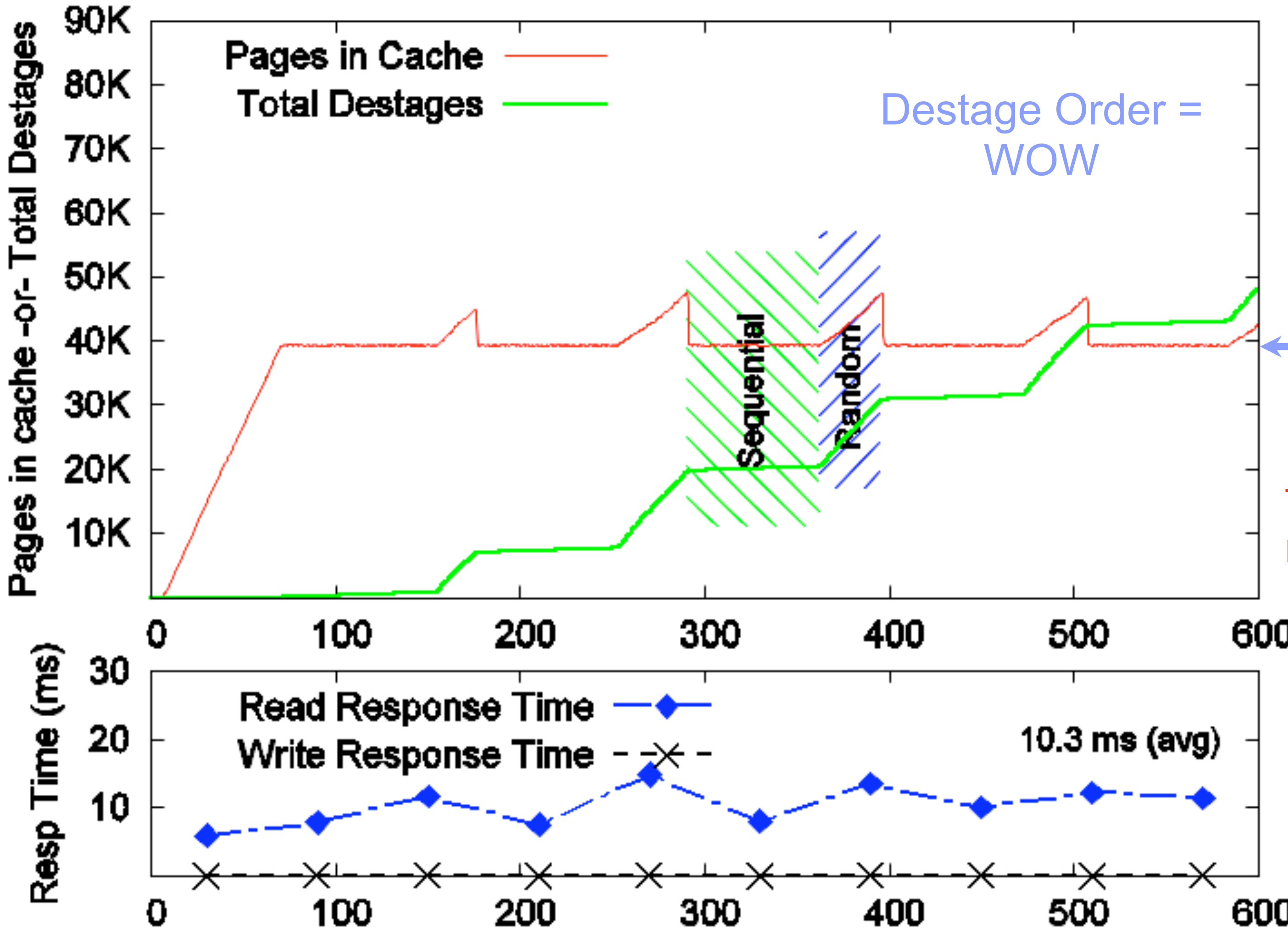
- **Ignore RAID Parity Groups while destaging**
  - **We need to destage all members of the same parity group together to the RAID array, not spread out in time**
  - **Simple but important**
  - **WOW already groups based on RAID stripes**

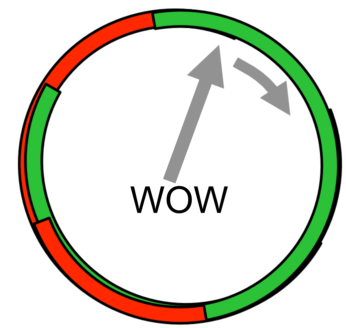
Tutorial: Destage rate = as quickly as you can



SPC1- Like Workload

Tutorial: Destage rate = as quickly as you can only when the cache occupancy reaches a fixed Threshold



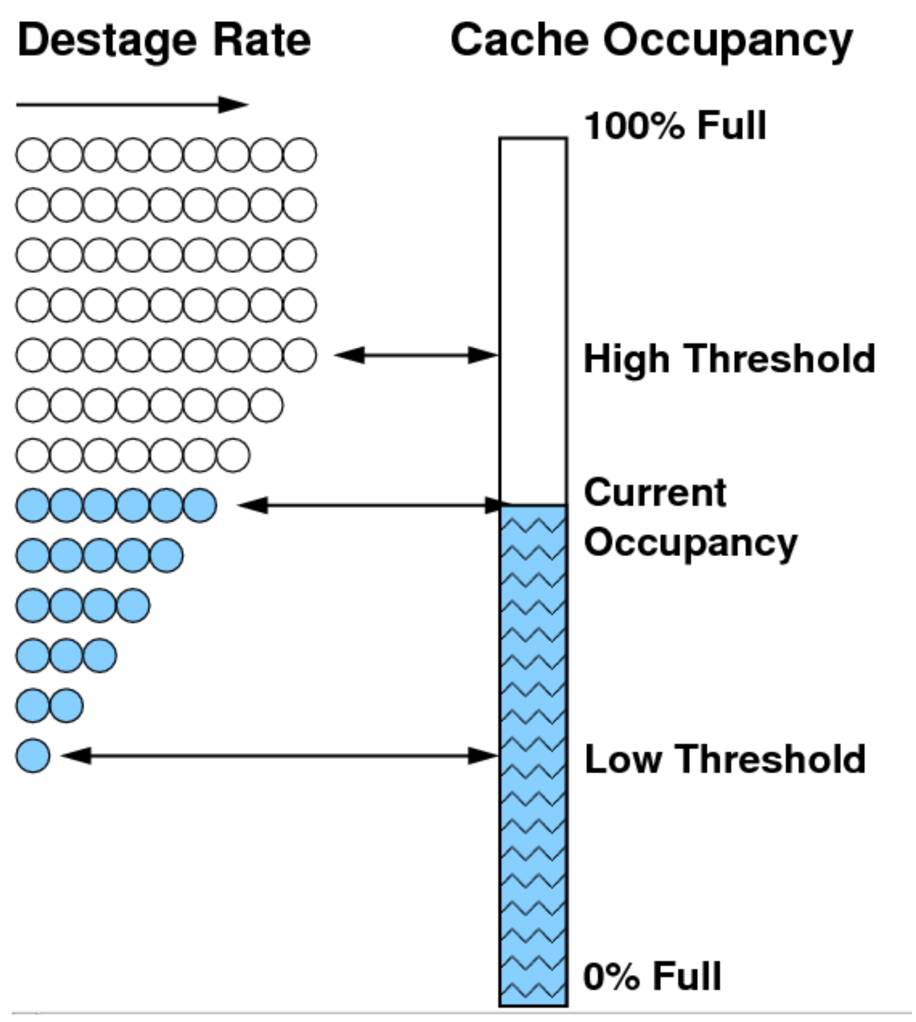


Fixed Threshold

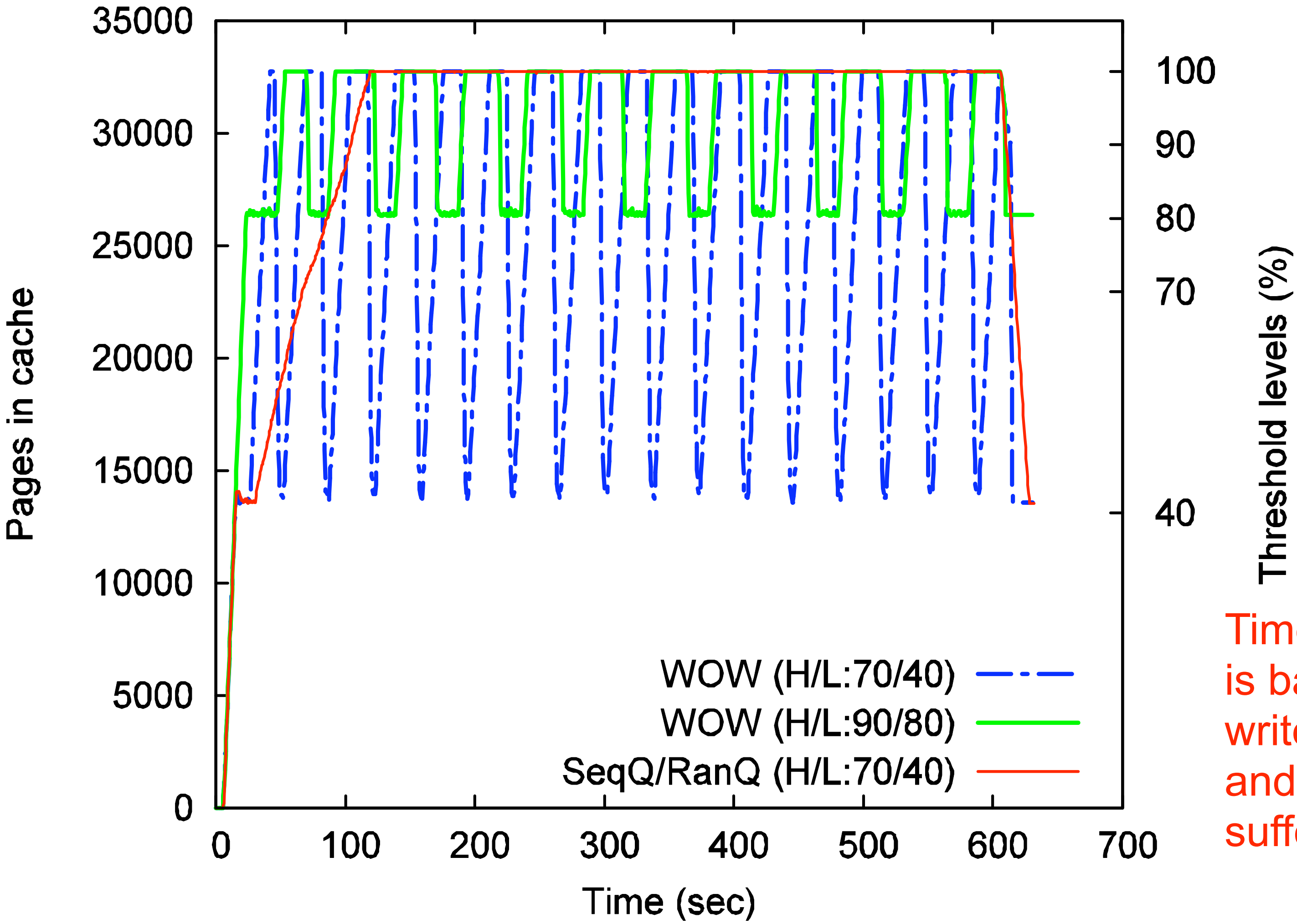
Destage rate toggles between none and full force

SPC1- Like Workload

Tutorial: Destage with Linear Thresholding



Tutorial: Destaging with Linear Threshold

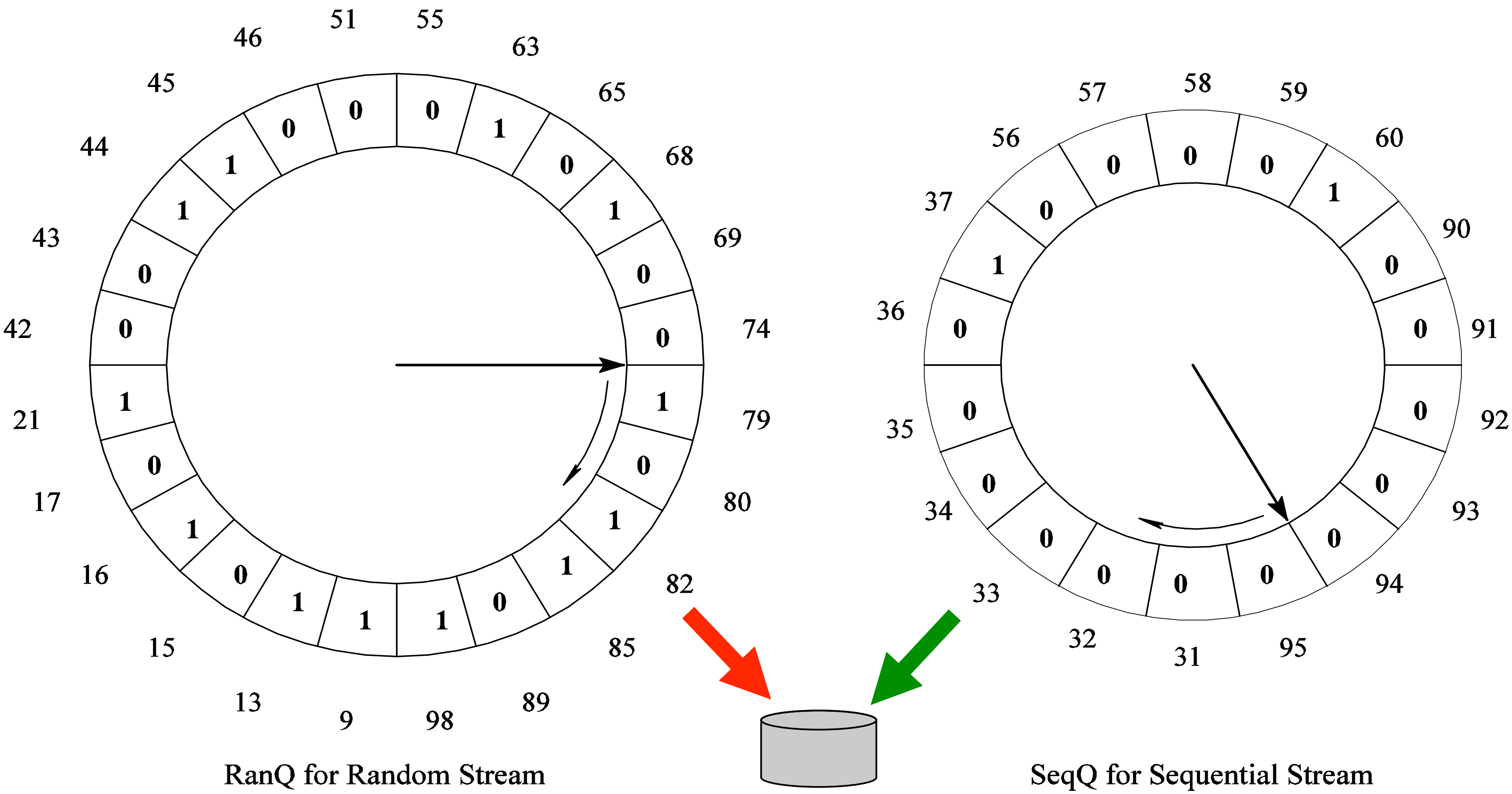


Linear threshold cannot keep cache away from 100% full

"Spikes" are due to long time spent in sequential and random regions

Time spent at 100% is bad. Spikes make write burst absorption and destage rate suffer.

Separate Random and Sequential data

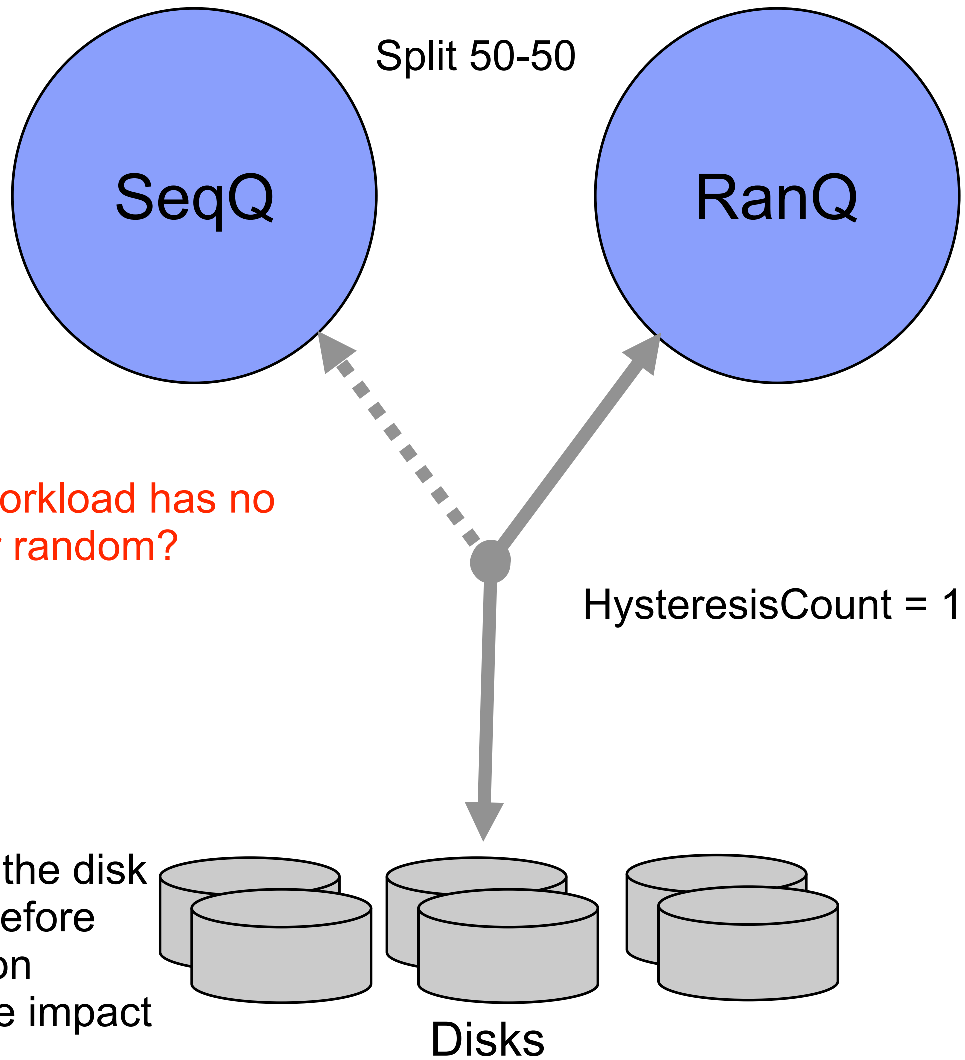


RanQ for Random Stream

SeqQ for Sequential Stream

Spikes are gone .. now there are two active areas on the disk platters => destage order suffers

Getting Warmer: Add hysteresis to the destages



But what if workload has no sequential or random?

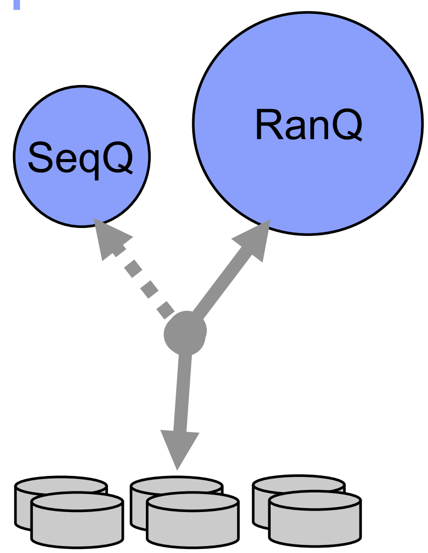
HysteresisCount = 128 * number of spindles in RAID array

Focus on one region of the disk platters for some time before moving to the next region =>minimize the negative impact on destage order

STOW: Adapting the size of RanQ and SeqQ

- **Queue sizes are adapted according to workload**
- **DesiredSeqQSize - - :**
  - Whenever a second write happens in a RAID stripe in RanQ
- **DesiredSeqQSize += n * |RanQ|/|SeqQ| :**
  - Where, n = number of spindles in array
  - Whenever there is a break in the LBA sequence of destages from SeqQ
- **If |SeqQ| > DesiredSeqQSize, then destage from SeqQ, else destage from RanQ**

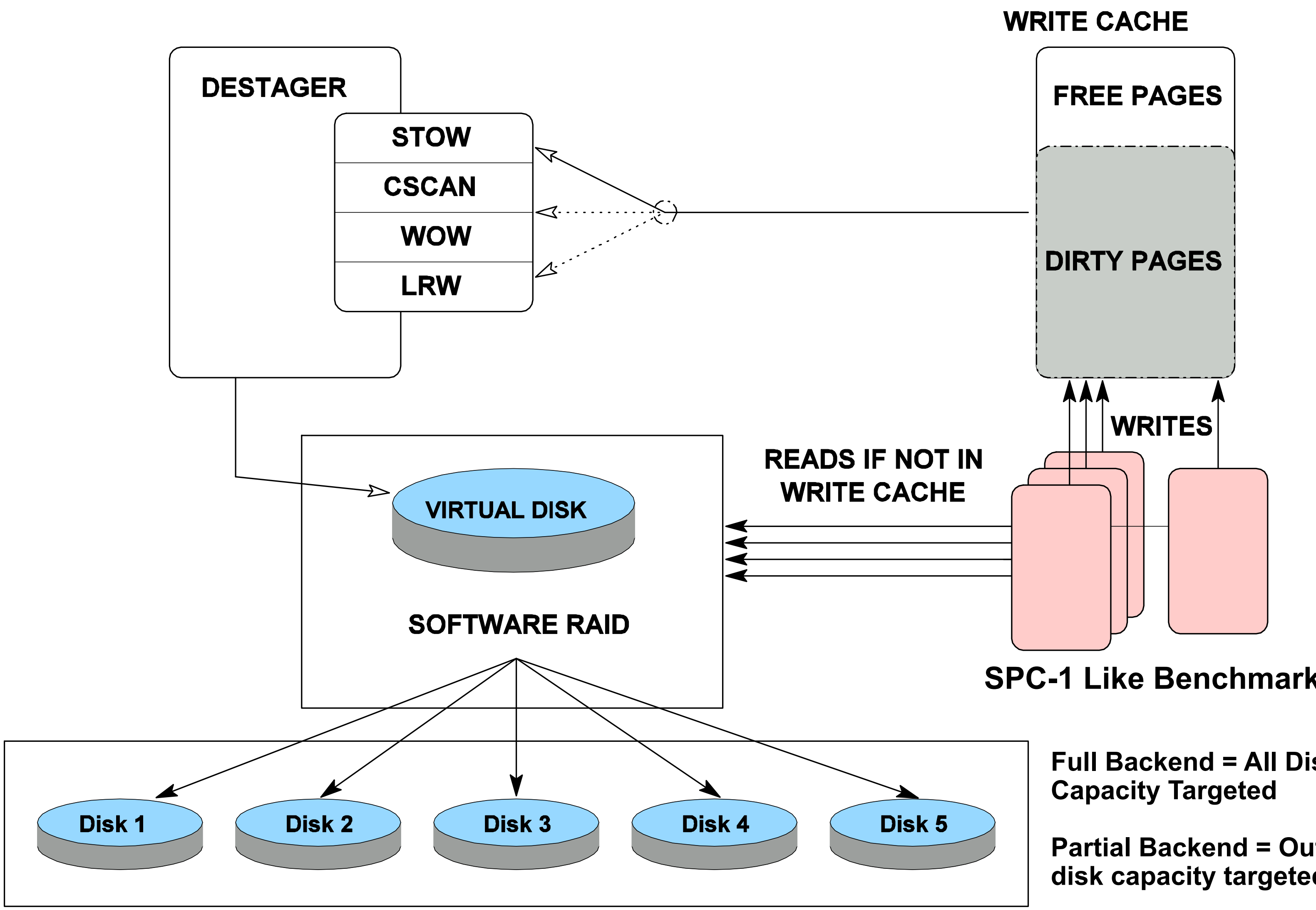
STOW vs Competition



Sizes are dynamically adapted according to real-time marginal utilities

	CSCAN	LRW	WOW	STOW
Spatial Locality	Yes	No	Yes	Yes
Temporal Locality	No	Yes	Yes	Yes
Scan Resistance	No	No	Little	Yes
Stable Destage Rate	No	Little	No	Yes
Stable Occupancy	No	Little	No	Yes

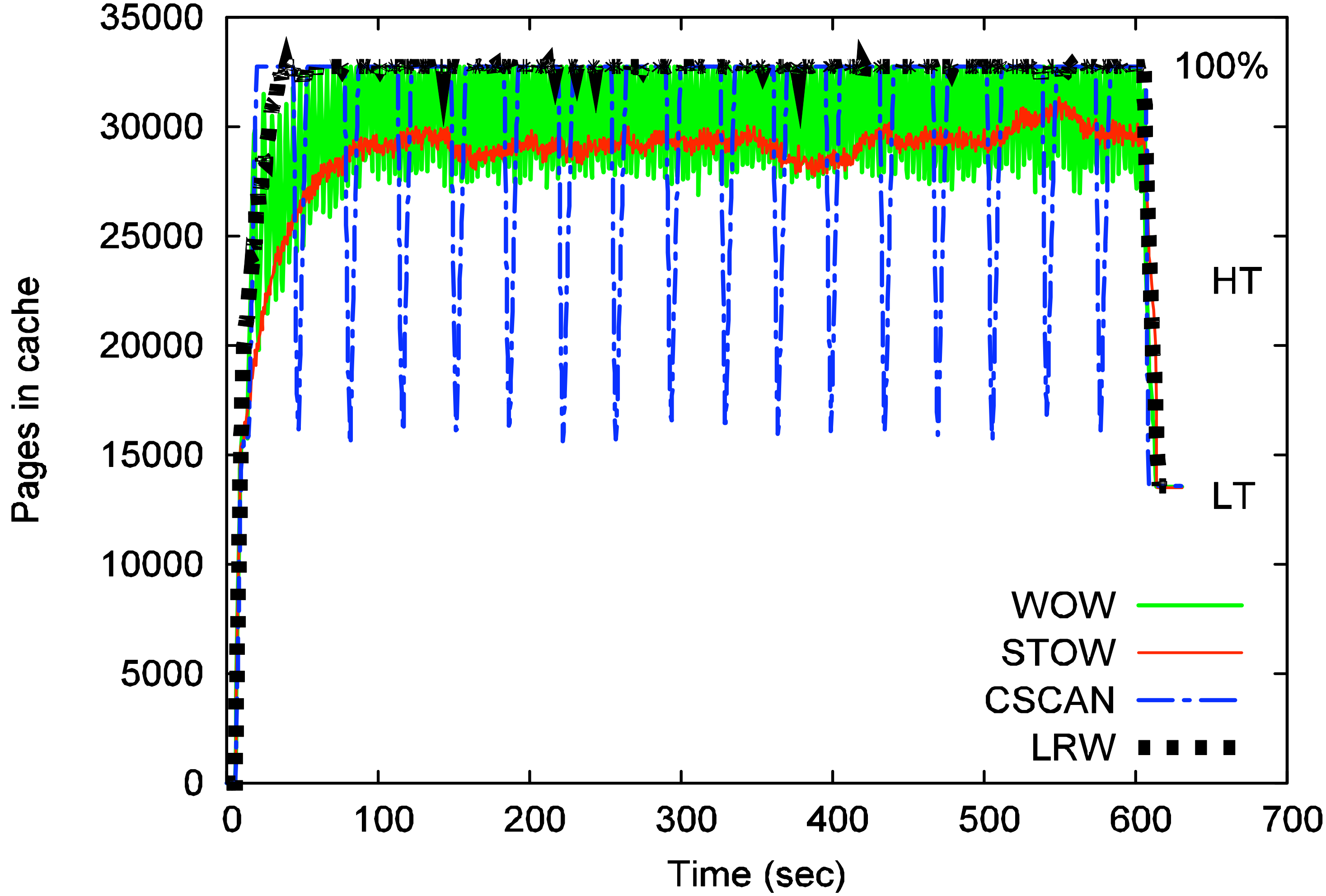
Experimental Setup



Full Backend = All Disk Capacity Targeted

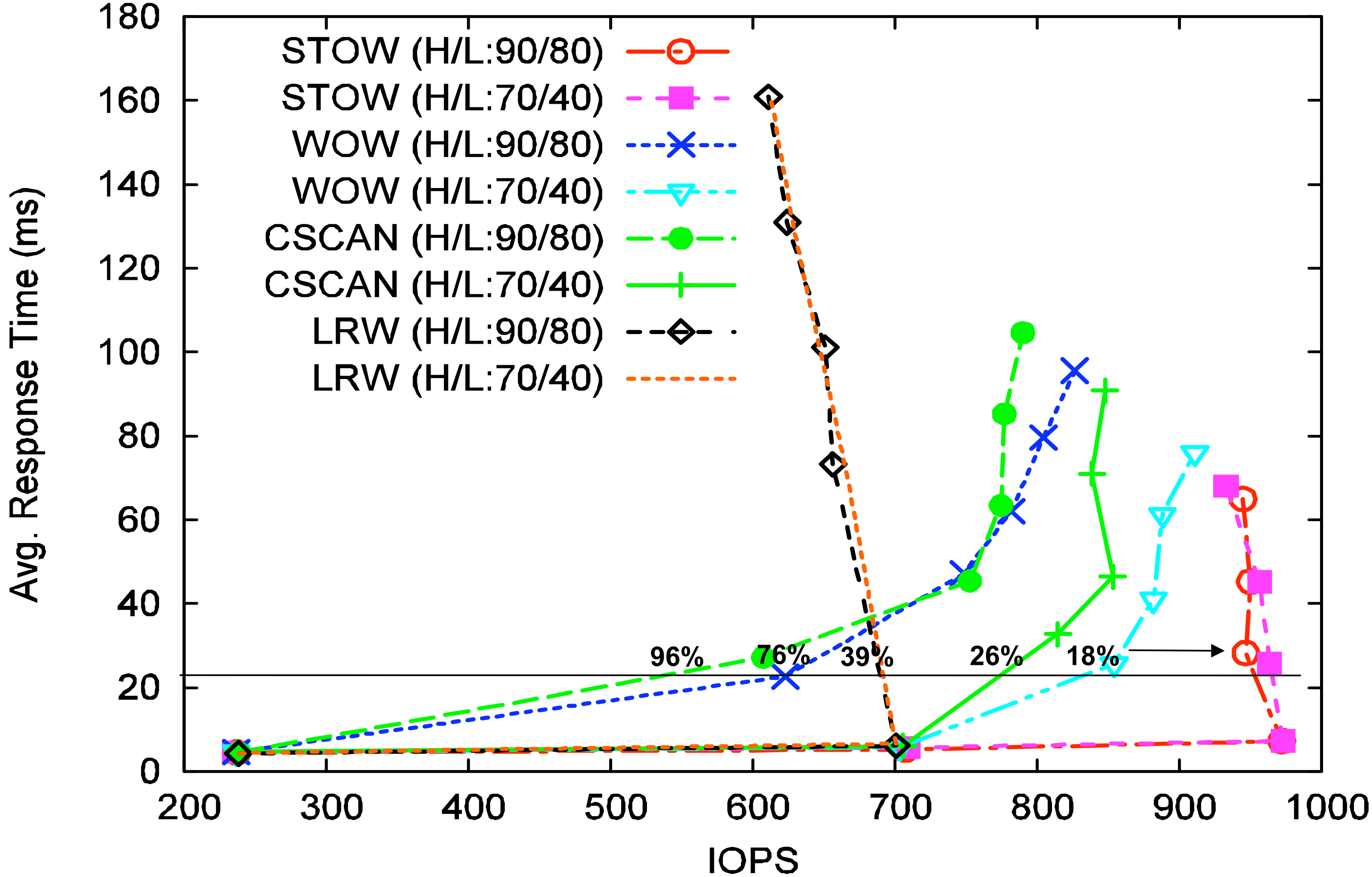
Partial Backend = Outer 1% of disk capacity targeted

STOW: No more spikes in cache occupancy



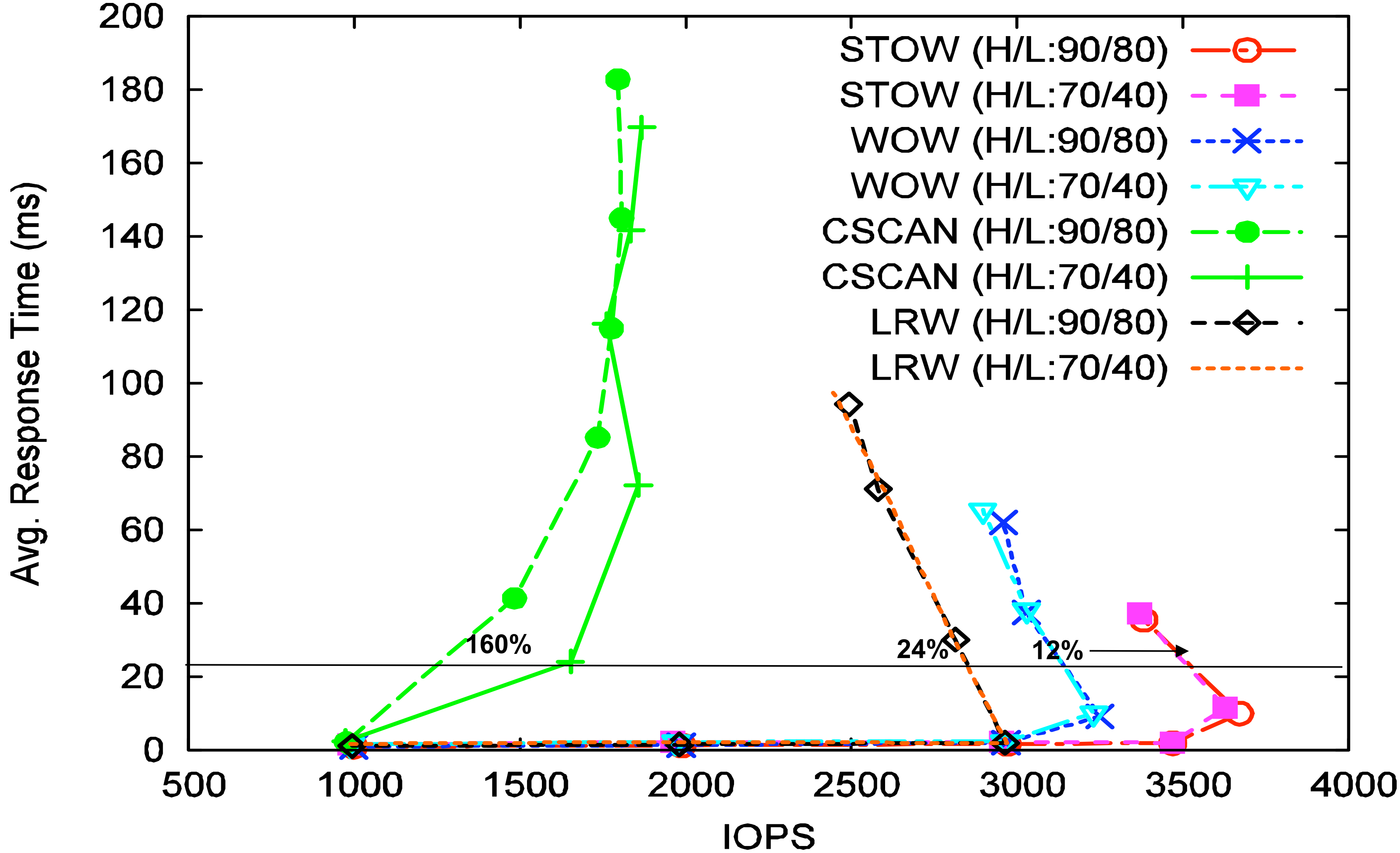
RAID 5 Partial Backend: target 3500 IOPS, threshold: 70/40

Full Backend : Throughput vs. Response Time



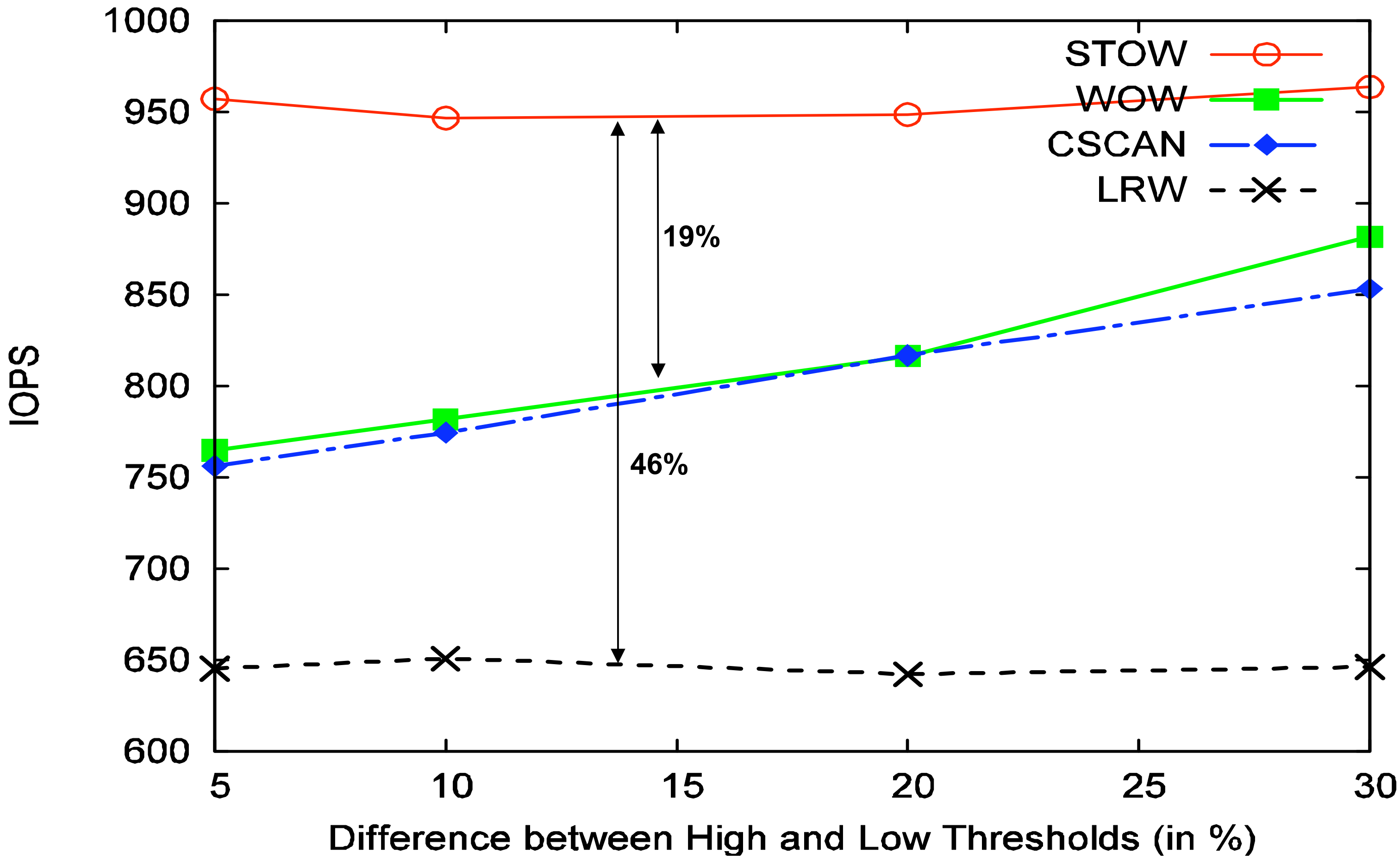
RAID 5

Partial Backend: Throughput vs. Response Time



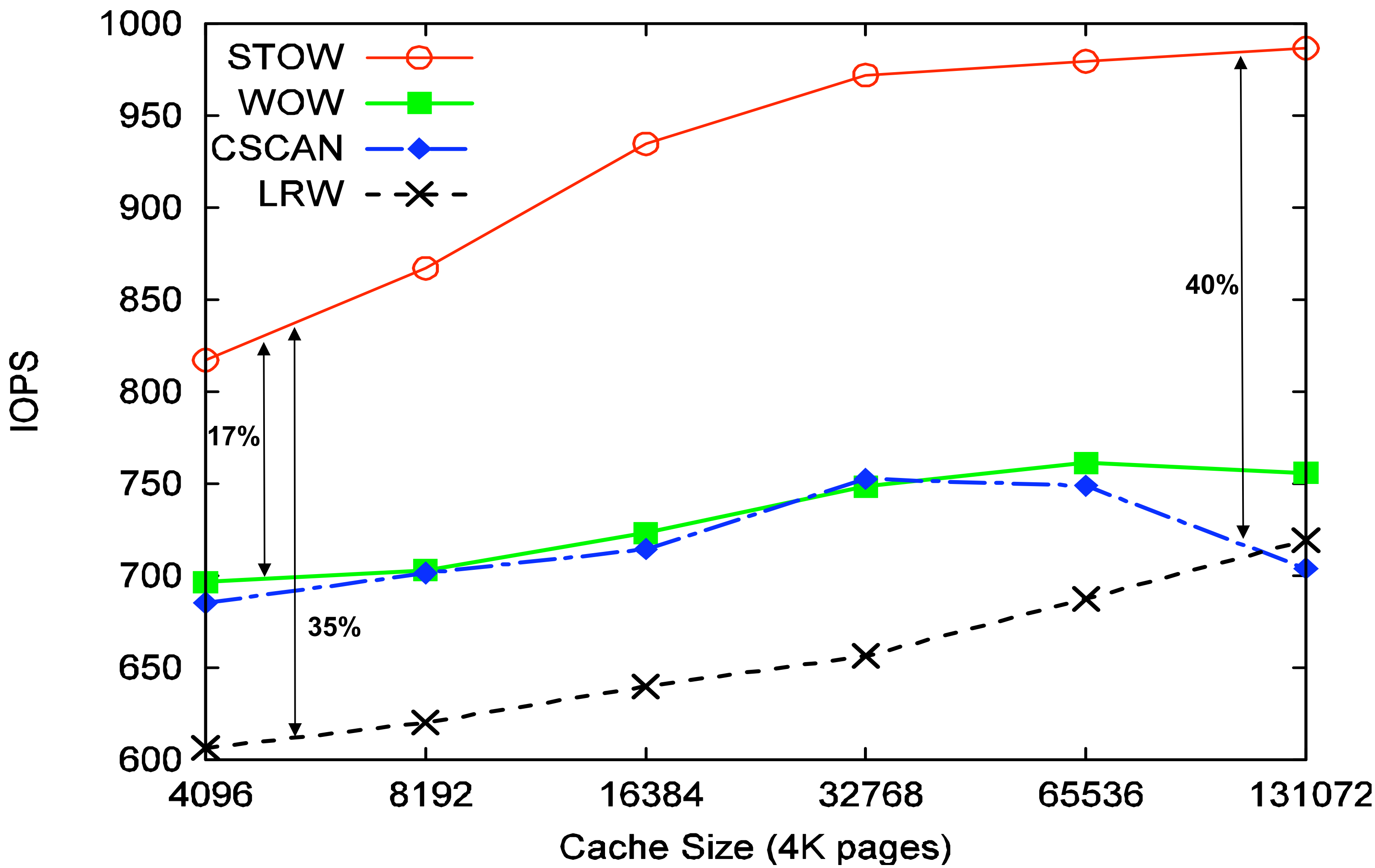
RAID 5

Vary the spread between high and low thresholds



RAID 5, Full Backend: Target: 1200 IOPS

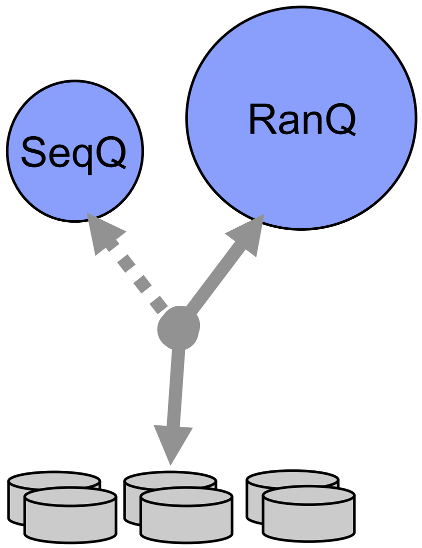
Vary the cache size



RAID 5, Full Backend: Target 1050 IOPS ; H/L : 90/80

Summary

- **Tackling both destage order and destage rate = powerful write cache algorithm**
- **STOW**
  - Leverages temporal locality
  - Creates spatial locality
  - Maintains steady free space to absorb write bursts
  - Destages uniformly
  - Protects Random data from Sequential bursts
  - Dynamically adapts the sizes of the sequential and random portions of the cache to maximize throughput
- **STOW > WOW > (LRW, CSCAN)**
- **Is there still more to it? :)**



Thank You!