Understanding scalability and performance requirements of I/O intensive applications on future multicore servers

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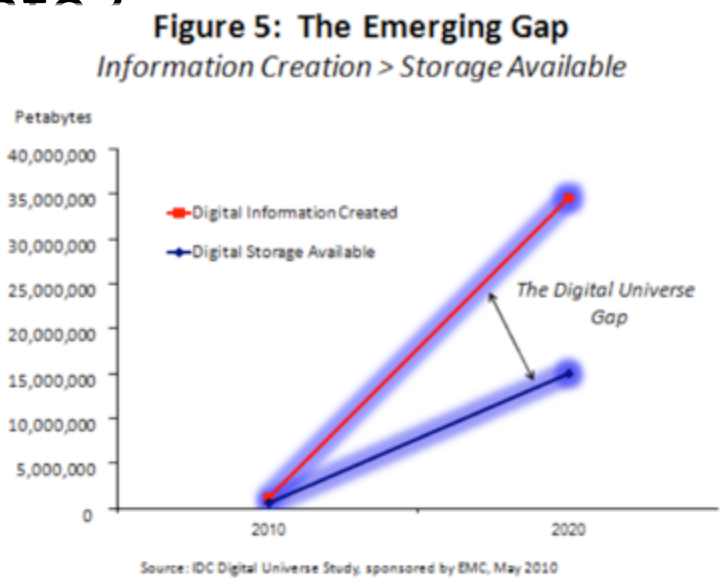
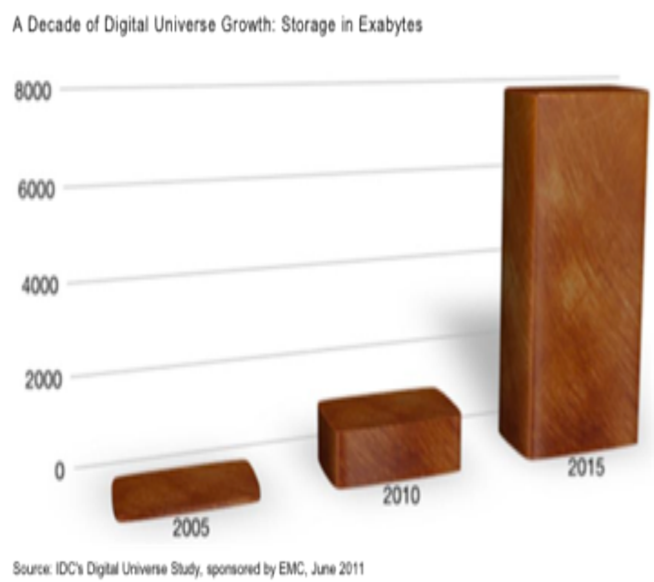
Demand for Data Grows Fast

- …Faster than storage capacity
  - Digital Universe 2010, 2011 [IDC/EMC]
  - Storage capacity grows faster than Moore's law
- Need to store and can store a lot of data
- Can we access and process data at the same rate?





Today Low "I/O Density"

- Typical server configuration
  - 4-8 cores
  - 8-32 GBytes
  - 2-4 disks
  - 2 cores to keep up with 1 disk-performance
- Emerging needs: process large amounts of data
  - Bring data to memory, process (data centric)
  - Compared to compute from main memory
  - Keeping up with data growth requires increasing I/O density
- So far slow disks limitation to increasing I/O density

Towards Higher "I/O Density"

- New device technologies (SSDs) allow higher access rate with fewer devices and better latency (IOPS)
- This allows and requires increasing #cores per server
- Broadly, what is the role of storage I/O?

Goals

- This presentation centered around 3 questions
  1. Does I/O scale with cores?
  2. How much I/O in ten years?
  3. How energy (in)efficient is application I/O?
- Contribute to methodology
  - How can we characterize I/O across applications?
  - We measure using real applications, workloads
  - We project to large numbers of cores

Outline

- ✓ Motivation and Goals
- Metrics & Methodology
- Applications & Platforms
- Does I/O scale?
- How much I/O?
- How much Energy?
- Conclusions

Methodology

- Get a number of applications
  - Data-centric, I/O intensive
- Figure out parameters and configurations
- Run them on a real system
- Examine how much I/O they require
- Methodology is interesting by itself

cpio: Abstract I/O behavior

- We use cycles per I/O (cpio) as a metric
  - Used in the past in certain cases
  - Recently used more in networking as cycles per packet
- System-level metric
  - Not related to application output
  - Includes both CPU and I/O
- Computing cpio
  - Calculate execution time breakdown
  - Count number of I/Os – 512 bytes
  - cpio = (system + user) / #ios
- Ignore idle and iowait time
  - Energy proportionality -> idle+iowait not a problem
  - Not straight-forward to distinguish idle form iowait

Use Experimental Approach

- Server-type specs with aggressive I/O subsystem
  - 24 SSDs, 4x LSI controllers, 6 SSDs per controller
- Two configurations: More, less aggressive (CPU, I/O)

DISKS	SSDS
2 Intel Xeon E5620 (Quad-core)	2 Intel Xeon E5405 (Quad-core)
No Hyper-threading	Hyper-threading
8 GB RAM	12 GB RAM
1 Storage Controller (8 Disks)	4 Storage Controllers (24 SSDs)
XFS on Hardware RAID 0	XFS on Software RAID 0
1 GB/s Storage Throughput	6 GB/s Storage Throughput
CentOS distribution; 2.6.18	CentOS distribution; 2.6.32

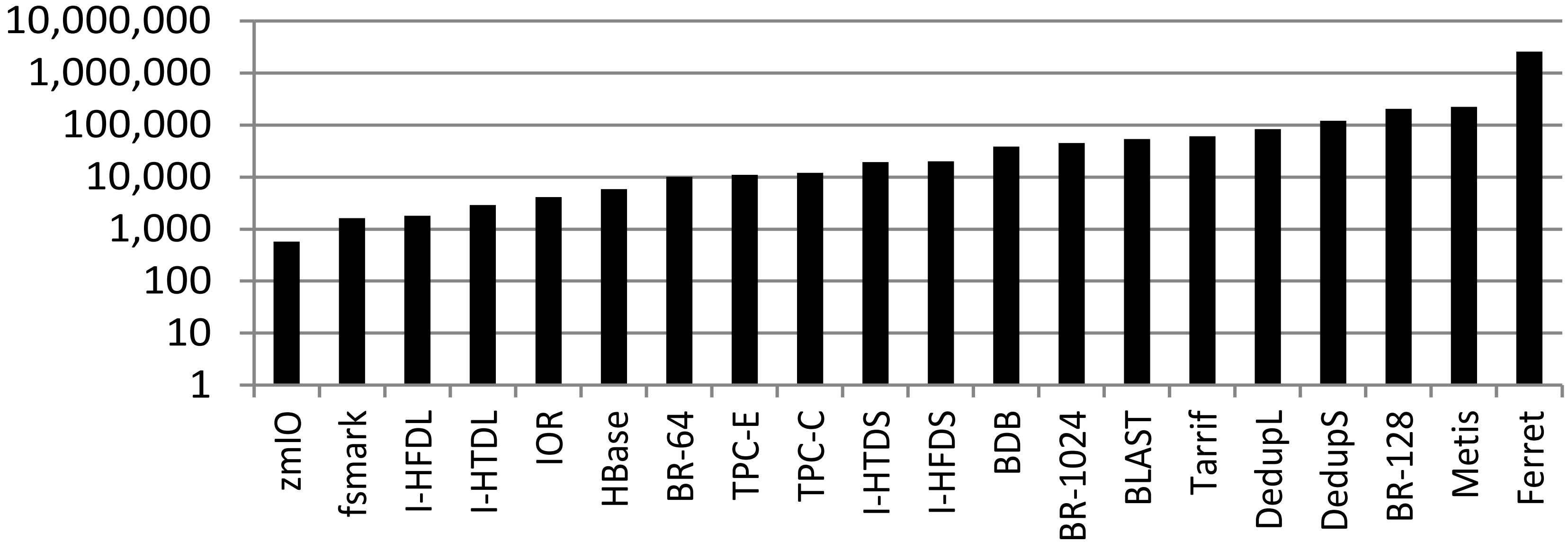
Benchmarks and Applications

- Applications from diverse domains
  - Benchmarks (zmIO, fsmark, IOR)
  - OLTP workloads (TPC-C, TPC-E)
  - NoSQL Data Stores (HBase, BDB)
  - HPC Domain (Ferret, BLAST)
  - Backend Applications (Deduplication,Psearchy,Metis)
  - Data Streaming (Borealis)
  - Business Intelligence (Tariff)
- Applications are tuned to perform large amounts of I/O
  - Applications and runtime parameters available at [www.iolanes.eu]

Two Broad Categories

- Sweep
  - Do a pass over the data to calculate metadata
  - E.g. indexing, deduplication, streaming
- Metadata
  - Quickly calculate metadata
  - Operate mostly from metadata and only access necessary data
  - OLTPL, OLAP, key-value stores, image processing

Measured cpio – Range

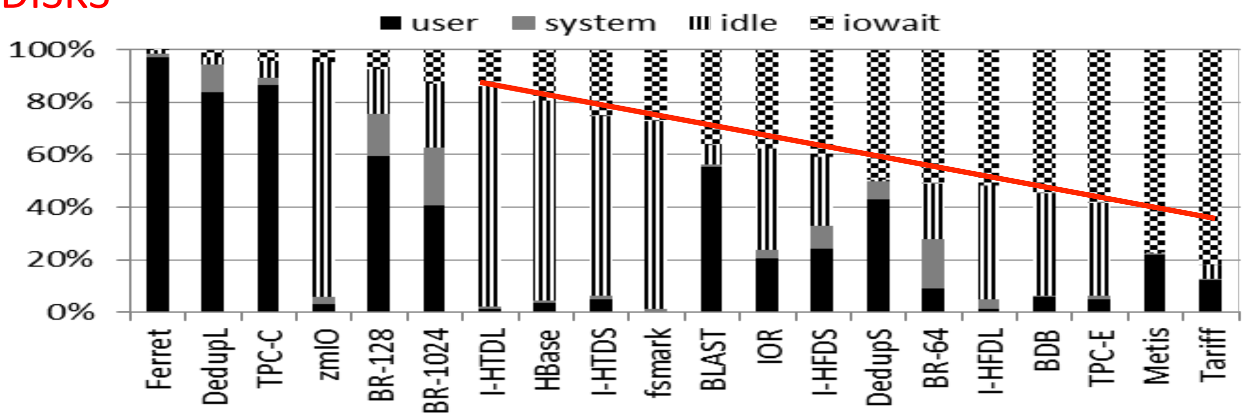


- Range from 1K to 2M
- cpio not appropriate in absolute terms to say “good” or “bad”
    - Memory caching plays an important role
- Captures behavior assuming same amount of work to devices
- Can be as tricky as speedup

I/O Characterization

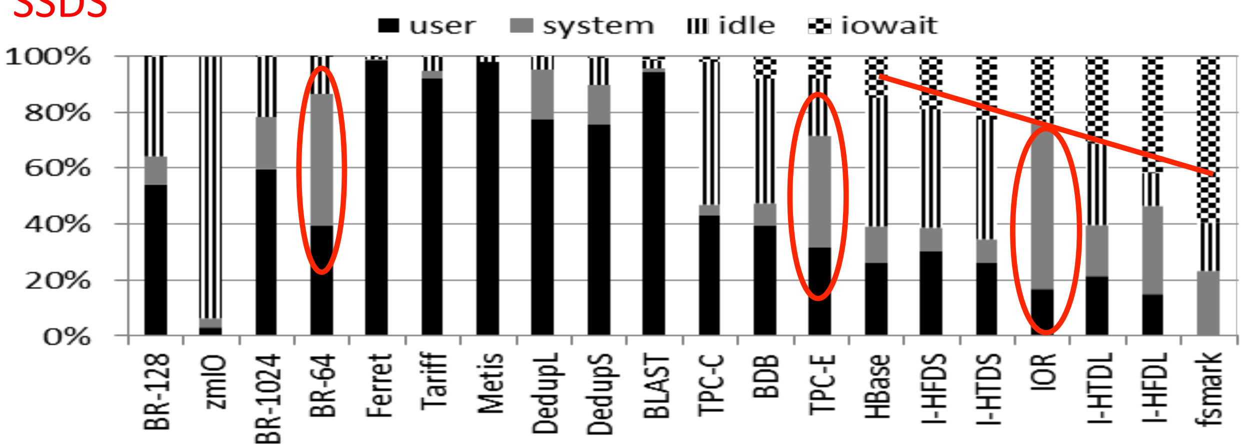
- Breakdown of execution time (user,system,idle,iowait)

DISKS



Average system time: 3%

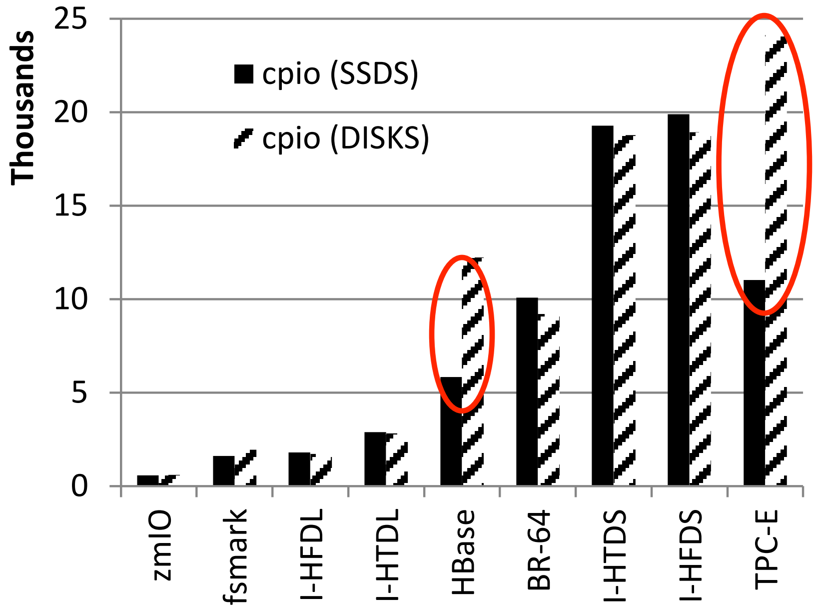
SSDS

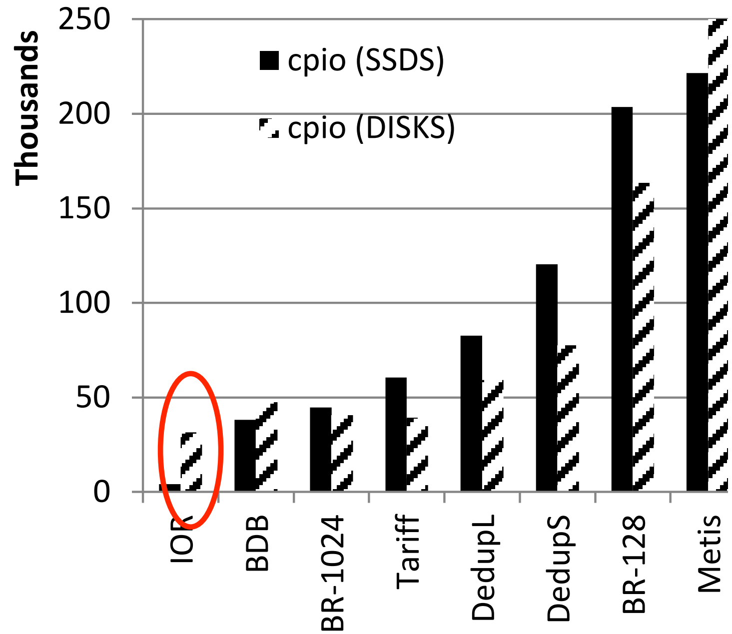


Average system time: 26%

cpio Sensitivity to Devices

- cpio largely independent of configuration
- Spinning effects in IOR, HBase and TPC-E



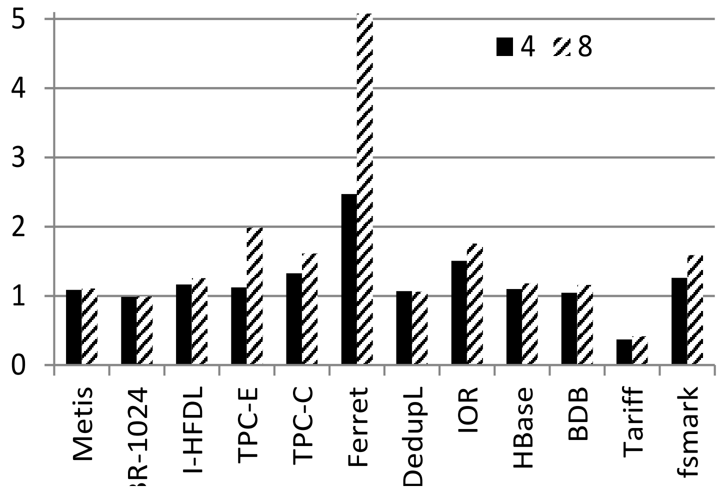


Outline

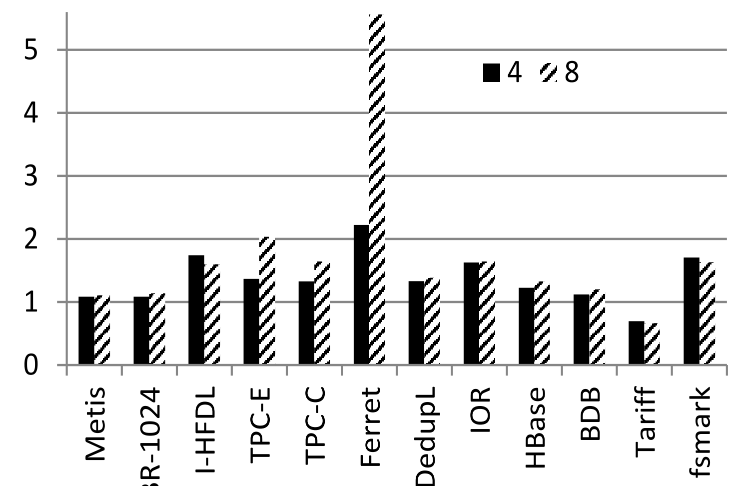
✓ Motivation and Goals
✓ Applications and Metrics
✓ Test System Configurations
- Does I/O Scale?
- How much I/O?
- How much Energy?
- Conclusions

Does I/O Scale?

- cpio does not scale with cores
- Overhead/work for a single I/O increases – ideally constant
- hw threads = cores (80% of perf at much less area)



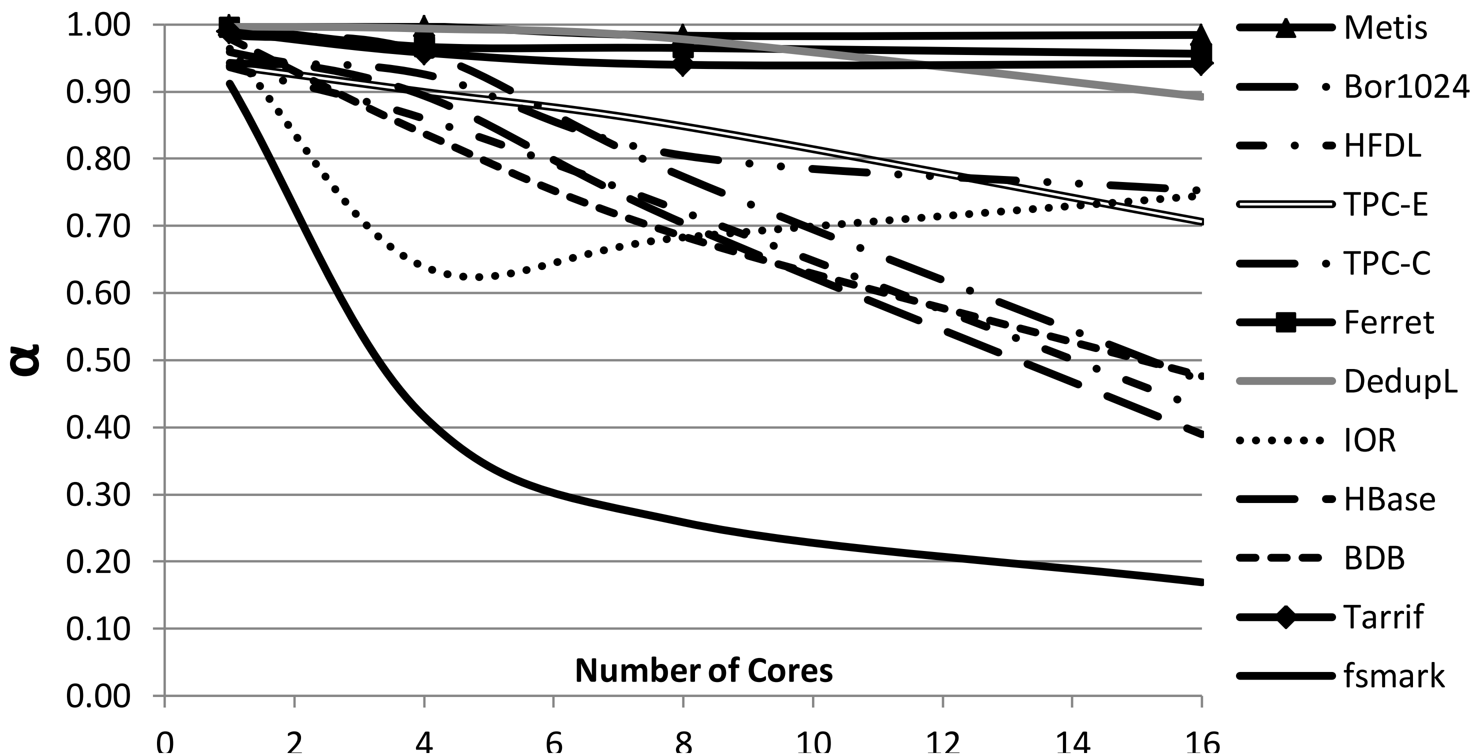
(a) Cores



(b) Hardware Threads

Application Scaling

- Hard to saturate cores with a single application
- Much bigger problem in the future



Outline

- ✓ Motivation and Goals
- ✓ Applications and Metrics
- ✓ Test System Configurations
- ✓ I/O Scalability Trends
- How much IO?
- How much Energy?
- Conclusions

We Project via cpio

- How do we calculate I/O requirements with increasing #cores?
- Once we know cpio
- Available cycles = #cores*freq
- Divide cycles with cpio
  - We get IOPS requirement for given #cores
  - Multiply with I/O size to get required I/O xput for #cores
- Which cpio do we use?

Various Projection Scenarios

- cpio
  - Measured with 16 cores (optimistic)
  - Measured with 1 core (desired)
  - Linear projection to N cores (pessimistic)
- CPU Utilization
  - 30%-40% range
    - Low utilization common today
  - 80%-100% (full) utilization
    - Desirable for better efficiency

How much I/O?

Millions of IOPS for 4096 Cores

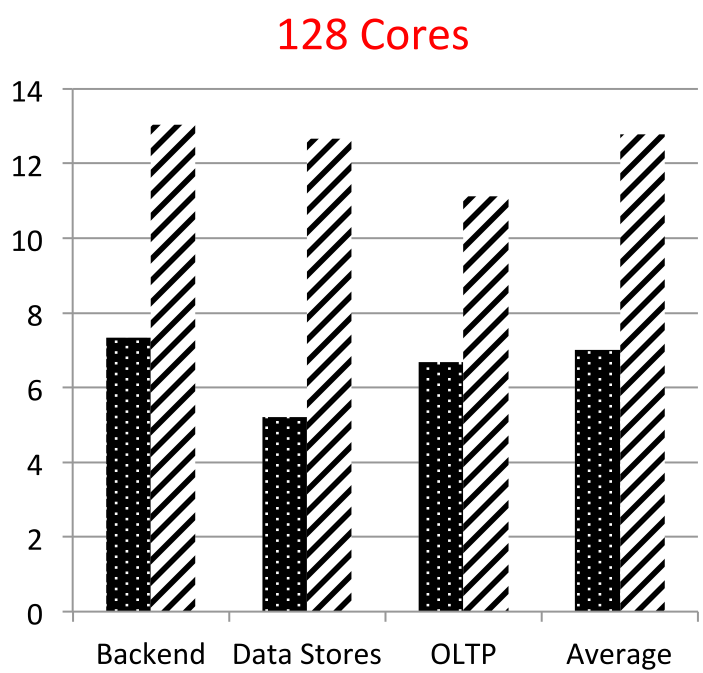
utilization&cpio	Average	TPC-E	HBase	PSearchy
Low&Projected	7.5	9	12	12
High&Projected	59	14	107	65
Low&Today	476	535	563	2207
High&Today	818	743	1405	4509
Low&Desired	969	1743	644	2540
High&Desired	1810	2469	1652	5941

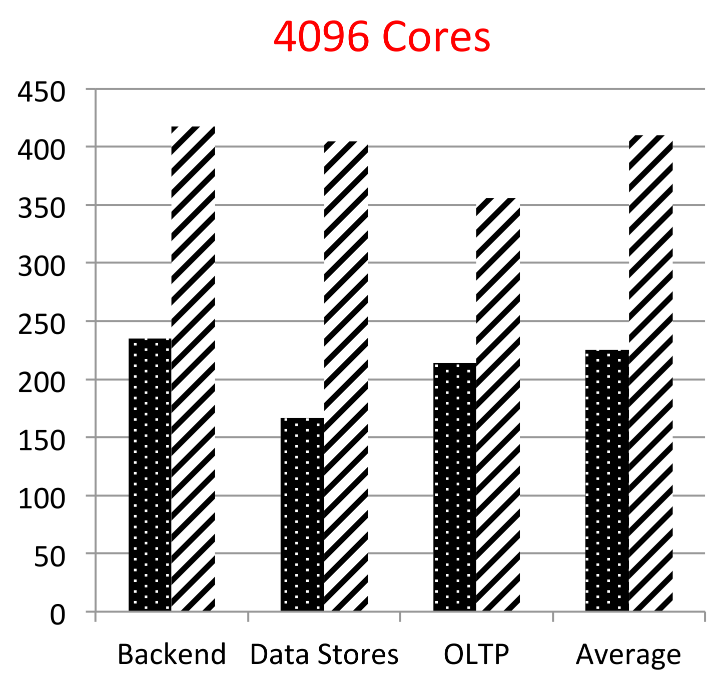
I/O Bandwidth

- Once we know cpio
- #ios = (#cores*freq) / cpio
- required I/O bw = #ios * iosize
- Per core
  - 100K – 500K IOPS
  - 1 GBit/s

How much I/O as #Cores Increases?

- GB/s on Y-axis
- Low utilization (left) and High utilization (right)





I/O Requirements: Quick Summary

- Requirements per core
  - 100K IOPS
  - 1 GBit/s I/O bandwidth
  - 1 GBytes/s memory bandwidth
- At 128 cores
  - 10M IOPS
  - 10 GBytes/s I/O bandwidth
  - 100 GBytes/s memory bandwidth
- Difficult to saturate systems with single application
- More work per I/O as # cores increases

Energy Requirements

- cpio easy to convert to energy
- BkWH to sweep over 35 ZettaBytes of data
- Calculate number of cores and translate to energy
  - 0.5W/core at 4K cores/server (2.5KW/server)
  - Idle power 0% -> perfect energy proportionality

Power Assumptions	Projected cpio	Today's cpio	Desired cpio
0.5 Watts per core (2.5 KW)	29	0.27	0.175
1.25 KW	17.5	0.16	0.107
2006 Level (0.675 KW)	9.5	0.09	0.057

- Between 0.1 – 0.3 BkWH for a single pass
  - A city of 200K, energy for a year
- Close to energy star projections
  - But we are using applications whereas they use market growth

Conclusions

- A methodology for characterizing I/O
- Scalability of I/O stack with cores
  - More overhead per I/O as number of cores increase
  - Contention and interference in the system stack
  - A single server is not saturated
- I/O requirements
  - At 128 cores (10M IOPS)
- Opportunity to save energy by better scalability

Thank you for your attention! Questions?

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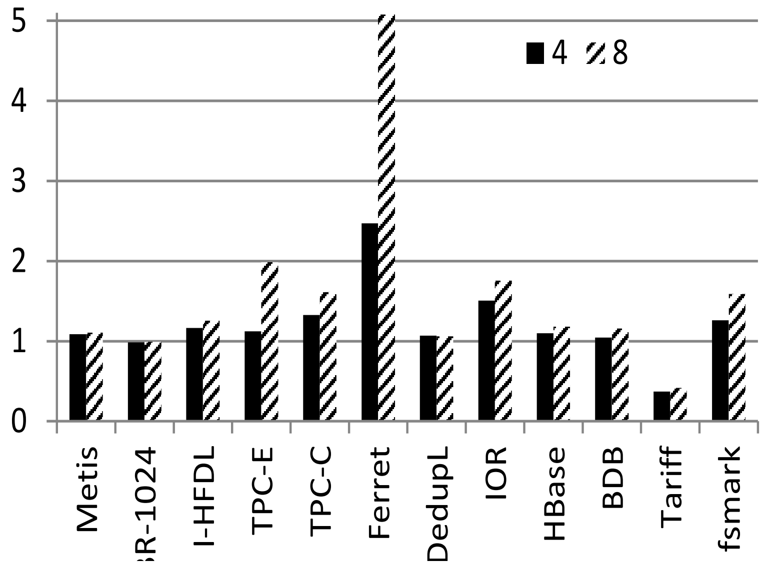
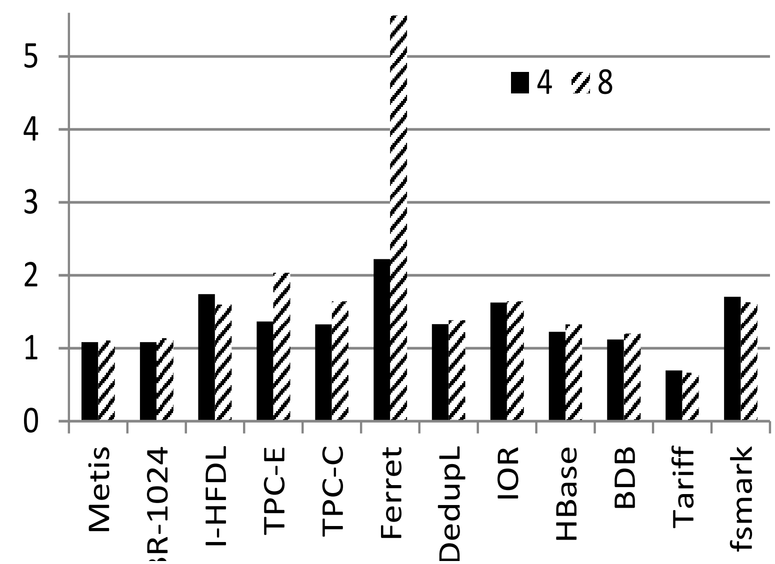
Hyper-threading



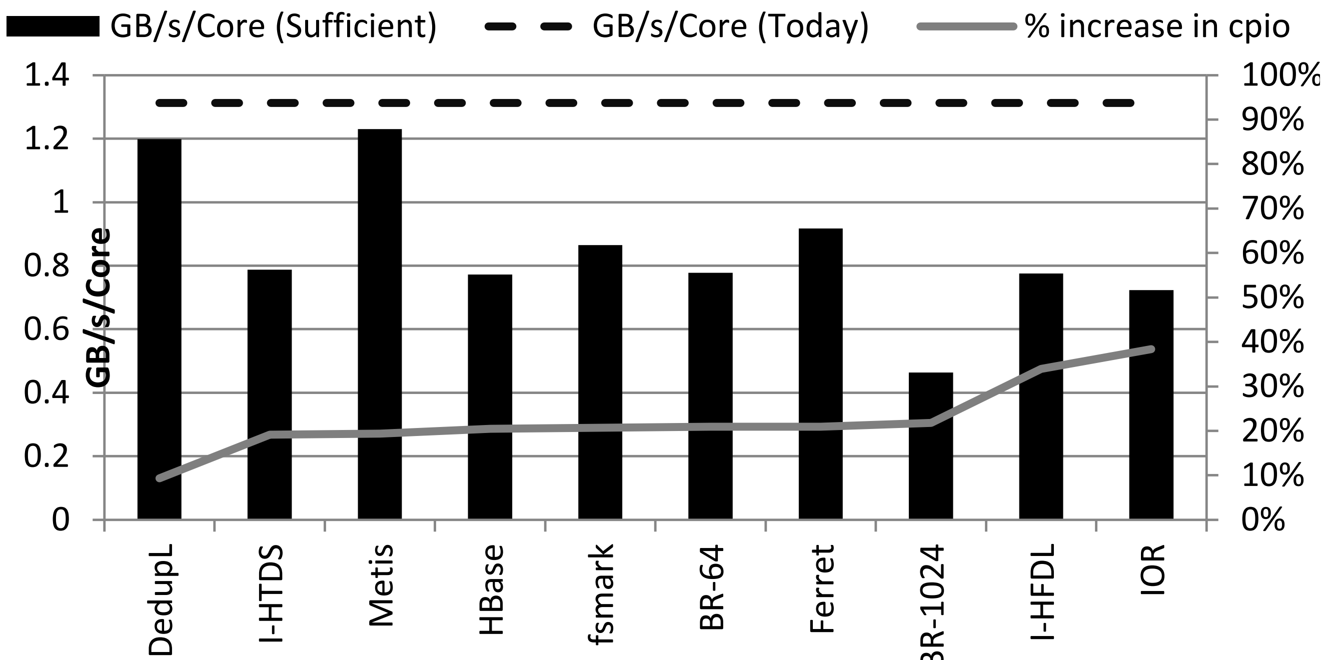
(a) Cores



(b) Hardware Threads

- Effectively h/w threads = cores (for these apps)
- 80% of perf at much less area

Memory Bandwidth



- Today systems overprovisioned for memory
  - Base: 1.3 GBy/s/core
  - At 0.8 GBy/s/core only 25% increase in cpio
- Going forward: 1 Gbytes/s/core memory bandwidth