Navigating Heterogeneous Processors with Market Mechanisms

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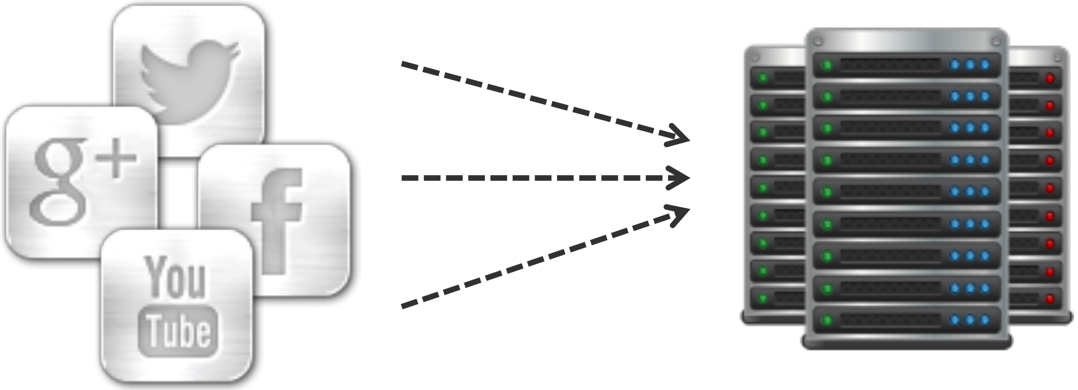
Growth of Cloud Applications



- Data volumes are growing geometrically
- Cloud applications are diversifying rapidly
- Computing capability must grow

- Datacenters consume tens of megawatts of power

Datacenter Scaling Limitations

- Dennard scaling is over
  - On-chip power density is a constraint
- Adding servers is expensive
  - Power determines operating costs

- Heterogeneity improves energy efficiency
  - Small cores consume a fraction of big core power
  - Big cores ensure service quality

Executive Summary

Goal:

- Improve service quality in heterogeneous datacenters

Methods:

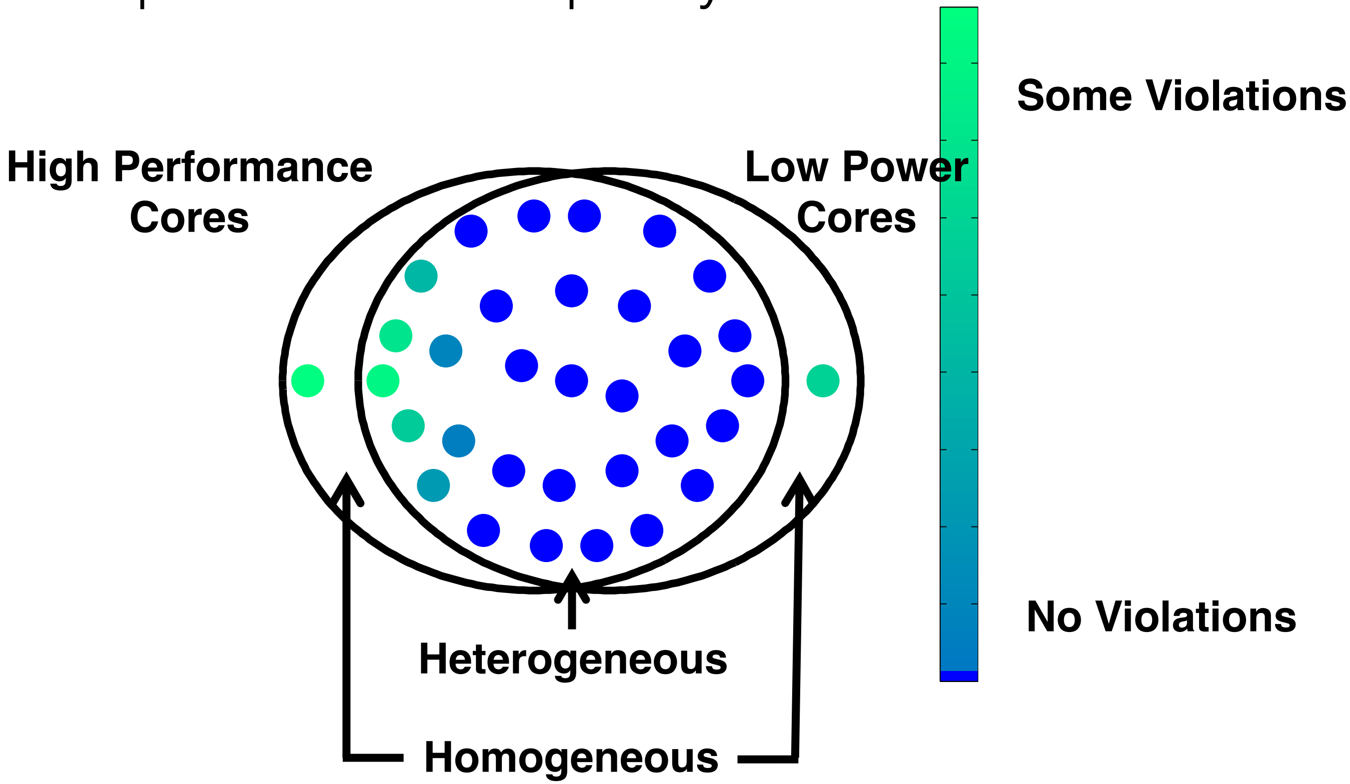
- Leverage processor heterogeneity
- Mitigate performance risk using market

Evaluation:

- Big/Small core heterogeneity improves service quality
- Three core types reduce service violations by 12x

Risks of Heterogeneity

- Heterogeneity introduces performance risk
- Yet it can improve service quality



Managing Risk

1. Types of processors?
2. Number of each?
3. How to allocate?

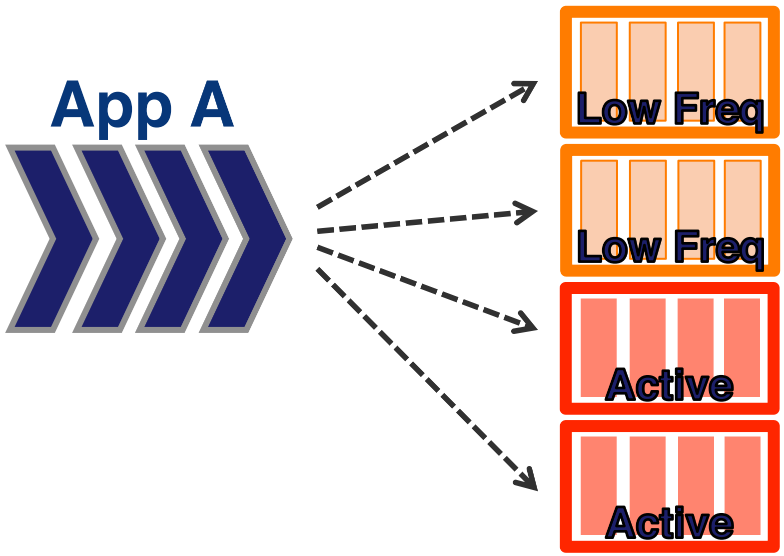
- Resource allocation that mitigates performance risk
  - Hide hardware complexity
  - Trade-off performance and power
  - Allocate small cores when possible
- Coordinate design and management

Allocating Time

Market periodically allocates time on hardware resource

$$\frac{\text{Tasks}}{\text{Sec}} = \frac{\text{Tasks}}{\text{Cycles}} \times \boxed{\frac{\text{Cycles}}{\text{Sec}}}$$

Right-size datacenter via server activation and DVFS

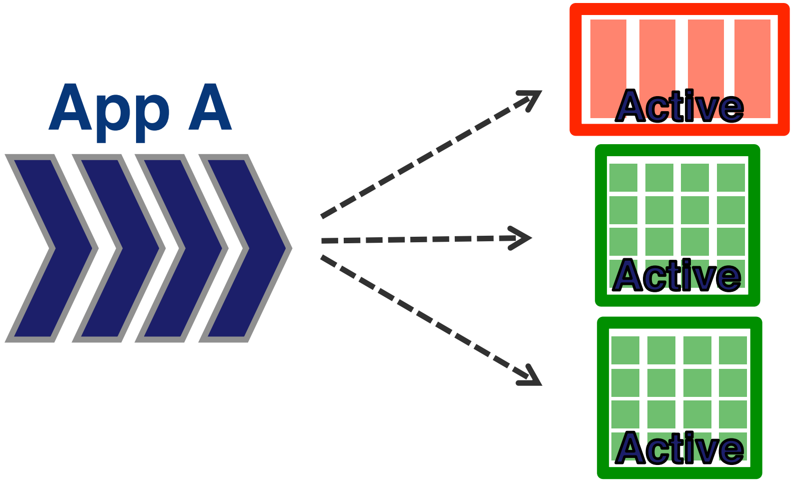


Accommodating Heterogeneity

Profile task-specific performance on each processor:

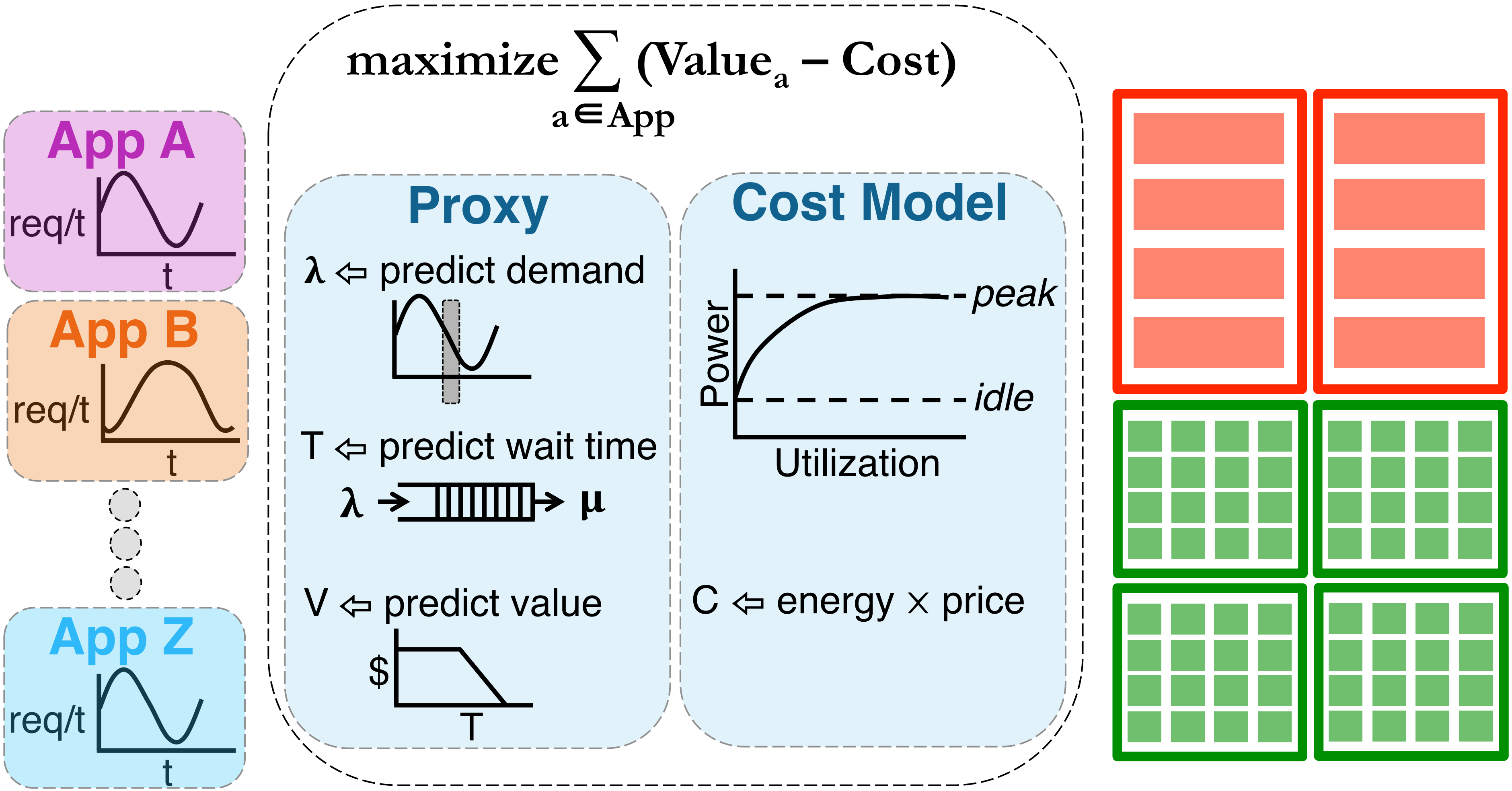
$$\frac{\text{Tasks}}{\text{Sec}} = \frac{\text{Tasks}}{\text{Inst}} \times \boxed{\frac{\text{Insts}}{\text{Cycle}}} \times \frac{\text{Cycles}}{\text{Sec}}$$

Store $\mathrm{IPC}_{a,m}$ as scaling factor relative to baseline IPC_0



Market Resource Allocation

$$\text{maximize} \sum_{a \in App} (\text{Value}_a - \text{Cost})$$



Experimental Methodology

Real tasks

Diurnal arrivals

Java implementation,
CPLEX solver for optimization

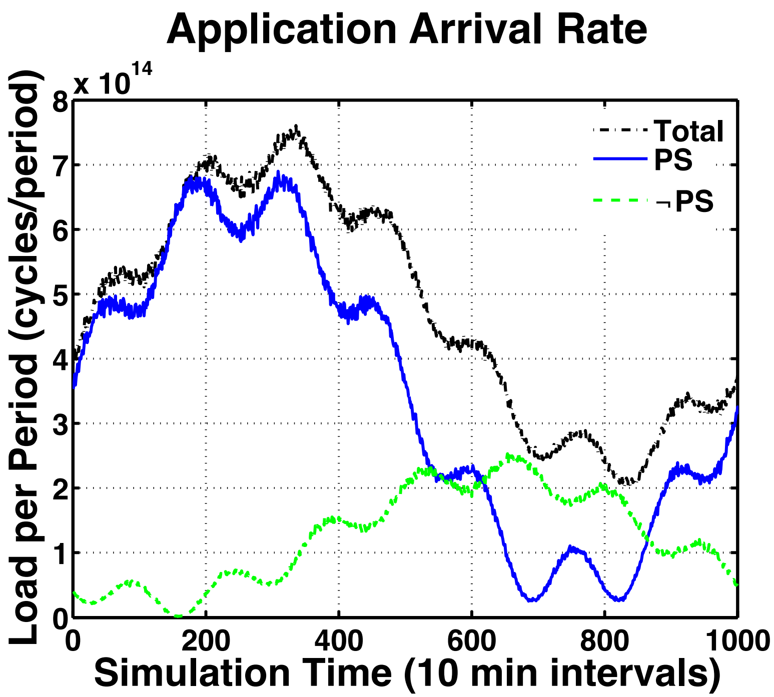
System profiles

Simulation

Defining Big and Small Cores

- Within fixed power budget, vary number of:
  - 4-core Xeon servers
  - 16-core Atom servers
- Core measurements [ISCA'10]
  - 0.3 – 1.0 relative IPC
  - 1.5 W Atom vs.15 W Xeon
- System model
  - Equal die area
  - Fixed system power overhead (65 W)

Modeling Application Behavior

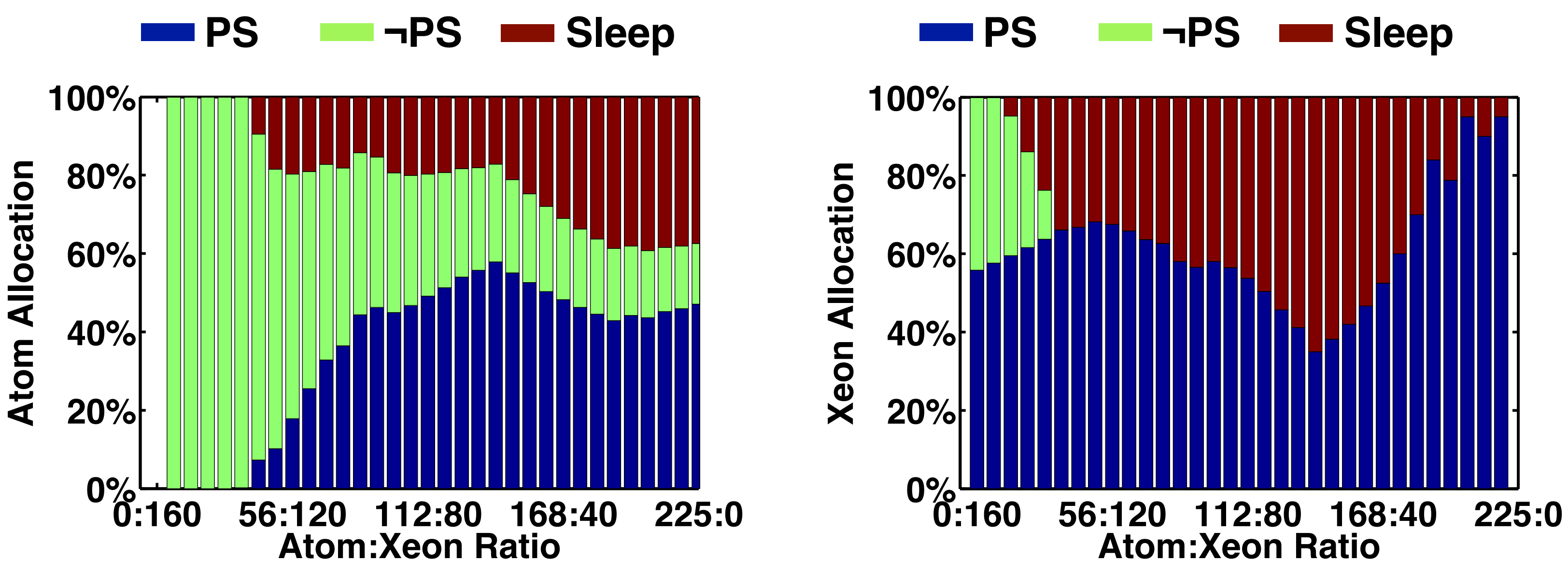


- One week of requests
- Diurnal pattern

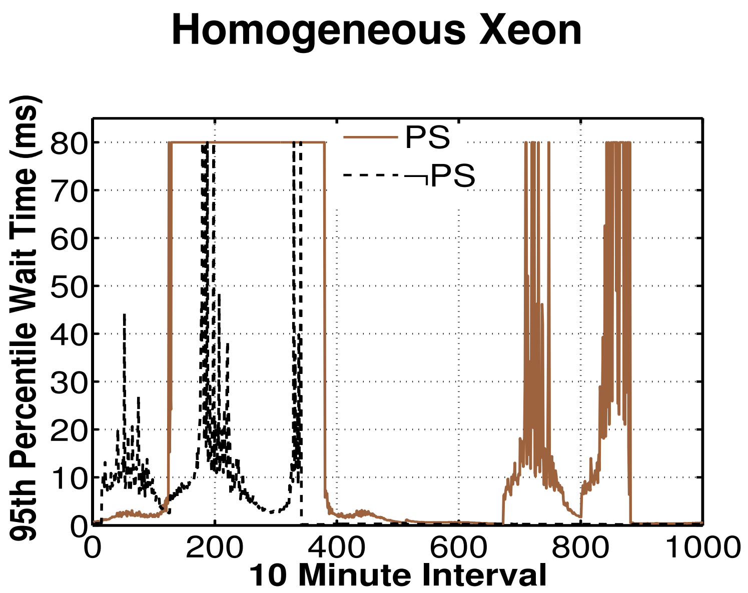
- Processor Sensitive (PS) – Atom throughput ⅓ that of Xeon
- Processor Insensitive (¬PS) – same throughput

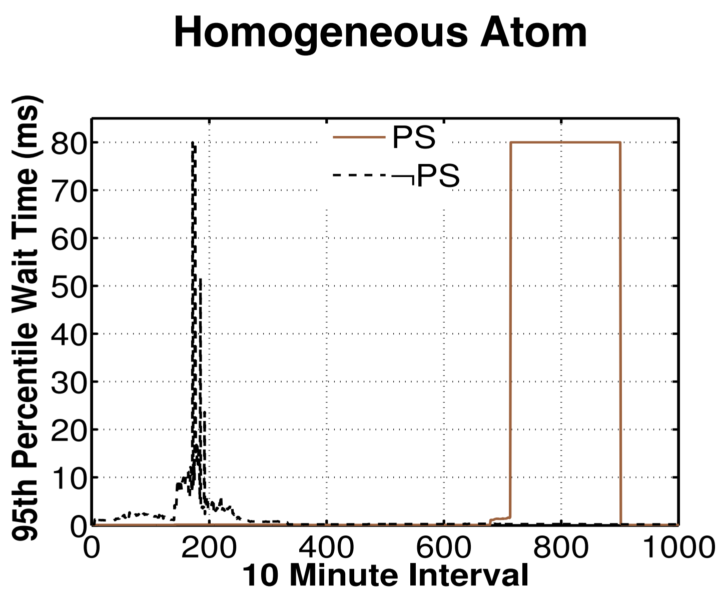
Understanding Datacenter Dynamics

- Vary Atom to Xeon ratio
- Examine allocations to each task
- Identify a balanced mix (e.g. 147:55)



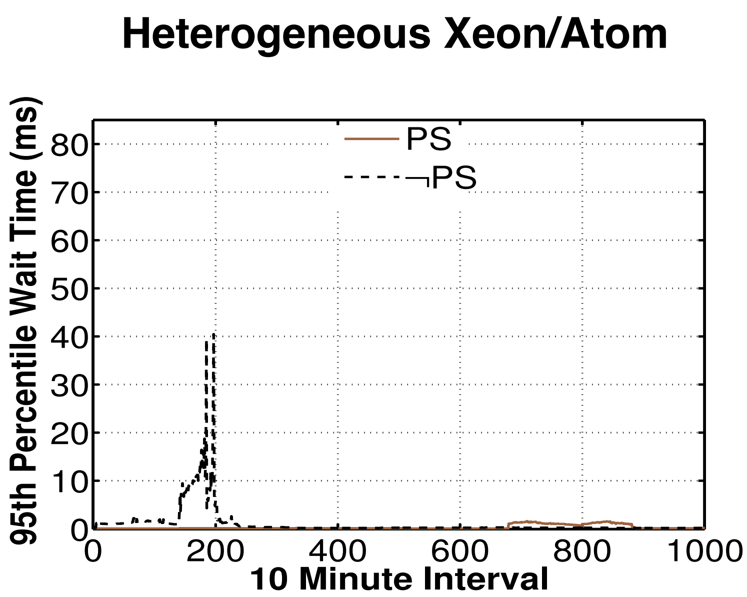
Improving Service Quality





- Xeon-only has insufficient resources
- Atom-only incurs violations due to cost

Improving Service Quality



- Xeon/Atom mix reduces waiting time
  - Atoms mostly allocated to ¬PS
  - Xeons freed to service PS peaks

Defining Greater Heterogeneity

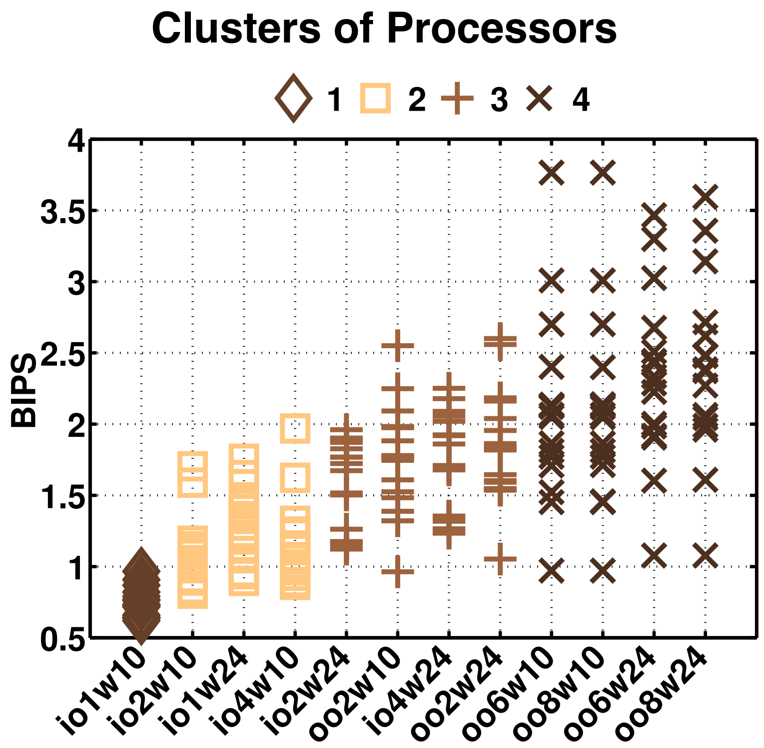
- Within fixed power budget, vary core designs
  - Dynamic scheduling (IO vs OO)
  - Issue Width (1,2,4,6,8)
  - Frequency (1.0,2.4 GHz)

- Processor simulation
  - 0.4 – 1.5 relative IPC (gem5)
  - 1.1 W – 28 W (McPAT)

- System model
  - Equal die area
  - Fixed system power overhead (65 W)

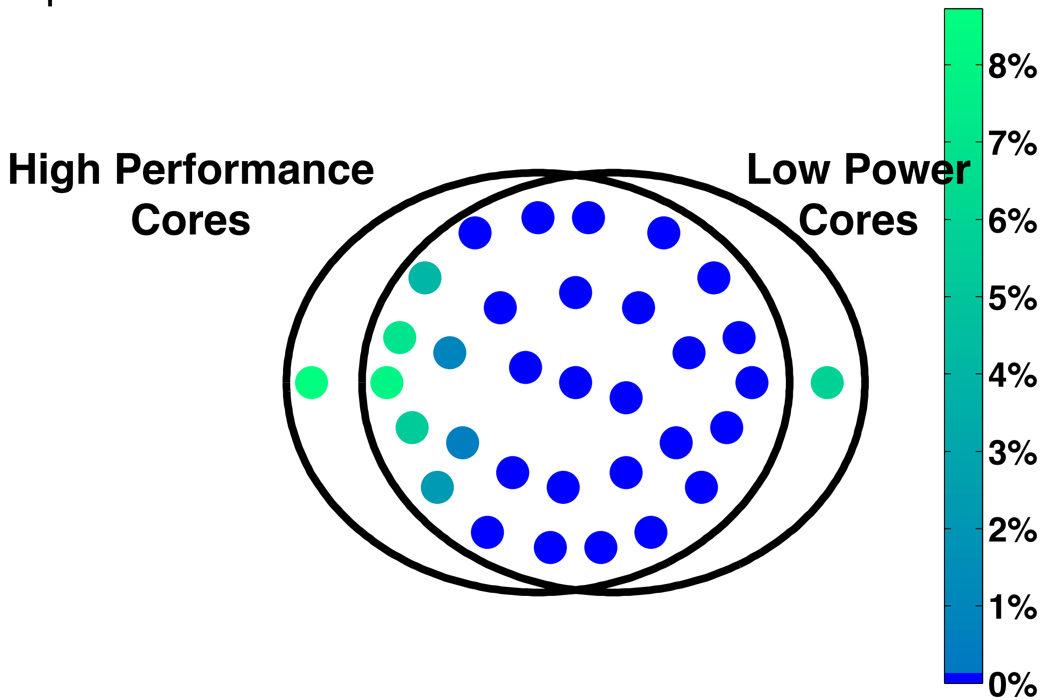
Clustering Heterogeneous Processors

- Cluster cores with similar SPEC performance
- Select core with lowest performance variation from each cluster
- Evaluate with diverse SPEC task streams

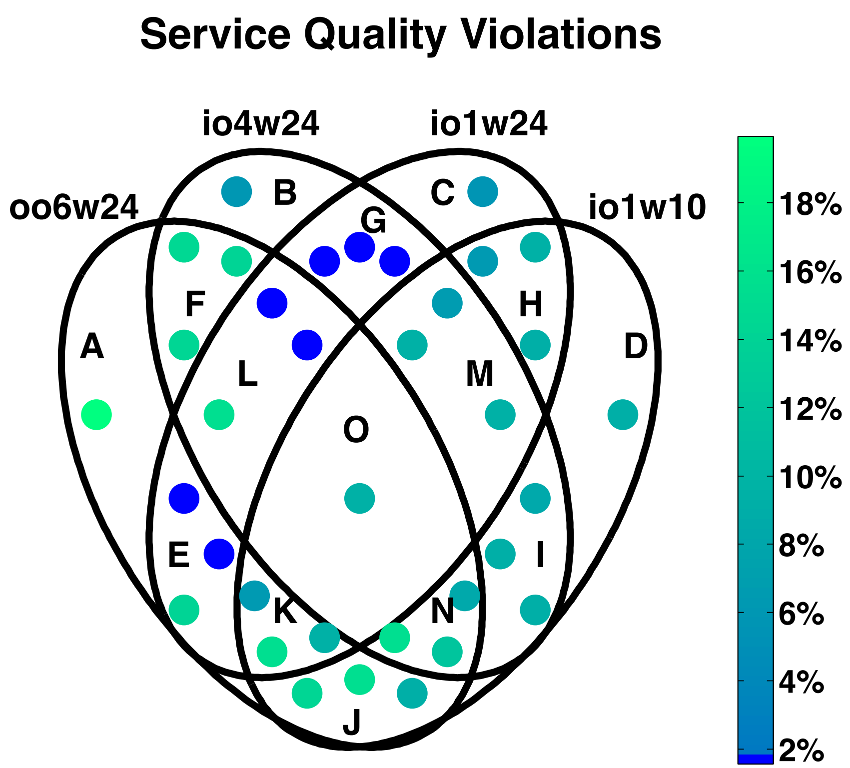


Visualizing the Design Space

- Ellipses represent core types
- Points are combinations of cores
- Colors represent service violations



Design Space with Four Processors



- Identify right core types
- Prune design space
- Best configuration is heterogeneous
  - RT violations reduced from 15.5% to 1.6%

Conclusions and Future Directions

- Leverage market to mitigate heterogeneity's risk
  - Embed microarchitectural insight into the market
  - Allocate multiple resources
- Deploy heterogeneous hardware in a datacenter
  - Optimal balance improves service
  - Sophisticated trade-offs require further study
- Propose a datacenter research methodology
  - Simulating detailed server architecture
  - Modeling user and datacenter dynamics
  - Tractability for web search, memcached, map/reduce

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