Application Modeling and Hardware Partitioning Mechanisms for Resource Management

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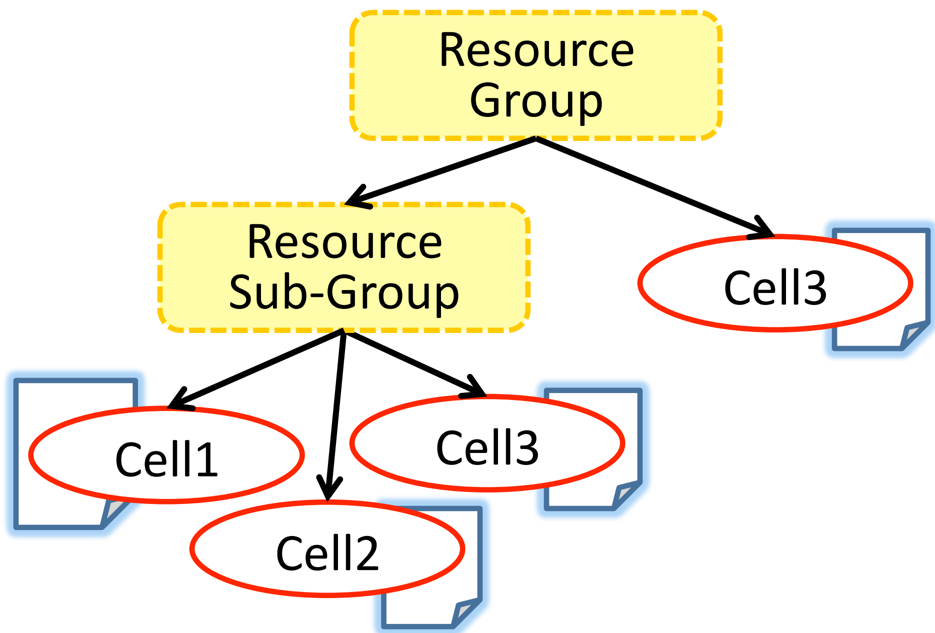
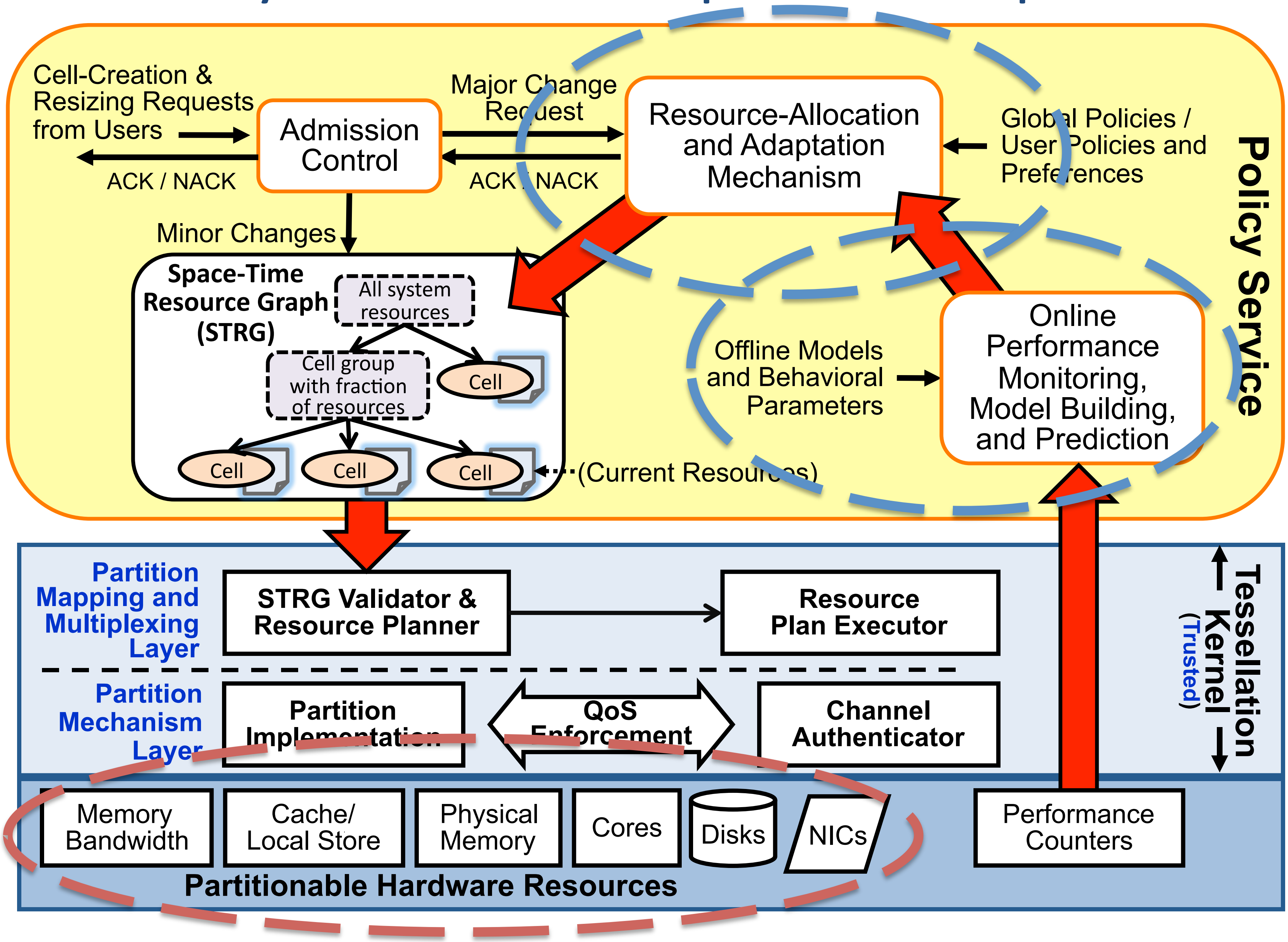
ParLab Arch and OS Groups

Resource Allocation Objectives

- Each partition receives a **vector of basic resources** dedicated to it
  - Some number of processing elements (e.g., cores)
  - A portion of physical memory
  - A portion of shared cache memory
  - A fraction of memory bandwidth
- Allocate minimum resources necessary for each applications QoS requirements
- Allocate remaining resources to meet some system-level objective
  - Best performance
  - Lowest Energy
- Doesn't require application developers to worry about low-level resources



System-wide Adaptation Loop



Techniques and Tradeoffs

APPLICATION MODELING

Motivation

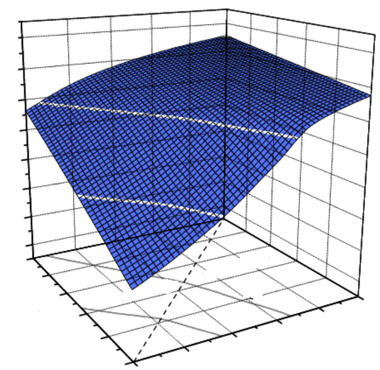
- Programmers are unlikely to know exactly how low-level resources effect performance
  - Developers are concerned application-level metrics
    - e.g., frames/sec, requests/sec
  - Operating system has to make decisions about resource qualities
    - e.g., number of cores, cache slices, memory bandwidth
- Automatically constructing performance models is a good way to bridge the gap between application-level metrics and hardware resources

Model Building

- Collect data points of performance for specific resource allocation vectors

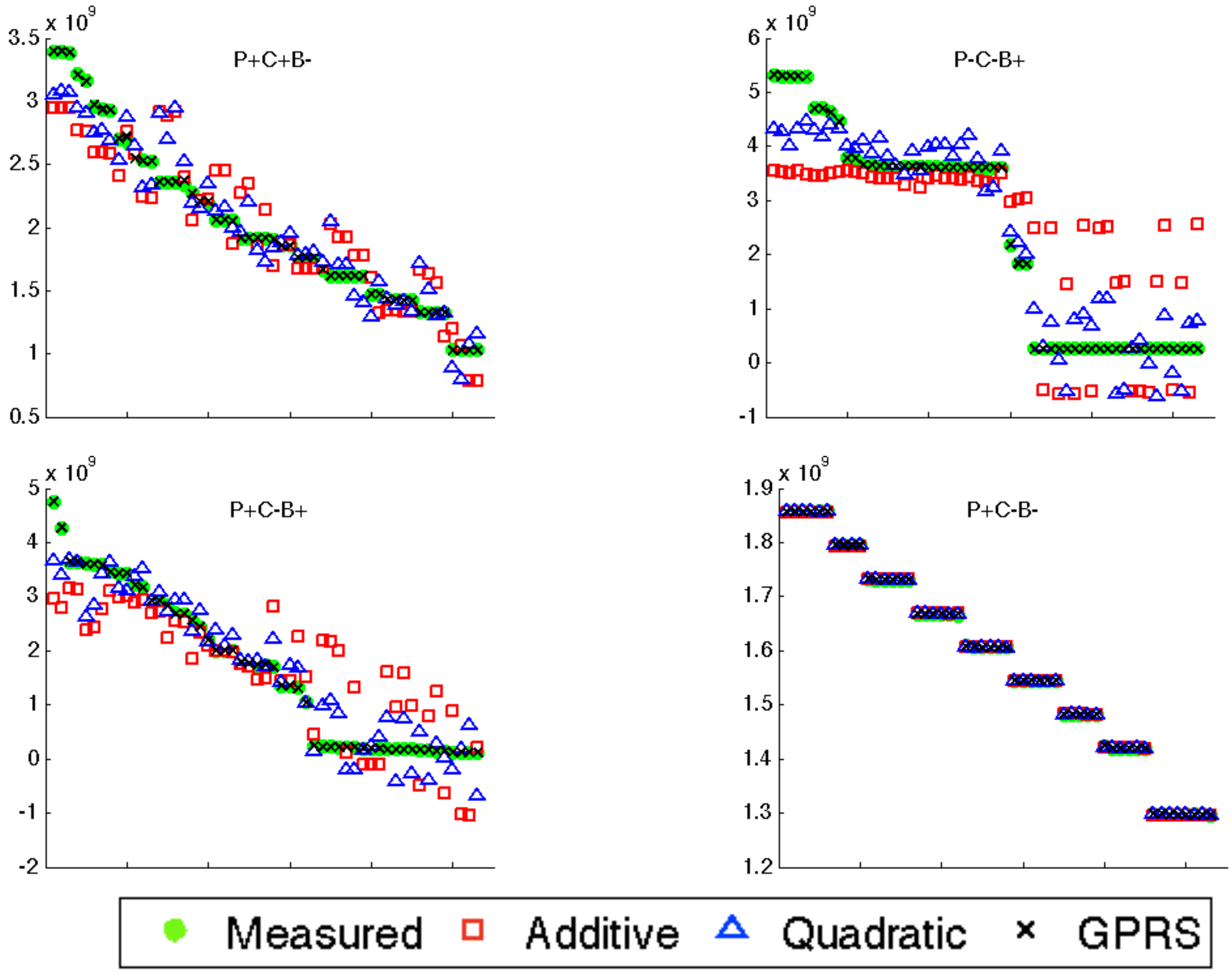
$$L_i = PM_i(r_{(0,i)}, r_{(1,i)}, \ldots, r_{(n-1,i)})$$

- Use multivariate regression techniques to fit a model to the data points



Linear and Quadratic	GPRS	KCCA
•**Advantages** •Simple to build •Work well with simple optimizers •**Disadvantages** •Potentially inaccurate •Can't represent variable interaction	•**Advantages** •Very Accurate •**Disadvantages** •Can overfit the data •Computationally expensive to build •Doesn't work with simple optimizers	•**Advantages** •Can represent all output metrics in one model •Successful in the past •**Disadvantages** •Doesn't work with simple optimizers

Model Accuracy



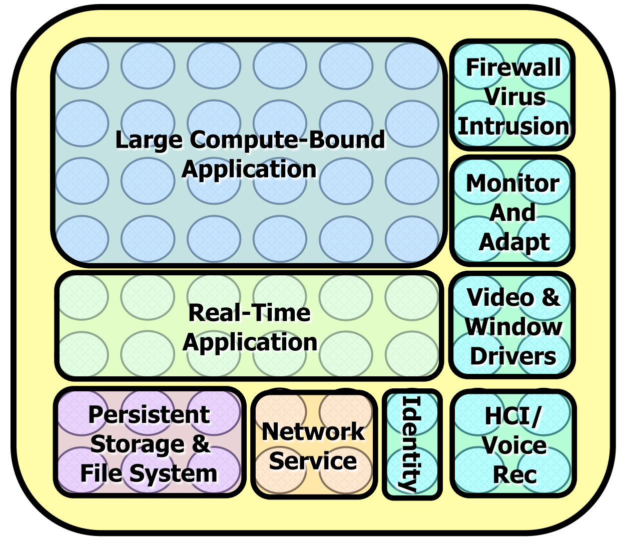
Model Creation

Online vs. Offline Training

- Offline profiling options
  - – Profile applications in advance
    - Distribute with application
    - iTunes App Store or Android Market
  - – Create application profiles in the Cloud
    - Record performance and resource statistics from users
    - MSR is currently doing this to make perf. models for app developers
- Online profiling options
  - – Install time profiling
    - Operating system tests out a variety of configurations
  - – Online refinement of models
    - Operating system starts with a generic model
    - Retrains the model with new information as the application runs

Performance Isolation

- Without performance isolation,
  - An applications performance could vary widely as a result of concurrently running applications
  - Inaccurate models
  - Requires different models of the application based on the system load



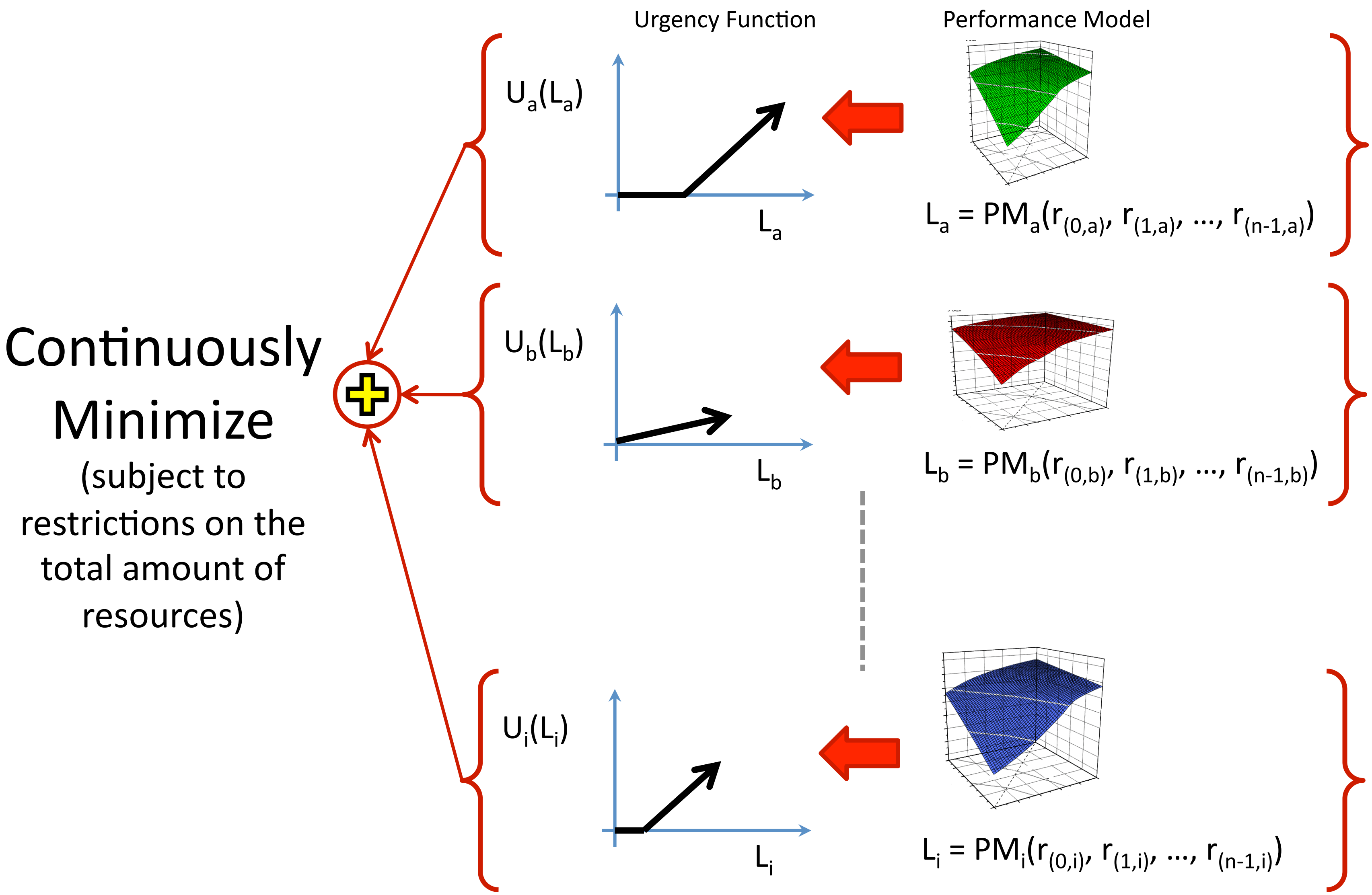
- Performance predictability is an important component for application modeling
  - Other advantages
    - Better tuned, more efficient applications
    - Easier to make QoS guarantees

An Example

RESOURCE ALLOCATION USING CONVEX OPTIMIZATION

Minimizing the Urgency of The System

[Burton Smith (MSR), Operating System Resource Management (Keynote), IPDPS 2010]

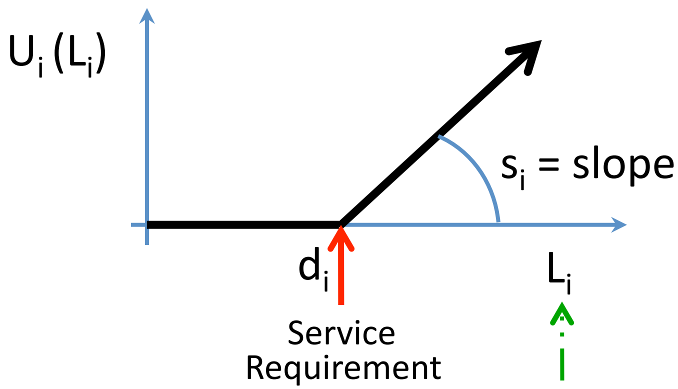


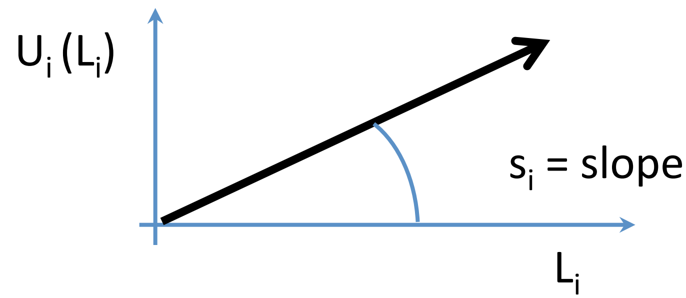
Urgency Function

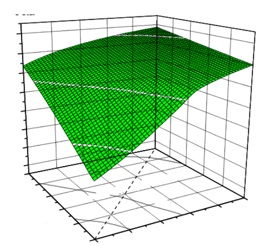
[Burton Smith (MSR), Operating System Resource Management (Keynote), IPDPS 2010]

- Reflects the importance of cell C_i to the user

$$U_i(L_i) = MAX(s_i \cdot (L_i - d_i), 0)$$







Performance Model (PM)
Expected to decrease with resources

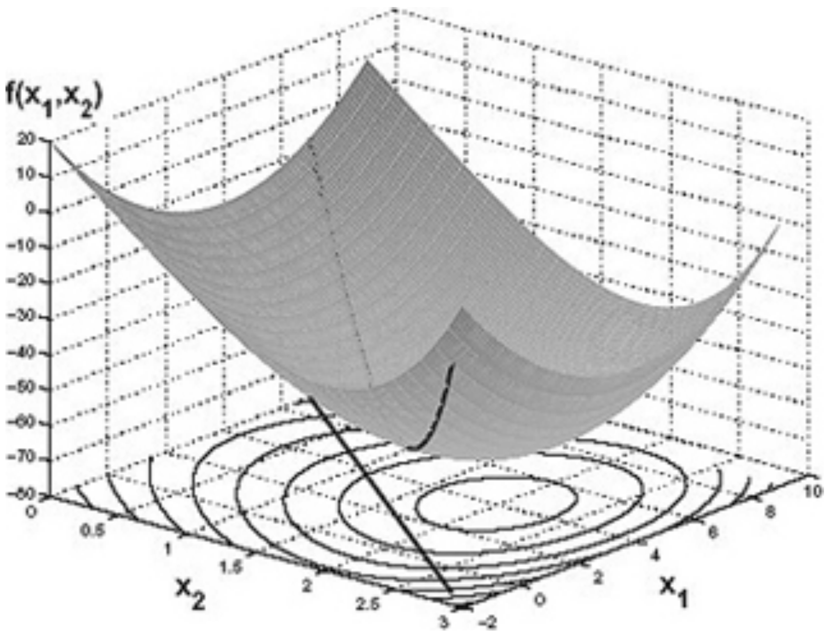
$$L_i = PM(r_{(0,\, i)}, r_{(1,\, i)}, \ldots, r_{(n-1,\, i)})$$

$r_{(1,i)}$: Allocation of resource of type 1 to Cell C_i

Performance-Aware Convex Optimization

for Resource Allocation

[Burton Smith (MSR), Operating System Resource Management (Keynote), IPDPS 2010]



- Advantages
  - Convex optimization is **relatively inexpensive** optimization problem with a **single extreme point**
  - Urgency Function Slopes allow the system to express **relative priorities** of application
  - Priorities change as a function of performance
  - Urgency Function Intercept **encapsulates QoS requirements**
  - And additional process can be used to **represent system energy**

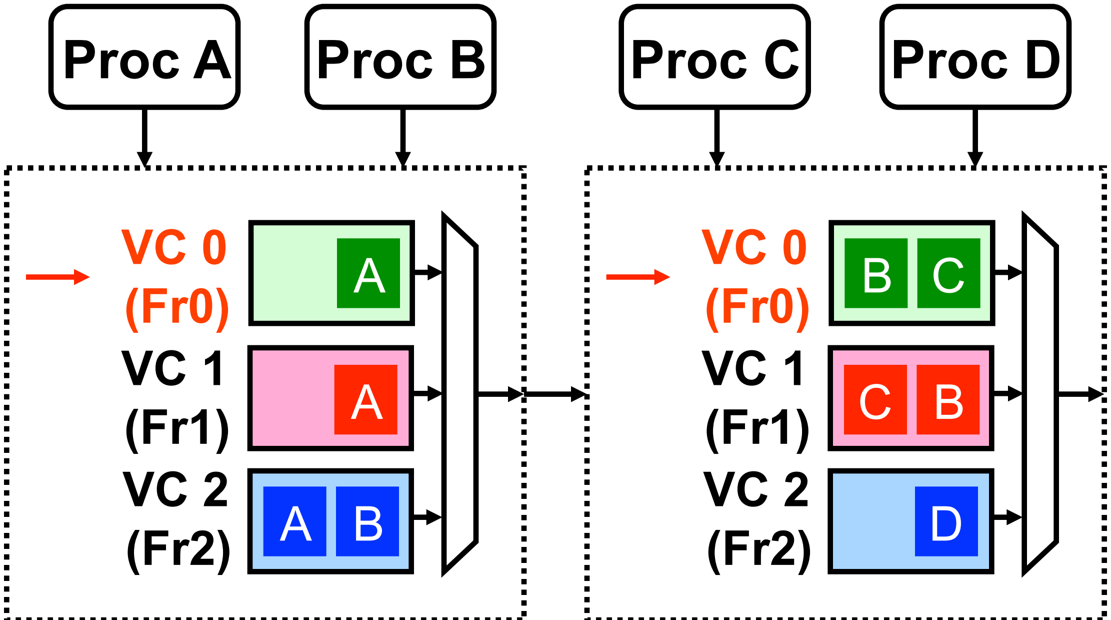
Very sensitive to the performance models of the applications

Approaches + Mechanisms

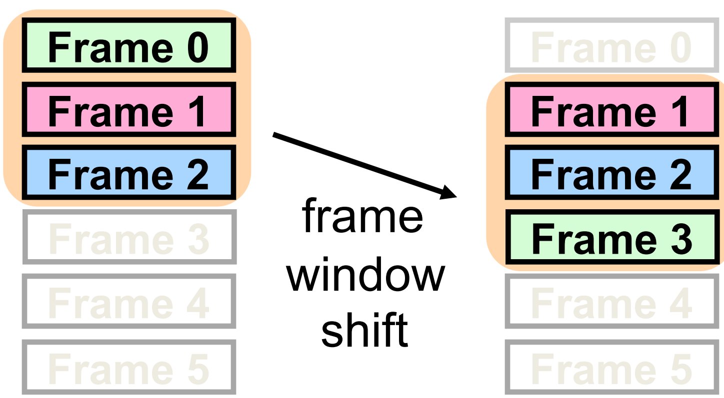
HARDWARE PARTITIONING

GSFm: Globally Synchronized Frames

Bandwidth Partitioning for the memory hierarchy



- Frame-Based QoS System
  - Transactions are labeled with a frame number
  - Head frame moves through the network with a top priority

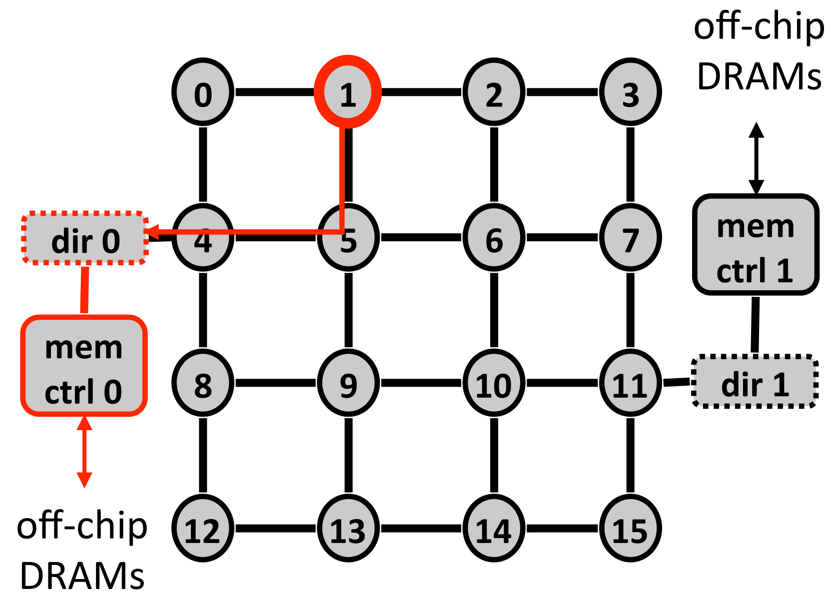


with Jae Lee, MIT

GSFm: Globally Synchronized Frames

Bandwidth Partitioning for the memory hierarchy

- Uses source-side suppression
- Applications are given a bandwidth allocation per frame
  - Credits per resource
    - Memory channels and memory bank, network link, etc
  - Memory transactions are charged for all possible resources
    - Delayed into a future frame if the app doesn't have enough credits

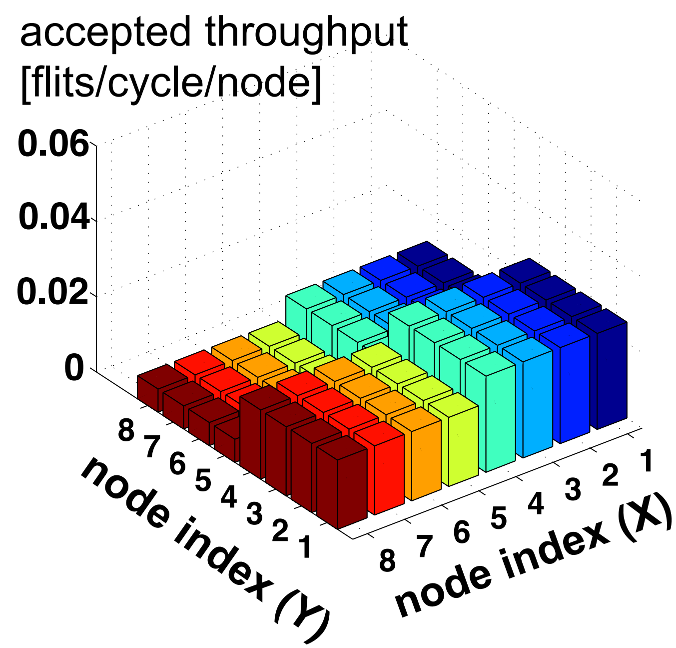


Networks				Memory	
c2hREQ	*h2cRESP*	*h2cREQ*	*c2cRESP*	*channel*	*bank*
1H	1P	0	0	1T	1T

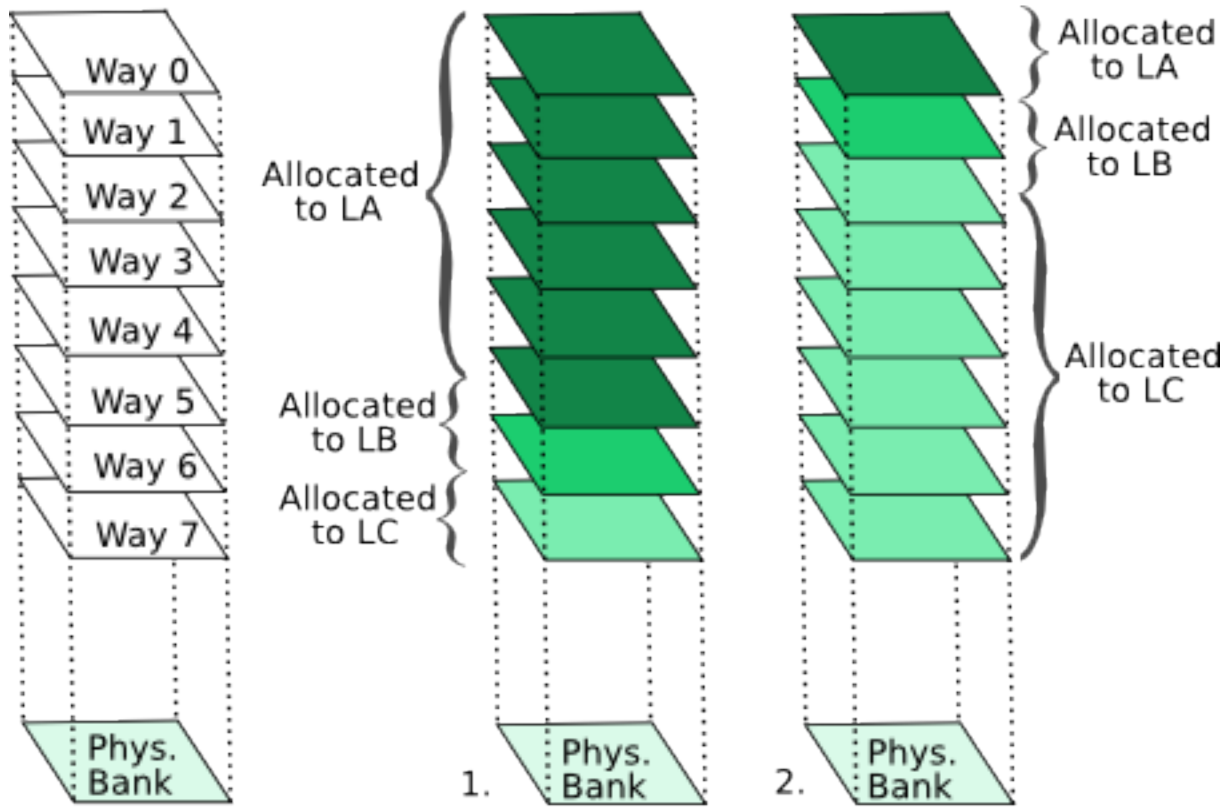
H: header-only message
P: header+payload message
T: memory transaction

Advantages of GSFm

- Minimum Bandwidth Guarantees
  - Flexible
  - Differentiated
  - Weighted sharing of the excess bandwidth
- Good Utilization
  - Early frame reclamation
  - Excess bandwidth
- Minimal Hardware Requirements
  - Reasonable area
  - Distributed



Cache Partitioning



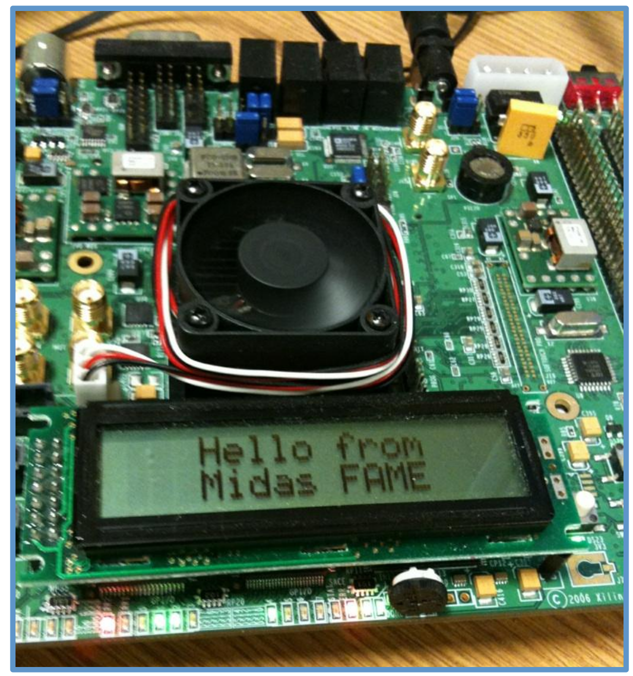
- Way-Based
  - Simple Indexing
  - Changes the replacement policy
  - Reduced associativity
  - Limited by number of ways
  - No locality for NUCA systems
- Bank-Based
  - Locality in NUCA
  - More complex indexing
  - Requires flush on reconfiguration
  - Limited by number of banks

RAMP Gold Experiments

A SIMPLE EVALUATION

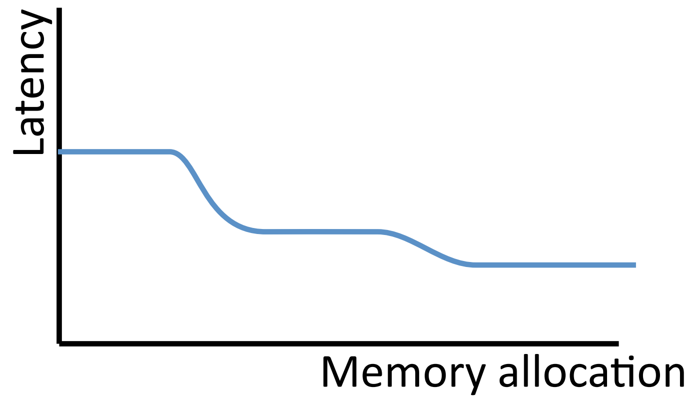
Experimental Platform

- RAMP Gold: FPGA-Based Simulator Target Machine
  - 64 single-issue in-order cores @ 1GHz
    - Partitionable into sets of 8
  - Private L1 Instruction and Data Caches each 32KB
  - Shared L2 Cache 8MB inclusive 10 ns latency
    - Partitionable into 8 slices using page coloring
  - Memory bandwidth with magic interconnect
    - Partitionable into 3.4 GB/s units assigned to a set of cores
- ROS Kernel Code
  - Microbenchmarks & PARSEC Benchmarks



Application Modeling

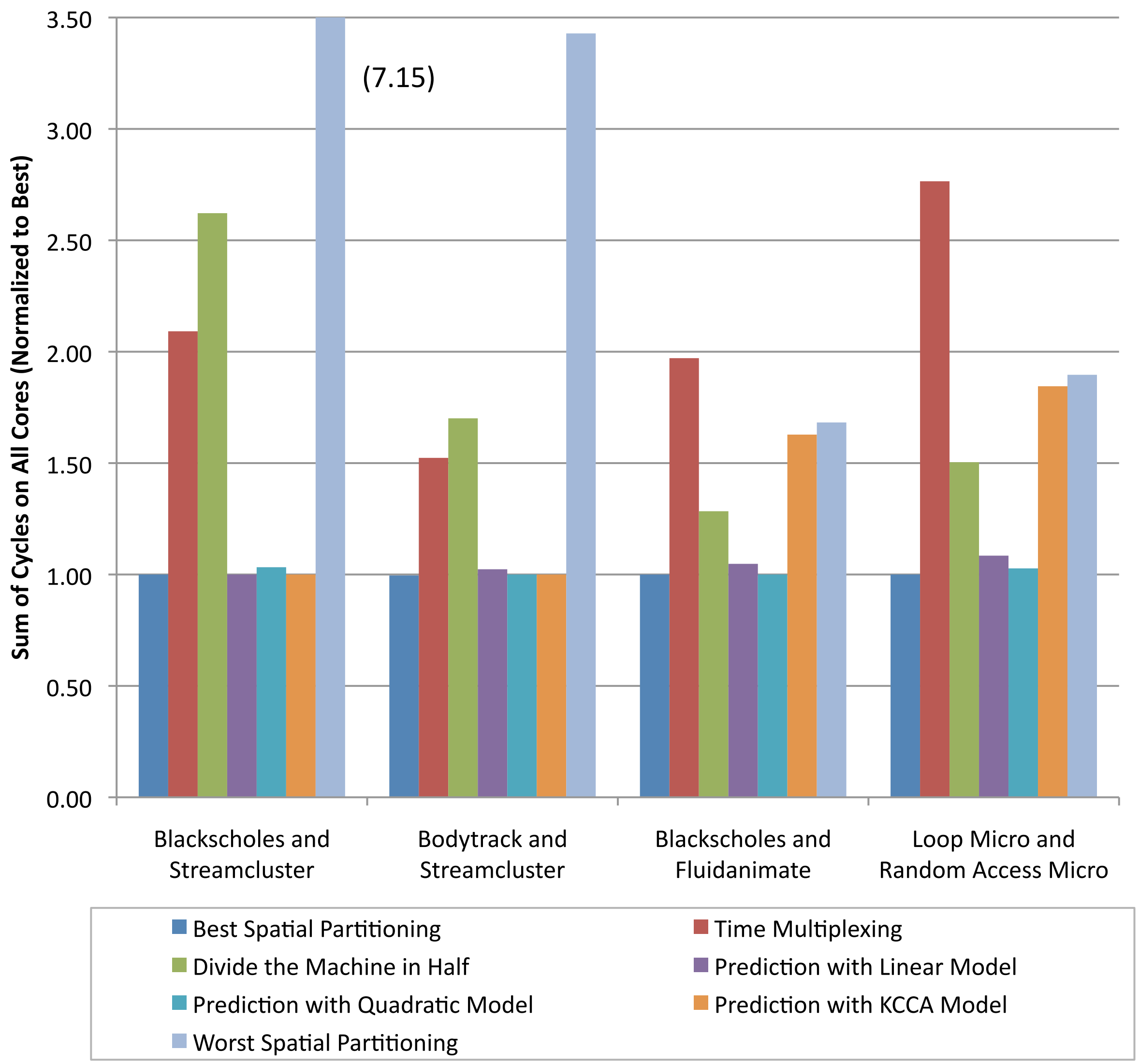
- Use 10 sample points
  - 18.5% of the 54 Possible Allocations
  - Selected using Audze-Eglais Design of Experiments
- Create a model of the application
  - Input: Resources
  - Output: Performance
- Explore different types of models
  - Linear
  - Quadratic
  - KCCA (Machine Learning)
  - Genetically Programmed Response Surfaces (GPRS)
- Run all 54 Allocations to test model accuracy



Scheduling Experiment

- Evaluate Objective Function for a Pair of Benchmarks using the models
  - Race to Halt
    - Min Max(Cycle1, Cycle2)
  - Least Cycles
    - Min (Cycle1*Cores1 + Cycle2*Cores2)
  - Lowest Energy
    - Min Σ_i (resource utilization i*energy parameter i)
  - Using MATLAB's fmincon
- Run all 54 possible resource allocations for each pair of benchmarks
  - Assumes that all resources must be allocated

Spatial Partitioning Results



- Time-Mux'ing is on average of 2x worse than the best spatial partition
- However the worst spatial partition is quite bad.
- Naively dividing the machine in half is 1.75x worse than the best spatial partition
- Linear model is within 8% of optimal every time
- Quadratic Model is within 3% of optimal every time
- KCCA does well in some cases but very poorly in others

Conclusions

- Simple application models show promise
  - Still lots of challenges
    - When to build?
    - How to store?
    - Variability
- Resource allocation using convex optimization potentially very interesting
  - Lots of parameters to tune
    - How do we set the urgency functions?
  - How does it compare with other options?

QUESTIONS?