Performance Prediction Engineering

Francine Berman
U. C. San Diego

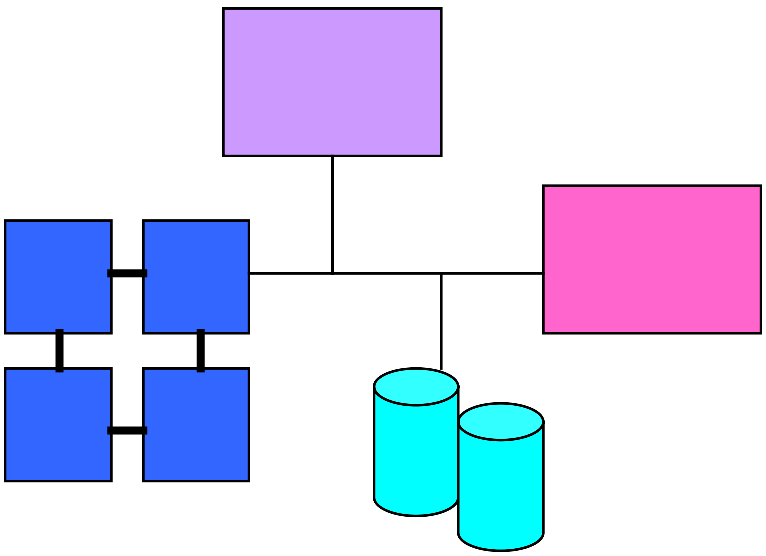
Rich Wolski
U. C. San Diego and University of Tennessee

The Computational Grid

Computer = ensemble of resources

"Computer" may consist of

- computational sites
- dist. databases
- remote instruments
- visualization
- distinct networks



Grid Programs

Grid programs

– may couple distributed and dissimilar resources

– may incorporate tasks with different implementations

– may adapt to dynamic resource load

Performance Models for Grid Programs

- Grid applications may couple dissimilar resources
  - **models must accommodate heterogeneity**
- Grid applications may incorporate tasks with different implementations
  - **model must accommodate multiple task models**
- Grid applications may adapt to dynamic resource load
  - **models must allow for dynamic parameters**

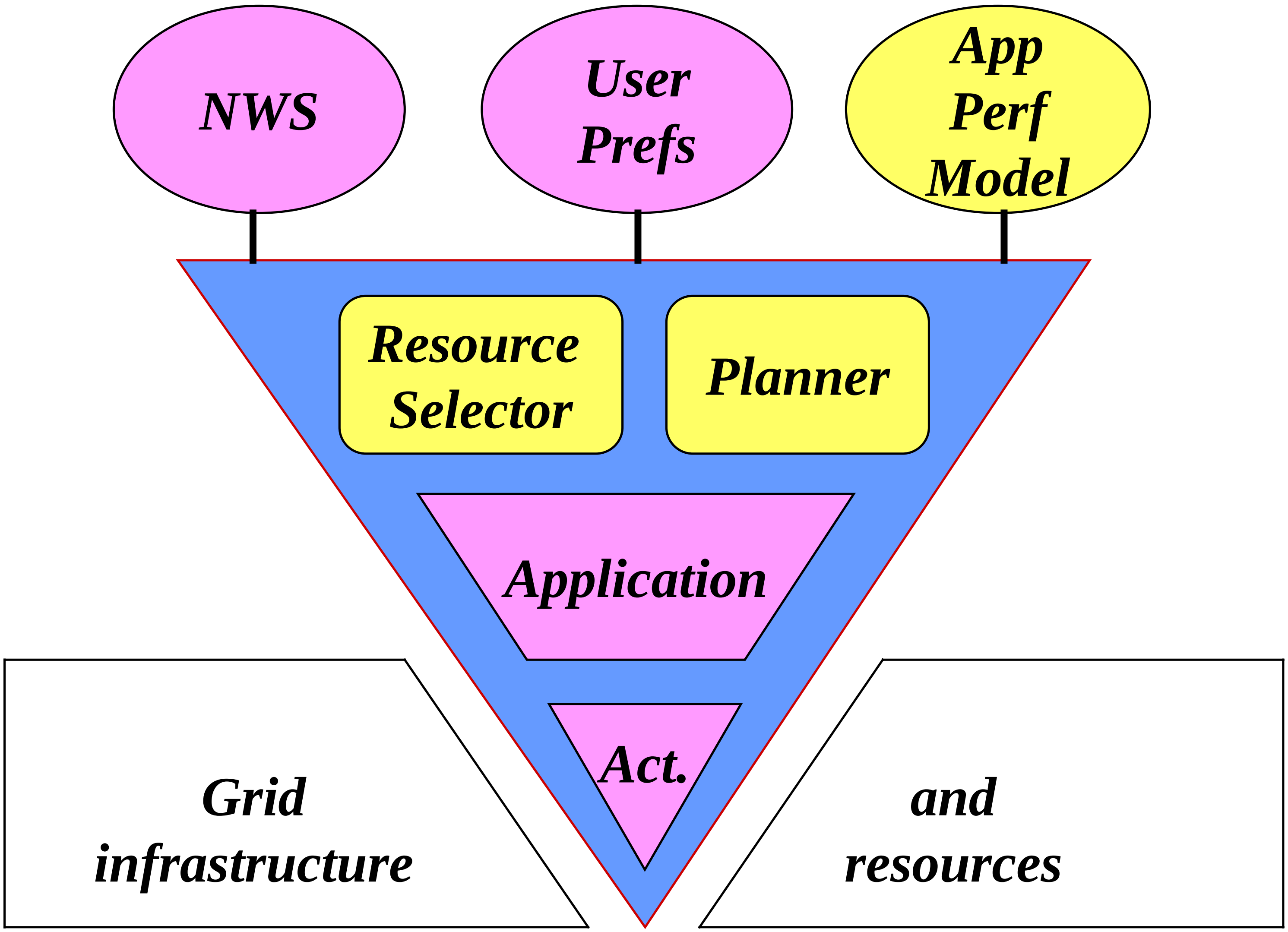
Compositional Models

- Grid programs can be represented as a ***composition*** of tasks
- “Tasks” consist of relevant performance activities
- Model parameters may reflect performance variations of grid
  – may be parameterized by *time*

Using Grid Performance Models

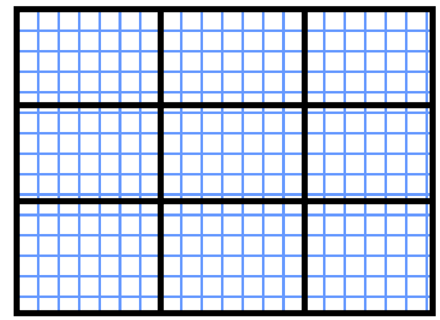
- Compositional models particularly useful for grid ***application scheduling***
- Application schedulers use performance prediction models to
  - select resources
  - estimate potential performance of candidate schedules
  - compare possible schedules

AppLeS = Application-Level Scheduler

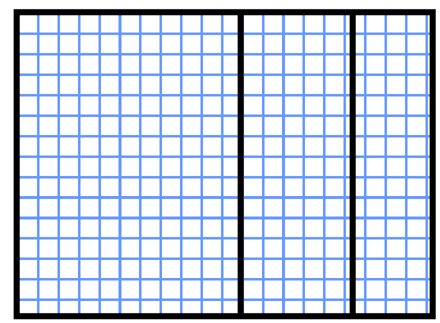


Partitionings

- Block partitioning

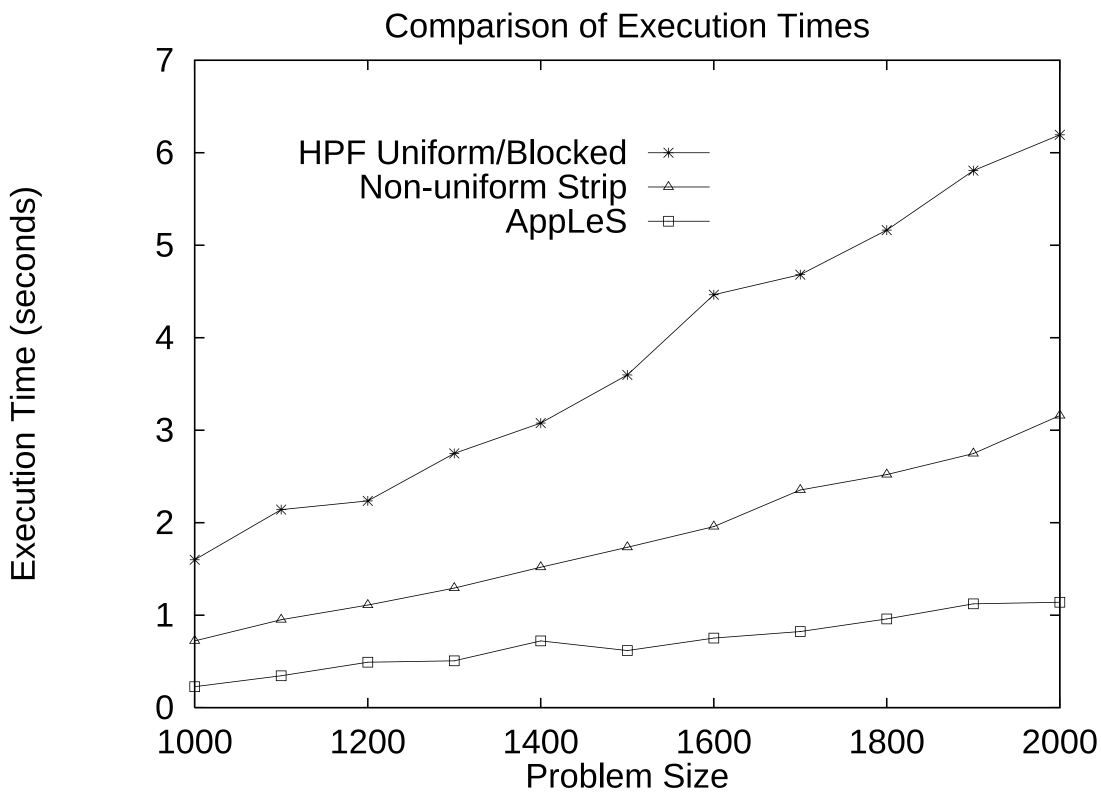


- Compile-time non-uniform strip partitioning
- AppLeS dynamic strip partitioning



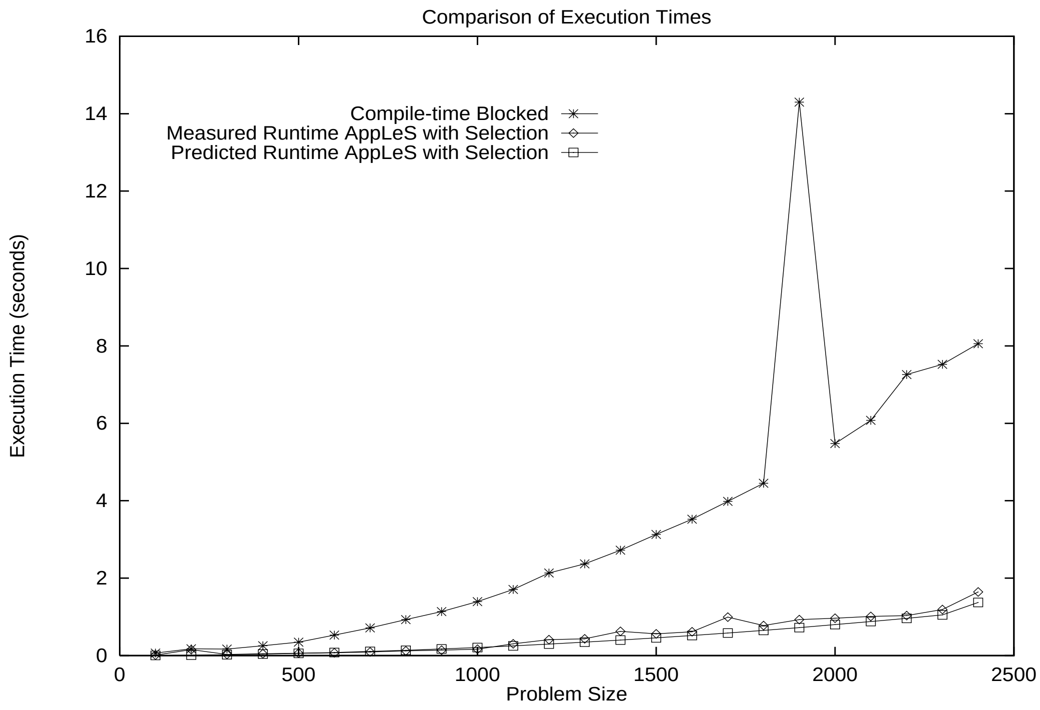
Application Scheduling Jacobi2D

Dynamic information key to leveraging deliverable performance from the Grid environment



Performance is Time-Dependent

Jacobi2D AppLeS (strip) vs. Block partitioning



Schedulers and Performance Models

- **Predictions may be used at different levels of accuracy**
  - predictions can be “engineered”
- **Knowing something about a prediction can make it more useful**
  - performance range of predictions may provide additional information
  - meta-information about predictions can improve schedules

Performance Prediction Engineering

- ***Performance Prediction Engineering*** **(PPE) System** is a methodology for modeling performance in dynamic Grid environments

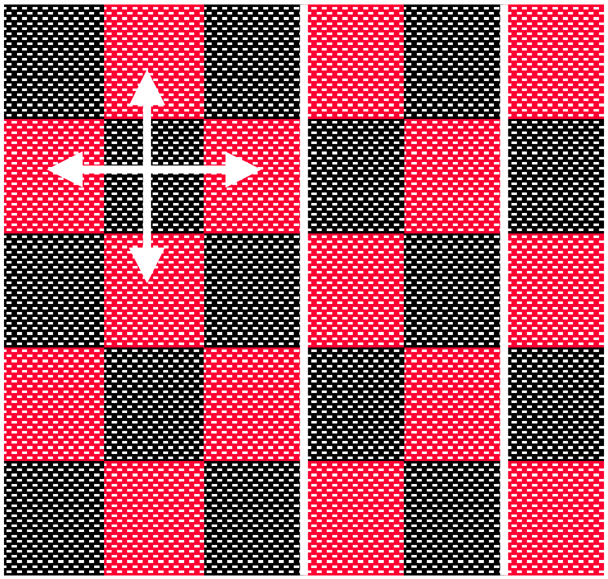
- ***3 Components:***
  - **Structural performance prediction models**
  - **Quantitative meta-information**
  - **Dynamic Forecasting**

Structural Models

- **Top-level Model** ***=*** **performance equation**
  - describes composition of application within a specific time frame *(performance grammar)*
- **Component models**
  - represent application performance activities *(nonterminals)*
- **Model parameters**
  - represent system or application values *(terminals)*

Example: Modeling the Performance of SOR

- Regular, iterative computation
- 5 point stencil
- Divided into a **red phase** and a **black phase**
- 2D grid of data divided into strips
- Targeted to WS cluster



SOR Structural Model

SOR performance equation

$$ExecTime(t_0) = \sum_{i=0}^{n} IterTime(t_i)$$

$$IterTime(t_i) = Max_p\{RComp(p,t_i) + RComm(p,t_i + \Delta_1) + BComp(p,t_i + \Delta_2) + BComm(p,t_i + \Delta_3)\}$$

SOR component models

{ RComp(p,t), RComm(p,t), BComp(p,t), BComm(p,t)}

SOR Component Models

$$RComp(p,t) = \frac{NumElts(p) * Benchmark(p, Elt)}{FracAvailCPU(p,t)}$$

$$RComm(p,t) = \frac{ColumnSize * Size(Elt)}{BWAvail(p, p+1, t)} + \frac{ColumnSize * Size(Elt)}{BWAvail(p, p-1, t')}$$

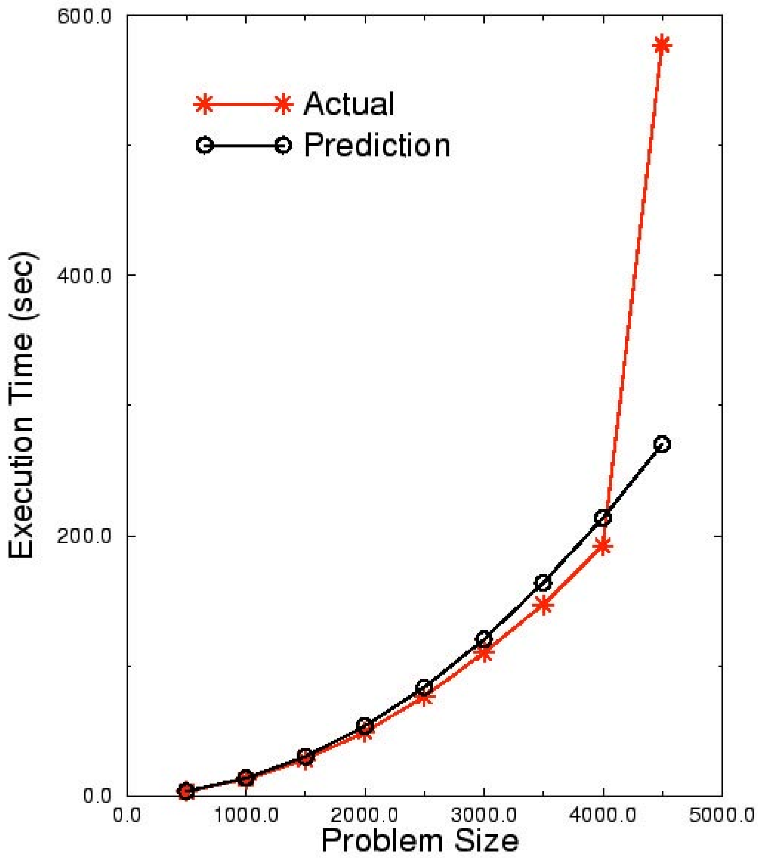
Dynamic Parameters

FracAvailCPU(p,t), BWAvail(x,y,t)

Single-User Experiments

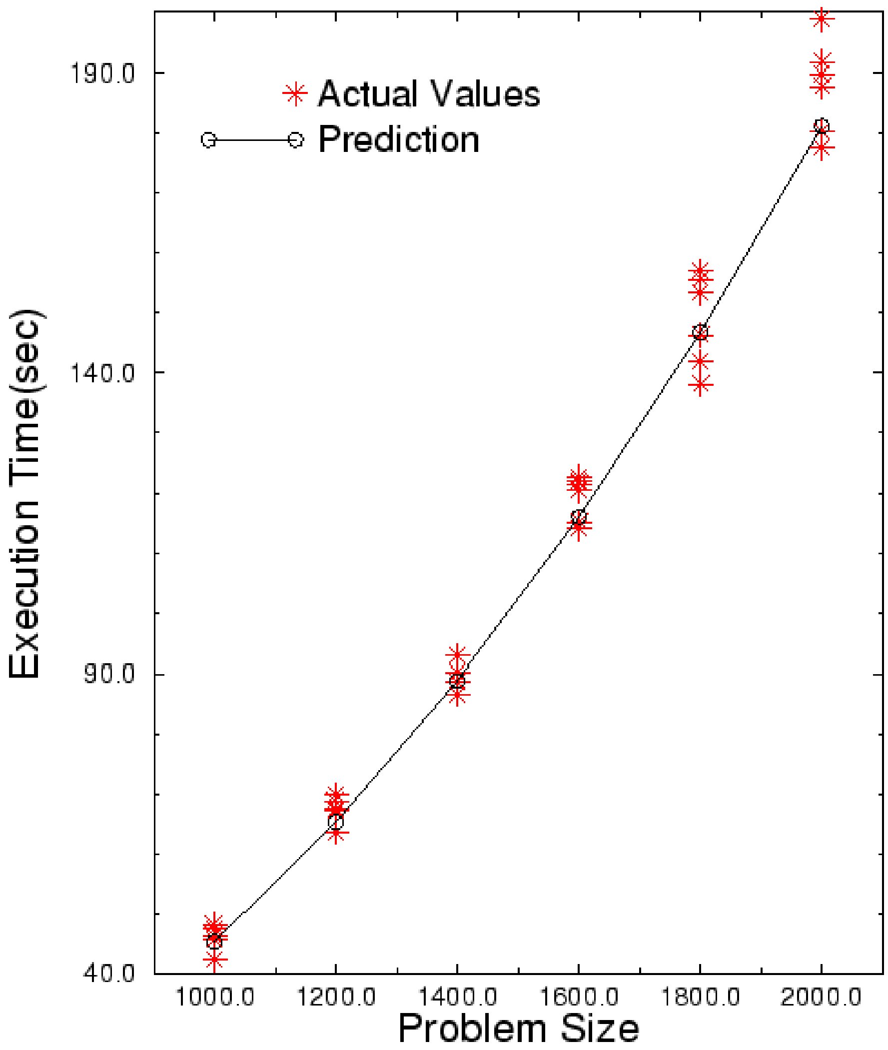
- **Question:** How well does the SOR model predict performance in a single-user cluster?
- **Platform**
  - heterogeneous Sparc cluster
  - 10 Mbit ethernet connection
  - quiescent machines and network
- Prediction within 3% before memory spill

Dedicated Platform Experiments



What happens when other users share the system?

Non-dedicated SOR Experiments

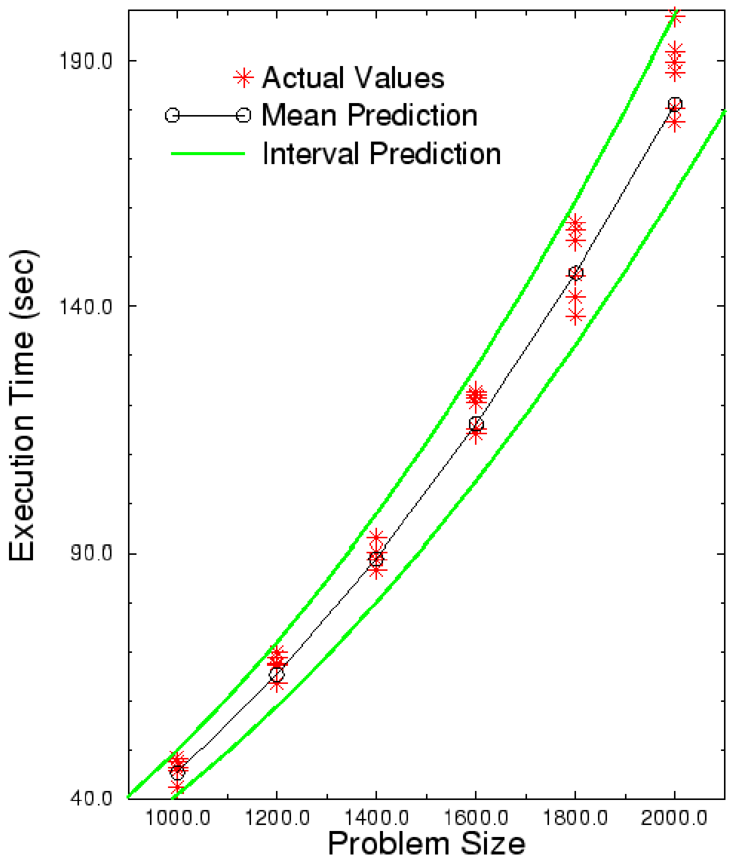


Improving Predictions

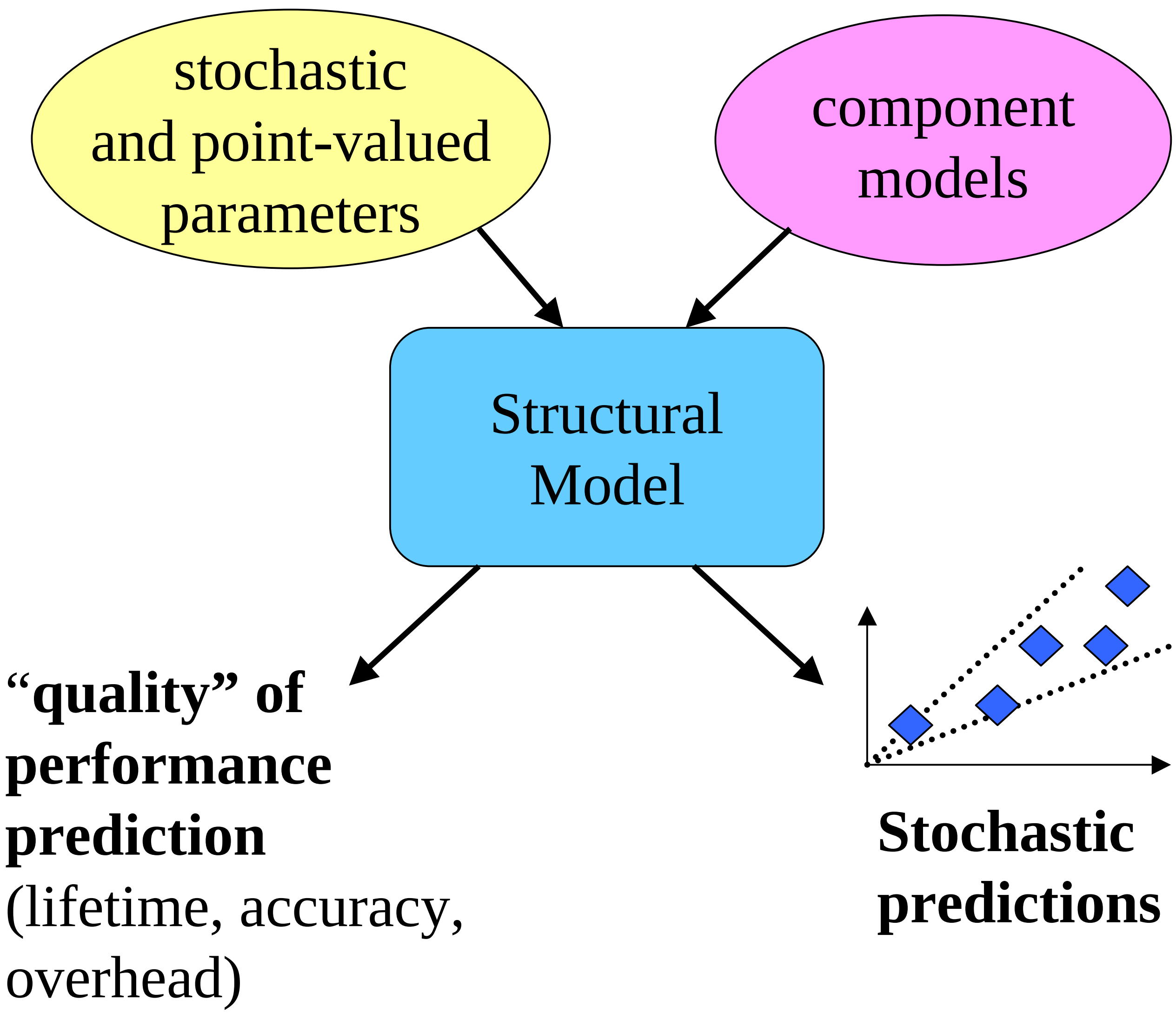
- Many parameters represent values which ***vary over time***
- Range of behavior of time-dependent parameters represented by ***distributions***
- Structural models can be extended to accommodate ***stochastic parameters*** and render ***stochastic predictions***

Stochastic Predictions

Stochastic predictions capture range of possible behavior



Stochastic Structural Models



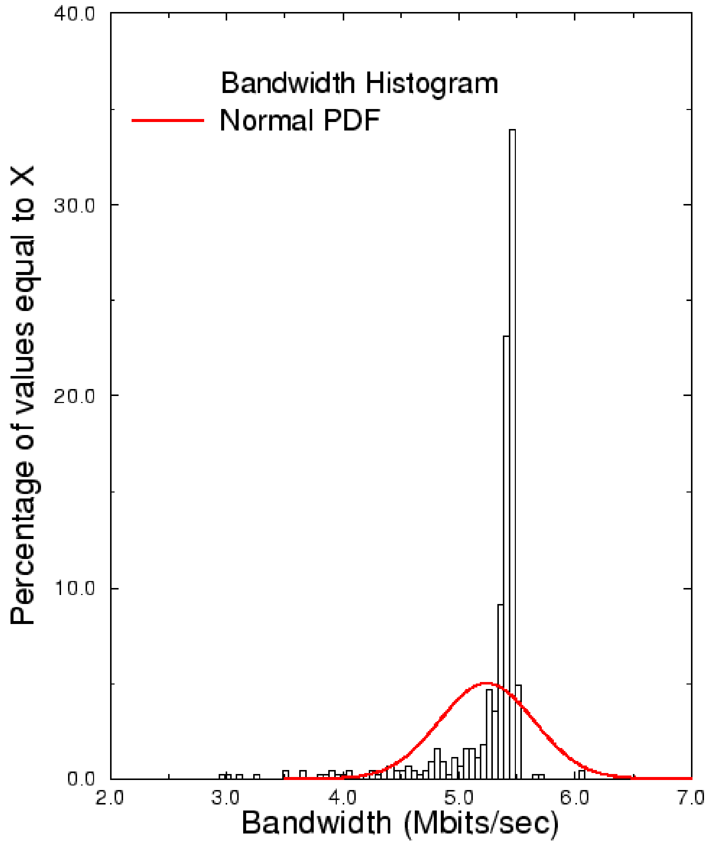
Stochastic SOR Performance Model

- *FracAvailCPU, BWAvail* given by stochastic parameters
- **Network Weather Service** improved to provide better performance information
- ***First cut:*** consider stochastic parameters which can adequately be represented by **normal distributions**
  - normal distributions make math tractable

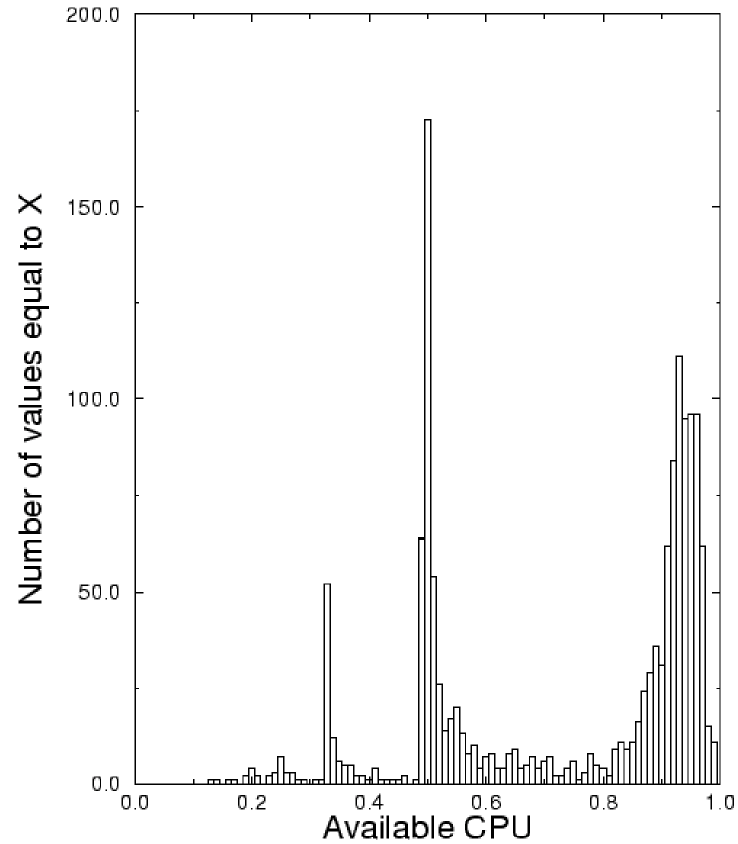
Experiments with Multi-user Systems

- Platform
  - Sun workstation cluster
  - 10Mbit ethernet
  - experiments run in lab environment with additional generated load
- Experiments run back-to-back for multiple trials

SOR Stochastic Parameters

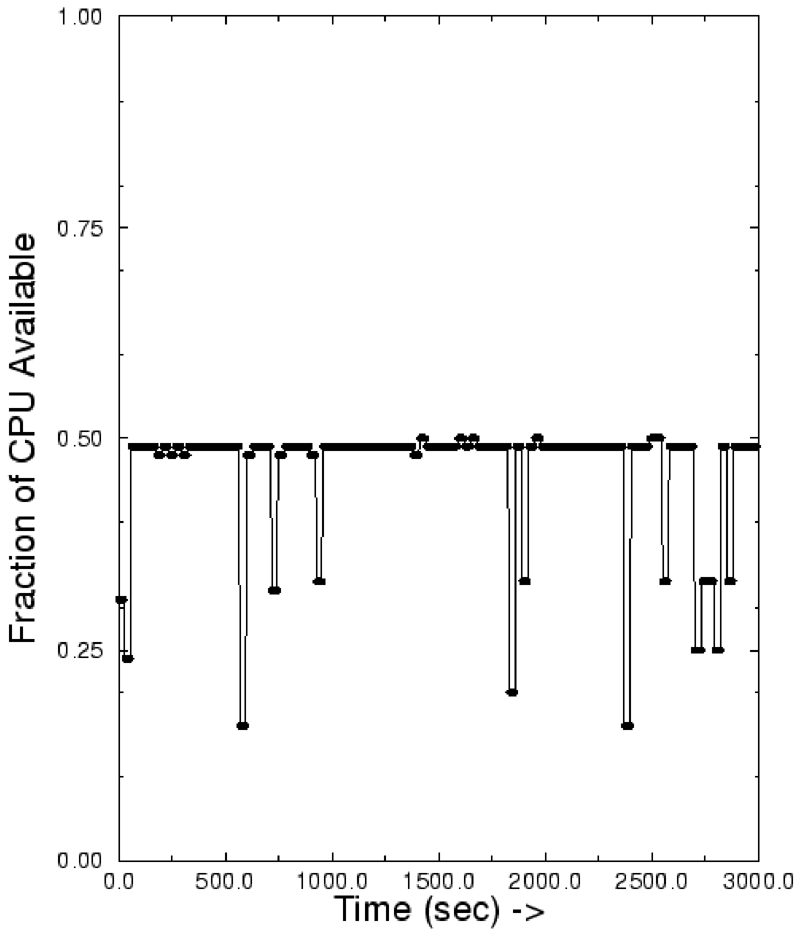


BWAvail

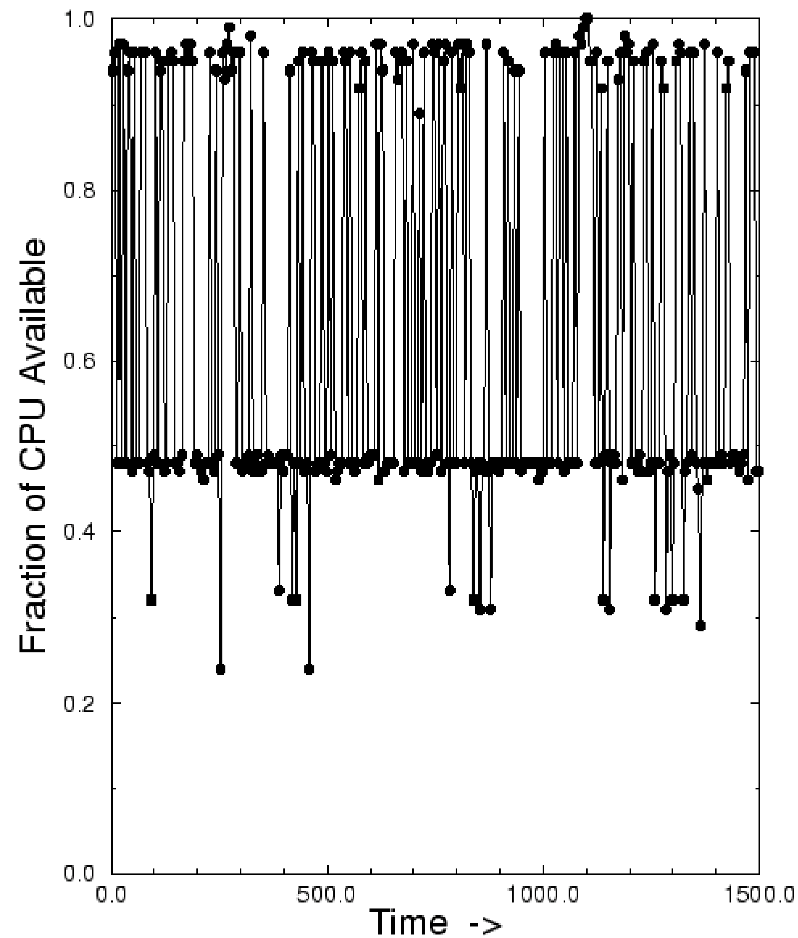


FracAvailCPU

Data stays within single mode

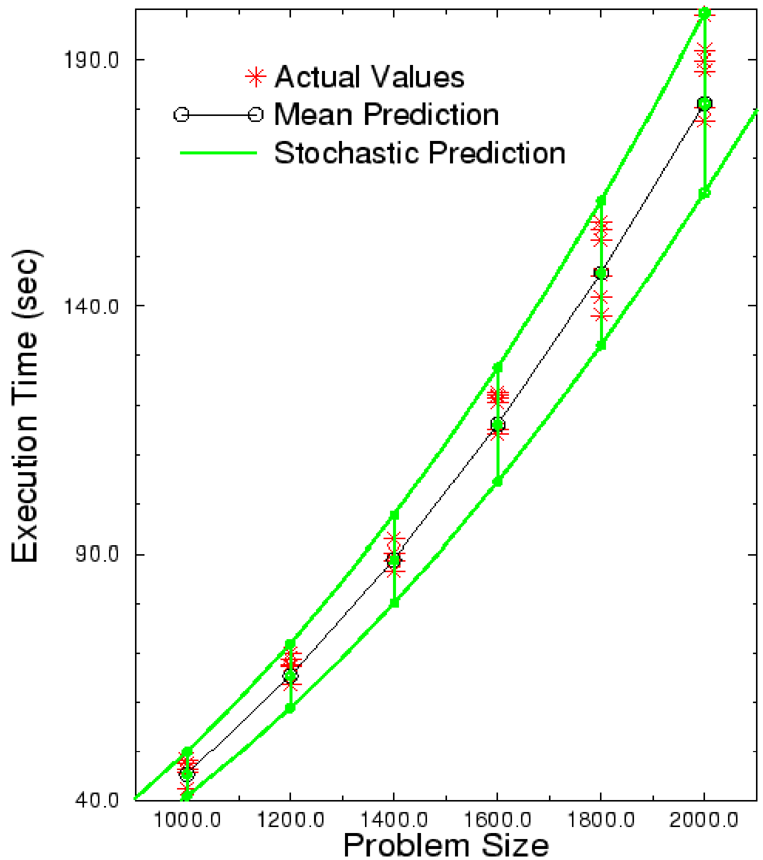


Data changes modes



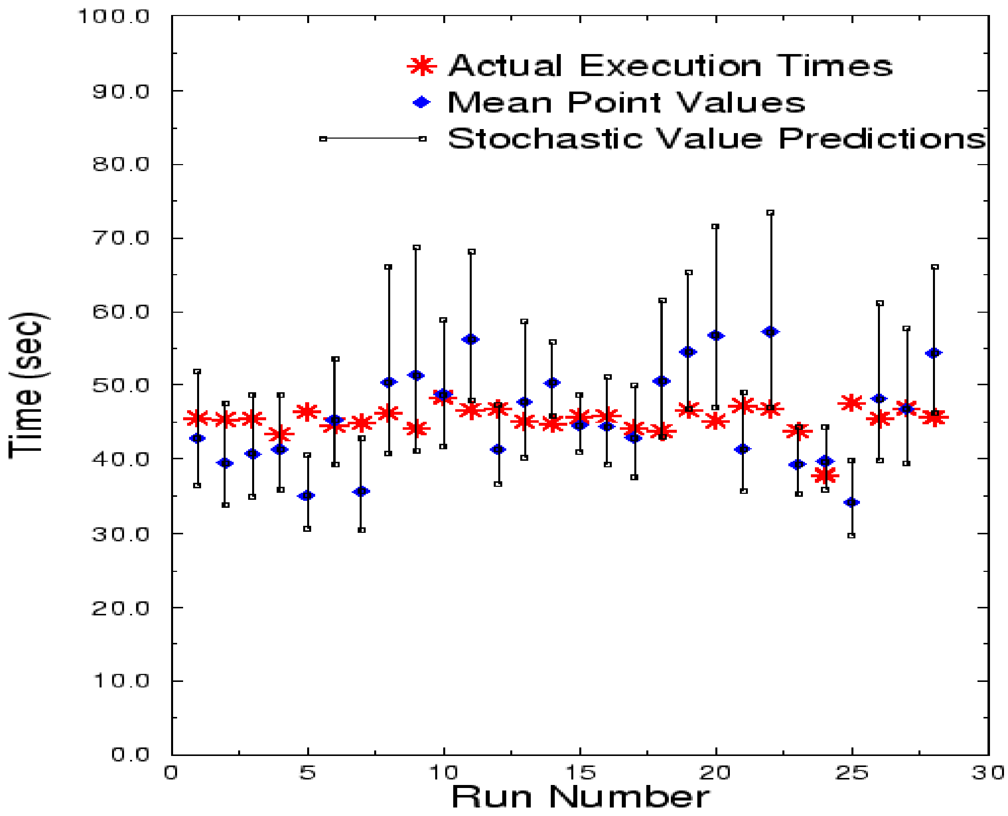
“Single-mode” Experiments

- All values captured by stochastic predictions
- Maximum absolute error between means and actual values is 10%



"Multiple Mode" Experiments

- 80% of actual values captured by stochastic prediction
- Max discrepancy between stochastic prediction and actual values is 14%
- Max absolute error between means and actual values is 39%



The Next Step

What if performance range of parameters cannot be adequately represented by normal distributions?

- Can we identify distributions for model parameters?
- Can we combine non-normal distributions efficiently? Is the math tractable?
- Can we use empirical data to determine performance ranges if distributions cannot be identified?

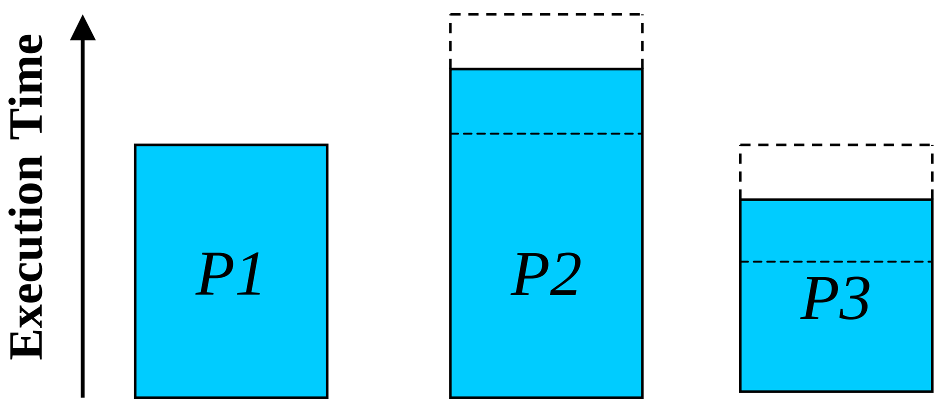
Using PPE for Application Scheduling

Basic Strategy:

- Develop **structural model** for application
- Use **stochastic parameters** to provide information about performance range
- Use profiling to determine desired level of accuracy for component models
- Use stochastic prediction and **meta-information** to develop application schedule

Scheduling with Meta-Information

- Stochastic predictions provide information about range of behavior
- Stochastic predictions and meta-information provide additional information for schedulers



Quality of Information

- Meta-information = **Quality of Information**
- SOR stochastic predictions provide a measure of ***accuracy***
- Other qualitative measures are possible
  - lifetime
  - overhead
  - complexity
- Quality of Information attributes can be used to improve scheduling

Preliminary Experiments: Application Scheduling with PPE

Simple scheduling scenario:

- SOR with strip decomposition
- Scheduling strategies adjust strip size to minimize execution time
- Multi-user cluster
  - machines connected by 10 Mbit ethernet
  - available CPU on at least half of the machines is multi-modal with data changing between modes frequently

Adjusting Strip Size

- **Time balancing** used to determine strip size
- Set all $T(p,t)$ equal and solve for $NumElts(p,t')$

$$\begin{aligned} T(p,t) &= RComp(p,t) + RComm(p,t+\Delta_1) \\ &\quad + BComp(p,t+\Delta_2) + BComm(p,t+\Delta_3) \\ &= A(p,t) * NumElts(p) + B(p,t) \end{aligned}$$

$$\sum_p NumElts(p) = n^2$$

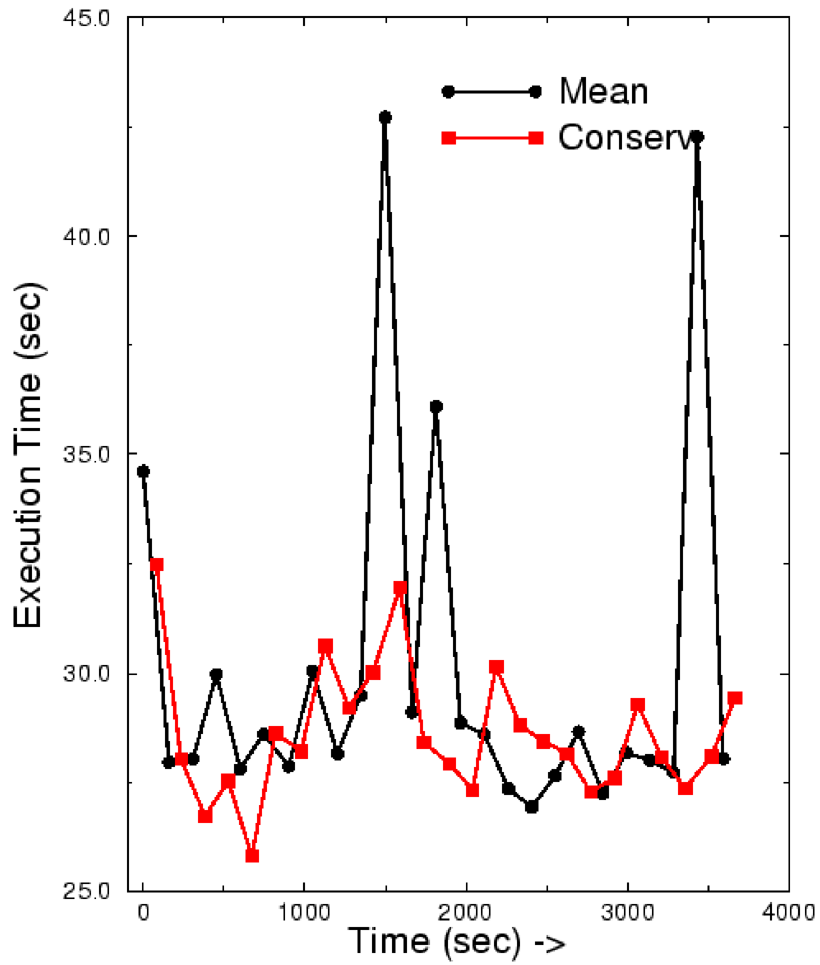
Scheduling Strategies

- **Mean**
  - data assignments determined using *mean* (point-valued) application execution estimates

- **Conservative**
  - data adjusted so that machines with high-variance application execution estimates receive less work $(\mu + 2\sigma)$
  - goal is to reduce penalty of being wrong

Preliminary Scheduling Results

- Conservative scheduling strategy misses big spikes, but is sometimes too conservative.



Research Directions

- **Quality of Information (QoIn)**
  - How can we develop useful mechanisms for obtaining and quantifying performance meta-information?
  - How do we combine different QoIn measures?
  - How can QoIn measures enhance scheduling?
- **Contingency Scheduling**
  - Can we develop schedules which adapt dynamically **during** execution?

More Research Directions

- **Performance-enhanced Tools**
  - **Netsolve** enhanced with **NWS** and **AppLeS** scheduling methodology
- **Performance contracts**
  - How should performance information be exchanged and brokered in grid systems?
  - How can we develop “grid-aware” programs?

Project Information

- Thanks to Dr. Darema and DARPA for support and very useful feedback.

- **Performance Prediction Engineering Home Page:**

  http://www-cse.ucsd.edu/groups/hpcl/apples/PPE/index.html

- **PPE team**: Jennifer Schopf, Neil Spring, Alan Su, Fran Berman, Rich Wolski

Up Next: Rich Wolski

Dynamic Forecasting for Performance Prediction Engineering with the **Network Weather Service**