Achieving Application Performance on the Computational Grid

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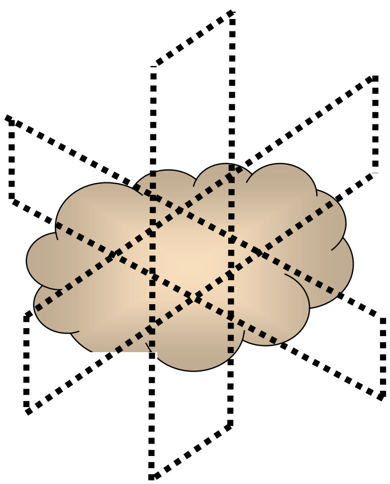
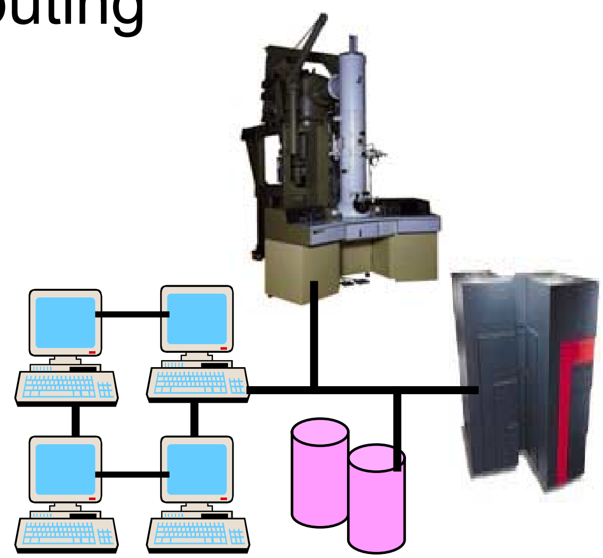
The Computational Grid

- **The Computational Grid**
  - ensemble of heterogeneous, distributed resources
  - emerging platform for high-performance and resource-intensive computing

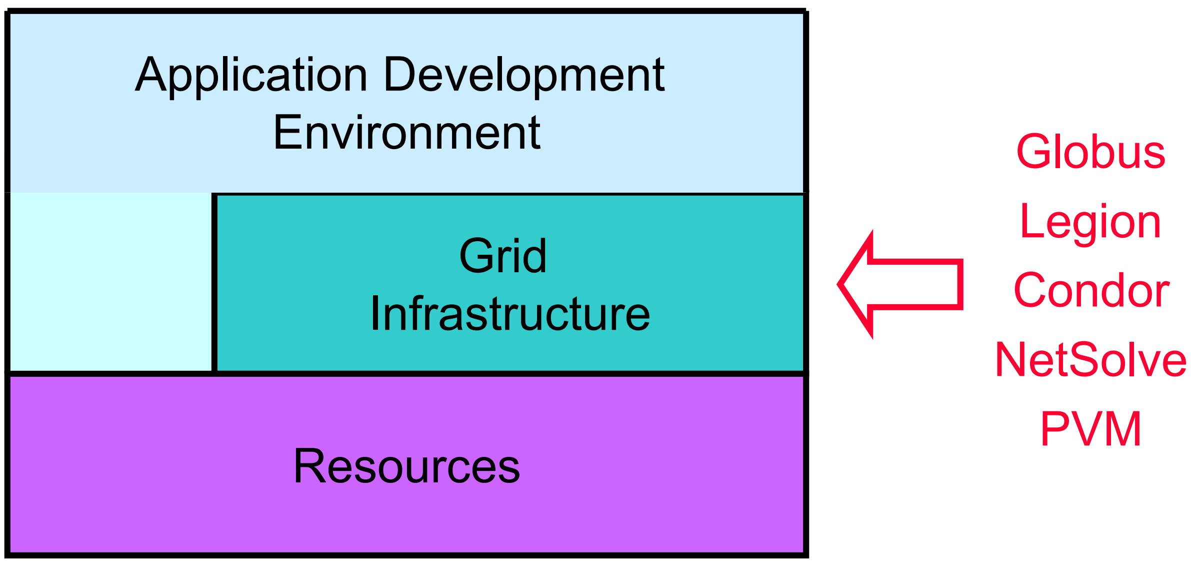




How do we write programs for the Grid?

Programming the Grid I

- **Basics**
  - Need way to login, authenticate in different domains, transfer files, coordinate execution, etc.



Programming the Grid II

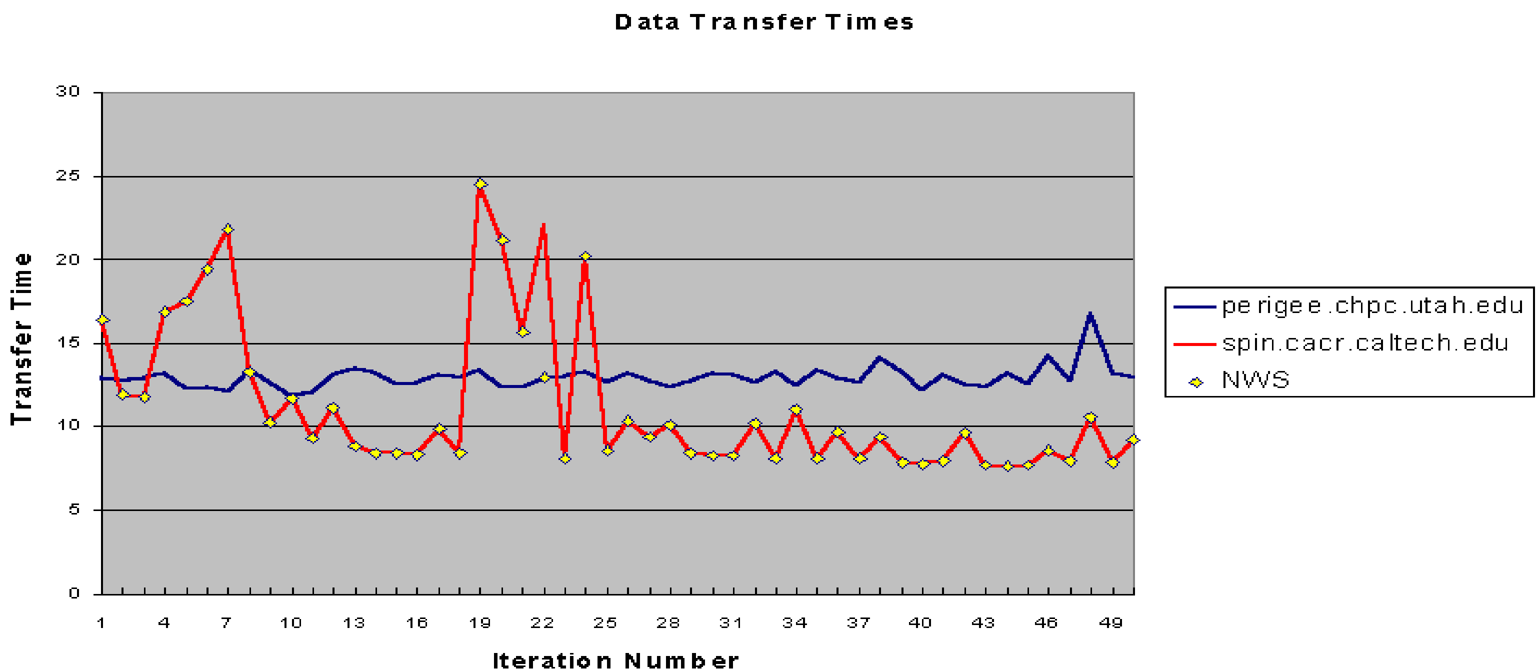
- **Performance-oriented programming**
  - **Need way to develop and execute performance-efficient programs**
  - Program must achieve performance in an environment which is
    - **heterogeneous**
    - **dynamic**
    - **shared by other users with competing resource demands**

    This can be extremely challenging.
  - **Adaptive application scheduling** is a fundamental technique for achieving performance

- **Why scheduling?**
  - Experience with parallel and distributed codes shows that careful coordination of tasks and data required to achieve performance

- **Why *application* scheduling?**
  - No centralized scheduler which controls all Grid resources, applications are on their own
  - Resource and job schedulers prioritize utilization or throughput over application performance

- **Why *adaptive* application scheduling?**
  - Heterogeneity of resources and dynamic load variations cause performance characteristics of platform to vary over time and with load
  - To achieve performance, application must adapt to deliverable resource capacities



Adaptive Application Scheduling

- **Fundamental components:**
  - **Application-centric performance model**
    - Provides quantifiable measure of system components in terms of their potential impact on the application
  - **Prediction of deliverable resource performance at execution time**
  - **User's performance criteria**
    - Execution time
    - Convergence
    - Turnaround time

These components form the basis for AppLeS.

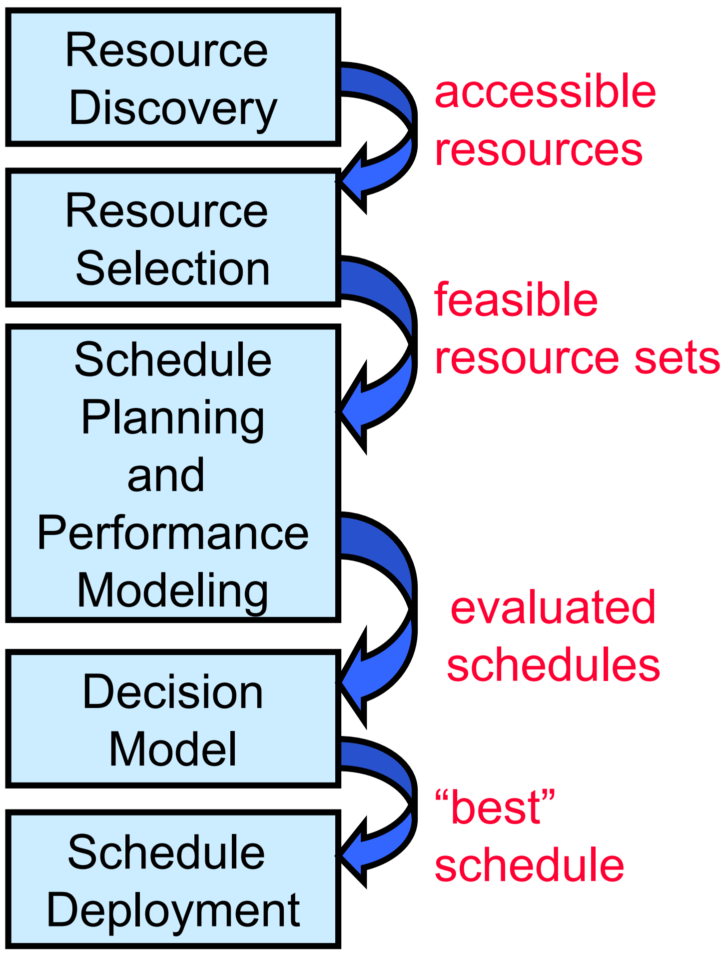
What is AppLeS ?

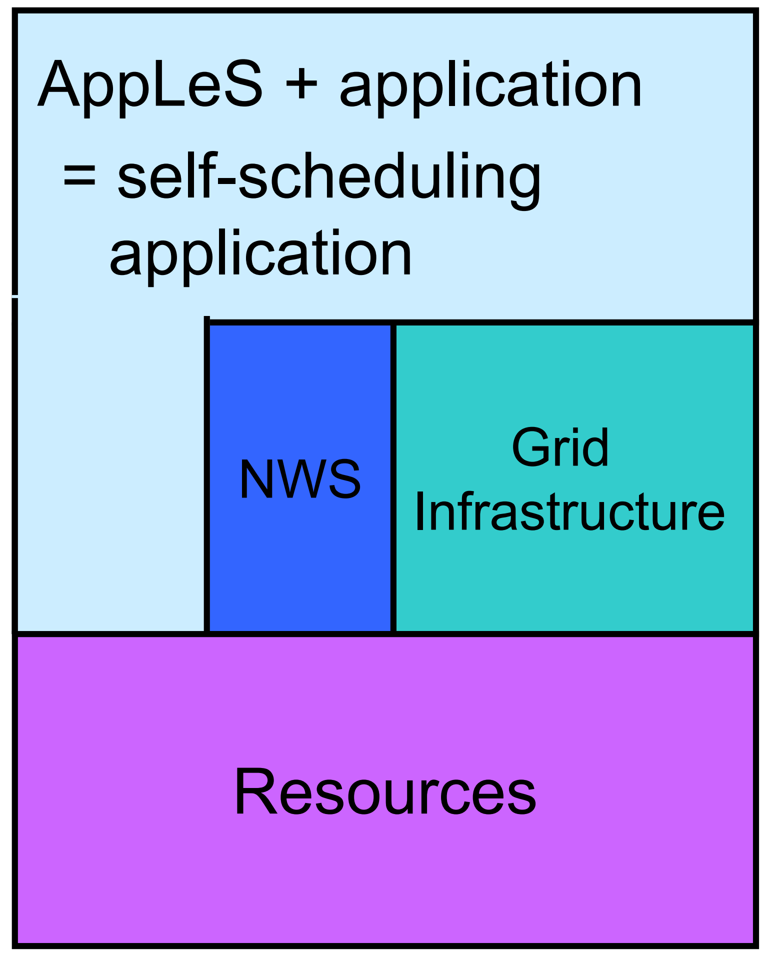
- **AppLeS = Application Level Scheduler**
  – Joint project with Rich Wolski (U. of Tenn.)

- **AppLeS is a methodology**
  – Project has investigated **adaptive application scheduling** using dynamic information, application-specific performance models, user preferences.
  – AppLeS approach based on real-world scheduling.

- **AppLeS is software**
  – Have developed multiple AppLeS-enabled applications and templates which demonstrate the importance and usefulness of adaptive scheduling on the Grid.

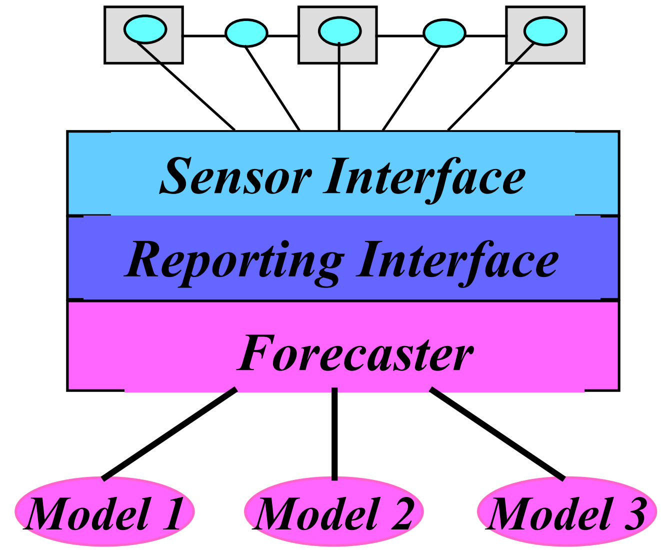
How Does AppLeS Work?

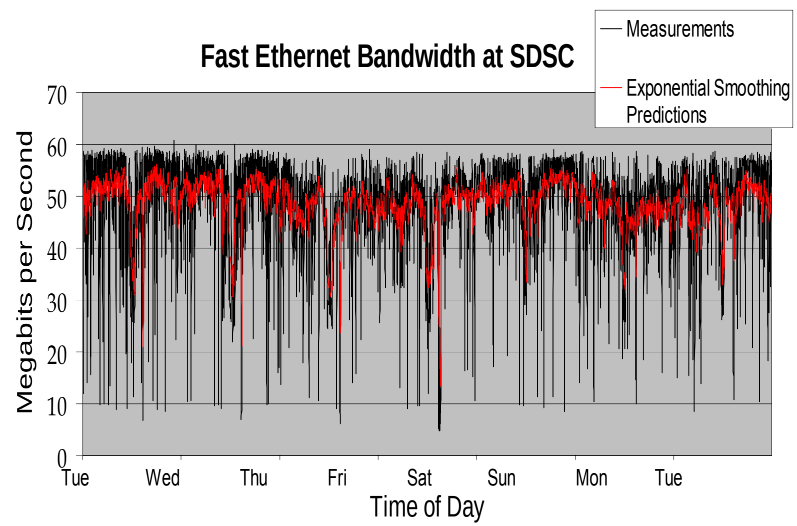




Network Weather Service (Wolski, U. Tenn.)

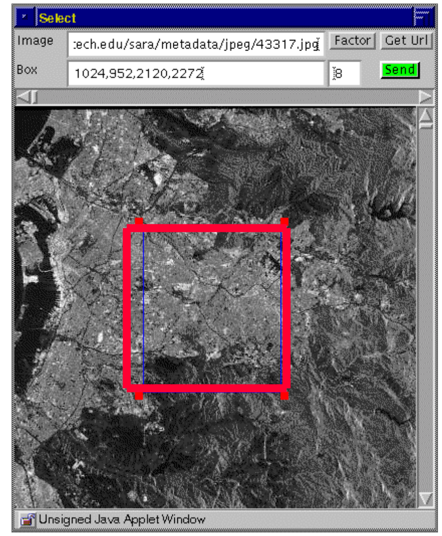
- The NWS provides dynamic resource information for AppLeS
- NWS is stand-alone system
- NWS
  - *monitors current system state*
  - *provides best forecast of resource load from multiple models*





AppLeS Example: Simple SARA

- **SARA = Synthetic Aperture Radar Atlas**
  - application developed at JPL and SDSC
- **Goal: Assemble/process files for user's desired image**
  - Radar organized into tracks
  - User selects track of interest and properties to be highlighted
  - Raw data is filtered and converted to an image format
  - Image displayed in web browser

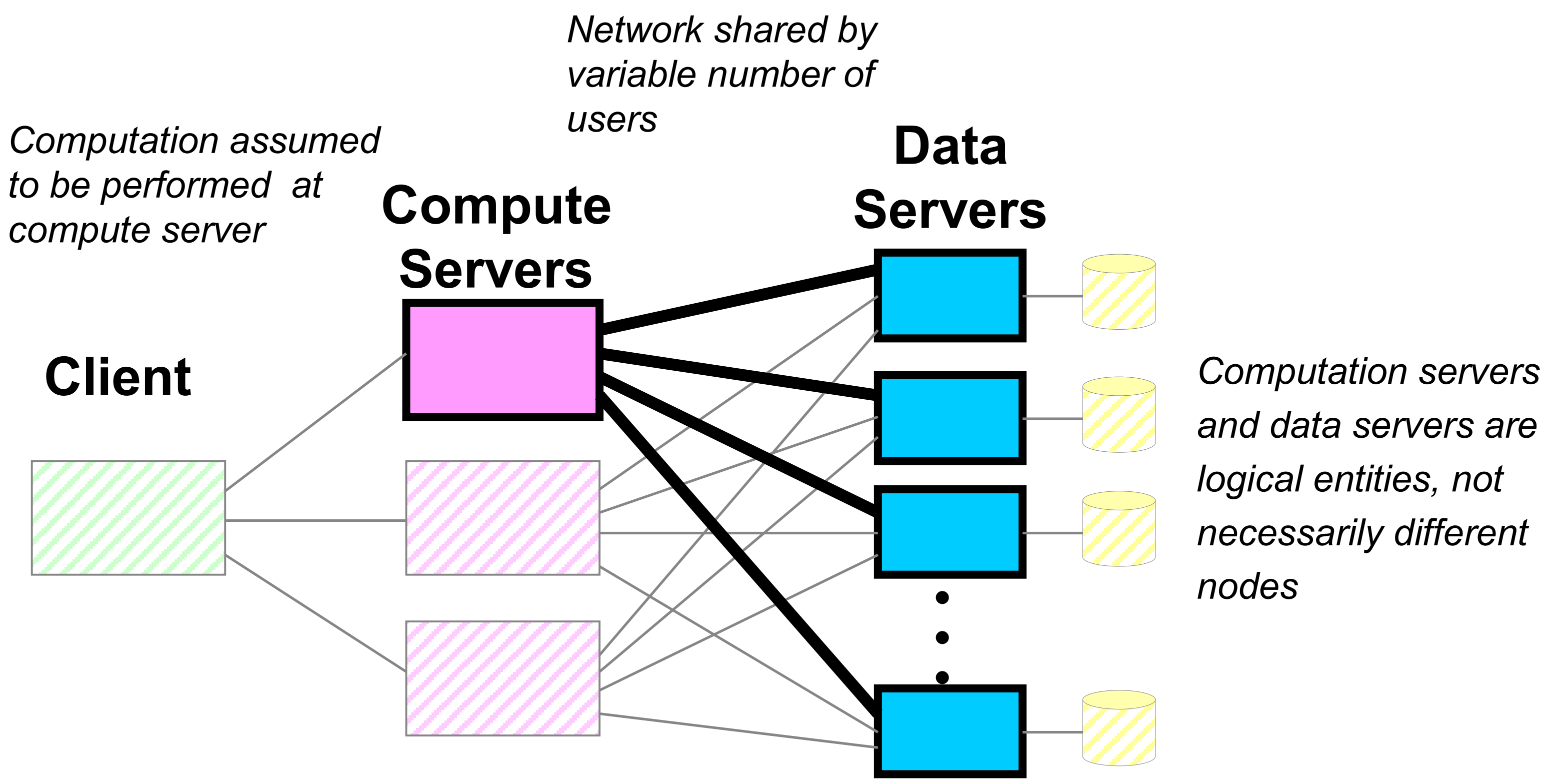


Simple SARA

- AppLeS focuses on **resource selection problem**:

  Which site can deliver data the fastest?

- Code developed by Alan Su



Simple SARA

- Simple Performance Model

$$FileTransferTime = \frac{DataSize}{AvailableBandwidth}$$

- Prediction of available bandwidth provided by Network Weather Service
- User’s goal is to optimize performance by minimizing file transfer time
- **Common assumptions:** (> = performs better)
  - vBNS > general internet
  - geographically close sites > geographically far sites
  - west coast sites > east coast sites

Experimental Setup

- Data for image accessed over **shared** networks
- Data sets 1.4 - 3 megabytes, representative of SARA file sizes
- Servers used for experiments

via vBNS
  - *lolland.cc.gatech.edu*
  - *sitar.cs.uiuc*
  - *perigee.chpc.utah.edu*

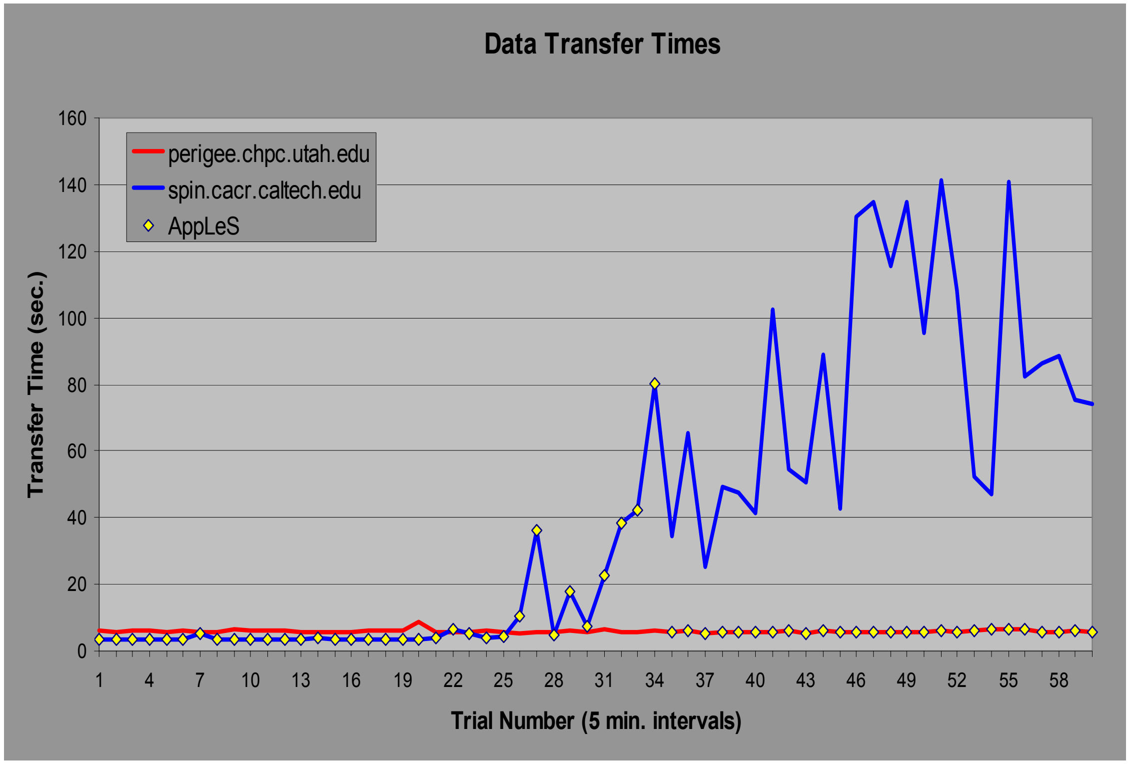
via general internet
  - *mead2.uwashington.edu*
  - *spin.cacr.caltech.edu*

Preliminary Results

- Experiment with larger data set (3 Mbytes)
- During this time-frame, farther sites provide data faster than closer site

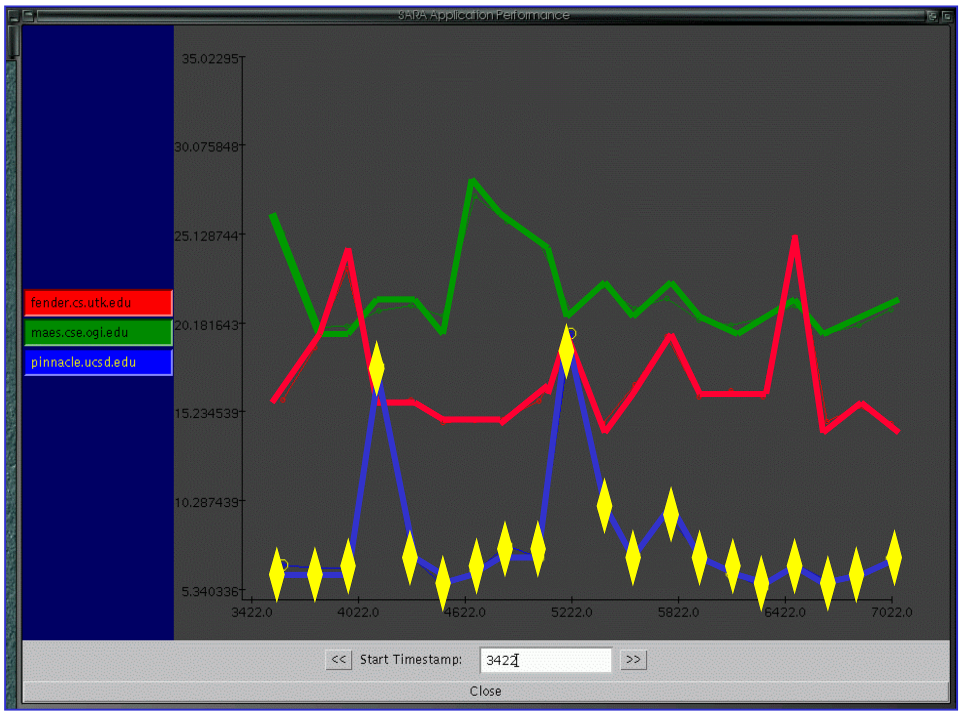
9/21/98 Experiments

- Clinton Grand Jury webcast commenced at trial 25
- At beginning of experiment, general internet provides data faster than vBNS



Supercomputing ’99

- From Portland SC’99 floor during experimental timeframe, **UCSD** and **UTK** generally “closer” than Oregon Graduate Institute (**OGI**) in Portland



OGI

UTK

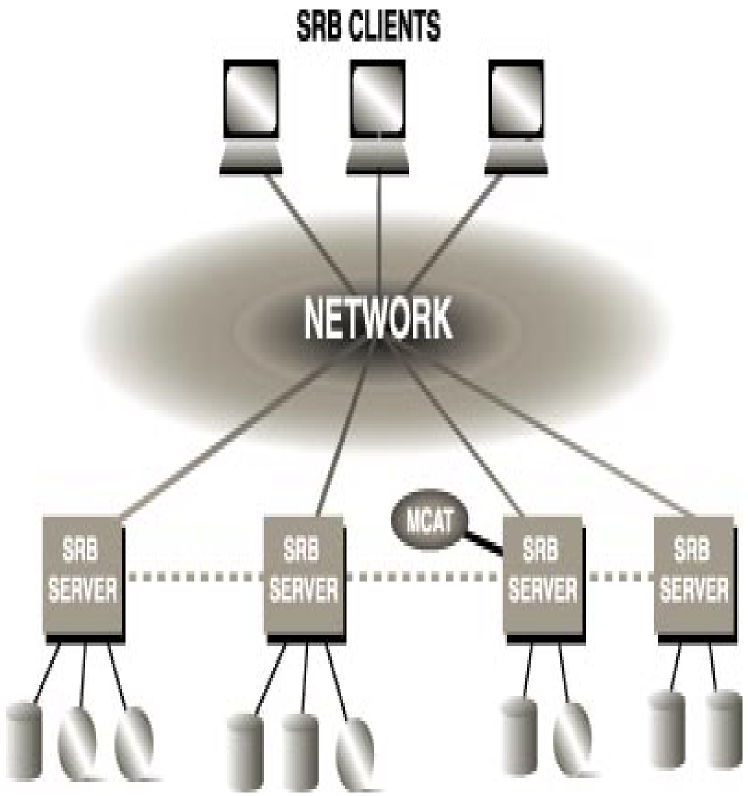
UCSD

AppLeS/NWS

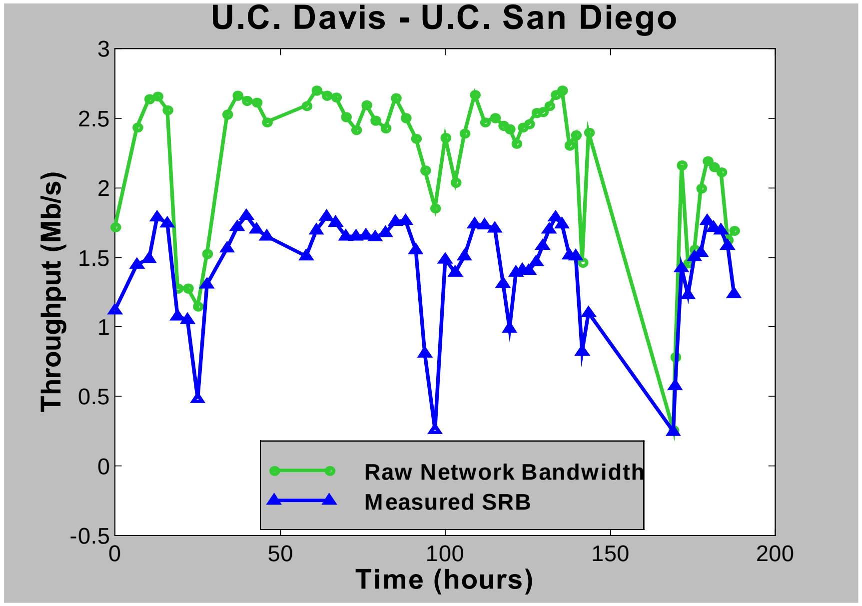
What if File Sizes are Larger?

Storage Resource Broker (SRB)

- **SRB provides access to distributed, heterogeneous storage systems**
  - UNIX, HPSS, DB2, Oracle, ..
  - ***files can be 16MB or larger***
  - resources accessed via a common SRB interface



Predicting Large File Transfer Times



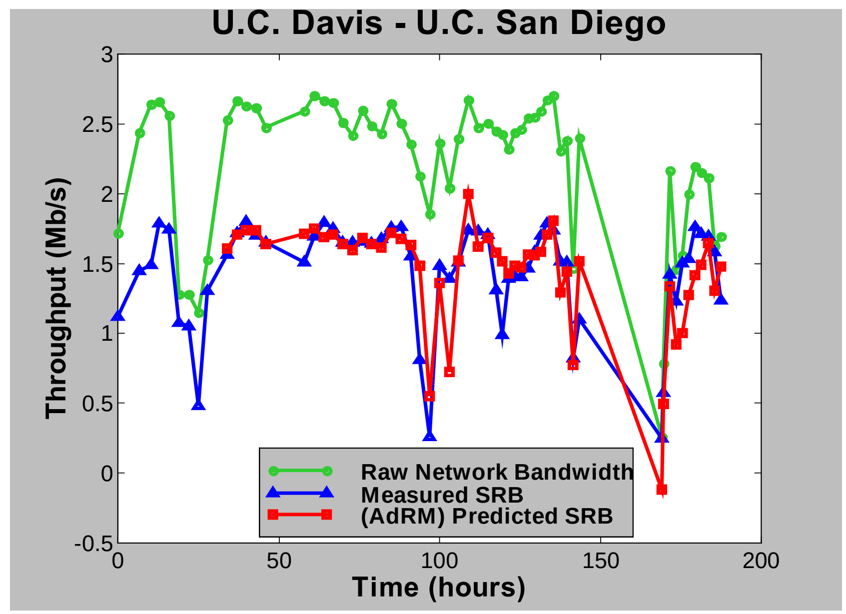
- NWS and SRB present distinct behaviors

NWS probe is 64K, SRB file size is 16MB

Adaptive approach:

- Use adaptive linear regression on sliding window of NWS bandwidth measurements to track SRB behavior

SRB Performance model being developed by Marcio Faerman

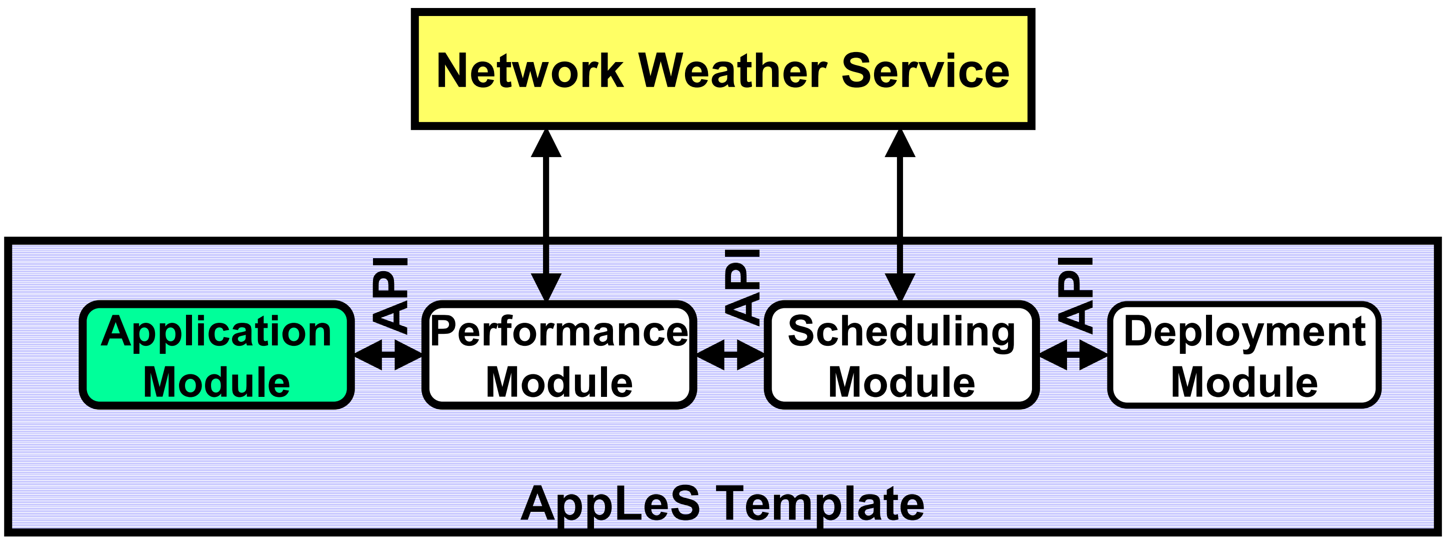


Challenges for AppLeS

- **AppLeS-enabled applications perform well in multi-user environments**
  - Have developed AppLeS for
    - Stencil codes (Jacobi2D, magnetohydrodynamics, LU Decomposition …)
    - Distributed data codes (SARA, SRB, …)
    - Master/Slave codes (DOT, Ray Tracing, Mandelbrot, Tomography, …)
    - Parameter Sweep codes (MCell, INS2D, CompLib, …)
- **Methodology is right on target but …**
  - AppLeS must be integrated with application –-- labor-intensive and time- intensive
  - You generally can’t just take an AppLeS and plug in a new application

AppLeS Templates

- Current thrust is to develop **AppLeS templates** which
  - **target structurally similar classes of applications**
  - **can be instantiated in a user-friendly timeframe**
  - **provide good application performance**

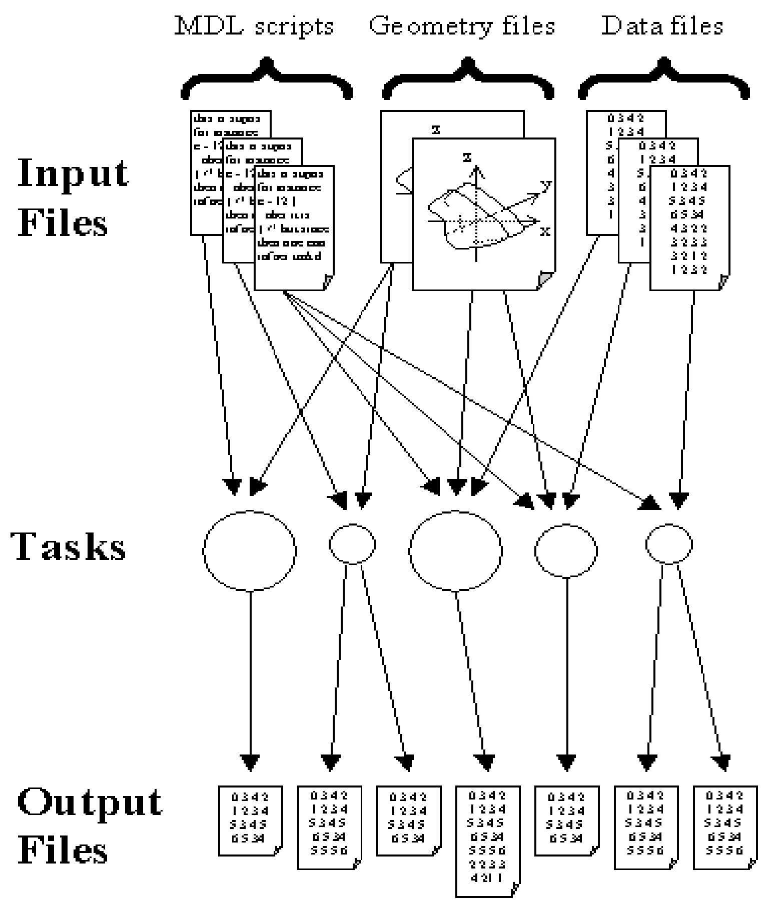


Case Study: Parameter Sweep Template

- **Parameter Sweeps** = class of applications which are structured as multiple instances of an "experiment" with distinct parameter sets

- Independent experiments may share input files

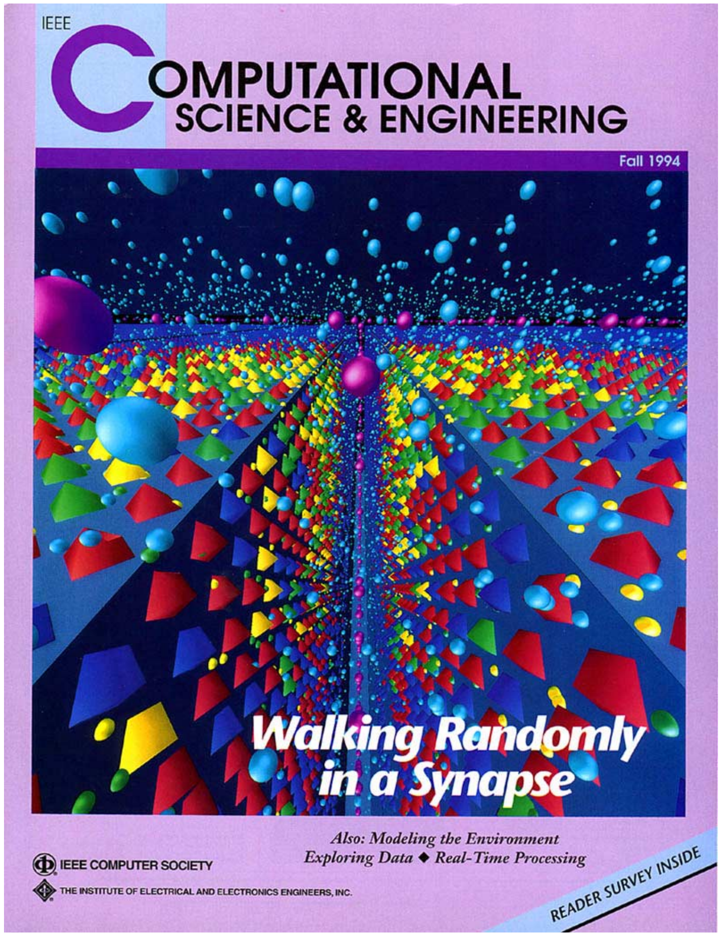
- Examples:
  - MCell
  - INS2D



Application Model

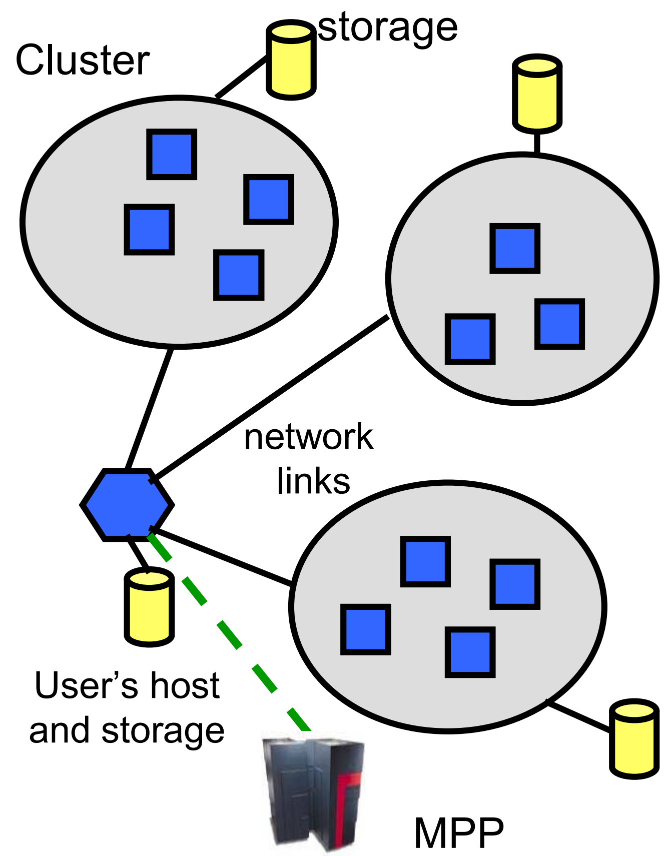
Example Parameter Sweep Application: MCell

- **MCell** = General simulator for cellular microphysiology
- Uses Monte Carlo diffusion and chemical reaction algorithm in 3D to simulate complex biochemical interactions of molecules
  - Molecular environment represented as 3D space in which trajectories of ligands against cell membranes tracked
- Researchers plan huge runs which will make it possible to model entire cells at molecular level.
  - Would like to perform execution-time computational steering , data analysis and visualization



PST AppLeS

- Template being developed by Henri Casanova and Graziano Obertelli
- **Resource Selection:**
  - For **small** parameter sweeps, can dynamically select a performance efficient number of target processors [Gary Shao]
  - For **large** parameter sweeps, can assume that all resources may be used



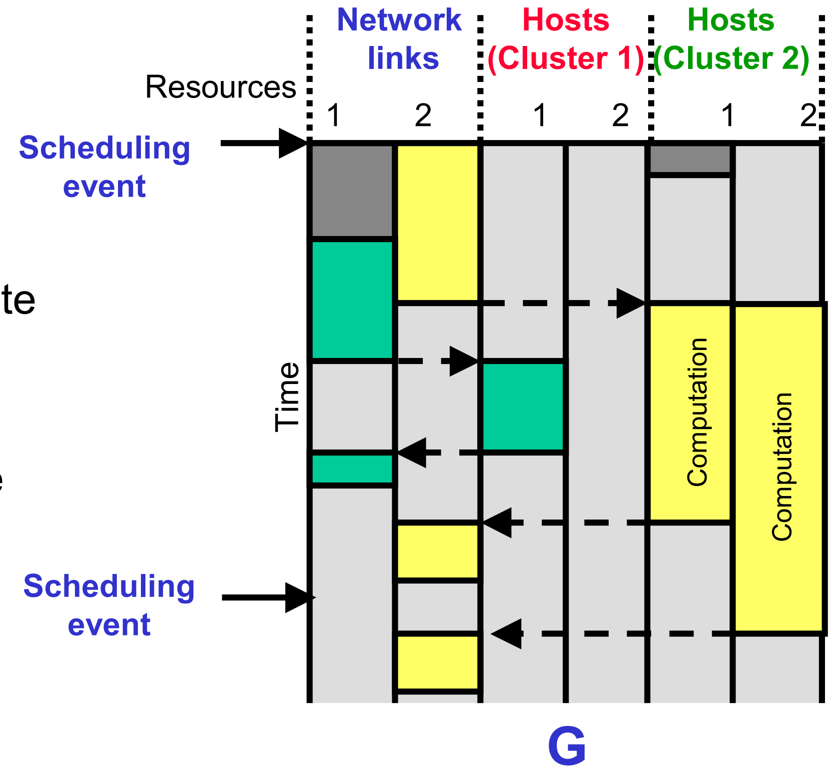
Platform Model

Scheduling Parameter Sweeps

- **Contingency Scheduling:** Allocation developed by dynamically generating a Gantt chart for scheduling unassigned tasks between scheduling events

- Basic skeleton

1. Compute the next scheduling event
2. Create a Gantt Chart G
3. For each computation and file transfer currently underway, compute an estimate of its completion time and fill in the corresponding slots in G
4. Select a subset T of the tasks that have not started execution
5. **Until each host has been assigned enough work, heuristically assign tasks to hosts, filling in slots in G**
6. Implement schedule

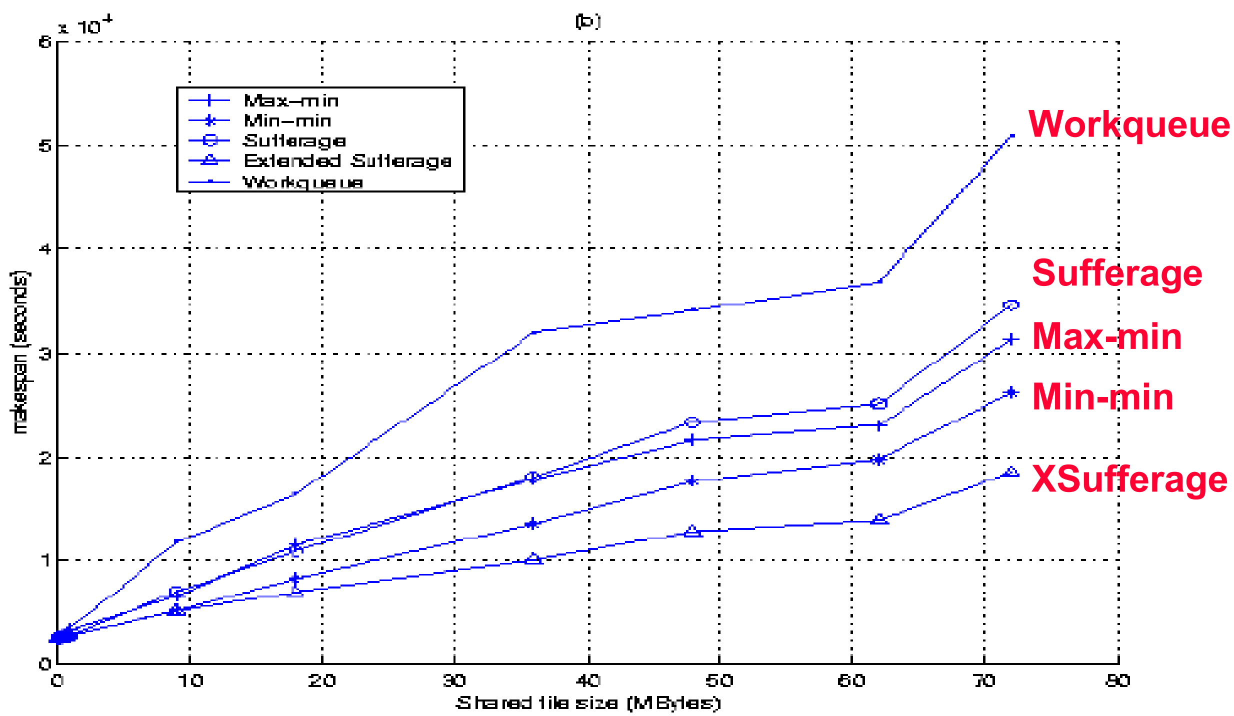


Parameter Sweep Heuristics

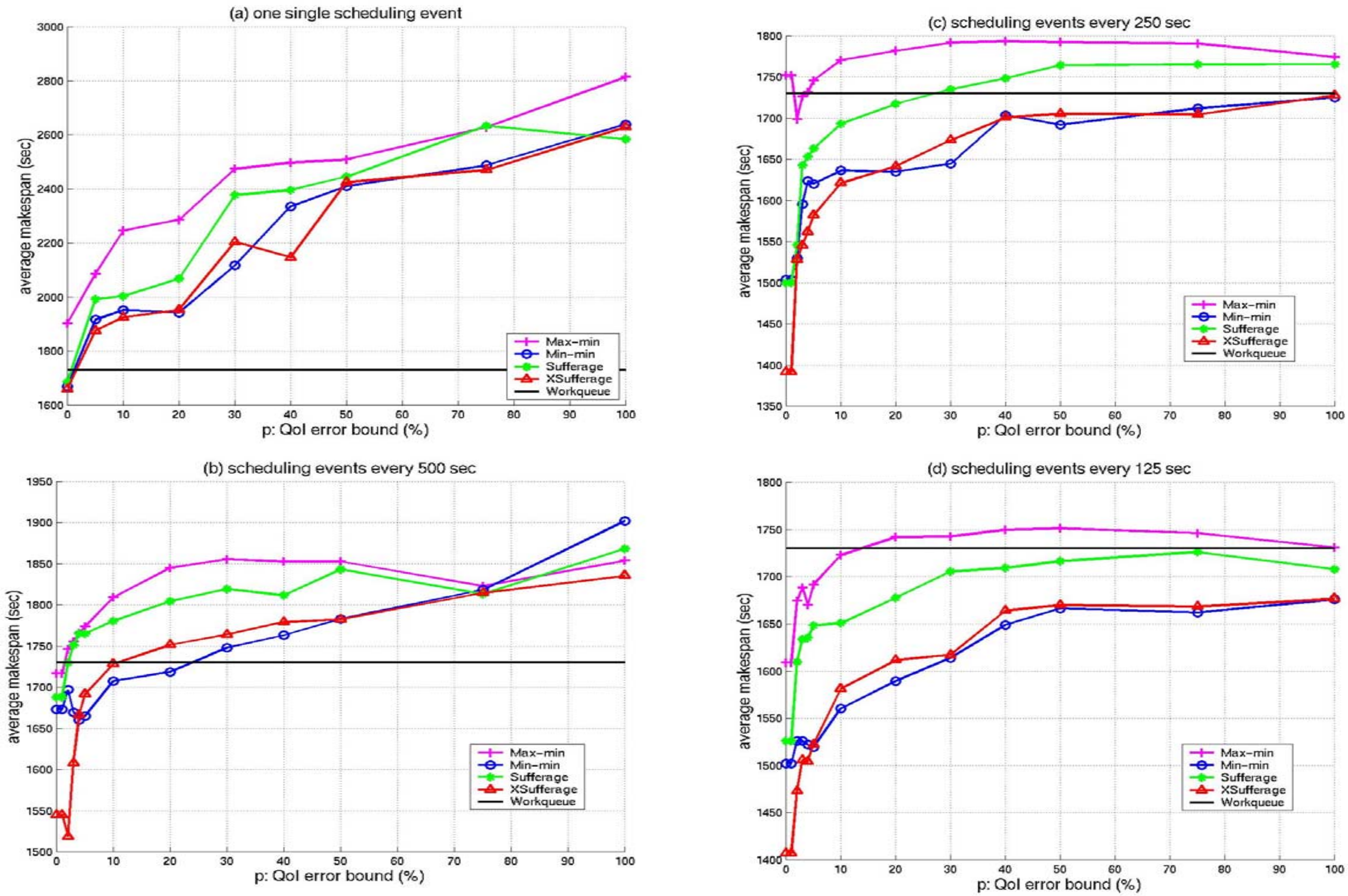
- Currently studying scheduling heuristics useful for parameter sweeps in Grid environments
- HCW 2000 paper compares several heuristics
  - **Min-Min** [task/resource that can complete the earliest is assigned first]
  - **Max-Min** [longest of task/earliest resource times assigned first]
  - **Sufferage** [task that would “suffer” most if given a poor schedule assigned first, as computed by max - second max completion times]
  - **Extended Sufferage** [minimal completion times computed for task on each cluster, sufferage heuristic applied to these]
  - **Workqueue** [randomly chosen task assigned first]
- **Criteria for evaluation:**
  - **How sensitive are heuristics to location of shared input files and cost of data transmission?**
  - **How sensitive are heuristics to inaccurate performance information?**

Preliminary PST/MCell Results

- Comparison of the performance of scheduling heuristics when it is up to 40 times more expensive to send a shared file across the network than it is to compute a task
- "Extended sufferage" scheduling heuristic takes advantage of file sharing to achieve good application performance



Preliminary PST/MCell Results with "Quality of Information"



Work-in-Progress: Half-Baked AppLeS

- **Quality of Information**
  - Stochastic Scheduling
  - AppLePilot / GrADS
- **Resource Economies**
  - Bushel of AppLeS
  - UCSD Active Web
- **Application Flexibility**
  - Computational Steering
  - Co-allocation
  - Target-less computing

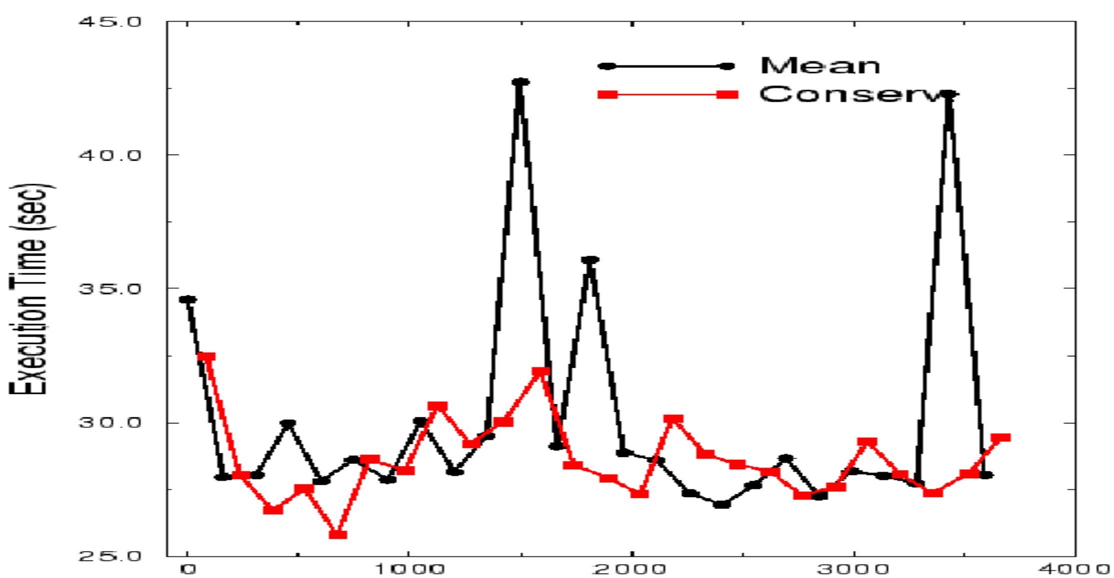
Quality of Information

- How can we deal with imperfect or imprecise predictive information?

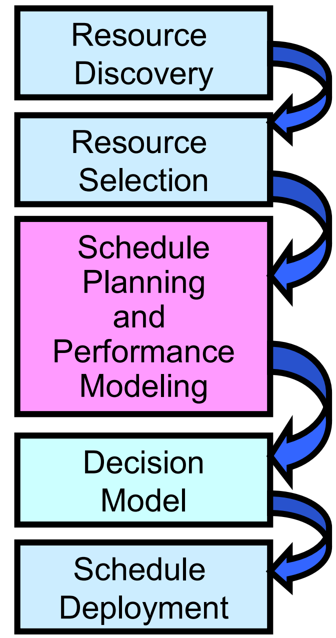
- Quantitative measures of qualitative performance attributes can improve scheduling and execution
  - *lifetime*
  - *cost*
  - *accuracy*
  - *penalty*

Using Quality of Information

- **Stochastic Scheduling:** Information about the variability of the target resources can be used by scheduler to determine allocation
  - **Resources with more performance variability assigned slightly less work**
  - Preliminary experiments show that resulting schedule performs well and can be more predictable



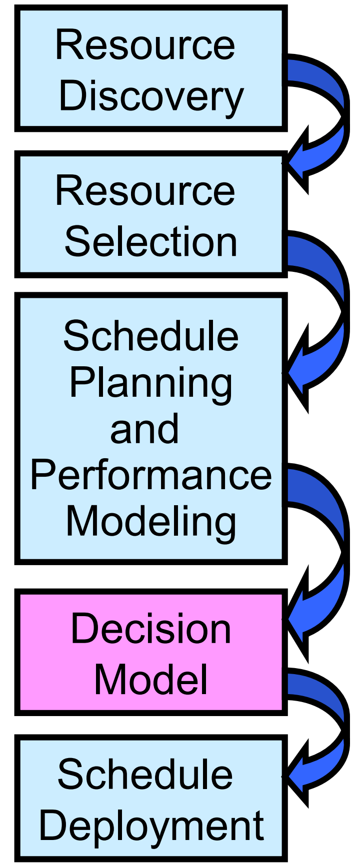
SOR Experiment [Jenny Schopf]



AppLeS Architecture

Quality of Information and "AppLePilot"

- **AppLePilot** combines **AppLeS** adaptive scheduling methodology with fuzzy logic decision making mechanism from **Autopilot**
  - Provides a framework in which to negotiate Grid services and promote application performance
  - Collaboration with Reed, Aydt, Wolski
- Builds on the software being developed for **GrADS**



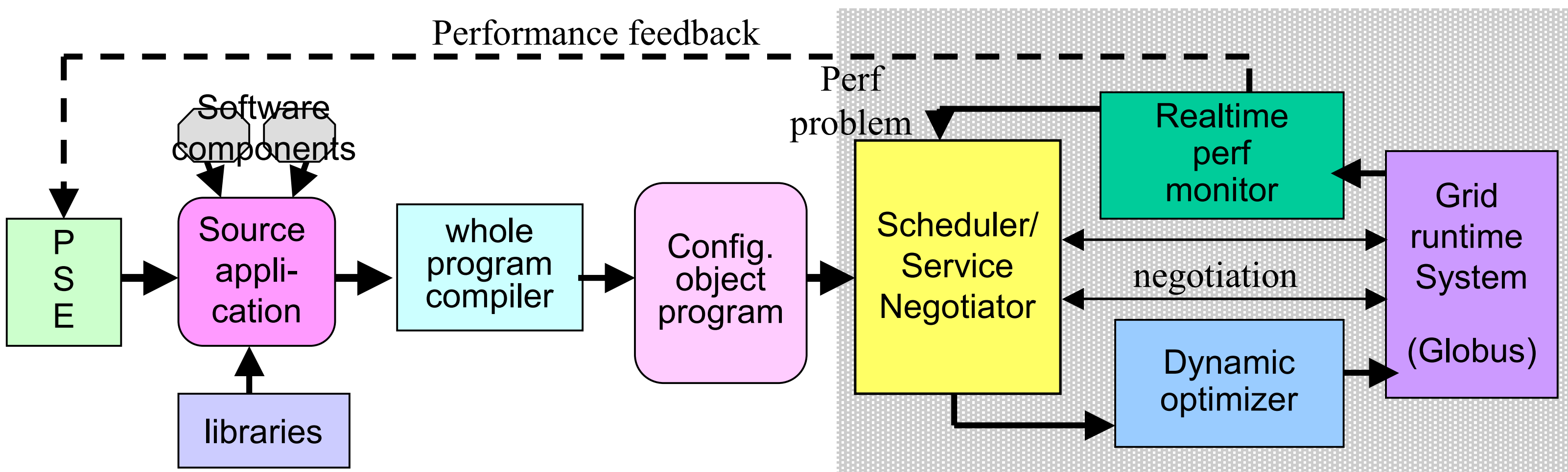
AppLeS Architecture

GrADS – **Gr**id **A**pplication **D**evelopment and Execution Environment

- Prototype system which facilitates end-to-end "grid-aware" program development
- Based on the idea of a **performance economy** in which negotiated contracts bind application to resources

- Joint project with large team of researchers

Ken Kennedy	Andrew Chien
Jack Dongarra	Rich Wolski
Dennis Gannon	Ian Foster
Dan Reed	Carl Kesselman
Lennart Johnsson	Fran Berman



Grid Application Development System

Summary

- Development of **AppLeS** methodology, applications, templates, and models provides a careful investigation of **adaptivity** for emerging Grid environments

- Goal of current projects is to use real-world strategies to promote dynamic **performance**
  - *adaptive scheduling*
  - *qualitative and quantitative modeling*
  - *multi-agent environments*
  - *resource economies*

- **Thanks** to NSF, NASA, NPACI, DARPA

- **AppLeS Home Page:** *http://apples.ucsd.edu*

- **AppLeS Corps:**
  - ***Fran Berman, UCSD***
  - ***Rich Wolski, U. Tenn***
  - *Henri Casanova*
  - *Walfredo Cirne*
  - *Holly Dail*
  - *Marcio Faerman*
  - *Jim Hayes*
  - *Graziano Obertelli*
  - *Gary Shao*
  - *Otto Sievert*
  - *Shava Smallen*
  - *Alan Su*