Why Performance Models Matter for Grid Computing

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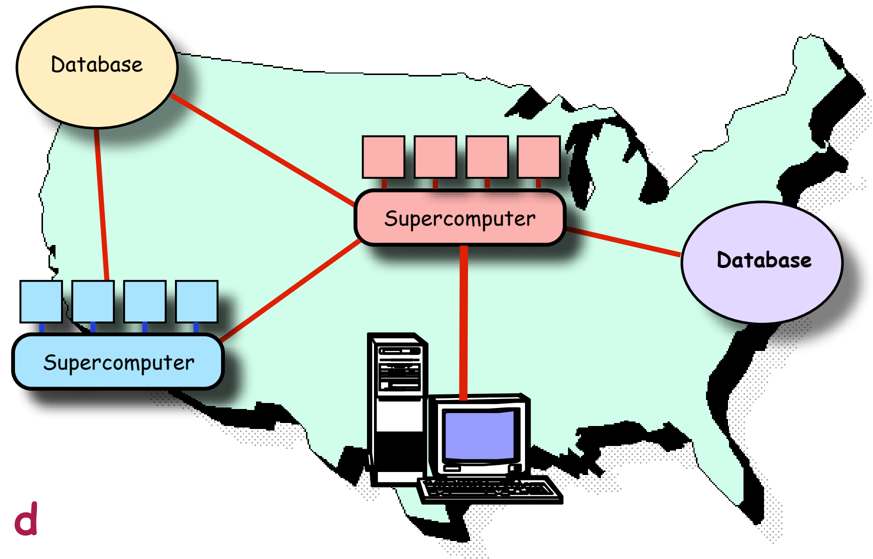
http://vgrads.rice.edu/WoCo9Overview07-06.pdf

Vision: Global Distributed Problem Solving

- Where We Want To Be
  - Transparent Grid computing
    - Submit job
    - Find & schedule resources
    - Execute efficiently
- Where We Are
  - Low-level hand programming
  - Programmer must manage:
    - Heterogeneous resources
    - Scheduling of computation and d
    - Fault tolerance and performance adaptation



- What Do We Propose as A Solution?
  - Separate application development from resource management
    - Through an abstraction called the Virtual Grid
  - Provide tools to bridge the gap between conventional and Grid computation
    - Scheduling, resource management, distributed launch, simple programming models, fault tolerance, grid economies

The VGrADS Team

- **VGrADS is an NSF-funded Information Technology Research project**

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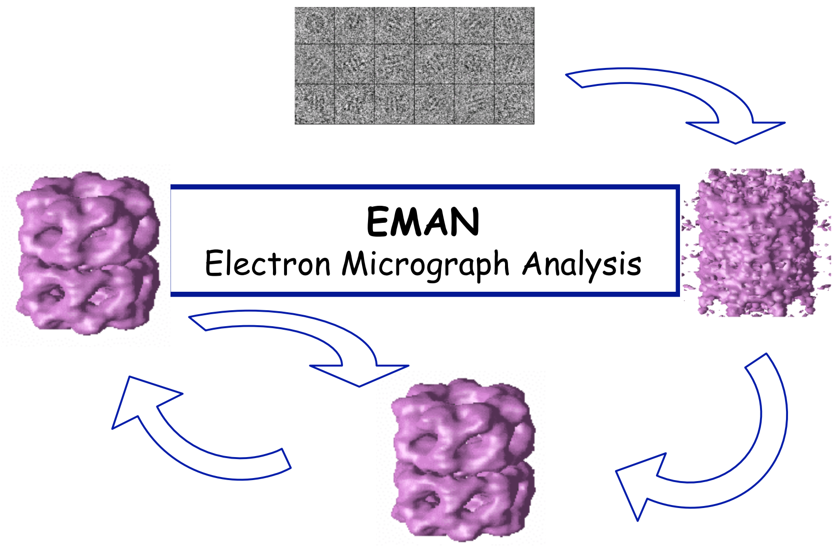
VGrADS Project Vision

- Virtual Grid Abstraction
  - Separation of Concerns
    - Resource location, reservation, and management
    - Application development and resource requirement specification
  - Permits true scalability and control of resources
- Tools for Application Development
  - Easy application scheduling, launch, and management
    - Off-line scheduling of workflow graphs
    - Automatic construction of performance models
  - Abstract programming interfaces
- Support for Fault Tolerance and Rescheduling/Migration
  - Collaboration between application and virtual grid execution system
- Research Driven by Real Application Needs
  - EMAN, LEAD, GridSAT, Montage

VGrADS Application Collaborations



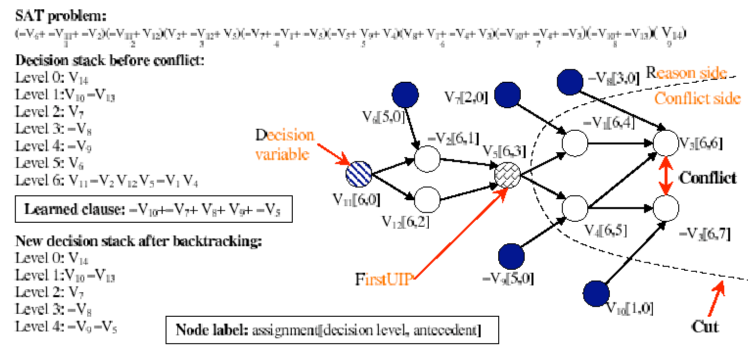
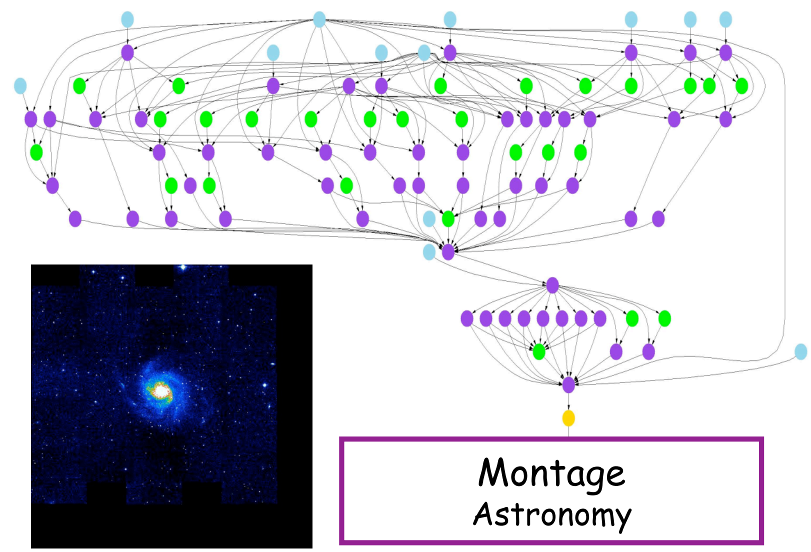
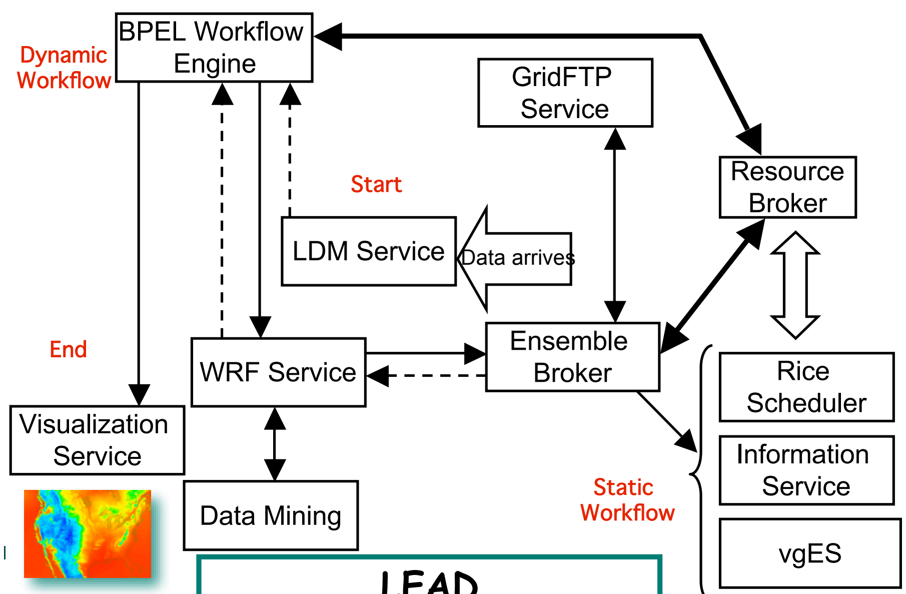


Figure 1: Example of conflict analysis with learning and non-chronological backtracking

GridSAT
Boolean Satisfiability



Montage
Astronomy



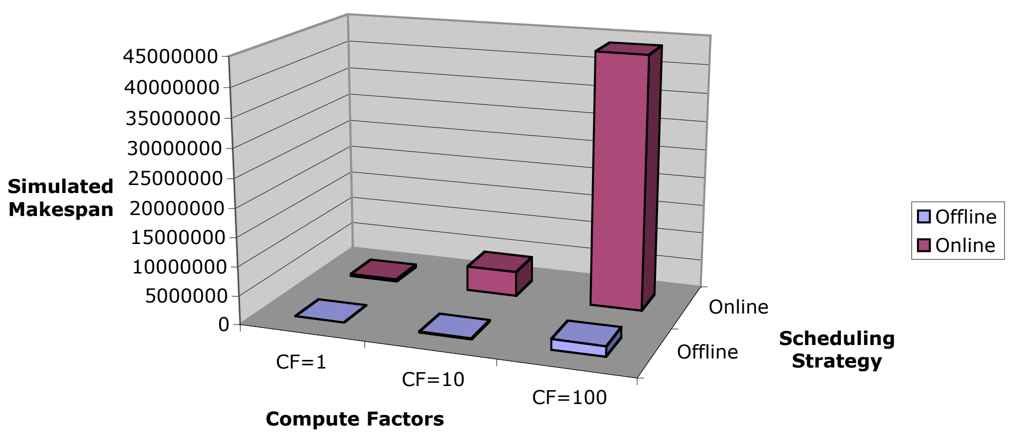
LEAD
Atmospheric Science

VGrADS Big Ideas

- Virtualization of Resources
  - Application specifies required resources in Virtual Grid Definition language (vgDL)
    - Give me a loose bag of 1000 processors, with 1 Gb memory per processor, with the fastest possible processors
    - Give me a tight bag of as many Opterons as possible
  - Virtual Grid Execution System (vgES) produces specific virtual grid matching specification
  - Avoids need for scheduling against the entire space of global resources
- Generic In-Advance Scheduling of Application Workflows
  - Application includes performance models for all workflow nodes
    - Performance models automatically constructed
  - Software schedules applications onto virtual Grid, minimizing total makespan
    - Including both computation and data movement times

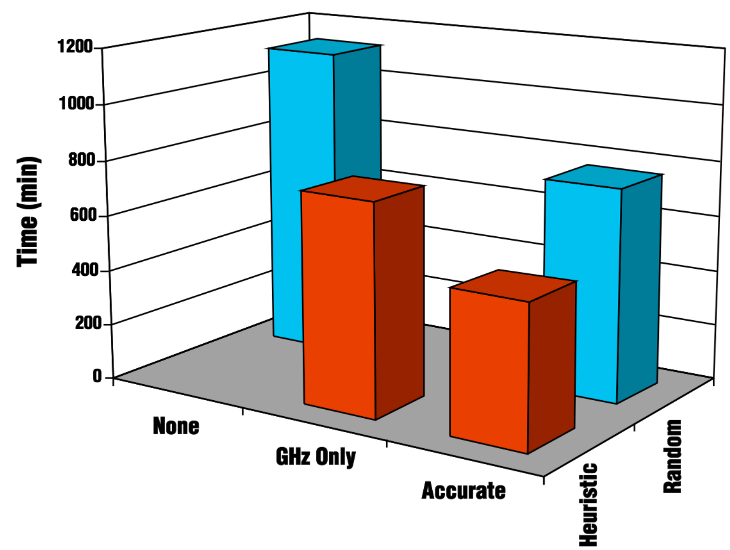
Workflow Scheduling Results

Dramatic makespan reduction of *offline* scheduling over *online* scheduling – Application: **Montage**



"Resource Allocation Strategies for Workflows in Grids"
CCGrid'05

Value of *performance models* and *heuristics* for offline scheduling – Application: **EMAN**



"Scheduling Strategies for Mapping Application Workflows onto the Grid"
HPDC'05

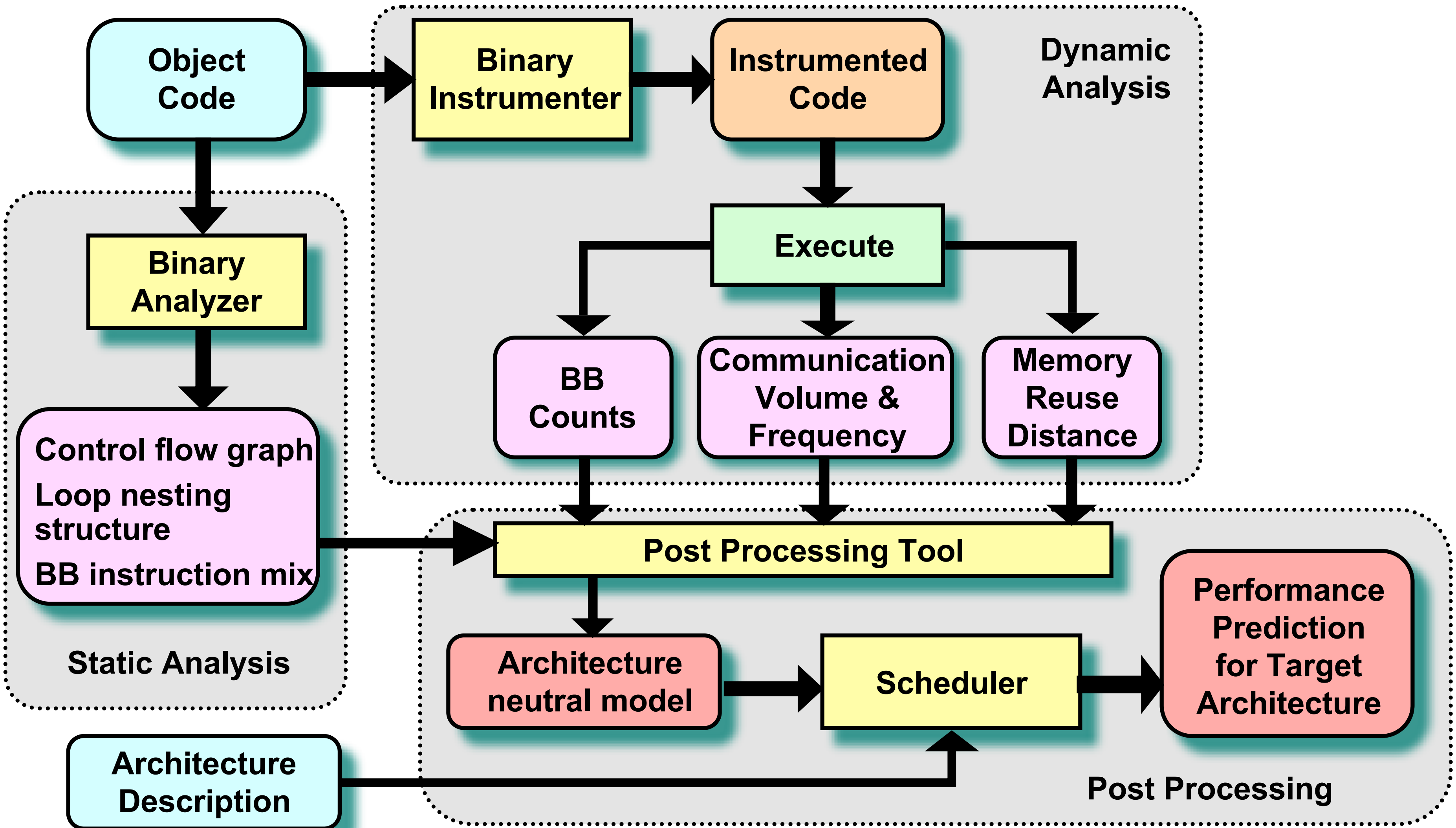
Virtual Grid Results

- Virtual Grid prescreening of resources produces schedules dramatically faster without significant loss of schedule quality
  - Huang, Casanova and Chien. Using Virtual Grids to Simplify Application Scheduling. IPDPS 2006.
  - Zhang, Mandal, Casanova, Chien, Kee, Kennedy and Koelbel. Scalable Grid Application Scheduling via Decoupled Resource Selection and Scheduling. CCGrid06.
- Current VGrADS heuristics are quadratic in number of distinct resource classes
  - Two-phase approach brings this much closer to linear time

Performance Model Construction

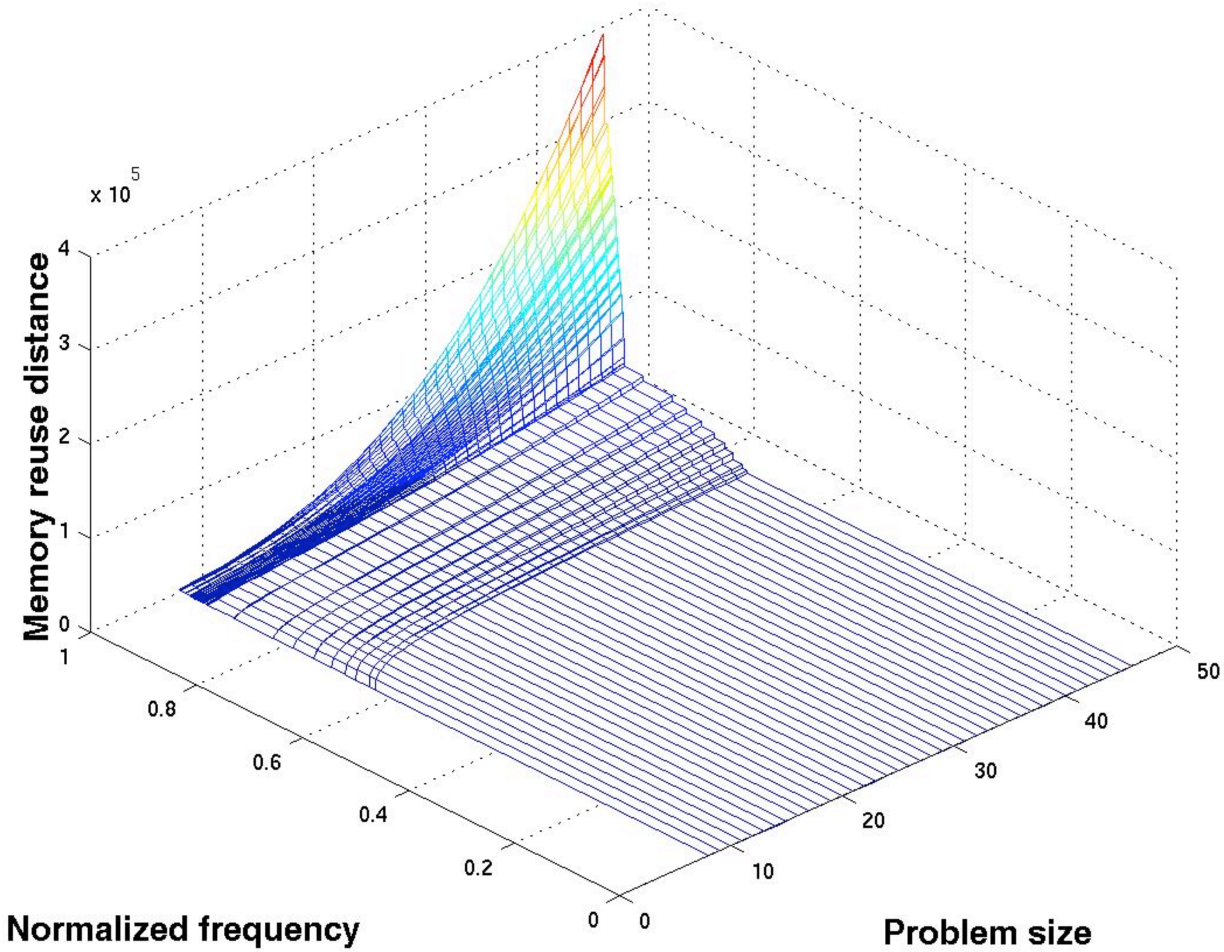
- Problem: Performance models are difficult to construct
  - By-hand and models take a great deal of time
  - Accuracy is often poor
- Solution (Mellor-Crummey and Marin): Construct performance models automatically
  - From binary for a single resource and execution profiles
  - Generate a distinct model for each target resource
- Current results
  - Uniprocessor modeling
    - Can be extended to parallel MPI steps
  - Memory hierarchy behavior
  - Models for instruction mix
    - Application-specific models
    - Scheduling using delays provided as machine specification

Performance Prediction Overview



VGrADS
Virtual Grid Application Development Software Project

Modeling Memory Reuse Distance



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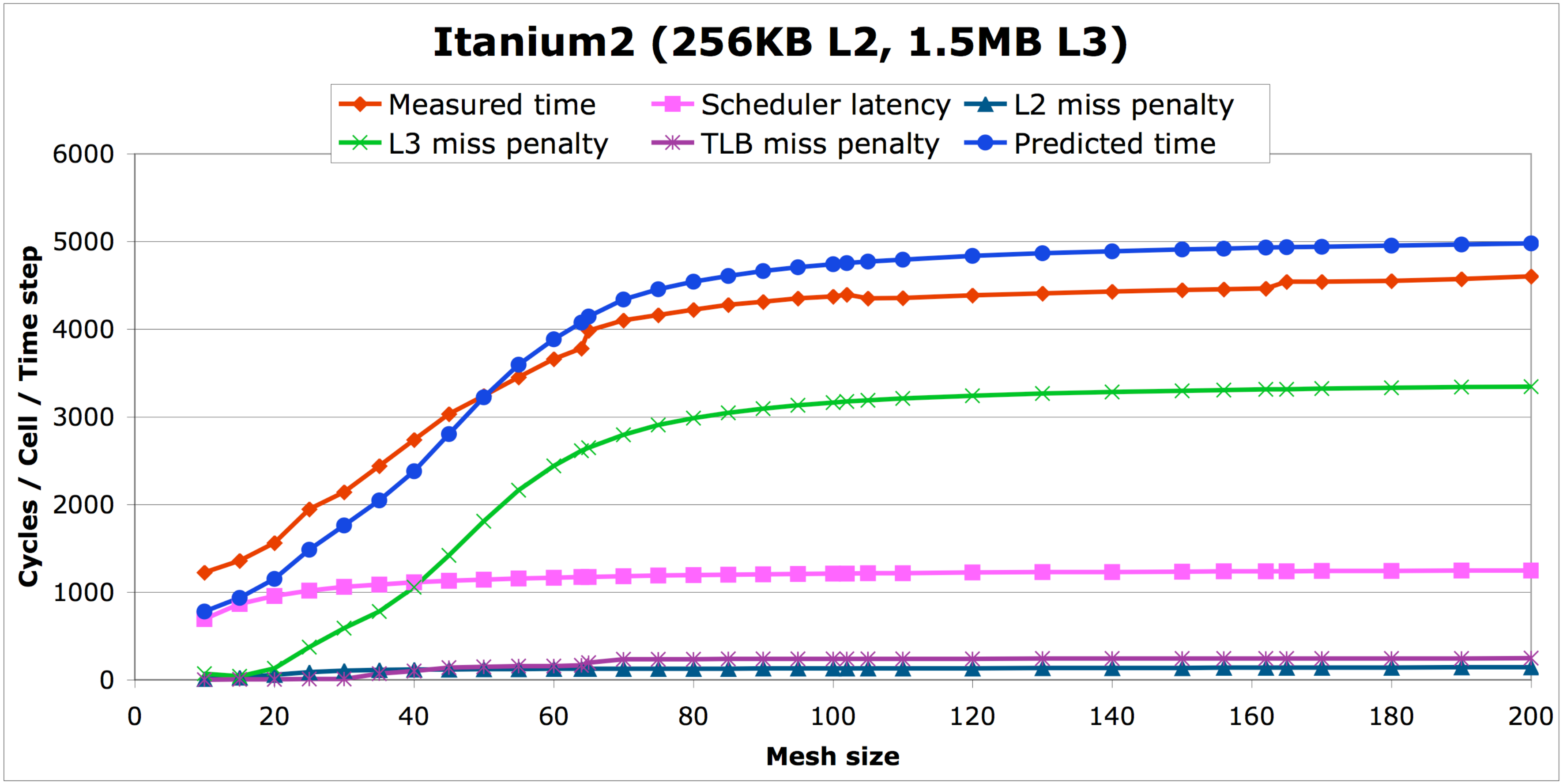
Execution Behavior: NAS LU 2D 3.0



Value of Performance Models

- True Grid Economy
  - All resources have a "rate of exchange"
    - Example: 1 CPU unit Opteron = 2 units Itanium (at same Ghz)
  - Rate of exchange determined by averaging over all applications
    - Weighted by application global resource usage percentage
- Improved Global Resource Utilization
  - A particular application may be able to take advantage of performance models to reduce costs
    - Example: For EMAN, 1 Opteron unit = 3 Itanium units
    - Thus, EMAN should always favor Opterons when available
  - If all applications do this, the total system resources will be used far more efficiently

Performance Models and Batch Scheduling

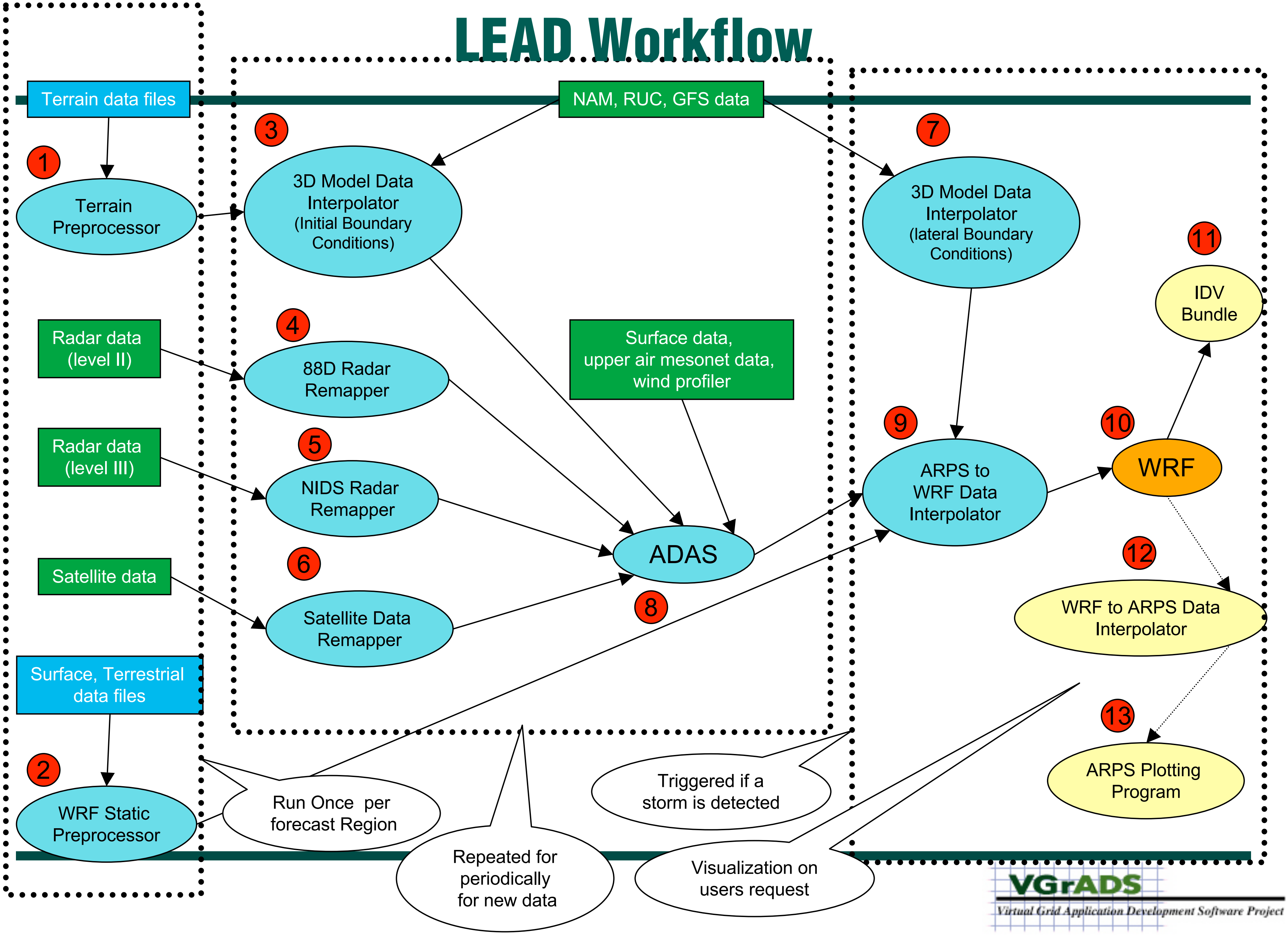
- Currently VGrADS supports scheduling using estimated batch queue waiting times
  - Batch queue estimates are factored into communication time
    - E.g., the delay in moving from one resource to another is data movement time + estimated batch queue waiting time
  - Unfortunately, estimates can have large standard deviations
- Next phase: limiting variability through two strategies:
  - Resource reservations: partially supported on the TeraGrid and other schedulers
  - In advance queue insertion: submit jobs before data arrives based on estimates
    - Can be used to simulate advance reservations
- Exploiting this requires a preliminary schedule indicating when the resources are needed
  - Problem: how to build an accurate schedule when exact resource types are unknown

Solution to Preliminary Scheduling Problem

- Use performance models to specify alternative resources
  - For step B, I need the equivalent of 200 Opterons, where 1 Opteron = 3 Itanium = 1.3 Power 5
    - Equivalence from performance model
- This permits an accurate preliminary schedule because the performance model standardizes the time for each step
  - Scheduling can then proceed with accurate estimates of when each resource collection will be needed
  - Makes advance reservations more accurate
    - Data will arrive neither too early or too late
- It may provide a mixture to meet the computational requirments, if the specification permits
  - Give me a loose bag of tight bags containing the equivalent of 200 Opterons, minimize the number of tight bags and the overall cost
    - Solution might be 150 Opterons in one cluster and 150 Itaniums in another

Scheduling to a Deadline

- LEAD Project has a feedback loop
  - After each preliminary workflow, results are used to adjust doppler radar configurations to get more accurate information in the next phase
  - This must be done on a tight time constraint
- Performance models make this scheduling possible
  - What happens if the first schedule misses the deadline?
    - The time must be reduced, either by doing less computation or by using more resources
    - But how many more resources?
  - Suppose we can differentiate the model to compute for each step, the sensitivity of running time to more resources
    - Automatic differentiation technologies exist, but other strategies may also make this possible
  - Derivatives can be used to predict resources needed to meet the deadline along the critical path


LEAD Workflow
Terrain data files
NAM, RUC, GFS data
1
Terrain Preprocessor
3
3D Model Data Interpolator (Initial Boundary Conditions)
7
3D Model Data Interpolator (lateral Boundary Conditions)
11
IDV Bundle
Radar data (level II)
4
88D Radar Remapper
Surface data, upper air mesonet data, wind profiler
Radar data (level III)
5
NIDS Radar Remapper
9
ARPS to WRF Data Interpolator
10
WRF
ADAS
Satellite data
6
Satellite Data Remapper
8
12
WRF to ARPS Data Interpolator
Surface, Terrestrial data files
13
ARPS Plotting Program
2
WRF Static Preprocessor
Run Once per forecast Region
Triggered if a storm is detected
Repeated for periodically for new data
Visualization on users request
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Summary

- VGrADS Project Uses Two Mechanisms for Scheduling
  - Abstract resource specification to produce preliminary collection of resources
  - More precise scheduling on abstract collection using performance models
    - Combined strategy produces excellent schedules in practice
    - Performance models can be constructed automatically
- New Challenges Require Sophisticated Methods
  - Minimizing cost of application execution
  - Scheduling with batch queues and advanced reservations
  - Scheduling to deadlines
- Current Driving Application
  - LEAD: Linked Environments for Atmospheric Discovery
    - Requires deadlines and efficent resource utilization

Relationship to Future Architectures

- Future supercomputers will have heterogeneous components
  - Cray, Cell, Intel, CPU + coprocessor (GPU), …
- Scheduling subcomputations onto units while managing data movment costs will be the key to effective usage of such systems
  - Adapt VGrADS strategy
  - Difference: must consider alternative compilations of the same computation, then model performance of the result
- Could be used to tailor systems or chips to particular users' application mixes