Cloudy Skies: Astronomy and Utility Computing

Ewa Deelman
Gurmeet Singh
University of Southern California
Information Sciences Institute

Work in collaboration with Miron Livny, UW Madison
Bruce Berriman, John Good, Montage Project, IPAC, Caltech
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Scientific Applications

- Complex
  - Involve many computational steps
  - Require many (possibly diverse resources)

- Composed of individual application components
  - Components written by different individuals
  - Components require and generate large amounts of data
  - Components written in different languages
Issues Critical to Scientists

- Reproducibility of scientific analyses and processes is at the core of the scientific method.
- Scientists consider the “capture and generation of provenance information as a critical part of <…> generated data.”
- “Sharing <methods> is an essential element of education, and acceleration of knowledge dissemination.”

Computational challenges faced by applications

- Be able to compose complex applications from smaller components
- Execute the computations reliably and efficiently
- Take advantage of any number/types of resources
- Cost is an issue
  - Cluster, CI, Cloud
Possible solution

somewhat subjective

- Structure an application as a workflow
  - Describe data and components in logical terms (resource independent)
- Can be mapped onto a number of execution environments
- Can be optimized and if faults occur the workflow management system can recover
- Use a workflow management system (Pegasus-WMS) to manage the application on a number of resources
Pegasus-Workflow Management System

- Leverages abstraction for workflow description to obtain ease of use, scalability, and portability
- Provides a compiler to map from high-level descriptions to executable workflows
  - Correct mapping
  - Performance enhanced mapping
- Provides a runtime engine to carry out the instructions (Condor DAGMan)
  - Scalable manner
  - Reliable manner
- Can execute on a number of resources: local machine, campus cluster, Grid, Cloud

Ewa Deelman, deelman@isi.edu
www.isi.edu/~deelman
pegasus.isi.edu
Science-grade Mosaic of the Sky

Point on the sky, area

Image Courtesy of IPAC, Caltech

Ewa Deelman, deelman@isi.edu
www.isi.edu/~deelman
pegasus.isi.edu
**Generating mosaics of the sky (Bruce Berriman, Caltech)**

*The full moon is 0.5 deg. sq. when viewed from Earth, Full Sky is ~ 400,000 deg. sq.*

<table>
<thead>
<tr>
<th>Size of the mosaic in degrees square*</th>
<th>Number of jobs</th>
<th>Number of input data files</th>
<th>Number of Intermediate files</th>
<th>Total data footprint</th>
<th>Approx. execution time (20 procs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>232</td>
<td>53</td>
<td>588</td>
<td>1.2GB</td>
<td>40 mins</td>
</tr>
<tr>
<td>2</td>
<td>1,444</td>
<td>212</td>
<td>3,906</td>
<td>5.5GB</td>
<td>49 mins</td>
</tr>
<tr>
<td>4</td>
<td>4,856</td>
<td>747</td>
<td>13,061</td>
<td>20GB</td>
<td>1hr 46 mins</td>
</tr>
<tr>
<td>6</td>
<td>8,586</td>
<td>1,444</td>
<td>22,850</td>
<td>38GB</td>
<td>2 hrs. 14 mins</td>
</tr>
<tr>
<td>10</td>
<td>20,652</td>
<td>3,722</td>
<td>54,434</td>
<td>97GB</td>
<td>6 hours</td>
</tr>
</tbody>
</table>
Montage/IPAC Situation

- Provides a service to the astronomy community
  - Delivers data to the community
  - Delivers a computational service to the community (mosaics)
- Has its own computing infrastructure
  - Invests ~ $75K for computing (over 3 years)
  - Appropriates ~ $50K in human resources every year to maintain hardware and do programming
- Expects to need additional resources to deliver services
- Wants fast responses to user requests

Ewa Deelman, deelman@isi.edu  www.isi.edu/~deelman  pegasus.isi.edu
Cloudy Questions

- Applications are asking:
  - What are Clouds?
  - How do I run on them?
- How do I make good use of the cloud so that I use my funds wisely?
  - And how do I explain Cloud computing to the purchasing people?
- How many resources do I allocate for my computation or my service?
- How do I manage data transfer in my cloud applications?
- How do I manage data storage—where do I store the input and output data?

Ewa Deelman, deelman@isi.edu  www.isi.edu/~deelman  pegasus.isi.edu
Montage Infrastructure
Computational Model

- Simulations done using a modified Gridsim simulator
- Based on Amazon’s fee structure
  - $0.15 per GB-Month for storage resources
  - $0.10 per GB for transferring data into its storage system
  - $0.16 per GB for transferring data out of its storage system
  - $0.10 per CPU-hour for the use of its compute resources
- Normalized to cost per second
- Does not include the cost of building and deploying an image
How many resources to provision?

Montage 1 Degree Workflow

203 Tasks

60 cents for the 1 processor computation versus almost $4 with 128 processors, 5.5 hours versus 18 minutes
4 Degree Montage

3,027 application tasks

1 processor $9, 85 hours; 128 processors, 1 hour with and $14.
How to manage data?

1 Degree Montage

4 Degree Montage

Ewa Deelman, deelman@isi.edu www.isi.edu/~deelman pegasus.isi.edu
How do data cost affect total cost?

- Data stored outside the cloud
- Computations run at full parallelism
- Paying only for what you use
  - Assume you have enough requests to make use of all provisioned resources

Cost in $
Where to keep the data?

- Storing all of 2 Mass data
  - 12 TB of data → $1,800 per month on the Cloud
- Calculating a 1 degree mosaic and delivering it to the user
  - $2.22 (with data outside the cloud)
- Same mosaic but data inside the cloud: $2.12
- To overcome the storage costs, users would need to request at least $1,800/($2.22-$2.12) = 18,000 mosaics per month
- Does not include the initial cost of transferring the data to the cloud, which would be an additional $1,200
- Is $1,800 per month reasonable?
  - ~$65K over 3 years (does not include data access costs from outside the cloud)
  - Cost of 12TB to be hosted at Caltech $15K over 3 years for hardware
The cost of doing science

- Computing a mosaic of the entire sky (3,900 4-degree-square mosaics)
  - 3,900 x $8.88 = $34,632

- How long it makes sense to store a mosaic?
  - Storage vs computation costs

<table>
<thead>
<tr>
<th>Mosaic size</th>
<th>Cost of generation</th>
<th>Mosaic size</th>
<th>Length of time to save</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 degree^2</td>
<td>$0.56</td>
<td>173MB</td>
<td>21.52 months</td>
</tr>
<tr>
<td>2 degree^2</td>
<td>$2.03</td>
<td>558MB</td>
<td>24.25 months</td>
</tr>
<tr>
<td>4 degree^2</td>
<td>$8.40</td>
<td>2.3GB</td>
<td>25.12 months</td>
</tr>
</tbody>
</table>

Remember virtual data from GriPhyN? Now we can quantify things a bit better.
Summary

- We started asking the question of how can applications/scientific workflows best make use of clouds
- Assumed a simple cost model based on the Amazon fee structure
- Conducted simulations
  - Need to find balance between cost and performance
  - Computational cost outweighs storage costs in the case of Montage
  - Storage can be expensive in the long run
- Did not explore issues of data security and privacy, reliability, availability, ease of use, etc
Will scientific applications move into clouds? (a myopic view)

- There is interest in the technology from applications
- They often don’t understand what are the implications of using the new technology
- They need support from CS folks to navigate the dark clouds
- Need tools to manage the cloud
  - Build and deploy images
  - Request the right number of resources
  - Manage costs of individual computations
  - Manage project costs—does your purchasing department know about Cloud computing?
- Projects need to perform cost/benefit analysis
Issues Critical to Scientists

- **Reproducibility** – yes—maybe--through virtual images, if we package the entire environment, the application and the VMs behave
- **Provenance** – still need tools to capture what happened
- **Sharing** – can be easier to share entire images and data
  - Data could be part of the image
Getting tired of Clouds?
Black Hole Computing
a New Computing Paradigm!

Data and Computing

Results?

http://www.nasa.gov/vision/universe/starsgalaxies/integral_blackholes.html

Black Hole Provisioning
New International Collaboration

LHC Experiment at CERN
http://www.cern.ch

Ewa Deelman, deelman@isi.edu
Relevant Links

- **Pegasus-WMS**: pegasus.isi.edu
- **DAGMan**: www.cs.wisc.edu/condor/dagman


- **Montage**: montage.ipac.caltech.edu/
- **Condor**: www.cs.wisc.edu/condor/