Metadata and Provenance Capture: Fins in Sea of Data

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Purdue, Mar 2012
The Data Deluge

“This year digital information will grow to 988 exabytes or equivalent to a stack of books from the sun to Pluto and back.”

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IBM Research, February 2010 quoting statistic from IDC White Paper 2007

“We’re going to find ourselves in the not-too-distant future swimming in sensors and drowning in data,”

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Riches of the Data Deluge

• A lot of data being generated is in sciences – through ocean instruments, air quality sensors, through gene sequencing machines, through climate models ...

• Research funding agencies want to see data public pays for to be available for multiple uses, for researchers decades from now
  
  – “The National Science Foundation is committed to the principle that the various forms of data collected with public funds belong in the public domain.”

*Data Archiving Policy, NSF Social Behavioral and Economic Sciences*

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Challenges of Data Deluge

• Metadata must be preserved when scientific data is generated because metadata is ephemeral – *Jim Gray*

• “The management, organization, access, and preservation of digital data is arguably a ‘grand challenge’ of the information age” – Fran Berman (2008)

• If annotation is left to the scientist, it is not done (U.K. e-Science Core)

• The further the distance between data producer and re-use, the more detailed the metadata that’s required.
Key Role of the Scientist in Data Lifecycle

- Scientific researcher present at data creation, archivist is not
  - E.g., researcher is who makes keep/discard decisions on critical data!

- Use of scientific data 50 years from now requires that scientists have tools to help with preservation in earliest stages of data’s life.

`Diagram from Berman et al. “Sustainable Economics for a Digital Planet”`
Data sharing **today** and **next decade**: same problem, same challenges

- It’s available on my department’s server, and I’m happy to share it with you if you ask
- It’s available on the web, but you need to know the file name to find it
- It’s available on the web, but only until the machine it sits on gets too old
- *None of these is good enough*
A collection belonging in public domain should:

- Be findable ........................................ Discover
- Be useable in another’s research ................. Actionable
- Be as useful in 10 years as it is in 10 months .......... Preservation

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Discover

• The legacy solution to discovering data is to embed lots of metadata into file names
  – http://lead.unidata.ucar.edu:8080/thredds/dodsC/LEAD/radar2/KVTX/20090914/Level2_KVTX_20090914_1321.ar2v
  – http://lead.unidata.ucar.edu:8080/thredds/fileServer/LEAD/model/NCEP/NAM/CONUS_80km/NAM_CONUS_80km_20090914_1200.grib1

• Good for those initiated into “inner-circle”
• Relying on long file names isn’t enough
**Discover**

**Name:** wrfout_d01_2009-03-05_12:00:00  
**GUID:** urn:uuid:b419247e-876d-4842-b463-e79fc50aea3b  
**Owner:** /O=LEAD Project/OU=portal.leadproject.org/OU=cs.indiana.edu/CN=plale/EMAIL=plale@cs.indiana.edu  
**Create time:** ...

**File system (e.g., Data Capacitor)**

b419247e-876d-4842-b463-e79fc50aea3b

**Metadata in database**

**Objects stored to file system, OPeNDAP, iRods**

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**DATA TO INSIGHT CENTER**  
**INDIANA UNIVERSITY**  
Pervasive Technology Institute

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Actionable

• Actions on data at source (move computation to data)
  – Regrid array data to match co-ordinate system of some other data set
  – Sequence pattern matching
    • e.g., computer execution traces, DNA sequence
  – Statistical analysis
    • e.g., regression analysis, confidence interval
  – Building inverted index to support full text search
“Downscaling" of climate/ensemble forecasts from large scale, coarse-resolution to high-resolution using local high-resolution terrain and vegetative coverage datasets. 40km grid using 5km terrain after the fact.

Fig. 1. NAM 2-m temperature forecast in degrees Fahrenheit, displayed on a 40 km grid, valid 1800 UTC 22 April 2009.

Geoffrey Manikin, NCEP/EMC, AMS IIPS 2010

Fig. 2. Same NAM temperature forecast as in Fig. 1, but downscaled onto a 5 km grid.
Scientific Data Lifecycle: support of preservation for long term discovery and use

Create → Distribute → Archive collection → Long term access → Preservation Action → Preservation Action → Preservation Action

What is it that flows?

That is, what does science data that enables discovery and use look like?

http://pti.iu.edu/d2i/xmccat-metadata-concepts-LEAD

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Diagram from Berman et al. “Sustainable Economics for a Digital Planet”
- **NSF DataNet SEAD project:**
- Data services that address needs of researchers advancing science behind sustainable planet
- Active and social curation infrastructure
- Datasets packaged and migrated to virtual archive of university Institutional Repositories
Data Provenance

Provenance is lineage of data object or collection.
Explains what contributed to object’s creation

• Standalone tool for
  – Unmanaged workflows
  – Semi-structured workflows
  – e.g., NASA satellite imagery ingest
  – e.g., GENI computer network

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Data Provenance: analogy to provenance of works of art

- Trace of history of work of art from moment it was made until it comes into a collection.
- Impartial and authoritative information on authenticity, ownership, theft, and other artistic, legal, and ethical issues concerning art objects.
Types of Provenance Information

Actions in Workflow

- User 1
  - [1] produces
  - File 1
    - [2] consumes
    - Service 1
      - [3] produces
      - File 2
        - [4] transformation
      - [5] invokes
    - Service 2

Equivalent OPM Causal Dependencies

- Agent 1
  - [1] wasControlledBy
  - Process 1
    - [2] used
  - Artifact 1
    - [3] wasGeneratedBy
    - Process 2
      - [4] generatedFrom
      - Artifact 2

Legend:
- Direct Actions (solid)
- Derivation (dashed)
NASA AMSR-E imagery ingest processing schedule
Workflow Processed

- Products Date Range: Sept 02 – Oct 04
- Detailed Statistics

<table>
<thead>
<tr>
<th>Workflow</th>
<th># of data product per workflow</th>
<th># of input files per workflow</th>
<th># of output files per workflow</th>
<th># of processes per workflow</th>
<th>Metadata Annotated</th>
<th>Avg OPM file size (KB)</th>
<th># of workflows processed</th>
</tr>
</thead>
<tbody>
<tr>
<td>ocean (L2B)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>Granule</td>
<td>13</td>
<td>905</td>
</tr>
<tr>
<td>rain (L2B)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>Granule</td>
<td>13</td>
<td>905</td>
</tr>
<tr>
<td>land (L2B)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>Granule</td>
<td>13</td>
<td>905</td>
</tr>
<tr>
<td>dayocean (L3)</td>
<td>1</td>
<td>34</td>
<td>2</td>
<td>4</td>
<td>Granule</td>
<td>250</td>
<td>33</td>
</tr>
<tr>
<td>seaice (L3)</td>
<td>3</td>
<td>43</td>
<td>6</td>
<td>8</td>
<td>Granule, Process, Product</td>
<td>458</td>
<td>33</td>
</tr>
<tr>
<td>drift (L3)</td>
<td>1</td>
<td>10</td>
<td>1</td>
<td>2</td>
<td>Granule</td>
<td>97</td>
<td>29</td>
</tr>
<tr>
<td>daysnow (L3)</td>
<td>1</td>
<td>33</td>
<td>3</td>
<td>5</td>
<td>Granule</td>
<td>151</td>
<td>33</td>
</tr>
<tr>
<td>land3 (L3)</td>
<td>1</td>
<td>33</td>
<td>4</td>
<td>6</td>
<td>Granule</td>
<td>119</td>
<td>33</td>
</tr>
<tr>
<td>5daysnow (L3)</td>
<td>1</td>
<td>8</td>
<td>2</td>
<td>4</td>
<td>Granule</td>
<td>62</td>
<td>6</td>
</tr>
<tr>
<td>weekocean (L3)</td>
<td>1</td>
<td>70</td>
<td>2</td>
<td>4</td>
<td>Granule</td>
<td>729</td>
<td>5</td>
</tr>
<tr>
<td>monthocean (L3)</td>
<td>1</td>
<td>874</td>
<td>2</td>
<td>4</td>
<td>Granule</td>
<td>8689</td>
<td>1</td>
</tr>
<tr>
<td>monthsnow (L3)</td>
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<td>32</td>
<td>2</td>
<td>4</td>
<td>Granule</td>
<td>342</td>
<td>1</td>
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<tr>
<td>monthrain (L3)</td>
<td>1</td>
<td>1709</td>
<td>2</td>
<td>4</td>
<td>Granule</td>
<td>13732</td>
<td>1</td>
</tr>
</tbody>
</table>

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Selected Workflow Annotations in MonthRain provenance graph

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Workflow; steps to build

• User logs into web portal,
• Through user interface constructs workflow as directed graph of tasks executed in sequence. Edges are flows of data.
• Workflow (graph) handed off to scheduler that executes each task on cluster or cloud
Visualization of provenance of weather forecast workflow without and with failures
We capture provenance of “DoS Attacks Exploiting WiMAX System Parameters”, Clemson. Experiment uses 100 subscribers with varied configurations of 6 parameters. Current version runs on NS2.

Table 1. Parameter Values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Treatment 1</td>
</tr>
<tr>
<td>frame duration</td>
<td>0.004</td>
</tr>
<tr>
<td>number of attackers/user</td>
<td>20/80</td>
</tr>
<tr>
<td>dos_backoff_start</td>
<td>1</td>
</tr>
<tr>
<td>dos_request_retry</td>
<td>2</td>
</tr>
<tr>
<td>bw_backoff_start</td>
<td>1</td>
</tr>
<tr>
<td>bw_request_retry</td>
<td>2</td>
</tr>
</tbody>
</table>

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Provenance of WiMAX DDoS Experiment

- Provenance capture with NetKarma. NetKarma captures
  - provenance of packet movement, and
  - infers critical provenance about packets that were dropped, and by doing so is able to convey information about DDoS attacks through visualization
  - Improvement over earlier hand-worked ANOVA analysis.

- NetKarma’s provenance filters and visualization extensions for Cytoscape enable side-by-side performance comparison of different experiment configurations. Visualizations show packets dropped and received. Visualization automatically adjusted for provenance volume (of total number of packets sent.)
Dropped packets increases as frame duration increases from 0.01s to 0.02s

<table>
<thead>
<tr>
<th>Run id</th>
<th>Frame duration</th>
<th>number of attackers</th>
<th>attack backoff start</th>
<th>attack request retry</th>
<th>bw backoff start</th>
<th>bw request retry</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.004</td>
<td>20/80</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>244</td>
<td>0.01</td>
<td>20/80</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>487</td>
<td>0.02</td>
<td>20/80</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Run id</td>
<td>Frame duration</td>
<td>number of attackers</td>
<td>attack backoff start</td>
<td>attack request retry</td>
<td>bw backoff start</td>
<td>bw request retry</td>
</tr>
<tr>
<td>--------</td>
<td>---------------</td>
<td>---------------------</td>
<td>----------------------</td>
<td>---------------------</td>
<td>----------------</td>
<td>----------------</td>
</tr>
<tr>
<td>406</td>
<td>0.01</td>
<td>80/20</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>407</td>
<td>0.01</td>
<td>80/20</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>408</td>
<td>0.01</td>
<td>80/20</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>10</td>
</tr>
</tbody>
</table>

Decrease in dropped packets as `bw_request_retry` increases from 2 to 6
<table>
<thead>
<tr>
<th>Run id</th>
<th>Frame duration</th>
<th>number of attackers</th>
<th>attack backoff start</th>
<th>attack request retry</th>
<th>bw backoff start</th>
<th>bw request retry</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.004</td>
<td>20/80</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>0.004</td>
<td>20/80</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>0.004</td>
<td>20/80</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>2</td>
</tr>
</tbody>
</table>

Dropped packets decreases as `bw_backoff_start` increases from 1 to 3
Ongoing Work: Provenance of WiMAX Experiments on ORBIT

- Provenance captured for WiMAX DDoS experiments run on ORBIT.
- NetKarma harvests provenance from measurements made by Orbit Measurement Library (OML), and infers critical provenance about packets dropped.
- Clemson investigating impact of “backoff_start” and “backoff_end” in WiMAX DDoS experiment on ORBIT.
Ongoing Work: Capturing Provenance of GENI eXtensible Session Protocol (XSP)

- Provenance for XSP experiments includes:
  - Logical view of XSP experiment’s execution and data associated with experiment including topology of nodes, commands, outputs, etc.
  - Metadata (start-time, end-time, and bytes or packets transferred)
  - Passive measurements, including (CPU load, etc.)
  - Active measurements from GENI measurement archive.
Metadata Enhanced Pipeline for Storm Surge Ensemble Runs on Azure*

- An immediate and dangerous impact of climate change is change in strength of storms that form over oceans making coastal communities increasingly vulnerable to storm surge.
- There have already been indications that even modest changes in ocean surface temperature can have a disproportionate effect on hurricane strength and damage inflicted by these storms.

* New project with Craig Mattocks, UMIami

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Sea, Lake and Overland Surges from Hurricanes (SLOSH) model: hydrodynamic coastal ocean model

<table>
<thead>
<tr>
<th>Hurricane Andrew (1992) Input:</th>
</tr>
</thead>
<tbody>
<tr>
<td>hmi3dta (model configuration file) = 198,264</td>
</tr>
<tr>
<td>andrew.stm (input storm track file) = 703</td>
</tr>
<tr>
<td>andrew.trk (above file interpolated) = 7,767</td>
</tr>
<tr>
<td>hmi3.llx  (Miami basin grid file) = 190,168</td>
</tr>
<tr>
<td>Total input = 396,902 bytes</td>
</tr>
<tr>
<td>Total input for 15,000 ensemble members = 5,953,530,000 bytes = 5.54 GB</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hurricane Andrew (1992) output:</th>
</tr>
</thead>
<tbody>
<tr>
<td>andrew.rex (rex output file) = 528,896</td>
</tr>
<tr>
<td>andrew.env (envelope file) = 47,668</td>
</tr>
<tr>
<td>Total output = 576,564 bytes</td>
</tr>
<tr>
<td>Total output for 15,000 ensemble members = 8,648,460,000 bytes = 8.055 GB</td>
</tr>
</tbody>
</table>

Small input, small output, 15,000 3-min jobs

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Probabilistic product shows considerable surge threat to Pensacola area
Plots of maximum water surface elevation from historical Hurricane Andrew (1992) test case generated by the SLOSH storm surge prediction model.
Figure 7: Parallel Efficiency
Pipeline architectural layering

Client interfaces
- Trident workbench
- Extensibility template
- Web browser (Azure)
  - Context db
  - Client library

Sigiri framework layer
- Resource manager web service
  - Pipeline planner
  - Monitor feedback
  - Data movement
  - Context db
  - Daemons
    - Azure
    - EC2
    - Grid cluster

Resource platform layer (Azure shown)
- Azure Management API
  - Sigiri Worker service (IIS)
  - SLOSH
  - Windows 2008R2
  - VM Instance
  - Azure Blob Store
  - Azure Fabric
  - Azure Custom VM roles
Provenance and metadata are critical for reuse. Completeness of automatic capture is still an open question.

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