Provenance-Aware Storage Systems

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April 29, 2005
Outline

• What is Provenance?
• What is a Provenance-Aware Storage System
• Approaches and Challenges in PASS
• Conclusions
Provenance

• From the French word for “source” or “origin”
• The complete history or lineage of an object
• In computer terms:
  – On what is this object based?
  – How was this object created?
  – How can it be re-created?
  – Source code control is a provenance system.
  – make is a provenance system
Provenance in Homeland Security

- Massive quantities of data are mined looking for “suspicious” activity.
- Learning and reasoning techniques are applied to these data to draw conclusions.
- Given an important conclusion (e.g., Al Qaeda is planning an event for tomorrow):
  - We would like to understand the chain of sources we used to draw that conclusion.
  - Based on those sources, we may weight the conclusion appropriately.
Provenance in Archival

• Archivists are concerned with preserving documents and providing proof of authenticity.

• Document provenance includes a record of
  – All changes in “ownership” of the document
  – Any format conversions
  – The “copy” number
Provenance in Science

• Provenance provides reproducibility and/or validation.

• Given a data set, provenance includes:
  – Input data
  – Unique identification of the software/experiment that produced the data
  – Complete description of the environment in which the experiment was run (e.g., OS, compiler, CPU, etc).
Our Definition of Provenance

- Attribute-value pairs.
- Some attributes are standard (OS, CPU)
- Some attributes are application-specific (e.g., a particular experiment has a value for nParticles)
- Some attributes may be domain-specific (e.g., all LHC experiments have a particle type)
- Attribute set must be extensible
The State of Provenance Today

- Most provenance is entered manually.
- Provenance is a parallel, but separate data set from the actual data.
- In many fields, provenance is simply lacking.

There must be a better way!
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Provenance-Aware Storage Systems (PASS)

• Storage systems (e.g., file systems) in which provenance is a first class object (meta-data).
• Provenance is the single, unique name of an object (other, human-friendly names are simply a convenience).
• Provenance is generated and maintained as automatically as possible.
• Support for rich indexing of provenance.
First Class Object

• Maintained by the file system.
• Kept consistent with the data itself.
• Maintain provenance relationships in the face of deletes, for example:
  – Data set A is used to produce data set B
  – Data set B is used to produce data set C
  – Delete data set B; need to make sure that you can still find the complete provenance of C
Provenance and Naming

• If two data sets are produced using identical inputs and identical processing, the resulting output should be identical.
  – If identical provenance yields different data, then the provenance is not complete.

• Provenance is a way of uniquely identifying an object.

• We should think of provenance as the real name of objects, and provide other user-defined names as convenience.
Automatic Provenance Generation

- Consider processes where all input comes from objects that reside in a PASS.
- With no human intervention, it is possible to automatically construct the provenance for any objects produced/created.
  - Removes any source of inconsistency
  - Guarantees that all objects are “provenanced”
- Still need a solution for “new data.”
  - What is provenance of a file into which you type?
  - What is the provenance of file generated by a measurement device?
Index and Query

• Users will want to query on provenance
  – Show me everything derived from my file
  – Show me everything upon which I depend
• Provenance schema is not fixed
  – My experiment will have different parameters from yours; parameters are part of the provenance of the result.
• This is the intersection of databases and file systems.
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The PASS Agenda

- PASS-I: Integrate provenance with the file system.
- PASS-II: Automatically generate and maintain provenance on a local system.
- PASS-III: Automatically generate and maintain provenance in a network file system or other distributed environment.
PASS-I

- Implement provenance as extended attributes (EA).
- Construct index across all EA.
- Implementation strategy:
  - Build on kbdbfs: in-kernel database implemented at SUNY Stonybrook (Zadok et al).
  - Use transactions to maintain consistency between provenance and data.
  - Should we be looking at LDAP or other non-relational engines for our schema?
PASS-I: Open Questions

• When is provenance created?
• Does provenance change?
  – Can users add to provenance?
  – Is all meta-data provenance?
• How do you index provenance?
• What is the right query interface?
PASS-II

• Modify the OS to construct provenance on-the-fly based upon:
  – Provenance of input data sets
  – Provenance of the software
  – System configuration and environment parameters

• When the output is complete, the provenance should be complete.

• Not a complete solution.
PASS-II: Open Questions

• How do you generate provenance for “new” data?
  – Manual entry.
  – Semi-automated: provide provenance parsing for some data types (e.g., parameter input files).

• How do you maintain the provenance in the face of deletion?

• How do you avoid cycles in the provenance graphs?

• How do you keep the provenance for a particular item from getting unwieldy?
PASS-III

• PASS-II is possible because the system controls access to the store; in PASS-III, that is no longer true.
• Define a PA-Protocol.
• PAP functions much like PASS-II, but the wire protocol encapsulates known provenance on file create.
  – Must support equivalent of setattr as running process encounters additional provenance.
PASS-III: Questions

• How do we guarantee maintenance of provenance over the wire?
• Do we need a new protocol or can we co-opt an existing one?
• If we develop a new protocol, how do we encourage adoption?
PASS-IV

• This is distributed PASS.
• The challenge is to build a global index across a collection of PEER PASS boxes.
  – Centralization seems dumb, but …
  – It works for Google
• We are still struggling with feasible strategies in this space.
PASS-IV: Questions

• Can you do better than Google?
• How do you evaluate a system?
• Can you do distributed queries without agreement on provenance attributes?
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• The “Provenance Problem” arises in many domains.
• There is sufficient commonality among the domains that we should be building a common infrastructure on which to develop domain-specific approaches.
• We see a pretty clear path to PASS-I, II, III.
• Building this will be fun!
Why am I here?

• I believe that provenance is the next “big thing” in storage systems.
• Ten years from now, PASS will be as ubiquitous as RAID is today.
• Come collaborate with us.