Security of Shared Data in Large Systems

Arnon Rosenthal
Marianne Winslett

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Agenda

• Introduction
  – History, and an attempt to diagnose what inhibited technology transfer
  – Challenge problems appetizer
• Security basics
• State of the art and open problems
• Policies as a unifying framework
• Security issues and opportunities in example application areas

This tutorial is unusual

We want to help researchers move into this area, and produce results with broad impact
• Most tutorials teach you about the state of the art
• We emphasize open problems (research+ practical steps)
  – Securing large systems and large information structures
    (databases, middleware objects, document bases)
    • From n-tier to emerging
  – Security problems where data management skills are helpful
  – General DB problems whose solutions
    • help us improve security
    • can benefit from security techniques
• We select problems for
  – leverage with previous DB research and skills
  – benefit to the most widespread DB applications
What’s been added to DBMS security since 1980s

- Roles, role hierarchies
  - SQL role is a set of privileges or users
  - But industry did roles, DB researchers arrived after
- Receive “identity” information from middleware or OS
  - But can’t use it in a view definition
- Filter query response based on row or column security labels (described later)
- Security for new features added to SQL
  - Triggers, nested tables, objects, procedures
  - Security features are tightly coupled to data model

Which additions owed a debt to data security researchers?

Why were we unable to help vendors (enterprises) improve this (now-critical) aspect?

- Vendors’ interest in security was mild (but nonzero)
- Too few ideas were worth transferring --- why?
  - Do we respect the concerns of DBMS and tool vendors?
    - Few fundamental constructs
    - Few tricky feature interactions
    - Compatibility with the past
    - Manageable size for each extension

Wrong problems

- Inelegant – unlikely to yield clear insights that may be useful in other situations
- Unrealistic: fail the “giggle test”, even long term
  - Without laughing, describe a full scenario where customers might pay — buy the software, capture system descriptions, specify policies, …
- Too many preconditions that are difficult to meet
  - Distributed DB security: relied on Deny to override Grant
  - Prevent an adversary from inferring info they cannot access: Enterprise must first protect individual columns! Also, document what an adversary knows, forbid anonymous access, be able to query past accesses.
Right problems, wrong proposals

Results were unready to transfer to developers

• Non-modular
  − Reinvents non-security functionality, e.g., new query optimizers, temporal and spatial datatypes
  − Need several difficult features at once (distribution, negatives)

• Useful functionality, but administration did not scale

• Semantics were filled with special cases (e.g., Deny)

• Features not reconciled with full SQL
  − Often created for middleware policy engines
  − Unknown interactions with view and metadata security, trigger semantics, …

Excellent problems for a beginning researcher

Three “big” research challenges to whet your appetite

• Allow one DBMS to support multiple security models

• Compile high level policies down to executable mechanisms

• Rewrite another system’s policy in your own terms

1. How can one DBMS best support multiple security models?

DBMS Security

SQL security model  XML sec. model  RDF sec. model  OWL sec. model

How can security model be orthogonal to data model?
Security policy chaos in today’s n-tier systems

Application Server
(e.g., WebSphere, WebLogic)

Authenticate

Product

Order

Buy
Sell
Ship
Bill

Databases (tables/docs)

View/Proc

2. Compile “business” policies to physical implementation

Individually identified medical data shall be available only to professionals treating the patient, with medium-high confidence.

Install policies on tables, documents

Suitable
• data allocation
• execution plan

3. Translate, transfer policy across organization and system boundaries

Aetna Travel Insurance
Enforcement: Application server
Policy applied: US (NY)
Roles: HIPAA (Aetna version)

Paris Hospital
Enforcement: DBMS
Policy applied: France
Roles: Hospital (Emergency Care)
Common themes to these and other research challenges

• Reduce workload and skill to administer policies
• Cope with heterogeneity
  – In security info (formalisms, role sets, policies)
  – In data (data model, schema, instances, semantics)
• Compare desired policy and actual result
• Trust in partners for policy specification and/or enforcement
• Cope with distribution, autonomy, evolution, but exploit favorable simpler cases

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  – Getting there
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security basics

Confidentiality

• Prevent information from going to the wrong recipient
• Not synonymous with privacy
“Privacy-preserving X” harmfully blurs a useful distinction

Inhibits communication with conventional systems, privacy advocates

- Confidential info sharing (non-disclosure) is useful for proprietary info, with no privacy issues
- Privacy advocates include many other measures in their policy – e.g., must notify

security basics

Integrity

- Ensuring data is right
- Definitions of “right” in different communities:
  System Security: Not changed inappropriately
  - E.g., tamper-evident signed message digests
  IT Security: Produced appropriately [Biba, Clark-Wilson]
  IT: Data quality (freshness, precision, provenance, …)
  DB: Satisfies all relevant constraints
  - E.g., ACID transactions, key constraints

- Related issue: trust
- Too rarely all considered together

security basics

Trust & data provenance

- Trust: willingness to rely on an entity for a particular purpose
  - Hot topic in open systems
- Trust in data depends on its integrity, freshness, accuracy, provenance, its source’s reputation and objective properties, etc.
  - Data provenance is a hot issue for scientists and intelligence analysts
- How can we integrate these concepts to specify and reason about the level of trust in a data item?
  - Particularly interesting in the context of derived data and in information integration
security basics

Authorization

• Can this party do this action on this object
  – Should there be a side effect (e.g., audit log entry, email notification, …)
• Some approaches to authorization policies
  – Unix file system
  – Role-based access control
  – Attribute-based access control
  – Security levels

security basics

Intellectual property issues

• Easy case: recipient cooperates, e.g., between government agencies
  – Pass policy to recipient, in terms of objects the recipient understands
  – IBM, others work on sticky policies
• Tough case: adversary owns the machine
  – Not necessarily about secrecy
  – Goal: cradle-to-grave control over access
  \textit{Not addressed in this tutorial}

security basics

Confidence

• Likelihood that desired security properties hold
  – Relative to a threat model
• Some practices to judge confidence, and use it:
  – Certify: reviewer announces their confidence in a description of system behavior
  – Accredit: executive decides that benefits exceed the risks
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**Security basics**

**Access control and release**

- **Access control policy** governs pull situations
  - Bob wants to do an action on Alice’s object; will Alice let him?
- **Release policy** governs push situations
  - Assuming Alice has read an object, can she send Bob a copy?
  - Used in government, and for proprietary info (mostly for read-only objects)
- Not independent:
  Bob can Access $\implies$ Alice can Release to Bob

**Delegation**

- Your declaration of when another party will be speaking for you / acting for you
- Most often: one party grants a right to another party
  - E.g., to perform a specific kind of action on a specific object
- **Examples**
  - SQL “with grant option”: unconditional delegation
  - Verisign delegates right to create identity credentials
  - Trust management languages offer conditional delegation
    Authorize(Arnie, Purchase) := Authorize(Marianne, Purchase), Purchase.Amt < $100
Enforcement, credentials

- Enforcement approaches
  - Server routes all requests through a "reference monitor" (DBMS, application server, OS)
  - Check when a boundary is crossed (usually physical): firewalls, gateways
    - Can be very small server, hardware assisted, with high confidence for simple policies (e.g., filter for forbidden words, XML filtering)
- Credentials approaches
  - Server holds them and checks (e.g., DBMS authorization)
  - Mobile (single sign-on, trust management)

How to decide if you’re “there”

1. Where is “there”?
   - Decide what actions/states wrt your data are legitimate/forbidden (create your policies)
   - Determine the likely threats
2. Pick/develop technology to mitigate the risks to acceptable levels
   - Consider implementation constructs’ resistance to known threats (e.g., data partitioning in case of machine takeover)
   - Do a cost/benefit analysis
3. Evaluate your proposed technology as follows

Evaluation criteria (for both researchers and developers), 1

- Passes the giggle test (on cost/benefit)
- Usable
  - No CS degree should be required of users or administrators
- Cheap enough
  - Development effort, learning curve, admin
- Scalable
  - To large numbers of objects, subobjects, actions, subjects, organizations, sites
- Analyzable
  - Current state: what a given subject/object can do/have done to it
  - What-if queries: determine effect of changes in advance
Evaluation criteria, 2

- Flexible, extensible
  - Rapid response to unanticipated emergencies, opportunities
- Modular/universal/orthogonal/composable/compatible
  - Applicable in many places, many futures
  - Can others build on your solution (clean, high quality)?
- Rigorous (thorough)
  - Behavior of foundational components should be fully captured by the model—hard to anticipate future uses
  - If implementations leak info (e.g., about "secret" view definition), bring into the model by requiring release privilege

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- State of the art and open problems
  - Problem context (a reality check)
  - SQL
  - Privilege limitation
  - Role-Based & Attribute-Based Access Control (RBAC, ABAC)
  - Label-based access control
- Policies as a unifying framework
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A common architecture: each DB object belongs to ~one server
Policy administration in enterprises

- DBs are not the center of the policy admin universe
  - Few researchers at the Access Control conference (SACMAT04) really knew the SQL security model
- A policy must be conceptually near the resources it controls
  - Middleware knows application methods, e.g., Admit(Patient)
  - DBMS is smart, fast with structured info, consistent when there are multiple paths to same datum
- Database security administration is often ignored
  - 30% assign privileges to real users or roles, mostly to entire tables
  - 70% use DBMS security only to restrict each table to one app
- Consider nontechnical fixes: Packaged applications may move to a built-in security policy

Scale

- SAP has 10^4 tables, GTE over 10^5 attributes
- A brokerage house has 80,000 applications, a US government entity thinks that it has 350K
- Admin and implementation require
  - Automated help
  - Massive delegation (within limits)
- Our advice
  - Start with broad, general security policy statements
  - Refine under pressure
  - Beware: in formal acquisitions, contractors often build to the letter of specifications, not the spirit

Policy administration in enterprises

- DBAs are considered untrustworthy (too casual) to be given superuser-type powers
  - But they still have complete privileges
  - Thus: extra layer, controlled by security officers, to limit/audit DBAs
- Administrators need training in both technology and judgment – making evolution costly and slow. Simplify!
- Single sign-on is typically the top priority, rather than policy specification
Management of security data

- We collect lots of security-related data
  - Audit trails, surveillance video/camera, RFIDs, GPS, cell phones, electronic lock records, etc.
- How can we analyze it and assess its quality in a scalable manner?
  - Relevant research: mining patterns of normal/anomalous operation, metadata management, protection against alteration, privacy issues
  - Not discussed much in this tutorial

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SQL security model overview

- Privileges on data objects (tables, columns), schema objects, stored procedures, triggers, more in the future
  
  grant <list of operations>
  in <list of objects>
  to <list of identities>
  [with grant option] /* right to delegate */

- A privilege must be supported by a chain from owner
  - When grantor loses rights, revoke cascades. So DBA grants all?
- Object creator is "owner", with full privileges
  - Ownership cannot be transferred
- Schema is visible iff user has some rights on the object
  - View/procedure definitions only for the owner

Models for distributed trust, label security, XML security diverge from these design choices
SQL lacks many essentials

Some (neatly bounded) extensions needed by SQL2003, RDBMSs, and many other data/query models

- Manage security for a distributed relational database (Issues: double admin for views (even synonyms); local autonomy)
- Infer a user’s right to view a subset of the data, transparent to application writers (views are not)
  - Without changing query semantics
- Guarantee that administrators do not delegate excessive privileges
- Decentralize power appropriately (ownership, DBA roles)
- Abstract and modularize the specification of the standard, so it can be extended safely and easily

Build grad students’ muscles

Rework “ownership”

- Owner of container currently gets full rights to the contents!
  - Owner’s real contribution was metadata and creating a container, not data content
  - So why should they have full privileges?
- Upon creation, transfer creator’s content and metadata privileges to “domain” administrators
- Allow any user (including owner) to “move” their rights to someone else
  - Avoid cascading revoke
  - Allow recipient to gain sole ownership

Build grad students’ muscles

Control metadata visibility

Select GoodCredit from Customer where scoringFunction(ZipCode, Age) > 6789

- Devise a suitable model for metadata protection
  - Publish or protect business process info in view definitions
  - Controlled browsing of catalogs by users who lack access to underlying data

- Requirements for the solution
  - Minimize admin work
  - Retain privileges that users have already granted
  - Avoid loose ends (e.g., who may use each m’data item to enforce a constraint or rewrite a queries)
Privileges on views and procedures (i.e., derived objects)

- Principle: Infer a privilege when you detect that it does not increase user's power
  - Interacts with metadata, distribution, ownership, ...
- Implement privilege inference efficiently
  - Adapt the query optimizer to generate equivalent forms
  - Detect equivalences that hold in the current db instance [Rizvi et. al. 04]
- Handle federation and warehouse (materialized) views, with minimum new semantics and mechanism
  - Autonomy: control over security stops at organizational boundaries.
  - Negative privileges are a big, controversial add-on

Often a query will not be answerable from user-visible info. (This is a general problem in publish/subscribe)
- Suggest an alternative query that the user can execute, and explain how it differs from what they requested

Build grad students’ muscles

Abstract models for SQL

- Help restate the standard (+ vendor products), in a way that enables easier extension, integration
  - Describe query/update execution semantics in a way that shows what operations may be executed [Rubolce]
  - Use it to explain needed privileges
  - Rewrite statements on views as SQL statements on underlying tables
  - Use abstract concepts, e.g., contains, is-a, derived object (perhaps from object models)
  - Compare with constructs in other models

SQL view privilege =
the right to use the view interface

Grant Read on Patient to Doctors
Grant Read on AdultPatient to Researcher
Kinds of privilege limitations

- Revoke: an extreme case of privilege limitation?
- Local Deny (w.r.t. a given grant): Equivalent to imposing a predicate restricting use of the privilege [Robbio00, Sadhigi03]
- Global “Deny” (asserted/revoked as grants), sometimes with predicates, overrides [many, e.g., Jonscher, Jajodia, Bertino, ...]
  - Violates delegated administration?
  - Can administrator understand the state?
- Privilege factors: separate concerns among collaborating administrators (Semi-static, organization-friendly)
  - Attach predicates to privileges (or denials)

Help administrators collaborate: Decompose privileges

Get an attribute if all children are satisfied or by direct assertion
Simpler decisions, single skill, independently administered
Changes easily: When situation changes, review just that part
Safety fence provides guarantees

Denial versus safety fences

- Compare pragmatics of denial-based approach and “safety fence” factors
  - Reformulate as a trust management problem, with factors as predefined attribute types
- Meta-problem: Define and apply criteria for comparing proposed facilities “simplicity”
  - Ease of administration (learning curve & admin effort at small/large scales)
  - Expressiveness and flexibility (saturing the needs)
  - Ease of implementation by vendors, in various architectures (e.g., policy mgmt system downloads grants to DBMS)
  - Efficient implementation
- Implement the best admin models (once known)
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Group/role graph

- Reduces admin labor
- Decentralizes admin

How far can this “graph” visualization go?
- Grants that require multiple authorizations
- Communities of mutual trust

Two guidelines for thinking about RBAC

- Security policy is hard, inevitably a tradeoff.
  - Minimize the need to make it!
  - Treat each group, each role as just a definition
  - Create a clear membership criterion for new arrivals, suited to routine
  - Now, authorizing a group for a role is the only real security decision
- The distinction between groups and roles is essential for admin, minor for enforcement
  - Debates are confusing, because both sides are right
RBAC is not sufficient

Groups
- Technical
  - EE
  - CS
  - QA
- Manager
  - Dept Mgr
  - Task Mgr

Roles
- Project Planning
  - Costing
  - Staffing
- Assign Work
- Read Skills

Policies can involve many other hierarchies

Vehicle
- Car
- Truck

Device

Session Security

Approvers

Attribute Based Access Control

- RBAC extensions are awkward
  - Unnecessarily asymmetric: Task Mgr in CS Department—which is the group?
  - Several attributes can have hierarchy
    - “Parameterized roles” bring in additional attributes, and allow predicates over all. But only one attribute can be hierarchical “Role”
  - Some attributes are not role-like (e.g., user location) or not associated with the user (e.g., time of request submission)

- Attribute-based access control: policy can be any predicate over any attributes
  - E.g., roles, groups, where/when submitted, alert-level, approvals...

- Beyond IS-A: Derive attributes from other attributes
  - Derive using logic? SQL? Arbitrary functions?
Unify reasoning about semantic aggregates (i.e., support “is-a” just once)

Intelligence about usage of hostile air defense facilities can be analyzed by operational planners with secure access.

Research issues for RBAC and ABAC

• Role engineering: How should an organization select groups and roles? (determine appropriate clusters)
  – Mine the existing workload, to suggest “good” roles, groups, and privilege assignments
• Policy admin: Which groups should get which roles (generalizes “Which users should get which privileges?”)
  – Infer logically, mine similar workloads to reduce effort
• Elegant models needed!
  – Provide clear criteria to explain why a model is good
    • E.g., be minimal, formalized enough to be analyzable
  – New feature = New paper? More is better? No!
• Issues from earlier sections still apply: Ownership, privilege limitation, use of ontologies in policy specification, ...

Supporting technologies for ABAC

• Standards
  – Pass attribute assertions (SAML)
    • E.g., Ed@bc.edu says Patient.BirthYear = 1984
  – For each action, attach predicates that reference attributes
    • Four valued propositional logic expressions
    • Connect actions to policies (with conflict resolution)
• Semantic web (OWL) or logic (many Datalog dialects) for reasoning about hierarchies, restriction predicates, derivations
• Federated data perspective needed to get attributes to evaluators
  – CORBA specified a standard way to pull an attribute from a particular server
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Mandatory versus discretionary security

- Discretionary: owner and owner’s delegates can change the access rights
  - Although controls over arbitrary delegation can be useful, to limit eventual spread of rights
- Mandatory: A party possessing an object cannot
  - Release it to arbitrary others
  - Change the policy
- Policy is often inherent in object label
  - E.g., Top Secret, Proprietary

A mandatory policy: multi-level secure databases (MLS)

- Read allowed if dominated: SessionLabel ≥ ObjectLabel
  (e.g., suppose Proprietary > Public)

<table>
<thead>
<tr>
<th></th>
<th>Public</th>
<th>Proprietary</th>
<th>aNewDrug</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public</td>
<td>.1</td>
<td>.5</td>
<td>.23</td>
</tr>
<tr>
<td>Proprietary</td>
<td>.6</td>
<td>.9</td>
<td>.85</td>
</tr>
<tr>
<td>aNewDrug</td>
<td>.6</td>
<td>.9</td>
<td>.85</td>
</tr>
</tbody>
</table>

- “High” session cannot put data where “low” sessions can read it
  - Write allowed if ObjectLabel ≥ SessionLabel

- Prevents inadvertent mistakes by programmers
  - Inadvertent writes without needed labels
  - Enforces hierarchical rules even if administrator is careless
  - Protect against malicious user or Trojan Horse – no info “leak” (?)
- For high confidence, must also restrict export from user program
Market drivers for commercial label-based access control

- Application hosting and outsourcing
  - Independent franchises share a single table at headquarters (e.g., Holiday Inn)
  - Application runs under requester’s label, cannot see other labels
  - Headquarters runs Read queries over them
- Proprietary data consolidated from many sources
  - E.g., at a government agency or system integration contractor
- Individuals’ privacy preferences?

Commercial label security

Guarantees that application requests are directed to a parameterized view (and handles the parameters)

- Runs in normal environment
- Policy applies to operations on policy-governed tables
  - Conjunction with ordinary SQL security
  - Finer grained than table privileges
  - Transparent to user code, but changes semantics
- Is easily turned off – everything is optional, controllable
- Programs can write files, send email, … since OS is not MLS

Oracle’s label security

- SessionLabel, ObjectLabel are tuples of atoms, e.g., (Secret, Manager, (heart, blood)) [see Oracle website]
  - Ordered slots: (Unclassified, …, Secret, Top Secret)
  - Group slots (management hierarchy, projects, …)
  - Unordered slots (compartments)
- Implementation: system creates, manages views (Read) and Instead-Of triggers (Write)
  - Admin declares a table as labeled (system adds “label” column)
  - System generates labels on insert
  - System rewrites user's action, to apply only to the view
  - For performance, tweaked the query optimizer
  - Semantics: “Return filtered result”, not “reject”
Research issues in label security

- Support both filter and reject semantics?
- Manage "structured", audited exceptions (downgrading)
  - Use SQL grant option for exception?
  - Integrate access controls with audit?
- Indexing and query opt. for row, column, cell labels
  - Too slow to first filter, then merge
  - Oracle labels were too slow until query processor was tweaked
- Allocate (partition) data to provide sufficient confidence
  - Precategorize potential implementations w.r.t. how much "confidence" they give
  - Partition data among rows, tables, DBMSs, machines, networks

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What is a policy?

- A statement regarding who/what is allowed/required/forbidden to take what actions, when and where, with respect to whom/what objects
  - May also describe what happens after the action is taken, or if the policy is not followed
  - May be stated in terms of abstract security properties such as availability, privacy, etc.
- A consistent set of assertions a system view must satisfy
  - System view may be partial, include history, and future (obligations)
  - Constraints, obligations are nondeterministic policies
Example policies for access control, authentication, info release

- EMTs can access blood type info in the ambulance
- Every patient can read their own medical record
- Physicians have dial-up access to medical records
- Nurses cannot examine billing information
- Hospital administrative staff can modify policies
- Purchase transactions over $1000 require 2 forms of authentication (retina scan, employee ID, passport)

- Asserted behavior can depend on many attributes
  - User, operation, role, object type, object attributes, where submitted, when submitted, + trust
  - Policy’s action may include "reject", filtering, notification, penalty,

- Policies are requirements, and have the whole gamut of software engineering issues (details later)

Security policy chaos in today’s n-tier systems

Gather into policy space: one server
Where are policies captured and enforced today?

• They tend to stay in one place
  – Captured for a database, app server, or policy server, in terms of objects that server knows
  – Delegation is checked there
  – Entire policy is enforced there

• Desired scenarios
  – Capture in server, enforce redundantly in client GUI (better interactive behavior)
  – Capture at one server, but delegate enforcement to elsewhere
  – Split enforcement into several parts
    • E.g., evaluate SecureChannel attribute, evaluate UserAuth, and conjoin to determine RequestAuth

Abstraction in policies aids decentralized security admin

• Subjects
  – Residents of California over 21 years of age
  – Parents and legal guardians of children enrolled in King School
  – Purchasing agents of the University of Illinois

• Objects
  – Anything containing the SSN "123456789"
  – Anything about underground democracy movements in country xyz
  – Any file in any subdirectory of this directory

• Actions
  – Sending email, FTP, GET/POST requests, IP packet transmission, queries, invoking a method,
  – "Push" systems: release control policy for object to be pushed to subject (see next slide)
  – Actions triggered by the user request (including actions of the security system itself)

ABAC had just IS-A hierarchies, but much more is needed

How can we provide a good formalism for deriving abstractions?

Making policies more abstract

• Describe policies
  – At all levels of a system
  – For all kinds of subjects, objects, and actions
    • At least DBs, formatted messages, service calls, general documents
    – From administrative and implementation viewpoints
  – Specify each of subject/object/action declaratively (e.g., queries, views, datalog, OWL) rather than by enumeration

• More detail in trust management section
• Hot in AI community for semantic web
Example policy in Cassandra

Treating-clinician reads patient’s record item

\[
\text{permit} (\text{cli}, \text{Read-record-item}(\text{pat}, \text{id})) \leftarrow
\text{hasActivated} (\text{cli}, \text{Clinician} (\text{org}, \text{spcty})),
\text{count-access-denied-by-patient} (\text{pat}, \text{id}), \text{canActivate} (\text{cli}, \text{Treating-clinician} (\text{pat}, \text{org}, \text{spcty})),
\text{count-access-denied-by-patient} (\text{org}, \text{cli}, \text{spcty}),
\text{Get-EHR-item-subjects} (\text{pat}, \text{id}) \subseteq \text{Permitted-subjects} (\text{spcty})
\]

Prerequisite for Treating-clinician

\[
\text{canActivate} (\text{cli}, \text{Treating-clinician} (\text{pat}, \text{org}, \text{spcty})) \leftarrow
\text{org}.\text{canActivate} (\text{cli}, \text{Group-treating-clinician} (\text{pat}, \text{group}, \text{spcty})),
\text{org}.\text{ra}.\text{hasActivated} (x, \text{NHS-health-org-cred} (\text{org}, \text{start}, \text{end})),
\text{ra} \in \text{NHS-registration-authorities}()
\]

Current-time \( t \in [\text{start}, \text{end}] \)

Source: http://www.cl.cam.ac.uk/users/mywyb2, encoding UK’s Electronic Health Record policies

ABAC+TM research issues

• TM policy languages are logic-based, not user friendly
  – Expression/reason about arbitrary relationships, e.g., delegation
  – TM style: “This attribute value has been asserted, and here’s why you should trust it”
    • Requires ability to formulate, reason about trust metrics
  – Classical style: RBAC, ABAC, privilege factors that are structured, updatable, visualizable
• Needed policy templates and methodologies for policy administration
  – Usable at enterprise, cross-enterprise levels
  – Appropriate expressiveness
    • Monitors privilege limitation constructs to guarantee what will never happen
    • Simple delegation models, with revocation
    • Privilege inference rules, integrated with data ontologies, rules, groups, derived data (views, procedures)

Policy analysis

• Administrator needs help to analyze policies
  – Show me all the policies that definitely/possibly apply in this situation
  – With the current set of delegations, are users of this type definitely (or possibly) able to perform this action?
    A killer app for logic databases? What logic? Datalog++ or OWL?
• Who can potentially obtain the right to perform this action (via delegation from untrusted users)?
  – Undecidable in traditional HRU model. Even simpler ones are NP-hard
  – Get user help with policy constructs that break the inference engine
• Metaquestion: can the underlying theory support convenient admin?
  – E.g., how does stratification (for clear semantics) affect admin?
New application domains that need security policy services

- Pervasive computing
- Sensor, mobile, wireless, and ad-hoc networks
- Semantic web, peer-to-peer systems, grid computing

Security and privacy for these applications are open areas for research

Arnie’s rebuttal: “Build a new world of your own design” problems are for wimps. For a big challenge:

Security research that simplifies multi-purpose enterprise systems
- Interaction of many technologies, policies, requirements
- Existing systems and languages
- Precise semantics

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  - Trust management in open systems
    - Trust middleware
  - Open problems
  - DB capabilities for data that really needs to be secure
  - Semantic web and XML
  - Enterprise security

Motivation: move toward open computing systems

Open = resources shared across organizational boundaries

Ability to rapidly form relationships, cooperate to solve urgent problems is vital
- Requires unanticipated sharing
- Supply chain management, crisis response, peer-to-peer computing, semantic web, grid computing, cross-national military activities, joint corporate ventures
Current DB app trust middleware is awkward in open systems

- Management headaches
  - No abstraction at user (subject) level
    - E.g., clothing vendor has to set up a separate login for each Walmart authorized purchaser
  - Managing passwords is #1 help desk call
  - High turnover in suppliers/users/customers
    - What happens when an authorized purchaser is fired?
- Error handling may be opaque

What’s missing

- Traditional security describes monolithic building blocks
  - Does not help in attaching separate blocks together to build a global perspective in distributed situations
- Distributed trust management, an emerging technology,
  - Gives a box of Legos™ and a language (usually Datalog + constraints) for connecting building blocks together

Key goals of work on supporting modular, distributed, decentralized trust management:
  - Make it easy to use and administer
  - Provide improved security and privacy
  - Make it ubiquitous
    - Facilities available to all types of parties
    - Wherever they are, whatever they might be doing

Ingredients for generalized trust middleware, 1

- Credentials, so subjects can prove what attributes they possess
  - Verifiable, unforgeable
  - Provide way to prove ownership or delegation of authority to use
- Party receiving a credential
  - Read and interpret fields (ontologies)
  - Verify ownership
- X.509, PKI and beyond
Ingredients for generalized trust middleware, 2

- Policy, e.g., for acceptable credit cards for purchases:
  - Acceptable issuers (VISA, MasterCard)
  - Require ownership/delegation to be demonstrated
  - Check for expiration
  - Contact card issuer
    - Revocation, credit limit
  - More generally, an access control policy (and possibly other policies) for every resource that a stranger might be allowed to access

Ingredients for generalized trust middleware, 3

- Ability to export policies (to be read elsewhere, enforced elsewhere)
  - A stranger may need to understand them to gain access to my resources
  - E.g., which credit cards does this merchant accept? What will I require from the merchant?
- Trust negotiation software to control the process of gaining trust

Example use of trust negotiation middleware in e-commerce

Step 1: Alice requests a service from Bob
Step 2: Bob disclosures his policy for the service
Step 3: Alice disclosures her policy for her VISA card credential
Step 4: Bob discloses his BBB credential
Step 5: Alice discloses her VISA card credential
Step 6: Bob grants access to the service
SMTP-based trust middleware for release policies

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Policy, credential capture and interpretation

- Expressive policy languages (details follow)
- Administrative tools and algorithms
  - Write, update, understand, and analyze (details follow) policies
- Standard schemas/ontologies for popular types of credentials and policies
- Efficient policy compliance checkers
- First-class policies
  - Search them, query them, ...
  - Give them protection as strong as for any other resource
- Policy integration, translation, compilation (details follow)
- Verification of approaches to all the above in the context of particular applications
Needed policy language features for trust negotiation

- Well-defined semantics
- Monotonicity (sort of)
- Everything relational algebra can do, plus transitive closure
- Support for delegation
- Clean integration with reputation-based trust systems
- References to the local environment and external functions (e.g., time of day, current user)
- Explicit specification of authentication requirements
- Tractable for analysis

Datalog + constraints [Cassandra, RT], OWL (for its ontologies) are viewed as likely policy language choices in various research communities

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Monotonicity and outcalls

Purely monotonic languages are not expressive enough for trust negotiation
- Do not want customer’s withholding of a credential to increase their privileges
- But need elegant handling of time, revocation checks, …
- Anything less than Turing-complete will require outcalls (but must bound them, as analysis capability is vital)

For realism, language design needs to be application driven

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Trust middleware architectures

- Trusted third parties that are not vulnerable to attack
- Direct peer-to-peer
  - With disclosure of credentials/policies
  - Zero knowledge/hidden credentials/OSBE
Obtaining and storing credentials

• How do I get them?
• Where do I keep them, to keep them private?
• How can I quickly find credentials I haven’t cached already, during a negotiation?
  – Credential chain discovery, n-party trust negotiation, push/pull paradigms, federated DBs, …
• Efficient ways to deal with revocation
  – Get rid of revocation, don’t check for revocation, check quickly, …

Scalability and deployment

• Good implementations of trust management facilities
  – Modular, scalable, reusable
  – Support ubiquitous trust negotiation
• Deployment of trust negotiation
  – In today’s popular communication and query/response protocols (SOAP, IPsec, TLS, etc.)
  – Backward compatible

Vulnerabilities

• What kinds of attacks is trust negotiation vulnerable to?
• How can we mitigate the danger?
• What parts of the process/system must be trusted, and to what degree?
• What integrity/privacy/confidentiality/… guarantees can we give?
Confidentiality guarantees

• Can outsiders eavesdrop on negotiations?
• Can I disclose just part of a credential?
• Can there be a concept of “need to know”?
  – Can its administration scale?
• What can be inferred about my credentials without my directly disclosing them?
  – Fix by adding release privileges for “leaked” info?

Managing multiple identities

• Support for many identities has many benefits for issuers and owners, today and in the future
• How to prove I possess several identities, while preventing or penalizing collusion?
• How to make my identities unlinkable?

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    – ABAC as a DB application
    – Data mgt challenges for security-critical data
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ABAC as a data intensive app:
How policies get attributes today

ABAC policy evaluation as an ordinary data intensive application

• We need to apply federated DB technology to security systems to manage:
  – Semantics: what do attributes mean?
    • Managing definitions and doing semantic integration (e.g., via communities of interest?)
  – Locating attributes: held in directories, DBs, services
  – Trust: why should I believe the attribute?
    • Integrate delegation, data quality, provenance, source selection…
• Metadata and policies need access controls too
  – Need fine grained protection!
Hardening a DBMS-based system against malice

- Secrecy, correctness are crucial in many data-intensive applications
  - Finance, medicine, military operations, control systems (chemical, nuclear, aircraft, …)
  - Security (user and other attributes)
- DBMSs are used in such environments (less for security), but … how to mitigate malice?
  - Example vulnerabilities:
    - Accessible from the Internet
    - Multiple classification levels on same system
    - Competitors on same system, e.g., Ford user reads Gen. Motors data
  - Help design physical separation

Approaches based on physical separation

- Harden the system against attack, e.g., “Appliance” offering few services, no end user access
- Physically separate sensitive data from users who may attack it

Methodologies are ad hoc, seem to have no tools
Approaches based on physical separation

- Harden the system against attack, e.g., "Appliance" offering few services, no end user access
- Physically separate sensitive data from users who may attack it
  
  Methodologies are ad hoc, seem to have no tools

Data intensive applications and security/correctness

Target systems: DBMSs, middleware, document managers

- Create models and tools to
  - Calculate attack resistance of a particular design, from a given threat
  - Allocate data automatically (extend autonomic admin)
  - Adjust query processing techniques
- Integrate data quality, provenance and transitive trust (for both "normal" and secure applications)

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XML security directions: examples

- Use XML as a language syntax for any sort of language, to make it tool-friendly
  - For security languages too: XACML for access policy on any resource
- There are standard ways to express security labels, now also in XML
  - "UltraProprietary, release to Drug_Trial(foo)"
  - "Secret, No Foreign except Canada"
- Many XML security issues also arose with object DBs
  - E.g., IS-A, part-of
  - Arise also with SQL’s object constructs

XML security research examples

- Several models to protect XML documents e.g., Bertino, Damiano
  - Factor the problem to exploit: X-languages, query processing, SQL security, temporal/spatial data types
- Policy partly at schema level, partly instance-specific
  - Accommodate nesting and other XML properties
- Efficient processing of schema-level labels
  - E.g., twig queries with MLS labels [Cho et al.]
    - Asking administrators to specify more goes against the trend toward zero-administration
    - Is MLS realistic there? DoD will not mix major levels on same system. What if labels are not totally ordered?
- Protect schema-less documents
  - Use IR to derive document attributes
Semantic web languages

- RDF and OWL are likely to become important, even if the ambitious vision remains elusive
  - RDF offers schema-less entry of individual facts, natural labeled “graph” structures
  - Resource is anything on the web
  - OWL adds inference
- There will be a niche for security models optimized for each of XML, RDF, OWL
  - But will they play well together? Will they require duplicate administration? Duplicate software?

Security for multi-model databases

- DBMSs are becoming dual personality
  - They see (+ store) the same data as relations or XML
  - Support SQL, XPath, XSL, XQuery, ...
  - But have separate security systems for each of these, plus RDF, OWL, etc.
- For vendors: Support SQL, XML, RDF, OWL security models on the same code base
- Avoid double administration, inconsistent policy, when crossing model boundaries
  - Translate policies across models
  - To provide consistency regardless of model used to access data
  - To apply policies consistently to subobjects/links
  - Double enforcement is often OK (e.g., at GUI and trusted)
How to support multiple security models?

A possible research approach

- Devise rich object metamodel and map it to SQL, XML
  - Identify common abstractions for models of
    - data (metadata, derived object, is-a, part-of, …)
    - security (delegation, revoke, limit privilege, session…)
  - Cover all objects that SQL protects
- Avoid gratuitous incompatibility with SQL
  - Where new applications really need more, generalize to apply to both models
- Specify and implement the delta, not separate systems

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    - From high level statement to implementation
    - Between organizations
what an enterprise needs:

Policy engineering environment

Reprise: Compile “business” policies to physical implementation

Individually identified medical data shall be available only to professionals treating the patient, with medium-high confidence.

Who are “professionals treating this patient”?

Confidence needed in:
- Technical measures
- Metadata admin
- Partners

Suitable
- Data allocation
- Execution plan

Install policies on tables, documents

Suitable
- Data allocation
- Execution plan

What data is “medical”, “individually identified”?

System m’data

Metadata, ontologies

Individually identified medical data shall be available only to professionals treating the patient, with medium-high confidence.
Subject/object/action each require own set of mappings

Policy written in terms of business model

- Info mapping
- User mapping
- System mapping

Substantive policy who can do what

Physical schemas

Info map M'data

User M'data

System M'data

Kinds of mappings needed

- Down: compile from policy specification to implementation
  - Up: Reverse engineer a rough high level policy from a detailed policy
- Analogy: derive ER schema from relational schema
- Down: allocate data and execution, for suitable confidence (next slide)
- Horizontal: translate policies between organizations, data models (later)

Giant Opportunity(?): Use same underlying theory and/or implementation for all?

Physical DB design problems

Physical design systems need to know about security req’s

- Organizations partition data to minimize the number of users “close” to sensitive info
  - Partition among machines, DBMSs (some not on internet), tables, tuples, … (increasingly easy to hack)
  - Which systems are trusted to filter what data in queries
  - Select appropriate communications (e.g., encrypt wireless)
  - Enhance data allocators, query planners to provide necessary confidence
- Index securely
  - Imagine the risk of having one file with a full text index for an entire intelligence agency
  - Encryption works in some cases. Will it make the system brittle?
  - How to partition indexes for security?
Reprise: Translate and transfer policy across organizations and systems

Aetna Travel Insurance
Enforcement: Application server
Policy applied: US (NY)
Roles: HiPAA spec (Aetna version)

Paris Hospital
Enforcement: DBMS
Policy applied: France
Roles: Hospital (Emergency Care)

What data is
• Medical
• Individually identified
Religion: required in US, forbidden in France

Who are
• Professionals
• Treating this patient
Insurance approver role only in US

Confidence in
• Technical measures
• Metadata admin
• Partners

Translate and transfer policy across organizations and systems

Aetna Travel Insurance
Enforcement: Application server
Policy applied: US (NY)
Roles: HiPAA spec (Aetna version)

Paris Hospital
Enforcement: DBMS
Policy applied: France
Roles: Hospital (Emergency Care)

Policy translation (horizontal mappings)

• Agencies won’t share unless they approve the partner’s protections. Each has its own policies
• How to enforce X’s policies in Y’s domain, overcoming differences in data and security?
  – Data: structures, query operators, instance identification [ss#, emp#], schema, ...
  – Security: model, policy language, policy implementations
• How to explain to X what Y is enforcing, and the difference?

Impression: 70% of semantic integration challenges have security analogs
  – Semantic integration seems to precede security integration
Policy integration challenges

Integration challenges: conventional semantic integration plus:
- Integrate role & group hierarchies
- Integrate policies
Consider OWL as a common formalism

Research areas applicable to mapping of security specs
- Semantic modeling
- Query processing for federated heterogeneous databases
  - Secrecy-friendly algorithms
- Automated physical design
- Model management theory [Bernstein]

Preventing disclosure during info integration: a contrarian view

Skeptical notes
- How often is such high confidence essential?
- Exact match rarely works for names!
- Do we want to treat these queries different from all others?

Unifying perspective (U. Maurer @ SIGMOD04)
- We can do it all with a “trusted subject” in the middle
  - Cryptography is one way to create a trusted subject.
  - Other techniques may be more flexible or efficient, but lower confidence, e.g., a trusted SQL DBMS appliance
- Start with the policy to be enforced:
  - What may be revealed to what system
  - Describe what they’re trusted to do, and how confident we’ll be
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• Summary

Summary advice, 1

• The big wins occur when tools drive the cost of something to zero (not 50%)
  – Compile specs (functional + implementation properties) to an implementation
  – Automate “where are we” and “what if” analyses
• Exploit common abstractions for multi-lingual security
  – Containment, IS-A, derived data, delegation
• Extend SQL smoothly -- do not be gratuitously different
  – Feature interactions, granularity differences appear when constructs are examined in full context

Summary advice, 2

• Security should not be a stovepipe
  – Reuse existing concepts from query languages/derived data/…, rather than reinventing them
  – Security components that can be reused (services, policies)
• Rich policies need rich runtime input
  – General data access and exchange services, federated DB capabilities will be needed at run time to feed into policy decisions
• Trust models are broadly relevant to data quality and suitability
Summary advice, 3

- Security system has high requirements for data integrity, availability, threat resistance
  - Could build DBMSs to treat these as “normal” requirements (i.e., to provide high integrity, availability, threat resistance)
- First define correctness criteria. Do algorithms afterward
  - e.g., for role hierarchy integration, privilege inference rules

Some relevant further reading

- Policies
  - IEEE Policy Conference
- Data security
  - Conferences: IFIP 11.3, ACM SACMAT
    - Modeling and analysis weak by SIGMOD standards
  - Journals: ACM TISSEC
  - Books: Castano et al. 1995, for earlier research
- General security
  - Textbooks: many choices
  - Conferences (systems-oriented): CCS, NDSS, Oakland
    - Mostly aim at securing systems and system access

What problems receive too much attention, in unreal settings?

Inference control (1990s)

- Limiting the ability of a party to use additional knowledge to figure out things that they have not been told explicitly
- Administration prerequisites are daunting
  - Need fine grained policies (e.g., columns, not tables)
  - Document adversary’s knowledge (logical and statistical)
- System prerequisites
  - Tracking requesters’ identity
  - Assuming requesters don’t collude
  - Keeping a history of all past requests and responses
Deserve lower priority, continued

- Conclusion re inference control:
  - Worth doing for carefully examined static publications (census bureau, health statistics)
  - For enterprise systems, it's like locking a 5th floor window
  - Research on inference control is unlikely to attract vendors, and hence will lack broad real-world impact

“Privacy-preserving” data mining
- The work to date looks costly, fragile
- Probably not a great place for a stampede of researchers unless more practical look is given
- Trusted third party appliances (stand-alone machine & software) could help