Formalizing and Refining Authorization in SQL

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Introduction

- Problems of current authorization semantics of SQL
  - too complex due to triggers, objects, and other features.
  - Numerous special cases and unnecessary restrictions.
  - DBA must cope with diverse user communities.

- Goal
  - Reduce the ad hoc nature of authorization semantics.
  - Introduce explicit, simple, and formal principles.
  - Formalization and simplification start from practice.

Formalizing authorization in SQL

- A database consists of a set of objects
  - Objects: schemas, base tables, views, columns and procedures.
  - Each object has a set of actions that can be performed on it; e.g., select, update, insert, delete and execute.
- Operation: (α, O)
  - Specifies a particular action α on a particular object O.
- ID (user): individuals, roles, groups, or Public.
- Privilege: (τ, θ)
  - Allows an ID τ to perform an operation θ.

Formalizing authorization in SQL

- Given a statement S, SQL implicitly defines a set of operations, OPS(S), for checking authorization.
  - That is, an ID τ is authorized to perform S iff τ has a privilege for every operation in OPS(S).
  - OPS(S) can be found by the following rules:
    - If S is a query, OPS(S) contains (select, A) for all columns A mentioned in S.
    - If S is an update, OPS(S) contains (update, A) for each column A being updated, plus (select, B) for all columns B mentioned in S.
    - If S is a call to routine P, OPS(S) contains (execute, P), plus (select, A) for all columns A mentioned in the argument list.
    - If S contains a nested statement S', OPS(S) contains all operations of S'.

Formalizing authorization in SQL

- Example: Update T set A = C + 2
  where B1 in (select B2 from V)
  - ➔ OPS(S) = { (select, T.B1), (select, T.C), (select, B.B2), (update, T.A)}
- If S is complex, the computation of OPS(S) may not be straightforward.
  - Unnecessary predicates; e.g., tautologies and constraints
  - select T.A from T where T.B is null or T.B * T.B >= 0
    - (select, T.B) should not be in OPS(S)
  - The detection of such predicates is not decidable; they are not considered.

Formalizing authorization in SQL

- Grant
  - An ID receives privileges via grant statements.
  - An ID is able to issue a grant statement for an operation if its privilege include a grant-option privilege for the operation.
- Ownership
  - When an object is created, the creator is given administrative authority over the object.
  - Two aspects: rights over the defined metadata and rights over the instance population

  1. Base table: the creator is given all possible privileges.
  2. Derived object: the creator is given full rights on the metadata and limited rights over the instance population.

Formalizing authorization in SQL

- Derived objects: procedures and views
  - Each derived object Z has a defining statement, DEF(Z).
  - Unlike base tables, when a derived object is created, the system infers the appropriate privileges based on the creator's privileges on underlying objects.
  - The general principle is that it is safe to infer privileges for tasks the user could accomplish by other means; i.e., inference may increase convenience, but not power.

- The SQL Inference Principle: Let θ be an operation on derived object Z. Then Z's creator τ should receive privileges on θ provided that τ's ability to access and modify data does not increase.

Formalizing authorization in SQL

- Example: create view Z as select A, C from T where T.B > 2
  - Say the creator τ has privileges on (select, T) and (update, T.A).
  - Then it is wrong to give τ the privilege on (update, Z).
  - But it is okay to give τ the privilege on (update, Z.A).

- Inferences are justified by using query modification
  - Take a statement S involving derived object Z, and produce an equivalent statement S' by replacing references to Z to tables in DEF(Z).
  - Select Z.A from Z ➔ select T.A from T where T.B > 2
  - Thus, it would be wrong to give τ an inferred privilege on (select, Z.A) unless τ already has privileges on (select, T.A) and (select, T.B).

Formalizing authorization in SQL

- Query modification technique can provide a counterexample, but it cannot prove that an inference is correct.
  - We would have to examine every possible statement involving Z.
- Definition. Let Z be a derived object, and let θ be an operation on Z. OPS(θ) is found as follows:
  - OPS((select, Z.B)) consists of those operations (select, T.A) such that changing A-value of T can change the B-value of Z.
  - OPS((insert, Z.B)) consists of those operations (insert, T.A) if inserting into Z can cause an insertion into T, and Z.B is derived from T.A.
  - OPS((delete, Z)) consists of (delete, T) if deleting Z can cause a deletion from T.
  - OPS((update, Z.B)) consists of those operations (update, T.A) if updating the B-value of Z can cause a change in the A-value of T.
  - OPS((execute, P)) consists of the operations required to execute the body of P. That is, it contains each operation in OPS(DEF(P)).

Formalizing authorization in SQL

- The SQL Privilege Inference Rule: Let τ be the creator of derived object Z and let θ be an operation on Z.
  1. Infer the privilege (τ, θ) if τ has a privilege for every operation in OPS(θ).
  2. Infer the privilege (τ, grantθ) if τ has grant-option privilege for every operation in OPS(θ).

- Theorem. The privileges inferred by this rule satisfies the SQL Inference Principle.
  - Proved in the paper

Proposed extension

- Inferred privileges on derived objects
  - In standard SQL, all privileges on a derived object stem from the creator.
  - The extension is to allow privileges on a derived objects to be inferred to any ID, not just the object's creator.

- The inference Principle
  - Let θ be an operation on derived object Z. An ID τ receive privilege on θ as long as τ's ability to access and modify data does not increase.

Proposed extension

- Who may create a derived object?
  - As all privileges on a derived object stem from the creator, SQL does not allow an ID to create an object unless the creator receives a reasonable number of privileges.
  - Without this restriction, any user can create a derived object and receives whatever privileges the system infer.
  - However, the metadata (definition) of derived object must be explicitly controlled.
  - Introduce a new action, Visible.
  - Privilege on (visible, Z) allows ID to see Z's definition.
  - Now some users can use Z without knowing the definition of Z. Also the creator can allow some users to see the definition of Z without giving them privileges to use it.

Proposed extension: Benefits

- Creators need not be administrators.
  - Subjects with (visible, Z) and privileges on OPS(θ) are immediately able to use θ without any explicit grant by the creator.
  - The creator can give access to Z to anyone with sufficient authorization on the underlying object by granting (visible, Z) to Public.

- Privileges can be kept consistent automatically.
  - Consider a data warehouse, whose contents are a materialized view of its underlying source databases.
  - The proposed model provides a way to enforce consistency between the warehouse privileges and the source privileges.

Proposed extension: Benefits

- Explicit control over metadata privileges
  - SQL allows an ID with any privilege on an object to have the ability to see all metadata about the object; more is revealed that required.
  - A user with select privilege can see the constraints.
  - A user who can execute a procedure can see the definition.
  - In some cases, this is not desirable.

- Untrusted IDs can create useful derived objects.
  - As the creator of a derived object is the source of all privileges in SQL, only trusted users can create useful views.
  - In the proposed model, IDs can access the object even if the creator is untrusted or lazy.

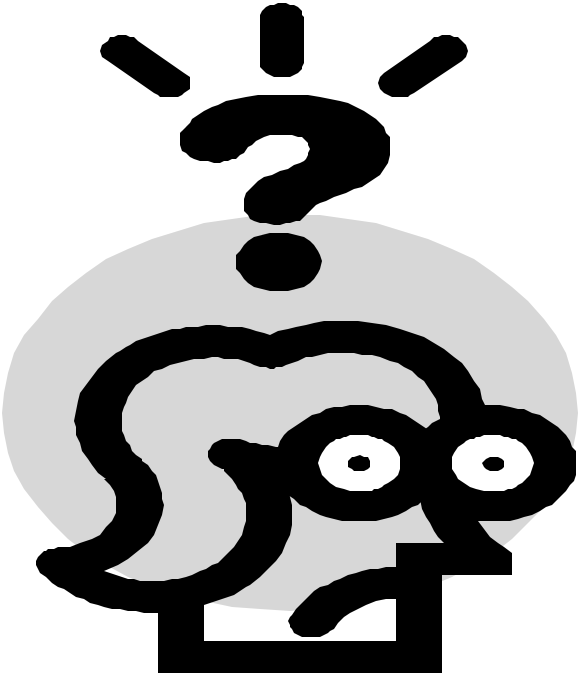
Proposed extension: Benefits

- Invoker's rights are integrated into the model.
  - The SQL standard requires that the creator of a procedure have grant-option privileges on all operations in the procedure.
  - Oracle introduced the invoker-right mechanism, which requires users have not only an execute privilege, but also all the privileges to execute operations in the procedure.
  - A contract programmer can write complex procedures and grant execute privilege to public. Then only the users having sufficient privileges can actually use the procedure.
  - The model extends invoker-right features beyond procedure to any operation θ on a derived object Z.
  - An administrator can choose to grant explicit privileges on θ to some IDs, and to allow possible inference of θ to other IDs by granting Visible privileges to them.

Another issue

- Base table ownership
  - It is beneficial to separate the metadata privileges on a derived object from the privileges on its content.
  - Is this separation possible for base tables? The creator obviously deserves all metadata privileges, but how do we assign the privileges on its content?
  - For example, a programmer or DBA can create a table, but should not have the right to see the data.
  - In SQL, one cannot remove the creator's rights since deletion cascades.
  - A simple way is to provide a way to remove the rights from the creator without affecting their delegatees. (non-cascading revoke)

Question?



View Security as the Basis for Data Warehouse Security

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Introduction

- Problem
  - Currently, access permissions in a data warehouse are managed in a separate world from the sources' policies.
  - The warehouse DBA has to manually specify access rights on all warehouse data.
  - The warehouse DBA must be trusted by all sources.
  - The consequences are inconsistencies, slow response to change, and a heavy work load for administrators.
  - Thus, the critical problem of data warehousing security is how to automatically coordinate the access rights of the warehouse with those of the sources.

Proposed extensions

- Three extensions to SQL
  1. Split the notion of "access permission on a table" into two separate issues:
     a. who is allowed to access what information (information permissions): enterprise-wide decision
        - Employee salary information is releasable to payroll clerks.
     b. who is allowed to access which physical tables (physical permissions): local decision
        - Payroll clerks are allowed to run queries on the warehouse.
  2. Provide a powerful inference mechanism
     – In SQL, a user is allowed to execute a query Q if the user has permissions on all tables mentioned in Q.
     – In the proposed model, a user can also execute Q if there is an equivalent query Q', called a witness for Q, for which the user has permissions.

Proposed extensions

- Three extensions to SQL

  3. Broaden the creation of views

     - In SQL, a view can be created only if there is a user that has Grant authority on all mentioned tables.
     - The extension allows the views to be over several mutually-suspicious sources, where no one is trusted to have Grant permission over all of them.

Basics

- Permission: (subject, operation, object, mode)
  - Subject: individual users, roles, group, process, etc.
  - Object: tables belonging to either a source or warehouse.
  - Operation: SQL operations (focus on Read and Grant-read).
  - Mode: either information or physical

- A view
  - Every warehouse table is a view over the tables exported by sources.
  - Defined by an SQL query Q.
  - The inputs to Q are the objects mentioned in Q; Q(T1, ..., Tn).

Permissions

- A subject s is allowed to access a table only if s has both information and physical permissions on the table.
  - A permission (s, op, T, “information”) indicates that the content in T should be accessible to s for operation op. It concerns releasability of knowledge, not physical access to T. They are globally applied and unaffected by creation of redundant copies or new interface.
  - A permission (s, op, T, “physical”) authorizes an execution strategy to use a single physical resource; i.e., local policy.

Permission Inference

- A permission is explicit if it is granted directly by an authorized grantor.
- Permissions can be inferred by the system as well.
  - A subject should have permission to execute a query iff the query can be expressed in terms of tables (base or view) for which user has explicit permissions.
- Two useful definitions for inference
  - A query Q is *equivalent* to T if the output of Q always contains the same tuples as T.
  - A permission (s, op, T, mode) is implied if there exists an equivalent query Q(T1, …, Tn) such that each permission (s, op, Ti, mode) has been granted explicitly. Query Q is called the *witness* for the implied permission.

Permission Inference

- An implied information permission (s, read, T) means that the information in T is releasable to s.
  - In effect, a subject need not care whether an information permission is explicit or implied, nor whether T is a materialized view or base table.

- An implied physical permission (s, read, T) asserts that there exists at least one way to compute T for which the physical permissions are available.
  - If T is a materialized table, the subject does not have physical access to T. The subject need to use the tables from the witness query.

Permission Inference

- Now, it is required for the systems to be able to a witness query equivalent to T.
  - Three important rewriting strategies
    1. View substitution: If a subject s has the necessary permissions on the source tables mentioned in a view, then s also has permission on the view. (SQL requires an explicit grant to access a view.)
    2. Semantic query optimization: If the user queries a view V, some source data that underlies V may be irrelevant to the query result. (Let V be a join of two tables. SQL requires permissions on both tables. This is not necessary in some cases.)
    3. Rewrite in terms of other views: Subjects are often given access to information though views when they do not have permissions on the base table.
  - A complete set of equivalents is impossible because the general rewrite problem is undecidable. Thus, the benchmark is to do better than others, rather than pursuing completeness.

Administering a warehouse

- SQL infers view privileges only when a view is defined.
  - The view definer receives the intersection of her privileges on the input tables.
  - Then the definer must explicitly specify all other permissions on the view.
- In the proposed model, view privileges are inferred whenever the view is accessed by any user.
  - Provides a more flexible way to coordinate the control of both the source administrator (controlling information permissions) and the warehouse administrator (controlling physical permissions).

Administering a warehouse

- Computing local permissions
  - When a query is issued to a warehouse, testing permissions should be performed there, not referring the sources.
  - The system needs to populate permission tables on the warehouse.
  - The set of users authorized to execute a query (not considering equivalence) is the intersection of the user sets of its inputs. Thus, the user set of a view can be determined by taking the union of these individual user sets for each equivalent query found.
  - Given T, first computes all queries equivalent to T, and structure as a DAG where each subexpression appears only once. Then traverse the graph (bottom up), computing permissions for each table in the graph from its predecessors.

Within-view permissions

- Consider a warehouse where multiple parts of an organization or multiple organizations participate.
  - With the current SQL, each organization must grant a warehouse DBA Read and Grant-read permissions on their exported data. Then a W-DBA define and administer a view over the combined information.
  - What happens if no one can be universally trusted?
  - One approach is to allow a source to stipulate that its exported data can be used only for computing a less sensitive view.
  - grant select to s on T within V
  - s can access T, but only from within V.

Within-view permissions

- Examples

1. Totals over a large set
   - A warehouse supporting financial studies of hospitals.
   - Each hospital chooses to release its information within state-wide totals or city-wide totals.
2. Peer-to-peer intersection
   - Table Entrant (border patrol): people entering the country
   - Table Wanted (Police): people who are wanted
   - Select * from Entrant, Wanted where match(Entrant, Wanted)
3. Intersection of child and parent
   - Table Patient(P#, Age, …): Parent table
   - Table Surgery(P#, Procedure, Date, …): Child table
   - Select * from Patient, Surgery where Patient.P# = Surgery.P# and Patient.Age > 80

Within-view permissions

- Semantics
  - A within-view permission: (subject, operation, object, mode, view).
  - A subject s is able to access view V if s has access to each input table within V.
  - The witness semantics is extended as follows:

    A permission (s, op, T, mode) is implied if there exists a query Q and views {vi} equivalent to T, such that for each object Ti mentioned in Q, either
    - The permission (s, op, Ti, mode) has been explicitly granted, or
    - The within-view permission (s, op, Ti, mode, Vi) has been explicitly granted, where Q is equivalent to Vi.
  - Users are able to access a view even when nobody is trusted to receive permissions to all underlying tables.

Question?