Intro to Database Systems (15-445/645)

24 Embedded Database Logic

Carnegie Mellon University
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Homework #5 is due Sunday Dec 4th @ 11:59pm

Project #4 is due Sunday Dec 11th @ 11:59pm

Upcoming Special Lectures:
→ Virtual Snowflake Lecture (Tuesday Dec 6th)
→ In-Person Q&A Lecture (Thursday Dec 8th)

Final Exam is Friday Dec 16th @ 1:00pm.
→ Study guide will be posted next week.
Until now, we have assumed that all the logic for an application is located in the application itself.

The application has a "conversation" with the DBMS to store/retrieve data.

→ Each DBMS has its own network protocol.
→ Client-side APIs: JDBC, ODBC
CONVERSATIONAL DATABASE API

Application

BEGIN
  execute(SQL)
  <Program Logic>
  execute(SQL)
  <Program Logic>
  ...
COMMIT

Parser
Planner
Optimizer
Query Execution
CONVERSATIONAL DATABASE API

Application

BEGIN
execute(SQL):
<Program Logic>
execute(SQL)
<Program Logic>
::
COMMIT

Parser
Planner
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CONVERSATIONAL DATABASE API

Application

```
BEGIN
    execute(SQL):
    <Program Logic>
    execute(SQL)
    <Program Logic>
    ;

COMMIT
```

Parser
Planner
Optimizer
Query Execution
BEGIN
execute(SQL): <Program Logic>
execute(SQL) <Program Logic>

COMMIT
CONVERSATIONAL DATABASE API

**Application**

BEGIN

\[
\text{execute}(\text{SQL}): <\text{Program Logic}>
\]

\[
\text{execute}(\text{SQL}) <\text{Program Logic}>
\]

\[
\vdots
\]

COMMIT

**Parser**

**Planner**

**Optimizer**

**Query Execution**
EMBEDDED DATABASE LOGIC

Moving application logic into the DBMS can (potentially) provide several benefits:
→ Fewer network round-trips.
→ Immediate notification of changes.
→ DBMS spends less time waiting during transactions.
→ Developers do not have to reimplement functionality.
TODAY'S AGENDA

User-defined Functions
Stored Procedures
Triggers
Change Notifications
User-defined Types
Views
A **user-defined function** (UDF) is a function written by the application developer that extends the system's functionality beyond its built-in operations.

→ It takes in input arguments (scalars)
→ Perform some computation
→ Return a result (scalars, tables)
**UDF DEFINITION**

**Return Types:**
→ Scalar Functions: Return a single data value
→ Table Functions: Return a single result table.

**Computation Definition:**
→ SQL Functions
→ External Programming Language
UDF - SQL FUNCTIONS

A SQL-based UDF contains a list of queries that the DBMS executes in order when invoked. → The function returns the result of the last query executed.

```sql
CREATE FUNCTION get_foo(int) RETURNS foo
LANGUAGE SQL AS $$
SELECT * FROM foo WHERE foo.id = $1;
$$;
```
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Return Args
UDF – SQL FUNCTIONS

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    SELECT * FROM foo WHERE foo.id = $1;
$$
```
A SQL-based UDF contains a list of queries that the DBMS executes in order when invoked. → The function returns the result of the last query executed.

```sql
CREATE FUNCTION get_foo(int)
RETURNS foo
LANGUAGE SQL AS $$
SELECT * FROM foo WHERE foo.id = $1;
$$

SELECT get_foo(1);
SELECT * FROM get_foo(1);
```
UDF - SQL FUNCTIONS

SQL Standard provides the **ATOMIC** keyword to tell the DBMS that it should track dependencies between SQL UDFs.

```sql
CREATE FUNCTION get_foo(int)
    RETURNS foo
    LANGUAGE SQL
    BEGIN ATOMIC;
        SELECT * FROM foo WHERE foo.id = $1;
    END;
```
Some DBMSs support writing UDFs in languages other than SQL.

→ **SQL Standard**: SQL/PSM
→ **Oracle/DB2**: PL/SQL
→ **Postgres**: PL/pgSQL
→ **MSSQL/Sybase**: Transact-SQL

Other systems support more common programming languages:
→ Sandbox vs. non-Sandbox
CREATE OR REPLACE FUNCTION get_foo(int)
RETURNS SETOF foo
LANGUAGE plpgsql AS $$
BEGIN
RETURN QUERY
  SELECT * FROM foo WHERE foo.id = $1;
END;
$$;
CREATE OR REPLACE FUNCTION sum_foo(i int) RETURNS int AS $$
DECLARE foo_rec RECORD;
DECLARE out INT;
BEGIN
  out := 0;
  FOR foo_rec IN SELECT id FROM foo WHERE id > i LOOP
    out := out + foo_rec.id;
  END LOOP;
  RETURN out;
END;
$$ LANGUAGE plpgsql;
CREATE OR REPLACE FUNCTION sum_foo(i int) RETURNS int AS $$
DECLARE foo_rec RECORD;
DECLARE out INT;
BEGIN
    out := 0;
    FOR foo_rec IN SELECT id FROM foo WHERE id > i LOOP
        out := out + foo_rec.id;
    END LOOP;
    RETURN out;
END;
$$ LANGUAGE plpgsql;
UDF ADVANTAGES

They encourage modularity and code reuse
→ Different queries can reuse the same application logic without having to reimplement it each time.

Fewer network round-trips between application server and DBMS for complex operations.

Some types of application logic are easier to express and read as UDFs than SQL.
UDF DISADVANTAGES (1)

Query optimizers treat UDFs as black boxes.
→ Unable to estimate cost if you don't know what a UDF is going to do when you run it.

It is difficult to parallelize UDFs due to correlated queries inside of them.
→ Some DBMSs will only execute queries with a single thread if they contain a UDF.
→ Some UDFs incrementally construct queries.
UDF DISADVANTAGES (2)

Complex UDFs in **SELECT / WHERE** clauses force the DBMS to execute iteratively.
→ RBAR = "Row By Agonizing Row"
→ Things get even worse if UDF invokes queries due to implicit joins that the optimizer cannot "see".

Since the DBMS executes the commands in the UDF one-by-one, it is unable to perform cross-statement optimizations.
TPC-H Q12 using a UDF (SF=1).

→ **Original Query:** 0.8 sec

→ **Query + UDF:** 13 hr 30 min

```
SELECT l_shipmode,
     SUM(CASE
         WHEN o_orderpriority <> '1-URGENT'
             THEN 1
         ELSE 0
    END)
     AS low_line_count
FROM orders, lineitem
WHERE o_orderkey = l_orderkey
AND l_shipmode IN ('MAIL','SHIP')
AND l_commitdate < l_receiptdate
AND l_shipdate < l_commitdate
AND l_receiptdate >= '1994-01-01'
AND dbo.cust_name(o_custkey) IS NOT NULL
GROUP BY l_shipmode
ORDER BY l_shipmode
```

```
CREATE FUNCTION cust_name(@ckey int)
RETURNS char(25) AS
BEGIN
    DECLARE @n char(25);
    SELECT @n = c_name
    FROM customer WHERE c_custkey = @ckey;
    RETURN @n;
END
```
TSQL Scalar functions are evil.

I've been working with a number of clients recently who all have suffered at the hands of TSQL Scalar functions. Scalar functions were introduced in SQL 2000 as a means to wrap logic so we benefit from code reuse and simplify our queries. Who would be daft enough not to think this was a good idea. I for one jumped on this initially thinking it was a great thing to do.

However as you might have gathered from the title scalar functions aren't the nice friend you may think they are.

If you are running queries across large tables then this may explain why you are getting poor performance.

In this post we will look at a simple padding function, we will be creating large volumes to emphasize the issue with scalar udfs.

```
create function padLeft(@val varchar(100), @len int, @char char(2))
returns varchar(100)
begin
  return right(replicate(@char, @len) + @val, @len)
end
``` interpreted

Scalar functions are interpreted code that means EVERY call to the function results in your code being interpreted. That means overhead for processing your function is proportional to the number of rows.

Running this code you will see that the native system calls take considerably less time than the UDF calls. On my machine it takes 2654 ms for the system calls and 2875 ms for the UDF. That's a 1% increase.

```
set statistics time on
```

```
go
select max(right(replicate('9', 100) + s.name + c.name, 199))
from msdb.sys.columns s
cross join msdb.sys.columns c
select max(dbo.padLeft(c.name + c.name, 199, '9'))
from msdb.sys.columns s
cross join msdb.sys.columns c
```

```
go
```

Source: Karthik Ramachandra
A stored procedure is a self-contained function that performs more complex logic inside of the DBMS.

→ Can have many input/output parameters.
→ Can modify the database table/structures.
→ Not normally used within a SQL query.

Some DBMSs distinguish UDFs vs. stored procedures, but not all.
STORED PROCEDURES

Application

BEGIN
  execute(SQL)
  <Program Logic>
  execute(SQL)
  <Program Logic>
  :
  COMMIT
STORED PROCEDURES

Application

CALL PROC(x=99)

PROC(x)

BEGIN
execute(SQL)
<Program Logic>
execute(SQL)
<Program Logic>
;
COMMIT
CREATE OR REPLACE PROCEDURE transfer(sender INT, receiver INT, amount FLOAT)
LANGUAGE plpgsql AS $$
DECLARE sndr_bal INT;
DECLARE sndr_name VARCHAR;
BEGIN
  SELECT name, balance INTO sndr_name, sndr_bal
  FROM accounts WHERE id = sender;
  IF sndr_bal < amount THEN
    RAISE EXCEPTION '% does not have enough money!', sndr_name;
  END IF;
  UPDATE accounts SET balance = balance - amount WHERE id = sender;
  UPDATE accounts SET balance = balance + amount WHERE id = receiver;
  COMMIT;
END;
$$;

CALL transfer(1, 2, 50);
STORED PROCEDURE VS. UDF

A UDF is meant to perform a subset of a read-only computation within a query.

A stored procedure is meant to perform a complete computation that is independent of a query.
DATABASE TRIGGERS

A trigger instructs the DBMS to invoke a UDF when some event occurs in the database.

The developer has to define:
→ What type of event will cause it to fire.
→ The scope of the event.
→ When it fires relative to that event.
TRIGGER EXAMPLE

CREATE TABLE foo (  
id INT PRIMARY KEY,  
val VARCHAR(16)  
);

CREATE TABLE foo_audit (  
id SERIAL PRIMARY KEY,  
foo_id INT REFERENCES foo (id),  
orig_val VARCHAR,  
cdate TIMESTAMP  
);
CREATE TABLE foo (  
id INT PRIMARY KEY,  
val VARCHAR(16)  );

CREATE TABLE foo_audit (  
id SERIAL PRIMARY KEY,  
foo_id INT REFERENCES foo (id),  
orig_val VARCHAR,  
cdate TIMESTAMP);  

CREATE OR REPLACE FUNCTION log_foo_updates()  
RETURNS trigger AS $$
BEGIN
  IF NEW.val <> OLD.val THEN
    INSERT INTO foo_audit
    (foo_id, orig_val, cdate)
    VALUES (OLD.id, OLD.val, NOW());
  END IF;
  RETURN NEW;
END;
$$
LANGUAGE plpgsql;
CREATE TABLE foo (  
  id INT PRIMARY KEY,  
  val VARCHAR(16)  
);

CREATE TABLE foo_audit (  
  id SERIAL PRIMARY KEY,  
  foo_id INT REFERENCES foo (id),  
  orig_val VARCHAR,  
  cdate TIMESTAMP  
);

CREATE OR REPLACE FUNCTION log_foo_updates()  
RETURNS trigger AS $$  
BEGIN  
  IF NEW.val <> OLD.val THEN  
    INSERT INTO foo_audit  
    (foo_id, orig_val, cdate)  
    VALUES (OLD.id, OLD.val, NOW());  
  END IF;  
  RETURN NEW;  
END;  $$  
LANGUAGE plpgsql;

CREATE TRIGGER foo_updates  
BEFORE UPDATE ON foo FOR EACH ROW  
EXECUTE PROCEDURE log_foo_updates();
## Trigger Definition

<table>
<thead>
<tr>
<th>Event Type:</th>
<th>Event Scope:</th>
<th>Trigger Timing:</th>
</tr>
</thead>
<tbody>
<tr>
<td>→ INSERT</td>
<td>→ TABLE</td>
<td>→ Before the query executes.</td>
</tr>
<tr>
<td>→ UPDATE</td>
<td>→ DATABASE</td>
<td>→ After the query executes</td>
</tr>
<tr>
<td>→ DELETE</td>
<td>→ VIEW</td>
<td>→ Before each row the query affects.</td>
</tr>
<tr>
<td>→ TRUNCATE</td>
<td>→ SYSTEM</td>
<td>→ After each row the query affects.</td>
</tr>
<tr>
<td>→ CREATE</td>
<td></td>
<td>→ Instead of the query.</td>
</tr>
<tr>
<td>→ ALTER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>→ DROP</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
A change notification is like a trigger except that the DBMS sends a message to an external entity that something notable has happened in the database.

→ Think a "pub/sub" system.
→ Can be chained with a trigger to pass along whenever a change occurs.

SQL standard: \textbf{LISTEN} + \textbf{NOTIFY}
CREATE OR REPLACE FUNCTION notify_foo_updates() 
    RETURNS trigger AS $$
DECLARE notification JSON;
BEGIN
    notification = row_to_json(NEW);
    PERFORM pg_notify('foo_update', notification::text);
RETURN NEW;
END;
$$ LANGUAGE plpgsql;
CREATE OR REPLACE FUNCTION notify_foo_updates() RETURNS trigger AS $$
DECLARE notification JSON;
BEGIN
  notification = row_to_json(NEW);
  PERFORM pg_notify('foo_update', notification::text);
  RETURN NEW;
END;
$$ LANGUAGE plpgsql;

CREATE TRIGGER foo_notify
AFTER INSERT ON foo_audit FOR EACH ROW
EXECUTE PROCEDURE notify_foo_updates();
OBSERVATION

All DBMSs support the basic primitive types in the SQL standard. They also support basic arithmetic and string manipulation on them.

But what if we want to store data that doesn't match any of the built-in types?

coordinate (x, y, label)
COMPLEX TYPES

Approach #1: Attribute Splitting
→ Store each primitive element in the complex type as its own attribute in the table.

Approach #2: Application Serialization
→ J
→ Google Protobuf, Facebook Thrift
→ JSON / XML

```
INSERT INTO locations
  (x, y, label)
VALUES
  (10, 20, "OTB");
```

```
CREATE TABLE locations
  (coord JSON NOT NULL);
```

```
INSERT INTO location (coord)
VALUES
  '{x:10, y:20, label:'"OTB"'}';
```
USER-DEFINED TYPES

A **user-defined type** is a special data type that is defined by the application developer that the DBMS can stored natively.
→ First introduced by Postgres in the 1980s.
→ Added to the SQL:1999 standard as part of the "object-relational database" extensions.

Sometimes called **structured user-defined types** or **structured types**.
Each DBMS exposes a different API that allows you to create a UDT.
→ Postgres/DB2 supports creating composite types using built-in types.
→ Oracle supports PL/SQL.
→ MSSQL/Postgres only support type definition using external languages (.NET, C)

```
CREATE TYPE coordinates AS (x INT, y INT, label VARCHAR(32));
```
VIEWs

Creates a "virtual" table containing the output from a \texttt{SELECT} query. The view can then be accessed as if it was a real table.

This allows programmers to simplify a complex query that is executed often.
→ It won't make the DBMS magically run faster though.

Often used as a mechanism for hiding a subset of a table's attributes from certain users.
Create a view of the CS student records with just their id, name, and login.

Original Table

<table>
<thead>
<tr>
<th>sid</th>
<th>name</th>
<th>login</th>
<th>age</th>
<th>gpa</th>
</tr>
</thead>
<tbody>
<tr>
<td>53666</td>
<td>RZA</td>
<td>rza@cs</td>
<td>53</td>
<td>3.5</td>
</tr>
<tr>
<td>53677</td>
<td>Justin Bieber</td>
<td>jb@ece</td>
<td>23</td>
<td>2.25</td>
</tr>
<tr>
<td>53688</td>
<td>Tone Loc</td>
<td>tloc@mld</td>
<td>56</td>
<td>3.8</td>
</tr>
<tr>
<td>53699</td>
<td>Andy Pavlo</td>
<td>pavlo@cs</td>
<td>41</td>
<td>3.0</td>
</tr>
</tbody>
</table>

CREATE VIEW cs_students AS

```
SELECT sid, name, login
FROM student
WHERE login LIKE '%@cs';
```

SELECT * FROM cs_students;

<table>
<thead>
<tr>
<th>sid</th>
<th>name</th>
<th>login</th>
</tr>
</thead>
<tbody>
<tr>
<td>53666</td>
<td>RZA</td>
<td>rza@cs</td>
</tr>
<tr>
<td>53699</td>
<td>Andy Pavlo</td>
<td>pavlo@cs</td>
</tr>
</tbody>
</table>
Create a view with the average age of all of the students.

```
CREATE VIEW cs_gpa AS
    SELECT AVG(gpa) AS avg_gpa
    FROM student
    WHERE login LIKE '%@cs';
```
**VIEWS VS. SELECT INTO**

**VIEW**

→ Dynamic results are only materialized when needed.

**SELECT...INTO**

→ Creates static table that does not get updated when student gets updated.

```sql
CREATE VIEW cs_gpa AS
SELECT AVG(gpa) AS avg_gpa
FROM student
WHERE login LIKE '%@cs';
```

```sql
SELECT AVG(gpa) AS avg_gpa
INTO cs_gpa
FROM student
WHERE login LIKE '%@cs';
```
The SQL-92 standard specifies that an application is allowed to modify a **VIEW** if it has the following properties:

→ It only contains one base table.
→ It does not contain grouping, distinction, union, or aggregation.
MATERIALIZED VIEWS

Creates a view containing the output from a SELECT query that is retained (i.e., not recomputed each time it is accessed).
→ Some DBMSs automatically update matviews when the underlying tables change.
→ Other DBMSs (PostgreSQL) require manual refresh.

```
CREATE MATERIALIZED VIEW cs_gpa AS
SELECT AVG(gpa) AS avg_gpa
FROM student
WHERE login LIKE '%@cs';
```
Moving application logic into the DBMS has lots of benefits.
→ Better Efficiency
→ Reusable across applications

But it has problems:
→ Not portable
→ DBAs don't like constant change.
→ Potentially need to maintain different versions.