Carnegie Mellon University

Embedded Database Logic

Lecture #15

Database Systems
15-445/15-645
Fall 2017

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ADMINISTRIVIA

Project #2 is due Wednesday October 25th @ 11:59am

Exams are available to view during my office hours.
→ Bring your CMU ID.
→ You are not allowed to take it with you.
→ Take a photo of any page that you want regraded.

EXTRA CREDIT (OPTIONAL)

We are building an open-source database benchmarking framework.

Pick a DBMS that you want to try.
→ Must support transactions
→ Must support SQL/JDBC

Get a benchmark to run on it.

Get 10% extra credit.

http://oltpbenchmark.com

DATABASE TALKS

Oracle In-Memory Database
→ Tuesday Oct 24th @ 6pm
→ GHC 6115

Battery Ventures Talk
→ Wednesday Oct 25th @ 4:30pm
→ GHC 4405

Kdb Time-series DB Talk
→ Thursday @ Oct 26th @ 12:00pm
→ CIC 4th Floor

OBSERVATION

Until now, we have assumed that all of the logic for an application is located in the application itself.

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

→ Protocols: JDBC, ODBC

CONVERSATIONAL DATABASE API

Application

```
BEGIN
  SQL
  Program Logic
  SQL
  Program Logic
  ⋮
COMMIT
```

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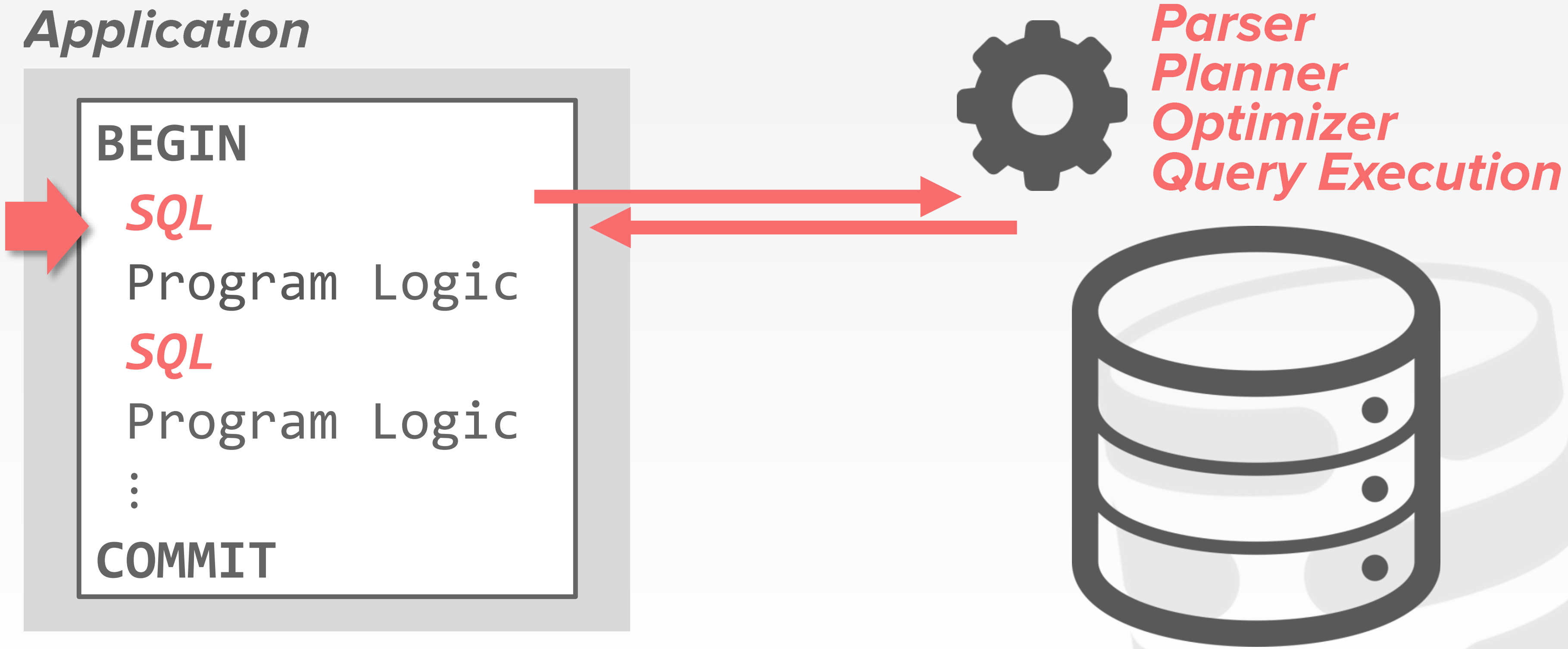
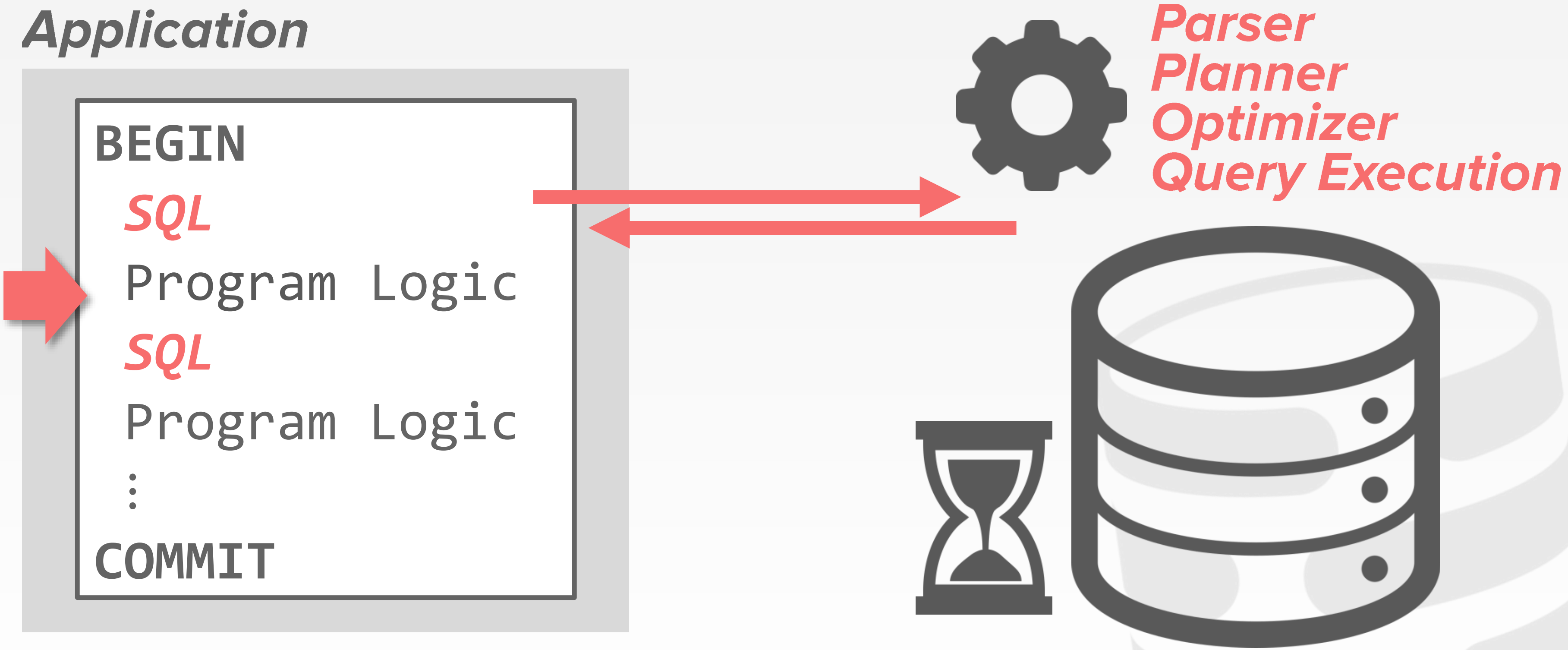
DATABASE GROUP

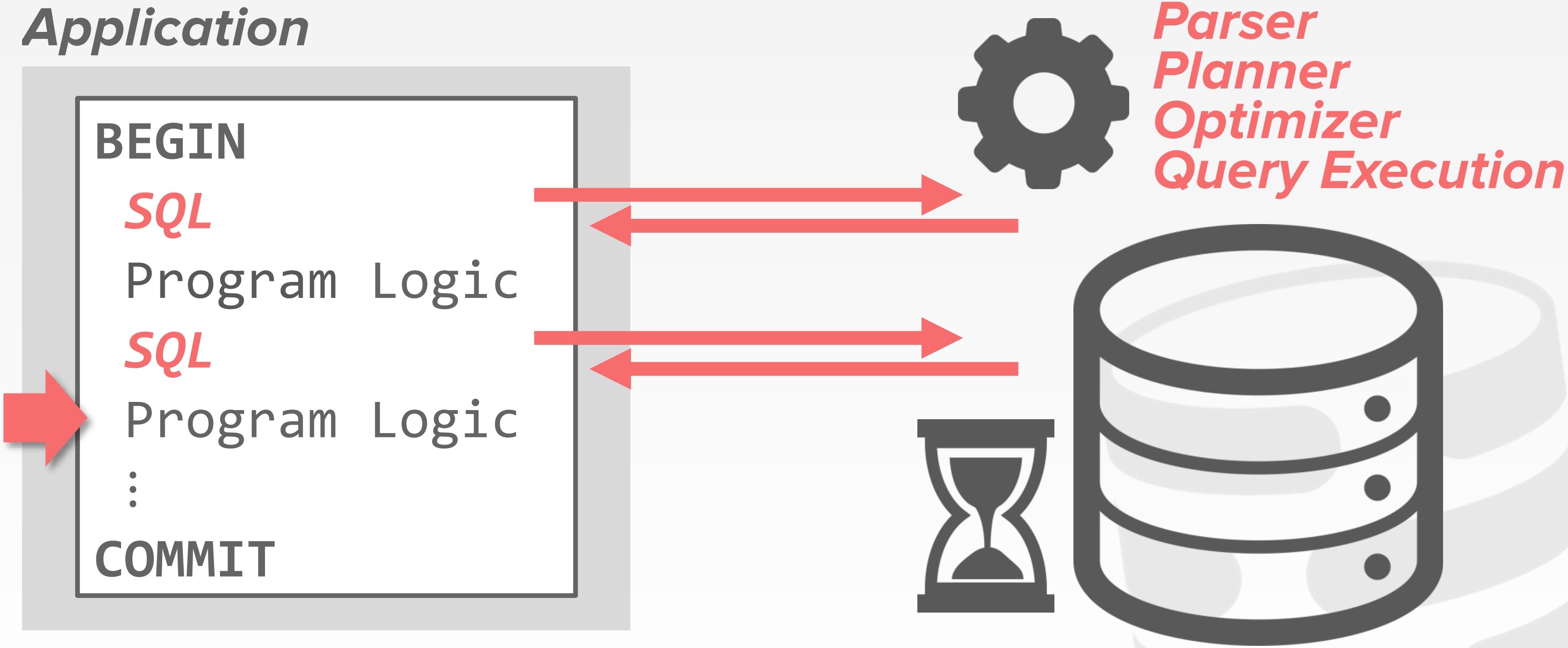
CONVERSATIONAL DATABASE API



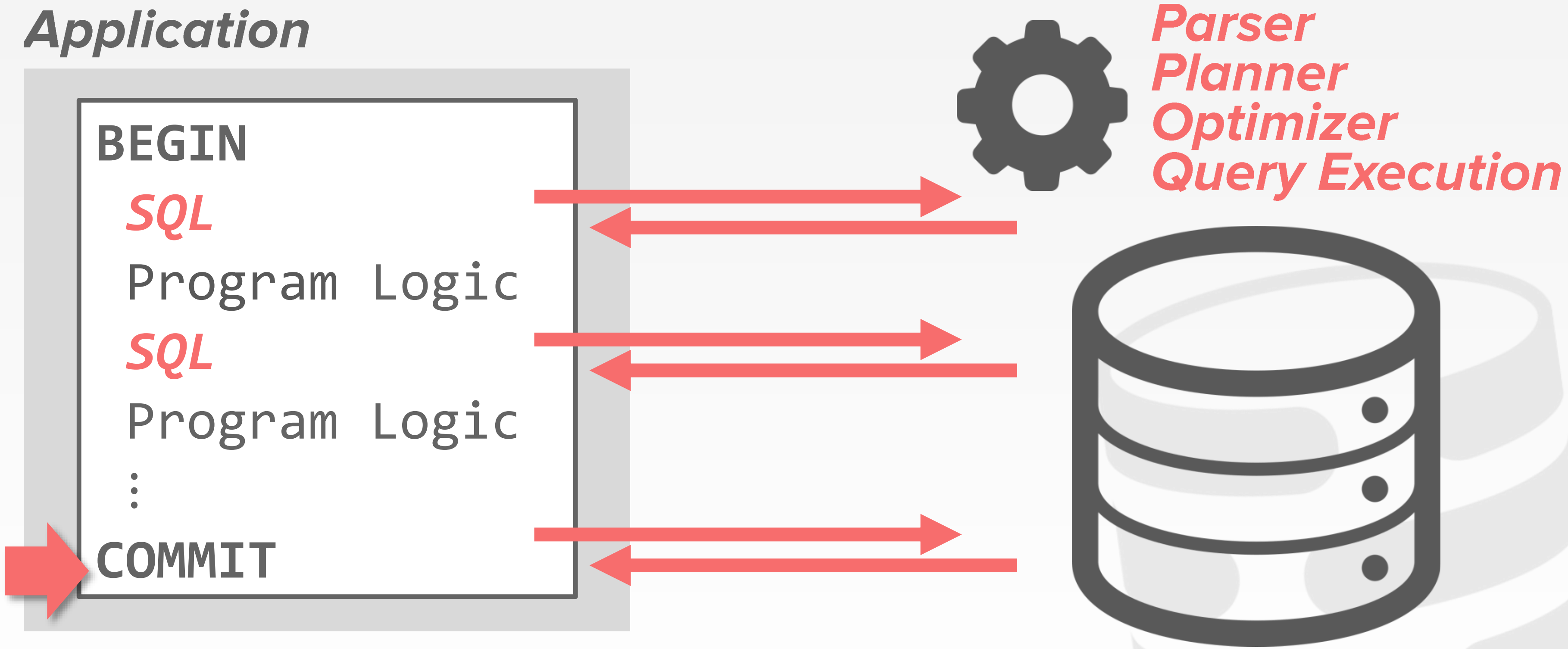
CONVERSATIONAL DATABASE API



CONVERSATIONAL DATABASE API



CONVERSATIONAL DATABASE API



EMBEDDED DATABASE LOGIC

What if we could move complex application logic into the DBMS to avoid multiple network round-trips?

Potential Benefits

→ Efficiency
→ Reuse

TODAY'S AGENDA

User-defined Functions
Stored Procedures
Triggers
Change Notifications
User-defined Types
Views

USER-DEFINED FUNCTIONS

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 SQL statements that the DBMS executes in order when the UDF is invoked.

→ The function returns whatever the result is of the last query executed;

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

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

Input Args

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CREATE TABLE foo (
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Return Args

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$$ LANGUAGE SQL;
```

Function Body

UDF – EXTERNAL PROGRAMMING LANGUAGE

Some DBMSs support writing UDFs in languages other than SQL.

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

Other systems support more common programming languages:

→ Sandbox vs. non-Sandbox

PL/PGSQL Example

```
CREATE OR REPLACE FUNCTION get_foo(int)
                        RETURNS SETOF foo AS $$
  BEGIN
    RETURN QUERY SELECT * FROM foo
                              WHERE foo.id = $1;
  END;
$$ LANGUAGE plpgsql;
```

PostgreSQL

PL/PGSQL Example (2)

```
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;
```

STORED PROCEDURES

A **stored procedure** is a self-contained function that performs more complex logic inside of the DBMS.

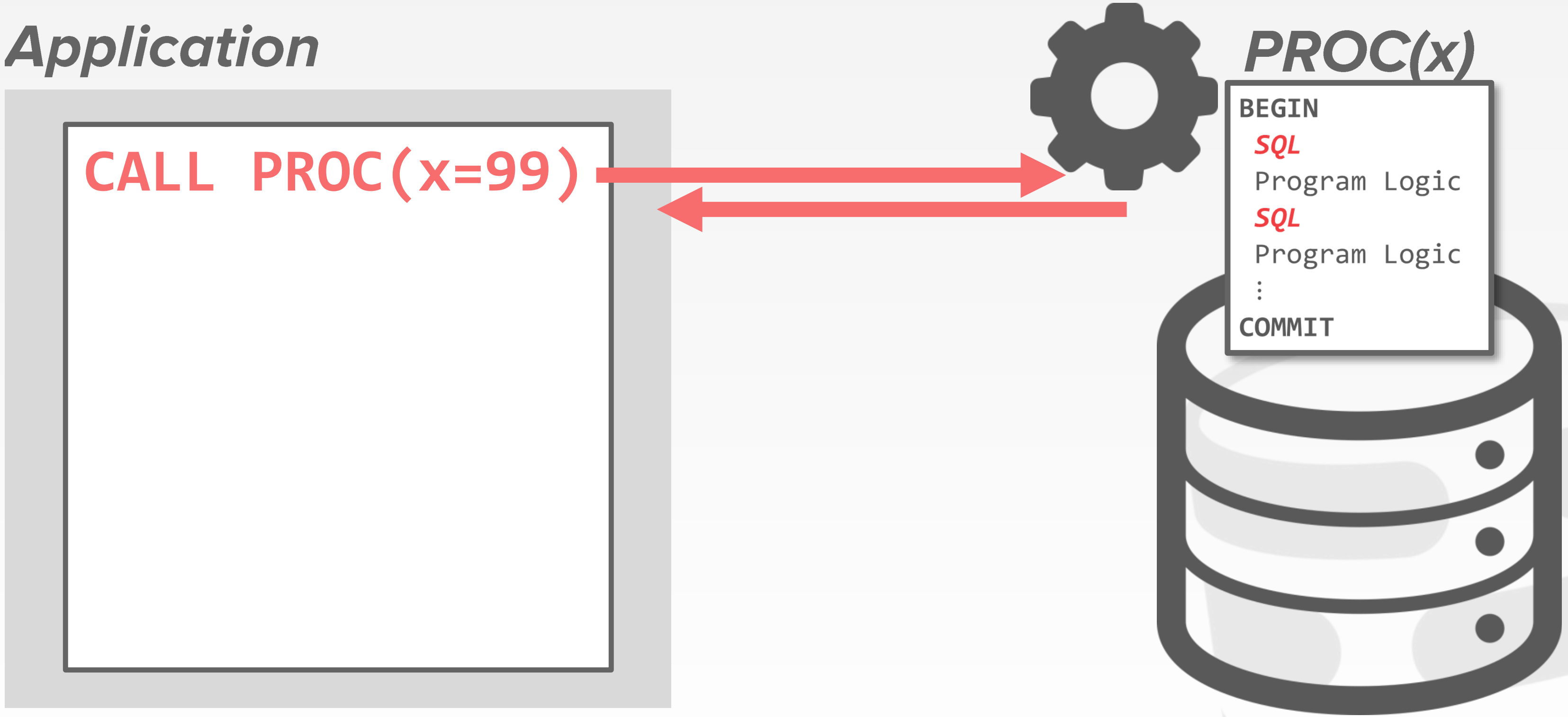
→ Can have many input/output parameters.
→ Can modify the database table/structures.
→ Not normally used within a SQL query.

STORED PROCEDURES

Application

```
BEGIN
  SQL
  Program Logic
  SQL
  Program Logic
  ⋮
COMMIT
```

STORED PROCEDURES



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 DEFINITION

Event Type:
- → INSERT
- → UPDATE
- → DELETE
- → TRUNCATE
- → CREATE
- → ALTER
- → DROP

Event Scope:
- → TABLE
- → DATABASE
- → VIEW
- → SYSTEM

Trigger Timing:
- → Before the statement executes.
- → After the statement executes
- → Before each row that the statement affects.
- → After each row that the statement affects.
- → Instead of the statement.

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
);
```

TRIGGER EXAMPLE

```
CREATE TABLE foo (
  id INT PRIMARY KE
  val VARCHAR(16)
);
```

```
CREATE TABLE foo_audit (
```

Tuple Versions

```
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;
```

TRIGGER EXAMPLE

```
CREATE TABLE foo (
  id INT PRIMARY KE
  val VARCHAR(16)
);
```

```
CREATE TABLE foo_audit (
```

```
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;
```

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

CHANGE NOTIFICATIONS

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: `LISTEN` + `NOTIFY`

NOTIFICATION EXAMPLE

```
CREATE OR REPLACE FUNCTION notify_foo_updates()
                    RETURNS trigger AS $$
  DECLARE notification JSON;
  BEGIN
    IF NEW.val <> OLD.val THEN
      notification = row_to_json(NEW);
      PERFORM pg_notify('foo_update',
                        notification::text);
    END IF;
    RETURN NEW;
  END;
$$ LANGUAGE plpgsql;
```

Notification Payload

```
CREATE TRIGGER foo_notify
   BEFORE UPDATE ON foo FOR EACH ROW
  EXECUTE PROCEDURE notify_foo_updates();
```

OBSERVATION

All DBMSs or less support all of the 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?

DATA SERIALIZATION

One potential solution is to just store the complex in its serialized form:

→ Java serialize, Python pickle
→ Google Protobuf, Facebook Thrift
→ JSON / XML

This has problems:

→ How do you edit a sub-element?
→ How does the optimizer estimate selectivity on predicates that access serialized data?
→ How do you execute aggregates and other functions on the serialized object?

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.**

USER-DEFINED TYPES

Each DBMS exposes a different API that allows you to create a UDT.

→ Oracle supports PL/SQL.
→ DB2 supports creating types based on built-in types.
→ MSSQL/Postgres only support type definition using external languages (.NET, C)

VIEWS

Creates a "virtual" table containing the output from a **SELECT** query.

Mechanism for hiding data from view of certain users.

Can be used to simplify a complex query that is executed often.
→ Won't make it faster though!

VIEW EXAMPLE (1)

Create a view of the CS student records with just their id, name, and login.

```
CREATE VIEW cs_students AS
  SELECT sid, name, login
    FROM student
   WHERE login LIKE '%@cs';
```

Original Table

sid	name	login	age	gpa
53666	Kanye West	kw@cs	40	3.5
53677	Justin Bieber	jb@ece	23	2.25
53688	Tone Loc	tloc@isr	51	3.8
53699	Andy Pavlo	pavlo@cs	36	3.0

View

sid	name	login
53666	Kanye West	kw@cs
53699	Andy Pavlo	pavlo@cs

VIEW EXAMPLE (2)

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.

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

```
SELECT AVG(gpa) AS avg_gpa
  INTO cs_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.

```
CREATE VIEW cs_gpa AS
  SELECT AVG(gpa) AS avg_gpa
    FROM student
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```

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

UPDATING VIEWS

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 automatically updated when the underlying tables change.

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

CONCLUSION

Moving application logic into the DBMS has lots of benefits.

→ Better Efficiency
→ Reusable across applications

But it has problems:

→ Not portable
→ PL/SQL is awkward to write.
→ DBAs don't like constant change.
→ Potentially need to maintain different versions.

NEXT CLASS

TRANSACTIONS!!!