PROCEDURAL LANGUAGE EXTENSIONS FOR THE PGSQL

PLpgSQL

Limitations of Basic SQL

What we have seen of SQL so far:

- data definition language (*create table(...)*)
- constraints (*domain, key, referential integrity*)
- query language (*select...from...where...*)
- views (give names to SQL queries)

This is not sufficient to write complete applications.

More extensibility and programmability are needed.

Extending SQL

Ways in which standard SQL might be extended:

- new data types (incl. constraints, I/O, indexes, ...)
- object-orientation
- more powerful constraint checking
- packaging/parameterizing queries
- more functions/aggregates for use in queries
- event-based triggered actions
- massive data, spread over a network

All are required to assist in application development.

SQL Data Types

SQL data definition language provides:

- atomic types: integer, float, character, boolean
- ability to define tuple types (*create table*)

SQL also provides mechanisms to define new types:

- basic types: CREATE DOMAIN
- tuple types: CREATE TYPE

SQL Data Types(cont.)

Defining an atomic type (as specialisation of existing type):

```
CREATE DOMAIN DomainName [ AS ] DataType
[ DEFAULT expression ]
[ CONSTRAINT ConstrName constraint ]
```

Example

```
create domain UnswCourseCode as text
check ( value ~ '[A - Z ]{4}[0 -9]{4} ' );
```

which can then be used like other SQL atomic types, e.g.

```
create table Course (
        id integer ,
        code UnswCourseCode ,
        ...
);
```

SQL Data Types(cont.)

Defining a tuple type:

```
CREATE TYPE TypeName AS
( AttrName1 DataType1 , AttrName2 DataType2 , ...)
```

Example

```
create type ComplexNumber as ( r float , i float );
create type CourseInfo as (
        course UnswCourseCode ,
        syllabus text ,
        lecturer text
);
```

If attributes need constraints, can be supplied by using a DOMAIN.

SQL Data Types(cont.)

Other ways that tuple types are defined in SQL:

- CREATE TABLE T (effectively creates tuple type T)
- CREATE VIEW V (effectively creates tuple type V)

CREATE TYPE is different from CREATE TABLE:

- does not create a new (empty) table
- does not provide for key constraints
- does not have explicit specification of domain constraints

Used for specifying return types of functions that return tuples or sets.

SQL as a Programming Language

SQL is a powerful language for manipulating relational data. But it is not a powerful programming language.

At some point in developing complete database applications

- we need to implement user interactions
- we need to control sequences of database operations
- we need to process query results in complex ways

and SQL cannot do any of these.

SQL cannot even do something as simple as factorial

What's wrong with SQL?

Consider the problem of withdrawal from a bank account:

If a bank customer attempts to withdraw more funds than they have in their account, then indicate ‘Insufficient Funds’, otherwise update the account.

An attempt to implement this in SQL

What's wrong with SQL?(cont.)

Solution:

```
select ' Insufficient Funds '
from Accounts
where acctNo = AcctNum and balance < Amount;

update Accounts
set balance = balance - Amount
where acctNo = AcctNum and balance >= Amount;

select ' New balance : ' || balance
from Accounts
where acctNo = AcctNum;
```

What's wrong with SQL?(cont.)

Two possible evaluation scenarios:

- displays ‘Insufficient Funds’, UPDATE has no effect, displays unchanged balance
- UPDATE occurs as required, displays changed balance

What's wrong with SQL? (cont.)

Some problems:

- SQL doesn't allow parameterisation (e.g. *AcctNum*)
- always attempts UPDATE, even when it knows it's invalid
- always displays balance, even when not changed

To accurately express the “business logic", we need facilities like conditional execution and parameter passing.

Database programming(cont.)

Database programming requires a combination of

- manipulation of data in DB (via SQL)
- conventional programming (via procedural code)

This combination is realised in a number of ways:

- passing SQL commands via a "call-level" interface
  (PL is decoupled from DBMS; most flexible; e.g. Java/JDBC, PHP)
- embedding SQL into augmented programming languages
  (requires PL pre-processor; typically DBMS-specific; e.g. SQL/C)
- special-purpose programming languages in the DBMS
  (integrated with DBMS; enables extensibility; e.g. PL/SQL, PLpgSQL)

Database programming(cont.)

Recap the example:

withdraw *amount* dollars from account *acctNum*

using a function with parameters *amount* and *acctNum*

returning two possible text results :

- 'Insufficient funds' if try to withdraw too much
- 'New balance *newAmount*' if withdrawal ok

an obvious side-effect is to change the stored balance

Requires a combination of

- SQL code to access the database
- procedural code to control the process

Database Programming(cont.)

Stored-procedure approach (PLpgSQL):

```
create function
        withdraw(acctNum text, amount integer) returns text as $$
declare bal integer;
begin
        select balance into bal
        from Accounts
        where acctNo = acctNum;
        if (bal < amount) then
                return 'Insufficient Funds';
        else
                update Accounts
                set balance = balance - amount
                where acctNo = acctNum;
                select balance into bal
                from Accounts where acctNo = acctNum;
                return 'New Balance: ' || bal;
        end if;
end;
$$ language plpgsql;
```

Stored Procedures

Stored procedures

- procedures/functions that are stored in DB along with data
- written in a language combining SQL and procedural ideas
- provide a way to extend operations available in database
- executed within the DBMS (close coupling with query engine)

Benefits of using stored procedures:

- minimal data transfer cost SQL ↔ procedural code
- user-defined functions can be nicely integrated with SQL
- procedures are managed like other DBMS data (ACID)
- procedures and the data they manipulate are held together

SQL/PSM

SQL/PSM is a 1996 standard for SQL stored procedures. (PSM = Persistent Stored Modules)

Syntax for PSM procedure/function dentitions:

```
CREATE PROCEDURE ProcName ( Params )
[ local declarations ]
procedure body ;

CREATE FUNCTION FuncName ( Params )
RETURNS Type
[ local declarations ]
function body ;
```

Parameters have three modes: IN, OUT, INOUT

PSM in Real DBMSs

Unfortunately, the PSM standard was developed after most DBMSs had their own stored procedure language -> No DBMS implements the PSM standard exactly.

IBM's DB2 and MySQL implement the SQL/PSM closely (but not exactly)

Oracle's PL/SQL is moderately close to the SQL/PSM standard

- syntax differences e.g. EXIT vs LEAVE, DECLARE only needed once, . . .
- extra programming features e.g. packages, exceptions, input/output

PostgreSQL's PLpgSQL is close to PL/SQL (95% compatible)

SQL Functions

PostgreSQL Manual: 35.4. Query Language (SQL) Functions

PostgreSQL allows functions to be defined in SQL

```
CREATE OR REPLACE FUNCTION
    funcName(arg1type, arg2type, ....)
    RETURNS rettype
AS $$
    SQL statements
$$ LANGUAGE sql;
```

SQL Functions(cont.)

Within the function, arguments are accessed as $1, $2, ...

Return value: result of the last SQL statement.

rettype can be any PostgreSQL data type (incl tuples,tables).

Function returning a table: returns setof *TupleType*

SQL Functions(cont.)

Examples:

```
-- max price of specified beer
create or replace function
    maxPrice(text) returns float
as $$
    select max(price) from Sells where beer = $1;
$$ language sql;
```

SQL Functions(cont.)

```
-- usage examples

select maxPrice('New');
maxprice
----------
2.8

select bar,price from sells
where beer='New' and price=maxPrice('New');
bar                price
---------------    -------
Marble Bar         2.8
```

SQL Functions(cont.)

Examples:

```
-- set of Bars from specified suburb
create or replace function
        hotelsIn(text) returns setof Bars
as $$
        select * from Bars where addr = $1;
$$ language sql;
```

SQL Functions(cont.)

```
-- usage examples
select * from hotelsIn('The Rocks');
```

name	addr	license
Australia Hotel	The Rocks	123456
Lord Nelson	The Rocks	123888

PLpgSQL

PostgreSQL Manual: Chapter 40: PLpgSQL

PLpgSQL = **P**rocedural **L**anguage extensions to **P**ost**g**re**SQL**

A PostgreSQL-specific language integrating features of:

- procedural programming and SQL programming

Functions are stored in the database with the data.

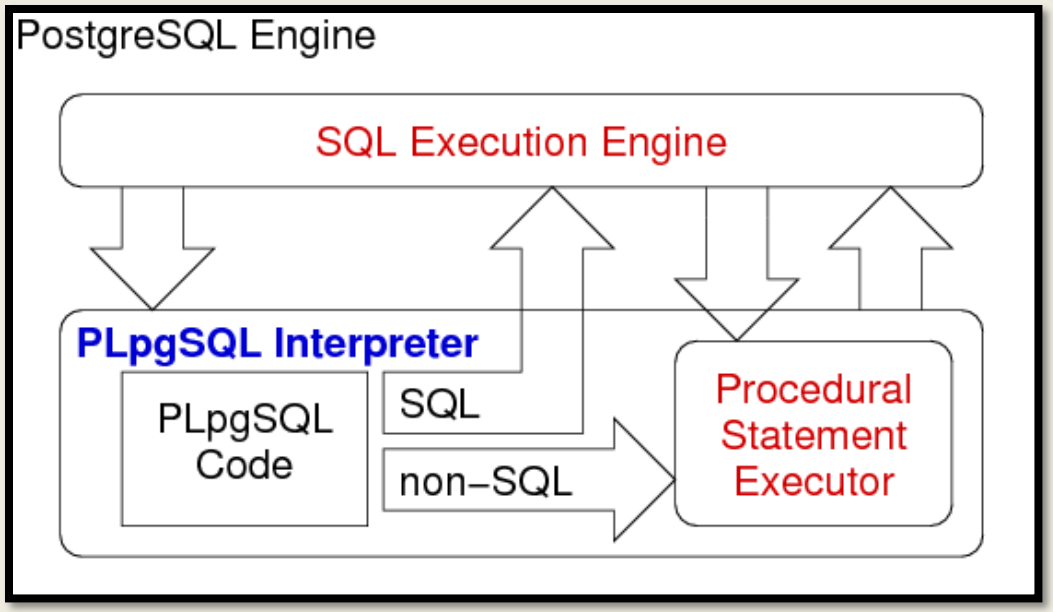
Provides a means for extending DBMS functionality, e.g.

- implementing constraint checking (triggered functions)
- complex query evaluation (e.g. recursive)
- complex computation of column values
- detailed control of displayed results

PLpgSQL(cont)

The PLpgSQL interpreter

- executes procedural code and manages variables
- calls PostgreSQL engine to evaluate SQL statements



Defining PLpgSQL Functions

PLpgSQL functions are created (and inserted into db) via:

```
CREATE OR REPLACE
    funcName(param1, param2, ....)
    RETURNS rettype
AS $$
DECLARE
    variable declarations
BEGIN
    code for function
END;
$$ LANGUAGE plpgsql;
```

Note: the entire function body is a single SQL string.

Defining PLpgSQL Functions(cont.)

Recap Stored-procedure approach (PLpgSQL):

```
create function
        withdraw(acctNum text, amount integer) returns text as $$
declare bal integer;
begin
        select balance into bal
        from Accounts
        where acctNo = acctNum;
        if (bal < amount) then
                return 'Insufficient Funds';
        else
                update Accounts
                set balance = balance - amount
                where acctNo = acctNum;
                select balance into bal
                from Accounts where acctNo = acctNum;
                return 'New Balance: ' || bal;
        end if;
end;
$$ language plpgsql;
```

PLpgSQL Function Parameters

All parameters are passed by value in PLpgSQL.

Within a function, parameters can be referred to:

- using positional notation ($1, $2, ...)
- via aliases, supplied either
  - as part of the function header (e.g. f(a int, b int))
  - as part of the declarations (e.g. a alias for $1; b alias for $2)

PLpgSQL Function Parameters(cont.)

Example: old-style function

```
CREATE OR REPLACE FUNCTION
        cat(text, text) RETURNS text
AS ‘
DECLARE
        x alias for $1; -- alias for parameter
        y alias for $2; -- alias for parameter
        result text; -- local variable
BEGIN
        result := x||""""||y;
        return result;
END;
‘ LANGUAGE ‘plpgsql’;
```

Beware: never give aliases the same names as attributes.

PLpgSQL Function Parameters(cont.)

Example: new-style function

```
CREATE OR REPLACE FUNCTION
        add(x text, y text) RETURNS text
AS $$
DECLARE
        result text; -- local variable
BEGIN
        result := x||""||y;
        return result;
END;
$$ LANGUAGE 'plpgsql';
```

Beware: never give aliases the same names as attributes.

PLpgSQL Function Parameters(cont.)

```
CREATE OR REPLACE FUNCTION
        add ( x anyelement , y anyelement ) RETURNS anyelement
AS $$
BEGIN
        return x + y ;
END ;
$$ LANGUAGE plpgsql ;
```

Restrictions: requires x and y to have values of the same “addable" type.

PLpgSQL Function Parameters(cont.)

PLpgSQL allows overloading (i.e. same name, different arg types)

Example

```
CREATE FUNCTION add ( int , int ) RETURNS int AS
$$ BEGIN return $1 + $2 ; END ; $$ LANGUAGE plpgsql ;

CREATE FUNCTION add ( int , int , int ) RETURNS int AS
$$ BEGIN return $1 + $2 + $3 ; END ; $$ LANGUAGE plpgsql ;

CREATE FUNCTION add ( char (1) , int ) RETURNS int AS
$$ BEGIN return ascii ( $1 )+ $2 ; END ; $$ LANGUAGE plpgsql ;
```

But must differ in arg types, so cannot also define:

```
CREATE FUNCTION add ( char (1) , int ) RETURNS char AS
$$ BEGIN return chr ( ascii ( $1 )+ $2 ); END ; $$ LANGUAGE plpgsql ;
```

i.e. cannot have two functions that look like add(char(1), int).

Function Return Types

A PostgreSQL function can return a value which is

- void (i.e. no return value)
- an atomic data type (e.g. integer, text, ...)
- a tuple (e.g. table record type or tuple type)
- a set of atomic values (like a table column)
- a set of tuples (i.e. a table)

A function returning a set of tuples is similar to a view.

Function Return Types(cont)

Examples of different function return types:

```
create type Employee as
        (id integer, name text, salary float, ...);

create function factorial(integer)
        returns integer ...
create function EmployeeOfMonth(date)
        returns Employee ...
create function allSalaries()
        returns setof float ...
create function OlderEmployees()
        returns setof Employee ...
```

Function Return Types(cont)

Different kinds of functions are invoked in different ways:

```
select factorial(5);
    -- returns one integer
select EmployeeOfMonth('2008-04-01');
    -- returns (x,y,z,...)
select * from EmployeeOfMonth('2008-04-01');
    -- one-row table
select * from allSalaries();
    -- single-column table
select * from OlderEmployees();
    -- subset of Employees
```

Using PLpgSQL Functions

PLpgSQL functions can be invoked in several ways:

- as part of a SELECT statement

```
select myFunction ( arg1 , arg2 );

select * from myTableFunction ( arg1 , arg2 );
```

- as part of the execution of another PLpgSQL function

```
PERFORM myVoidFunction ( arg1 , arg2 );

result := myOtherFunction ( arg1 );
```

- automatically, via an insert/delete/update trigger

```
create trigger T before update on R

for each row execute procedure myCheck ();
```

Special Data Types

by deriving a type from an existing database table, e.g.

```
account Accounts % ROWTYPE ;
```

Record components referenced via attribute name account.branchName%TYPE

Special Data Types(cont.)

Variables can also be defined in terms of:

- the type of an existing variable or table column
- the type of an existing table row (implict RECORD type)

Example

```
quantity INTEGER ;

start_qty quantity % TYPE ;

employee Employees % ROWTYPE ;

name Employees.name % TYPE ;
```

Control Structures

Assigment

- variable := expression;

Example:

```
tax := subtotal * 0.06;
my_record.user_id := 20;
```

Conditionals

- IF ... THEN
- IF ... THEN ... ELSE
- IF ... THEN ... ELSIF ... THEN ... ELSE

Example

```
IF v_user_id > 0 THEN
UPDATE users SET email = v_email WHERE user_id = v_user_id; END IF;
```

Control Structures(cont.)

Iteration

```
LOOP
    Satement
END LOOP ;
```

Example

```
LOOP
    IF count > 0 THEN
            -- some computations
    END IF;
END LOOP;
```

Control Structures(cont.)

Iteration

```
FOR int_var IN low .. high LOOP
    Satement
END LOOP ;
```

Example

```
FOR i IN 1..10 LOOP
    -- i will take on the values 1,2,3,4,5,6,7,8,9,10 within the loop
END LOOP;
```

SELECT ... INTO

Can capture query results via:

SELECT Exp1 , Exp2 , ... , Expn

INTO Var1 , Var2 , ... , Varn

FROM TableList

WHERE Condition ...

The semantics:

execute the query as usual

return “projection list" (Exp1, Exp2, ...) as usual

assign each Expi to corresponding Vari

SELECT ... INTO(cont.)

Assigning a simple value via SELECT ... INTO:

```
-- cost is local var , price is attr

SELECT price INTO cost

FROM StockList

WHERE item = ' Cricket Bat ';

cost := cost * (1 + tax_rate );

total := total + cost ;
```

Exceptions

Syntax

```
BEGIN
        Statements ...
EXCEPTION
        WHEN Exceptions1 THEN
                StatementsForHandler1
        WHEN Exceptions2 THEN
                StatementsForHandler2
        ...
END ;
```

Each Exceptionsi is an OR list of exception names, e.g.,

- division_by_zero OR floating_point_exception OR ...

Exceptions(cont.)

Example

```
-- table T contains one tuple ( ' Tom ' , ' Jones ')
DECLARE
        x INTEGER := 3;
BEGIN
        UPDATE T SET firstname = ' Joe ' WHERE lastname = ' Jones ';
        -- table T now contains ( ' Joe ' , ' Jones ')
        x := x + 1;
        y := x / y;  ---- y: = # of Tom Jones in Staff Table
EXCEPTION
        WHEN division_by_zero THEN
        -- update on T is rolled back to ( ' Tom ' , ' Jones ')
        RAISE NOTICE ' Caught division_by_zero ';
        RETURN x ;
        -- value returned is 4
END ;
```

Exceptions(cont.)

The RAISE operator generates server log entries, e.g.

- RAISE DEBUG ' Simple message ';
- RAISE NOTICE ' User = % ' , user_id ;
- RAISE EXCEPTION ' Fatal : value was % ' , value ;

There are several levels of severity:

- DEBUG, LOG, INFO, NOTICE, WARNING, and EXCEPTION
- not all severities generate a message to the client

Cursors

A cursor is a variable that can be used to access the result of a particular SQL query

Cursors move sequentially from row to row (cf., file pointers in C).

Employees

	Id	Name	Salary
	961234	John Smith	35000.00
cursor --->	954321	Kevin Smith	48000.00
	912222	David Smith	31000.00

Cursors(cont.)

Simplest way to use cursors: implicitly via FOR ... IN

Requires: RECORD variable or Table%ROWTYPE variable

Example:

```
CREATE FUNCTION totsal () RETURNS REAL AS $$
DECLARE
        emp RECORD ;
        total REAL := 0;
BEGIN
        FOR emp IN SELECT * FROM Employees
        LOOP
                total := total + emp . salary ;
        END LOOP ;
        RETURN total ;
END ; $$ LANGUAGE plpgsql ;
```

This style accounts for 95% of cursor usage.

Cursors(cont.)

Of course, the previous example would be better done as:

```
CREATE FUNCTION totsal () RETURNS REAL AS $$
DECLARE
    total REAL ;
BEGIN
    SELECT sum ( salary ) INTO total FROM Employees ;
    return total ;
END ; $$ LANGUAGE plpgsql ;
```

The iteration/summation can be done much more efficiently as an aggregation.

Cursors(cont.)

Basic operations on cursors: OPEN, FETCH, CLOSE

```
-- assume ... e CURSOR FOR SELECT * FROM Employees ;
OPEN e ;
LOOP
    FETCH e INTO emp ;
    EXIT WHEN NOT FOUND ;
    total := total + emp.salary ;
END LOOP ;
CLOSE e ;
```

Cursors(cont.)

The FETCH operation can also extract components of a row:

```
FETCH e INTO my_id , my_name , my_salary ;
```

There must be one variable, of the correct type, for each column in the result.

Triggers

Triggers are

- procedures stored in the database
- activated in response to database events (e.g. updates)

Examples of uses for triggers:

- maintaining summary data
- checking schema-level constraints (assertions) on update
- performing multi-table updates (to maintain assertions)

Triggers(cont.)

Triggers provide event-condition-action (ECA) programming:

- an event activates the trigger
- on activation, the trigger checks a condition
- if the condition holds, a procedure is executed (the action)

Triggers(cont.)

Consider two triggers and an INSERT statement

```
create trigger X before insert on T Code1;
create trigger Y after insert on T Code2;
insert into T values (a,b,c,...);
```

- Consider two triggers and an UPDATE statement

```
create trigger X before update on T Code1;
create trigger Y after update on T Code2;
update T set b=j,c=k where a=m;
```

Triggers in PostgreSQL

PostgreSQL triggers provide a mechanism for INSERT, DELETE or

UPDATE events to automatically activate PLpgSQL functions

Syntax for PostgreSQL trigger definition:

CREATE TRIGGER *TriggerName*

{AFTER|BEFORE} *Event1* [OR *Event2* ...]
ON *TableName*
[WHEN (*Condition*)]
FOR EACH {ROW|STATEMENT}
EXECUTE PROCEDURE *FunctionName*(*args*...);

Triggers in PostgreSQL(cont.)

PLpgSQL Functions for Triggers

CREATE OR REPLACE FUNCTION name () RETURNS TRIGGER ..

There is no restriction on what code can go in the function.

However

- RETURN OLD or RETURN new (depending on which version of the tuple is to be used)
- Raise an EXCEPTION. In that case, no change occurs

Trigger Example

Consider a database of people in the USA:

```
create table Person (
        id integer primary key,
        ssn varchar(11) unique,
        ... e.g. family, given, street, town ...
        state char(2), ...
 );
 create table States (
        id integer primary key,
        code char(2) unique,
        ... e.g. name, area, population, flag ...
 );
```

- Constraint: Person.state ∈ (select code from States), or exists (select id from States where code=Person.state)

Trigger Example(cont.)

Example: ensure that only valid state codes are used:

```
create trigger checkState before insert or update on Person for each row execute procedure
checkState();

create function checkState() returns trigger as $$
begin
        -- normalise the user-supplied value
        new.state = upper(trim(new.state));
        if (new.state !~ '^[A-Z][A-Z]$') then
                raise exception 'Code must be two alpha chars';
        end if;
        -- implement referential integrity check
        select * from States where code=new.state;
        if (not found) then
                raise exception 'Invalid code %',new.state;
        end if;
        return new;
end;
$$ language plpgsql;
```

Trigger Example(cont.)

Example: department salary totals

Scenario:

Employee(id, name, address, dept, salary, ...)

Department(id, name, manager, totSal, ...)

An assertion that we wish to maintain:

Department.totSal =

(select sum(e.salary) from Employee e where e.dept = d.id)))

Trigger Example(cont.)

Events that might affect the validity of the database

- a new employee starts work in some department
- an employee gets a rise in salary
- an employee changes from one department to another
- an employee leaves the company

A single assertion could check validity after each change.

With triggers, we have to program each case separately.

Each program implements updates to *ensure* assertion holds.

Trigger Example(cont.)

Implement the Employee update triggers from above in PostgreSQL:

Case 1: new employees arrive

```
create trigger TotalSalary1
after insert on Employees
for each row execute procedure totalSalary1();

create function totalSalary1() returns trigger
as $$
begin
        if (new.dept is not null) then
                update Department
                set totSal = totSal + new.salary
                where Department.id = new.dept;
        end if;
        return new;
end; $$ language plpgsql;
```

Trigger Example(cont.)

Case 2: employees change departments/salaries

```
create trigger TotalSalary2
after update on Employee
for each row execute procedure totalSalary2();


create function totalSalary2() returns trigger
as $$
begin
        update Department
        set totSal = totSal + new.salary
        where Department.id = new.dept;
        update Department set totSal = totSal - old.salary
        where Department.id = old.dept;
        return new;
end; $$ language plpgsql;
```

Trigger Example(cont.)

Case 3: employees leave

```
create trigger TotalSalary3
after delete on Employee
for each row execute procedure totalSalary3();

create function totalSalary3() returns trigger
as $$
begin
        if (old.dept is not null) then
                update Department
                set totSal = totSal - old.salary where Department.id = old.dept;
        end if;
        return old;
end; $$ language plpgsql;
```