PostgreSQL at the centre of your dataverse

Postgres Open 2011

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Who is Dave Page?

- Lead developer of pgAdmin
- postgresql.org webmaster and sysadmin

Senior Software Architect at EnterpriseDB, responsible for:
- PostgreSQL and component Installers
- Postgres Enterprise Manager
- Postgres Plus Standard Server
- PostgreSQL Solution Pack

Member of
- PostgreSQL Core Team
- PostgreSQL Europe Board of Directors
- PostgreSQL Community Association of Canada Board of Directors
Centre of my dataverse?

- Embarrassing “marketing moment”

Image credit: NASA/JPL-Caltech/ESA/Harvard-Smithsonian CfA
Why?

- Application integration
- Cross database/application reporting
- Data migration
- Data sharding
- Database federation
About SQL/MED
SQL/MED

- SQL standard for Management of External Data
- Specifies how external data sources are accessed from an SQL database
Before SQL/MED

- Import data into [temporary] tables:
  - COPY
  - psql scripts
  - Custom loader programs

- Stored functions/procedures:
  - PL/Proxy – primarily intended for advanced partitioning
  - DBI:Link – Perl project that uses views, functions and rules to make remote tables appear local
  - dblink – Contrib module allowing access to remote PostgreSQL servers
Disadvantages

- Custom loader/management code may be required
- May need to run batch tasks for incremental imports
- Data may not be presented as relations, but functions
- Custom stored functions may be required
- Different data sources may have different interfaces
With SQL/MED

- Data is presented to the user like any other table or relation
- Standardised set of object types and configuration commands used to setup and configure a remote data source
- Integrated credential management ensures usernames and passwords can be managed securely, for each role
- Deep integration with PostgreSQL’s planner for improved query planning and optimisation
Current Limitations

- Data is read only

- Planner limitations:
  - No defined API for qual (WHERE clause) push down
  - No join push down

- API deficiency: no simple way to pass complex data from the planner callback to the executor callbacks
Using SQL/MED
SQL Objects – Foreign Data Wrapper

Also known as an FDW

Defines the “type” or remote data source

Consists of:

• Handler function

• Validator function (optional)

Refers to both the SQL object, and less formally, the binary code that implements the interface to the remote data source
Relational DBMS FDWs

- **MySQL**
  - Written by Dave Page
  - [https://github.com/dpage/mysql_fdw](https://github.com/dpage/mysql_fdw)

- **ODBC**
  - Written by Zheng Yang (GSoC project)
  - [https://github.com/ZhengYang/odbc_fdw](https://github.com/ZhengYang/odbc_fdw)

- **Oracle**
  - Written by Laurenz Albe
  - [http://pgfoundry.org/projects/oracle-fdw](http://pgfoundry.org/projects/oracle-fdw)
NoSQL FDWs

▶ **CouchDB**
  - Written by Zheng Yang (GSoC project)
  - [https://github.com/ZhengYang/couchdb_fdw](https://github.com/ZhengYang/couchdb_fdw)

▶ **Redis**
  - Written by Dave Page
  - Includes experimental qual pushdown for key values
  - [https://github.com/dpage/redis_fdw](https://github.com/dpage/redis_fdw)
File FDWs

- **CSV**
  - Included as an extension with PostgreSQL 9.1
  - [http://www.postgresql.org/docs/9.1/static/file-fdw.html](http://www.postgresql.org/docs/9.1/static/file-fdw.html)

- **Text Array**
  - Written by Andrew Dunstan
  - Presents [ragged] CSV files as text[] data
  - [https://github.com/adunstan/file_text_array_fdw](https://github.com/adunstan/file_text_array_fdw)
Other FDWs

- **LDAP**
  - Written by Dickson S. Guedes
  - [https://github.com/guedes/ldap_fdw](https://github.com/guedes/ldap_fdw)

- **Twitter**
  - Written by Hitoshi Harada
  - [https://github.com/umitanuki/twitter_fdw](https://github.com/umitanuki/twitter_fdw)
Creating an FDW

Create the functions:

```sql
CREATE FUNCTION mysql_fdw_handler()
    RETURNS fdw_handler
    AS '$libdir/mysql_fdw'
    LANGUAGE C STRICT;

CREATE FUNCTION mysql_fdw_validator(text[], oid)
    RETURNS void
    AS '$libdir/mysql_fdw'
    LANGUAGE C STRICT;
```
Creating an FDW

Create the FDW object:

```
CREATE FOREIGN DATA WRAPPER mysql_fdw
    HANDLER mysql_fdw_handler
    VALIDATOR mysql_fdw_validator;
```
Creating an FDW

Or… use PostgreSQL 9.1’s EXTENSIONs mechanism:

CREATE EXTENSION mysql_fdw;
SQL Objects – Foreign Server

Defines a specific “server” or source of data, for example:

- A PostgreSQL database
- A MySQL server
- A Twitter account
- A delimited file

Each server uses one FDW. One FDW supports multiple servers.
Creating a Foreign Server

Create the foreign server object:

```
CREATE SERVER mysql_svr
    FOREIGN DATA WRAPPER mysql_fdw
    OPTIONS (address '127.0.0.1', port '3306');
```

mysql_fdw supports the following server options:

- **address** – The hostname or IP address of the MySQL server (default: 127.0.0.1)
- **port** – The port number that the MySQL server is listening on (default: 3306)
SQL Objects – Foreign Table

► Defines a “table” representing data on a foreign server, e.g:

- A PostgreSQL table or view
- A delimited file
- An SQL query against a MySQL database

► Each table uses one foreign server. Each server supports multiple tables

► The Foreign Table object may be used in PostgreSQL as a read-only table, e.g:

```
SELECT *
FROM foreign f JOIN local l ON (f.id = l.id)
ORDER BY f.name
```
Creating a Foreign Table

- Create the foreign table object:

```
CREATE FOREIGN TABLE tbl (c1 text, c2 text) SERVER mysql_svr;
```

- `mysql_fdw` supports the following table options:

  - `database` – The name of the MySQL database (optional)
  - `query` – An SQL query to return the desired data
  - `table` – The name of a table (quoted and qualified if needed) containing the desired data

Note: Either `table` or `query` must be specified, but not both.
SQL Objects – User Mapping

- Defines security information used to connect to a foreign server
- Other options may be specified, if the FDW supports it
- Each user mapping applies to one server. Each server supports multiple user mappings
- User mappings may be defined for “PUBLIC” or individual roles
Creating a User Mapping

- Create the user mapping object:

```
CREATE USER MAPPING FOR dpage
SERVER mysql_svr
OPTIONS (username 'dpage', password 'Foo');
```

- mysql_fdw supports the following user mapping options:
  - `username` – the username to use to connect to the MySQL server
  - `password` – the password corresponding to the username specified
Writing FDWs
Requirements – SQL Functions

- **Handler function**
  - Must be written in C
  - Provides pointers to callback functions in the FDW

- **Validator function**
  - Must be written in C
  - Optional
  - Validates options for:
    - *Foreign Data Wrapper*
    - *Foreign Servers*
    - *Foreign Tables*
    - *User Mappings*
Handler Function (pseudo code)

```c
/*
 * Foreign-data wrapper handler function: return a struct with pointers
 * to my callback routines.
 */

Datum
mysql_fdw_handler(PG_FUNCTION_ARGS)
{
    FdwRoutine  *fdwroutine = makeNode(FdwRoutine);

    fdwroutine->PlanForeignScan = mysqlPlanForeignScan;
    fdwroutine->ExplainForeignScan = mysqlExplainForeignScan;
    fdwroutine->BeginForeignScan = mysqlBeginForeignScan;
    fdwroutine->IterateForeignScan = mysqlIterateForeignScan;
    fdwroutine->ReScanForeignScan = mysqlReScanForeignScan;
    fdwroutine->EndForeignScan = mysqlEndForeignScan;

    PG_RETURN_POINTER(fdwroutine);
}
```
Requirements – SQL Functions

- **Handler function**
  - Must be written in C
  - Provides pointers to callback functions in the FDW

- **Validator function**
  - Must be written in C
  - Optional
  - Validates options for:
    - *Foreign Data Wrapper*
    - *Foreign Servers*
    - *Foreign Tables*
    - *User Mappings*
Validator Function (pseudo code)

/*
 * This tends to be a long and boring function, so here's some pseudo code
 * instead. See https://github.com/dpage/mysql_fdw/blob/master/mysql_fdw.c
 * for a working example.
 */

Datum mysql_fdw_validator(PG_FUNCTION_ARGS)
{
    List *options_list = untransformRelOptions(PG_GETARG_DATUM(0));
    Oid catalog = PG_GETARG_OID(1); /* Object type – table, user mapping etc. */

    foreach(option, options_list)
    {
        if(!mysqlIsValidOption(option, catalog)
            ereport(ERROR, (errcode(ERRCODE_FDW_INVALID_OPTION_NAME),
                errmsg("invalid option \"%s\"", option->name));

        /* If the option is valid, we may also want to validate the value... */
    }
}
Requirements – API Functions

► **PlanForeignScan**
  • Plans the foreign scan on the remote server
  • May or may not actually do anything remotely
  • Returns cost estimates to the planner

► **ExplainForeignScan**
  • Optionally adds additional data to EXPLAIN output

► **BeginForeignScan**
  • Performs initialisation required for the foreign scan
static FdwPlan *
mysqlPlanForeignScan(Oid foreigntableid, PlannerInfo *root, RelOptInfo *baserel)
{
    /* Connect to the remote server */
    MYSQL *conn = mysql_connect(server, port, username, password);

    /* Get statistics for the remote scan */
    rows = mysql_query("SELECT count(*) FROM table");

    /* Set the number of rows in the relation */
    baserel->rows = rows;

    /* Calculate a startup cost for the scan */
    fdwplan->startup_cost = 10;
    if (!IsLocal(server))
        fdwplan->startup_cost += 15;

    /* Finally, calculate the total cost */
    fdwplan->total_cost = rows + fdwplan->startup_cost;

    return fdwplan;
}
Requirements – API Functions

- **PlanForeignScan**
  - Plans the foreign scan on the remote server
  - May or may not actually do anything remotely
  - Returns cost estimates to the planner

- **ExplainForeignScan**
  - Optionally adds additional data to EXPLAIN output

- **BeginForeignScan**
  - Performs initialisation required for the foreign scan
static void
mysqlExplainForeignScan(ForeignScanState *node, ExplainState *es)
{
    /* Give some possibly useful info about startup costs, if needed */
    if (es->costs)
    {
        if (IsLocal(server))
            ExplainPropertyLong("Local server startup cost", 10, es);
        else
            ExplainPropertyLong("Remote server startup cost", 25, es);
    }
}
Requirements – API Functions

- **PlanForeignScan**
  - Plans the foreign scan on the remote server
  - May or may not actually do anything remotely
  - Returns cost estimates to the planner

- **ExplainForeignScan**
  - Optionally adds additional data to EXPLAIN output

- **BeginForeignScan**
  - Performs initialisation required for the foreign scan
static void
mysqlBeginForeignScan(ForeignScanState *node, int eflags)
{
    /* Connect to the remote server */
    MYSQL *conn = mysql_connect(server, port, username, password);

    /* Build the remote SQL query */
    query = sprintf(query, "SELECT * FROM %s", table);

    /* Stash away the state info for use by other API functions */
    festate = (MySQLFdwExecutionState *) palloc(sizeof(MySQLFdwExecutionState));
    node->fdw_state = (void *) festate;

    festate->conn = conn;
    festate->query = query;

    /* This will store the remote query result */
    festate->result = NULL;
}
Requirements – API Functions

- **IterateForeignScan**
  - Begin executing the foreign scan on first invocation
  - Returns one tuple per call

- **ReScanForeignScan**
  - Reset the scan to start again from the beginning

- **EndForeignScan**
  - Complete the foreign scan
  - Release resources
static TupleTableSlot *
mysqlIterateForeignScan(ForeignScanState *node)
{
    MySQLFdwExecutionState *festate = (MySQLFdwExecutionState *) node->fdw_state;
    TupleTableSlot *slot = node->ss.ss_ScanTupleSlot;

    /* Execute the query, if required */
    if (!festate->result)
        festate->result = mysql_query(festate->conn, festate->query);

    /* Get the next row from the remote server */
    row = mysql_fetch_row(festate->result);

    /* If there’s a row, convert to a tuple and store it in the slot */
    if (row)
    {
        ConvertMySqlRowToTuple(row, tuple);
        ExecStoreTuple(tuple, slot);
    }

    return slot;
}
Requirements – API Functions

- IterateForeignScan
  - Begin executing the foreign scan on first invocation
  - Returns one tuple per call

- ReScanForeignScan
  - Reset the scan to start again from the beginning

- EndForeignScan
  - Complete the foreign scan
  - Release resources
static void
mysqlReScanForeignScan(ForeignScanState *node)
{
    MySQLFdwExecutionState *festate = (MySQLFdwExecutionState *) node->fdw_state;

    /* Reset the scan so it can start over */
    mysql_free_result(festate->result);
    festate->result = NULL;
}
Requirements – API Functions

- **IterateForeignScan**
  - Begin executing the foreign scan on first invocation
  - Returns one tuple per call

- **ReScanForeignScan**
  - Reset the scan to start again from the beginning

- **EndForeignScan**
  - Complete the foreign scan
  - Release resources
EndForeignScan (pseudo code)

```c
static void
mysqlReScanForeignScan(ForeignScanState *node)
{
    MySQLFdwExecutionState *festate = (MySQLFdwExecutionState *) node->fdw_state;

    /* Cleanup the query string */
    pfree(festate->query);
    festate->query = NULL;

    /* Cleanup the scan result */
    mysql_free_result(festate->result);
    festate->result = NULL;

    /* Cleanup the remote connection */
    mysql_close(festate->conn);
    festate->conn = NULL;

    /* Cleanup the FDW state */
    pfree(festate);
    festate = NULL;
}
```
Using FDWs
Create the Objects

raptor:pgsql91 dpage$ bin/psql fdw
psql (9.1.0)
Type "help" for help.

fdw=# CREATE EXTENSION mysql_fdw;
CREATE EXTENSION
Create the Objects

```sql
raptor:pgsql91 dpage$ bin/psql fdw
psql (9.1.0)
Type "help" for help.

fdw=# CREATE EXTENSION mysql_fdw;
CREATE EXTENSION
fdw=# CREATE SERVER mysql_svr
fdw=#  FOREIGN DATA WRAPPER mysql_fdw
fdw=#  OPTIONS (address '127.0.0.1', port '3306');
CREATE SERVER
```
Create the Objects

```
raptor:pgsql91 dpage$ bin/psql fdw
psql (9.1.0)
Type "help" for help.

fdw=# CREATE EXTENSION mysql_fdw;
CREATE EXTENSION
fdw=# CREATE SERVER mysql_svr
fdw=# FOREIGN DATA WRAPPER mysql_fdw
fdw=# OPTIONS (address '127.0.0.1', port '3306');
CREATE SERVER
fdw=# CREATE FOREIGN TABLE employees (id integer,
fdw(# name text,
fdw(# address text)
fdw=# SERVER mysql_svr
fdw=# OPTIONS (table 'hr.employees');
CREATE FOREIGN TABLE
```
CREATE EXTENSION mysql_fdw;

CREATE SERVER mysql_svr
    FOREIGN DATA WRAPPER mysql_fdw
    OPTIONS (address '127.0.0.1', port '3306');

CREATE FOREIGN TABLE employees (id integer,
    name text,
    address text)
    SERVER mysql_svr
    OPTIONS (table 'hr.employees');

CREATE FOREIGN TABLE overtime_2010 (id integer,
    employee_id integer,
    hours integer)
    SERVER mysql_svr
    OPTIONS (query 'SELECT id, employee_id, hours FROM hr.overtime WHERE year = 2010;');
Run a Query

```sql
CREATE FOREIGN TABLE employees (
    id integer,
    name text,
    address text
) SERVER mysql_svr
OPTIONS (table 'hr.employees');

CREATE FOREIGN TABLE overtime_2010 (
    id integer,
    employee_id integer,
    hours integer
) SERVER mysql_svr
OPTIONS (query 'SELECT id, employee_id, hours FROM hr.overtime WHERE year = 2010;');

CREATE FOREIGN TABLE

SELECT * FROM employees;

<table>
<thead>
<tr>
<th>id</th>
<th>name</th>
<th>address</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dave Page</td>
<td>123 High Street, Oxford</td>
</tr>
<tr>
<td>2</td>
<td>John Smith</td>
<td>54 Church Lane, Glasgow</td>
</tr>
<tr>
<td>3</td>
<td>Fred Bloggs</td>
<td>3b Grouse Court, Birmingham</td>
</tr>
</tbody>
</table>

(3 rows)
```
Explain a Query

fdw=# CREATE FOREIGN TABLE overtime_2010 ( 
    id integer,
    employee_id integer,
    hours integer
)-# SERVER mysql_svr
-# OPTIONS (query 'SELECT id, employee_id, hours FROM hr.overtime WHERE year = 2010;');

CREATE FOREIGN TABLE
fdw=# SELECT * FROM employees;

<table>
<thead>
<tr>
<th>id</th>
<th>name</th>
<th>address</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dave Page</td>
<td>123 High Street, Oxford</td>
</tr>
<tr>
<td>2</td>
<td>John Smith</td>
<td>54 Church Lane, Glasgow</td>
</tr>
<tr>
<td>3</td>
<td>Fred Bloggs</td>
<td>3b Grouse Court, Birmingham</td>
</tr>
</tbody>
</table>

(3 rows)

fdw=# EXPLAIN SELECT * FROM employees;

QUERY PLAN

Foreign Scan on employees (cost=10.00..13.00 rows=3 width=68)
    Local server startup cost: 10
    MySQL query: SELECT * FROM hr.employees

(3 rows)
Run another Query

```
fdw=# SELECT * FROM employees;
   id |    name     |           address
----------------+----------------------------------------------------------
     1 | Dave Page   | 123 High Street, Oxford
     2 | John Smith  | 54 Church Lane, Glasgow
     3 | Fred Bloggs | 3b Grouse Court, Birmingham
(3 rows)
```

```
fdw=# EXPLAIN SELECT * FROM employees;
    QUERY PLAN

------------------------------------------------------------------
Foreign Scan on employees  (cost=10.00..13.00 rows=3 width=68)
  Local server startup cost: 10
  MySQL query: SELECT * FROM hr.employees
(3 rows)
```

```
fdw=# SELECT e.id, e.name, hours FROM employees e LEFT OUTER JOIN overtime_2010 o ON (e.id = o.employee_id);
   id |    name     |     hours
----------------+-------------+---------
     1 | Dave Page   |    23
     2 | John Smith  |         
     3 | Fred Bloggs |    14
(3 rows)
```
Explain another Query

<table>
<thead>
<tr>
<th>id</th>
<th>name</th>
<th>hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dave Page</td>
<td>23</td>
</tr>
<tr>
<td>2</td>
<td>John Smith</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Fred Bloggs</td>
<td>14</td>
</tr>
</tbody>
</table>

(3 rows)

fdw=# EXPLAIN SELECT e.id, e.name, hours FROM employees e LEFT OUTER JOIN overtime_2010 o ON (e.id = o.employee_id);

QUERY PLAN

--------------------------------------------------------------------------------------------------------------------------
Nested Loop Left Join (cost=20.00..25.09 rows=3 width=40)
  Join Filter: (e.id = o.employee_id)
    -> Foreign Scan on employees e (cost=10.00..13.00 rows=3 width=36)
      Local server startup cost: 10
      MySQL query: SELECT * FROM hr.employees
    -> Materialize (cost=10.00..12.01 rows=2 width=8)
      -> Foreign Scan on overtime_2010 o (cost=10.00..12.00 rows=2 width=8)
        Local server startup cost: 10
        MySQL query: SELECT id, employee_id, hours FROM hr.overtime WHERE year = 2010;

(9 rows)
Questions?
Thank you!