Writing A Foreign Data Wrapper

Bernd Helmle, bernd.helmle@credativ.de

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Why FDWs?

- ...it is in the SQL Standard (SQL/MED)
- ...migration
- ...heterogeneous infrastructure
- ...integration of remote non-relational datasources
- ...fun

`http://rhaas.blogspot.com/2011/01/why-sqlmed-is-cool.html`

Access remote datasources as PostgreSQL tables...

```
CREATE EXTENSION IF NOT EXISTS informix_fdw;

CREATE SERVER sles11_tcp FOREIGN DATA WRAPPER informix_fdw OPTIONS (
    informixdir '/Applications/IBM/informix',
    informixserver 'ol_informix1170'
);

CREATE USER MAPPING FOR bernd SERVER sles11_tcp OPTIONS (
    password 'informix',
    username 'informix'
);

CREATE FOREIGN TABLE bar (
    id integer,
    value text
)
SERVER sles11_tcp
OPTIONS (
    client_locale 'en_US.utf8',  database 'test',
    db_locale 'en_US.819', query 'SELECT * FROM bar'
);

SELECT * FROM bar;
```

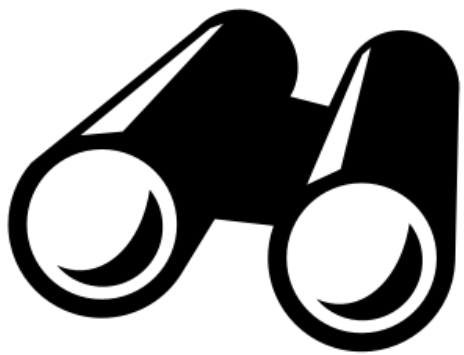
What we need...

- ...a C-interface to our remote datasource
- ...knowledge about PostgreSQL's FDW API
- ...an idea how we deal with errors
- ...how remote data can be mapped to PostgreSQL datatypes
- ...time and steadiness

Python-Gurus also could use `http://multicorn.org/`.

Before you start your own...

Have a look at
`http://wiki.postgresql.org/wiki/Foreign_data_wrappers`



Let's start...

```
extern Datum ifx_fdw_handler(PG_FUNCTION_ARGS);
extern Datum ifx_fdw_validator(PG_FUNCTION_ARGS);

CREATE FUNCTION ifx_fdw_handler() RETURNS fdw_handler
AS 'MODULE_PATHNAME'
LANGUAGE C STRICT;

CREATE FUNCTION ifx_fdw_validator(text[], oid) RETURNS void
AS 'MODULE_PATHNAME'
LANGUAGE C STRICT;

CREATE FOREIGN DATA WRAPPER informix_fdw
  HANDLER ifx_fdw_handler
  VALIDATOR ifx_fdw_validator;
```

FDW handler

Creates and initializes a FdwRoutine structure:

```
Datum
ifx_fdw_handler(PG_FUNCTION_ARGS)
{
    FdwRoutine *fdwRoutine = makeNode(FdwRoutine);
    fdwRoutine->ExplainForeignScan = ifxExplainForeignScan;
    fdwRoutine->BeginForeignScan   = ifxBeginForeignScan;
    fdwRoutine->IterateForeignScan = ifxIterateForeignScan;
    fdwRoutine->EndForeignScan     = ifxEndForeignScan;
    fdwRoutine->ReScanForeignScan  = ifxReScanForeignScan;

#if PG_VERSION_NUM < 90200

    fdwRoutine->PlanForeignScan    = ifxPlanForeignScan;

#else

    fdwRoutine->GetForeignRelSize = ifxGetForeignRelSize;
    fdwRoutine->GetForeignPaths   = ifxGetForeignPaths;
    fdwRoutine->GetForeignPlan    = ifxGetForeignPlan;

#endif
```

FDW validator callback

- Called via `CREATE FOREIGN TABLE` or `ALTER FOREIGN TABLE`
- Validates a `List *` of FDW options.
- Use `untransformRelOptions()` to get a list of FDW options
- Don't forget to test for duplicated options!
- Up to you which options you want to support

Helper functions

Functions to ease access to FDW options

```
foreign/foreign.h

extern ForeignServer *GetForeignServerByName(const char *name,
                                             bool missing_ok);

extern UserMapping *GetUserMapping(Oid userid, Oid serverid);

extern ForeignDataWrapper
*GetForeignDataWrapperByName(const char *name,
                             bool missing_ok);

extern ForeignTable *GetForeignTable(Oid relid);

extern Oid  get_foreign_data_wrapper_oid(const char *fdwname,
                                         bool missing_ok);
extern Oid  get_foreign_server_oid(const char *servername,
                                   bool missing_ok);
```

FDW API callback routines (1)

```
#ifdef PG_VERSION_NUM < 90200

static FdwPlan *PlanForeignScan(Oid foreignTableOid,
                                PlannerInfo *planInfo,
                                        RelOptInfo *baserel);
#else

static void GetForeignRelSize(PlannerInfo *root,
                                  RelOptInfo *baserel,
                                  Oid foreignTableId);
static void GetForeignPaths(PlannerInfo *root,
                                RelOptInfo *baserel,
                                Oid foreignTableId);
static ForeignScan *GetForeignPlan(PlannerInfo *root,
                                        RelOptInfo *baserel,
                                        Oid foreignTableId,
                                        ForeignPath *best_path,
                                        List *tlist,
                                        List *scan_clauses);

#endif
```

FDW API callback routines (2)

```
static void ExplainForeignScan(ForeignScanState *node,
                               ExplainState *es);

static void BeginForeignScan(ForeignScanState *node, int eflags);

static TupleTableSlot *IterateForeignScan(ForeignScanState *node);

static void EndForeignScan(ForeignScanState *node);
```

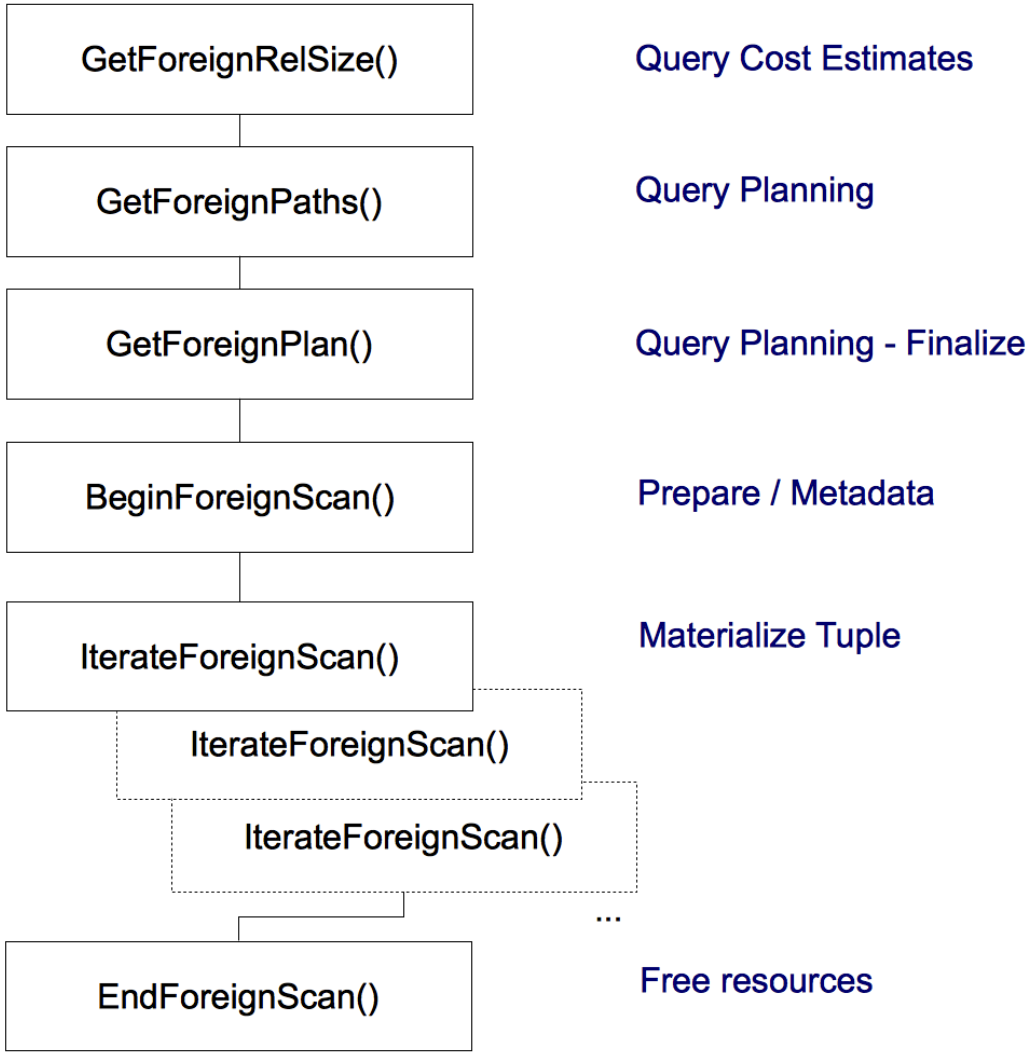
FDW API callback routines (3)

9.2 has callbacks for `ANALYZE`, too:

```
bool
AnalyzeForeignTable (Relation relation,
                     AcquireSampleRowsFunc *func,
                     BlockNumber *totalpages);

int
AcquireSampleRowsFunc (Relation relation, int elevel,
                       HeapTuple *rows, int targrows,
                       double *totalrows,
                       double *totaldeadrows);
```

FDW Flow


GetForeignRelSize()
Query Cost Estimates
GetForeignPaths()
Query Planning
GetForeignPlan()
Query Planning - Finalize
BeginForeignScan()
Prepare / Metadata
IterateForeignScan()
Materialize Tuple
IterateForeignScan()
IterateForeignScan()
...
EndForeignScan()
Free resources

FDW Query Planning

- Setup and Planning a scan on a foreign datasource
- E.g. establish and cache remote connection
- Initialize required supporting structures for remote access
- Planner info and cost estimates via `baserel` and `root` parameters.
- Big differences between 9.1 and 9.2 API

GetForeignRelSize() (1)

- Size restimates for remote datasource (table size, ...)
- `root`: Query Information Structure
- `baserel`: Table Information Structure, carry your FDW private information in `baserel->fdw_private`.
- Sets cost values

GetForeignRelSize() (2)

Save plan costs and estimates in baserel structure.

```
baserel->rows = ifxGetEstimatedNRows(&coninfo);
baserel->width = ifxGetEstimatedRowSize(&coninfo);
planState->coninfo   = coninfo;
planState->state     = state;
baserel->fdw_private = (void *) planState;
```

GetForeignPaths() (1)

- Create access path for foreign datasource.
- `ForeignPath` access path required at least.
- Multiple paths possible (e.g. presorted results, ...)
- Arbitrarily complex

GetForeignPaths() (2)

```
planState = (IfxFdwPlanState *) baserel->fdw_private;

/*
 * Create a generic foreign path for now. We need to consider any
 * restriction quals later, to get a smarter path generation here.
 *
 * For example, it is quite interesting to consider any index scans
 * or sorted output on the remote side and reflect it in the
 * choosen paths (helps nested loops et al.).
 */
add_path(baserel, (Path *)
         create_foreignscan_path(root, baserel,
            baserel->rows,
            planState->coninfo->planData.costs,
            planState->coninfo->planData.costs,
            NIL,
            NULL,
            NIL));
```

GetForeignPlan() (1)

- Creates a final ForeignScan plan node based on paths created by GetForeignPaths()
- Additional parameters
- ForeignPath *best_path: Choosen foreign access path (best)
- List *tlist: Target list
- List *scan_clauses: Restriction clauses enforced by the plan

GetForeignPlan() (2)

ForeignScan plan node should be created by make_foreignscan():

```
ForeignScan *
make_foreignscan(List *qptlist,
                 List *qpqual,
                 Index scanrelid,
                 List *fdw_exprs,
                 List *fdw_private)
```

- fdw_exprs: Expressions to be evaluated by the planner
- fdw_private: Private FDW data

Passing FDW planning info to execution state

- Save parameters in the `foreignScan->fdw_private` pointer.
- Must be copieable with `copyObject`.
- Use a `List *` with either `bytea` or/and constant values (via `makeConst`).

```
List *plan_values;

plan_values = NIL;
plan_values = lappend(plan_values,
                      makeConst(BYTEAOID, -1, InvalidOid, -1,
                                PointerGetDatum(ifxFdwPlanDataAsBytea(coninfo)),
                                false, false));
plan->fdw_private = plan_values;
```

Predicate Pushdown

Challenge: Filter the data on the remote dataset before transferring them, e.g.

```
SELECT COUNT(*) FROM sles11.inttest;
 count
-------
 10001
(1 row)

EXPLAIN SELECT * FROM foo
                  JOIN (SELECT f1 FROM sles11.inttest
                        WHERE f1 = 104 AND f2 = 120) AS t(id)
                       ON (t.id = foo.id);
                                  QUERY PLAN
------------------------------------------------------------------------------
 Nested Loop  (cost=1.00..9.28 rows=1 width=12)
   ->  Index Only Scan using foo_id_idx on foo  (cost=0.00..8.27 rows=1 width=4)
         Index Cond: (id = 104)
   ->  Foreign Scan on inttest  (cost=1.00..1.00 rows=1 width=8)
         Filter: ((f1 = 104) AND (f2 = 120))
         Informix query: SELECT * FROM inttest WHERE   (f1 = 104) AND (f2 = 120)
(6 rows)
```

Predicate Pushdown

- Nobody wants to filter thousands of rows to just get one
- Idea: push filter conditions down to the foreign datasource (if possible)
- Done during planning phase (`GetForeignRelSize()`, `GetForeignPaths()`)
- `baserel->baserestrictinfo`
- Hard to get it right

Predicate Pushdown

- `baserel->baserestrictinfo`: List of predicates belonging to the foreign table (logically AND'ed)
- `baserel->reltargetlist`: List of columns belonging to the foreign table
- Have a look at `expression_tree_walker()` and ruleutils API (`include/nodes/nodeFuncs.h`, `include/utils/ruleutils.h`)

```
ListCell *cell;

foreach(cell, baserel->baserestrictinfo)
{
    RestrictInfo *info;
    info = (RestrictInfo *) lfirst(cell);

    if (IsA(info->clause, OpExpr))
    {
        /* examine right and left operand */
    }
}
```

BeginForeignScan()

```
void
BeginForeignScan (ForeignScanState *node,
                  int eflags);
```

- Execute startup callback for the FDW.
- Basically prepares the FDW for executing a scan.
- `ForeignScanState` saves function state values.
- Use `node->fdw_state` to assign your own FDW state structure.
- Must handle `EXPLAIN` and `EXPLAIN ANALYZE` by checking `eflags & EXEC_FLAG_EXPLAIN_ONLY`

ExplainForeignScan()

```
void
ExplainForeignScan (ForeignScanState *node,
                    ExplainState *es);
```

- Only ran when `EXPLAIN` is used.
- "Injects" `EXPLAIN` information.
- If there's no additional information, just return
- E.g. calculated connection costs, timings etc.

IterateForeignScan() (1)

```
TupleTableSlot *
IterateForeignScan (ForeignScanState *node);
```

- Fetches data from the remote source.
- Data conversion
- Materializes a physical or virtual tuple to be returned.
- Needs to return an empty tuple when done.

IterateForeignScan() (2)

Returning a virtual tuple

```
TupleTableSlot *slot = node->ss.ss_ScanTupleSlot;

slot->tts_isempty = false;
slot->tts_nvalid = number_cols;;
slot->tts_values = (Datum *)palloc(sizeof(Datum) * slot->tts_nvalid);
slot->tts_isnull = (bool *)palloc(sizeof(bool) * slot->tts_nvalid);

for (i = 0; j < attrCount - 1; i)
{
    tupleSlot->tts_isnull[i] = false;
    tupleSlot->tts_values[i] = PointerGetDatum(val);
}
```

ReScanForeignScan()

```
void ReScanForeignScan (ForeignScanState *node);
```

- Prepares the FDW to handle a rescan
- Begins the scan from the beginning
- Must take care for changed query parameters!
- Better to just “instruct” `IterateForeignScan()` to do the right thing (tm)

EndForeignScan()

```
void
EndForeignScan (ForeignScanState *node);
```

- Run when `IterateForeignScan` returns no more rows
- Finalizes the remote scan
- Close result sets, handles, connection, free memory, etc...

Memory Management

- PostgreSQL uses `palloc()`
- Memory is allocated in `CurrentMemoryContext`
- Use your own MemoryContext where necessary (e.g. `IterateForeignScan()`)
- Memory allocated in external libraries need special care

Data conversion

- Easy, if the remote datasource delivers a well formatted value string (e.g. date strings formatted as `yyyy-mm-dd`).
- Use type input function directly
- Binary compatible types (e.g integer)
- Binary data should always be `bytea`
- String data must have a valid encoding!

Data conversion - Encoding

- Within a FDW, a backend acts like any other client: ensure encoding compatibility or encode your string data properly.
- A look at `mb/pg_wchar.h` might be of interest.
- `GetDatabaseEncoding()`
- `pg_do_encoding_conversion()`

Data conversion - Get type input function

```
regproc result;
HeapTuple type_tuple;

type_tuple = SearchSysCache1(TYPEOID, inputOid);
if (!HeapTupleIsValid(type_tuple))
{
    /*
     * Oops, this is not expected...
     */
    ifxRewindCallstack(&(state->stmt_info));
    elog(ERROR,
         "cache lookup failed for input function for type %u", inputOid);
}

ReleaseSysCache(type_tuple);
result = ((Form_pg_type) GETSTRUCT(type_tuple))->typinput;
```

Data conversion - Calling type input functions

Once having its OID, any type input function can be called like this:

```
/* errors out */
typinputfunc = getTypeInputFunction(state, PG_ATTRTYPE_P(state, attnum));
result = OidFunctionCall2(typinputfunc,
                          CStringGetDatum(buf),
                          ObjectIdGetDatum(InvalidOid));
```

Error Handling (1)

- Set FDW SQLSTATE according to your error condition *class HV*, see *http://www.postgresql.org/docs/9.1/static/errcodes-appendix.html*
- Alternative: map remote error conditions to PostgreSQL errors
- Be careful with `elog(ERROR, ...)`.

Error Handling (2)

Example (there is no FDW_WARNING SQLSTATE):

```
if (err == IFX_CONNECTION_WARN)
{
    IfxSqlStateMessage message;
    ifxGetSqlStateMessage(1, &message);

    ereport(WARNING, (errcode(WARNING),
                      errmsg("opened informix connection with warnings"),
                      errdetail("informix SQLSTATE %s: \"%s\"",
                                message.sqlstate, message.text)));
}
```

Catching Errors (1)

- Sometimes necessary to catch backend errors
- Synchronize error conditions between PostgreSQL and remote datasource
- Possibility: use a `PG_TRY...PG_CATCH` block.

Catching Errors (2)

```
PG_TRY();
{
    ...
    typinputfunc = getTypeInputFunction(state, PG_ATTRTYPE_P(state, attnum));
    result = OidFunctionCall2(typinputfunc,
      CStringGetDatum(pstrdup(buf)),
      ObjectIdGetDatum(InvalidOid));
}
PG_CATCH();
{
    ifxRewindCallstack(&(state->stmt_info));
    PG_RE_THROW();
}
PG_END_TRY();
```

Thank You!