Writing A Foreign Data Wrapper

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8. November 2013

Why FDWs?

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

`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;
```

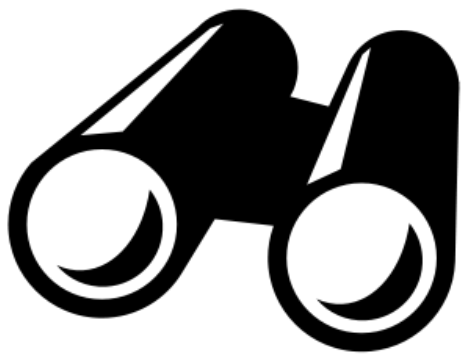
What we need...

- ...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`



Implementation example

`https://github.com/credativ/informix_fdw`

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, example:

```
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 handler

...and much more callbacks for DML with PostgreSQL 9.3

```
Datum
ifx_fdw_handler(PG_FUNCTION_ARGS)
{
  [...]

   #if PG_VERSION_NUM >= 90300

   fdwRoutine->AddForeignUpdateTargets = ifxAddForeignUpdateTargets;
   fdwRoutine->PlanForeignModify       = ifxPlanForeignModify;
   fdwRoutine->BeginForeignModify      = ifxBeginForeignModify;
   fdwRoutine->ExecForeignInsert       = ifxExecForeignInsert;
   fdwRoutine->ExecForeignDelete       = ifxExecForeignDelete;
   fdwRoutine->ExecForeignUpdate       = ifxExecForeignUpdate;
   fdwRoutine->EndForeignModify        = ifxEndForeignModify;
   fdwRoutine->IsForeignRelUpdatable   = ifxIsForeignRelUpdatable;

   #endif

   PG_RETURN_POINTER(fdwRoutine);
}
```

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
- Have a look into `foreign/foreign.h` for various helper functions

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 API callback routines (4)

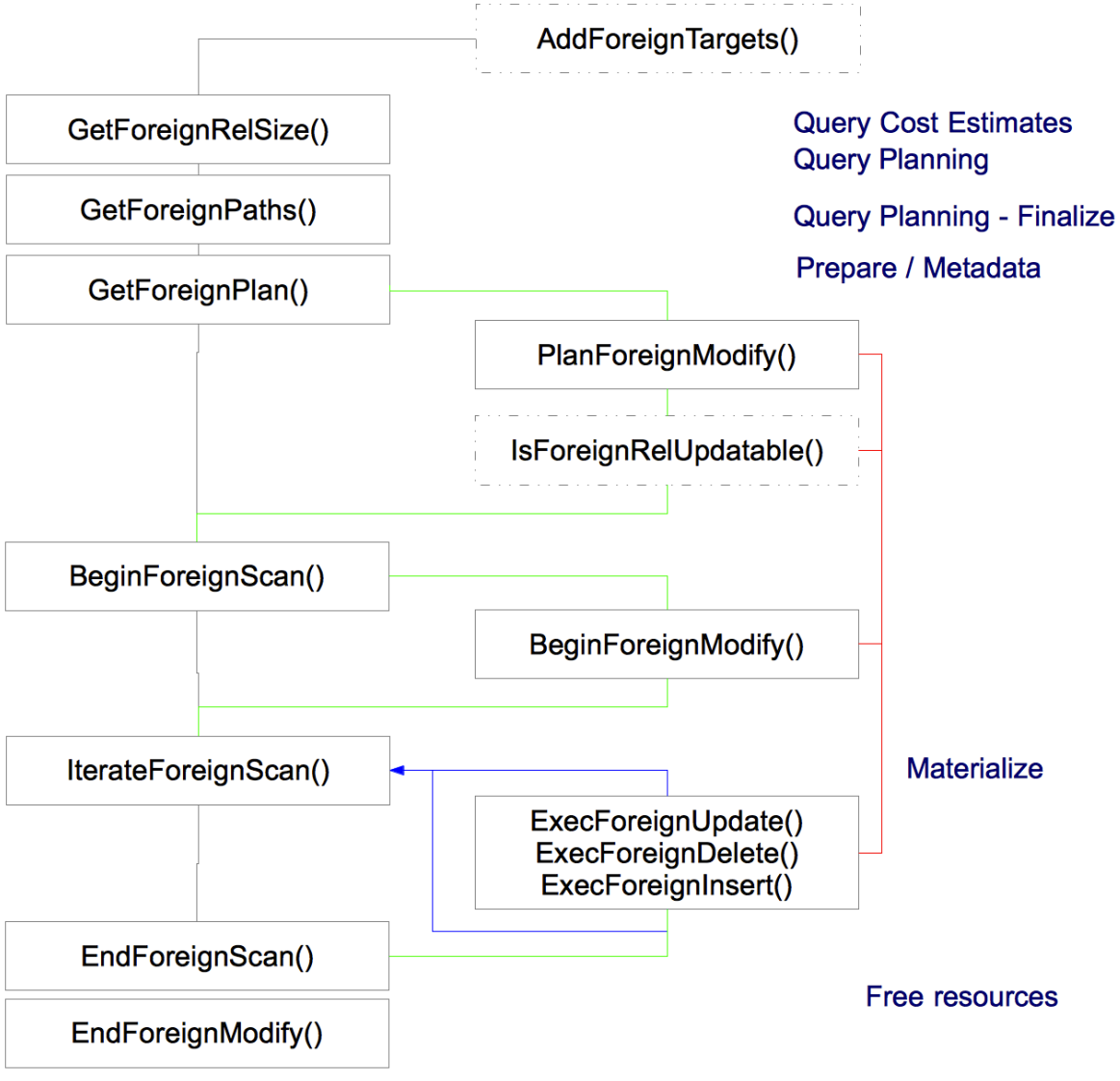
9.3 introduces callbacks for DML actions

```
#if PG_VERSION_NUM >= 90300

fdwRoutine->AddForeignUpdateTargets = ifxAddForeignUpdateTargets;
fdwRoutine->PlanForeignModify       = ifxPlanForeignModify;
fdwRoutine->BeginForeignModify      = ifxBeginForeignModify;
fdwRoutine->ExecForeignInsert       = ifxExecForeignInsert;
fdwRoutine->ExecForeignDelete       = ifxExecForeignDelete;
fdwRoutine->ExecForeignUpdate       = ifxExecForeignUpdate;
fdwRoutine->EndForeignModify        = ifxEndForeignModify;
fdwRoutine->IsForeignRelUpdatable   = ifxIsForeignRelUpdatable;
fdwRoutine->ExplainForeignModify    = ifxExplainForeignModify;

#endif
```

FDW Flow


AddForeignTargets()
GetForeignRelSize()
GetForeignPaths()
GetForeignPlan()
PlanForeignModify()
IsForeignRelUpdatable()
BeginForeignScan()
BeginForeignModify()
IterateForeignScan()
ExecForeignUpdate()
ExecForeignDelete()
ExecForeignInsert()
EndForeignScan()
EndForeignModify()
Query Cost Estimates
Query Planning
Query Planning - Finalize
Prepare / Metadata
Materialize
Free resources

AddForeignTargets

```
static void
ifxAddForeignUpdateTargets(Query *parsetree,
   RangeTblEntry *target_rte,
   Relation target_relation);
```

- *Injects* a custom column into the parsetree for `DELETE` and `UPDATE` commands.
- Can be NULL in case `DELETE` is not supported or `UPDATE` actions rely on unchanged unique keys.

FDW Query Planning

- Setup and Planning a scan or modify action 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, DML introduced with 9.3 API

GetForeignRelSize() (1)

- Size estimates for remote datasource (table size, number of rows, ...)
- `root`: Query Information Structure
- `baserel`: Table Information Structure, carry your FDW private information in `baserel->fdw_private`.
- `baserel->fdw_private` is a pointer to your state data structure.

GetForeignRelSize() (2)

```
baserel->rows         = ifxGetEstimatedNRows(&coninfo);
baserel->width        = ifxGetEstimatedRowSize(&coninfo);
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));
```

Predicate Pushdown

Challenge: Filter the data on the remote dataset before transferring them

- Nobody wants to filter thousands of rows to just get one
- Idea: push filter conditions down to the foreign datasource (if possible)
- Ideally 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 */
    }
}
```

Predicate Pushdown, Example

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

EXPLAIN SELECT * FROM foo JOIN centosifx.inttest t
                           ON (t.f1 = foo.id)
        WHERE t.f1 = 104 AND t.f2 = 120;

                                    QUERY PLAN
-------------------------------------------------------------------------------
 Nested Loop  (cost=2.00..1695.03 rows=1 width=18)
   ->  Seq Scan on foo  (cost=0.00..1693.01 rows=1 width=4)
         Filter: (id = 104)
   ->  Foreign Scan on inttest t  (cost=2.00..2.01 rows=1 width=14)
         Filter: ((f1 = 104) AND (f2 = 120))
         Informix costs: 2.00
         Informix query: SELECT * FROM inttest WHERE (f1 = 104) AND (f2 = 120)
(7 rows)
```

PlanForeignModify

- Create modify state information, e.g. get a connection, describe remote metadata, ...
- Private state information attached to `ModifyTable` plan node
- State information pushed down to `BeginForeignModify`
- Same with planning a scan: private state information must be in a `List *` format.
- **INSERT** probably needs more work here (connection preparing, ...)

PlanForeignModify - Access scan state

Possible to access the scan state created during planning phase

```
static List *
ifxPlanForeignModify(PlannerInfo *root,
                     ModifyTable *plan,
                     Index resultRelation,
                     int subplan_index)
{
    if ((resultRelation < root->simple_rel_array_size)
        && (root->simple_rel_array[resultRelation] != NULL))
    {
        RelOptInfo *relInfo = root->simple_rel_array[resultRelation];
        IfxFdwExecutionState *scan_state;

        /*
         * Extract the state of the foreign scan.
         */
        scan_state = (IfxFdwExecutionState *)
                     ((IfxFdwPlanState *)relInfo->fdw_private)->state;
    }
}
```

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`

BeginForeignModify

- Like `BeginForeignScan()`, starting callback for DML actions into the executor.
- Depending on the DML action, might be differences in preparing stuff
- E.g. setup connection or get connection from cache
- Deserialize plan data pushed down from `PlanForeignModify()`

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.
- Private FDW data located in `node->fdw_state`

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, e.g when used in scrollable cursors
- Must take care for changed query parameters!
- Better to just "instruct" `IterateForeignScan()` to do the right thing (tm)

Execute a modify action(1)

```
static TupleTableSlot *
ifxExecForeignUpdate(EState *estate,
                     ResultRelInfo *rinfo,
                     TupleTableSlot *slot,
                     TupleTableSlot *planSlot)
static TupleTableSlot *
ifxExecForeignInsert(EState *estate,
                     ResultRelInfo *rinfo,
                     TupleTableSlot *slot,
                     TupleTableSlot *planSlot);
static TupleTableSlot *
ifxExecForeignDelete(EState *estate,
                     ResultRelInfo *rinfo,
                     TupleTableSlot *slot,
                     TupleTableSlot *planSlot);
```

Execute a modify action (2)

`ExecForeignUpdate`, `ExecForeignDelete` and `ExecForeignInsert` callbacks

- Called for every tuple to work on
- An INSERT action doesn't employ a remote scan!
- Does all the necessary data conversion if necessary
- `slot` carries all information for the target tuple
- Private FDW data stored in `rinfo->ri_FdwState`

EndForeignScan(), EndForeignModify()

```
void EndForeignScan (ForeignScanState *node);

void EndForeignModify(EState *estate,
                      ResultRelInfo *rinfo)
```

- EndForeignModify() run when no more tuple to modify
- EndForeignScan() run when IterateForeignScan returns no more rows, but after EndForeignModify()
- Finalizes the remote scan and modify action
- Close result sets, handles, connection, free memory, etc...

Transaction Callbacks

Connect local transactions with remote transactions and savepoints

```
RegisterXactCallback(pgfdw_xact_callback, NULL);
RegisterSubXactCallback(pgfdw_subxact_callback, NULL);

static void fdw_xact_callback(XactEvent event, void *arg);

static void fdw_subxact_callback(SubXactEvent event, SubTransactionId mySubid,
                                 SubTransactionId parentSubid, void *arg)
```

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   typinputfunc;
Datum     result;
HeapTuple type_tuple;

type_tuple = SearchSysCache1(TYPEOID, inputOid);
if (!HeapTupleIsValid(type_tuple))
{
    /*
     * Oops, this is not expected...
     */
    ...
}

ReleaseSysCache(type_tuple);
typinputfunc = ((Form_pg_type) GETSTRUCT(type_tuple))->typinput;
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/9.3/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!

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