SEMANTICS-BASED RAPID PROTOTYPING OF A SUBSET OF SQL

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SubSQL: A Subset of SQL

SQL (Structured Query Language): a language for managing relational databases.

- The SQL data definition commands `CREATE TABLE` and `DROP TABLE`.
- The SQL data manipulation commands `INSERT INTO`, `UPDATE`, and `DELETE`.
- The SQL data query command `SELECT` with `FROM`, `WHERE`, `GROUP BY`, `HAVING`, and `ORDER BY`.
- Subqueries, i.e., `SELECT` queries nested inside other `SELECT` queries (at arbitrary depth) where inner queries may refer to variables from outer queries.
- The SQL aggregate functions `MIN()`, `MAX()`, `COUNT()`, `SUM()` and `AVG()` that reduce a table column to a single value.
- The combination of tables by `CROSS JOIN` (short: `","`), `(INNER) JOIN`, `LEFT (OUTER) JOIN`, `RIGHT (OUTER) JOIN`, `FULL (OUTER) JOIN`.
- Values of the integer type `INT(`n`)` and the string type `VARCHAR(`n`)` (where the parameter n, however, does actually not limit the size of the value but only the width of its display).
- `NULL` values and a 3-valued logic that includes the truth value `NULL` (interpreted as “unknown”).

Semantics-based implementation of a rapid prototype of SubSQL in SLANG.

SubSQL: Syntax

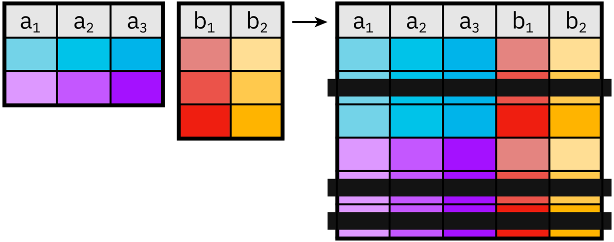
```
CREATE TABLE Persons (
    PersonId INT(6) PRIMARY KEY,
    LastName VARCHAR(255) NOT NULL,
    FirstName VARCHAR(255),
    Address VARCHAR(255) DEFAULT "(none)",
    City VARCHAR(255));

INSERT INTO Persons VALUES (1, "Schreiner", "Wolfgang", "Landstr. 1", "Linz");
UPDATE Persons SET PersonId = PersonId+1, Address="None" WHERE City <> "Linz" OR Address = "";
DELETE FROM Persons WHERE FirstName = "Wolfgang" OR PersonId > 3 AND City < "Linz";

SELECT P1.PersonId,P2.PersonId
  FROM Persons P1 JOIN Persons P2 ON (P1.PersonId=P2.PersonId)
  WHERE P1.FirstName = "Wolfgang" AND P2.PersonId=0
  GROUP BY P1.FirstName ORDER BY P1.PersonId;
SELECT P.PersonId,P.City FROM Persons P
  WHERE P.PersonId > (SELECT AVG(PersonId) FROM Persons WHERE City = P.City);

DROP TABLE Persons;
```

SubSQL Semantics



https://commons.wikimedia.org/wiki/File:Relational_Algebra_Join.svg

Based on tables, rows, columns, cells, their combination and manipulation.

Semantic Domains

SubSQL is given a denotational semantics that is based on the following domain.

$$
\begin{aligned}
\mathit{State} &:= \mathit{store}\colon \mathit{Store} \times \mathit{db}\colon \mathit{Database} \times \mathit{tables}\colon \mathit{Tables} \times \mathit{rows}\colon \mathit{Table} \\
\mathit{Store} &:= \mathit{Id} \to_{\perp} \mathit{Value} \\
\mathit{Database} &:= \mathit{Id} \to_{\perp} \mathit{Table} \\
\mathit{Tables} &:= \mathit{Table}^{*} \\
\mathit{Table} &:= \mathit{Row}^{*} \\
\mathit{Row} &:= \mathit{Value}^{*}
\end{aligned}
$$

The semantic value $v = [\![p]\!](s, \ldots)$ of a syntactic phrase p depends on a given "current state" $s \in \mathit{State}$.

The Meaning of Column References

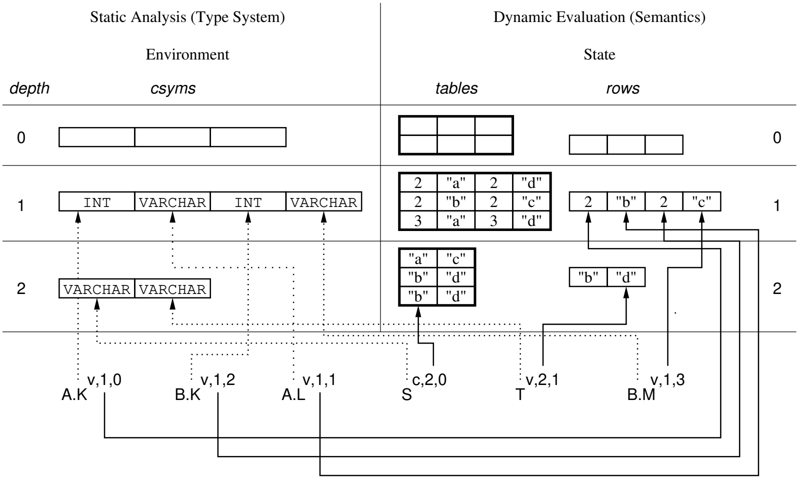
The meaning of a column reference $CRef$ is derived from the following information:

- $column$: a binary value that indicates whether the identifier refers to an entire table column (which can be determined from the *tables* stack) or just to a single value in a column (which can be determined from the *rows* stack).
- $depth$: the nesting depth at which the identifier has been introduced; it therefore also represents the stack depth at which the identifier can find its value (from the *tables* stack or from the *rows* stack).
- pos: the column position denoted by the identifier within the referenced table/row.

The type checker annotates every column reference as $CRef^{\langle column, depth, pos \rangle}$ which is used by the evaluator to determine its semantics.

Static Analysis and Semantic Evaluation

```
CREATE TABLE A (K INT(3), L VARCHAR(5)); CREATE TABLE B (K INT(3), M VARCHAR(8)); CREATE TABLE C (S VARCHAR(5), T VARCHAR(8));
```




```
... (SELECT * FROM A,B WHERE A.K = B.K AND A.L = (SELECT MIN(S) FROM C WHERE T = B.M)) ...
```

The Meaning of Column References: Static Analysis

The environment captures the information about the syntactic context of a phrase.

$$
\begin{aligned}
&\mathit{Env} := \mathit{db}\colon \mathit{TableEnv} \times \mathit{venv}\colon \mathit{VarEnv} \times \mathit{tenv}\colon \mathit{TableEnv} \times \\
&\quad \mathit{cstack}\colon \mathit{ColumnSymbols}^* \times \mathit{cenv}\colon \mathit{ColumnEnv} \times \\
&\quad \mathit{ckind}\colon (\mathit{ColumnSymbol} \to \mathit{Kind}) \times \mathit{cdepth}\colon (\mathit{ColumnSymbol} \to \mathbb{N}) \times \\
&\quad \mathit{depth}\colon N \times \mathit{gsyms}\colon \mathit{CoumnSymbolSet}
\end{aligned}
$$

```
Env ⊢ Exp: exp(ExpType)
=======================
env ⊢ ColumnRef: columnRef(csym)
type = type(csym.type)  kind = env.ckind(csym)  depth = env.cdepth(csym)
pos ∈ ℕ  env.cstack[depth][pos] = csym
grouped = depth < length(env.cstack)-1 ∨ csym ∈ env.gsyms
etype = ⟨type:type, kind:kind, group:grouped⟩
-----------------------------
env ⊢ ColumnRef^{csym,pos,kind,depth}: exp(etype)
```

The typechecker determines the annotation of CRef from the current environment.

The Meaning of Column References: SLANG Specification

```
judgement #Env# ⊢ Exp: exp(#ExpType#)
{
  inference env ⊢ ExpRef[ColumnRef,Annotation]: exp(etype)
  {
    env ⊢ ColumnRef: columnRef(csym);
    kind: #Kind# = #env.ckind().get(csym)#;
    depth: #Integer# = #env.cdepth().get(csym)#;
    pos: #Integer# = #env.cstack().get(depth).list().indexOf(csym)#;
    type: #Type# = #csym.ctype().type()#;
    # boolean grouped = depth < env.cstack().size()-1 ||
        env.gsyms().contains(csym); #
    etype = #new ExpType(type, kind, grouped)#;
    # Annotation.setColumnInfo(csym,pos,kind,depth); #
  }
}
```

The Meaning of Column References: Dynamic Evaluation

The semantics of an expression is a mapping from states to values.

```
⟦Exp⟧: State →⊥ Value
======================
⟦ColumnRef^{csym,pos,kind,depth}⟧(s) :=
  match kind with
    Kind.cell → s.rows[depth][pos]
  | Kind.column →
      Value.seq(λi∈domain(s.tables[depth]). s.tables[depth][i][pos])
```

The evaluator computes from the annotation the value of $CRef$ in the current state.

The Meaning of Column References: SLANG Specification

```
function ⟦Exp⟧: #State# → #Value#
{
  equation ⟦ExpRef[ColumnRef,Annotation]⟧(s) = v
  {
    # Integer pos = Annotation.getColumnPos();
      Kind kind = Annotation.getColumnKind();
      Integer depth = Annotation.getColumnDepth(); #
    v = #switch (kind) {
           case Kind.cell -> s.rows().list().get(depth).list().get(pos);
           case Kind.column -> {
             List<Value> values = new ArrayList<Value>();
             for (Row row : s.currentTable().list())
               values.add(row.list().get(pos));
             yield new Value.Seq(new Values(values));
            }
          }#;
  }
}
```

The SELECT Expression: Static Analysis

```
Env ⊢ SelectExp: selectExp(ColumnSymbols)
==========================================
env0 ⊢ FromClause: fromClause(env1)
env1 ⊢ WhereClause: whereClause
env1 ⊢ GroupByClause: groupByClause(env2)
env2 ⊢ HavingClause: havingClause
env2 ⊢ SelectClause: selectClause(env3,csyms)
env3 ⊢ orderByClause
---------------------------------
env0 ⊢
  "SELECT" DistinctClause SelectClause FromClause WhereClause
   GroupByClause HavingClause OrderByClause ";": selectExp(csyms)
```

The SELECT Expression: SLANG Specification

```
judgement #Env# ⊢ SelectExp: selectExp(#ColumnSymbols#)
{
  inference env0 ⊢ TheSelectExp[DistinctClause,SelectClause,FromClause,
    WhereClause,GroupByClause,HavingClause,OrderByClause]: selectExp(csyms)
  {
    env0 ⊢ FromClause: fromClause(env1);
    env1 ⊢ WhereClause: whereClause;
    env1 ⊢ GroupByClause: groupByClause(env2);
    env2 ⊢ HavingClause: havingClause;
    env2 ⊢ SelectClause: selectClause(env3,csyms);
    env3 ⊢ OrderByClause: orderByClause;
  }
}
```

The SELECT Expression: Dynamic Evaluation

```
⟦SelectExp⟧: State →⊥ Table
============================
⟦"SELECT" DistinctClause SelectClause FromClause^csyms0 WhereClause
          GroupByClause HavingClause OrderByClause ";"⟧(s) :=
  let table1 = ⟦FromClause⟧(s) in
  let s0 = newTable(s,table1) in
  let table2 = ⟦WhereClause⟧(s0,table1) in
  let tables3 = ⟦GroupClause⟧(table2) in
  let tables4 = ⟦HavingClause⟧(s0,tables3)) in
  let table5 = ⟦SelectClause⟧(s0,tables4) in
  let table6 = ⟦DistinctClause⟧(allRows,table5) in
  let table7 = ⟦OrderByClause⟧(table6) in
  table7
```

The SELECT Expression: SLANG Specification

```
function ⟦SelectExp⟧: #State# → #Table#
{
  equation ⟦TheSelectExp[DistinctClause,SelectClause,FromClause,
    WhereClause,GroupByClause,HavingClause,OrderByClause]⟧(s) = table
  {
    table1 = ⟦FromClause⟧(s);
    s0: #State# = #s.newTable(table1)#;
    table2 = ⟦WhereClause⟧(s0,table1);
    tables3 = ⟦GroupByClause⟧(table2);
    tables4 = ⟦HavingClause⟧(s0,tables3);
    table5 = ⟦SelectClause⟧(s0,tables4);
    allRows: #Function<Table,Table># = #(Table t)->t.allRows()#;
    table6 = ⟦DistinctClause⟧(allRows,table5);
    table = ⟦OrderByClause⟧(table6);
  }
}
```

The SubSQL Implementation in SLANG

Starting point: a semi-formal definition of SubSQL in 2,400 plain text lines.

- $\rightsquigarrow$ 3,500 SLANG lines (120 KB) $\rightsquigarrow$ 18,600 generated Java lines (590 KB)
  - Syntax domains: 100 SLANG lines.
  - Type system: 1,400 SLANG lines.
  - Semantics: 1,100 SLANG lines.
  - Printer: 400 SLANG lines.
  - Parser: 400 SLANG lines.
- Mathematical domains/operations: 1,300 Java lines.
- Persistent database: 500 Java lines.
- SubSQL Java API: 150 Java lines.

`https://www.risc.jku.at/research/formal/software/SLANG/public/SubSQL.tgz`

Wolfgang Schreiner and William Steingartner, *Semantics-Based Rapid Prototyping of a Subset of SQL*, RISC Report 25-02, doi:10.35011/risc.25-02.