A Typeful Integration of SQL into Curry

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Real World Applications with Databases

Access to relational databases in programming languages

1. Pass SQL statements as strings (JDBC,...)
   - \+ popular since SQL is well known
   - – source of security leaks in web applications
   - – SQL syntax errors at run time
   - – ill-typed database access or type casts
2. Language-specific database libraries (Haskell/DB,...)
   - \+ no syntax errors (and, maybe, no type errors)
   - \+ avoid security leaks with string checks/escapes
   - – expressiveness often limited (process data in programs)
   - – gap to SQL syntax (library combinators instead of SQL)

Our proposal: embed SQL in program code

- check SQL statements at compile time (preprocessor)
- compile-time detection of syntax and type errors
- exploit ER model of data, relations instead of foreign keys

Typeful SQL Embedding in Curry

Access to relational databases in programming languages

- implemented in functional logic language Curry
- ideas could be transferred to other higher-order typed languages
- concept: SQL queries are “integrated code”

```
-- Get name/age of students within a given age range:
studAgeBetween :: Int  → Int  → IO (SQLResult [(String,Int)])
studAgeBetween min max =
  ``sql Select Name, Age
        From Student Where Age between {min} and {max}
        Order By Name Desc;''
```

- SQL code replaced by type-safe calls to DB library operations

Tools:

Curry, Integrated Code, CDBI libraries, ER models, SQL compiler

Curry [POPL'97, www.curry-language.org]

- declarative multi-paradigm language
  (higher-order concurrent functional logic language)
- extension of Haskell (non-strict functional language)
- better (high-level) APIs (GUI, web, database,...), eDSLs,...

Datatypes (values): enumerate all constructors

```
data Bool      =  True    | False
data List a    =  []      | a  : List a   -- [a]
```

Program rules: $f\ t_1 \ldots t_n \mid c = r$

```
conc :: [a]  →  [a]  →  [a]
conc []     ys = ys
conc (x:xs) ys = x : conc xs ys
```

```
last ::  [a] -> a
last xs | conc _ [x] == xs
        = x   where x free
```

Integrated Code (aka Quasi Quotation)

Concept:

- string in source program with own syntax rules
- enclosed in back ticks and ticks: ``` ``lang ...'' ```
  `lang`: specifies kind of embedded language
- *code integrator* replaces integrated code by Curry expression

Example: regular expressions in POSIX syntax

```
if s ``regex (ab*)+'' then ... else ...
```

Code integrator: exploits `RegExp` library and replaces string by

```
`match` [Plus [Literal 'a', Star [Literal 'b']]]
```

Another example: predicate for Curry identifiers:

```
isID :: String → Bool
isID s = s ``regex [a-zA-Z][a-zA-Z0-9_']*''
```

Integrated Code

Currently embedded languages:

- regular expressions
- format printing (like C's `printf`)
- HTML and XML (with layout rules)
- SQL statements (new!)

  $\rightsquigarrow$ specific library support required!

CDBI: Curry Database Interface Libraries

Motivation

- abstract from concrete database access
- support type-safe access to database entities
- provide infrastructure for type-safe SQL embedding w.r.t. ER models

Base layer: raw database access

```
-- Return open connection to SQLite database:
connectSQLite :: String → IO Connection

-- Type of database actions:
type DBAction a = Connection → IO (SQLResult a)

-- Type of query results:
type SQLResult a = Either DBError a
```

CDBI: Curry Database Interface Libraries

Typed select operation

```
select :: String → [SQLValue] → [SQLType]
       → DBAction [[SQLValue]]
```

Arguments: SQL with “holes”, typed hole values, types of return values

Result: table of return values

```
data SQLValue = SQLString String | SQLInt Int | ...
data SQLType = SQLTypeString | SQLTypeInt | ...
```

Typed database access:

```
select "select Age,Email from Student
        where First = '?' and Name = '?';"
       [SQLString "Joe", SQLString "Fisher"]
       [SQLTypeInt, SQLTypeString]
```

CDBI: Curry Database Interface Libraries

Next level: typed entities

```
data EntityDescription a =
       ED String [SQLType] (a → [SQLValue]) ([SQLValue] → a)
```

Entity specification contains:

1. entity (table) name
2. column types
3. conversion (show/read) functions

Example: Student entity (generated from ER model)

```
data Student = Student String String Int String Int

studentDescription :: EntityDescription Student
studentDescription =
 ED "Student" [SQLTypeString,...,SQLTypeInt]
    (λ(Student name first num email age)  →  ...)
    (λ[SQLString name,...]  →  Student name first num email age)
```

CDBI: Curry Database Interface Libraries

Modeling SQL `where` clauses

```
-- Selection criteria
data Criteria = Criteria Constraint (Maybe GroupBy)

-- Greater-than constraint
(.>.) :: Value a → Value a → Constraint

-- Typed values: constants or DB columns
data Value a = Val SQLValue | Col (Column a)

int :: Int → Value Int
int = Val ∘ SQLInt

studentColumnAge :: Column Int   -- generated from ER model
```

Example: `...where Student.Age > 21`

```
Col studentColumnAge .>. int 21     ⇝ ok

Col studentColumnAge .>. float 3.4  ⇝ compile-time error
```

Entity-level type-safe selection: `getEntries`

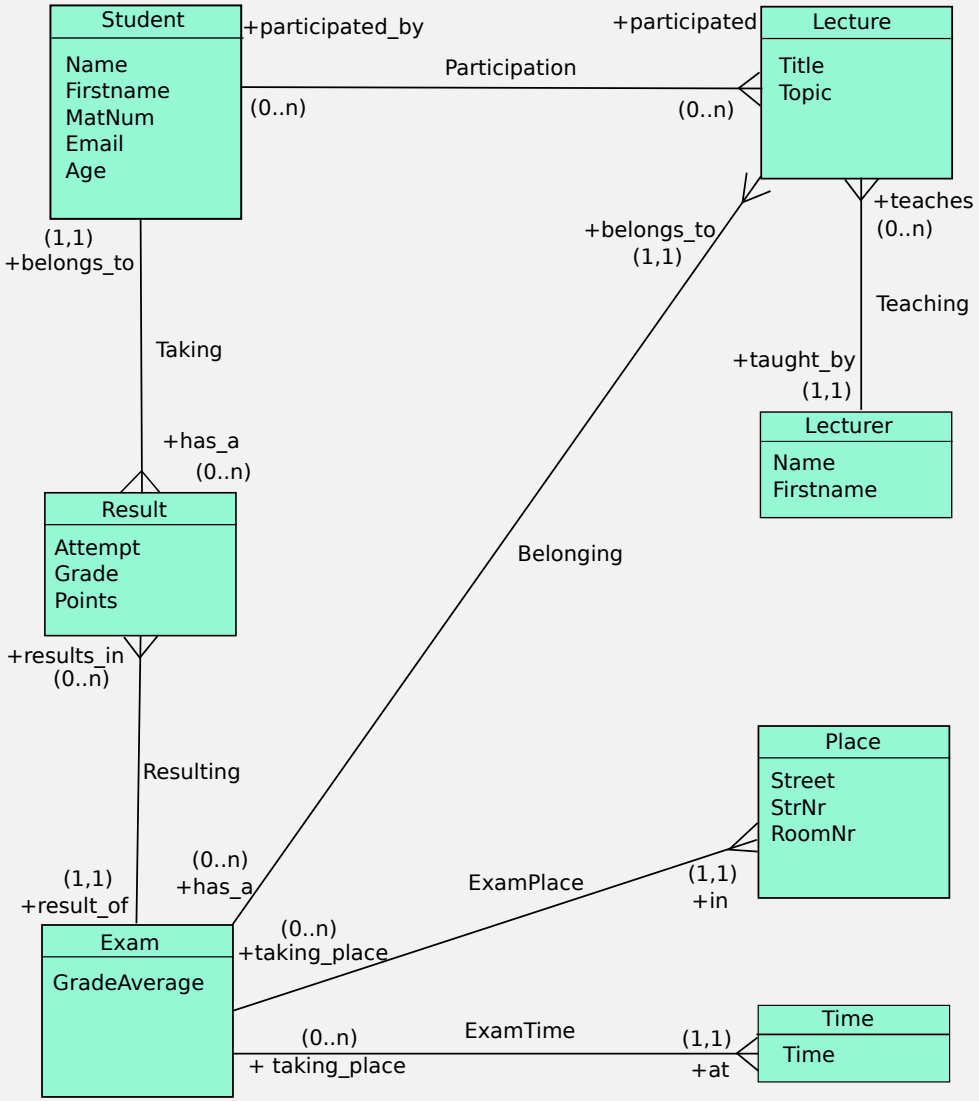
SQL query

```
Select * From Student
         Where Age > 21
         Order By Name Desc
         Limit 5;
```

corresponds to Curry expression

```
getEntries
  All                                    -- also:  Distinct
  studentDescription
  (Criteria (Col studentColumnAge .>. int 21) Nothing)
  [descOrder studentColumnName]          -- order specification
  (Just 5)                               -- limit result entries
```

Entity-Relationship Models



Entity-Relationship Models

Representation as Curry data term

```
data ERD       = ERD String [Entity] [Relationship]

data Entity    = Entity String [Attribute]
data Attribute = Attribute String Domain Key Null
...
```

ERD2CDBI translator

1. ER model $\mapsto$ relational data base (foreign keys,...)
2. Generates Curry module with entity descriptions
3. Generates *info file* for SQL translator

SQL Translator

Main tasks

- replace SQL string by Curry expression
- check conformity with ER model
- check types of columns and derive types for embedded Curry expressions

Get names of all students with a given age:

```
studNamesWithAge :: Int  → IO (SQLResult [String])
studNamesWithAge x =
  ``sql Select s.Name
        From Student as s
        Where s.Age = {x};''
```

SQL Translator

```
studNamesWithAge x =
  ``sql Select s.Name From Student as s Where s.Age = {x};''
```

Translation:

```
studNamesWithAge x = runWithDB "/.../Uni.db"
 (getColumn []
   [SingleCS All
      (singleCol studentNameColDesc 0 none)
      (TC studentTable 0 Nothing)
      (Criteria (equal (colNum studentColumnAge 0) (int x))
                Nothing)]
   [] Nothing)
```

SQL query string (passed to DB at run time):

```
select ("Student"."Name") from 'Student'
                          where (("Student"."Age") == 30);
```

SQL Translator

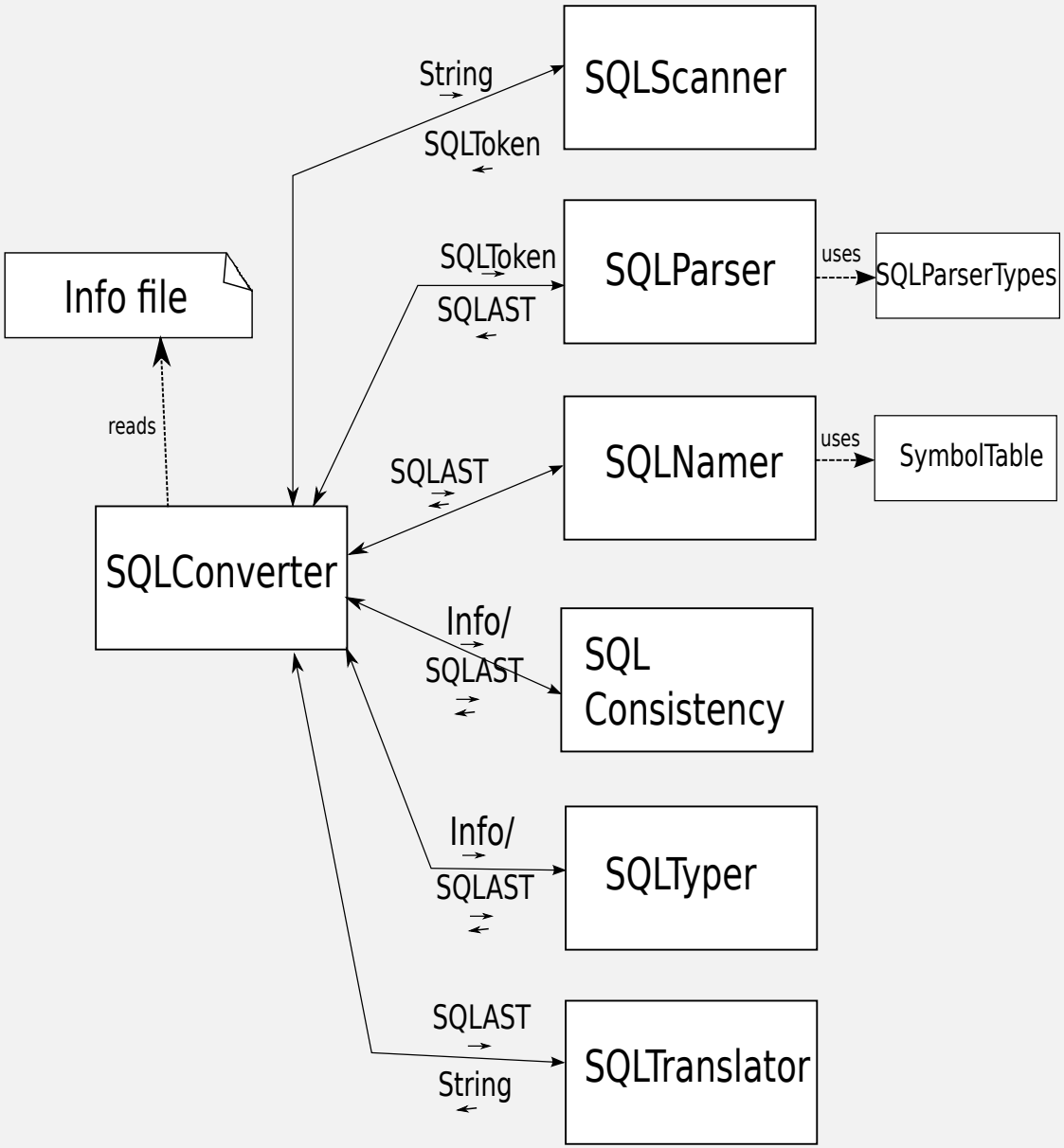
Extension to SQL: support for relations

```
-- Names/grades of students with grade better than 2.0
studGoodGrades :: IO (SQLResult [(String, Float])
studGoodGrades =
   ``sql Select Distinct s.Name, r.Grade
         From Student as s, Result as r
         Where Satisfies s has_a r And r.Grade < 2.0;''
```

Condition `Satisfies e1 rel e2`:

- entities `e1` and `e2` are in relation `rel` of ER model
- avoid explicit uses of foreign keys

Structure of the SQL Translator



Conclusions

Typeful SQL Integration

- high-level and reliable access to databases
- easy to use due to SQL syntax
- compile-time detection of ill-formed or ill-typed SQL statements
- use of logical (ER) database model with relationships to avoid foreign keys

Future work:

- support further database systems
- check ER model against schema of actual database