Coddfish

Functional Pearl: Strong Types for Relational Databases

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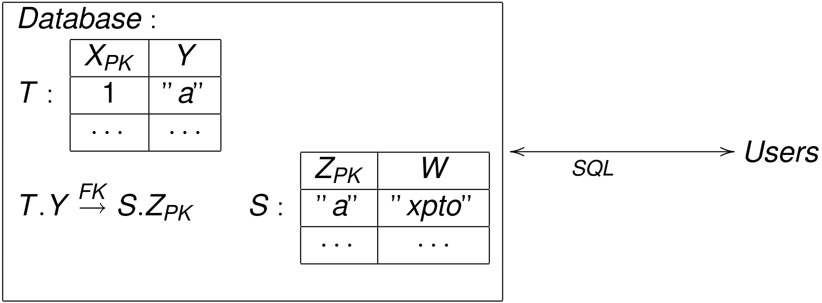
Outline

Motivation

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insert into T values (3)
select * from T join S on T.Y=S.Z
select * from T join S on T.Y=S.W
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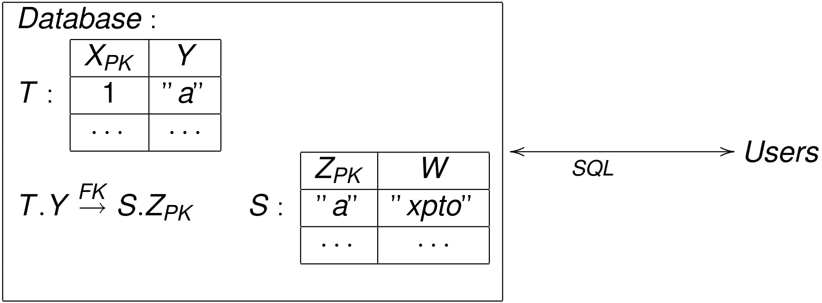


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- SQL is very flexible
- but... it could be more precise
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What will we show?

We will show how to...

- ... capture key meta-data in the types of tables
- ... encode standard (type-safe) SQL operators
- ... capture functional dependency information on the type level and ensure normal forms
- ... transport meta-data information through the operations

Type-level Programming

Extensive use of type level programming and heterogeneous collections

Recall:

`class P a` **Type-level predicate**
`class R a b` **Type-level relation**
`class F a b c | a b -> c` **Type-level function**
`  where f ::  a -> b -> c` (**with value-level counterpart**)

See:
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O. Kiselyov, R. Lämmel, and K. Schupke. Strongly typed heterogeneous collections.

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Tables

A table is a set of tuples

```
data HList row => Table row = Table (Set row)
```

But:

- We miss schema information;
- Tables are in reality **mappings** from key to non-key attributes.

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data HeaderFor h k v => Table h k v = Table h (Map k v)
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The constraint `HeaderFor`

A valid header should not have repeated attributes.
Captured in type level predicate:

```
class HeaderFor h k v | h -> k v
instance (
AttributesFor a k, AttributesFor b v,
HAppend a b ab, NoRepeats ab, Ord k
) => HeaderFor (a,b) k v
```

The fd `h -> k v` reflects the fact that the types for the key and non-key values on the table are **uniquely** determined by the header.

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Attributes

How did we model attributes?

Phantom types working

```
data Attribute t name
attr = undefined :: Attribute t name
```

Let us see some examples:

```
data ID; atID=attr :: Attribute Int (People ID)
data Name; atName = attr :: Attribute String (People Name)
data People a; people = undefined :: People ()
```

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people:

ID	Name	Age	City
12	"Ralf"	23	"Seattle"
67	"Oleg"	17	"Seattle"
50	"Dorothy"	42	"Oz"

Ok, we now have ingredients to construct our first table:

```
myHeader = ( atID.⋆.HNil , atName.⋆.atAge.⋆.atCity.⋆.HNil )


myTable = Table myHeader $
insert ( 12.⋆.HNil )( "Ralf".⋆.  23 .⋆."Seattle".⋆.HNil ) $
insert ( 67.⋆.HNil )( "Oleg".⋆.  17 .⋆."Seattle".⋆.HNil ) $
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Map.empty
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What about default and null attributes?

Easy:

```
data AttrNull t nm
data AttrDef t nm = Default t

atCountry ::  AttrDef String (Cities Country)
atCountry = Default "Afghanistan"
```

We have also modelled default system attributes.

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Foreign keys

Imagine we have the following table:

cities:

City	Country
Braga	Portugal

How do we model a foreign key from the previous table to this one?

```
data FK fk t pk

myFK = FK (atCity .*.  HNil)
          cities
          (atCity' .*.  HNil)
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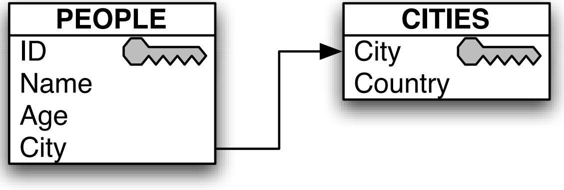
RDB = Tables + Foreign key information

```
myRDB = Record $
cities .=.  (yourTable, HNil) .*.
people .=.  (myTable, myFK .*.  HNil) .*.  HNil
```



The `join` operation

Typical SQL join:

```
select *
from People join Cities
on People.City = Cities.City
```

The `join` operation

In Haskell:

- First we define a join for maps

$$(k \rightharpoonup v) \bowtie (k' \rightharpoonup v') = (k \rightharpoonup vk'v')$$

```
joinM ::  ...  =>
(k -> v -> k') -> Map k v -> Map k' v' -> Map k vkv'
```

- Then we lift to tables

```
join :: ( ... , LookupMany a' r' k' ) => Table
(a,b) k v -> Table (a',b') k' v' -> (Record r -> r')
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- Notice how we do not allow the key of the second table to be underspecified

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What about functional dependencies?

Why FD's?

- Database normalization and de-normalization, for instance, are driven by functional dependencies
- Kernel of the classical relational database design theory (Codd, Maier, . . .)

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Adding them to tables:

```
data TableWithFD fds h k v => Table' h (Map k v) fds
```

- `TableWithFD fds h k v` ensures `HeaderFor h k v` and that `fds` does not refer to attributtes not present in the header.

What can we do with functional dependencies?

- We can improve the design of a database
  - Given a header and the corresponding set of fds we can determine the possible table keys
  - Given a database we can check several normal forms (and thus avoid data redundancy and update anomalies)
- We can transport (and transform) them in the operations **(cool!)**

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Transport through project

X	Y	Z	W
x	y	z	w
...	...	...	...

$$, \; X \to YZW, \; Z \to W$$

↓ *project XYW*

X	Y	W
x	y	z
...	...	...

$$, \; X \to YW$$

Conclusions

What I did not show

- Default system attributes
- Lifting of table operations to databases (*e.g.* selectInto)
- Database transformation operations (normalization and denormalization)

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- Haskell can be used to assign more precise types to SQL operations
- The join operator on tables guarantees that in the *on* clause a value is assigned to all keys in the second table
- We have defined a new level of operations that carry functional dependency information, automatically infered by the type-checker.

Haskell can be used for the design of typed languages for modeling, programming, and transforming relational databases.

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Future work

- Use our model for spreadsheet transformation
- We have shown how we can transport **fd** information from argument to result tables: develop a formal calculus to automatically compute this information for further operations