V0.2

Managing integrity constraints on relational databases

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Personal Motivation

- Hobby based on my personal background
  - Formal methods, development of formal tools
  - Directed towards classical SQL-based systems
- Not fundamental research
  - [Hesh84, Hsu85, Lloyd87, Sardi88, Qia88, Cha90, Deck94, Lee96, Selj99, Deck02, **Mar05**]
- Just target a robust enough implementation
  - Something that can be executed without requiring any form guidance or application-specific tuning

State of practice in DB development

- Integrity constraints are critical for high assurance systems (banking, state, etc)
- In general, integrity is handled by triggers
- Writing triggers by hand
  - Is difficult, error prone
  - Takes time, especially for complex constraints
  - Requires high expertise
- No automated solution available in DBMS, except for simple constraints (eg: foreing keys, single row constraints, type constraints)
  - We might cover eg. the patterns of [Hud10]

Approach [Mart05, etc.]

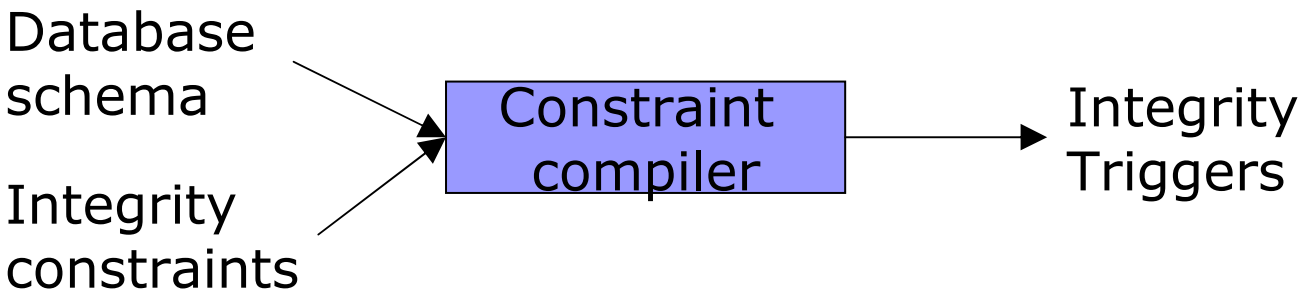
- Automatically generates integrity triggers from declarative integrity constraints
- What it gives
  - An improvement of quality
  - A gain in time
- What it costs
  - Writing the integrity constraints in SQL-like notation
  - Running the tool

Bad approach: querying integrity

- Each integrity constraint can be queried at each modification on database
- One can relatively easily generate the triggers implementing this approach
- This approach can be unnecessarily costly
  - Constraint was true before modification, modification only touches part of the domain, why check everything?
  - Some constraints might overlap each other, how about taking into account this overlap to speed up verification?

Product Description

- Given
  - Database schema
  - Integrity constraints
- Automatically generate
  - Triggers to be embedded into the schema
- Such that
  - Events violating the integrity are blocked by the triggers
  - Triggers have low overhead



How to ensure a low overhead of integrity checking?

- Triggers perform **incremental** verification
  - The constraint is supposed to be true before the event
  - Only verify the constraint on the part of data that has changed
- **Take into account other** integrity constraints
  - They might partially overlap
- Use of **two-step** checking
  - A first local check, sufficient, but not necessary
    - This is intended to filter out some of the updates
  - A second global check in case the first fails, possibly on the whole DB
    - Knowing that the local check failed

An example

- Input
  - Schema

Referencer
ForeignKey:Int
OtherField:Int

Referenced
PrimaryKey:Int

  - Integrity constraint

```
Forall r:Referencer
        r.OtherField = r.ForeingKey
        OR Exists d:Referenced
                r.ForeignKey = d.PrimaryKey
```

- Output: Five triggers monitoring events of the DB

```
INSERT(Referencer)      UPDATE(Referenced,PrimaryKey)
DELETE(Referenced)      UPDATE(Referencer,ForeignKey)
UPDATE(Referencer,OtherField)
```

Example: detail of one trigger

```
CREATE TRIGGER CHECK_INSERT_ON_REFERENCER

BEFORE INSERT ON Referencer
FOR EACH ROW

If NOT NEW.OtherField = NEW.ForeingKey THEN

  If NOT Exists d:Referenced
        d.Primarykey=NEW.ForeignKey THEN

    FAIL
  END
END
```

Event to monitor

Local condition

Global check on the database
Simplified version of the constraint

This is the output of my prototype

Example: detail of another trigger

```
CREATE TRIGGER CHECK_UPDATE_ON_REFERENCER_OTHERFIELD

BEFORE UPDATE ON Referencer.OtherField
FOR EACH ROW

If NOT(OLD.ForeignKey = NEW.OtherField
     OR OLD.ForeignKey != OLD.OtherField
     OR OLD.OtherField = NEW.OtherField) THEN

  If NOT Exists d:Referenced
        d.Primarykey=OLD.ForeignKey THEN
     FAIL
  END
END
```

Event to monitor

Local condition

Global check on the database
Simplified version of the constraint

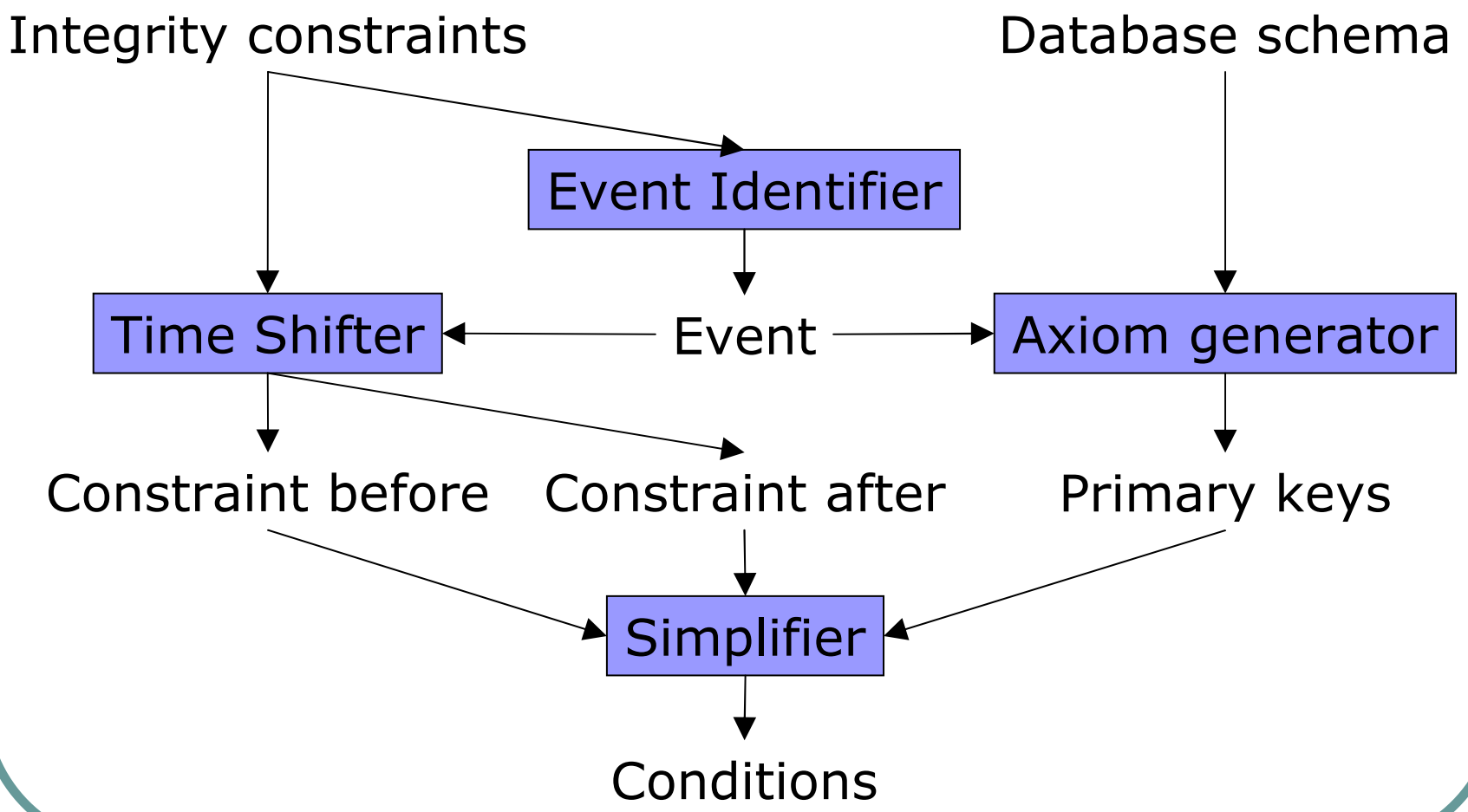
This is the output of my prototype

First order as constraint language

Assertion ::= **Exists** variable**:**Table Assertion
| **ForAll** variable**:**Table Assertion
| Assertion **AND** Assertion
| Assertion **OR** Assertion
| **NOT** Assertion
| Assertion **Implies** Assertion
| Expression **=** Expression
| **True**
| **False**

Expression ::= Constant
| Variable**.**Column

In the box


Integrity constraints
Database schema
Event Identifier
Time Shifter
Event
Axiom generator
Constraint before
Constraint after
Primary keys
Simplifier
Conditions

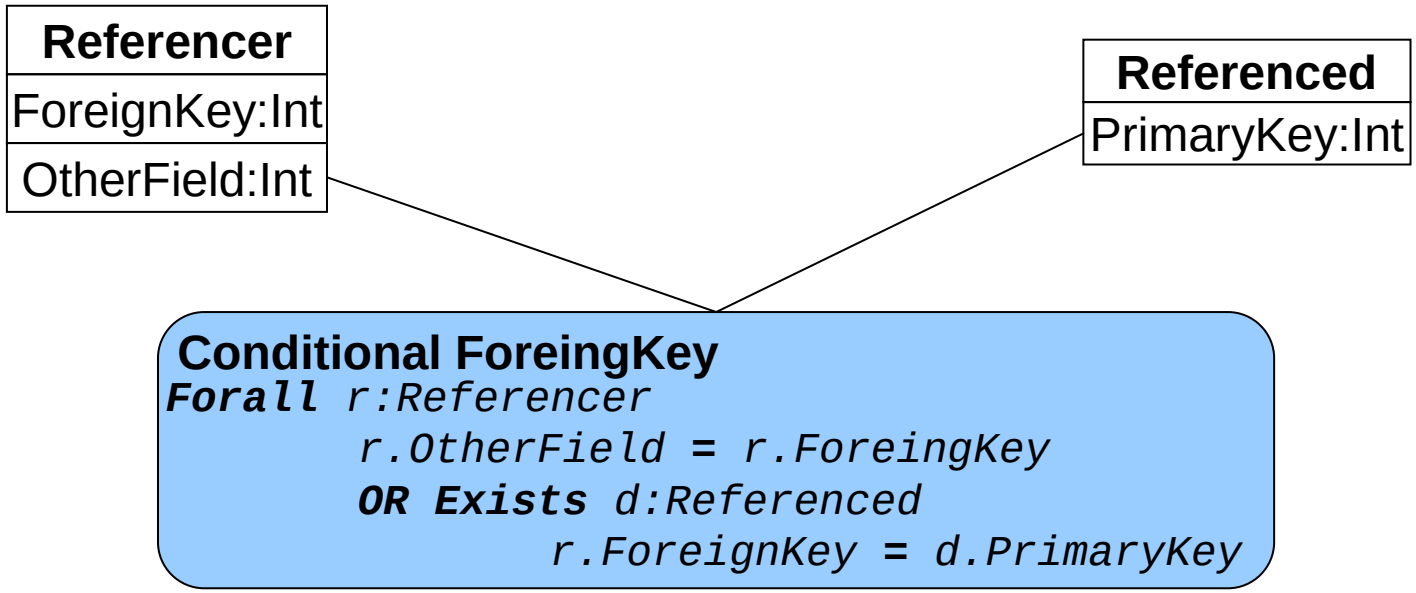
Example of time shifting

- Shifting problem:
  - Assertion: Forall x:X P(x)
  - Event: Insert(x)
  - Evaluated on the database before the modification
- Assertion before:
  - Forall x:X P(x)
- Assertion after:
  - (Forall x:X P(x)) AND P(new)

Key component: the simplifier

- My implementation:
  - BDD-based simplification on skolemized assertions
  - Borrows from abduction procedures and from PVS
- Greedy approach: simplify from left to right when visiting the assertion to simplify
- Limitation:
  - Some axioms are very costly (transitivity of equality), so need for heuristic simplification of axioms, based on assertions
  - Would be better to simplify according to the amount of data expected in each table

Targeted Look, integrated into graphical database development software



My targeted contribution

- Generate both local and global check (TTM inspiration)
- An implementation
  - What I have
    - 80% of condition generator
    - Conditions double-checked by automated theorem prover (Prover9)
  - SCALA implementation

Long term vision for fundamental research?

- This technique of integrity checking **discovers** updates to DB
- Better 1: Annotating values with their origin
  - For instance, when one inserts a row with a foreign key, one generally queries the referenced primary key before inserting
  - How about keeping track of the origin of the value set to the foreign key?
- Better 2: Adding condition checking to business code
  - From server-side verification to client-side verification
  - The technology advertised here could be used for this

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