Automated Generation of Database Mocks with Symbolic Execution

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Software applications and databases

- Most software applications need to persist information, typically via the interaction with databases
- Testing some methods within such applications thus requires producing database states, besides the direct inputs of the method under test
    - In particular, exercising certain program paths may depend on specific data stored in the database

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    while (i < newBooks.size()) {
        Book currBook = newBooks.get(i);
        int theShelf = shelfForBook(currBook.getId());
        boolean success = true;
        ResultSet shelves = con.createStatement()
                               .executeQuery("SELECT id FROM shelf WHERE id="
                                             + theShelf);
        if (!shelves.next()) {
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                                          + theShelf + ",1)");
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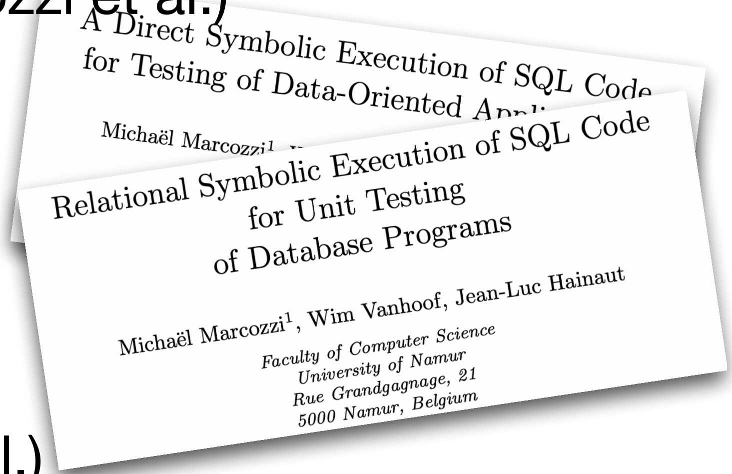
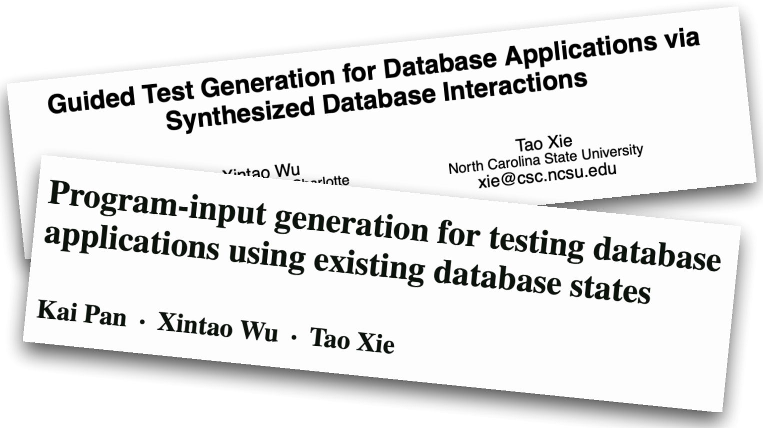
Symbolic execution can help us produce inputs, including database contents, to exercise such paths

Related (previous) Work

- Symbolic execution for DB applications (M. Marcozzi et al.)
  - Implemented for Java + JDBC
  - Ad hoc SE engine
  - **Z3** as backend solver



- Concolic execution for DB applications (T. Xie et al.)
  - Implemented for C# + .NET SqlClient
  - Realized as a PEX extension
  - **Z3** as backend solver



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M. Marcozzi, W. Vanhoof, J.-L. Hainaut: *Relational symbolic execution of SQL code for unit testing of database programs*. Sci. Comput. Program. (2015)
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K. Pan, X. Wu, T. Xie: *Guided test generation for database applications via synthesized database interactions*. ACM Trans. Softw. Eng. Methodol. (2014)

Is Z3 the “right” solver for relational constraints?

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  - Essentially, each relation $R \subseteq T_1 \times T_2 \times \ldots \times T_k$ is encoded as uninterpreted function $f_R : T_1 \times T_2 \times \ldots \times T_k \rightarrow$ Bool, and relational constraints as constraints on these functions

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- But relational constraint solving in an area on its own
  - *Are we missing relational constraint solving advances by using "non-relational" SMT?*

State-of-the-art in Relational Constraint Solving

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- Bounded relational constraint solving
    - Alloy/KodKod
    - Based on SAT, implements many optimizations

Kodkod: A Relational Model Finder

Emina Torlak and Daniel Jackson

MIT Computer Science and Artificial Intelligence Laboratory
{emina, dnj}@mit.edu

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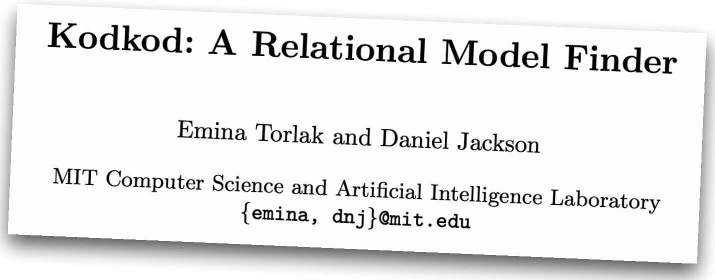
- Relational constraint solving based on set theory
    - {log}
    - Complete for a theory of finite relations



Kodkod: A Relational Model Finder

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Solving quantifier-free first-order constraints over finite sets and binary relations

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- Relational constraint solving based on set theory
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  - Complete for a theory of finite relations
- Relational constraint solving based on an algebraic theory of finite relations
  - Implemented on CVC4
  - Complete for a language over many sorted finite relations (including transitive closure)

Kodkod: A Relational Model Finder

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Solving quantifier-free first-order constraints over finite sets and binary relations

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Relational Constraint Solving in SMT

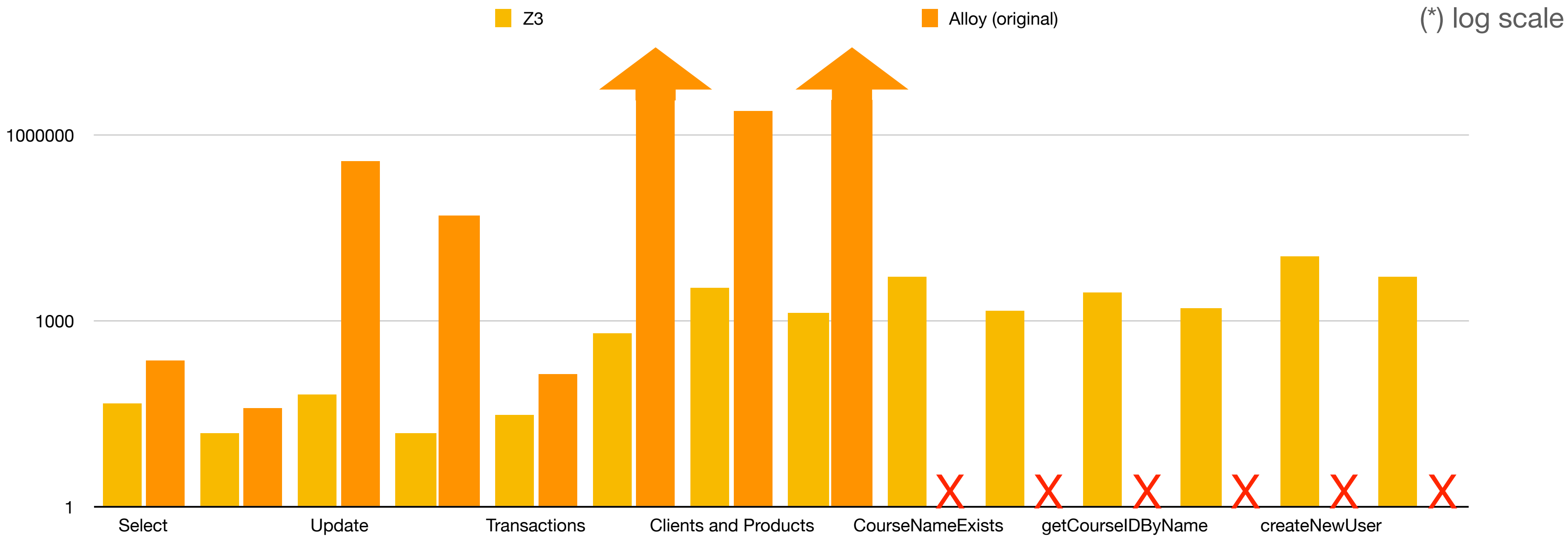
Baoluo Meng[1], Andrew Reynolds[1], Cesare Tinelli[1], and Clark Barrett[2]

[1] Department of Computer Science, The University of Iowa
[2] Department of Computer Science, Stanford University

“Non-relational” SMT vs Relational Constraint Solving

- No comprehensive comparison of existing approaches
- Some studies compare some specific techniques
  - e.g., Alloy vs non-relational SMT, Alloy vs a relational decision procedure, …
  - Some studies are outdated, and use restricted datasets, among other issues

Database application constraints: “Non-relational” SMT vs Relational Constraint Solving



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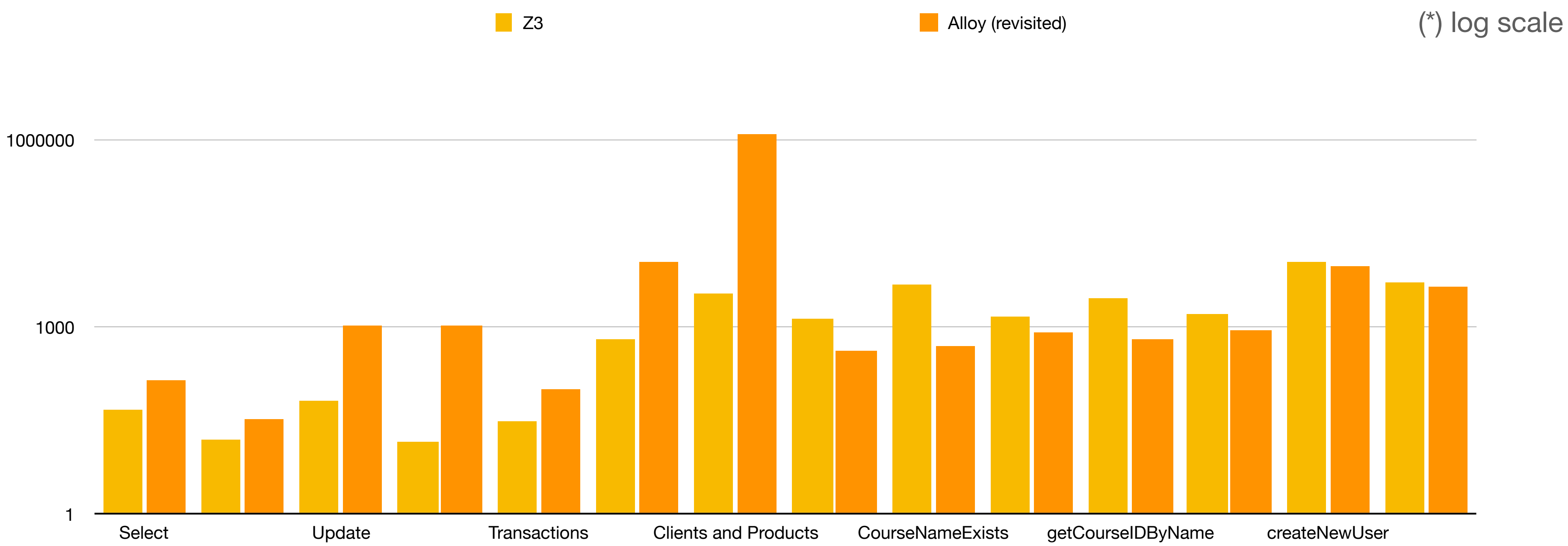
Database application constraints: “Non-relational” SMT vs Relational Constraint Solving

Our revisited study



Opportunities with relational constraint solving (in the context of DB Applications)

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- Efficiency
  - SAT bounded relational solving is more efficient for satisfiable constraints (*)

(*) Baoluo Meng, Andrew Reynolds, Cesare Tinelli, Clark W. Barrett: *Relational Constraint Solving in SMT*. CADE 2017

Opportunities with relational constraint solving (in the context of DB Applications)

- Efficiency
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- Effectiveness
  - E.g., {log} generates finite representation of all models of a relational formula
    - Kind of “symbolic” interpretation of a formula

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Opportunities with relational constraint solving (in the context of DB Applications)

- Efficiency
  - SAT bounded relational solving is more efficient for satisfiable constraints (*)
- Effectiveness
  - E.g., {log} generates finite representation of all models of a relational formula
    - Kind of “symbolic” interpretation of a formula
- Room for combined techniques for relational constraint solving

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Interaction between SMT and SAT in DB constraint solving

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public List<Integer> addBooks (Connection con, List<Book> newBooks) {
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Standard SMT

Path condition

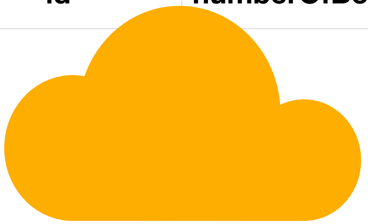
theShelf = x0 $\wedge$ success = true $\wedge$ shelves $\neq \emptyset \wedge \#Shelf > 1$

Relational SAT

Symbolic DB

Shelf

id	numberOfBooks



id is primary key
numberOfBooks > 0

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x0	n0
y0	n1

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$y0 \neq x0 \wedge n0 > 0 \wedge n1 > 0$

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$\text{y0} \neq \text{x0} \wedge \text{n0} > 0 \wedge \text{n1} > 0 \wedge \text{n0'} = \text{n0} + 1$

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Remarks

- Testing and test generation of db applications based on symbolic execution needs to handle database constraints in combination with path constraints
- Solely using standard SMT prevents us from exploiting advances in relational constraint solving
- Solving techniques that combine standard SMT with relational constraint solving can have an important impact in db application testing