Z3: An Efficient SMT Solver

POWERFUL

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Overview

- Z3 is a *Satisfiability Modulo Theories (SMT)* solver.
- Z3 integrates several decision procedures.
- Z3 is used in several program analysis, verification, test-case generation projects at Microsoft.
- Z3 1.2 is freely available for academic research:
  - http://research.microsoft.com/projects/z3

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Satisfiability Modulo Theories (SMT)

$$\boxed{x+2=y} \Rightarrow \boxed{f}(\boxed{read}(\boxed{write}(a,x,\boxed{3}),\boxed{y-2})) = \boxed{f}(\boxed{y-x+1})$$

Arithmetic

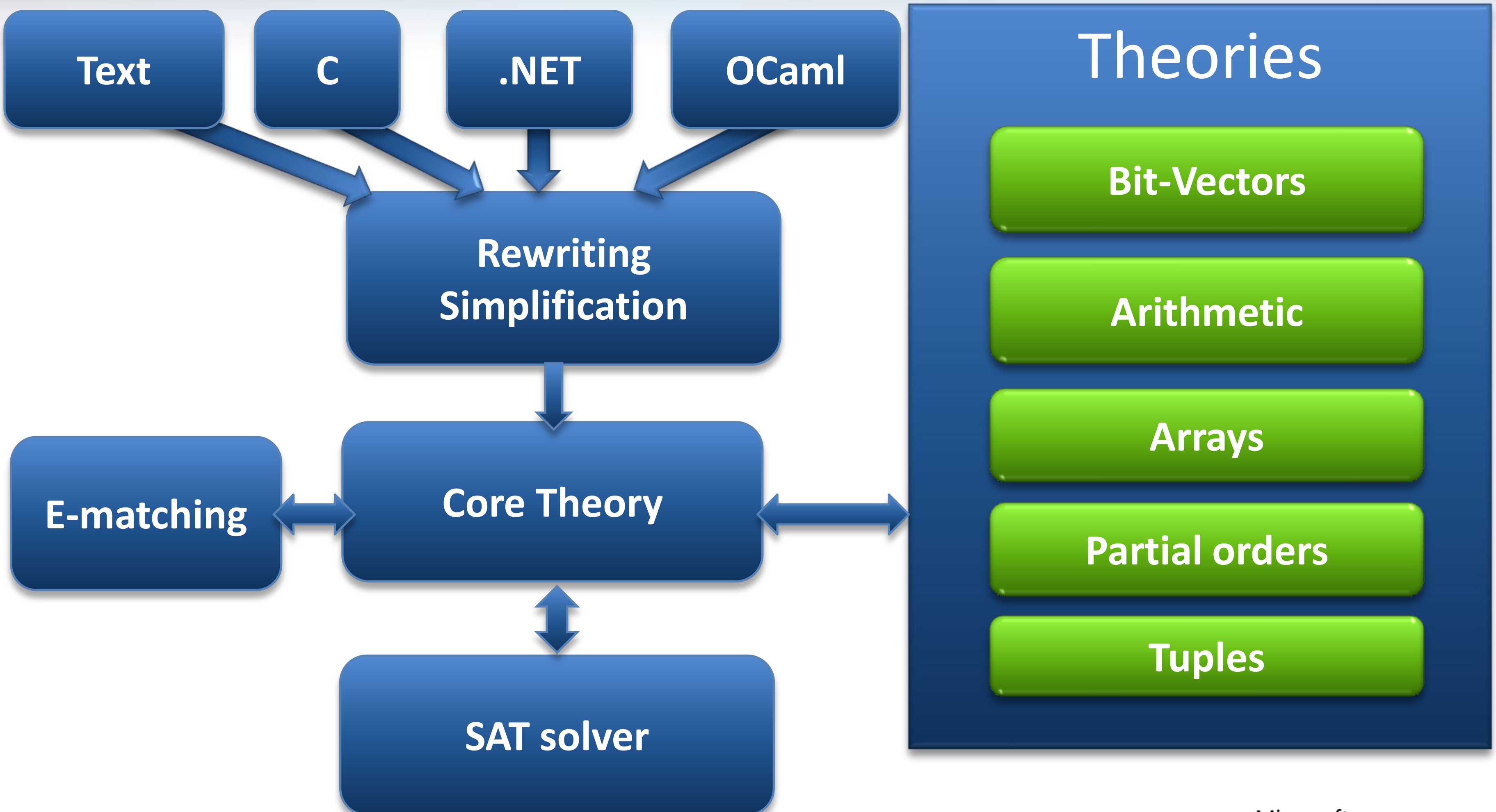
Array Theory

Uninterpreted Functions

Main features

- Linear real and integer arithmetic.
- Fixed-size bit-vectors
- Uninterpreted functions
- Extensional arrays
- Quantifiers
- Model generation
- Several input formats (Simplify, SMT-LIB, Z3, Dimacs)
- Extensive API (C/C++, .Net, OCaml)

Z3: Core System Components



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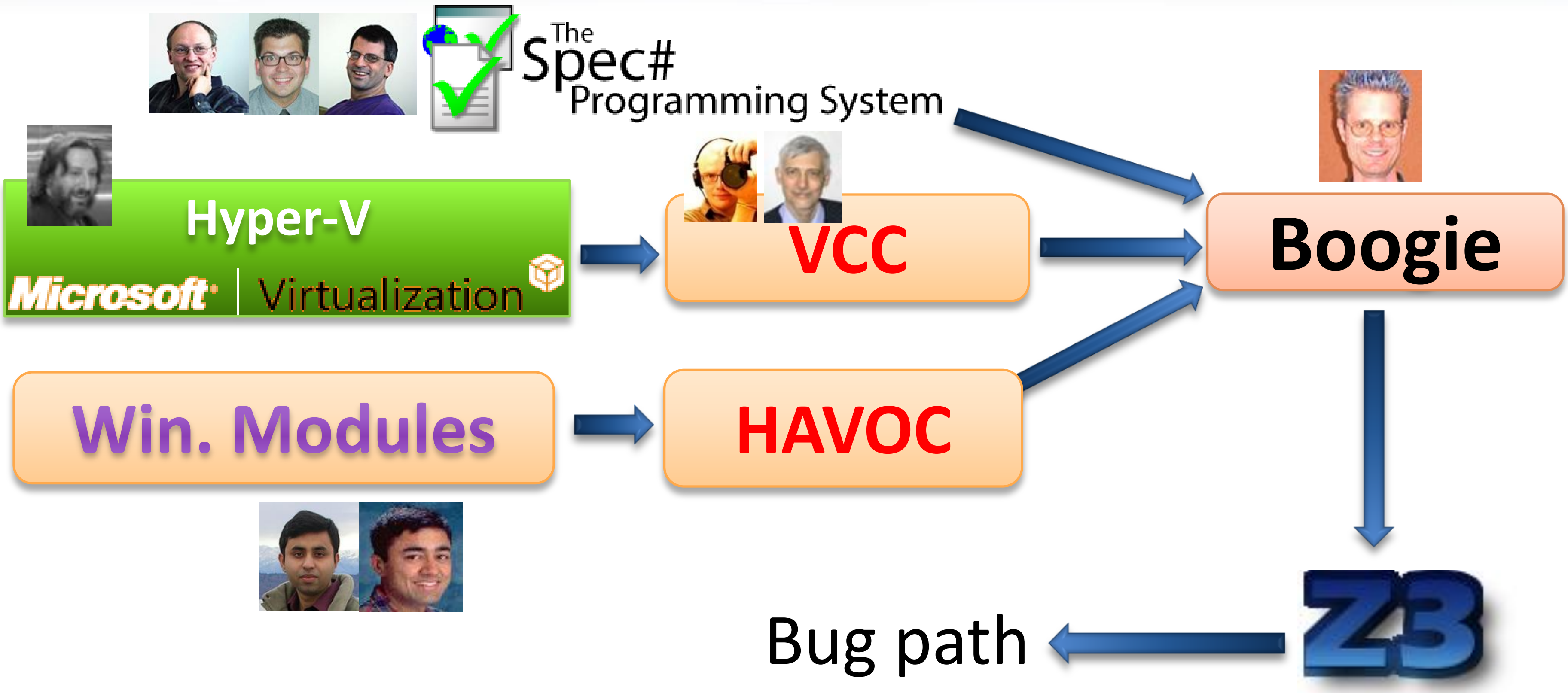
Clients: Program Verification

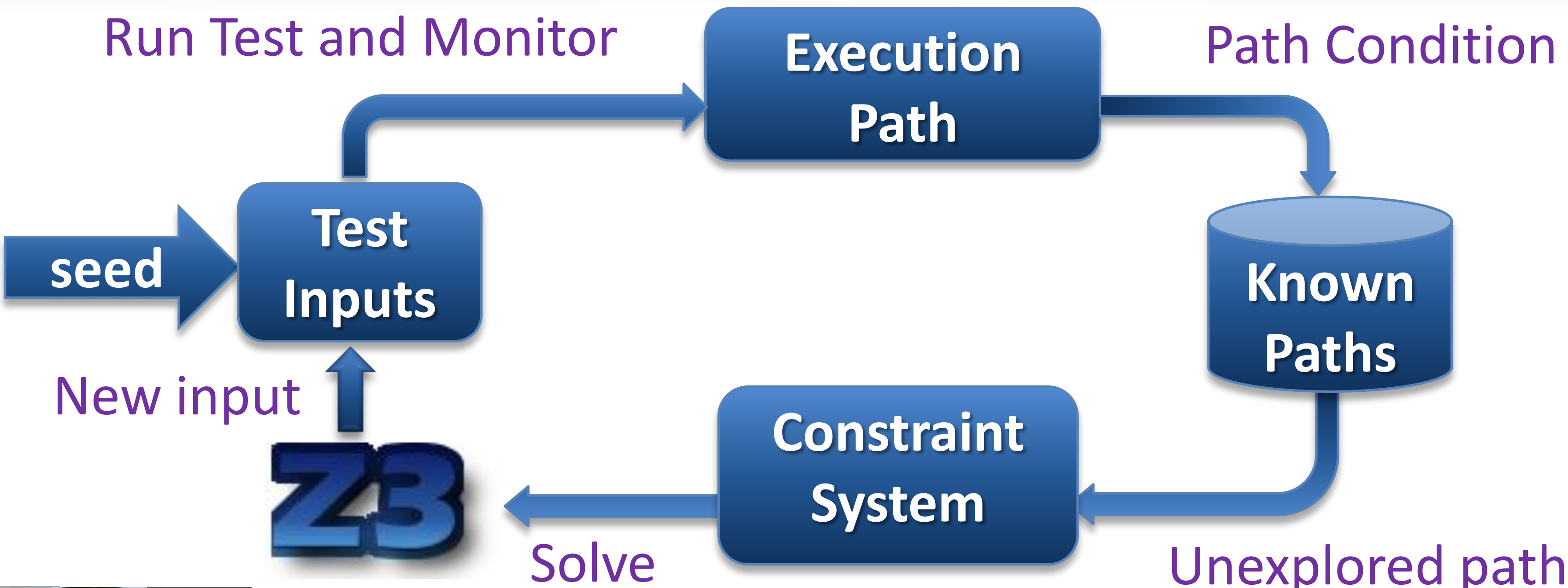


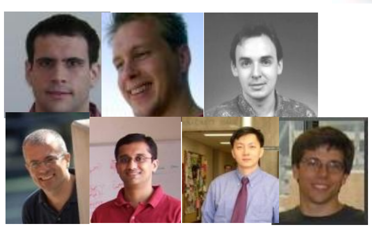
Rustan Leino, Mike Barnet, Michal Moskal, Shaz Qadeer,
Shuvendu Lahiri, Herman Venter, Peter Muller,
Wolfram Schulte, Ernie Cohen

Z3 & Program Verification

- Quantifiers, quantifiers, quantifiers, …
  - Modeling the runtime
  - Frame axioms ("what didn't change")
  - Users provided assertions (e.g., the array is sorted)
  - Prototyping decision procedures (e.g., reachability, heaps, …)
- *Solver must be fast in satisfiable instances.*
- Trade-off between precision and performance.
- *Candidate (Potential) Models*

Clients: Test case generation





Vigilante

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Aditya Nori, Jean Philippe Martin, Miguel Castro,
Manuel Costa, Lintao Zhang

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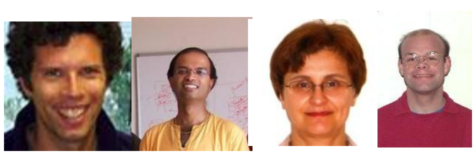
Z3 & Test case generation

- Formulas may be a big conjunction
  - Pre-processing step
  - Eliminate variables and simplify input format
- Incremental: solve several similar formulas
  - New constraints are asserted.
  - **push** and **pop**: (user) backtracking
  - Lemma reuse
- "Small Models"
  - Given a formula *F*, find a model *M*, that minimizes the value of the variables $x_0 \ldots x_n$

Client: Static Driver Verifier

- Z3 is part of SDV 2.0 (Windows 7)
- It is used for:
  - Predicate abstraction (c2bp)
  - Counterexample refinement (newton)



Ella Bounimova, Vlad Levin, Jakob Lichtenberg,
Tom Ball, Sriram Rajamani, Byron Cook

Z3 & Static Driver Verifier

- All-SAT
  - Fast Predicate Abstraction
- Unsatisfiable cores
  - Why the abstract path is not feasible?

More Microsoft clients

- Bounded model-checking of model programs 
- Termination 
- Security protocols  
- Business application modeling 
- Cryptography 
- Model Based Testing (SQL-Server)
- *Your killer-application here*

Some Technical goodies

- Model-based Theory Combination
  - *How to efficiently combine theory solvers?*
  - Use models to control Theory Combination.
- E-matching abstract machine
  - Term indexing data-structures for incremental matching modulo equalities.
- Relevancy propagation
  - Use Tableau advantages with DPLL engine

Example: C API

```
for (n = 2; n <= 5; n++) {
    printf("n = %d\n", n);
    ctx = Z3_mk_context(cfg);

    bool_type   = Z3_mk_bool_type(ctx);
    array_type  = Z3_mk_array_type(ctx, bool_type, bool_type);

    /* create arrays */
    for (i = 0; i < n; i++) {
        Z3_symbol s = Z3_mk_int_symbol(ctx, i);
        a[i]        = Z3_mk_const(ctx, s, array_type);
    }

    /* assert distinct(a[0], ..., a[n]) */
    d = Z3_mk_distinct(ctx, n, a);
    printf("%s\n", Z3_ast_to_string(ctx, d));
    Z3_assert_cnstr(ctx, d);

    /* context is satisfiable if n < 5 */
    if (Z3_check(ctx) == l_false)
        printf("unsatisfiable, n: %d\n", n);

    Z3_del_context(ctx);
}
```

Given arrays:

bool a1[bool];
bool a2[bool];
bool a3[bool];
bool a4[bool];

All can be distinct.

Add:

bool a5[bool];

Two of a1,..,a5 must be equal.

Future/Current Work

- Coming soon (Z3 2.0):
  - Proofs & Unsat cores
  - Superposition Calculus
  - Decidable Fragments
  - Machine Learning
  - Non linear arithmetic (Gröbner Bases)
  - Inductive Datatypes
  - Improved Array & Bit-vector theories
- Several performance improvements
- More “customers” & Applications

Conclusions

- Z3 is a new SMT solver from Microsoft Research.
- Z3 is used in several projects.
- Z3 is freely available for academic research:
  - http://research.microsoft.com/projects/z3