Regression Tests and the Inventor's Dilemma

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RiSE

SAGE

How do we make progress?

We are trying to solve HARD problems

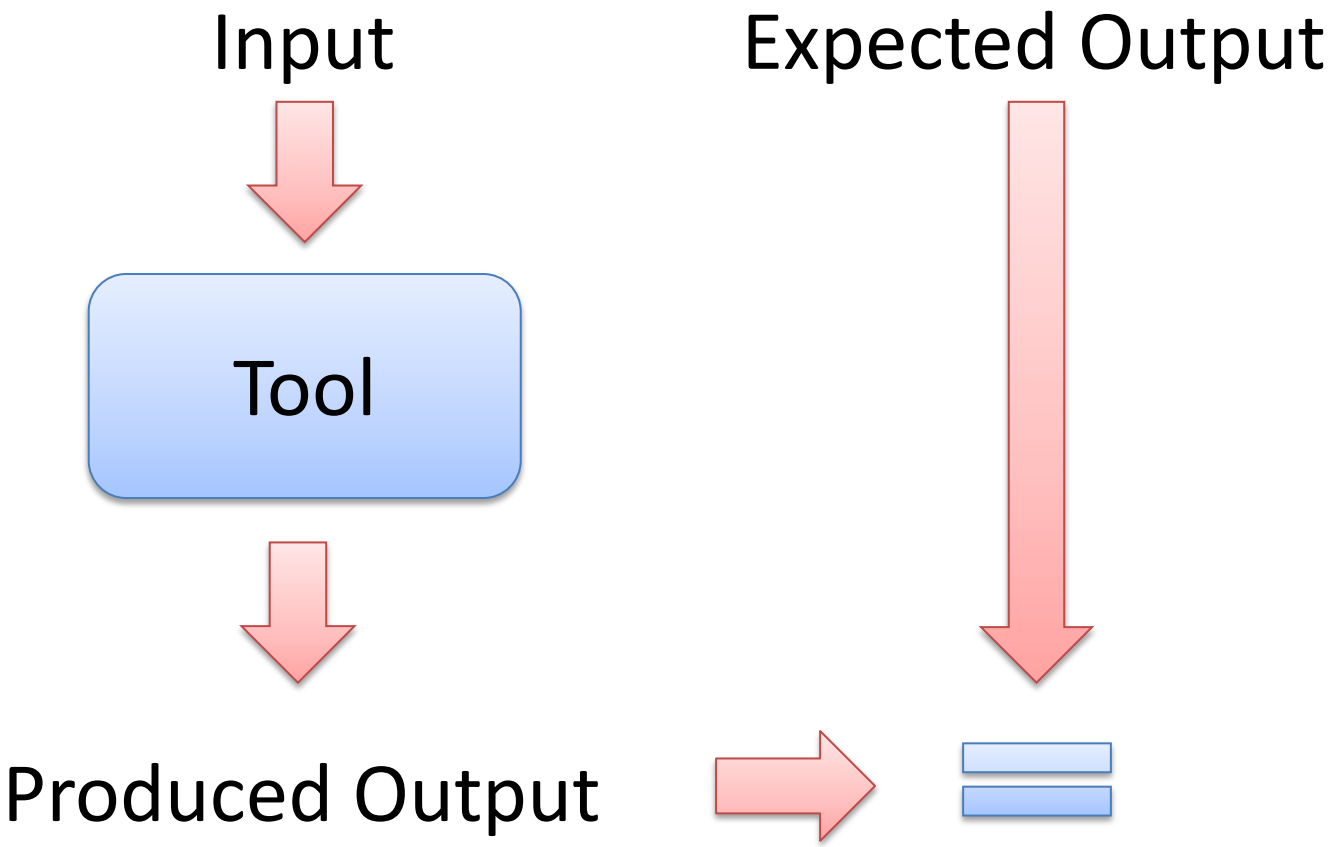
Automated Reasoning Tools use heuristics

Progress is not monotonic

How do we release new versions?

How do we find bugs?

Regression tests



Regression tests: the 1st directive

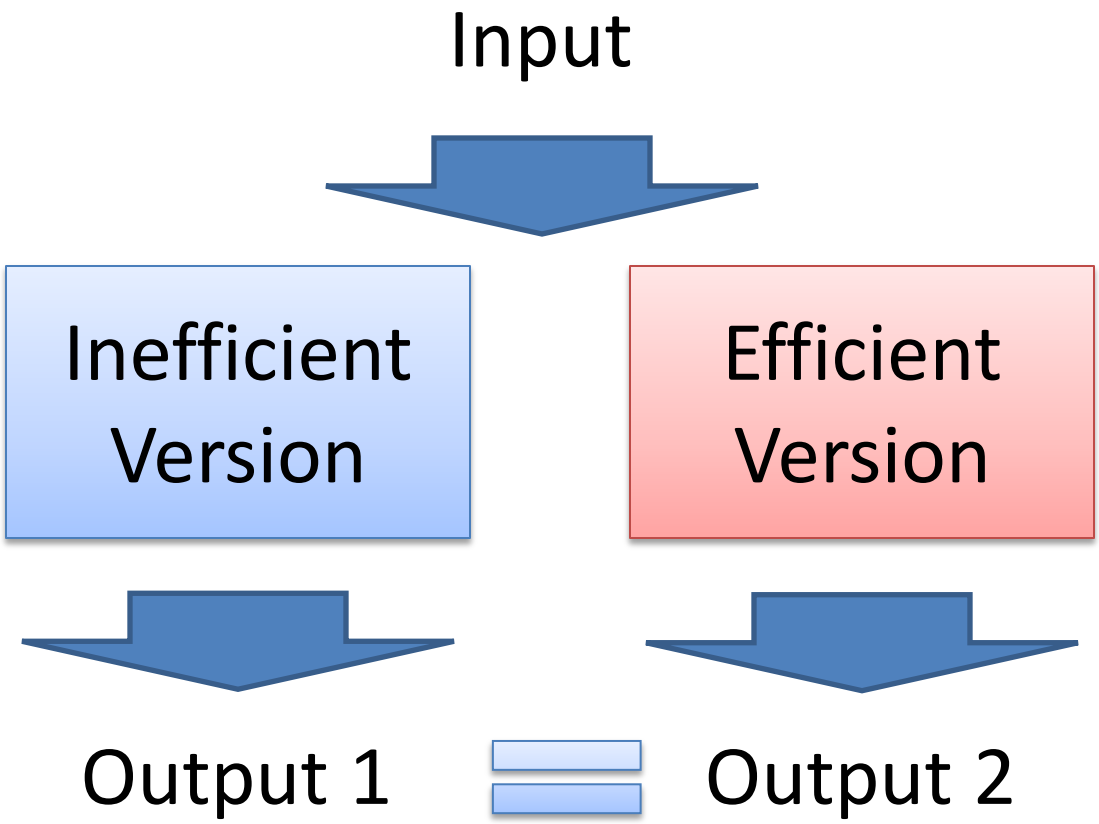
Every bug report becomes a regression test

Fuzzer

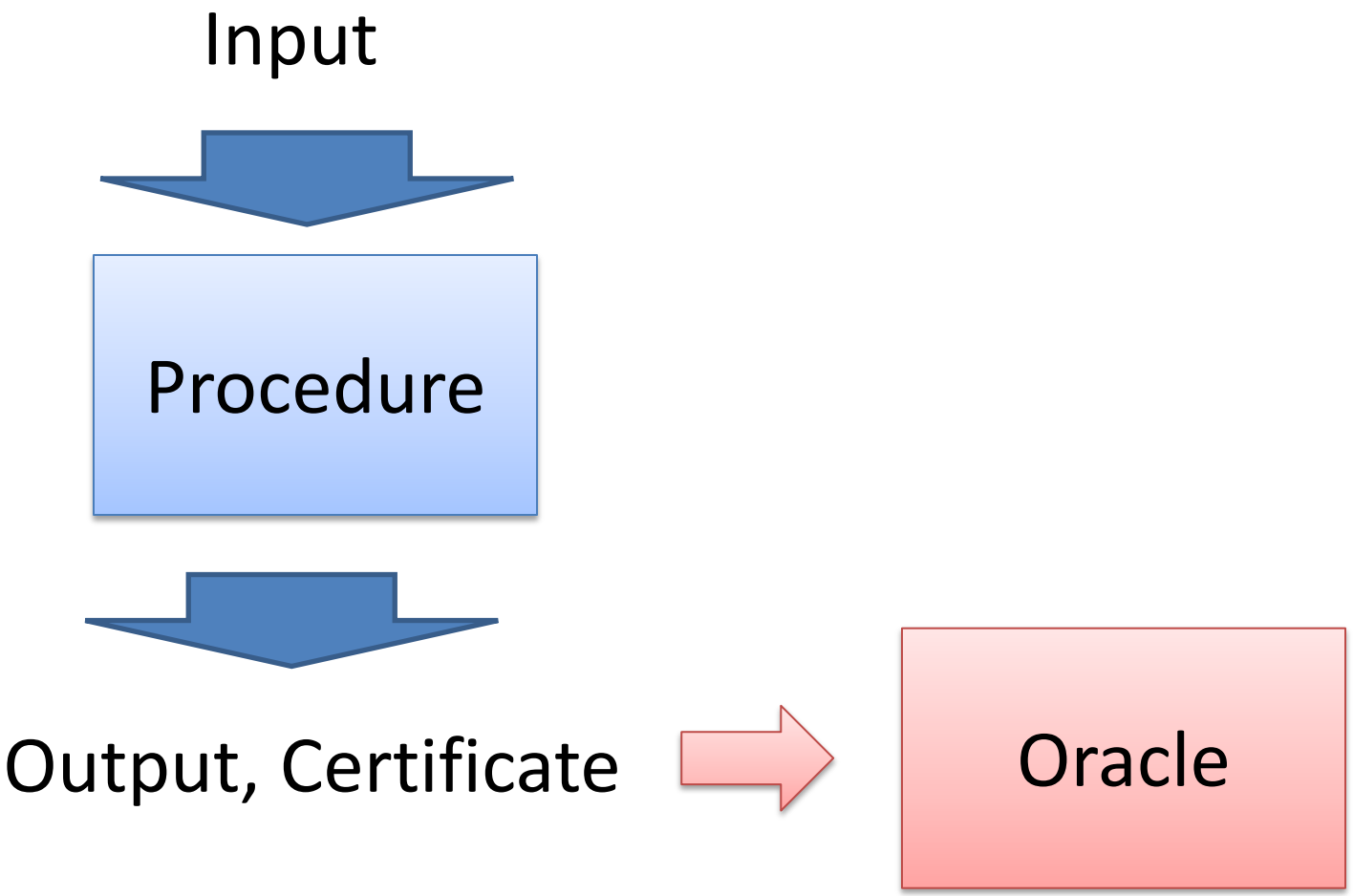
"Random" input generator

- Syntactically valid input
- It is not trying to expose bugs in the parser

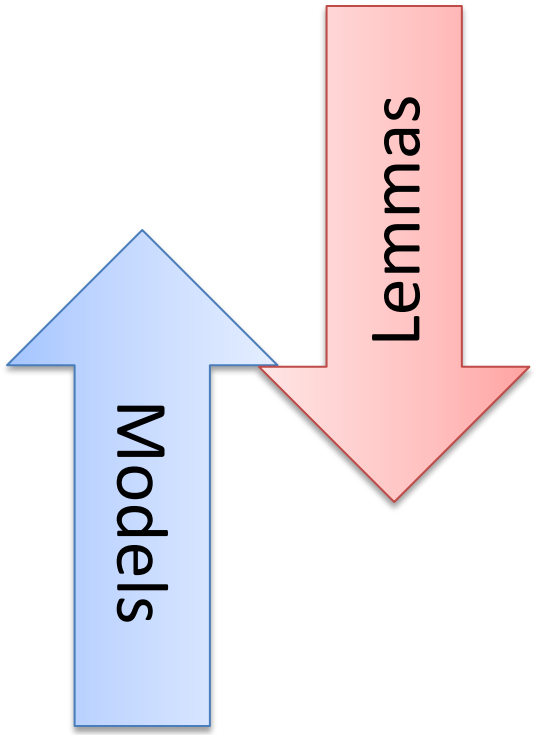
Runtime assertions



External Oracle



Example: Oracles in nlsat



Example: Oracles in nlsat

Current Assignment

$x \quad \sqrt{2}, \qquad y \to 1$

Conflicting Core

$$\neg\, z < 0,$$
$$2z^2 - y^2 = 0,$$
$$\neg x\, z\, - y = 0$$

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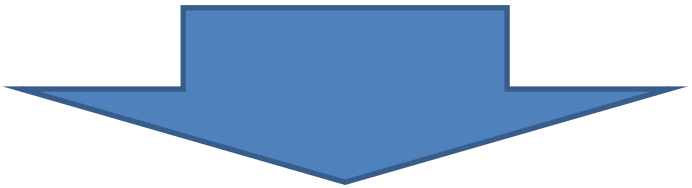


To Oracle: Mathematica

```
Resolve[ForAll[{x, y, z}, !(x== Root[#1^2 - 2 &, 2] && y == 1) ||
                                  z < 0 ||
                                  !(2*z^2 - y^2 == 0) ||
                                  x*z - y == 0],
        Reals]
```

“Telemetry”

“Call home” feature.

Collect stats from every run.

Store stats in a server.

Inventor’s Dilemma

“The new version is slower.”

“The new version fails on my problem.”




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

SDV: STATIC DRIVER VERIFIER

SLAM

Overview

http://research.microsoft.com/slam/

SLAM/SDV is a software model checker.

Ships with DDK

Application domain: *device drivers*.

Architecture:

c2bp C program → boolean program (*predicate abstraction).*

bebop Model checker for boolean programs.

newton Model refinement (check for path feasibility)

SMT solvers are used to:

Perform predicate abstraction,

Check path feasibility.

c2bp makes several calls to the SMT solver.

The formulas are relatively small.

SLAM/SDV Summary

Regression tests are extensively used

Rigid process for incorporating new modules

- Several months to move from Z3 1.x $\rightarrow$ Z3 3.x
- Long process for integrating Yogi

CLOUSOT: STATIC ANALYZER

```
public static string[] InsertAtTheEnd(this string[] list, ref int count,
{
    Contract.Requires(list != null);
    Contract.Requires(0 <= count);
    Contract.Requires(count <= list.Length);

    if (list.Length == count)
    {
        var tmp = new string[count * 2];
        Arr
        lis
    }
    list[count++] = newElement;
}
```

(parameter) ref int count

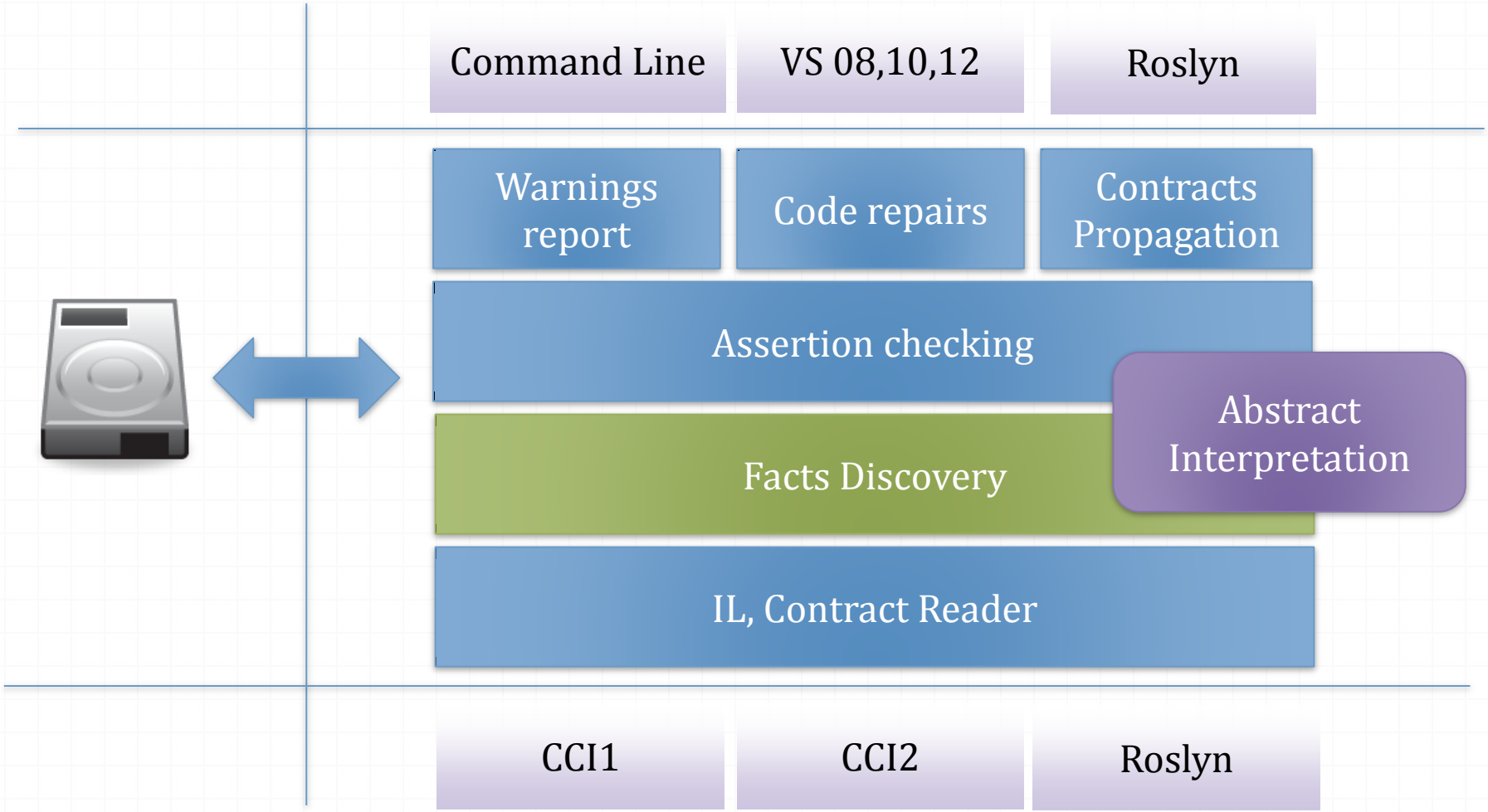
Suggestion: Consider initializing the array with a value larger than count * 2. Fix: count * 2 + 1

(parameter) string[] list

warning: Array access might be above the upper bound

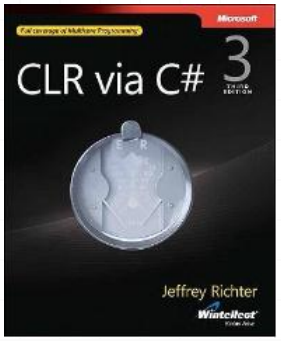
- Clousot checks the code as you type
- It reports warnings and verified code fixes

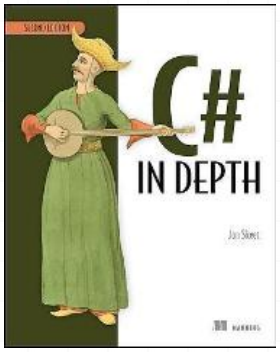
Architecture

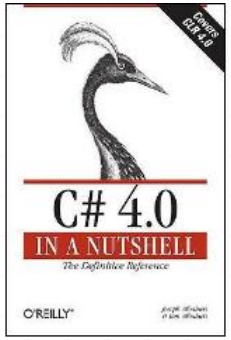


Clousot/CodeContracts impact

- API .NET standard since v4
- Externally available
  - > 60,000 downloads
  - Active forum (>1,500 threads)
  - Book chapters, blogs …
- Internal and External adoption
  - Mainly professional programmers
  - A few university courses
- Publications, talks, tutorials
  - Academic (POPL, OOPSLA, ECOOP, VMCAI, SAS …)
  - Programmers conferences







Clousot Summary

Regression tests

Inventor's dilemma scenario

User X invests time in the following loop:

Inspect warnings

Add more contracts

Fix bugs

Finally the code is warning free

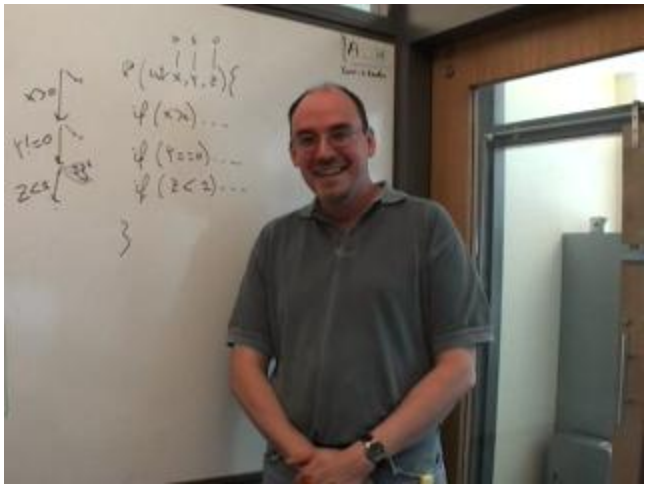
New version is released $\rightarrow$ New warnings

Some users use multiple versions

Clousot Summary

Inventor's Dilemma Apocalypse

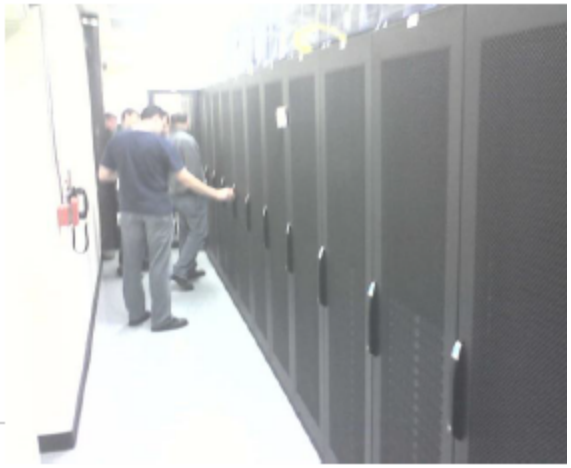
- May ship as part of Visual Studio
- Potential for millions of users

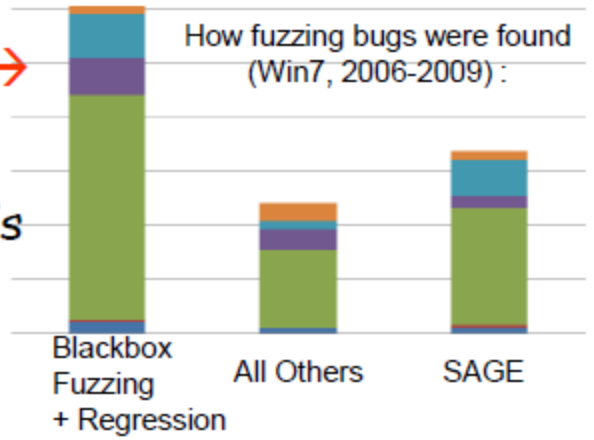


SAGE: TEST-CASE GENERATION

Test Generation is Big Business

- #1 application for SMT solvers today (CPU usage)
- SAGE @ Microsoft:
  - 1st whitebox fuzzer for security testing
  - 400+ machine years (since 2008) →
  - 3.4+ Billion constraints
  - 100s of apps, 100s of security bugs
  - Example: Win7 file fuzzing
    ~1/3 of all fuzzing bugs found by SAGE →
    (missed by everything else…)
  - Bug fixes shipped (quietly) to 1 Billion+ PCs
  - Millions of dollars saved
    - for Microsoft + time/energy for the world





SAGAN: Fuzzing in the (Virtual) Cloud

- Since June 2010, new centralized server collecting stats from all SAGE runs !
  - 200+ machine-years of SAGE data (since June 2010)
- Track results (bugs, concrete & symbolic test coverage), incompleteness (unhandled tainted x86 instructions, Z3 timeouts, divergences, etc.)
- Help troubleshooting (SAGE has 100+ options…)
- Tell us what works and what does not

Picking and Choosing

- Typical SAGE run can fill up 300 GB in 1 week
- Problem: 100s of machines * 300+ GB = lots of data
- Solution: pick and choose what to ship up
  - Configuration files
  - Counters from each SAGE execution
  - Run "heartbeats" at random intervals
  - Crashing test information
- Key principles
  - Enough information to repro SAGE run results
  - Support key analyses for improving SAGE

Sage Summary

Tool as a service

Extensive use of “telemetry”

Automatically find issues that are relevant for their customers

Satisfiability

Solution/Model

$x^2 + y^2 < 1 \; and \; xy > 0.1$ ⇒ sat, $x = \frac{1}{8}, y = \frac{7}{8}$

$x^2 + y^2 < 1 \; and \; xy > 1$ ⇒ unsat, Proof

Is execution path *P* feasible?

SAGE

WITNESS

Is assertion *X* violated?

Is Formula *F* Satisfiable?

Theorem Prover

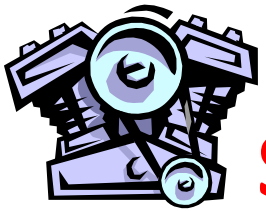
SMT Solver

DPLL

Simplex

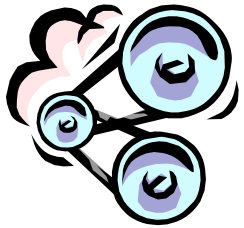
Rewriting

Superposition



Z3 is a collection of

Symbolic Reasoning Engines



Congruence Closure

Groebner Basis

∀∃ elimination

Euclidean Solver

Z3 Impact

Z3 is used by many research groups (> 700 citations)

More than 18k downloads

Z3 placed 1st in 17/21 divisions in the SMT-COMP 2011

history

2007-2008 Competition-oriented years

Just check if it produces the right answer

2007 Z3 0.1 (SMT-COMP'07) Z3 1.0 released later

Tested using 1 machine with 8 cores

2008 Z3 2.0 (SMT-COMP'08)

Small cluster with 12 cheap machines

Painful transition from Z3 1.x $\rightarrow$ Z3 2.x

history

2009-2010 Decline

- Machines in the small cluster started dying
- No regressions or measurements
- Randomly adding features and fixing/adding bugs
- No idea whether making progress or not
- Many users consider Z3 2.19 much worse than 2.16

history

2011-2012 Revival Z3 3.x and 4.x

- Fuzzers running nonstop 24x7
- Rerun all SMT-LIB and key benchmarks every night
- Huge shared cluster
- Z3 3.0 won 17/21 divisions in SMT-COMP'11
- Z3 3.0 best 9/10 divisions in SMT-COMP'12
- Thousands of regression tests executed every night
  - Testing several internal modules
  - Testing exposed APIs

Next Steps…

Adding telemetry

More model/proof validation regression tests

More unit tests

Multiplatform testing: Linux and OSX versions

Monitoring system a-la Sagan

SMT-Lib benchmarks

Not good for testing corner cases

- Fuzzer is great for that
- Manually written tests

Most benchmarks use only the basic SMT 2.0 features

- New Fuzzer?

Z3 & Inventor's Dilemma

"The new Z3 is 20% slower on my problem"

Come on, move on

"The new Z3 is 3x slower on my problem"

Does he work for Microsoft?

"The new Z3 is 10x slower on my problem"

Let me check what is going on

Z3 & Inventor's Dilemma

Incorporate problems from key customers in the regression tests.

It is very hard to make progress.

Z3 2.x search engine is still there.

Be careful when adding obscure features.

Users will find and use them.

Inventor's Dilemma: a Solution

Orchestrating Decision Engines
(more about it tomorrow at IWS)

Leonardo de Moura (Microsoft Research)
Grant Passmore (University of Cambridge)

What is a Strategy?

Theorem proving as an exercise of combinatorial search

Strategies are adaptations of general search mechanisms which reduce the search space by tailoring its exploration to a particular class of formulas.

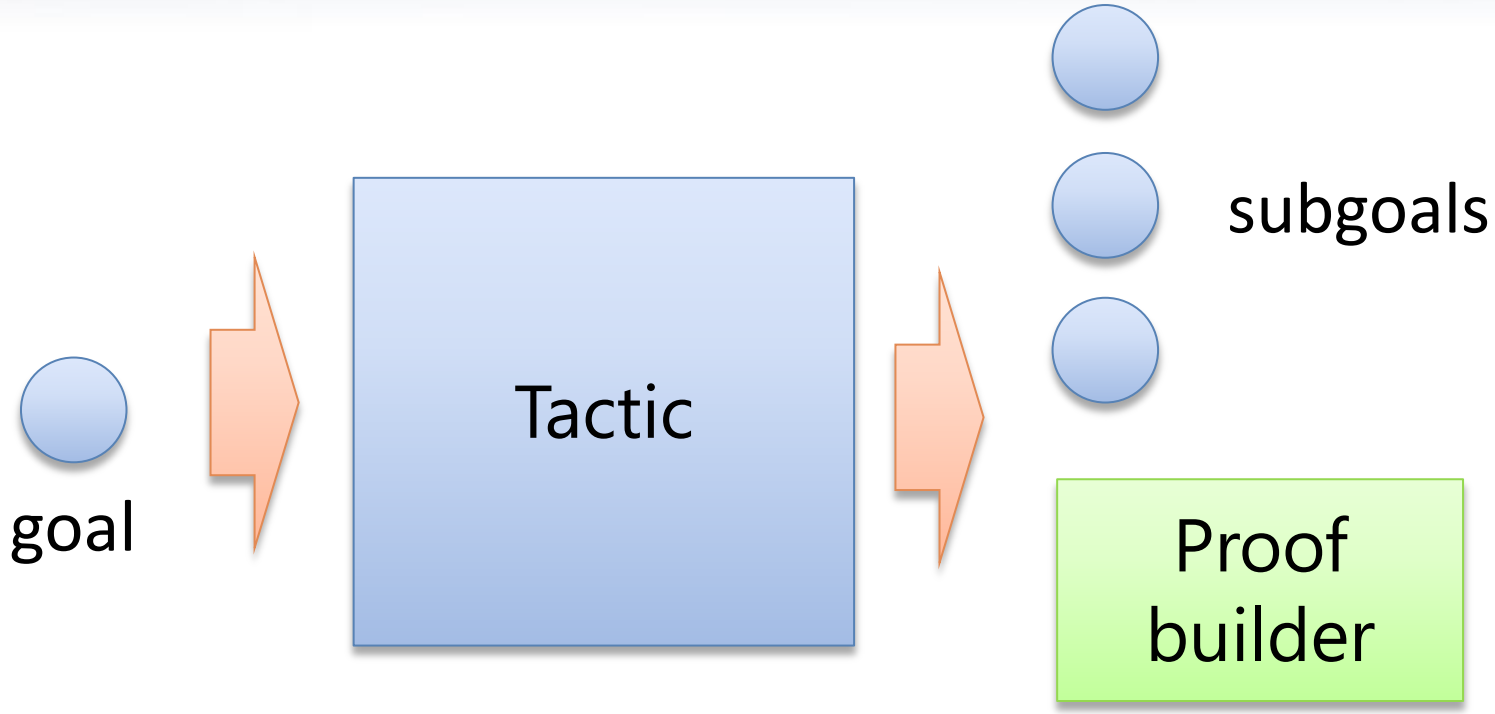
Different Strategies for Different Domains.

The "Message"

SMT solvers are collections of little engines.

They should provide access to these engines.
Users should be able to define their own strategies.

Main inspiration: LCF-approach



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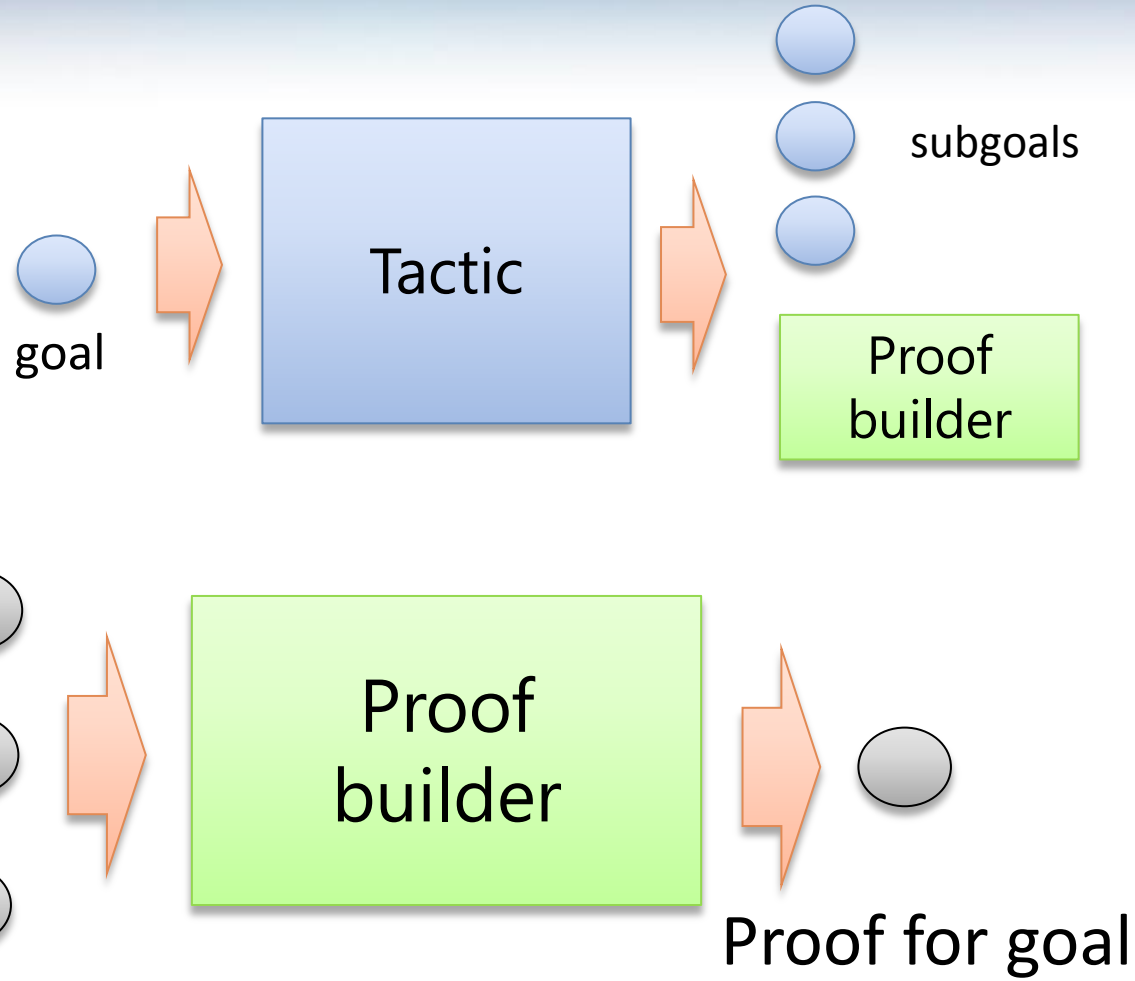

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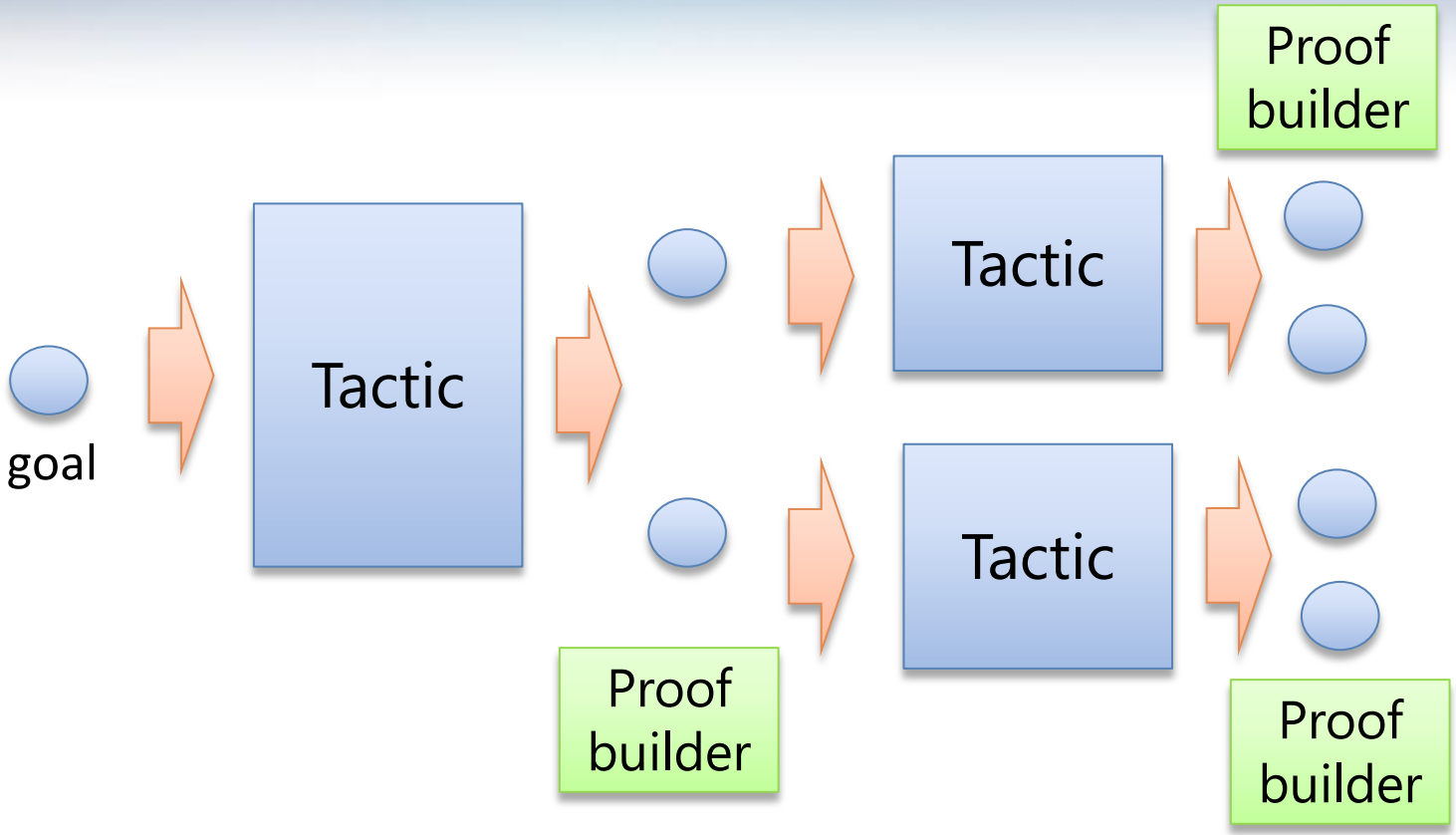

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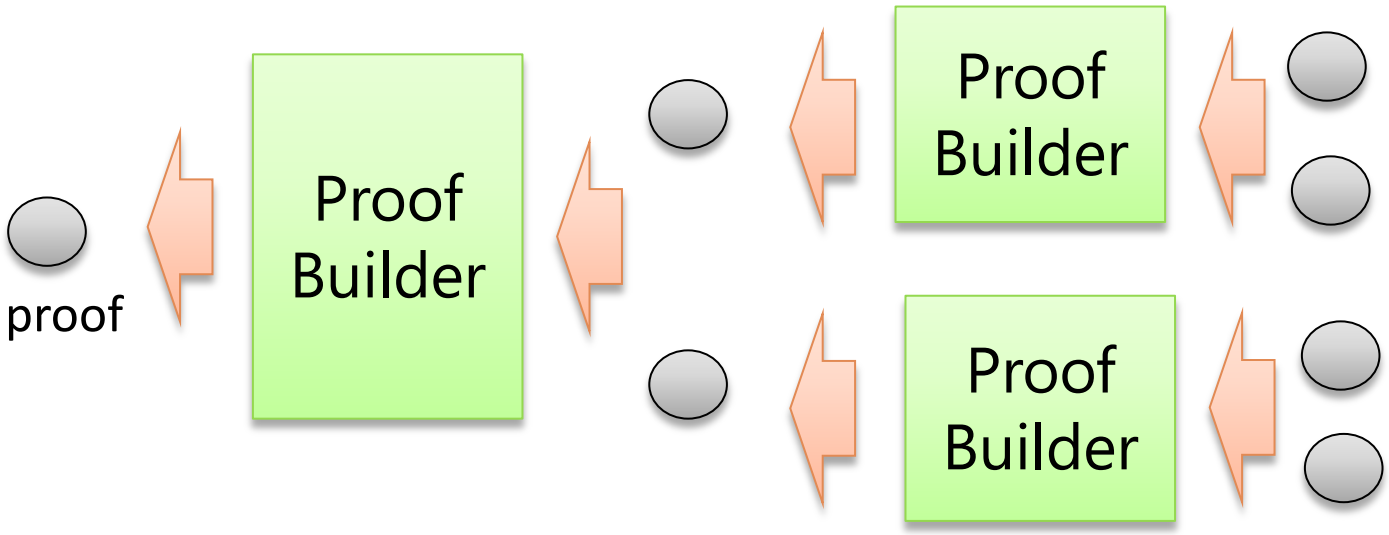

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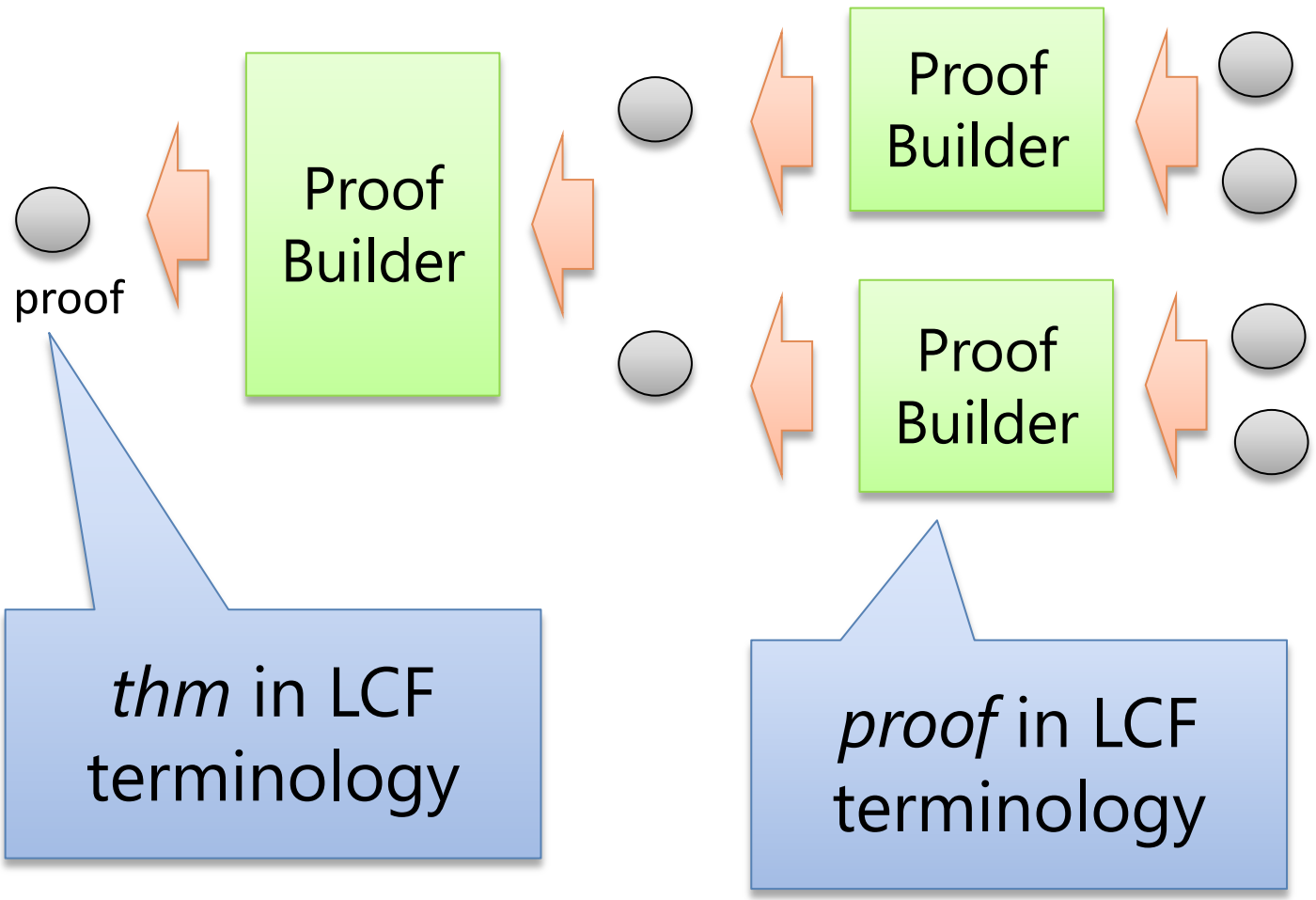
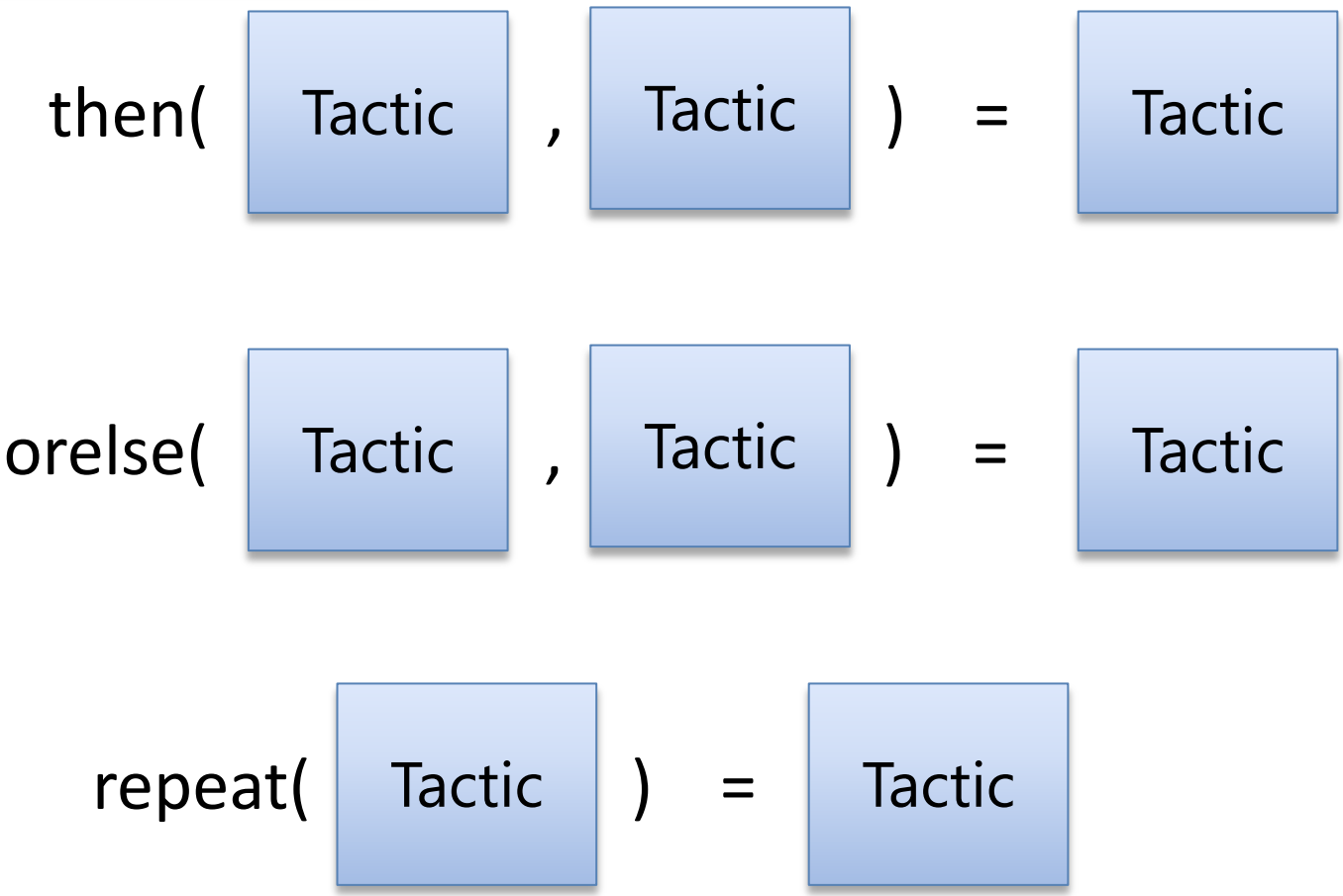
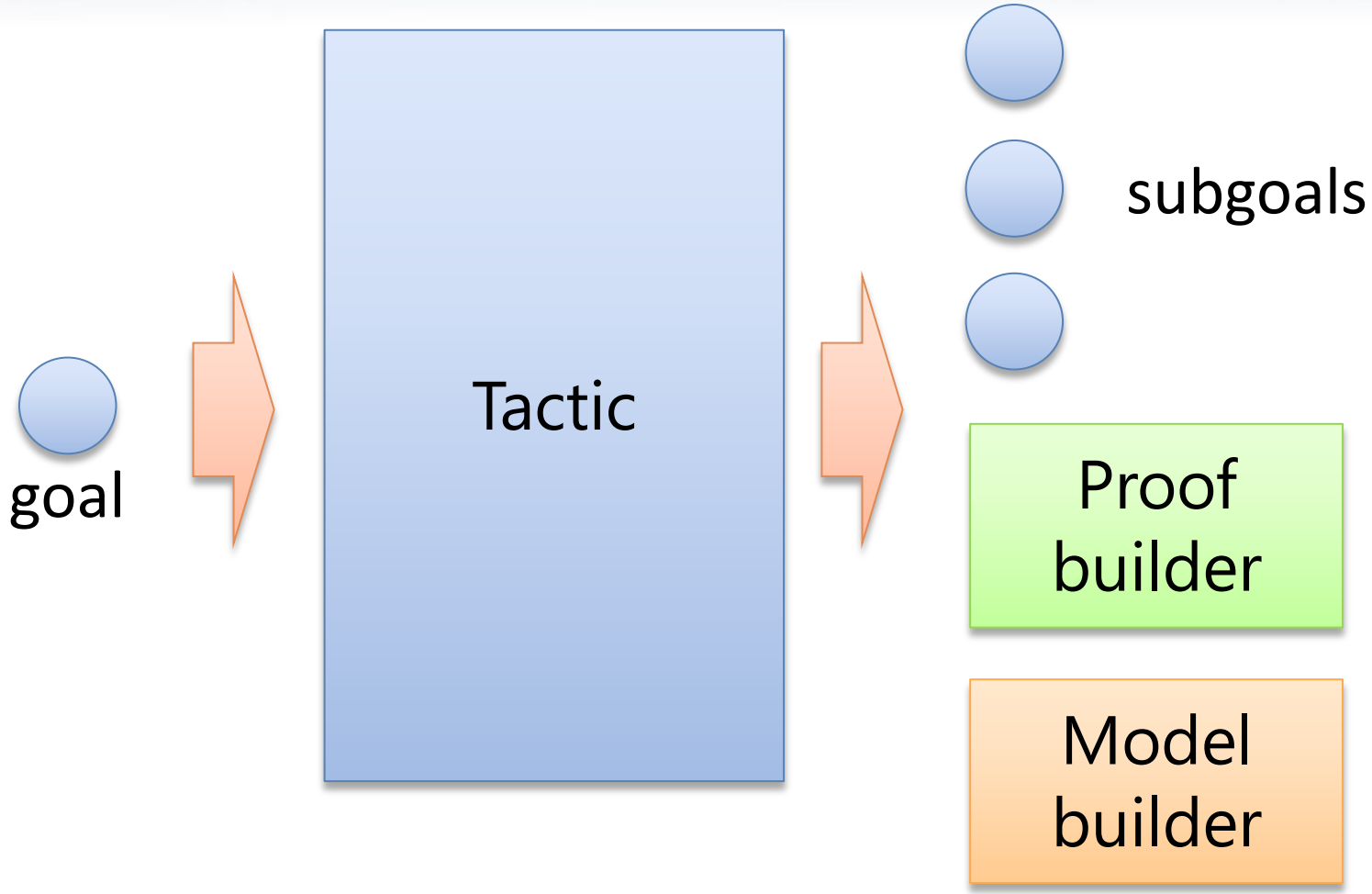


Tacticals aka Combinators



SMT Tactic



SMT Tactic

$$
\begin{array}{lll}
goal & = & formula\ sequence \times attribute\ sequence \\
 & & \\
proofconv & = & proof\ sequence \rightarrow proof \\
modelconv & = & model \times nat \rightarrow model \\
trt & = & \mathsf{sat}\ model \\
 & | & \mathsf{unsat}\ proof \\
 & | & \mathsf{unknown}\ goal\ sequence \times modelconv \times proofconv \\
 & | & \mathsf{fail} \\
tactic & = & goal \rightarrow trt
\end{array}
$$

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$$

end-game tactics:
never return unknown(sb, mc, pc)

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non-branching tactics:
sb is a sigleton in
unknown(sb, mc, pc)

Trivial goals

Empty goal [ ] is trivially satisfiable

False goal […, false, …] is trivially unsatisfiable

basic : tactic

SMT Tactic example

$$[\ a = b + 1,\ (a < 0 \vee a > 0),\ b > 3\ ]$$

Tactic:
elim-vars

Proof builder

$$[\ (b + 1 < 0 \vee b + 1 > 0),\ b > 3\ ]$$

Model builder

SMT Tactic example

$[\ a = b + 1,\ (a < 0 \vee a > 0),\ b > 3\ ]$

Tactic:
elim-vars

$[\ (b + 1 < 0 \vee b + 1 > 0),\ b > 3\ ]$

Proof
builder

M, M(a) = M(b) + 1

Model
builder

M

SMT Tactic example

$$[\ a = b + 1,\ (a < 0 \vee a > 0),\ b > 3\ ]$$

Tactic:
split-or

$$[\ a = b + 1,\ a < 0,\ b > 3\ ]$$

$$[\ a = b + 1,\ a > 0,\ b > 3\ ]$$

Proof builder

Model builder

SMT Tacticals

then : $(tactic \times tactic) \rightarrow tactic$

then(t_1, t_2) applies t_1 to the given goal and t_2 to every subgoal produced by t_1.

then$*$: $(tactic \times tactic\ sequence) \rightarrow tactic$

then$*(t_1, [t_{2_1}, ..., t_{2_n}])$ applies t_1 to the given goal, producing subgoals $g_1, ..., g_m$. If $n \neq m$, the tactic fails. Otherwise, it applies t_{2_i} to every goal g_i.

orelse : $(tactic \times tactic) \rightarrow tactic$

orelse(t_1, t_2) first applies t_1 to the given goal, if it fails then returns the result of t_2 applied to the given goal.

par : $(tactic \times tactic) \rightarrow tactic$

par(t_1, t_2) excutes t_1 and t_2 in parallel.

Z3 QF_LIA Strategy

then(preamble, orelse(mf, pb, bounded, smt)

Simplification
Constant propagation
Interval propagation
Contextual simplification
If-then-else elimination
Gaussian elimination
Unconstrained terms

Conclusion

Regression tests are extensively used at MS

"Telemetry"

Analyze your data

Inventor's Dilemma is a major issue for any tool based on heuristics.

Gets worse as complexity increases

NP, PSPACE, NEXPTIME, Undecidable

Our partial solution:

Orchestrating Decision Engines