SMT-COMP 2020
15th International Satisfiability Modulo Theories Competition

Haniel Barbosa, Jochen Hoenicke, Antti Hyvärinen, July 7, 2020
SMT-COMP

Annual competition for SMT solvers
On (a selection of) benchmarks from SMT-LIB
  • First held in 2005
  • 2013: evaluation instead of competition
  • since 2014: hosted by StarExec

Goals
  • encourage scientific advances in SMT solvers
  • stimulate community to explore shared challenges
  • promote tools and their usage
  • engage and include new members of the community
  • support the SMT-LIB project to promote and develop the SMT-LIB format and collect relevant benchmarks
New this year

An attempt at containing the **workload**
- Soft **limits** on number of **solvers** per **team**
- Select **less benchmarks**
- Set **lower timeout**
- Give **more time to run** the actual competition

**Extension** of the Model Validation track

A ban for **portfolio-style** solvers
SMT-Solvers

Determine **satisfiability** of instances from first-order logic fragments

- benchmarks in **SMT-LIB** format

This year participants:

- CDCL(T)-based “classic” SMT solvers
- Automated Theorem Provers
- **Wrapper Tools**: call at least one other SMT solver

This year **no derived tool submissions**
Competition overview

- Single-query
  - Divisions: e.g. ALIA QF_DT ...
- Unsat Core
  - Divisions: e.g. ALIA QF_DT ...
- Model Validation
  - Divisions: e.g. ALIA QF_DT ...

Incremental
- Divisions: e.g. ALIA QF_DT ...

- non-incremental benchmarks
- incremental benchmarks
Tracks

**Single-Query Track** (previously Main Track)
- One single `check-sat` command, no push/pop commands
- Remove all benchmarks solved by all solvers in 2018 or 2019 in $\leq 1\ s$
- Partly randomised selection of at least 40% of instances
- Time limit 1200s (20 min)

**Incremental Track** (previously Application Track)
- Multiple `check-sat` commands, and push/pop commands
- Solvers are executed on benchmarks via the trace executor
- Partly randomised selection of at least 40% of instances
- Time limit 1200s (20 min)
Tracks

Unsat Core Track

• One single check-sat command, $\geq 2$ assert commands
• Benchmarks with status UNSAT
• Extract unsat core as set of top-level assertions
• Partly randomised selection of at least 40% of instances
• Time limit 1200s (20 min)

Model Validation Track

• One single check-sat command
• Selection of benchmarks with status SAT
• Produce full, correct, well-formed model in SMT-LIB format
• for division QF_BV, experimental for QF_IDL, QF_LIA, QF_LIRA, QF_LRA, QF_RDL
• Time limit 1200s (20 min)
Divisions

Tracks are split into divisions
Divisions correspond to logics in SMT-LIB

- Solvers are submitted to divisions in a track
- winners are declared:
  - per division and track
  - with respect to different scoring schemes per track

We do not run non-competitive divisions
Solver Presentations by Participants
Alt-Ergo @ SmtComp 2020

Alt-Ergo:
• Shostak based SMT solver
• Specialised in quantified formulas and program verification

Developers:
• Sylvain Conchon, Albin Coquereau, Mattias Roux and Guillaume Bury

News:
• Overall performance optimisation
... mainly a (non-)termination and complexity bounds prover, but also ...

- SMT-LIB 2 front-end for QF_NIA
- use bit-blasting for binary arithmetic, back-end: MiniSat [Eén, Sörensson, SAT ’03]
- bit-length for unknowns fixed
- bit-length for constants, sums, products etc. as needed (unlike QF_BV)
- SAT encoding: [Fuhs, Giesl, Middeldorp, Schneider-Kamp, Thiemann, Zankl, SAT ’07]
  \[ \implies \text{back-end for proof techniques for termination/complexity bounds} \]
- approach for SMT-COMP
  - start with small search space
  - if MiniSat says satisfiable: return with model
  - else: retry with larger search space until satisfiable (or out of resources)
- NB: small solver id 1229 (next higher id at SMT-COMP ’20: 28001), scored highest in 2015
Bitwuzla

...is the successor of Boolector.

New Features

- Floating-points: word-blasting with SymFPU
- Unsat cores for all supported quantifier-free logics

Improvements

- Improved propagation-based local search for bit-vectors
- CaDiCaL version 1.2.1 as default SAT back end for all logics

Tracks/Divisions

Single Query: \(BV, \text{QF}_{-\{A,BV,FP,UF\}}^+\)
Incremental Track: \(\text{QF}_{-\{A,UF,BV,FP\}}^+\)
Unsat Core: \(\text{QF}_{-\{A,BV,FP,UF\}}^+\)
Model Validation: \(\text{QF}_{-BV}\)

https://bitwuzla.github.io
COLIBRI(2020)

Goal participate to all $QF_{\_FP}$ division:

- support N-dimension arrays
- better integration of multi-theories other than $QF_{FP}$

Wins of COLIBRI:

- $QF_{BVFPLRA}$: unsat
- $QF_{ABVFPLRA}$: 24s
- $QF_{FP}$: 24s (Bravo Bitwusla !)
- $QF_{FPLRA}$: all category. Nothing proved after the first 24s
Divisions

This year’s configuration of CVC4 enters all divisions in all tracks.

New Features/Improvements

- String solver:
  - More aggressive context-dependent simplifications
  - Better reductions of extended functions
  - Lazy processing of regular expression intersections
- Eager bit-blasting solver:
  - New version of CADICAL
  - Ackermannization of uninterpreted sorts
- Arithmetic solver:
  - Linear integer arithmetic: Branch-and-bound modified to use ternary splitting lemmas inspired by unit-cube tests
  - Non-linear arithmetic: Backward implication of tangent lemma adopted from MATHSAT-NA-EXT

Configurations

- Similar to last year
- Model-Validation Track uses same configuration as Single Query Track but disables simplification of unconstrained terms
lazybv2int at the SMT Competition 2020
Yoni Zohar, Ahmed Irfan, Makai Mann, Andres Nötzli, Andrew Reynolds, Clark Barrett

New participant in QF_BV incremental and non-incremental tracks

Highlights
- Prototype solver
- Wrapper tool – uses smt-switch
- Uses MathSAT5 and CVC4
- Playground for integer-based solving

Approach
- Translation from BV to integers
- Arithmetic operations are easy
- Shift operations: UF
- Bit-wise operations: UF

Eager Mode
- Shifts:
  - Replace with a UF
  - Equate with a big ITE
  - ITE simulates exponentiation
- Bitwise Operators:
  - Replace with a UF
  - Equate with sum or “compare bits”

Lazy Mode
- Shifts:
  - Replace with a UF
  - Lazily instantiate axioms
  - Worst case: ITE
- Bitwise Operators:
  - Replace with a UF
  - Lazily instantiate axioms
  - Check candidate model with BV solver
  - Worst case: sum/bits
A CDCL(T)-based SMT solver
Supports **QF_UF**, **QF_LRA**, and to some extent **QF_LIA**, **QF_BV**

New in 2020:

- Performance improvements for **QF_LRA**:
  - Theory guided choice of polarity for decision vars
  - Lazy tableau maintenance (quasi-basic vars)
  - Single consistent backup assignment
- Models in SMT-LIB2
- Interpolation in incremental mode

[http://verify.inf.usi.ch/opensmt](http://verify.inf.usi.ch/opensmt)
SMT-RAT 20.04

Parser

Frontend

- SAT
- Unsat Cores
- MaxSMT
- Optimization

Strategy Manager

- M-1
- M-2
- M-3
- M-4
- M-5
- M-6
- M-7
- M-8

SMT-RAT

I SMT-RAT strategy
I SAT solver: minisat adapted for less-lazy SMT solving
I non-linear arithmetic: subtropical satisfiability, interval constraint propagation, virtual substitution and cylindrical algebraic decomposition
I non-linear integer arithmetic: bit-blasting and branch&bound

SMT-RAT-MCSAT strategy: MCSAT module based on
Fourier-Motzkin, interval constraint propagation, virtual substitution, one-cell construction, NLSAT-style model based projections

SMT-RAT-CAlC strategy: less-lazy SMT module implementing the novel method cylindrical algebraic coverings (CAlC)
**SMT-RAT strategy**

- **SAT solver**: minisat adapted for less-lazy SMT solving
- **non-linear arithmetic**: subtropical satisfiability, interval constraint propagation, virtual substitution and cylindrical algebraic decomposition
- **non-linear integer arithmetic**: bit-blasting and branch&bound
SMT-RAT strategy

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SMT-RAT-MCSAT strategy: MCSAT module based on minisat

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SMT-RAT strategy

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SMT-RAT-MCSAT strategy: MCSAT module based on minisat

- Fourier-Motzkin, interval constraint propagation, virtual substitution, one-cell construction, NLSAT-style model based projections

SMT-RAT-CA1C strategy: less-lazy SMT module implementing the novel method cylindrical algebraic coverings (CAIC)
SMTInterpol
Jürgen Christ, Jochen Hoenicke, Tanja Schindler

- CDCL(T) based SMT solver
- for Arrays, Uninterpreted Functions, Linear Integer and Real Arithmetic (AUFLIRA)

\[
\begin{align*}
    b &= a \langle i < v \rangle \\
    \forall x. b[x] &= i \rightarrow a[x] = v \\
    f(b) &= v \\
    f(a) &= v \\
    f(a) &= v \\
    b[i] &\geq i \\
    i &\leq y \\
    f(b) &\leq i \\
    y \leq i + 1 \\
    i &\leq y \\
    y - \text{to_int}(y) &< .3 \\
    \forall x. f(x) + i &= g(2v) \text{ (since 2019) has support for quantifiers (E-matching based unit/conflict propagation, MBQI).}
\end{align*}
\]

- that supports model/proof production and interpolation, and
- Open Source (LGPL)

https://github.com/ultimate-pa/smtinterpol
https://ultimate.informatik.uni-freiburg.de/smtinterpol
The adapter that adds quantifier support to your SMT solver!

https://ultimate.informatik.uni-freiburg.de/eliminator/

- Origin: Quantifier elimination of the Ultimate Automizer software verifier
- Supported theories: Arrays, Bitvectors, Floats, Integers, Reals

2020 competition candidate:

**UltimateEliminator**+**MathSAT-5.6.3**

Max Barth, Daniel Dietsch, Leonard Fichtner, Matthias Heizmann, Andreas Podelski
Vampire 4.5

Reger, Suda, Voronkov, Kovács, Kotelnikov, Robillard, Riener, Rawson, Gleiss, Rath, Hozzova, Schoisswohl

https://vprover.github.io

Entering SMTCOMP (single query) since 2016
SMT Logics: A, DT, LIA, LRA, NIA, NRA, UF
Uses a portfolio of strategies and wraps Z3 for ground reasoning.

General Approach is proof search using the Superposition and Resolution Calculus (also using finite model finding in UF)

Theory Reasoning:
- Theory axioms and Evaluation
- AVATAR modulo theories (ground splitting via Z3)
- Theory instantiation (using Z3)
- Induction on Datatypes
Haniel Barbosa, Daniel El Ouraoui, Pascal Fontaine, Hans-Jörg Schurr

Department of Computer Science, Universidade Federal de Minas Gerais (UFMG)
CNRS, Inria, and the University of Lorraine, Nancy, France
Université de Liège, Belgium

- New instantiation heuristics
  - Restrict number of instances per quantified formula
  - Restrict the total number of skolem constants
- Automatically generated option scheduler
  - Generated using integer programming
  - Non-competing variant for 24s timeout: veriT+vite
- Improved support for higher-order logic
- Better proof production
- Instantiation (Learned instance selection, improved conflicting instantiation)
Yices 2 in SMTCOMP 2020

Yices 2
- Supports linear and non-linear arithmetic, arrays, UF, bitvectors
- Supports incremental solving and unsat cores
- Includes two types of solvers: classic CDCL(T) + MCSAT
- [https://github.com/SRI-CSL/yices2](https://github.com/SRI-CSL/yices2)
- [https://yices.csl.sri.com](https://yices.csl.sri.com)

Entered in all Supported Logics and Divisions
- **Single Query**: Quantifier-free logics including linear and nonlinear arithmetic, bitvectors, and combination with UF and Arrays.
- **Model Validation**: All logic supported
- **Incremental**: Same logics
- **Unsat Core**: Same logics minus non-linear arithmetic
New Developments in 2020

Main Solver
- New backend SAT solver
- More bit-vector simplification and rewriting
- Improvements to MCSAT-BV (presented at IJCAR)
- Improvements to MCSAT (better handling of equalities, interval reasoning)
- Better SMT-LIB Models

Language Bindings
- Python, Ocaml, Go (on GitHub) + Java (to be released)

Experimental/In Progress
- Support for quantifiers
- Interpolants via MCSAT
Two-armed solver incorporating three sub-solvers:
- Z3str3
- LAS (Length Abstraction Solver)
- Z3seq (Microsoft Research sequence solver)

Arm selection is done via a syntax-driven “probe” that predicts which arm will have the best runtime.

LAS is a novel CEGAR-style algorithm that solves abstractions and refinements of integer constraints implied by string equations.

Z3str3 leverages a bit-vector reduction to combine the efficiency of an unfolding-based strategy with the ability to reason about unbounded string terms.

Sequence solver and LAS augmented with “dynamic difficulty estimation” heuristic.

Full system description at https://z3str4.github.io/smtcomp.pdf
Non-Competitive Solvers

Total: 24 (SQ), 17 (Inc), 15 (UC), 7 (MV)

Submitted by organisers:
- Z3-4.8.8
- MathSAT 5.6.3
- Division winners from last year (27 solvers)

Submitted by participants:
- Late submission (veriT+vite)
- Fixed solvers (Bitwuzla, MinkeyRink, SMTInterpol, Yices2)
Benchmark Selection

Remove easy benchmarks
  • SQ: all benchmarks solved by all solvers in $\leq 1$ s in 2018 or 2019

Ensure minimum number of instances in a division
  • $n \leq 300$: all instances
  • $300 < n \leq 750$: 300 instances
  • $n > 750$: 40% of the instances

Guarantee inclusion of new benchmarks (at least one per family)
Select benchmarks uniformly at random
Scores

Single Query: number of correctly solved instances
Incremental: number of correctly solved check-sat calls
Unsat Core: reduction number of top-level assertions
Model Validation: number of correctly solved instances with validated models
Scores

**Sequential score** (SQ, MV): time limit applied to CPU time

**Parallel score** (all): time limit applied to wall-clock time

**SAT score** (SQ): parallel score for satisfiable instances

**UNSAT score** (SQ): parallel score for unsatisfiable instances

**24s score** (SQ): parallel score for time limit of 24s
Competition-Wide Recognitions

Two competition-wide rankings

Biggest lead
• in terms of score over the solver in the next place
• tie: ranked by biggest lead in CPU/wall-clock time

Largest contribution
• ranked by contribution to virtual best solver in terms of score
• tie: ranked by largest contribution in terms of CPU/wall-clock time
Competition overview

Teams: 16 (-7)

StarExec Stats: 943’564 jobs (-79’258), 9.9 CPU years (-11.5)

<table>
<thead>
<tr>
<th>Track</th>
<th>Solvers</th>
<th>Divisions</th>
<th>Benchmarks</th>
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<tbody>
<tr>
<td></td>
<td>Total</td>
<td>C/NC</td>
<td>Total</td>
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<tr>
<td>SQ</td>
<td>42 (-9)</td>
<td>20/22</td>
<td>67 (+10)</td>
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<tr>
<td>Inc</td>
<td>24 (+2)</td>
<td>9/15</td>
<td>26 (-3)</td>
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<tr>
<td>UC</td>
<td>18 (+4)</td>
<td>5/13</td>
<td>40 (+2)</td>
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<tr>
<td>MV</td>
<td>13 (+3)</td>
<td>7/6</td>
<td>6 (+5)</td>
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C — competitive, NC — non-competitive, Exp — experimental
### Results

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**SMT-COMP 2020 Results**

**Competition-Wide Recognitions**

**Largest Contribution Ranking**
- Incremental Track
- Model Validation Track
- Single Query Track
- Unreal Core Track

**Biggest Lead Ranking**
- Incremental Track
- Model Validation Track
- Single Query Track
- Unreal Core Track

**Tracks Summary**
- Incremental Track
- Model Validation Track
- Single Query Track
- Unreal Core Track

**Disagreements**

Solvers disagreed on some benchmarks marked as unknown in the following tracks and divisions.
- Single Query Track
  - FP
  - LIA
  - CSABMFLRA
  - CS_S

Competition-Wide Recognitions
## Largest contribution

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<td>seq</td>
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### Unsat Core

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<tbody>
<tr>
<td>seq</td>
<td>Bitwuzla</td>
<td>CVC4</td>
<td>STP + MergeSAT</td>
</tr>
<tr>
<td>par</td>
<td>Bitwuzla</td>
<td>STP + CMS</td>
<td>CVC4</td>
</tr>
</tbody>
</table>
New entrants

In 2020 the new solvers are

- **Bitwuzla:**
  - Aina Niemetz, Mathias Preiner

- **LazyBV2Int:**
  - Ahmed Irfan, Makai Mann, Andres Nötzli, Andrew Reynolds, Yoni Zohar, and Clark Barrett

- **veriT+vite**
  - Haniel Barbosa, Daniel El Ouraoui, Pascal Fontaine, Hans-Jörg Schurr

- **Z3str4**
  - Murphy Berzish, Mitja Kulczynski, Federico Mora, Vijay Ganesh, Dirk Nowotka
Benchmark contributors

The 2020 competition new benchmarks were provided by

- David Deharbe
- Matthias Heizmann
- Johannes Kanig
- Andres Nötzli
- Dennis Yurichev
Solver disagreements

Two solvers disagree on a benchmark with unknown status:

- One says SAT and the other UNSAT

This is particularly problematic if one of the solvers was not found unsound on a benchmark with known status in the same division.

This year we had disagreements

- on 149 benchmarks (115 SQ, 34 Inc, 44 with an unsound solver)
- on 8 divisions (6 SQ, 2 Inc)
- Involving 15 solvers (some of them from last year)

Last year there were no disagreements
Discussion

Model Validation Solvers are not standard compliant

Two DL extensions
  • First was necessary because we were not ready
  • Second caused some harm, we plan to address this in the rules

Running fixed solvers on all divisions where they were submitted
  • We found this very insightful

Inclusion of Par4 from last year
  • Portfolio solvers were not allowed this year, so was this unfair?
<p>| | |</p>
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>meetings</td>
<td>15</td>
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<tr>
<td>git commits</td>
<td>400</td>
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<td>Slack discussions</td>
<td>numerous</td>
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<td>Shell script lines</td>
<td>1'055</td>
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<tr>
<td>Liquid HTML lines</td>
<td>1'369</td>
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Acknowledgements

Aina Niemetz and Mathias Preiner (insights and support)
Aaron Stump (StarExec)