CVC5

A Versatile and Industrial-Strength SMT Solver

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History

Introduction

- Support for *all* standard SMT-LIB and additional non-standard theories
- Beyond SMT solving
  - Proof generation
  - Syntax-Guided Synthesis (SyGuS)
  - Interpolation
  - Abduction

A Versatile and Industrial-Strength SMT Solver

- Extensively used in industry
- Comprehensive, stable API and documentation
- Permissive license

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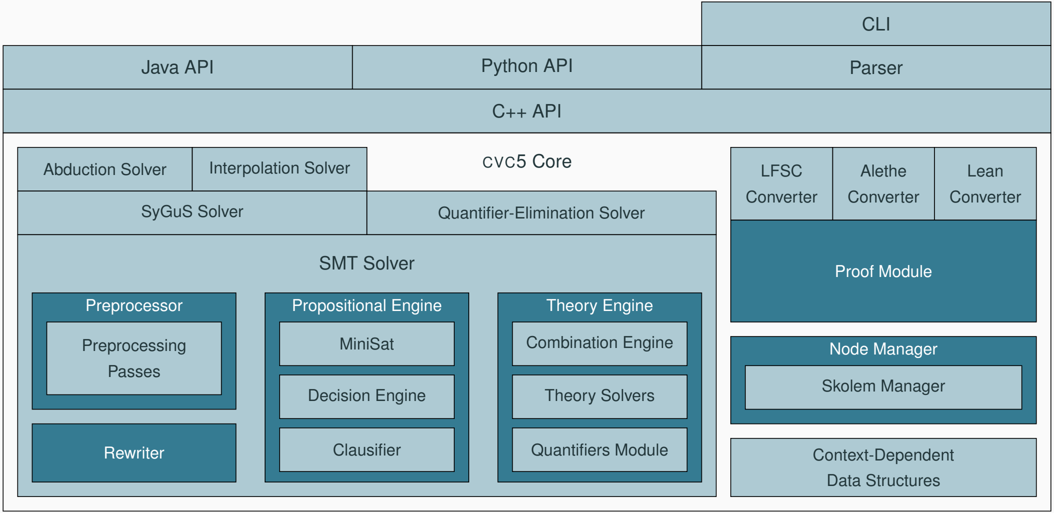
Agenda

- Architecture
- Feature Highlights
  - New API
  - Proofs
  - SyGuS
  - Interpolation and Abduction
- Evaluation

Architecture

Workflow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MiniSat
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Quantifiers Module
LFSC Converter
Alethe Converter
Lean Converter
Proof Module
Node Manager
Skolem Manager
Context-Dependent Data Structures

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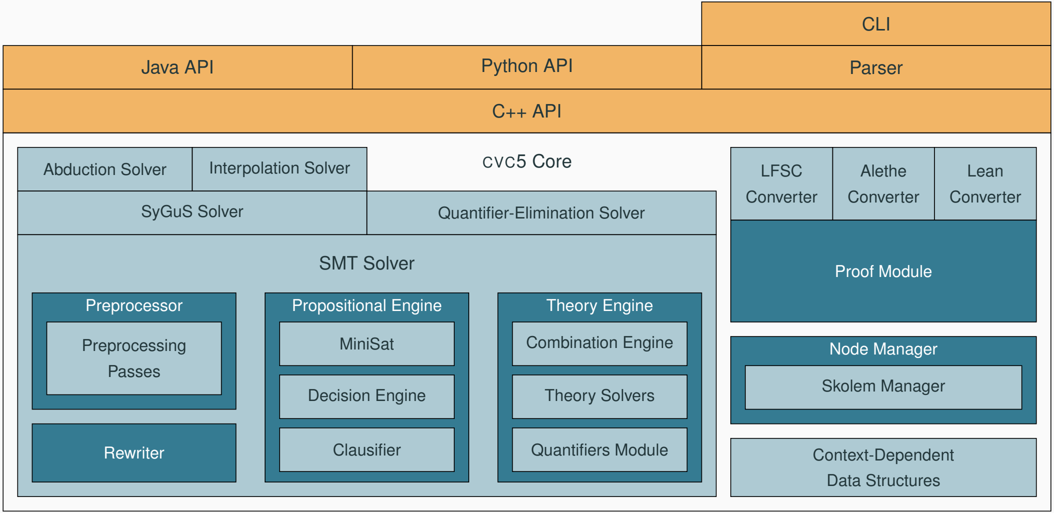
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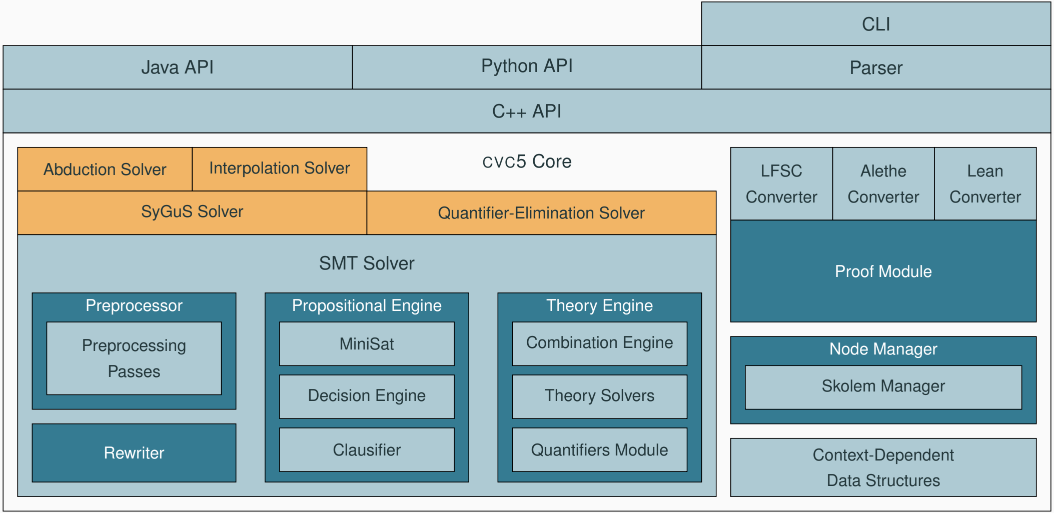

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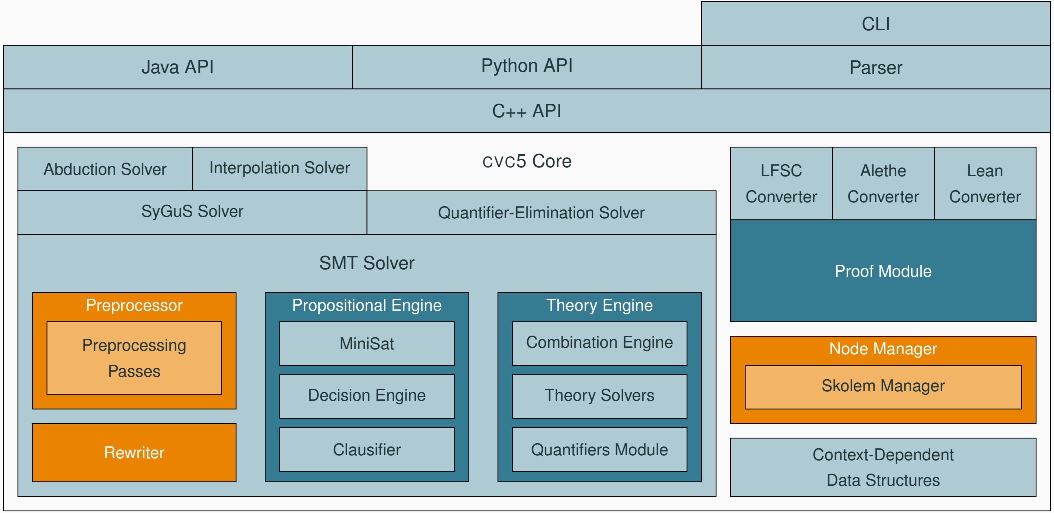
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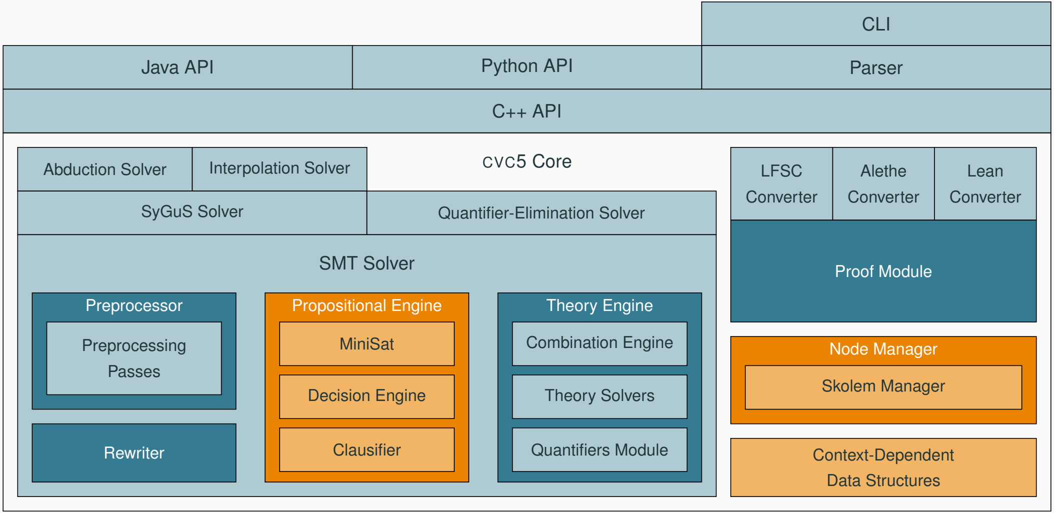
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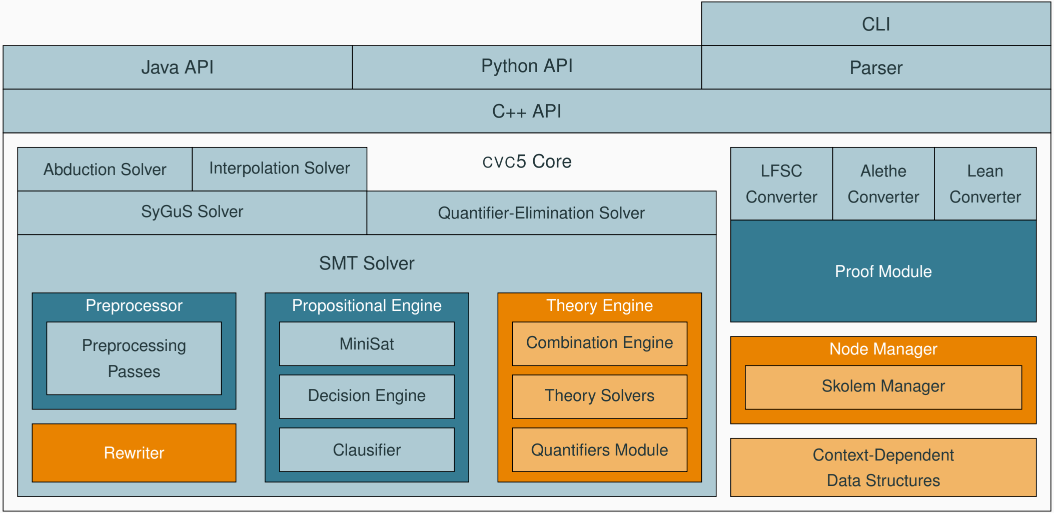
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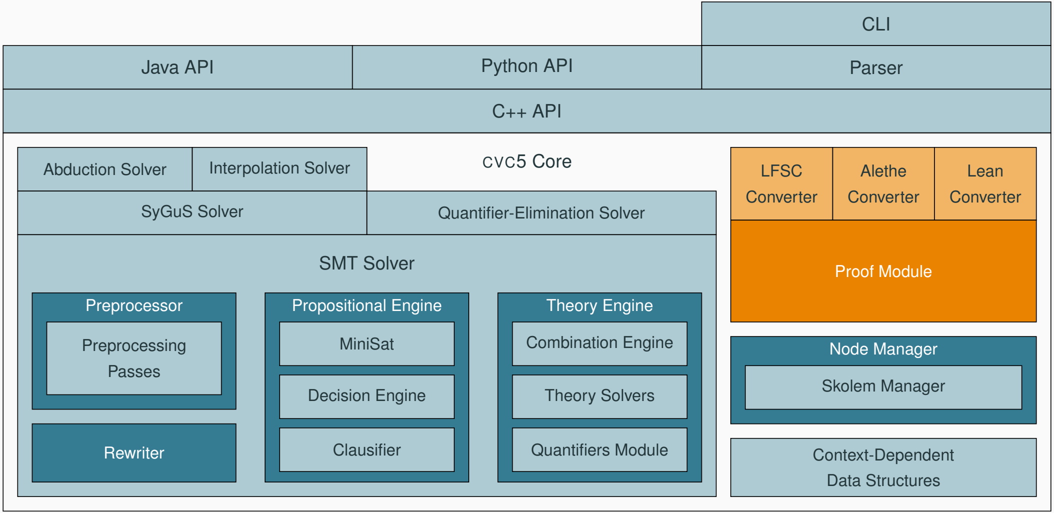
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Theory Solvers

- Linear arithmetic [Kin14, KBD13, KBT14]
- Non-linear arithmetic [RTJB17], *transcendental functions*
- Arrays [JB13]
- Bit-vectors
- Datatypes [BST07, RB15, RVB+18]
- Floating-point arithmetic [BSS19]
- *Sets and relations* [BBRT17, MRTB17]
- *Separation logic* [RISK16]
- Strings and *sequences* [LRT+14, RWB+17, LTR+15, RNBT19, RNBT20]
- Uninterpreted functions (with support for *finite cardinality constraints*) [RTGK13]
- Quantifiers [RTdM14, BFR17, RTG+13, RBF18, RKK17, NPR+21a, NPR+21b, RK15, RBCT16, RDK+15]

Feature Highlights

Feature Highlights: API

- New C++ API
  - Lean, comprehensive, feature-complete
  - Parser module uses the same API
  - Comprehensive documentation
- Python bindings: 2 variants
  - Base bindings: Complete Cython-based bindings for the API
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- Java bindings
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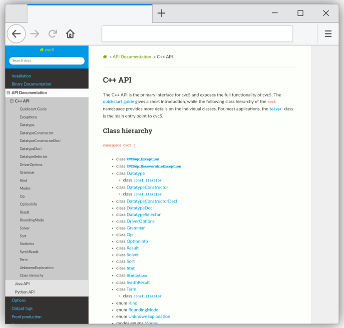

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Solving a simple problem using the Pythonic API

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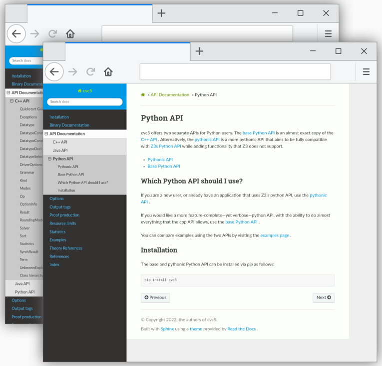

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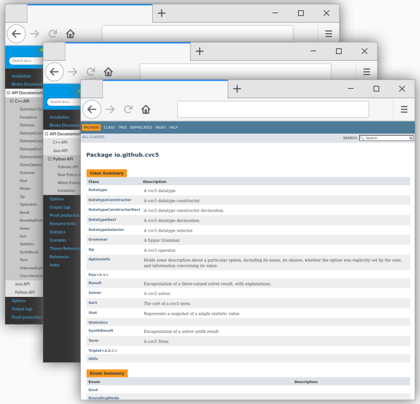

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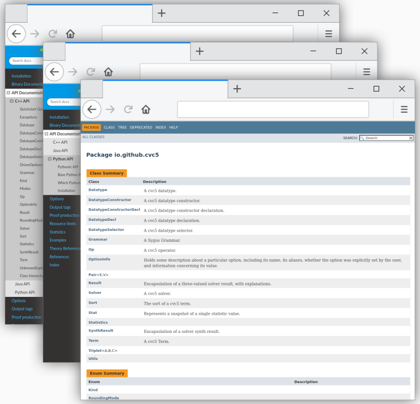

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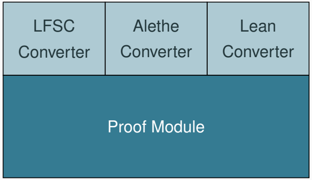
Feature Highlights: Proofs

- New module for producing proofs for unsatisfiable inputs
  - Enables independent checking of answers
  - Automating proofs in interactive theorem provers
- Goals
  - Low overhead
  - Detailed, efficiently checkable proofs
  - Support all performance-critical components
  - Output in different proof formats



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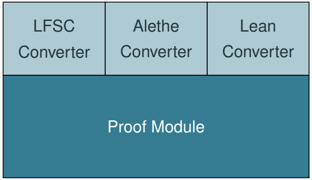
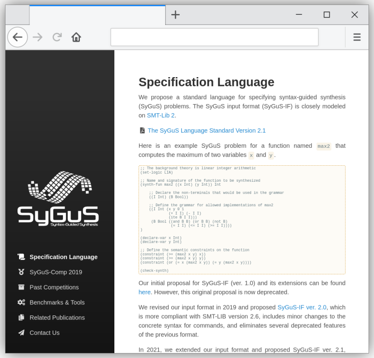


Feature Highlights: Syntax-Guided Synthesis (SyGuS)



Specification

$$\exists f. \forall x. P(f, x)$$

There exists a function f for which property P holds for all x in some theory T.

Syntax

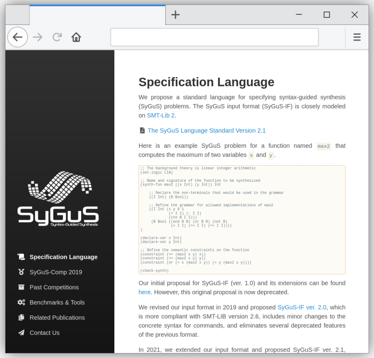
$$A := A + A \mid -A \mid x \mid y \mid 0 \mid 1 \mid \text{ite}(B, A, A)$$

$$B := B \wedge B \mid \neg B \mid A = A \mid A \geqslant A \mid \bot$$

Demo

Flash Fill-style synthesis.

Feature Highlights: Syntax-Guided Synthesis (SyGuS)



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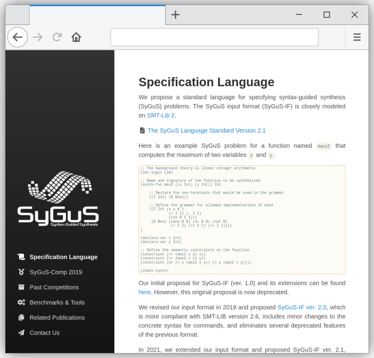

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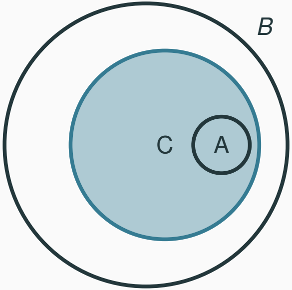
Feature Highlights: Interpolation/Abduction

Interpolation



Find a formula C such that $A \models C$ and $C \models B$. Free symbols in C are from set of shared symbols between A and B.

Abduction

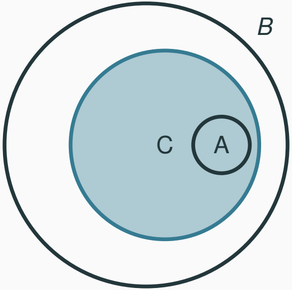
Find a formula C such that $A \wedge C$ is satisfiable and $A \wedge C \models B$.

Demo

Fixing a floating-point rewrite using abduction.

Feature Highlights: Interpolation/Abduction

Interpolation



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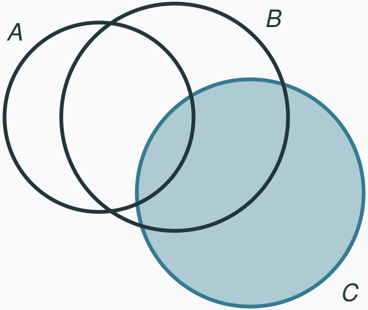

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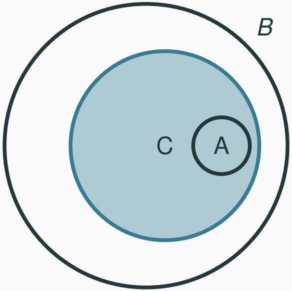
Interpolation



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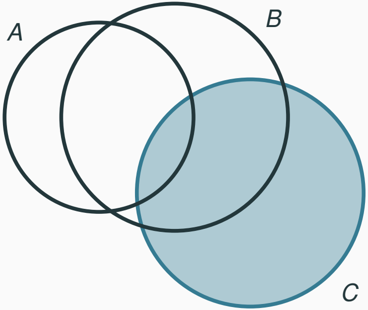

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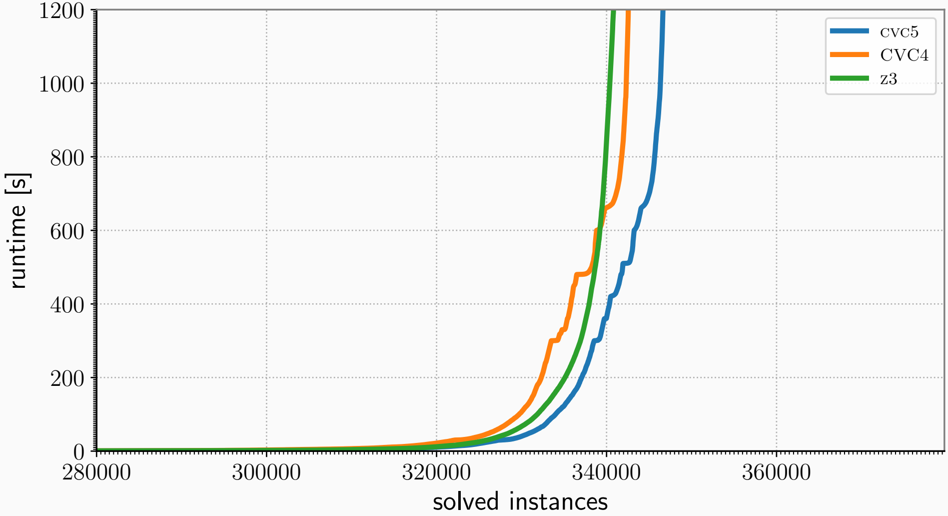
Evaluation

Evaluation: Setup

- Comparison with CVC4 1.8 and Z3
- Benchmark set: 379,750 non-incremental SMT-LIB benchmarks
  - All logics (quantified and quantifier-free)
  - Excluding 1,173 misclassified benchmarks
- Timeout: 1,200 seconds (like SMT-COMP)

Evaluation: Results



Future Work

- Optimization solver
  - Computing satisfying assignments that optimize objectives
- New theories/extensions of theories
  - Support for higher-order map/fold combinators
- Parallel SMT solving
  - Support for running multiple configurations in parallel/sequence
  - Problem Partitioning
- Performance tuning
  - Complete replacement of ANTLR parser
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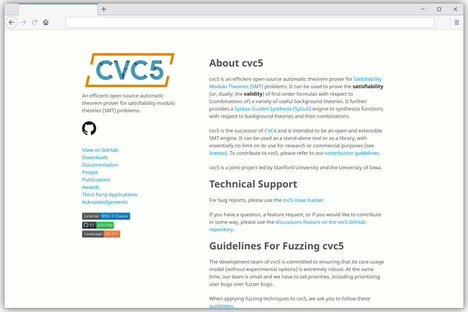
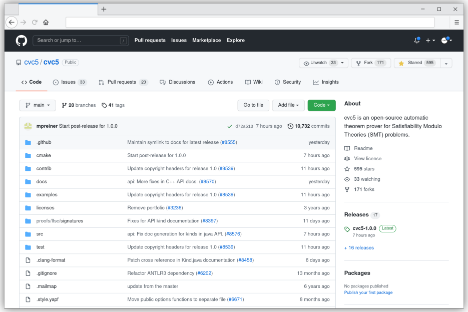
More Information



https://cvc5.github.io/



https://github.com/cvc5/cvc5/

Results

Division	**cvc5**	**CVC4**	**Z3**
Arith (7104)	6593	6498	**6844**
Bitvec (6045)	**5741**	5690	5664
Equality (12159)	6677	**6681**	4688
Equality+LinearArith (55948)	49395	48487	**49503**
Equality+MachineArith (4712)	**2065**	1832	1804
Equality+NonLinearArith (17260)	**11088**	10906	9341
FPArith (3170)	**2625**	2113	2593
QF Bitvec (42450)	**41569**	41448	40582
QF Equality (16254)	**16124**	16121	16115
QF Equality+Bitvec (16518)	16274	**16333**	16318
QF Equality+LinearArith (3924)	3778	3782	**3822**
QF Equality+NonLinearArith (673)	598	610	**616**
QF FPArith (76084)	**75998**	75965	75816
QF LinearIntArith (9765)	8619	**8778**	8464
QF LinearRealArith (2008)	1849	**1881**	1864
QF NonLinearIntArith (24261)	17525	16860	**18357**
QF NonLinearRealArith (11552)	**10889**	9207	10354
QF Strings (69863)	69231	**69367**	68074
Total (379750)	**346638**	342559	340819

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