# Is Static Analysis Successful?

Patrick Cousot

IMDEA Software, Madrid & NYU, New York

pcousot@cs.nyu.edu    cs.nyu.edu/~pcousot

Tuesday, July $7^{\text{th}}$, 2020

# Abstract

When I was invited for the online seminar, I first thought of a technical subject (more precisely, *symbolic terms, substitutions, and systems of equations* which abstract interpretation clarifies by giving them various ground semantics).

*Assume* $\langle \mathcal{C},\ \sqsubseteq\rangle \xleftrightarrow[\alpha]{\gamma} \langle \mathcal{A},\ \preccurlyeq\rangle$ *is a Galois connection between posets and* $\alpha$ *is surjective. If* $\langle \mathcal{C},\ \sqsubseteq\rangle$ *is a complete lattice then so is* $\langle \mathcal{A},\ \preccurlyeq\rangle$.

*So symbolic terms, substitutions, and equations are complete lattices* $\langle \mathcal{A},\ \preccurlyeq\rangle$ *where* $\langle \mathcal{C},\ \sqsubseteq\rangle$ *is a powerset with ground terms (already well-known but proved "in abstracto" in the literature).*

*The problem is that substitutions do not have a unique interpretation! This is the origin of great difficulties, misunderstandings, and lot of confusion about substitutions in the literature.*

# Abstract

But then, the conversation Andreas and I had on the mainstream success of deductive methods while static analysis stays in the shade, led me to another idea:

discuss whether static analysis is successful, or not, and what are the conditions to make it mainstream, and, why not, immensely popular?

# The successes of deductive methods

# Deductive methods

- Theorem provers
- Proof assistants
- SMT solvers

# Theorem provers

# Theorem provers

- First-order theorem proving started with Jacques Herbrand (invents unification in 1930), John Robinson (invents resolution in 1965), ...;
- Great academic tools: ACL2, B prover of Atelier B, iProver, Prover9, PVS, etc;
- Industrial successes: e.g.
  - B method used to prove the security software of the new Paris driverless metro line 14 (not the control/command software);
  - Verification of all elementary floating-point arithmetics on the AMD Athlon by ACL2[1];
- Not simple, slow, requires specialists, proofs must be changed after each program modification, etc;
- Punctual successes not easily replicated (e.g. B not used for renovation of existing line A of Paris RER).

[1] J. Strother Moore, Marijn J. H. Heule: Industrial Use of ACL2: Applications, Achievements, Challenges, and Directions. ARCADE@CADE 2017: 42-45

# Theorem provers

- Full automation is hopeless[2];
- Real successes mostly came from reducing the initial ambitions:
  - Restrict automation: Proof assistants;
  - Prove less: SMT solvers.

[2] Henry Gordon Rice, Classes of Recursively Enumerable Sets and Their Decision Problems, *Trans. Amer. Math. Soc.*, 74:1, 1953, 358–366.

# Proof assistants

# Proof assistants

- Interact or program the proof;
- Great academic tools: Isabelle[3], Coq[4], etc;
- Great successes, e.g. for Coq:
  - Four color theorem, Feit–Thompson theorem by Georges Gonthier,
  - CompCert by Xavier Leroy;
- Industrialization (of software proved by Coq):
  - CompCert sold by AbsInt (used by Airbus France);

[3] first-order logic (FOL), higher-order logic (HOL) or Zermelo–Fraenkel set theory (ZFC)

[4] Calculus of constructions

# Proof assistants

- Despite proving already known theorems, proof assistants are not used
  - by mathematicians (who favor creation over verification),
  - by production engineers;
- Real compilers (LLVM, GCC, etc) are 10 to 50 times larger than CompCert, proofs become inhuman.
- The hope is more for small complex algorithms (e.g. EasyCrypt [5] in cryptography).

[5] Gilles Barthe, François Dupressoir, Benjamin Grégoire, César Kunz, Benedikt Schmidt, Pierre-Yves Strub: EasyCrypt: A Tutorial. FOSAD 2013: 146-166

# SMT solvers

# SMT solvers

- Restrict what you can prove;
- Fixed reduced product of abstract domains[6];
- An unexpected formalization by abstract interpretation[7];
- Great academic tools: CVC3, CVC4, Z3, and many, many, others;
- Some industrial successes e.g.:
  - In R&D on very specific subjects (most often small but complex algorithms) [8],
  - Used by AdaCore to check SPARK contracts;
- Rather unstable over time in competitions;
- At the limit one SMT solver per application[9].

---

[6] Patrick Cousot, Radhia Cousot, Laurent Mauborgne: Theories, solvers and static analysis by abstract interpretation. J. ACM 59(6): 31:1-31:56 (2012)

[7] Vijay D'Silva, Leopold Haller, Daniel Kroening: Abstract satisfaction. POPL 2014: 139-150.

[8] e.g. Z3 and SMT in Industrial R&D, Nicolaj Bjørner, 2018

[9] could be done by incorporating the adequate abstract domains in the product, presently customization is done by hand.

# Is static analysis successful?

# Static analysis is hard to understand

Contrary to deductive methods (check the work of mathematicians), static analysis (check the work of programmers) is more difficult to perceive

- by the general public;
- by programmers (who learn to prove theorems at school but not to prove and, even less, to analyze a program with a tool[10]).

[10] Compilers are the only universally used static analyzers.

# Static analysis is harder than verification (by deductive methods)

## Program Analysis Is Harder Than Verification: A Computability Perspective

Patrick Cousot[1], Roberto Giacobazzi[2,3], and Francesco Ranzato[4(✉)]

[1] New York University, New York City, USA
[2] University of Verona, Verona, Italy
[3] IMDEA Software Institute, Madrid, Spain
[4] University of Padova, Padova, Italy
ranzato@math.unipd.it

**Abstract.** We study from a computability perspective static program analysis, namely detecting sound program assertions, and verification, namely sound checking of program assertions. We first design a general computability model for domains of program assertions and corresponding program analysers and verifiers. Next, we formalize and prove an instantiation of Rice's theorem for static program analysis and verification. Then, within this general model, we provide and show a precise statement of the popular belief that program analysis is a harder problem than program verification: we prove that for finite domains of program assertions, program analysis and verification are equivalent problems, while for infinite domains, program analysis is strictly harder than verification.

# Two additional difficulties for static analysis

- induction (no inductive invariants are given to static analysers);
- no universal interface (to many programming languages, libraries, and systems).

# The context of static analysis is quite diverse

- Academic and industrial tools;
- Academic and industrial users;
- Explicit versus implicit specifications;
- Small models to large programs;
- Sound and unsound tools;
- Bug finding versus verification;
- Terminology is confusing (static analysis versus software checking);
- Many different levels of ambitions (from compilers, linters, unsound commercial tools, semantic-based, sound, and precise tools, to verifiers);

  → hard for non-specialists to have a clear understanding of the field;

  → a lot of space for unscrupulous charlatans.

# Keys to static analysis successes

# Specifications are inexistent

- Formal semantics of languages;
- Requirements for programs;
- Few exceptions: e.g. MISRA C for automobile, DO-178C for the avionics.


DOI:10.1145/2736348 Leslie Lamport

**Viewpoint**

**Who Builds a House without Drawing Blueprints?**

[11]

[11] Static analysis of blueprints is certainly also useful!

# Program certification is not mandatory

- No regulation on software quality;
- A facility rather than an obligation;
- Obligation of means rather than results;
- Software engineering is empiricism but no science;

# Benchmarks are biased

- Academic benchmarks do not reflect industrial needs;
- Industrial benchmarks are not publicly available.

# Independent evaluations are rare

- Few independent comparative evaluations;

  $\rightarrow$ choosing the appropriate static analysis tool is very difficult for engineers and managers.

# Example 1 of benchmarks

**Benchmarking Software Model Checkers on Automotive Code**

Lukas Westhofen[1], Philipp Berger[2], and Joost-Pieter Katoen[2]

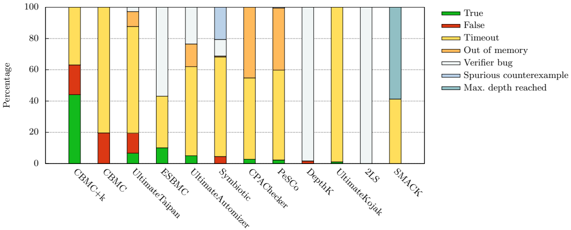
[1] OFFIS e.V., Oldenburg, Germany
lukas.westhofen@offis.de
[2] RWTH Aachen University, Aachen, Germany
{berger, katoen}@cs.rwth-aachen.de

| Metric | DSR | ECC |
|---|---|---|
| *Complexity* | | |
| Source lines of code | 1,354 | 2,517 |
| Cyclomatic complexity | 213 | 268 |

**Requirement Characteristics.**

Invariant properties are assertions that are supposed to hold for all reachable states. Bounded-response properties request that a certain assertion holds within a given number of computational steps whenever a given, second assertion holds.

*Coverage.* Fig. 2 shows the verification results of running the open-source verifiers on the two case studies, omitting the results of the witness validation.



# Example 2 of benchmarks

**NISTIR 8304**

**SATE VI Ockham Sound Analysis Criteria**

Paul E. Black
Kanwardeep Singh Walia

https://doi.org/10.6028/NIST.IR.8304

**National Institute of Standards and Technology**
U.S. Department of Commerce

The criteria were:

1. The tool is claimed to be sound.
2. For at least one weakness class and one test case the tool produces findings for a minimum of 75 % of appropriate sites.
3. Even one incorrect finding disqualifies a tool for this SATE.

Our conclusion is that Astrée and Frama-C with Eva satisfied the SATE VI Ockham Sound Analysis Criteria.

Astrée produces 36316 alarms including all 18954 known bugs in the test suite (plus a number that where unknown but real). Note: Astrée is not a general purpose static analyzer, which is not reflected in the Juliet 1.3 (https://samate.nist.gov/SRD/testsuite.php) test suite.

Frama-C with Eva produces 42056 alarms including all 18954 known bugs in the test suite.

The analyzers that fail the test are not mentioned in the politically-correct report.

Of course not everybody agrees with the significance of the test suite:

SYNOPSYS®

WHITE PAPER

# Coverity: Risk Mitigation for DO-178C

Gordon M. Uchenick, Lead Aerospace/Defense Sales Engineer

...

## Don'ts

- Don't overestimate the limited value of standard test suites such as Juliet.[††] These suites often exercise language features that are not appropriate for safety-critical code. Historically, the overlap between findings of different tools that were run over the same Juliet test suite has been surprisingly small.

†† Juliet Test Suites are available at https://samate.nist.gov/SRD/testsuite.php.

# Tool qualification is inexistent

- Almost no requirements on the static analysis tools used in industry;
  $\rightarrow$ you can run any tool to have a clear conscience!
- An exception: DO-333 (Formal Methods) for avionics (Astrée is DO-333-qualified, meaning it can replace unit tests for runtime errors[12]).

[12] Astrée 20.4 supports Annex J of ISO/IEC 9899:1999 (E) and ISO/IEC TS 17961:2013 C guidelines, the Common Weakness Enumeration (CWE) catalog, the SEI CERT C Coding Standard, the MISRA-C:2004, MISRA-C:2012 (including Amendments 1 and 2), MISRA-C++:2008 rules.

# Education is parcimonious

- Static analysis theory and practice is (almost) not taught;
- The use of static analysis is not even mentioned in programming courses.

# Human resources are scarce

- Very few high-priced specialists for designing static analyzers;
- But, after one month engineers can use static analyzers autonomously;
- Not true for deductive methods.

Google

**Google Cloud DevOps is hiring!**

Published on January 8, 2019

Domagoj Babic | ✓ Following
Tech Lead & Manager @ Google
2 articles
15 0 1

**Job Description:**

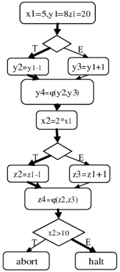
The DevOps organization is looking for Software Engineers passionate about research and development of Google-scale deep program analysis tools, based on abstract interpretation. We are starting a new team that will develop cutting-edge deep Go static analysis tools and deploy them in production. We are looking for individuals who enjoy collaborative teamwork, thrive on computationally hard problems, are motivated by impact, deeply care about software correctness and security, and have a strong academic background in program analysis.

**Peter Backes** If data is the new oil, then program analysis grads are the rarest element on earth ... Wish you good luck
Like · Reply · 2d 2

**Francesco Ranzato** Even worse, program analysis grads who seriously know principles and practice of abstract interpretation are almost inexistent
Like · Reply · 2d 1

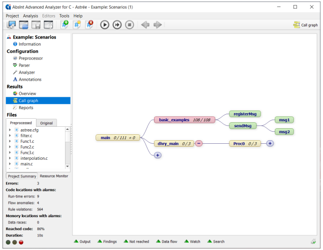
# Many bad designs

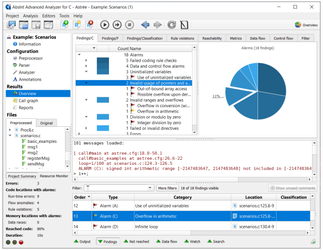
- Control: graph, SSA, etc versus structural induction (e.g. Astrée, Zoncolan at FB);
- Data; unique representation of properties (e.g. Infer) versus structured in abstract domains (e.g. Astrée);
- Extensibility: most often not considered in the original design (e.g. Infer), with exceptions (Astrée, Frama-C with Eva plugin);



# Long term support

- Academic: require permanent self-funded institutions (e.g. INRIA for Ocaml/Coq);
- Free-software: too complicated (e.g. Clousot is public domain makes no significant progress since Fähndrich & Logozzo left MS research for FB);
- Industrial: indispensable but few competent and not extremely profitable (academic Astrée: 60.000 lines of Ocaml, AbsInt: 265.000, not counting the much larger user interface).





# Irresponsibility

- Programmers are never held responsible for their errors, even when the human and economic consequences are huge[13];
- Software engineers are guaranteed qualified immunity under the pretext that verification is beyond best practice;
- If best practice would include the mandatory use of standards and qualified tools, programmers and their hierarchy could be held accountable at least for definite bugs automatically found be static analysis tools.

DOI:10.1145/2631185 Vinton G. Cerf

**Responsible Programming**

[13] e.g. 2009–11 Toyota vehicle recalls, Boeing 737 MAX groundings.

# Successes remain unknown

- AbsInt has sold thousands of industrial licenses of Astrée;
- Who knows that?
- Which formal methods can make such a claim?

**Towards an Industrial Use of Sound Static Analysis for the Verification of Concurrent Embedded Avionics Software**

Antoine Miné
École Normale Supérieure
45, rue d'Ulm
F-75230 Paris Cedes 05, France
mine@di.ens.fr

David Delmas
Airbus Operations S.A.S.
316, route de Bayonne
31060 Toulouse Cedex 9, France
david.delmas@airbus.com

Nucl Eng Technol 47 (2015) 212–218

Available online at www.sciencedirect.com
ScienceDirect
journal homepage: http://www.journals.elsevier.com/nuclear-engineering-and-technology/
ELSEVIER


Technical Note

**EVALUATION OF STATIC ANALYSIS TOOLS USED TO ASSESS SOFTWARE IMPORTANT TO NUCLEAR POWER PLANT SAFETY**

*ALAIN OURGHANLIAN**

*EDF Lab CHATOU, Simulation and Information Technologies for Power Generation Systems Department, EDF R&D, 6 quai Watier, BP 49, 78401 Chatou Cedex, France*

Google scholar citations: 21 — 4

# Conclusion

# Necessary conditions to make static analyzers mainstream

- Specify before programming;
- Program certification is mandatory;
- Benchmarks are publicly available;
- Independent evaluations are fair and public;
- Tools qualification is mandatory;
- Education on static analyzers starts with programming
- Human resources are considerably developed;
- Tool designs are principled;
- Tools are supported in the long term;
- Programmers are made responsible for their errors;
- Industrial successes are glorified.

# Necessary conditions to make static analyzers mainstream

- Specify before programming;
- Program certification is mandatory;
- Benchmarks are publicly available;
- Independent evaluations are fair and public;
- Tools qualification is mandatory;
- Education on static analyzers starts with programming
- Human resources are considerably developed;
- Tool designs are principled;
- Tools are supported in the long term;
- Programmers are made responsible for their errors;
- Industrial successes are glorified.

Hopefully, sufficient! 😂

# The End, Thank you