Sound Static Analysis: 5-point seat belts for your code

Paul E. Black

paul.black@nist.gov

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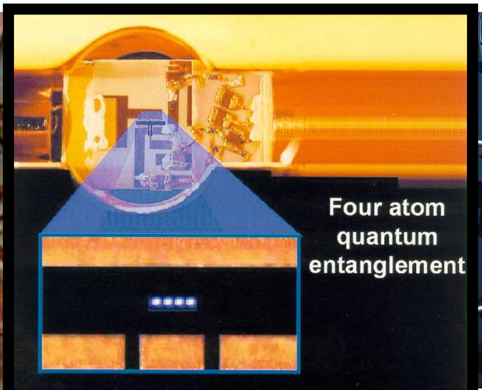
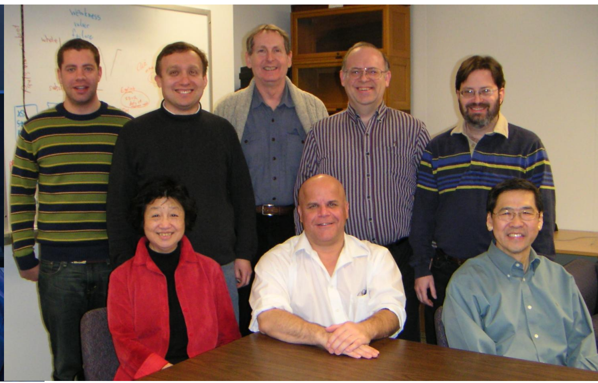
What is NIST?

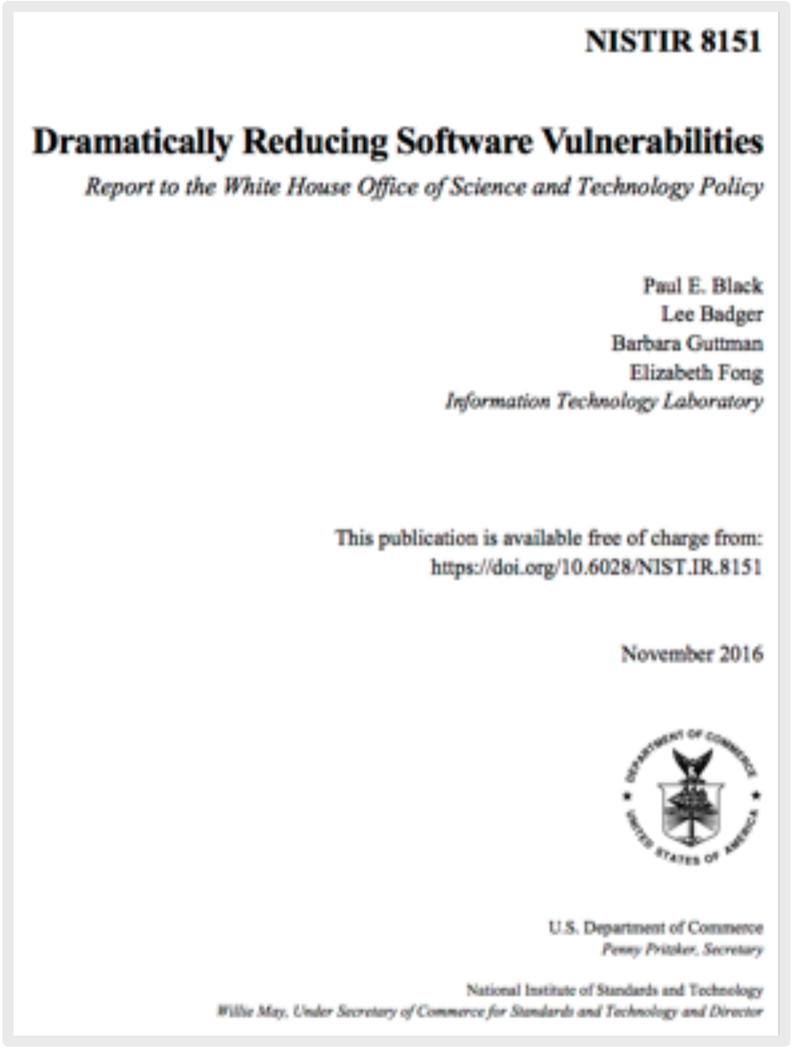
- U.S. National Institute of Standards and Technology
- A non-regulatory agency in Dept. of Commerce
- 3,000 employees + adjuncts
- Gaithersburg, Maryland and Boulder, Colorado
- Primarily research, not funding
- Over 100 years in standards and measurements: from dental ceramics to microspheres, from quantum computers to fire codes, from body armor to DNA forensics, from biometrics to text retrieval





Who Cares About Good Software?

- **The White House Office of Science and Technology Policy (OSTP) asked NIST to compile a list of approaches to dramatically reduce software vulnerabilities.**



NISTIR 8151

Dramatically Reducing Software Vulnerabilities

Report to the White House Office of Science and Technology Policy

Paul E. Black
Lee Badger
Barbara Guttman
Elizabeth Fong
Information Technology Laboratory

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November 2016

U.S. Department of Commerce
Penny Pritzker, Secretary

National Institute of Standards and Technology
Willie May, Under Secretary of Commerce for Standards and Technology and Director

What DRSV Covers

- Vulnerabilities
- New *and* existing code
- Approaches in 5 areas that may have dramatic impact in three to seven years.
- Other stuff
  - Software measures
  - Education, contracts, and other non-technical matters

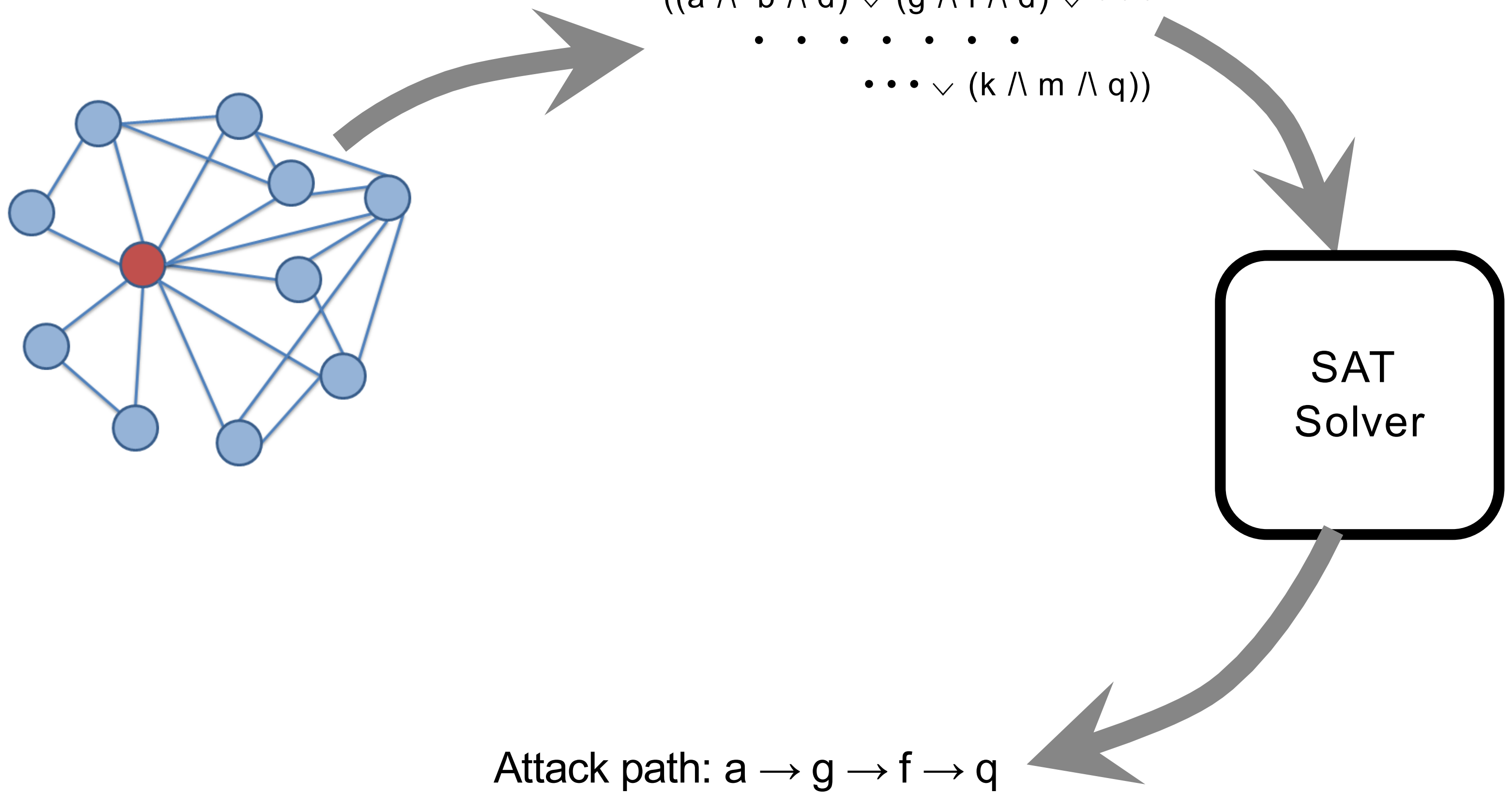
2.1 Formal Methods

- Assertions, Pre- and Postconditions, Invariants, Aspects, and Contracts
- Correct-by-Construction & Model-Based
- Directory of Verified Tools and Code
- Cyber Retrofitting
- Sound Static Analysis
- Model Checkers, SAT Solvers, and Other "Light Weight" Decision Algorithms

Cyber Retrofitting

- **Can't rework *all* existing code.**
- **Instead, identify key components.**
- **One approach is to recompile with built-in hardening.**

Model Checkers, SAT Solvers, etc.



((a /\ b /\ d) ∨ (g /\ f /\ d) ∨ • • •

• • • • • • •

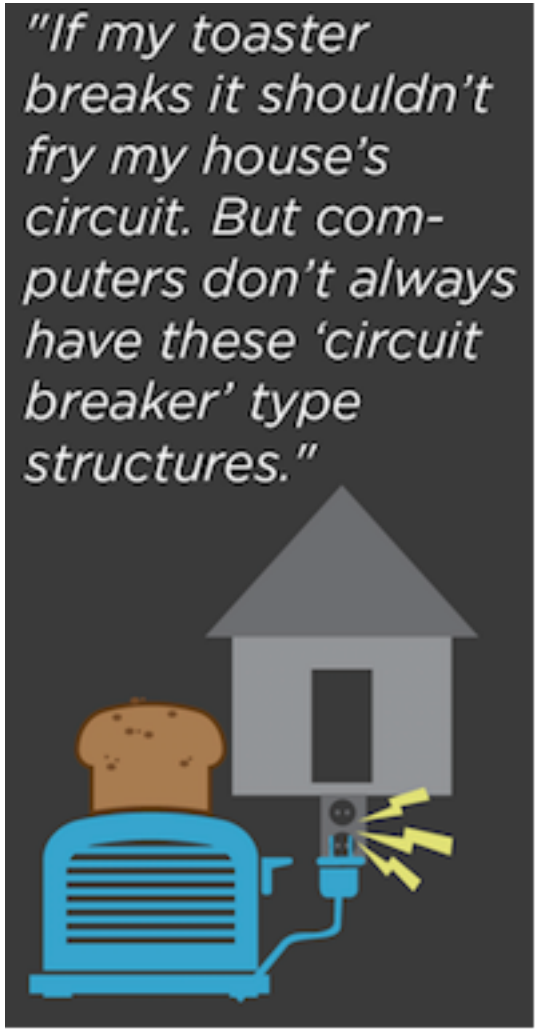
• • • ∨ (k /\ m /\ q))

Attack path: $a \rightarrow g \rightarrow f \rightarrow q$

I will return to formal methods and sound static analysis later. For now, on with DRSV …

2.2 System Level Security

- **Containers**
- **Microservices**


"If my toaster breaks it shouldn't fry my house's circuit. But com-puters don't always have these 'circuit breaker' type structures."

2.3 Additive Software Analysis

- **Software Information Exchange Standards**
- **Tool Analysis Exchange Framework**
- **Strategy and Technology to Combine Analysis**

2.4 Domain-Specific Software Development Frameworks

- **Finding and Learning New Frameworks**
- **Resolving Dependencies, Conflicts, and Incompatibilities**
- **Rapid Framework Adoption**
- **Advanced Test Methods**

2.5 Moving Target Defenses and Automatic Software Diversity

- **Compile-Time Techniques**
- **System or Network Techniques**

Section 3. Measures & Metrics

- ***Deals with software product, not process***
- **Four dimensions of software measures**
  - **Level, e.g. high or low**
  - **Static or dynamic**
  - **Point of view: exterior (blackbox) or interior**
  - **Property: Buginess, Quality, Corectness**
- **In the "Metric System", counted quantities are all dimensionless.**

- **Quote DRSV to support the use of formal methods.**
  - **"The absence of flaws does not indicate the presence of excellence." Sect. 3, page 30**
  - **"While previously deemed too time-consuming, formal methods have become mainstream in many behind-the-scenes applications and show significant promise for both building better software and for supporting better testing." Sect. 4.4, page 43**

What are Formal Methods?

Romans and medieval Europeans built great structures,

… but expertise passed haphazardly from master to apprentice.

- **Formal Methods are "techniques based on mathematical foundations and analysis."**[†]
  - **Program model,**
  - **Specifications, and**
  - **Rules to analyze their relations.**

- **Chief benefit: 100% coverage of design space**
- **Chief drawback: difficulty building models and reasoning**

† Black, Hall, Jones, Larson, and Windley, "A Brief Introduction to Formal Methods," IEEE CICC 96, pp. 377-380

The Specification

- **Unambiguous statements of desired behaviors, properties, etc.**
- **May be comprehensive or may be just a few critical requirements**
- **Choose level of abstraction**

Use Assertions, Pre- and Post-conditions, Invariants, etc.

- **Programmers think the software is right – *write down why!***
- **Disadvantage (?): It takes extra thought to express exactly what is happening.**
- **Benefits:**
  - **Generate tests automatically**
  - **Detect faults earlier**
  - **Enable proofs**
  - **Stay consistent with code**

Ariane 5: A Striking Example

- **1996 first flight of Ariane 5 failed.**
- **If the code had a precondition, “Any team worth its salt would have checked … [preconditions, which] would have immediately revealed that the Ariane 5 calling software did not meet the expectation of the Ariane 4 routines that it called.”**

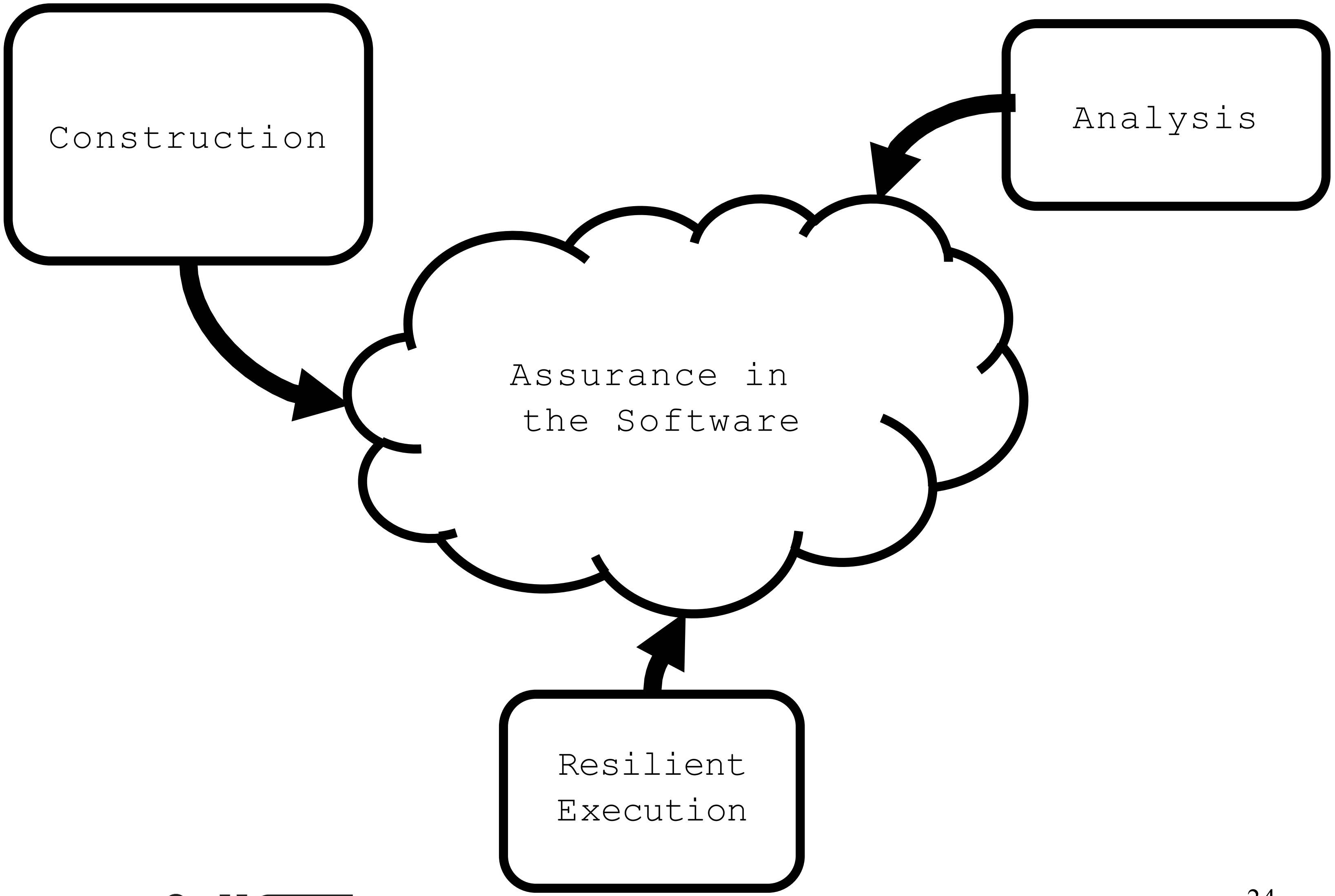
Reasoning & Rules for Analysis

- Some methods (“logics”) are
  - model checking
  - theorem proving
  - equivalence checking
  - stress analysis
- Some methods are automatic.
- Other methods are interactive.

Use Formal Methods Wisely

- **Be sure that assumptions, limitations, and sensitivities are justified.**
- **Remember: *it does not answer questions you don't ask.***

How Do I Get Good Software?



Construction

- **Code should be analyzable.**
- **Limits: Halting Problem, Rice’s Theorem**
- **Good tools are vital to safely use languages.**

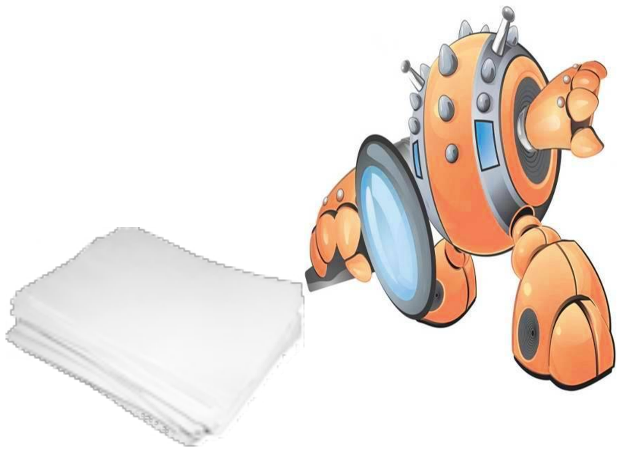
Two Approaches to Analysis: Static and Dynamic

Static Analysis

- Code review
- Binary, byte, or source code scanners
- Model checkers & property proofs
- Assurance case

Dynamic Analysis

- Execute code
- Simulate design
- Fuzzing, coverage, MC/DC, use cases
- Penetration testing
- Field tests



Static and Dynamic Analysis Complement Each Other

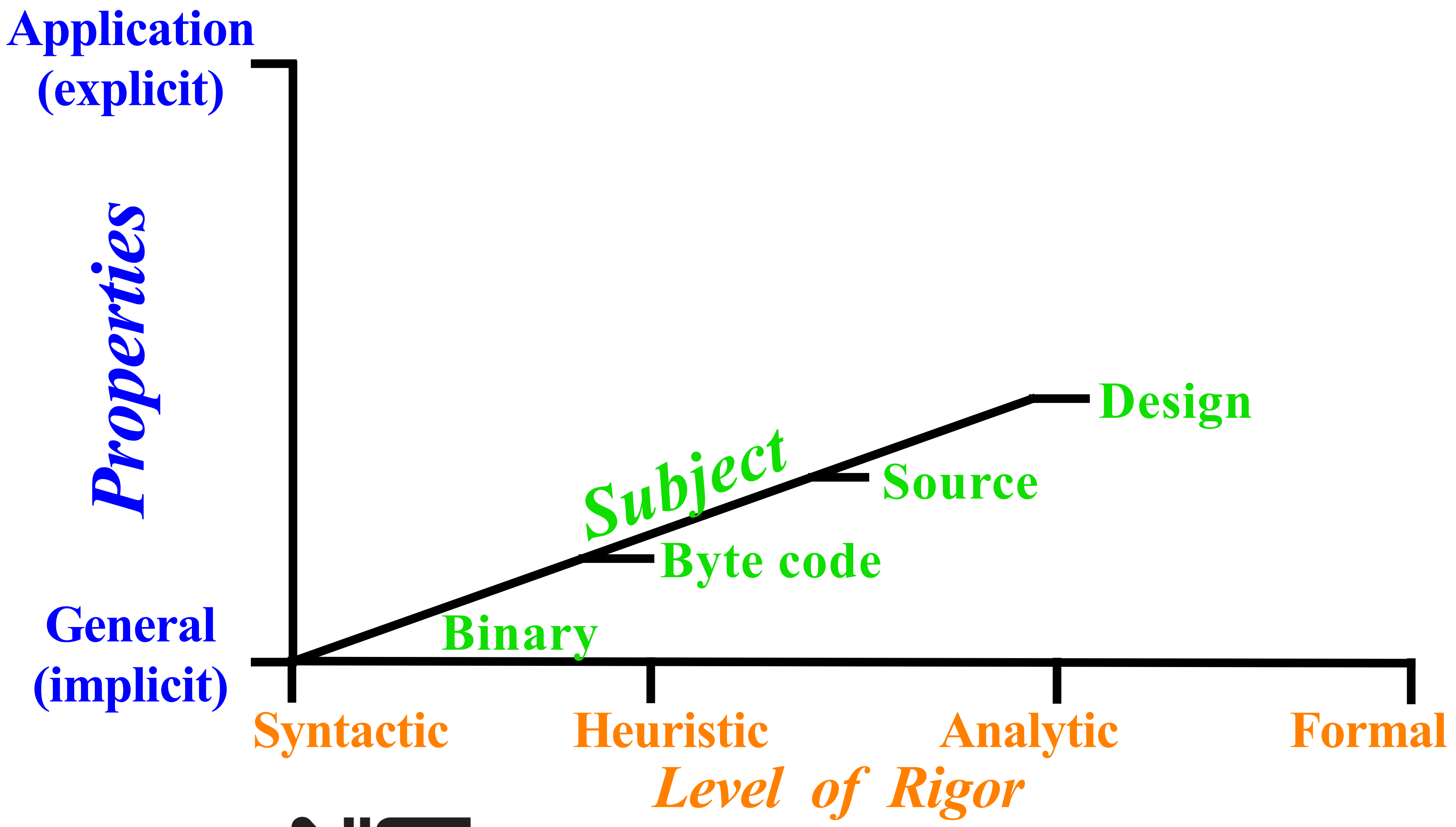
Static Analysis

- **Handles unfinished code**
- **Higher level artifacts**
- **Can find backdoors, e.g., full access for user name “JoshuaCaleb”**
- **Potentially complete**

Dynamic Analysis

- **Code not needed, e.g., embedded systems**
- **Has few(er) assumptions**
- **Covers end-to-end or system tests**
- **Assess as-installed**

Dimensions of Analysis



Different Static Analyzers Exist For Different Purposes

- To check intellectual property violation
- For developers to decide what needs to be fixed (and learn better practices)
- For auditors or reviewer to decide if it is good enough for use

What do I Mean by ”Sound”?

- **Based on mathematical concepts; amenable to provable reasoning; yielding guaranteed results.**

- **“A deductive system is *sound* if and only if every statement that can be deduced is true.” [Ockham]**

Sound Does Not Mean Perfect

```
data = Float.parseFloat(stringNumber.trim());
```

data: [MIN_VALUE, MAX_VALUE]

```
if (Math.abs(data) > 0) {
```

data: [MIN_VALUE, MAX_VALUE]

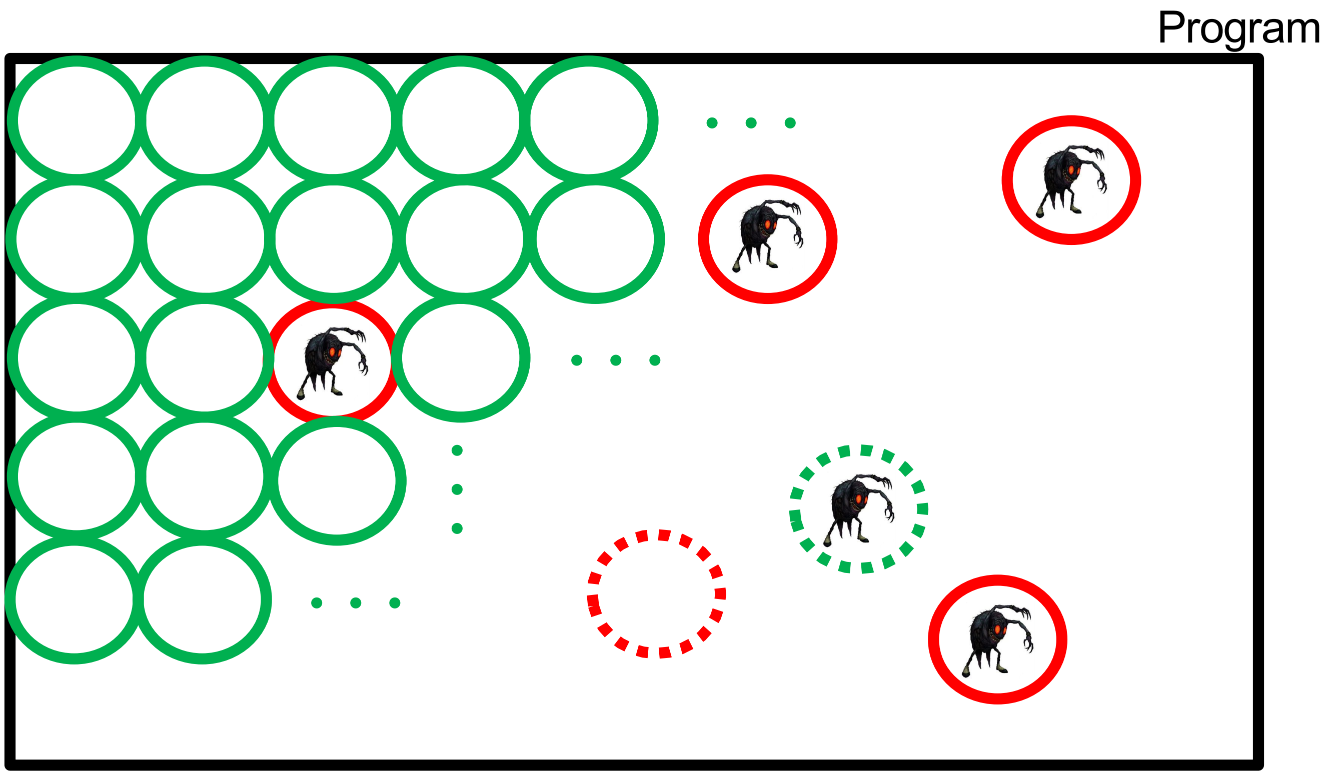
```
    int result = (int)(100.0 / data);

    IO.writeLine(result);

}
```

Sound Static Analysis

- **Guarantee that no bug escapes.**



Sound Static Analysis

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“The best way to prevent BOF is to reduce the use of C.”

— A colleague and me, just a year and a half ago

Higher-Level Languages

- Correct-by-construction
  - Model-based development
  - Design by refinement
  - Domain-specific languages
- Developer rarely touches low level code.
- May generate test suites, UI with help, etc.
- Systematic concerns can be built-in.
- Disadvantages: requires huge effort to design, build, and prove language suites.

Society has 3 options:

- **Accept failing software**
- **Limit size or authority of software**
- **Learn how to make software that *works***

Buckle Up, Buttercup

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