More Test Input Generation

Martin Kellogg

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B. it derives oracles using mutation testing
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  - “feedback-directed” random testing
  - brief introduction to mutation testing
  - EvoSuite: mutation testing + a genetic algorithm
- Lens of Logic: symbolic execution for test input generation
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        - tests are discarded if they do not discover **new states**

Randoop: input/output example

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For example:

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Map h = new HashMap();
Collection c = h.values();
Object[] a = c.toArray();
List l = new LinkedList();
l.addFirst(a);
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Set u =
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fails when executed

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  - classify the new sequence by executing it: may discard, output as a test case, or add it to the pool of sequences

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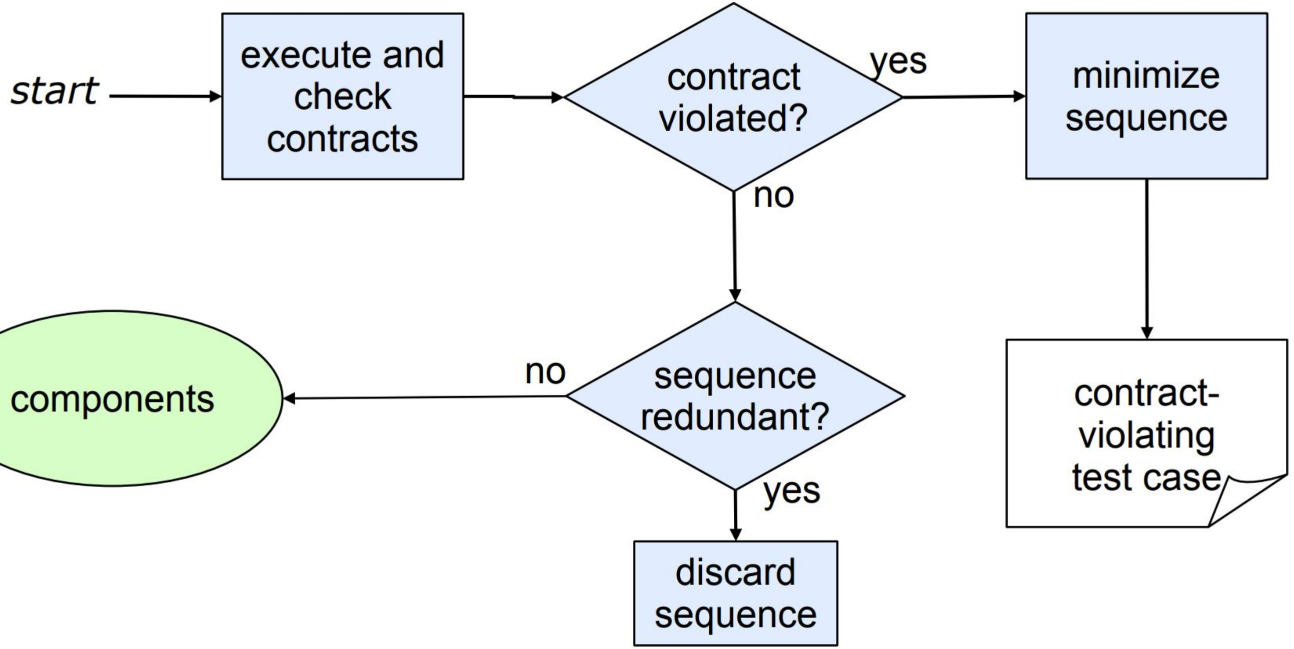

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  - during generation, it maintains a set *O* of all objects that it has ever created
  - a sequence is considered redundant if all of the objects created during its execution are members of *O* (using **`.equals`**)
  - Randoop would work with other reasonable definitions of redundant, too
    - e.g., heap canonicalization

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- The tool is **still maintained** (so you could use it yourself)
    - https://randoop.github.io/randoop/
- It is commonly used in research papers as a ***baseline***: that is, a method that any new technique is expected to outperform
    - Randoop is fast and easy enough to use that if a new technique cannot outperform it, it's probably not worth using!

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- Suppose you wanted to evaluate the quality of two bug-finding test suites …

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- Informally: “You claim your test suite is really great at finding security bugs? Well, I'll just **intentionally add a bug** to my source code and see if your test suite finds it!”

Mutation testing: defect seeding

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- The defect introduced is typically intentionally similar to defects introduced by real developers.
- The seeding is typically done by changing the source code.
- For mutation testing, defect seeding is typically done automatically (given a model of what human bugs look like)

Mutation testing: mutation operators

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- Example mutations:
    - `if (a < b)` → `if (a <= b)`
    - `if (a == b)` → `if (a != b)`
    - `a = b + c` → `a = b - c`
    - `f(); g();` → `g(); f();`
    - `x = y` → `x = z`

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// original                        // 2nd-order mutant
if (a < b):                    if (a <= b):
x = a + b           →              x = a - b
print(x)                       print(x)
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- test suites that kill more mutants are generally considered better
- (sorry for all the vocabulary, but it's necessary to understand how EvoSuite works)

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- My intention today is to give you a high-level idea of how mutation testing works
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  - because EvoSuite (which you'll use for HW4) relies on it
- We will discuss mutation testing in much more detail in two weeks
  - and you'll get a chance to try your hand at it in HW6

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- EvoSuite also uses mutation testing to produce **oracles**
  - **key idea**: assertions that **kill mutants** make good oracles
    - we'll come back to this idea next week

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- by contrast, AFL is looking to **find bugs**
  - leads to test inputs that aren't easy to understand!

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  - compares to the sort of tests that you might write by hand
  - does it achieve its goal of creating useful regression suites?

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  - EvoSuite: mutation testing + a genetic algorithm
- **Lens of Logic: symbolic execution for test input generation**
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  - but what if we just try to figure out **which inputs would improve coverage** directly?
- this is the key idea behind using **symbolic execution** to generate test inputs that improve coverage

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- our plan: choose an uncovered bit of code, and then symbolically execute **backwards** from there to figure out what values the input variables would need to take on in order to cover the code
    - this is the **Lens of Logic** again, but applied in a different way

Lens of Logic: maximize coverage

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foo(a,b,c,d,e,f):
   if a < b: this
   else: that
   if c < d: foo
   else: bar
   if e < f: baz
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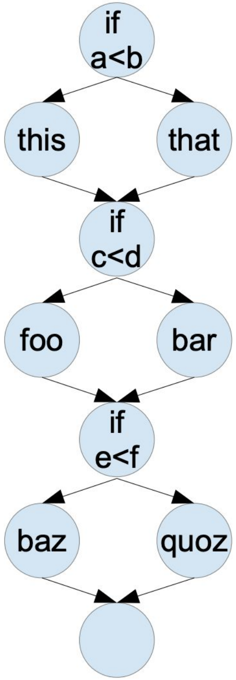

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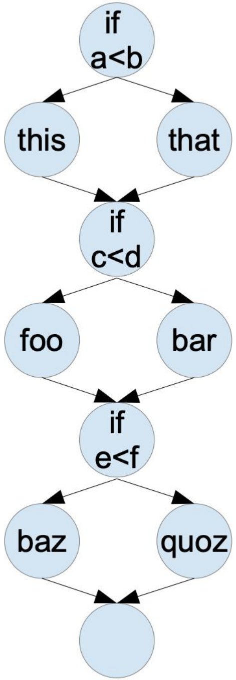

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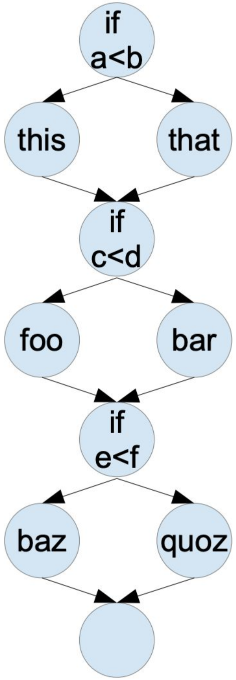

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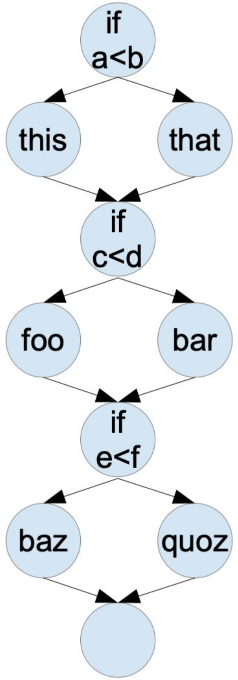

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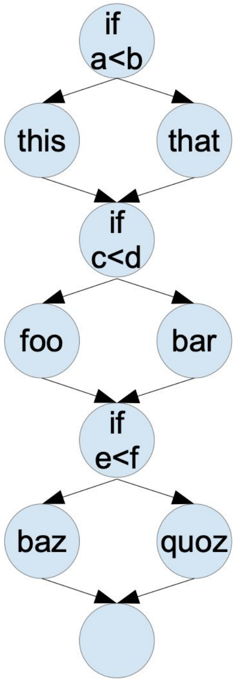

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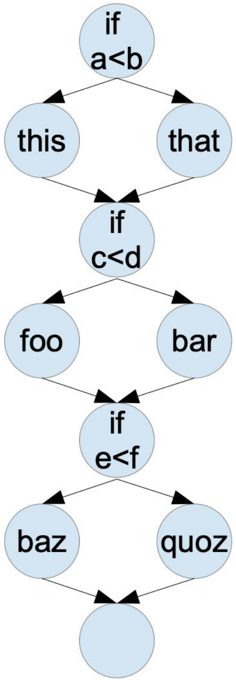

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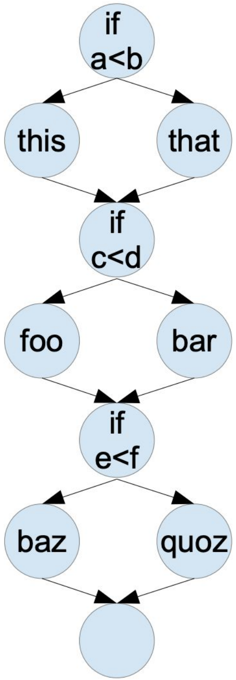

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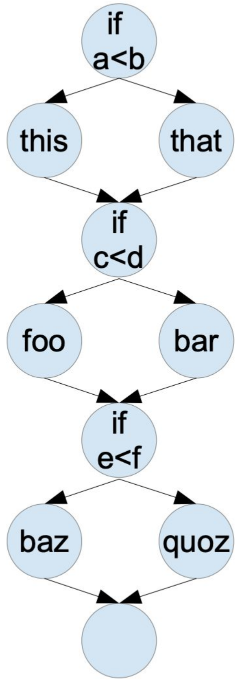

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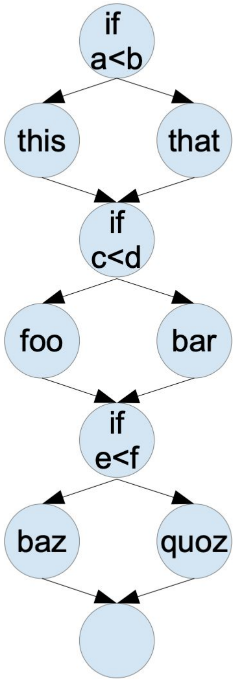

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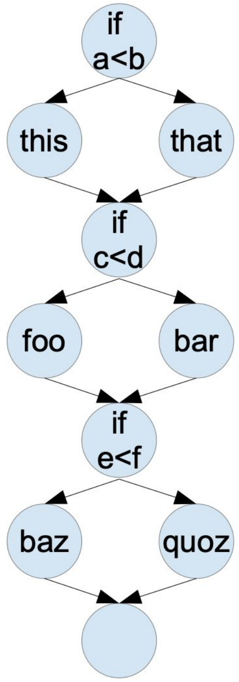

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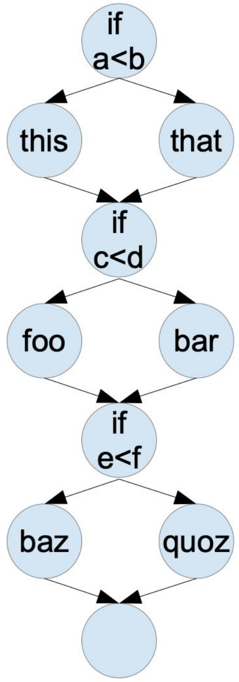
- Recall that path coverage **subsumes** branch coverage



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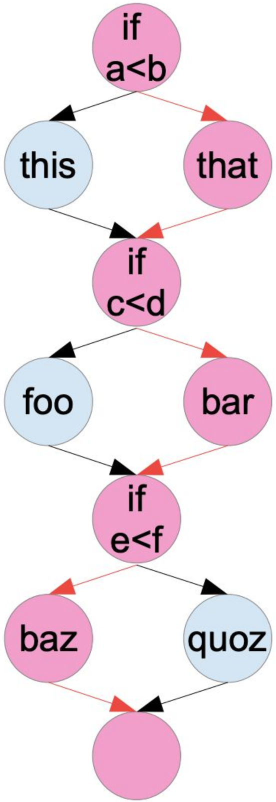

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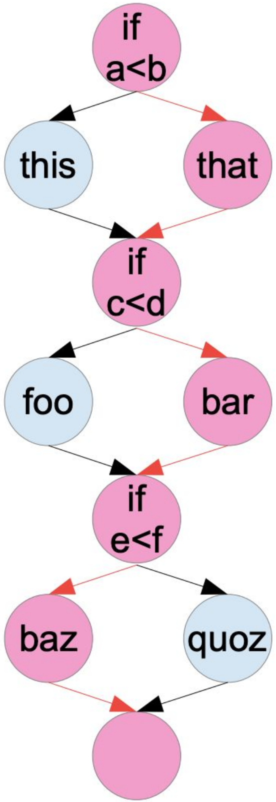

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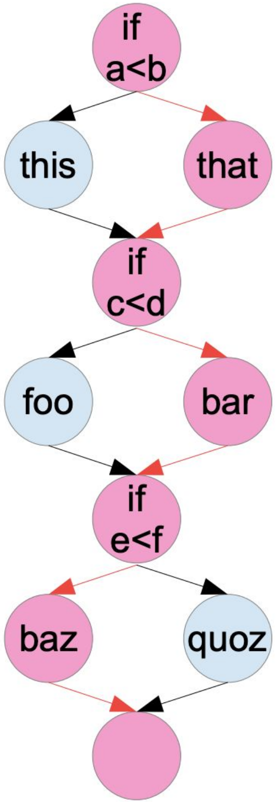

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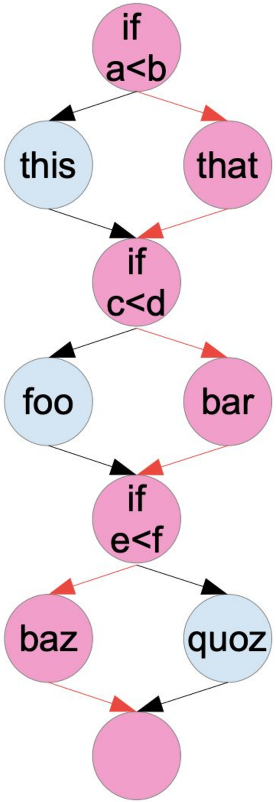

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    - … many more

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while a < b:
  a = a + 1
return a
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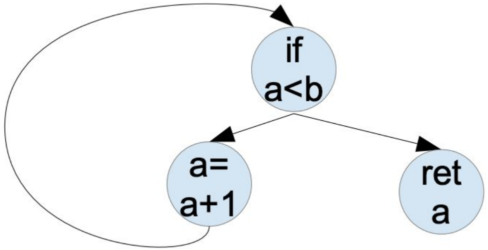

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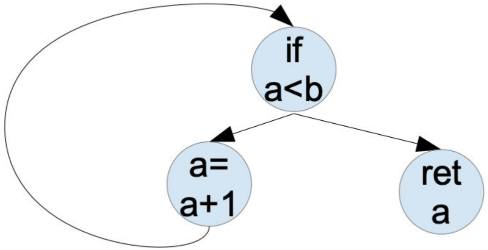

- One path corresponds to executing the loop once, another to twice, another to three times, etc.

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  - Concretely execute the program and see what it does (we'll come back to this later when we discuss **concolic testing**)

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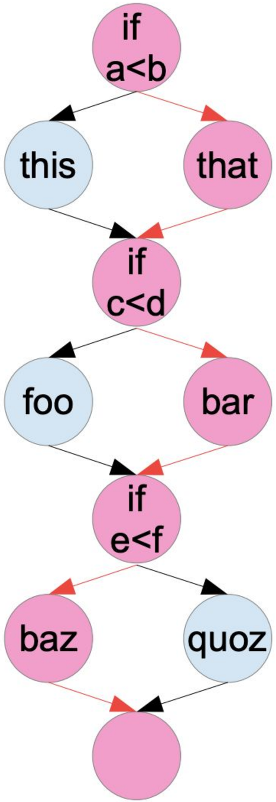

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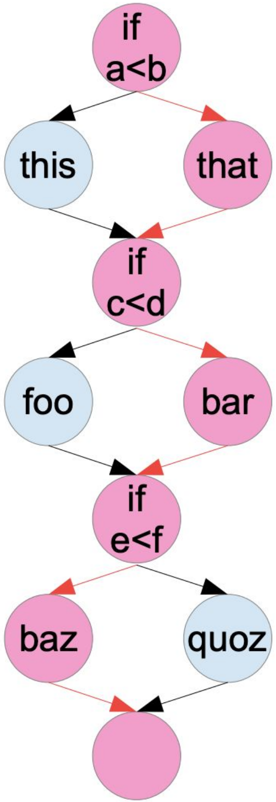

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  str1 = read_from_url("abc.com")
  str2 = read_from_url("xyz.com")
  if (str1 == str2): bar()
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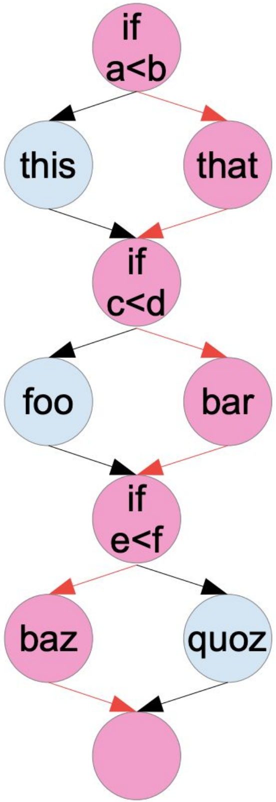

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Suppose we want to exercise the path that calls `bar`. One predicate is `str1==str2`. What do you assign to `a` and `b`?

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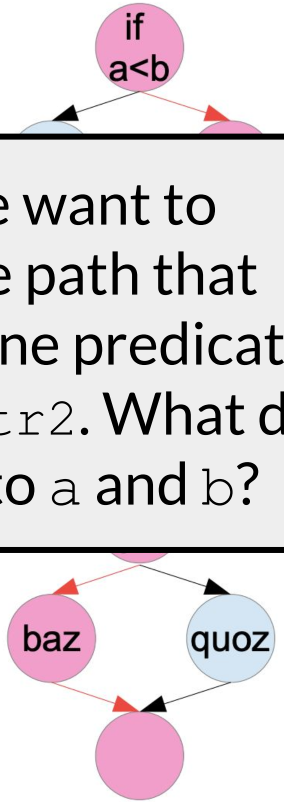

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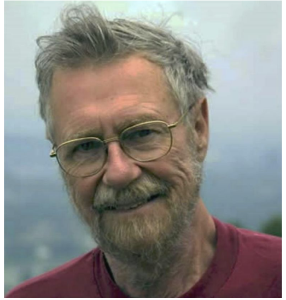

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  - If it can't (because the math is too hard, we don't control the input, etc.), we give up

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- We have an approach that works well in practice:
  - **Enumerate** some paths
  - **Extract** their path constraints
  - **Solve** those path constraints

Symbolic execution in practice

- symbolic execution was invented in the 1970s
  - but theorem provers of the time could **rarely solve predicates**, and the available hardware could enumerate **few paths**
- modern **SMT solvers** can handle the first problem, while second problem is less relevant due to **Moore's Law**

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Modern SMT solvers (e.g., Z3, cvc5) are **extraordinarily effective** at solving most instances (millions or billions of clauses in < 30s)

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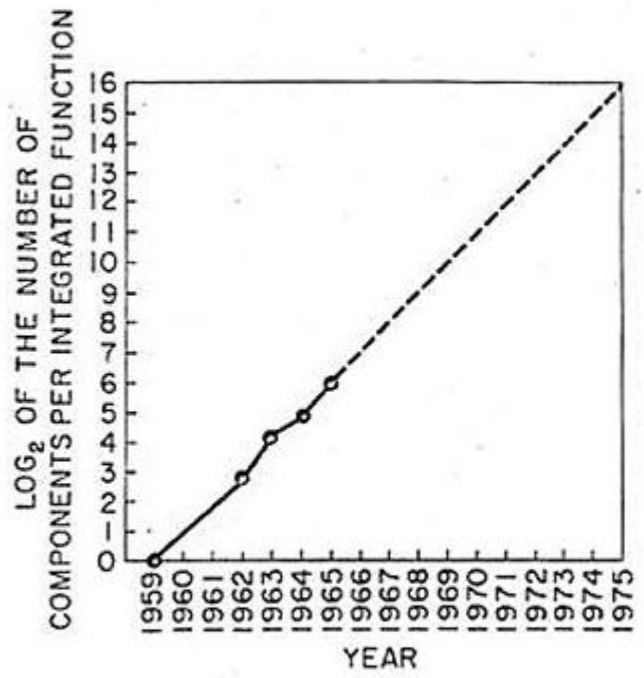

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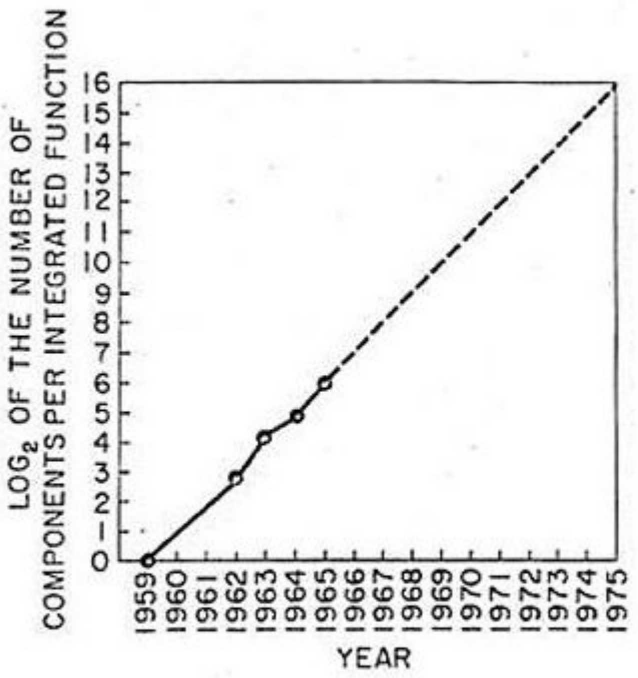

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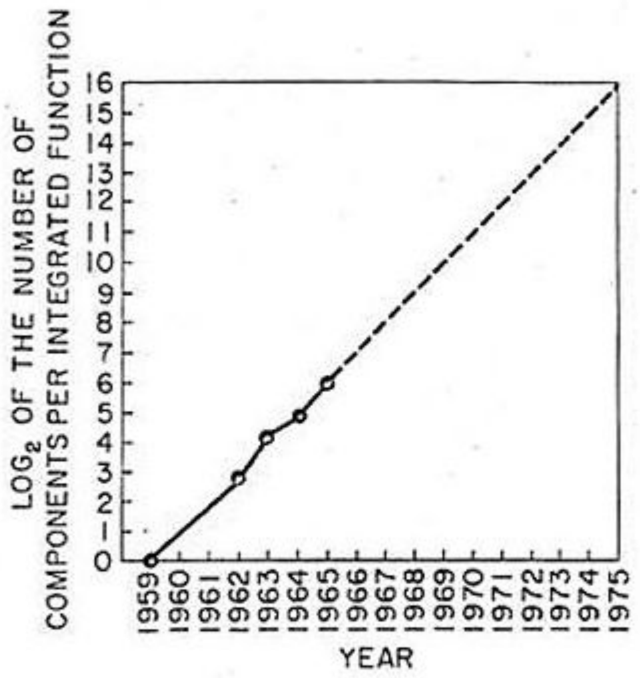

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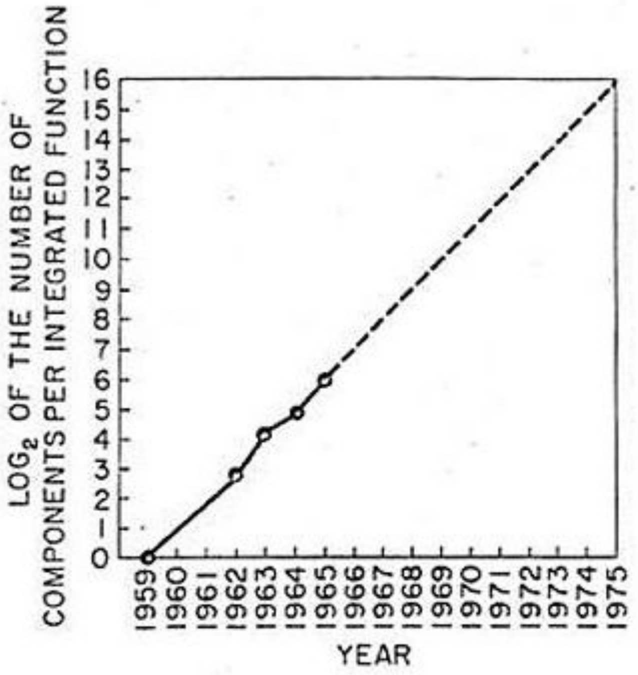

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- **implication**: symbolic execution has been **widely deployed in industry** since the early 2000s
  - e.g., PREfix (Microsoft), Coverity, KLEE

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  - it **cannot cover** many parts of programs (recall: solving path predicates is NP-complete, so solvers sometimes fail!)

More test input generation: agenda

- Other approaches that use random testing
  - “feedback-directed” random testing
  - brief introduction to mutation testing
  - EvoSuite: mutation testing + a genetic algorithm
- Lens of Logic: symbolic execution for test input generation
  - **concolic testing**

Limits of Symbolic Execution

- however, symbolic execution has **serious limitations**
  - for example, consider the function to the right:

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testme(int x, int y) {
  if (bbox(x) == y) {
    ERROR;
  } else {
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Key question: how could we get around this limitation?

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- “concolic” is a portmanteau of “***conc***rete” and “symb***olic***”
- **key idea**: when symbolic execution gets stuck, actually execute the program and record what values the uninterpretable code **actually produces**

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- replace the call to bbox(x) with **whatever it returned** on the concrete execution
- let symbolic execution **solve for y**

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HW4 in-class

- in today's in-class/homework, you'll run EvoSuite
    - in general, students usually report that this assignment is easier and less time-consuming than HW3
    - however, there are **two full length papers** to read for next week
        - so you'll have plenty to do this week :)