Bug Catching: Automated Program Verification
15414/15614 Fall 2017
Lecture 1:
Introduction

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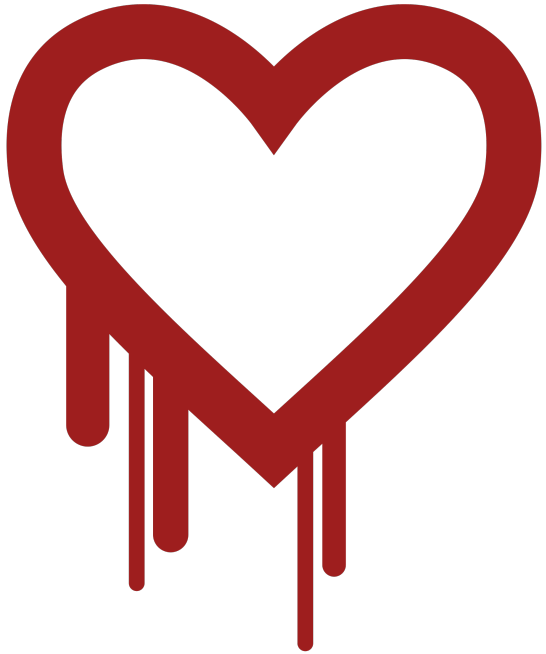
What This Course is About

Does the software do what it is supposed to do?

What happens when software misbehaves



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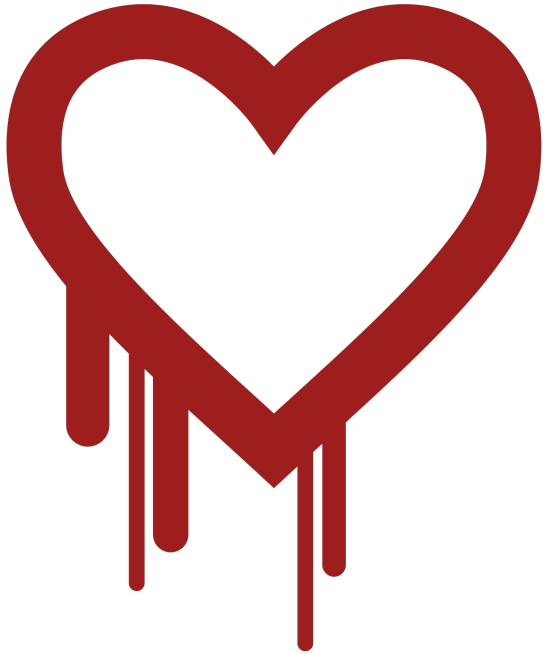

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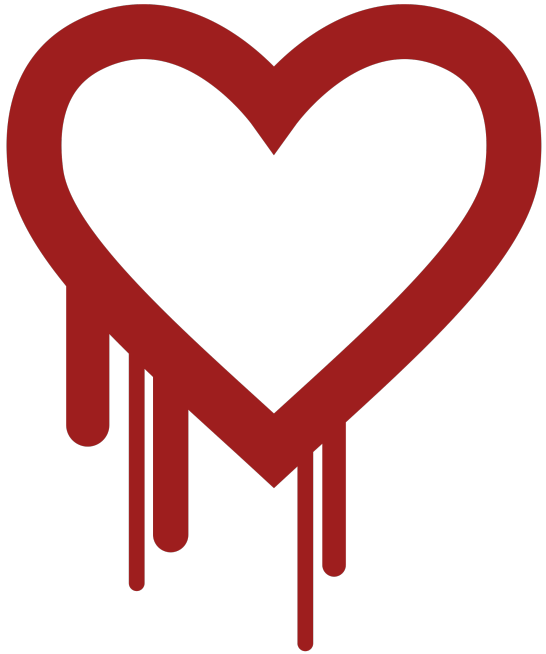

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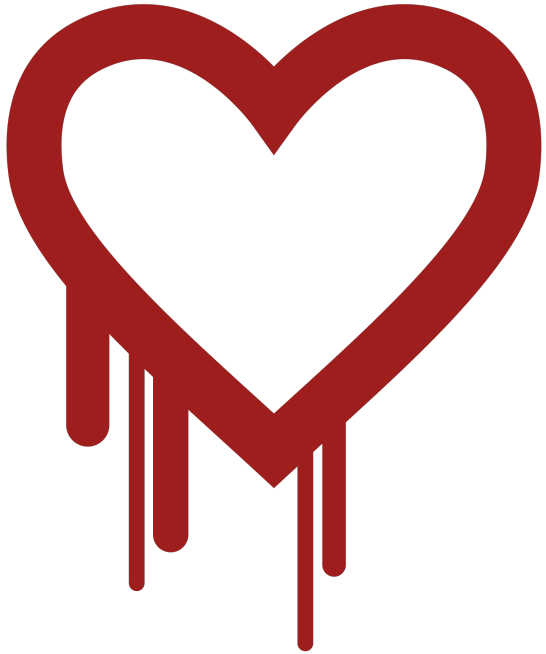
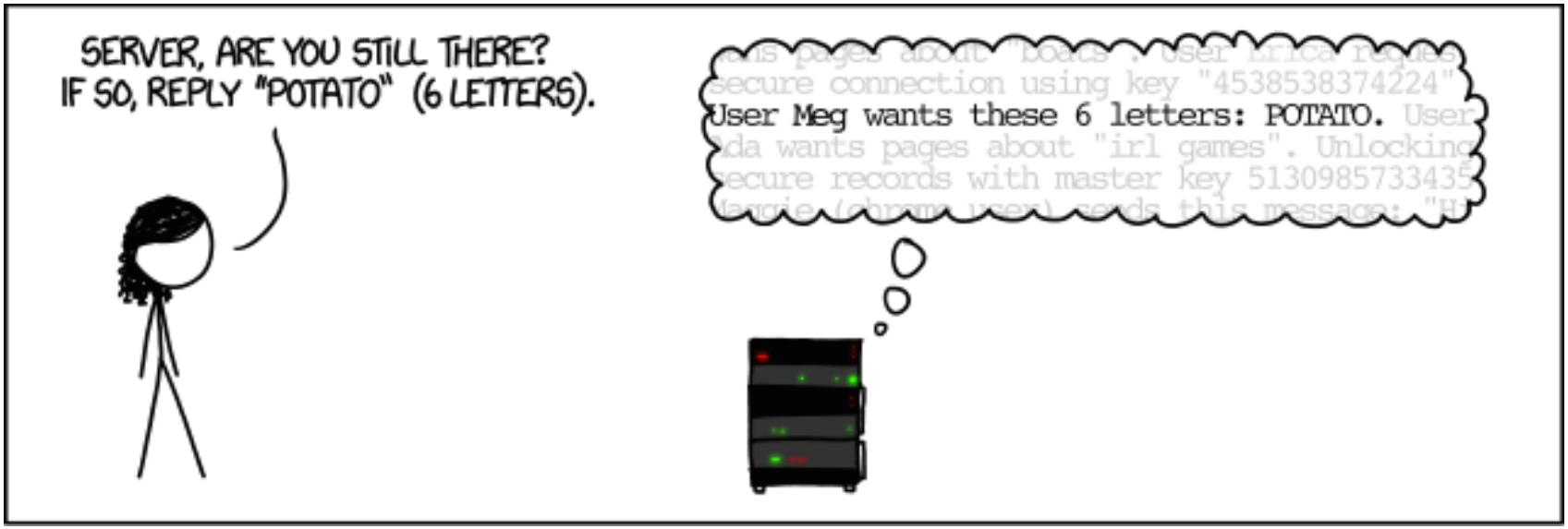
- “The Heartbleed bug allows anyone on the Internet to read the memory of the systems protected by the vulnerable versions of the OpenSSL software.”
- “...this allows attackers to eavesdrop on communications, steal data directly from the services and users and to impersonate services and users.”



Heartbleed, explained



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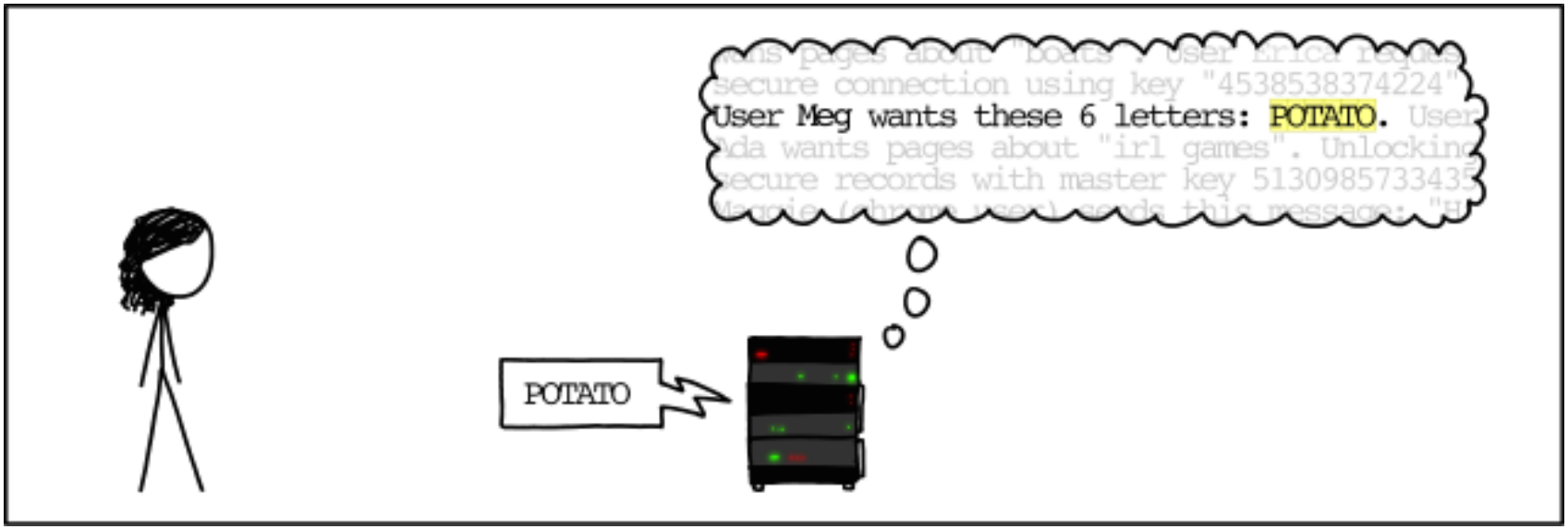

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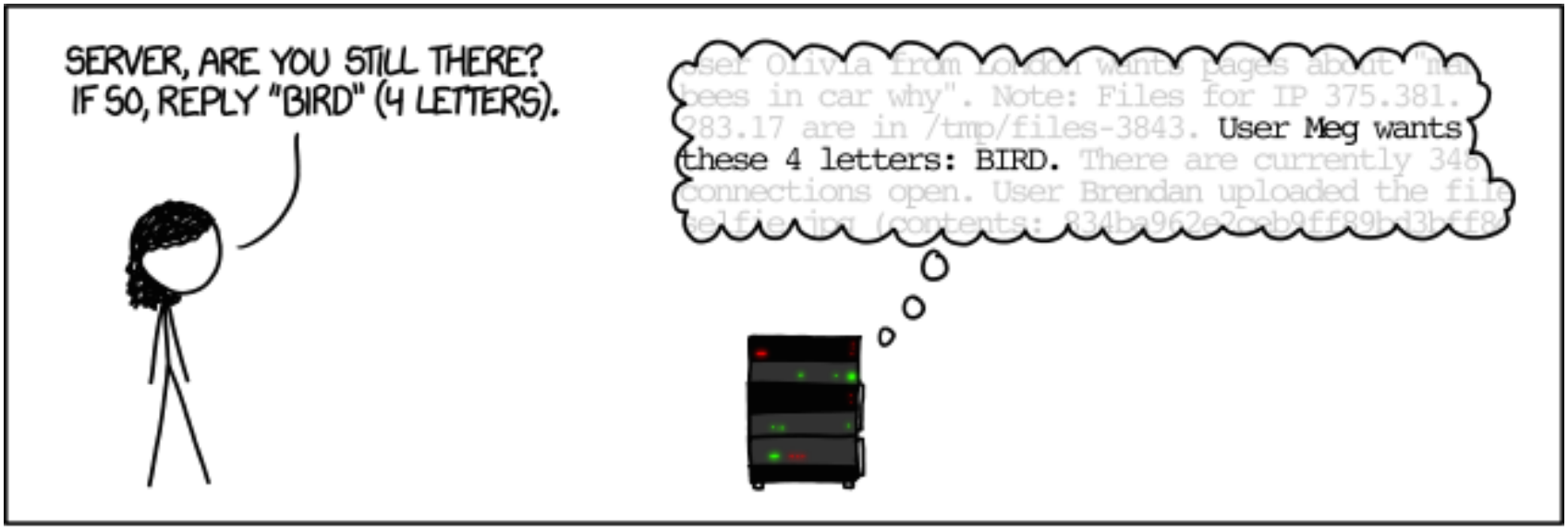

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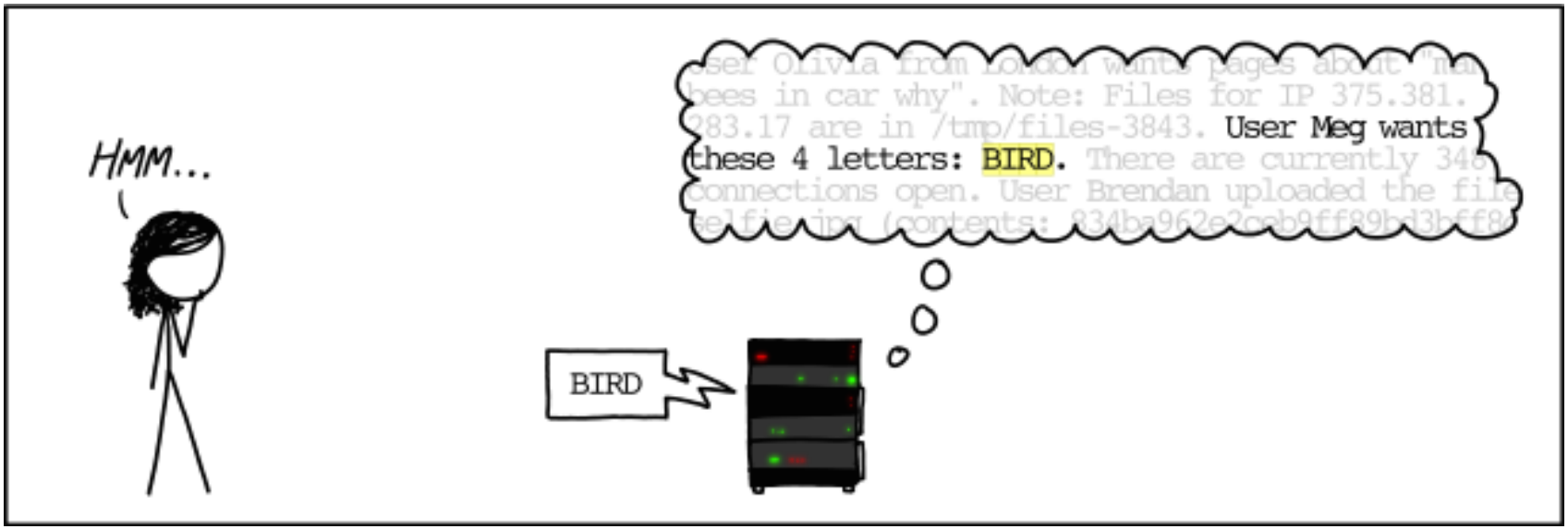

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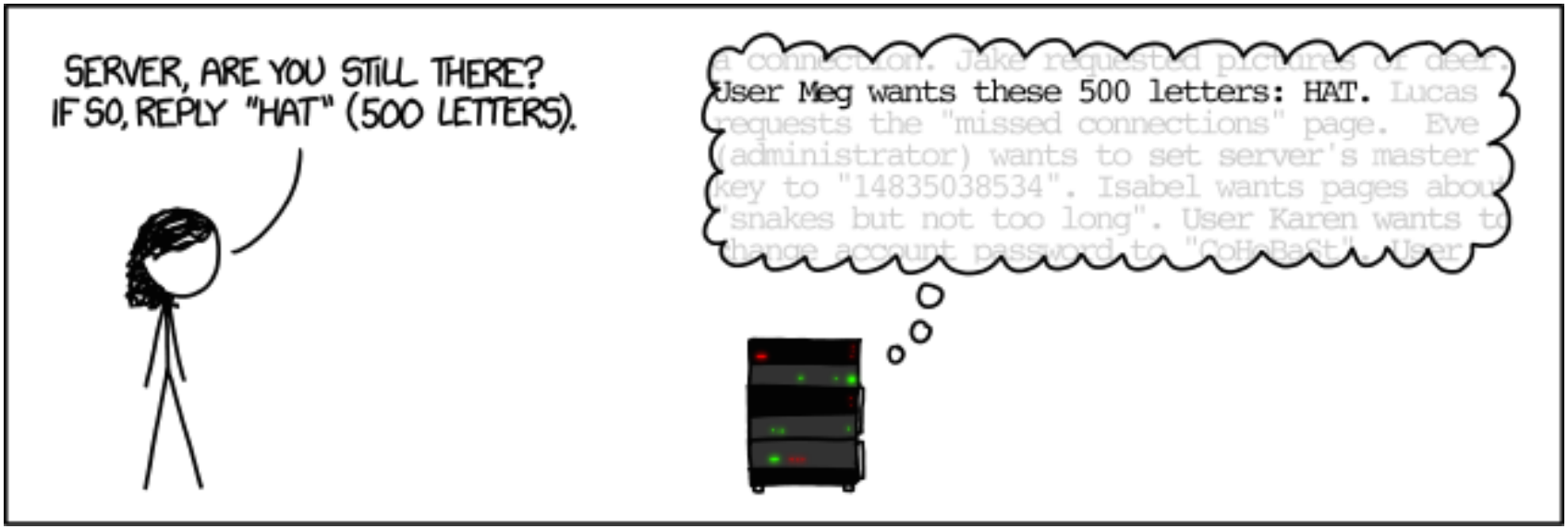

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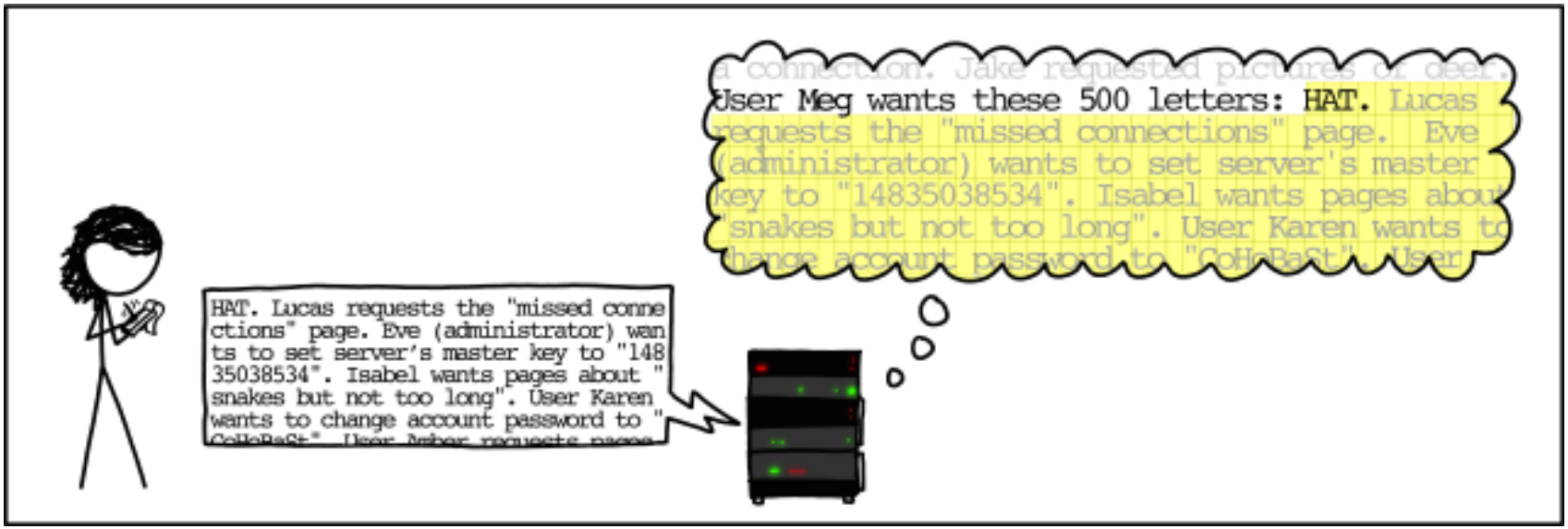

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Does this do what it is supposed to?

```
1  int binarySearch(int key, int[] a, int n) {
2      int low = 0;
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5      while (low < high) {
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8          if(a[mid] == key) return mid; // key found
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Algorithm may be correct. The code, another story...

How do we fix it?

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The fix

```
1  int binarySearch(int key, int[] a, int n)
2  //@requires 0 <= n && n <= \length(a);
3  //@requires is_sorted(a, 0, n);
4  /*@ensures (\result == -1 && !is_in(key, A, 0, n))
5    @      || (0 <= \result, \result < n
6    @           && A[\result] == key); @*/
7  {
8      int low = 0;
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- Specifications must be validated
- Proofs must be correct
- Reasoning must be sound

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Formal proofs are tedious,
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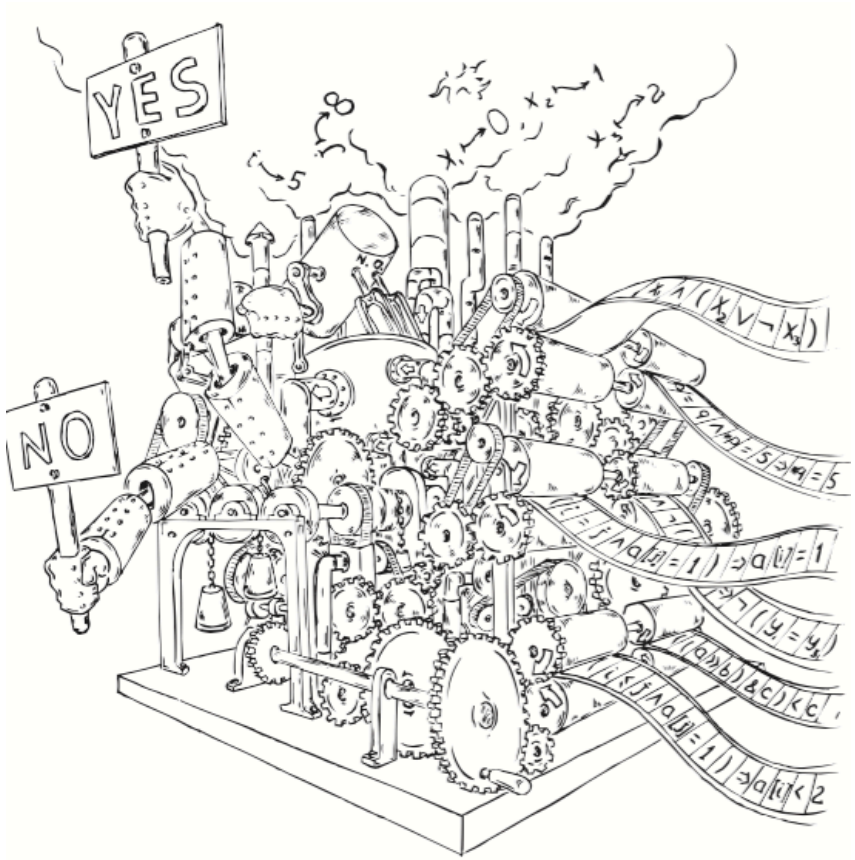

Image source: Daniel Kroening & Ofer Strichman, *Decision Procedures*

Course objectives

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- Use automated tools that assist verifying your code
- Understand how verification tools work

Reasoning about correctness

```
1  int[] array_copy(int[] A, int n)
2  //@requires 0 <= n && n <= \length(A);
3  //@ensures \length(\result) == n;
4  {
5    int[] B = alloc_array(int, n);
6
7    for (int i = 0; i < n; i++)
8    //@loop_invariant 0 <= i;
9    {
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Reasoning about correctness

Functional Correctness

- Specification
- Proof

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Systematic proof techniques

- Based on language semantics
- Exhaustive proof rules
- Ideally, automatable

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Programmer writes specification, proof annotations

Compiler checks correctness automatically*!

Binary search in Why3

```
let binary_search (a : array int) (v : int)
  requires { sorted(a) }
  ensures  { 0 <= result < length a && a[result] = v }
  raises   { Not_found -> forall i:int. 0 <= i < length a -> a[i] <> v }
= try
    let l = ref 0 in
    let u = ref (length a - 1) in
    while !l <= !u do
      invariant { 0 <= !l /\ !u < length a }
      invariant { forall i : int. 0 <= i < length a -> a[i] = v -> !l <= i <= !u }
      variant { !u - !l }
      let m = !l + div (!u - !l) 2 in
      assert { !l <= m <= !u };
      if a[m] < v then
        l := m + 1
      else if a[m] > v then
        u := m - 1
      else
        raise (Break m)
    done;
    raise Not_found
  with Break i ->
    i
  end
```

Automated Verification

Algorithms for proving that programs match their specifications

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Basic idea:

1. Translate programs into *proof obligations*
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Verifiers are non-trivial tools

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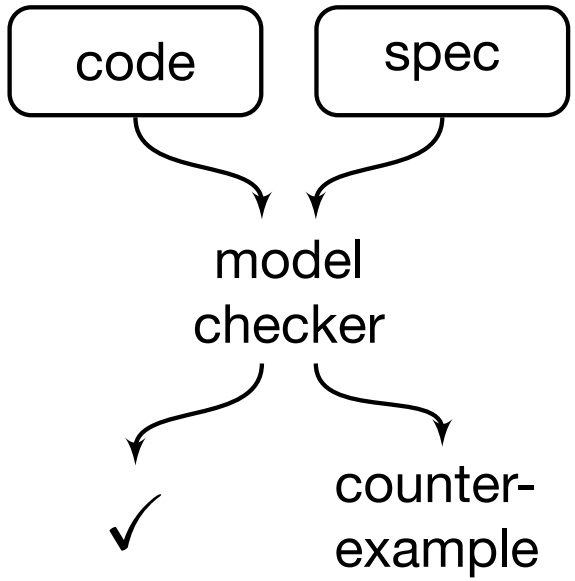

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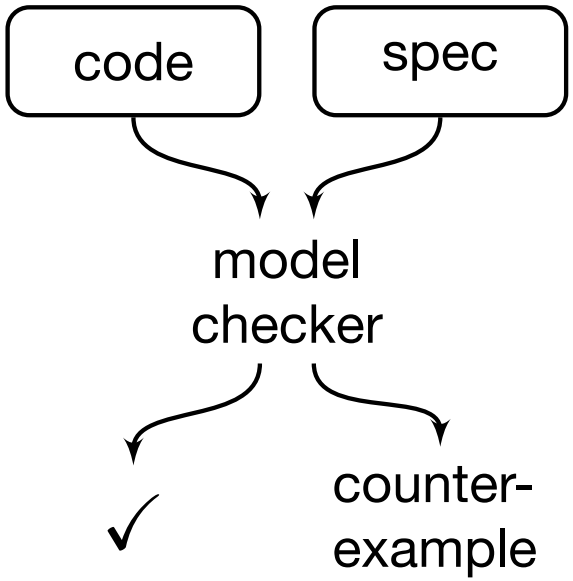

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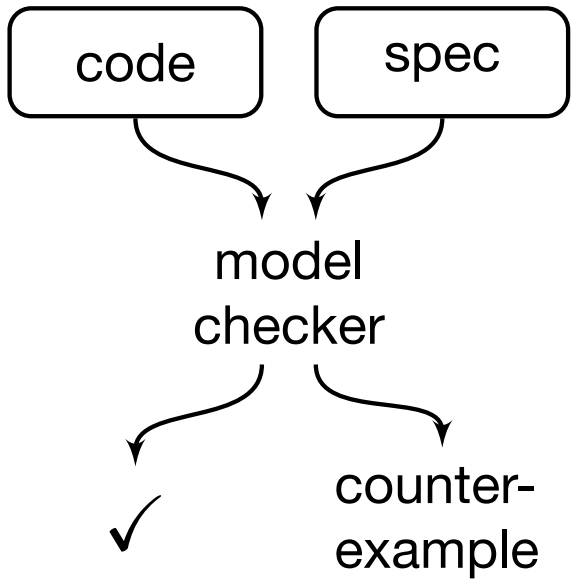

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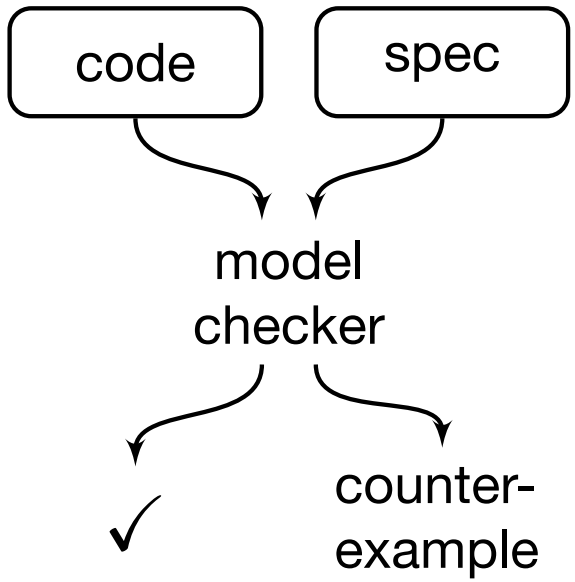

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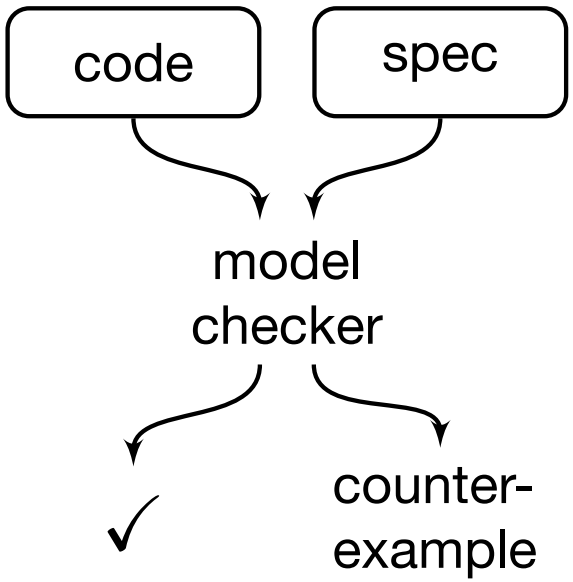

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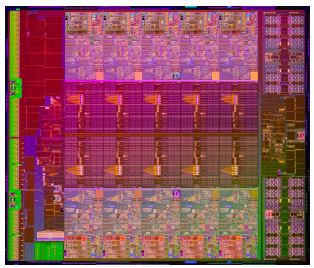
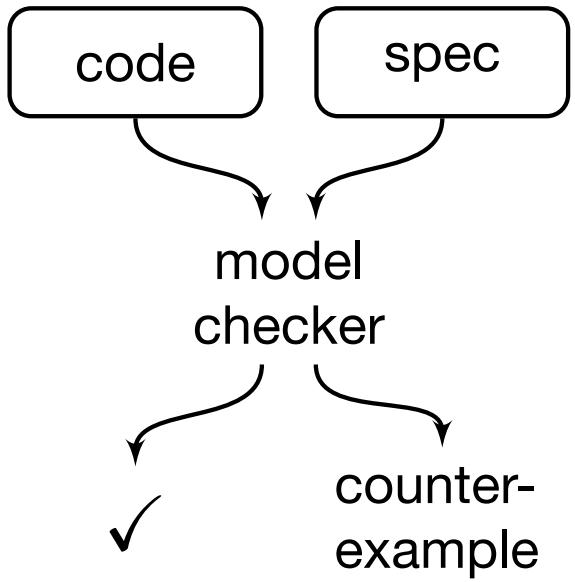
- **Downside**: "State explosion"





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Ed Clarke
Turing Award,
2007

Grading

Breakdown:

- 40% labs
- 25% written homework
- 30% exams (15% each, midterm and final)
- 5% participation

5 labs

Weekly written homework

In-class exams, closed-book

Participation:

- Come to lecture
- Ask questions, give answers
- Contribute to discussion

Grading

For the labs, you will:

- Implement some functionality (usually)
- Specify correctness for that functionality
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Partial credit depending on how many of these you achieve

Clarity & conciseness is necessary for partial credit!

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Strive for **clarity & conciseness**

- Show each step of your reasoning
- State your assumptions
- Answers without well-explained reasoning don't count!

Late Policy

No late days on written homework

- Not intended to be time-intensive
- 25% deduction for each day past deadline

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Can earn back missed points for proofs on labs

- Must submit original lab by the deadline
- Resubmit **once** within three days of deadline
- If proof is complete & correct, earn back points *only on the proof*

Logistics

Website: `http://www.cs.cmu.edu/~15414`

Course staff contact: Piazza or
`15414-staff@lists.andrew.cmu.edu`
Lecture: Tuesdays & Thursdays, 10:30-11:50 GHC 4211

Matt Fredrikson, André Platzer

- Location: CIC 2126, GHC 9103
- Office Hours: TBD
- Email: mfredrik@cs, aplatzer@cs

Jonathan Laurent, Tianyu Li

- Office Hours: TBD
- Email: jonathan.laurent@cs, tli2@cs