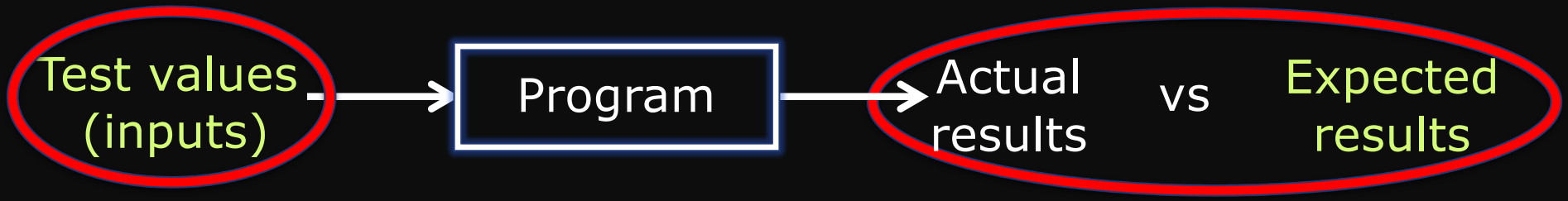
Faults, Errors, Failures
RIPR Model

CS 3250
Software Testing

[Ammann and Offutt, "Introduction to Software Testing," Ch.1, Ch. 2.1]

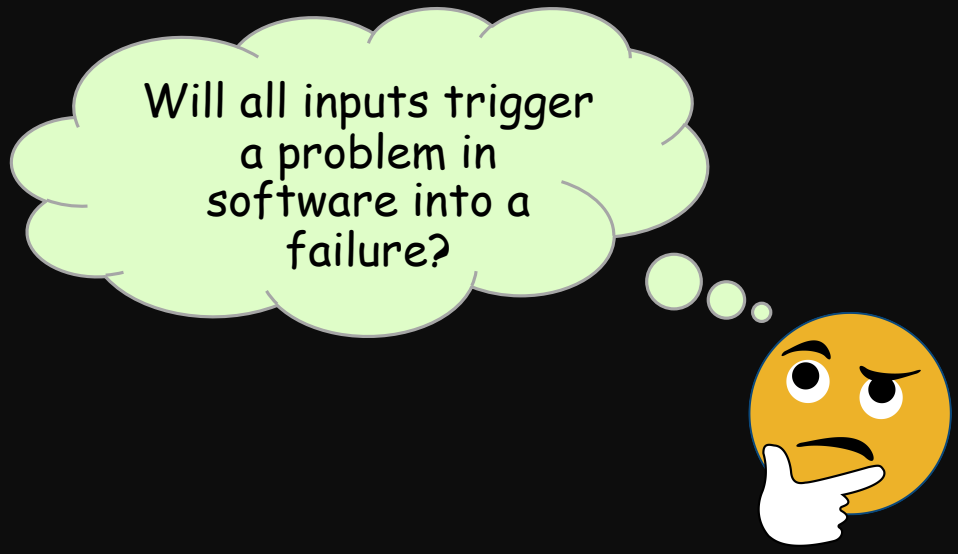
Software Testing



Testing can only reveal the presence of faults;
Not showing the absence of faults

Test case consists of

- test input value(s)
- expected result(s)



[Ref: emoji by Ekarin Apirakthanakorn]

Today's Objectives

- Understand the differences between faults, errors, and failures
- Understand how faults, errors, and failures affect the program
- Understand the four conditions that must be satisfied when designing tests
  - Reachability
  - Infection
  - Propagation
  - Revealability

"**RIPR** model"

Bug?

" 'Bug' – *as such little faults and difficulties are called – show themselves, and months of anxious watching, study, and labor are requisite before commercial success – or failure – is certainly reached." [Thomas Edison, 1878]*

[Ref: Did You Know? Edison Coined the Term "Bug", http://theinstitute.ieee.org/tech-history/technology-history/did-you-know-edison-coined-the-term-bug, IEEE 2013]

"A software bug is an error, flaw, failure or fault in a computer program or system that causes it to produce an incorrect or unexpected result, or to behave in unintended ways."

[Ref: https://en.wikipedia.org/wiki/Software_bug]

- "Bug" is used informally.
- Fault? Error? Or failure?

- This course will try to use words that have precise, defined, and unambiguous meaning – and avoid using the term "bug"

Fault, Error, and Failure

- Fault: a static defect in the software's source code
  - Cause of a problem – "fault location"
- Error: An incorrect internal state that is the manifestation of some fault
  - Erroneous/infected program state caused by execution of the defect
- Failure: External, incorrect behavior with respect to the requirements or other descriptions of the expected behavior
  - Propagation of erroneous state to the program outputs

Example

```
public static int numZero (int[] arr)
{  // If arr is null throw NullPointerException
   // else return the number of occurrences of 0 in arr
   int count = 0;
   for (int i = 1; i < arr.length; i++)
      if (arr[i] == 0)
         count++;
   return count;
}
```

- There is a simple fault in **`numZero`**
- Where is the fault location in the source code?
- How would you fix it?
- Can the fault location be reached? How does it corrupt program state? Does it always corrupt the program state?
- If the program state is corrupted, does **`numZero`** fail? How?

Example – Let's Analyze

```
public static int numZero (int[] arr)
{  // If arr is null throw NullPointerException
   // else return the number of occurrences of 0 in arr
   int count = 0;
   for (int i = 1; i < arr.length; i++)
      if (arr[i] == 0)
         count++;
   return count;
}
```

- Fault: a defect in source code

  `i = 1` [should start searching at 0, not 1]

- Error: erroneous program state caused by execution of the defect

  `i` becomes 1 [array entry 0 is not ever read]

- Failure: propagation of erroneous state to the program outputs

  Happens as long as `arr.length > 0` and `arr[0] = 0`

Example – Test Cases

```
public static int numZero (int[] arr)
{   // If arr is null throw NullPointerException
    // else return the number of occurrences of 0 in arr
    int count = 0;
    for (int i = 1; i < arr.length; i++)
       if (arr[i] == 0)
          count++;
    return count;
}
```

Fault: `i = 1` [should start searching at 0, not 1]

- Test 1: [4, 6, 0], expected 1

  Error: `i` is 1, not 0, on the first iteration

  Failure: none

- Test 2: [0, 4, 6], expected 1

  Error: `i` is 1, not 0, error propagates to the variable **`count`**

  Failure: **`count`** is 0 at the return statement

Example – State Representation

```
   public static int numZero (int[] arr)
   {  // If arr is null throw NullPointerException
      // else return the number of occurrences of 0 in arr
L1    int count = 0;
L2    for (int i = 1; i < arr.length; i++)
L3       if (arr[i] == 0)
L4          count++;
L5    return count;
   }
```

- Assume that we want to represent program states using the notation **<var_1 = v_1, …, var_n = v_n, PC = program counter>**

- Sequence of states in the execution of **numZero({0, 4, 6})**

  1: < arr={0, 4, 6}, PC=[**int count=0** (L1)] >
  2: < arr={0, 4, 6}, **count=0**, PC=[**i=1** (L2)] >
  3: < arr={0, 4, 6}, **count=0**, **i=1**, PC=[**i<arr.length** (L2)] >
  …
  < arr={0, 4, 6}, **count=0**, **i=3**, PC=[**return count** (L5)] >

Example – Error State

- Error state
  - The first different state in execution in comparison to an execution to the state sequence of what would be the correct program

- If the code had i=0 (correct program), the execution of **`numZero({0, 4, 6})`** would be

  1: < arr={0, 4, 6}, PC=[**`int count=0`** (L1)] >
  2: < arr={0, 4, 6}, **`count=0`**, PC=[**`i=0`** (L2)] >
  3: < arr={0, 4, 6}, **`count=0`**, **`i=0`**, PC=[**`i<arr.length`** (L2)] >
  …

- Instead, we have

  1: < arr={0, 4, 6}, PC=[**`int count=0`** (L1)] >
  2: < arr={0, 4, 6}, **`count=0`**, PC=[**`i=1`** (L2)] >
  3: < arr={0, 4, 6}, **`count=0`**, **`i=1`**, PC=[**`i<arr.length`** (L2)] >
  …

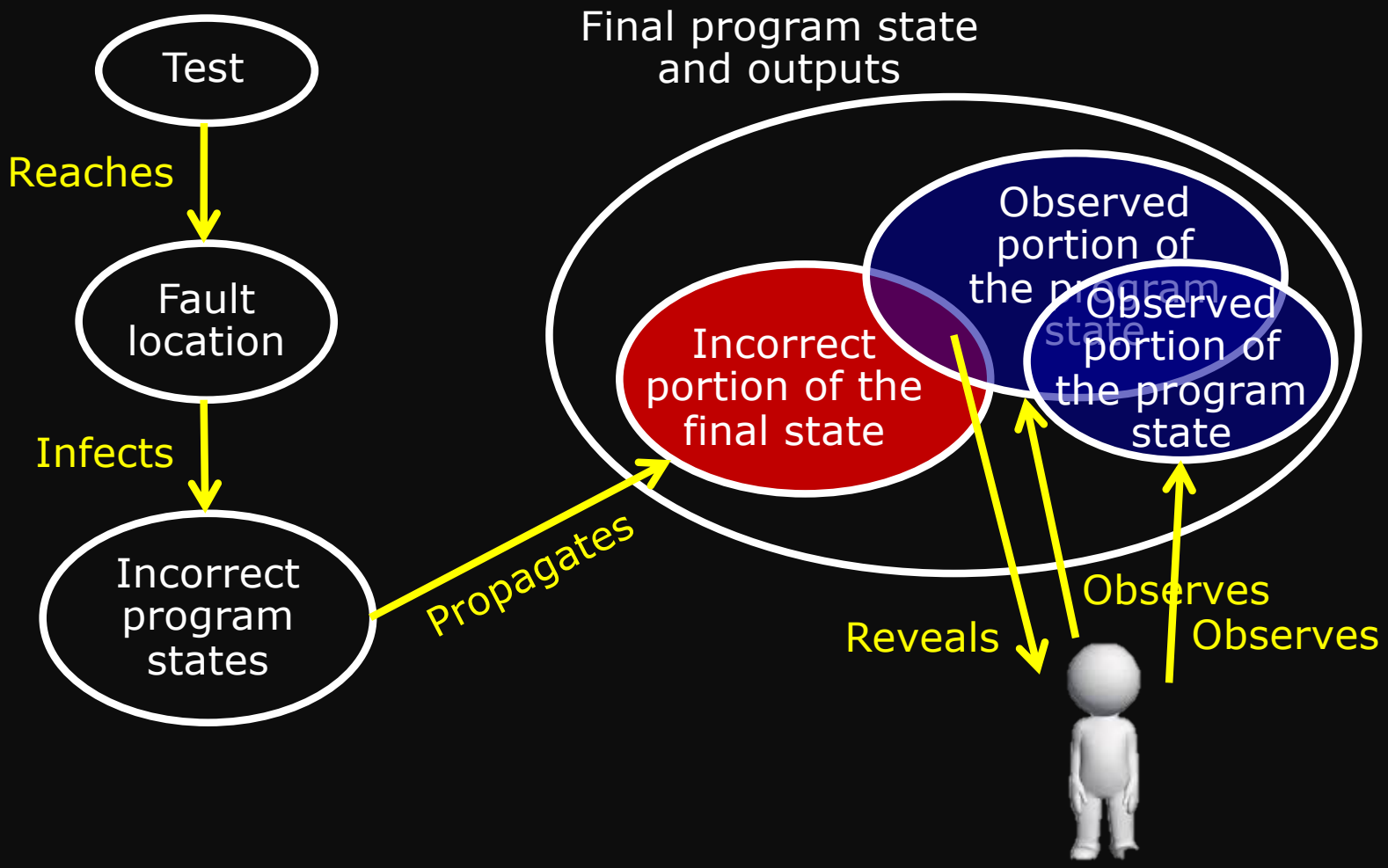
The first error state is immediately after executing **`i=1`** (line L2)

RIPR Model

Four conditions necessary for a failure to be observed

- **R**eachability
  - The fault is reached
- **I**nfection
  - Execution of the fault leads to an incorrect program state (error)
- **P**ropagation
  - The infected state must cause the program output or final state to be incorrect (failure)
- **R**evealability
  - The tester must observe part of the incorrect portion of the program state

RIPR Model



[AO, p.21]

Example – Applying RIPR

```
   public static int numZero (int[] arr)
   {  // If arr is null throw NullPointerException
      // else return the number of occurrences of 0 in arr
L1    int count = 0;
L2    for (int i = 1; i < arr.length; i++)
L3       if (arr[i] == 0)
L4          count++;
L5    return count;
   }
```

Revisit the example, what characteristics (or constraints) the inputs should have (or satisfy)?

- Reach a fault (i.e., execute the fault)
- Cause the program state to be incorrect (i.e., error)
- Cause the infected state to be propagated (i.e., failure)

Did you consider "happy paths" or "non happy paths" ?

Example – RIPR (Error, No Failure)

```
   public static int numZero (int[] arr)
   {  // If arr is null throw NullPointerException
      // else return the number of occurrences of 0 in arr
L1    int count = 0;
L2    for (int i = 1; i < arr.length; i++)
L3       if (arr[i] == 0)
L4          count++;
L5    return count;
   }
```

Revisit the example, apply RIPR to design tests that

- Reach a fault (i.e., execute the fault)
- Cause the program state to be incorrect (i.e., error)
- Does not propagate (i.e., no failure)
  - One possible test is [4, 6, 0] – now, design some more
- How does RIPR model help designing tests?

Example – RIPR (Error, Failure)

```
   public static int numZero (int[] arr)
   {  // If arr is null throw NullPointerException
      // else return the number of occurrences of 0 in arr
L1    int count = 0;
L2    for (int i = 1; i < arr.length; i++)
L3       if (arr[i] == 0)
L4          count++;
L5    return count;
   }
```

Revisit the example, apply RIPR to design tests that

- Reach a fault (i.e., execute the fault)
- Cause the program state to be incorrect (i.e., error)
- Propagate (i.e., failure)
  - One possible test is [0, 4, 6] – now, design some more
- How does RIPR model help designing tests?

Wrap-up

- Faults, errors, failures
- Fault location
- Infected state
- RIPR model
- Observability and revealibility

What's Next?

- Model-Driven Test Design (MDTD)