

CS 4530: Fundamentals of Software Engineering

Module 12: Testing Larger Things

Jon Bell, Adeel Bhutta, Mitch Wand
Khoury College of Computer Sciences

Learning Objectives for this Lesson

- By the end of this lesson, you should be prepared to:
 - Design test cases for code using fakes, mocks and spies
 - Explain why you might need a test double in your testing
 - Explain why you might need tests that are larger than unit tests
 - Explain how large, deployed systems lead to additional testing challenges

Story so far: Tests Check Return Values

```
test('addStudent should add a student to the database', () => {  
  // const db = new DataBase ()  
  expect(db.nameToIDs('blair')).toEqual([])  
  
  const id1 = db.addStudent('blair');  
  
  expect(db.nameToIDs('blair')).toEqual([id1])  
});
```

Challenge: How to test the ProducerClock?

clockWithObserverPattern.test.ts

```
export interface IClockWithListeners {  
  reset():void // resets the time to 0  
  tick():void // increment time and notify all listeners  
  // add a listener and initialize it with the current time  
  addListener(listener:IClockListener):void  
}
```

4

```
export interface IClockListener {  
  // @param t - the current time, as reported by the clock  
  notify(t:number):void  
}
```

```
export class ProducerClock implements IClockWithListeners {  
  // some implementation  
}
```

Test the ProducerClock with a Fake ClockListener

clockWithObserverPattern.test.ts

```
export interface IClockWithListeners {  
    reset():void // resets the time to 0  
    tick():void // increment time and notify all listeners  
    // add a listener and initialize it with the current time  
    addListener(listener:IClockListener):void  
}
```

```
class ClockListenerForTest implements IClockListener {  
    private _time : number = 0  
    constructor (private masterClock:IClockWithListeners) {  
        masterClock.addListener(this)  
    }  
    notify (t:number) : void {this._time = t}  
    getTime () : number {return this._time}  
}
```

Now we can test using the custom observer

```
import { ProducerClock } from "../clockWithObserverPattern";
```

```
const clock1 = new ProducerClock
```

```
const listener1 = new ClockListenerforTest(clock1)
```

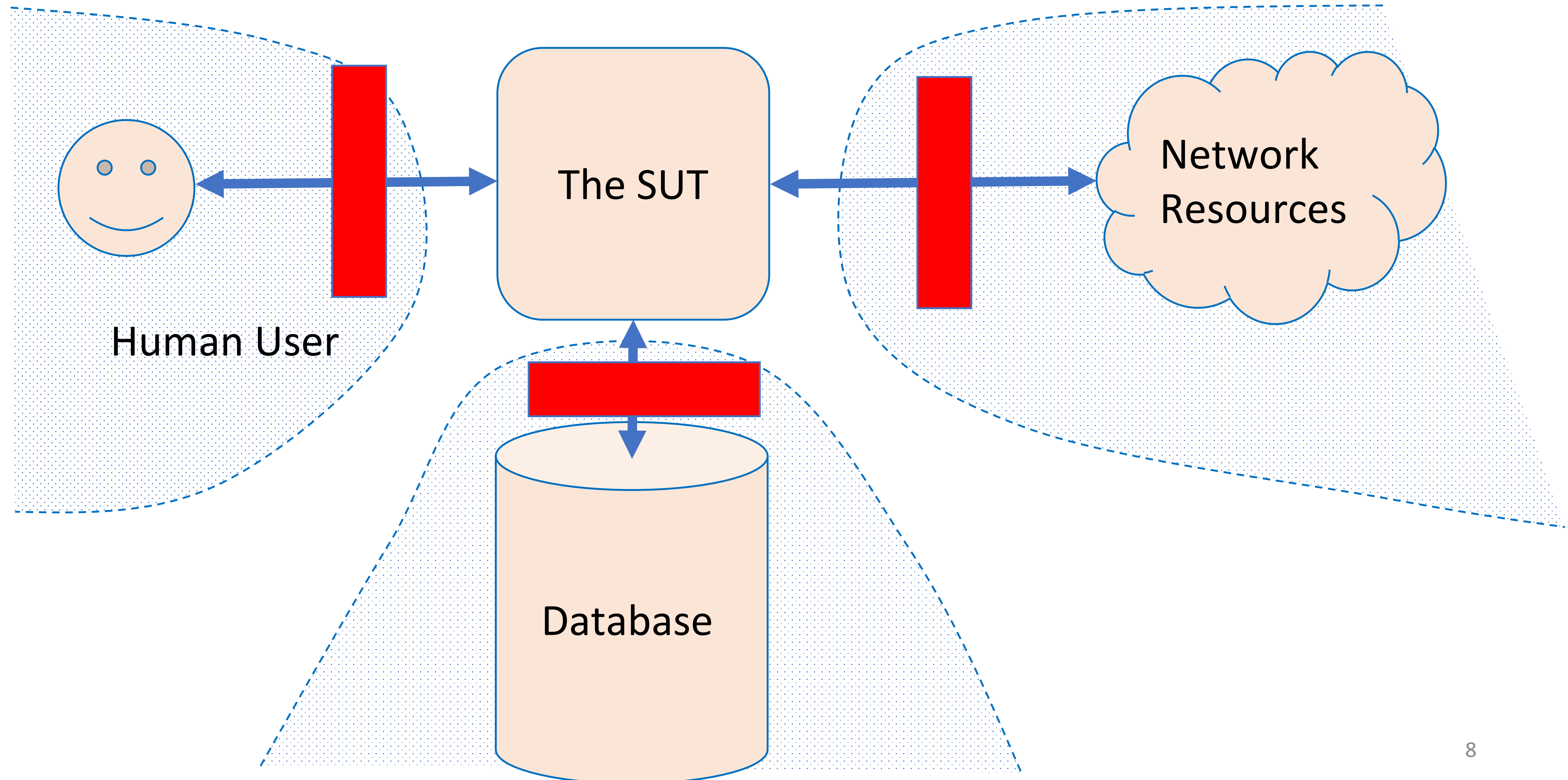
clockWithObserverPattern.test.ts

```
describe("tests for ProducerClock", () => {  
  test("after reset, listener should return 0", () => {  
    clock1.reset()  
    expect(listener1.getTime()).toBe(0)  
  })  
  test("after one tick, listener should return 1", () => {  
    clock1.reset(); clock1.tick()  
    expect(listener1.getTime()).toBe(1)  
  })  
  test("after two ticks, listener should return 2", () => {  
    clock1.reset(); clock1.tick(); clock1.tick()  
    expect(listener1.getTime()).toBe(2)  
  })  
})
```

“Test Doubles” Stand In For Other Components

- Act as a stand-in for components, allowing for testing in isolation
- Fakes: Replace client implementations with dummies for testing
- Mocks: Automatically-generated fake implementations for an interface
- Spies: Automatically-instrument internals of objects, classes or modules

Test doubles replace uncontrollable things with things that you do control



Fake Listener: Discussion

```
class ClockListenerForTest implements IClockListener {  
    private _time : number = 0  
    constructor (private masterClock:IClockWithListeners) {  
        masterClock.addListener(this)  
    }  
    notify (t:number) : void {this._time = t}  
    getTime () : number {return this._time}  
}
```

- Good news:
 - It works!
 - It doesn't require learning other libraries
- Bad news:
 - It's a maintenance burden (what if new methods are added to IClockListener?)
 - It took manual effort to write
 - Richer fakes (e.g. track how many times a method called) are even more effort to write

Mocks are automated fakes

- Jest's mocks return "undefined" by default (can be customized), and track calls to the function

```
test("simplest mock behavior", () => {  
  const mockFunction1 = jest.fn();  
  
  const result1 = mockFunction1("17");  
  const result2 = mockFunction1("42")  
  
  expect(result1).toBeUndefined();  
  expect(result2).toBeUndefined()  
  
  expect(mockFunction1).toHaveBeenCalled();  
  expect(mockFunction1).toHaveBeenCalledTimes(2);  
  
  expect(mockFunction1).toHaveBeenCalledWith("17");  
  expect(mockFunction1).toHaveBeenCalledWith("42")  
});
```

You can customize your mock in many ways

```
test("customizing mock functions", () => {  
  
  // you can specify the the return value  
  const mockFunction3 = jest.fn();  
  mockFunction3.mockReturnValue("baz");  
  
  expect(mockFunction3(17)).toBe("baz");  
  expect(mockFunction3).toHaveBeenCalledWith(17);  
  
  // or give the mock an implementation  
  const mockFunction2 = jest.fn()  
  mockFunction2.mockImplementation((n: number) => n + n);  
  
  expect(mockFunction2(3)).toBe(6);  
  expect(mockFunction2(14)).toBe(28)  
  expect(mockFunction2).toHaveBeenCalledWith(3);  
  expect(mockFunction2).toHaveBeenCalledWith(14);  
  
  // you can also reset the mock's history and implementation  
  mockFunction2.mockReset()  
  expect(mockFunction2).not.toHaveBeenCalledWith(14);  
});
```

simpleMocks.test.ts

Mock Classes and Interfaces with Jest-Mock-Extended

```
import { mock, mockClear } from 'jest-mock-extended';  
import { IClockListener, ProducerClock } from './clockWithObserverPattern';
```

clockWithObserverPatternMock.test.ts

```
const clock1 = new ProducerClock();  
//Automatically create an implementation of IClockListener, each method is a mock function  
const listener1 = mock<IClockListener>();  
clock1.addListener(listener1);
```

```
describe('tests for ProducerClock', () => {  
  beforeEach(() => {  
    mockClear(listener1); //Clear the mock function's history  
  });  
  test('after one tick, listener should return 1', () => {  
    clock1.reset();  
    clock1.tick();  
    expect(listener1.notify).toHaveBeenLastCalledWith(1);  
  });  
  test('after two ticks, listener should return 2', () => {  
    clock1.reset();  
    clock1.tick();  
    expect(listener1.notify).toHaveBeenLastCalledWith(1);  
    clock1.tick();  
    expect(listener1.notify).toHaveBeenLastCalledWith(2);  
    expect(listener1.notify).toHaveBeenCalledTimes(2);  
  });  
});
```

Unlike mocks, spies *instrument* existing implementations

- Consider cases where you *don't* want a complete fake, but *do* want to check side-effects:
 - What was sent on the network?
 - How many times was a problem logged?
 - What was inserted in the database?
- Jest can automatically instrument existing code to make it into a “spy” – a mock but with the original implementation

Spy
"remembers"

Use `jest.spyOn` to create a spy on an object

```
import { ClockListener, ProducerClock } from './clockWithObserverPattern';

const clock1 = new ProducerClock();
const clockClient = new ClockListener(clock1);
const notifySpy = jest.spyOn(clockClient, 'notify'); // Spy on calls to notify on this clock
describe('tests for ProducerClock', () => {
  beforeEach(() => {
    notifySpy.mockClear(); // Clear the mock function's history
  });
  test('after one tick, listener should return 1', () => {
    clock1.reset();
    clock1.tick();
    expect(notifySpy).toHaveBeenCalledTimes(1);
  });
  test('after two ticks, listener should return 2', () => {
    clock1.reset();
    clock1.tick();
    expect(notifySpy).toHaveBeenCalledTimes(1);
    clock1.tick();
    expect(notifySpy).toHaveBeenCalledTimes(2);
    expect(notifySpy).toHaveBeenCalledWith(2);
  });
});
```

clockWithObserverPatternSpy.test.ts

Spies can be used even when you can't control the SUT

- Syntax: `jest.spyOn(object, methodName)`
- Example from last slide:

```
const clock1 = new ProducerClock();
```

```
/** Some listener that we happen to know about */  
const clockClient = new ClockListener(clock1);
```

```
/** Spy on calls to 'notify' on this listener */  
const notifySpy = jest.spyOn(clockClient, 'notify');
```

- You can specify *any* object, and *any* method name (even private methods)
- Spy on objects *or* entire modules
- The spy intercepts *all* calls to that method of that object or module

Let's mock the http client from the async module

```
import axios from 'axios'
```

echo.ts

```
export async function echo(str: string) : Promise<string> {  
  const res =  
    await axios.get(`https://httpbin.org/get?answer=${str}`)  
  return res.data.args.answer  
}
```


Use `jest.spyOn` to create a spy on a *module*

```
import axios from 'axios'  
import { echo } from './echo'
```

echo.test.ts

```
describe("tests for echo", () => {  
  
  beforeEach(jest.resetAllMocks)  
  
  test('just spying on a function runs the original', async () => {  
    const spy1 = jest.spyOn(axios, 'get')  
    const str = '43'  
    const correctURL = `https://httpbin.org/get?answer=${str}`  
    expect(await echo(str)).toEqual(str); // better idiom than in Module 6  
    expect(spy1).toBeCalledWith(correctURL);  
    expect(spy1).toBeCalledTimes(1)  
  })  
})
```

Pattern: add a mock response to turn a spy into a mock

echo.test.ts

```
test('mocking the http call doesn\'t actually do a live call', async () => {
  const spy1 = jest.spyOn(axios, 'get')

  // have the mock return this
  const mockAnswer = '777'
  const mockResponse = { data: { args: { answer: mockAnswer } } }
  spy1.mockResolvedValue(mockResponse) // don't run the original!

  const realInput = '43' // put this in the URL
  const realQuery = `https://httpbin.org/get?answer=${realInput}`

  // 'echo' takes the realInput, but returns the mockAnswer,
  // so the http call must not have taken place
  expect(await echo(realInput)).toEqual(mockAnswer);
  expect(spy1).toBeCalledWith(realQuery);
  expect(spy1).toBeCalledTimes(1)
})
```

This pattern creates close coupling between the SUT and the test

echo.test.ts

```
test('mocking the http call doesn\'t actually do a live call', async () => {
  const spy1 = jest.spyOn(axios, 'get')

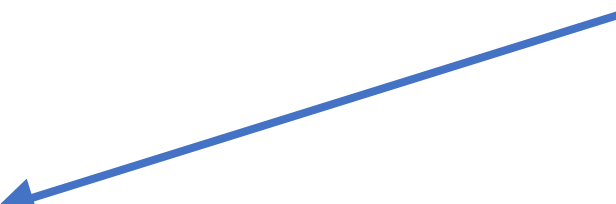
  // have the mock return this
  const mockAnswer = '777'
  const mockResponse = { data: { args: { answer: mockAnswer } } }
  spy1.mockResolvedValue(mockResponse) // don't run the original!

  const realInput = '43' // put this in the URL
  const realQuery = `https://httpbin.org/get?answer=${realInput}`

  // 'echo' takes the realInput, but returns the mockAnswer,
  // so the http call must not have taken place
  expect(await echo(realInput)).toEqual(mockAnswer);
  expect(spy1).toBeCalledWith(realQuery);
  expect(spy1).toBeCalledTimes(1)
})
```

Test Doubles Have Weaknesses

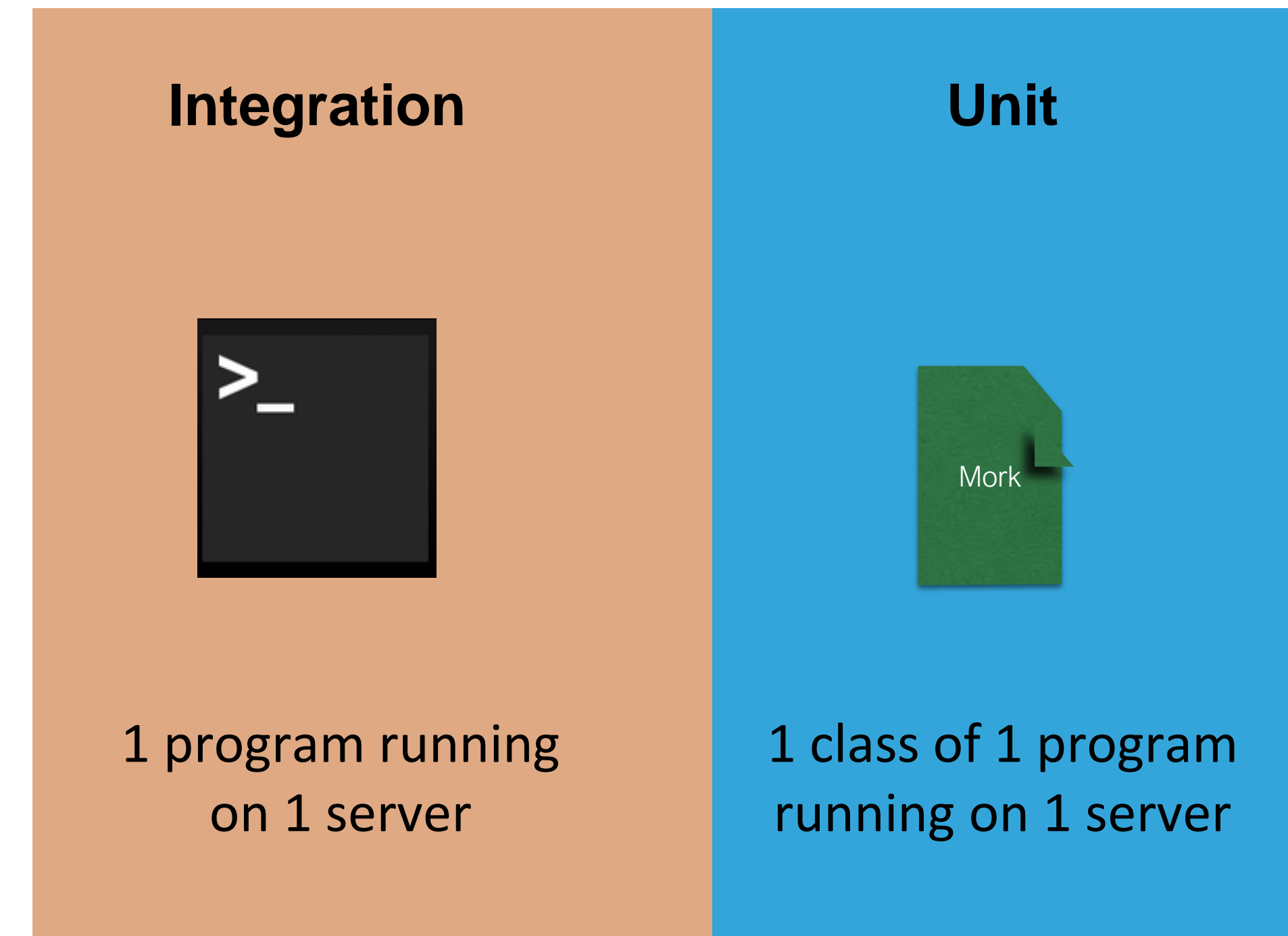
- Some failures may occur purely at the integration between components:
 - The test may assume wrong behavior (wrongly encoded by mock)
 - Higher fidelity mocks can help, but still just a snapshot of the real world
- Test doubles can be brittle:
 - Spies expect a particular usage of the test double;
 - The test is "brittle" because it depends on internal behavior of SUT;
- Potential maintenance burden: as SUT evolves, mocks must evolve.



We just saw
this

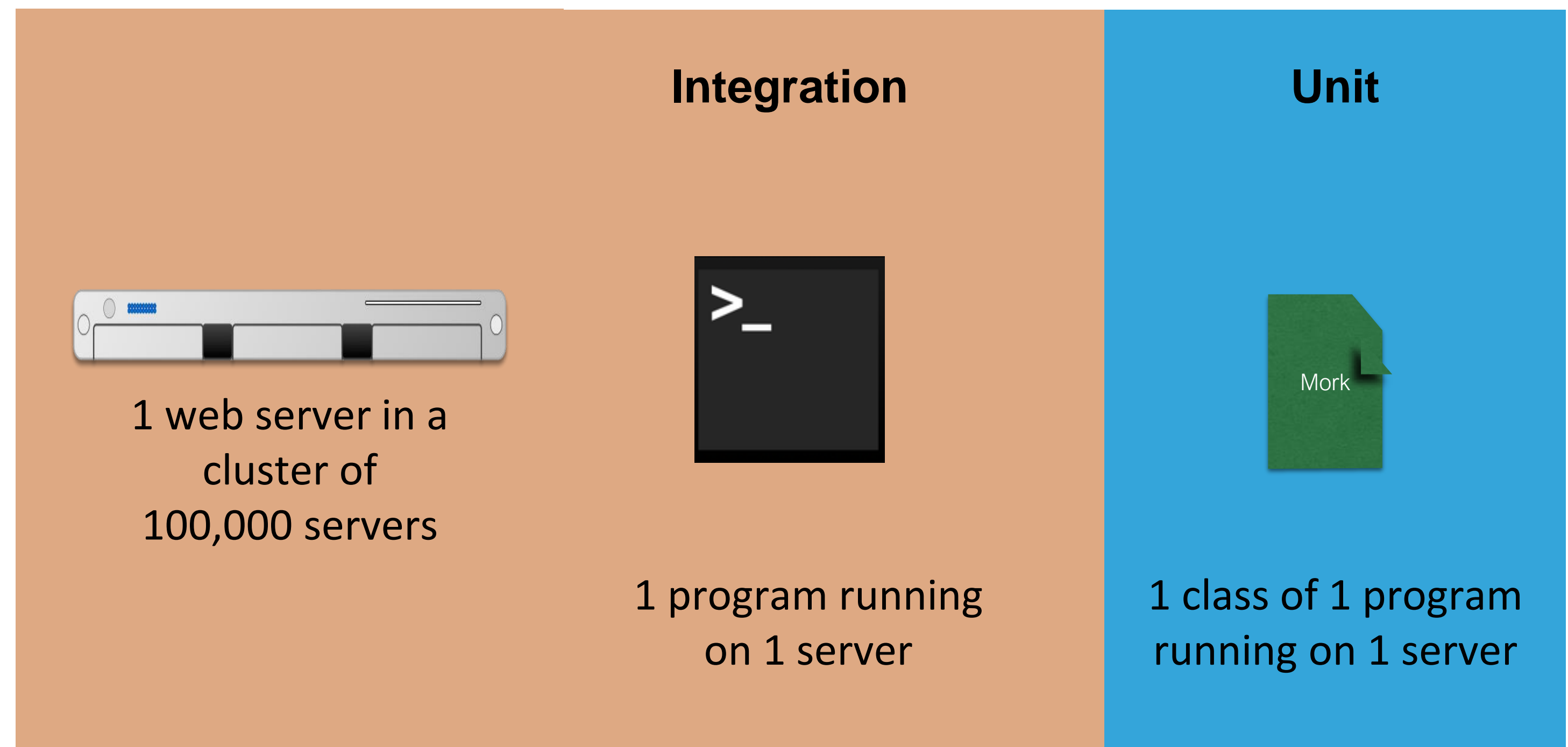
But some bugs are observable only when multiple components interact.

- These are usually because one module has made incorrect assumptions about some other module
- Unit tests won't reveal such bugs
- Mocks won't help, either (since they may incorporate our incorrect assumptions)
- So you really need integration tests

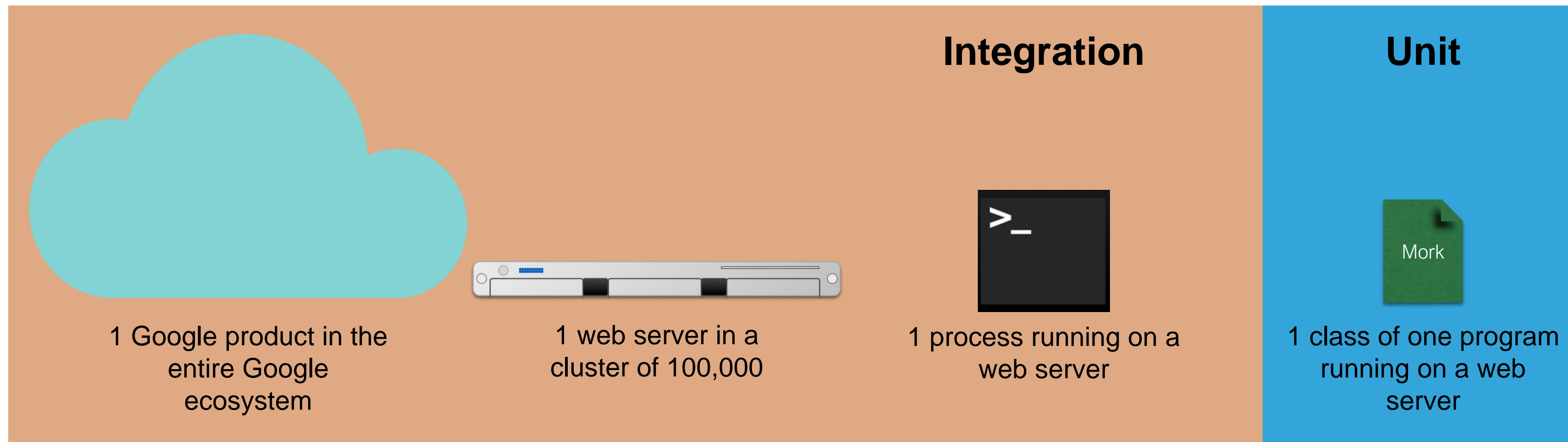


Integration tests may be larger

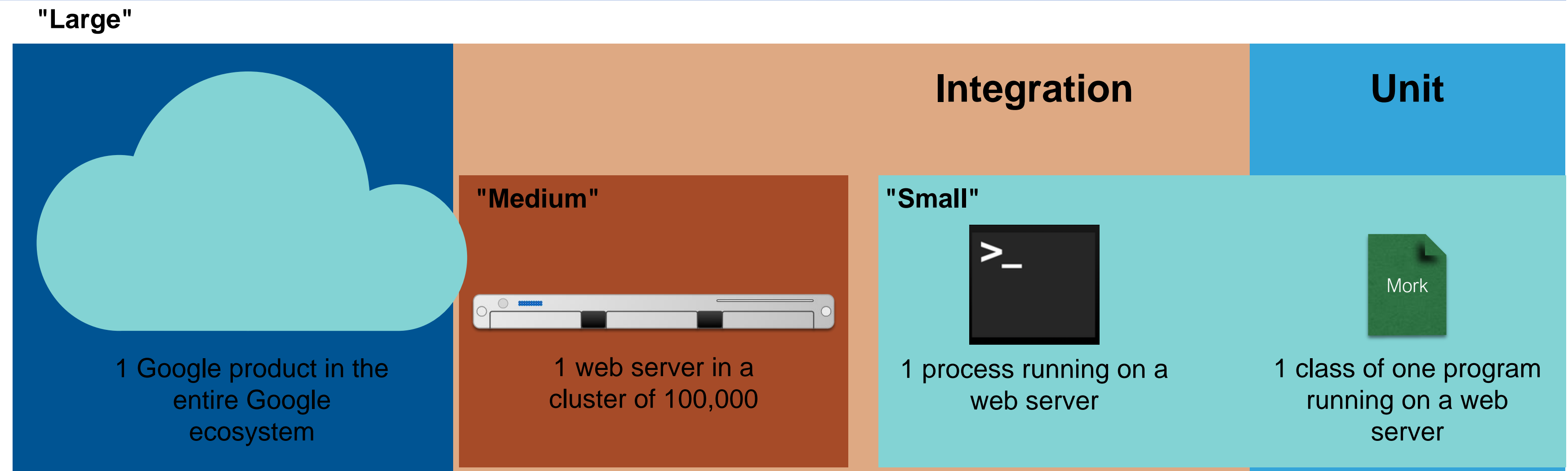
- Does the presence of other jobs on our server change the behavior of our program?
- Does the presence of the other servers change the behavior of our program?



Some Tests are Enormous



Google classifies tests by “size”

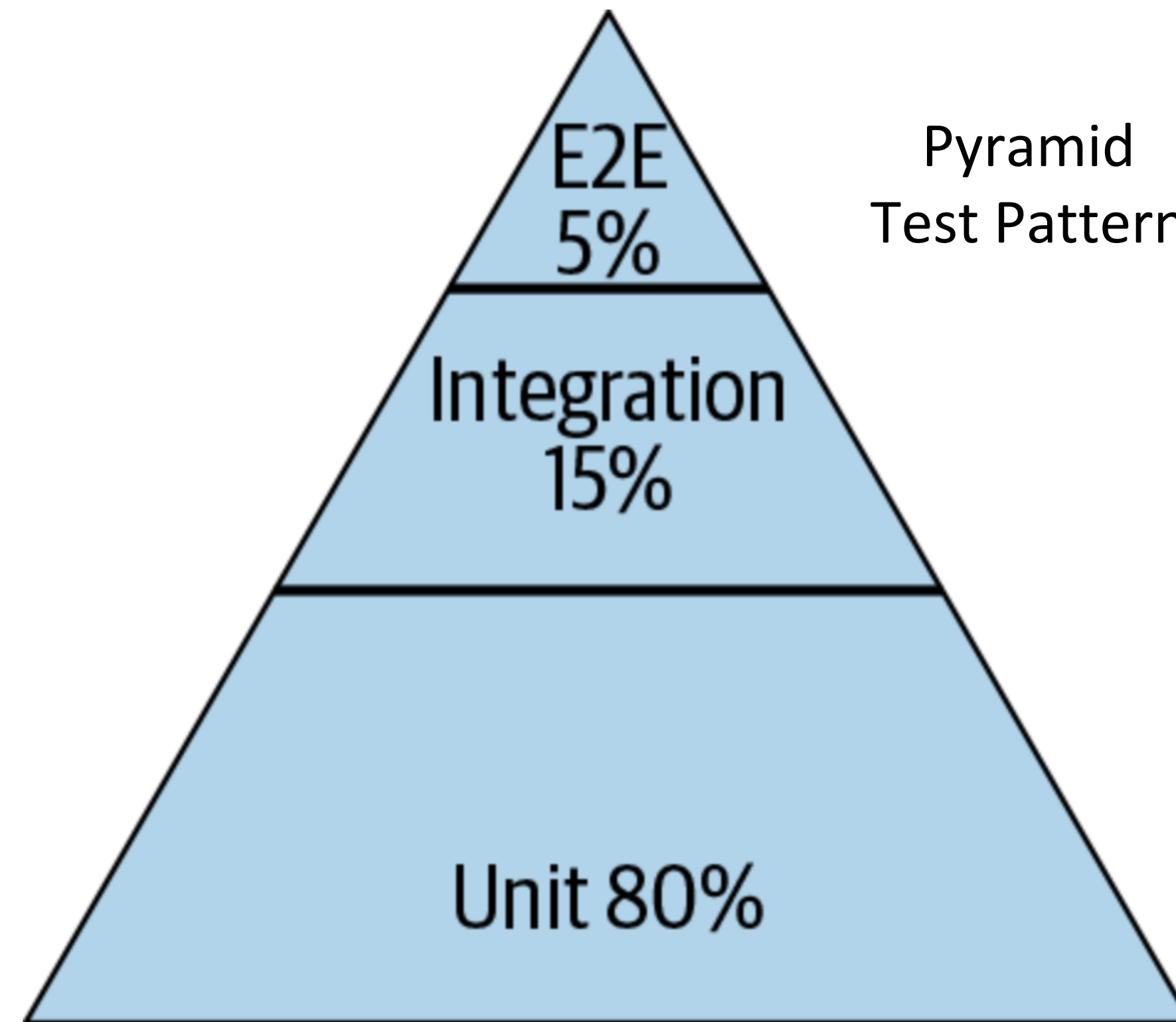
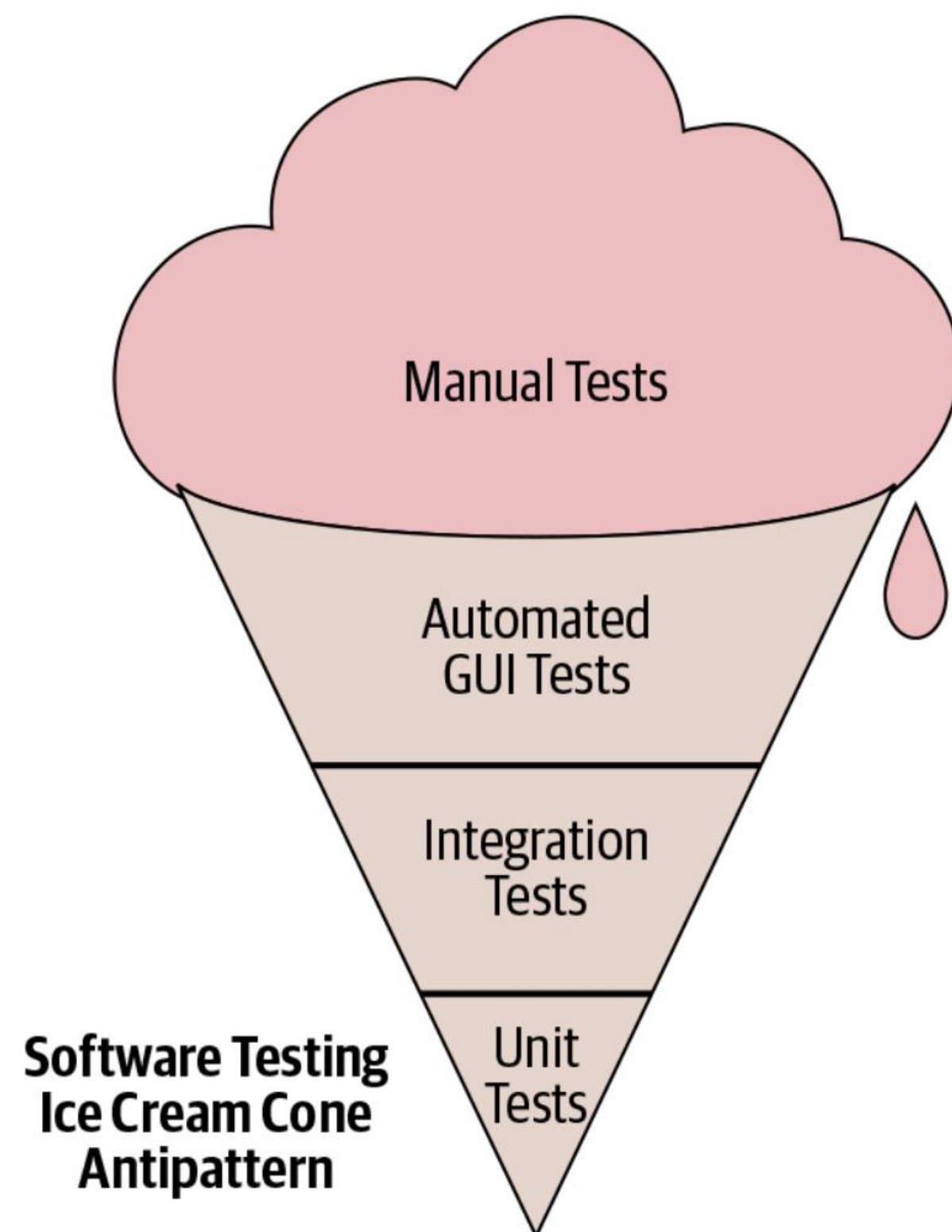


- “small” = single process
- “medium” = single machine
- “large” = bigger than that.

How big is my test?

- Small: run in a single thread, can't sleep, perform I/O or make blocking calls
- Medium: run on single computer, can use processes/threads, perform I/O, but only contact localhost
- Large: Everything else

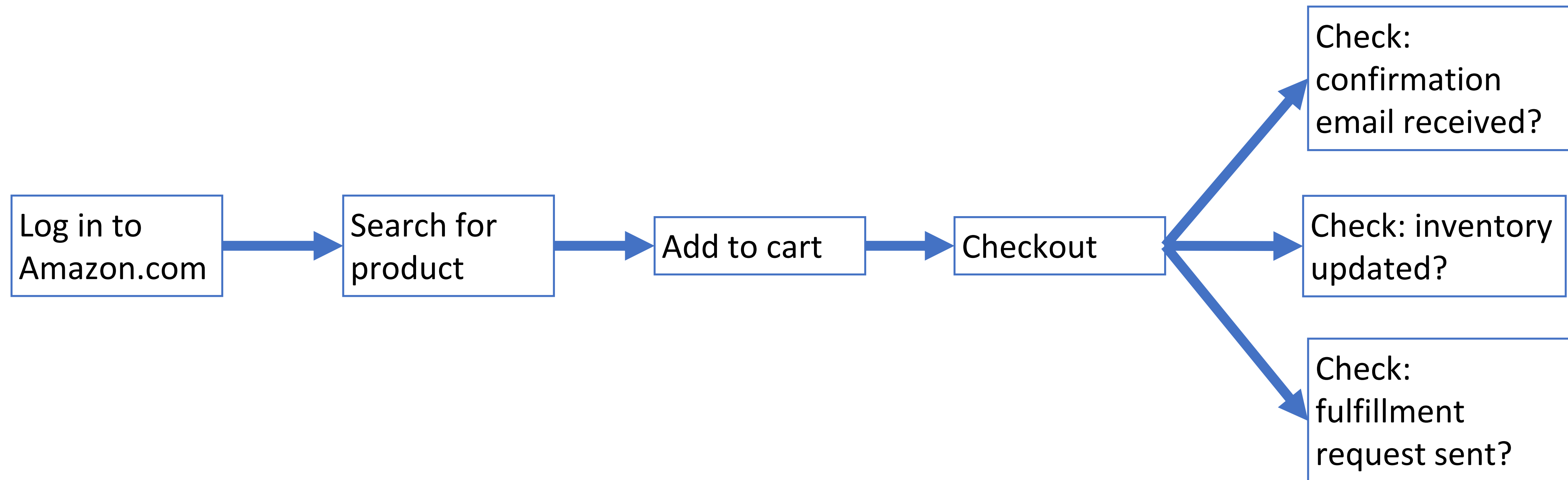
Testing Distribution (How much of each kind of testing we should do?)



From SoftEng @ Google Chapter 11

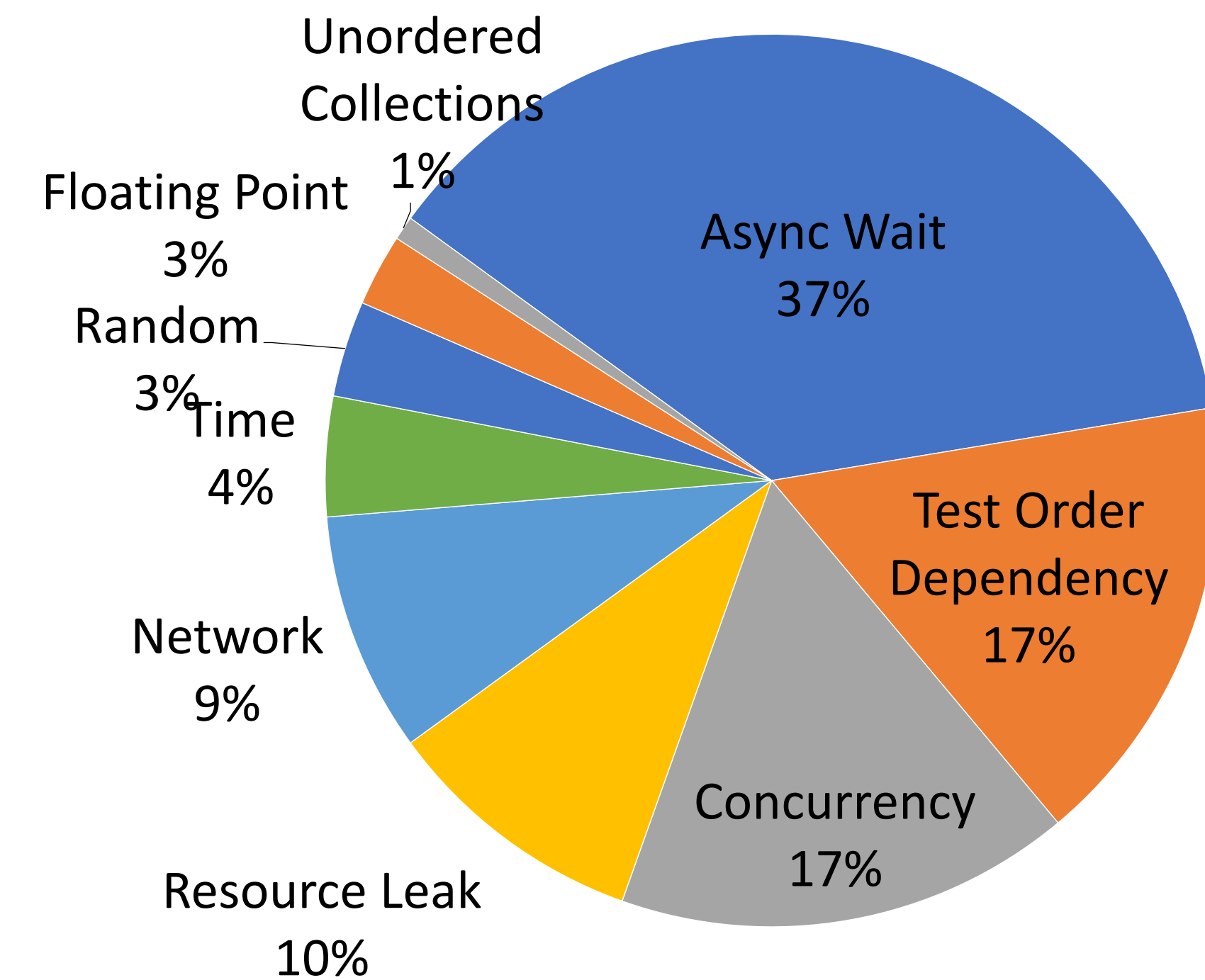
- https://learning.oreilly.com/library/view/software-engineering-at/9781492082781/ch11.html#testing_overview

“End-to-End” Tests are Enormous



Medium and Large Tests can be Flaky

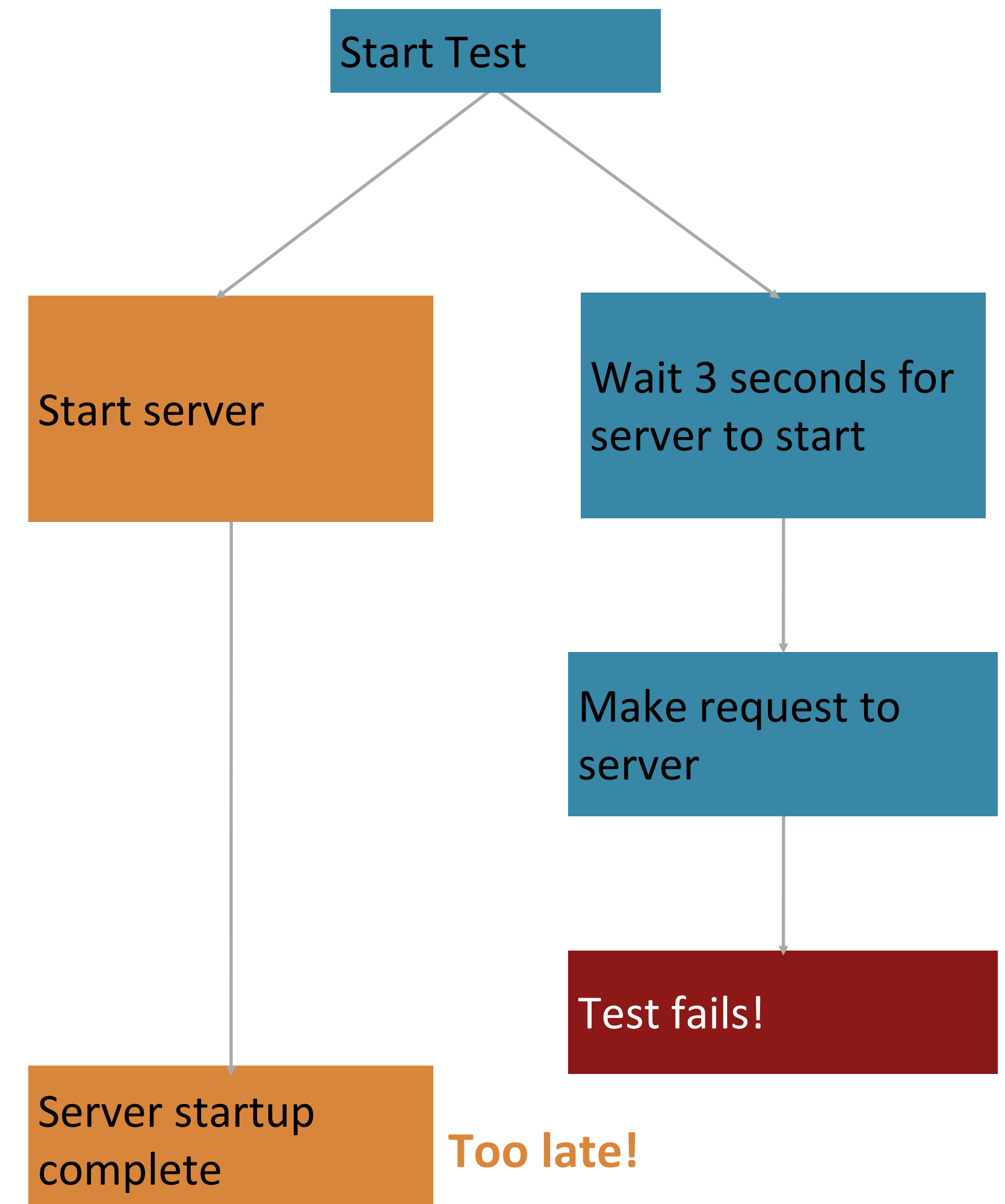
- Flaky test failures are false alarms
- Tests that are hermetic defend against “test order dependency” - failures due to tests running in other orders
- Most common cause of flaky test failures: “async wait” - tests that expect some asynchronous action to occur within a timeout
- Good tests avoid relying on timing



[Luo et al, FSE 2014 “An empirical analysis of flaky tests”]

Flaky Test Example: Async/Wait

- Most common root cause of flakiness
- Difficult to avoid, but consider:
 - Have more “small” tests that don’t require concurrency
 - Ensure sufficient resources available for running tests
 - Embed reasonable error detection to classify test failures as likely to be “flaky” vs true failures

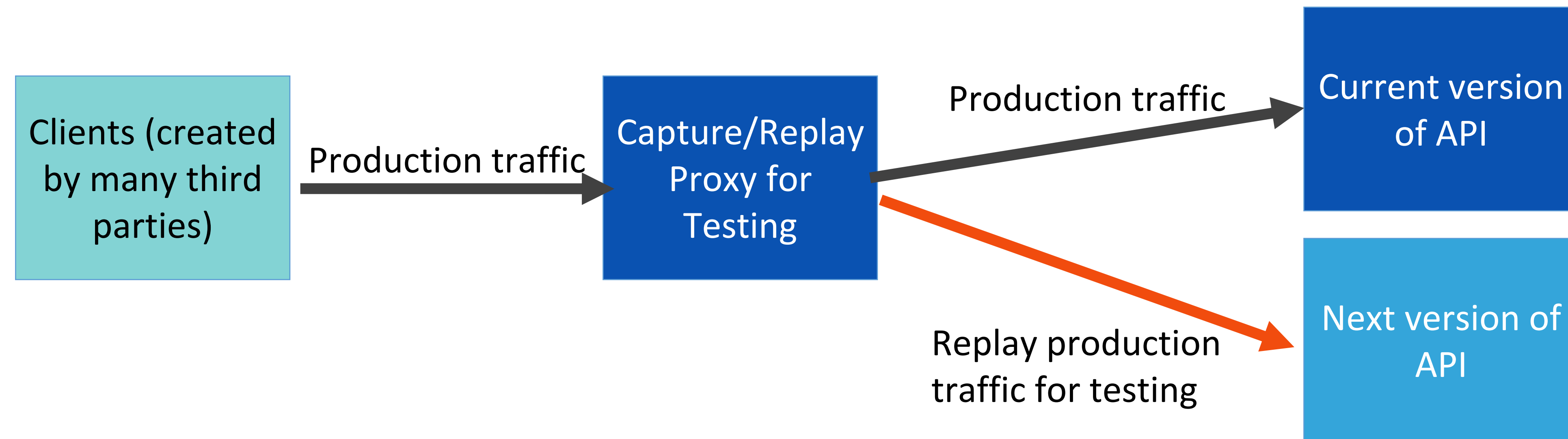


Deployed systems create even more testing challenges

- Clients believe “how it is now is right”,
 - Not “how the API intended it to be is right”
 - Writing thorough test suite is even harder, less useful
 - What is a “breaking change”?
- Still: vital to detect breaking changes
- Examples:
 - Detailed layout of GUIs
 - Side-effects of APIs, particularly under corner-cases

Mock System-Level Components with Capture/Replay

- Record the API requests and responses that clients make
- Test new versions of the API by identifying requests that result in different responses ("breaking changes")

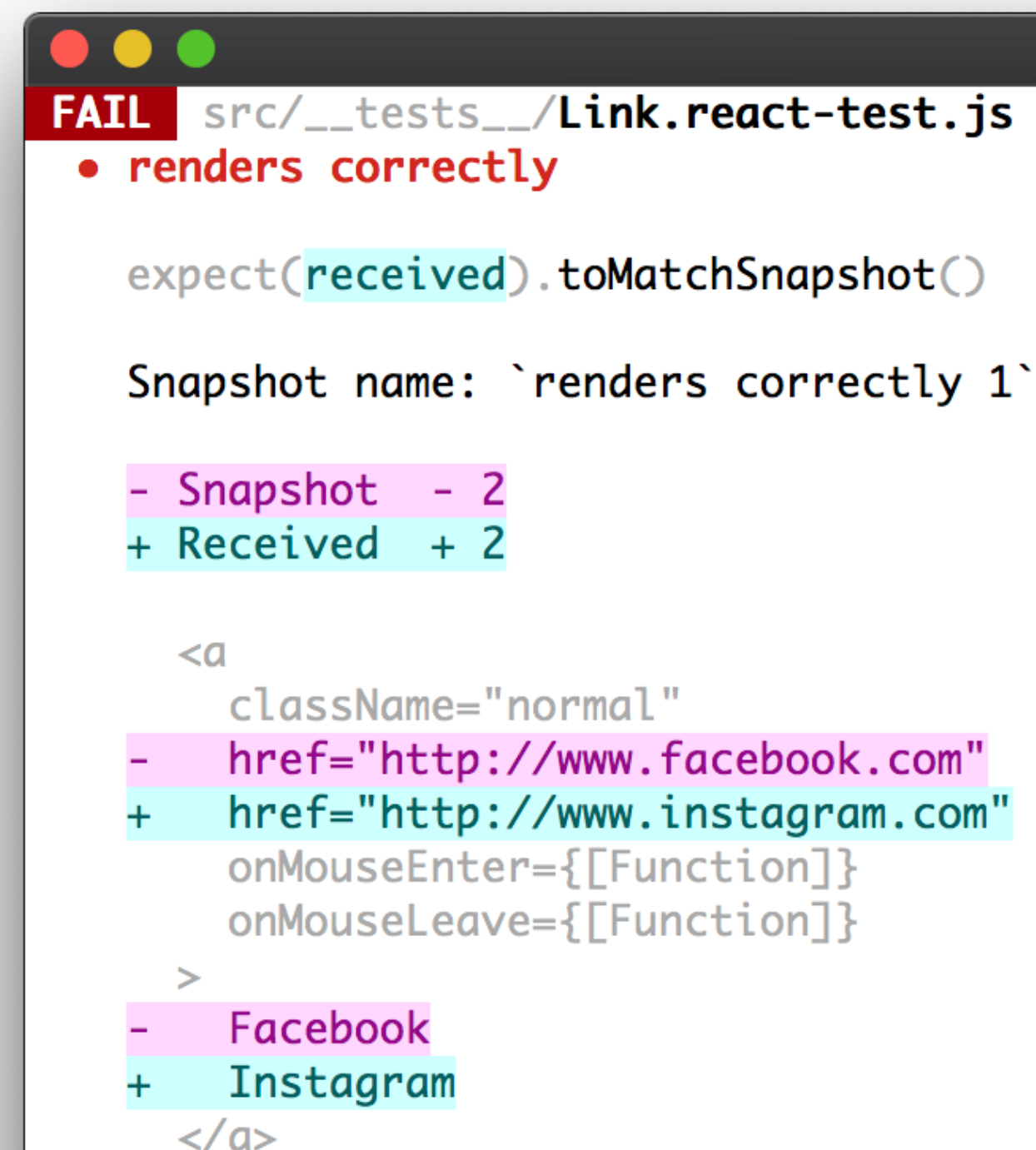


Snapshot Tests Can Detect GUI Changes

- The first time the test runs, it saves a "snapshot" of the rendered GUI
- Subsequent runs will fail if the snapshot changes

```
import renderer from 'react-test-renderer';
import Link from '../Link';

it('renders correctly', () => {
  const tree = renderer
    .create(<Link
page="http://www.facebook.com">Facebook</Link>)
    .toJSON();
  expect(tree).toMatchSnapshot();
});
```



```
FAIL src/__tests__/Link.react-test.js
  • renders correctly

expect(received).toMatchSnapshot()

Snapshot name: `renders correctly 1`

- Snapshot - 2
+ Received + 2

<a
  className="normal"
- href="http://www.facebook.com"
+ href="http://www.instagram.com"
  onMouseEnter={[[Function]]}
  onMouseLeave={[[Function]]}
>
- Facebook
+ Instagram
</a>
```


- Capture a visual snapshot of an application under a state
- If that snapshot changes, produce a visual report for manual sign-off



Learning Objectives for this Lesson

- You should now be prepared to:
 - Design test cases for code using fakes, mocks and spies
 - Explain why you might need a test double in your testing
 - Explain why you might need tests that are larger than unit tests
 - Explain how large, deployed systems lead to additional testing challenges