CS 4530: Fundamentals of Software Engineering

Module 12: Testing Larger Things

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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

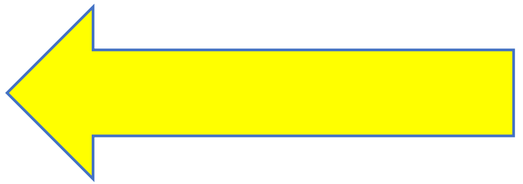
Why do we test?

- Unit Testing
  - Does the SUT satisfy its specification?
- Integration Testing
  - Do the SUT and its context work correctly *together*?
- Acceptance Testing
  - Does the SUT satisfy the customer
  - “Good” test suite answers: Are we building the right system ?

Unit Testing

What does it mean for a unit test to succeed?

- *Test Oracles* define the criteria for a test to suceedPossible kinds of test oracles
  - Function returns the exact “right” answer
  - Function returns an acceptable answer
  - Returns the same value as last time
  - Function returns without crashing
  - Function crashes (as expected)
  - Function has the right effects on its environment



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?

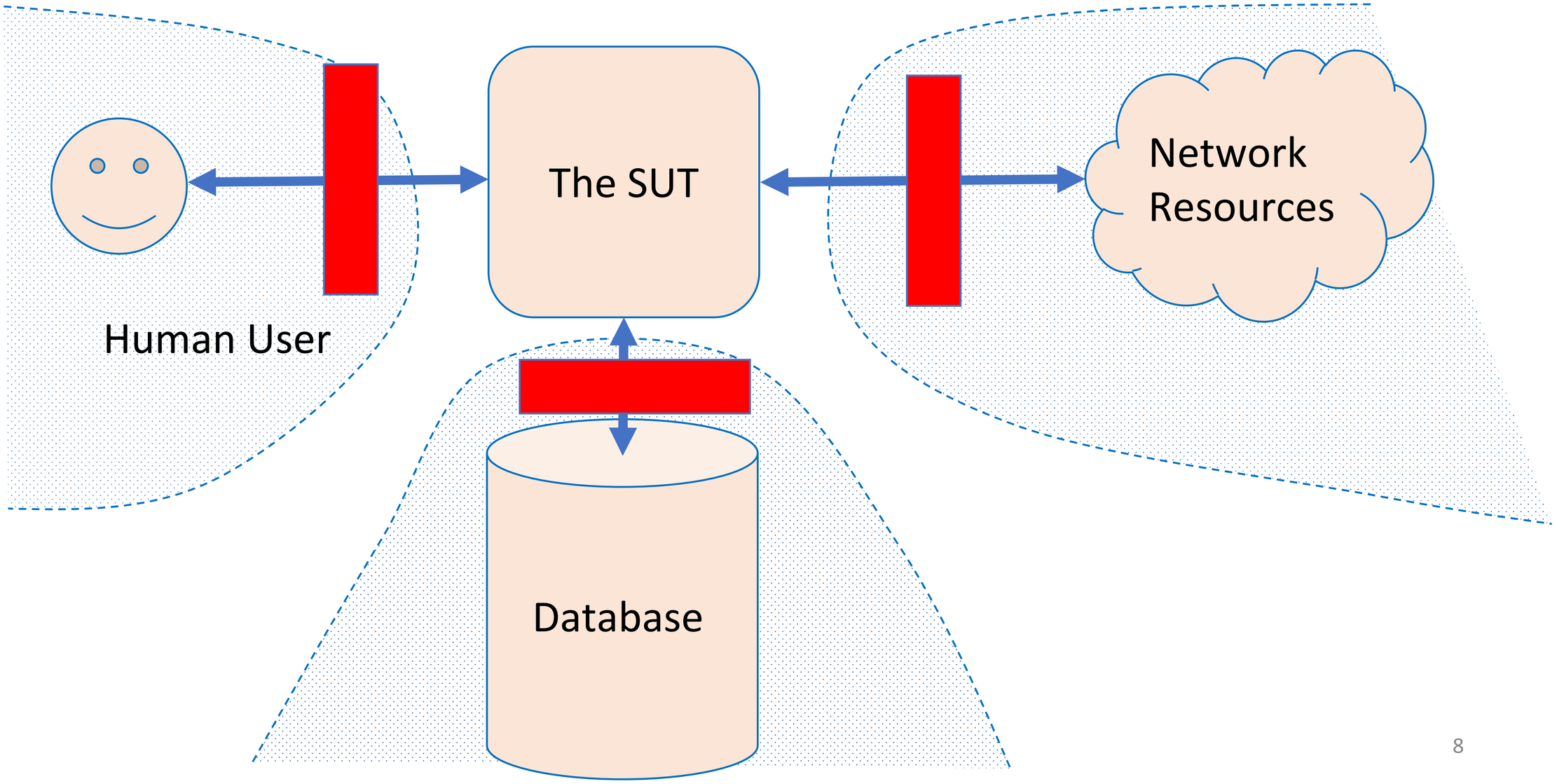
clockWithObserverPattern.test.ts

```
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
}

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 doubles replace uncontrollable things with things that you do control



“Test Doubles” Stand In For Other Components

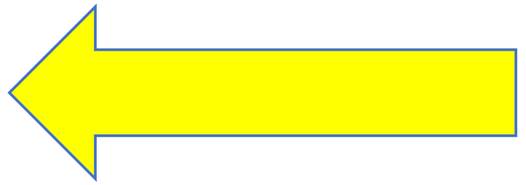
- Act as a stand-in for components, allowing for testing in isolation
- Fakes: Replace client implementations with dummies for testing
- Mocks: Automatically-generated fake implementations for an interface
- Spies: Automatically-instrument internals of objects, classes or modules

You could test the Producer Clock with a hand-built test double (a "fake")

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 fake observer

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

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

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)
    })
})
```

clockWithObserverPattern.test.ts

Does using the fake listener solve the problem?

```
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) would take 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")
});
```

Jest's Mock API: https://jestjs.io/docs/mock-function-api

You can customize your mock in many ways

simpleMocks.test.ts

```
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);
});
```

MockReset erases history; returns implementation to 'undefined'

You can mock Classes and Interfaces using Jest-Mock-Extended

https://www.npmjs.com/package/jest-mock-extended

clockWithObserverPatternMock.test.ts

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

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 have been notified with 1', () => {
        clock1.reset();
        clock1.tick();
        expect(listener1.notify).toHaveBeenLastCalledWith(1);
    });
    test('after two ticks, listener should have been notified with 1 and 2', () => {
        clock1.reset();
        clock1.tick();
        expect(listener1.notify).toHaveBeenLastCalledWith(1);
        clock1.tick();
        expect(listener1.notify).toHaveBeenLastCalledWith(2);
        expect(listener1.notify).toHaveBeenCalledTimes(2);
    });
});
```

Construct a mock listener (1 line!)

All the methods of IClockListener are mocked.

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"

Real implementation is used

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).toHaveBeenLastCalledWith(1);
  });
  test('after two ticks, listener should return 2', () => {
    clock1.reset();
    clock1.tick();
    expect(notifySpy).toHaveBeenLastCalledWith(1);
    clock1.tick();
    expect(notifySpy).toHaveBeenLastCalledWith(2);
    expect(notifySpy).toHaveBeenCalledTimes(2);
  });
});
```

clockWithObserverPatternSpy.test.ts

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

Syntax: jest.spyOn(object, methodName)

- You can specify *any* object, and *any* method name (even private methods)
- Spy on objects *or* entire modules
- The spy logs *all* calls to that method of that object or module
- The call to the **original still gets made**, unless the spy explicitly supplies a substitute
  - we'll illustrate this a few slides from now.

Let’s use mocks and spies to test the http client from the async module

EchoClass.ts

```
export class Echo  {

  /** @argument a string
   * @returns a promise to return the same string
   * @requires axios
   * @calls https://httpbin.org/get?answer=${str}
   */

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

}
```

Create a spy on (axios, 'get')

echo.test.ts

```
import { Echo } from './EchoClass';

// etc...

test('just spying on a function runs the original', async () => {
    test('echo should return its argument', async () => {
      const spy1 = jest.spyOn(axios, 'get');
      const str = '34';
      const res = await Echo.echo(str);
      expect(spy1).toHaveBeenCalled();
      expect(res).toEqual(str);
    });
  });
```

- GET call was made to https://httpbin.org

Next step: define a mock for the axios call

echo.test.ts

```
async function mockAxiosCall(url: string) {
  return { data: { args: { answer: url.split('=')[1] } } };
 }

// Hmm, we better test mockAxiosCall!

describe('tests for mockAxiosCall', () => {
  test('mockhttpbin should return its argument', async () => {
    const url = 'https://httpbin.org/get?answer=33'
    const res = await mockAxiosCall(url);
    expect(res).toEqual({ data: { args: { answer: "33" } } });
  });
})
```

Now install the mock, so the 'get' doesn't get called.

echo.test.ts

```
test('mock axios.get so httpbin is not called', async () => {
    jest.resetAllMocks();
    const spy1 = jest.spyOn(axios, 'get').mockImplementation(mockAxiosCall);
    const str = '34';
    const res = await Echo.echo(str);
    expect(spy1).toHaveBeenCalled();
    expect(res).toEqual(str);
  })
```

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.

Did we correctly model the behavior of httpbin?

Not just its IO behavior, but also its dependencies

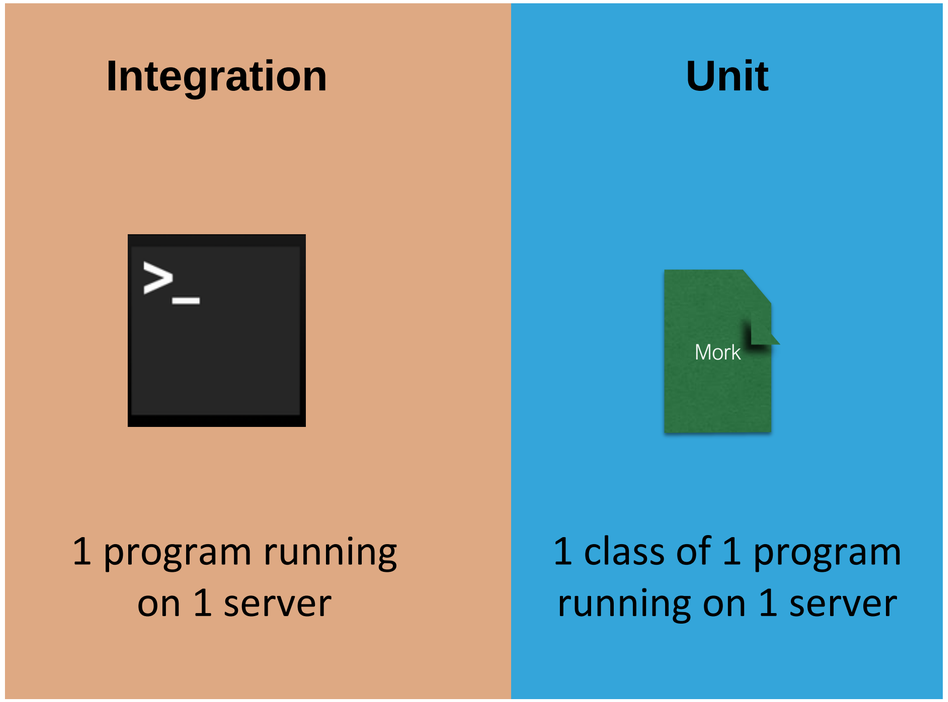
What if we didn't want to make assumptions about how httpbin behaves?

- We'd need to actually call httpbin.
- This is no longer a unit test; it's an integration test
- Which brings us to our next topic.

Integration Testing

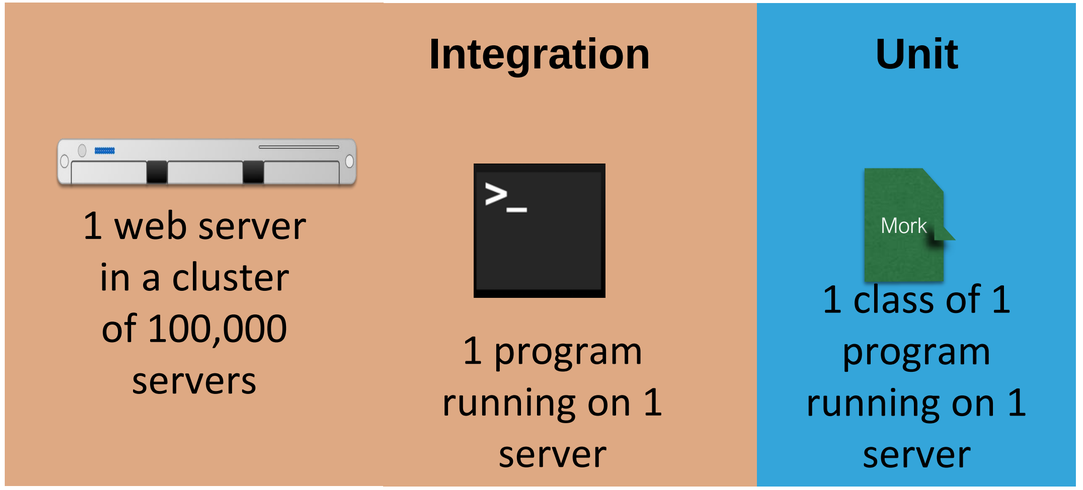
But some bugs are observable only when multiple components interact.

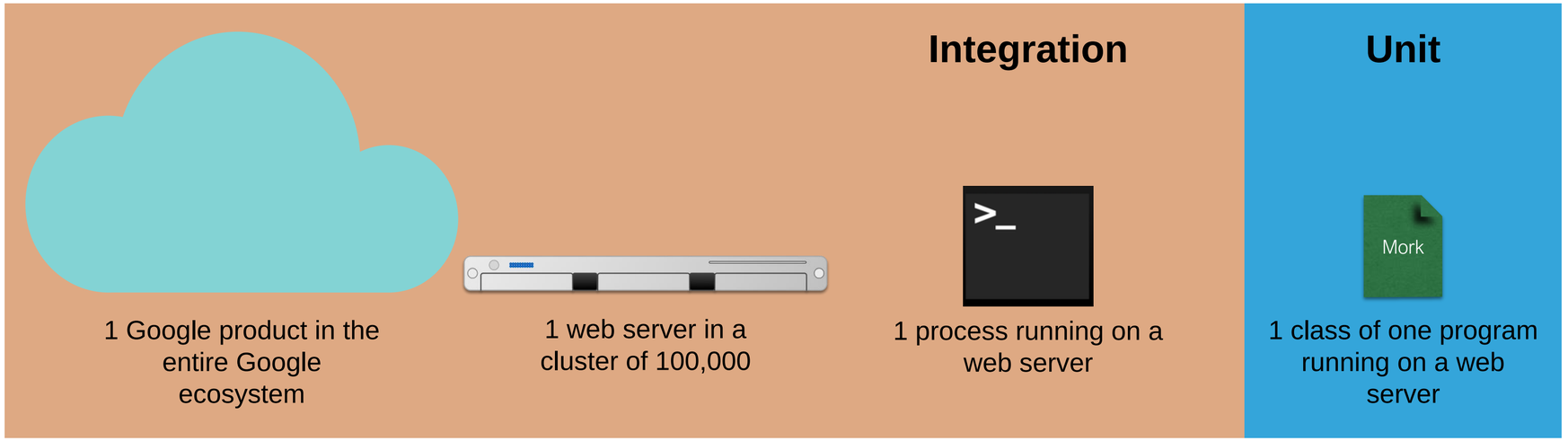
- These are usually because one module has made incorrect assumptions about some other module
- Unit tests won't reveal such bugs
- Mocks won't help, either (since they may incorporate our incorrect assumptions)
- So you really need integration tests



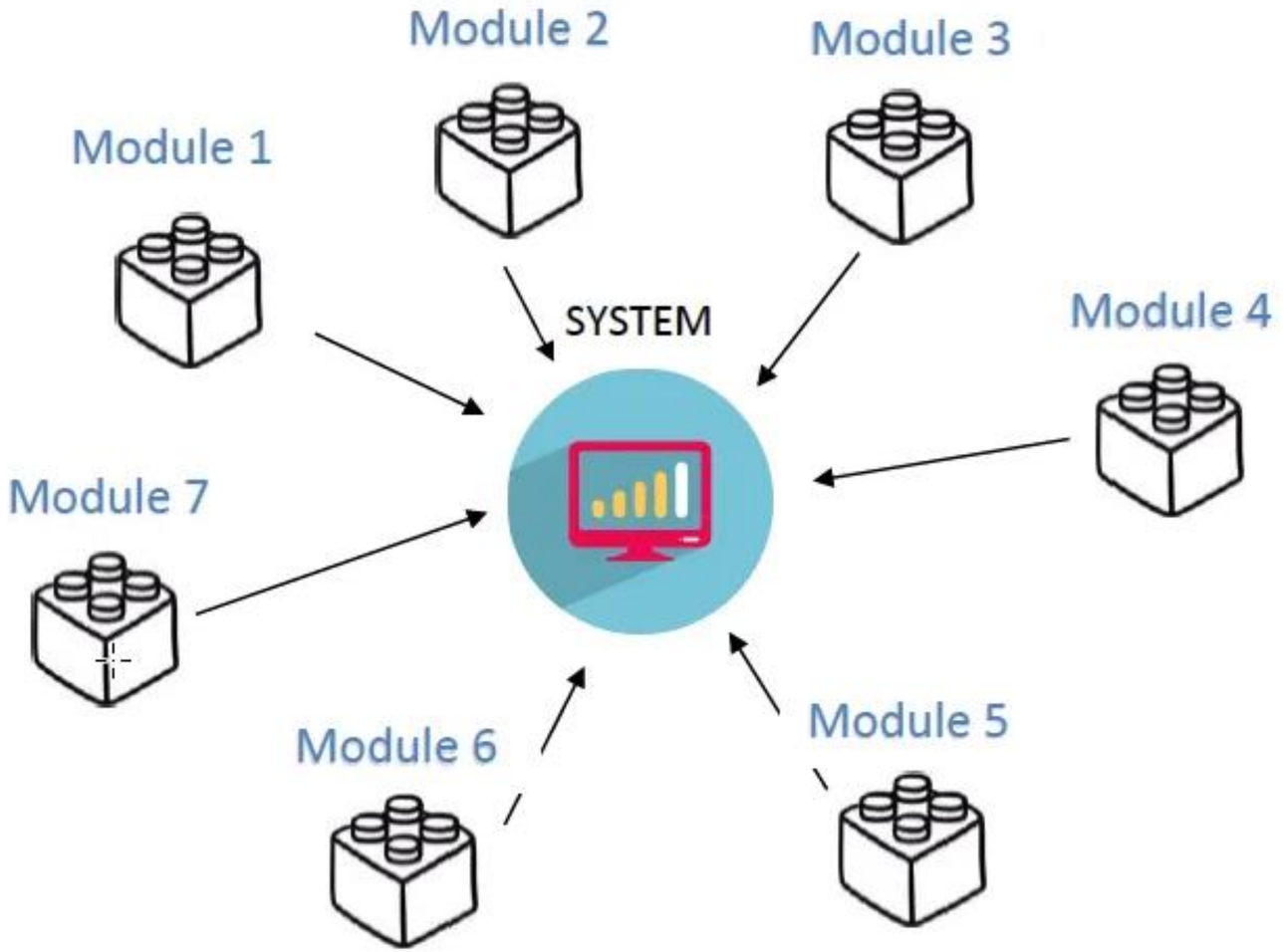
Integration tests may be larger, even enormous

- 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?



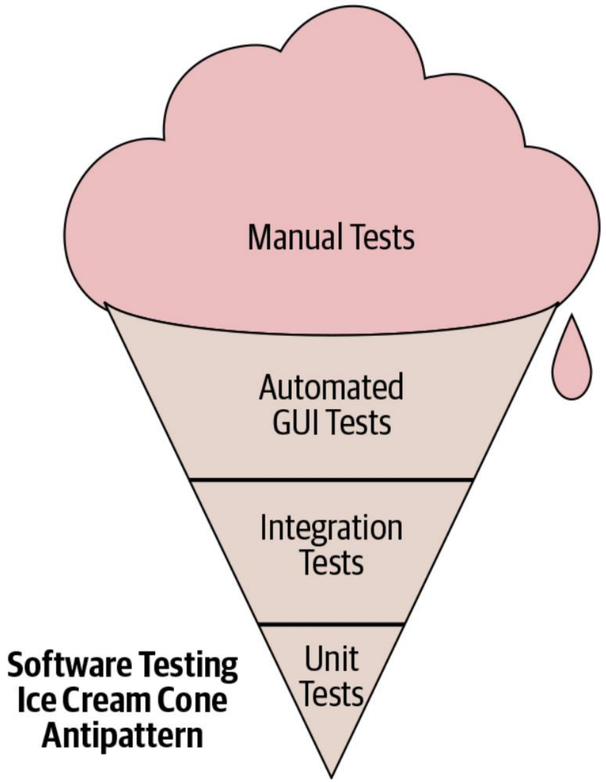


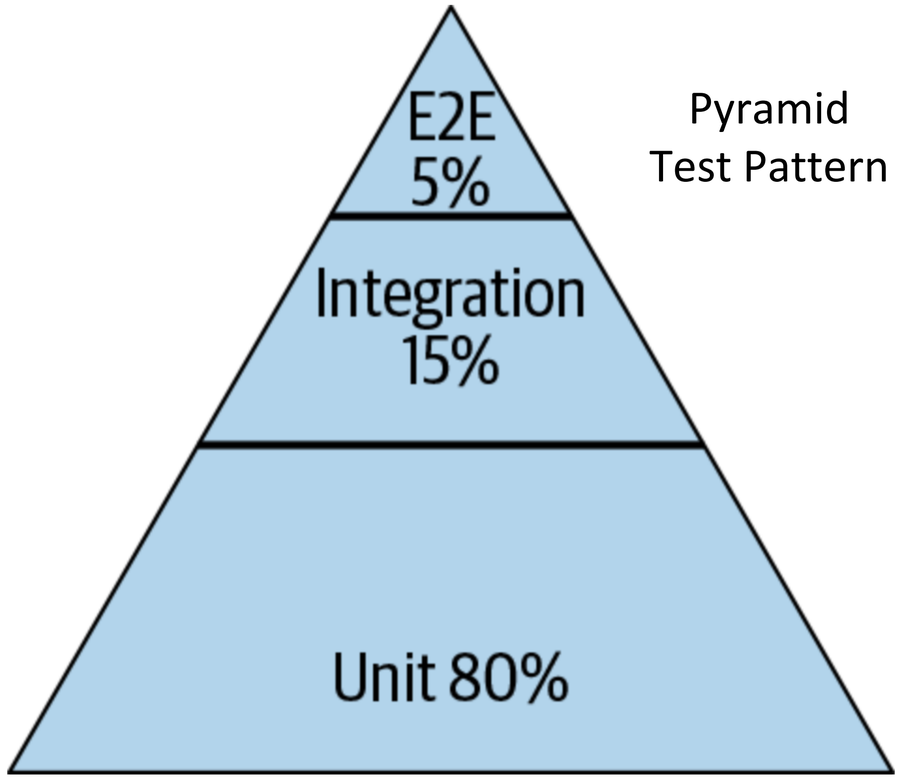
Integration tests can be done in many ways



- All at once ("Big Bang")
- Top-down
- Bottom-up
- Middle-out
- Top-Bottom-Middle
- etc., etc., etc.

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





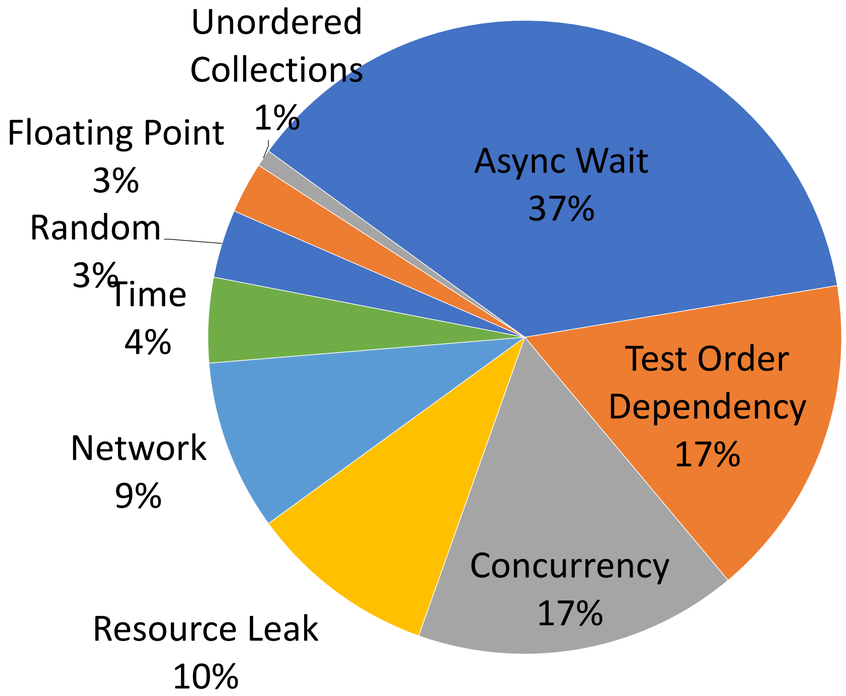
Pyramid Test Pattern

From SoftEng @ Google Chapter 11

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

Integration Tests can be Flaky

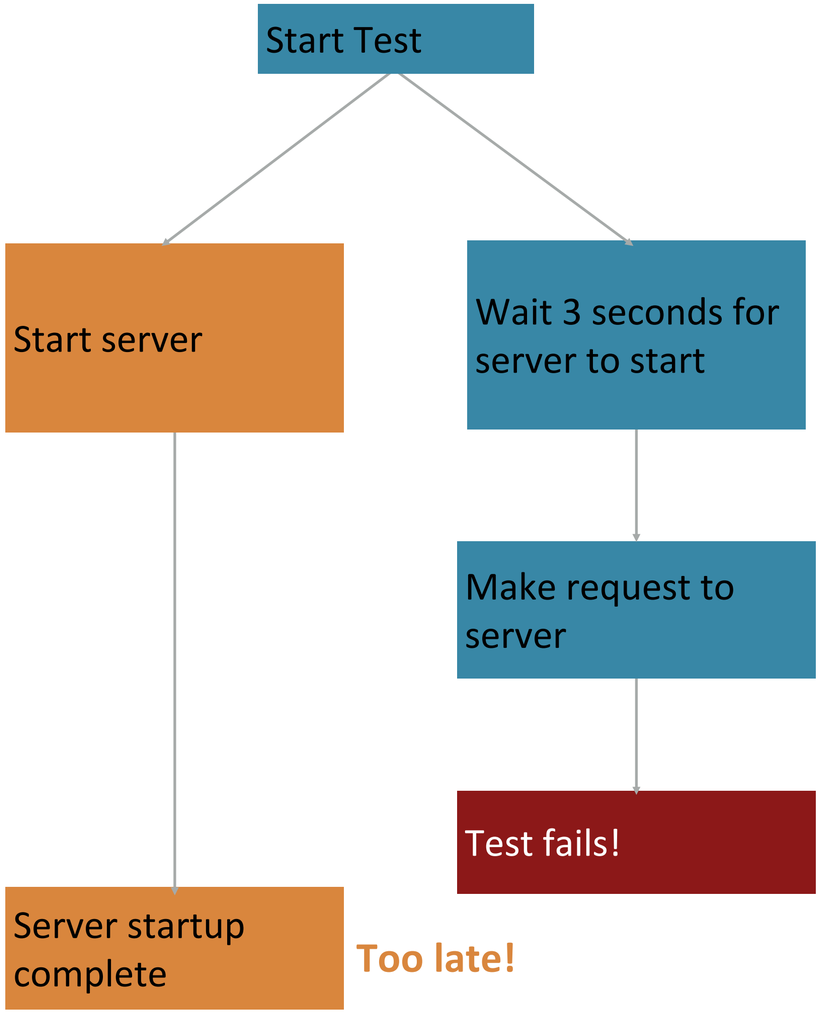
- Flaky test failures are false alarms
- Most common cause of flaky test failures: “async wait” - tests that expect some asynchronous action to occur within a timeout
- UI Testing is often flaky and slower
- Good tests avoid relying on timing
- Good tests avoid relying on the order in which the tests are run



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

Flaky Test Example: Async/Wait

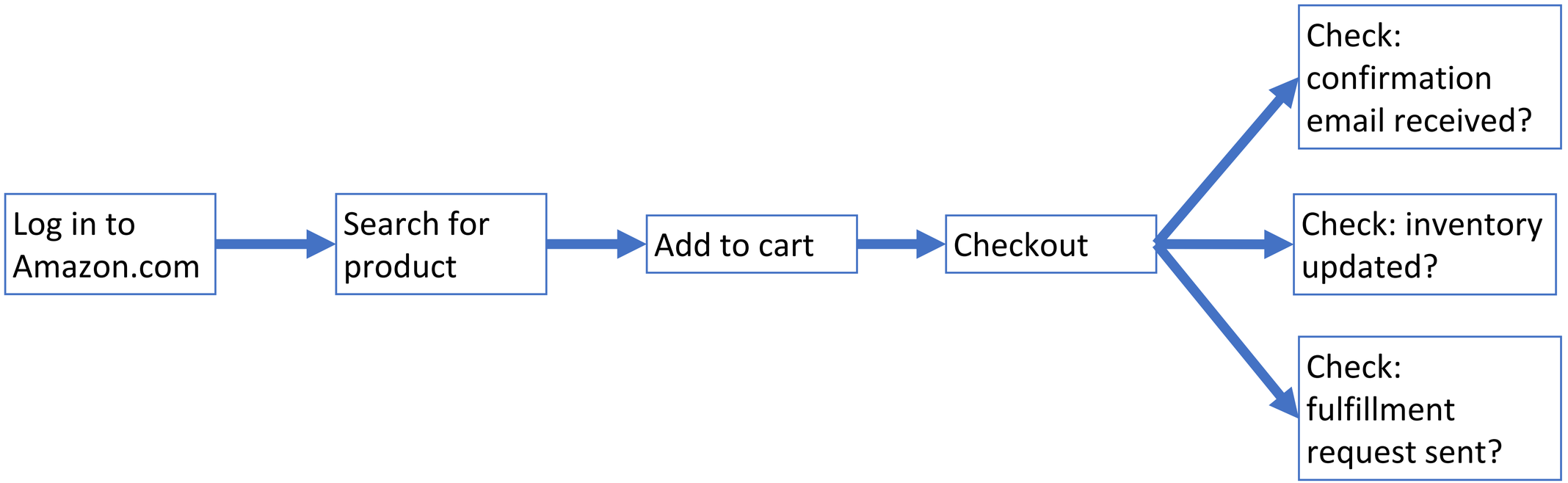
- Most common root cause of flakiness
- Difficult to avoid, but there are mitigations:
  - Have more “small” tests that don’t require concurrency
  - Ensure sufficient resources available for running tests
  - Embed reasonable error detection to classify test failures as likely to be “flaky” vs true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



Avoiding the GUI can help reduce flakiness

- GUI makes your tests slow.
- To help reduce flakiness:
  - find a way to fire real HTTP requests without the browser (e.g., supertest library)
  - actual dependencies instead of mocks
  - Setup the test data before every test

“End-to-End” Tests can be Enormous



- Most effective end-to-end tests focus on high value user interactions (UI Testing)

Acceptance Testing

Acceptance Tests can be formulated as scenarios

- Acceptance tests are written to verify behavior from a user's perspective.
- The focus is on treating the application as a black-box
- Tests may be specified as given-when-then scenarios:

given there's a logged in user
and there's an article "bicycle"
when the user navigates to the "bicycle" article's detail page
and clicks the "add to basket" button
then the article "bicycle" should be in their shopping basket

https://docs.cypress.io/guides/end-to-end-testing/writing-your-first-end-to-end-test

But how to make these human-readable scenarios into executable tests?

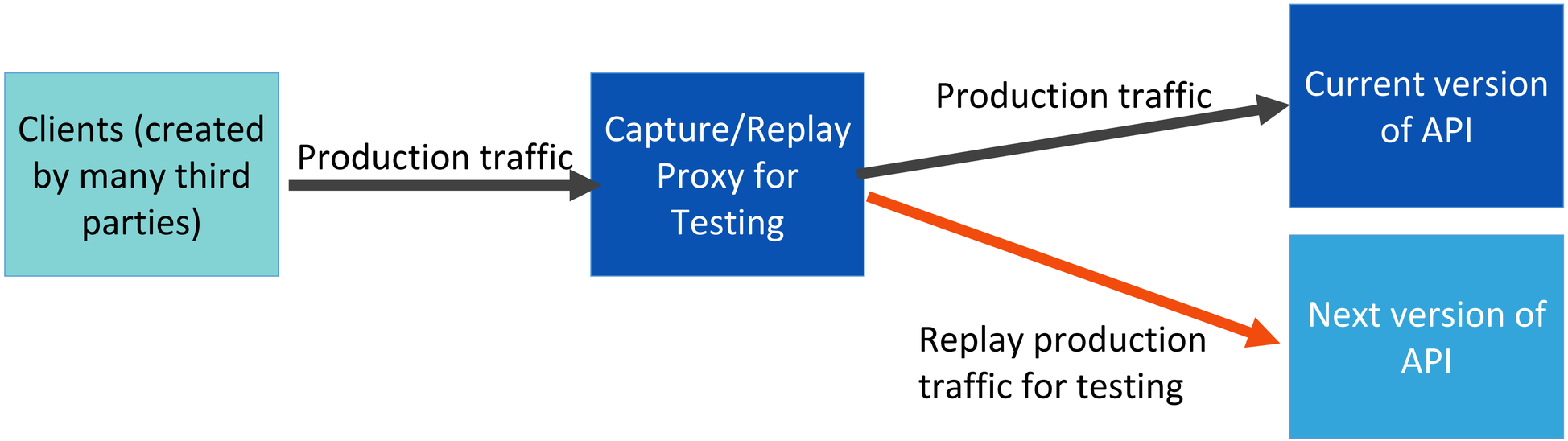
- Scenarios like the one above are readable by humans (e.g. customers)
- But they are not directly executable
- Tools like Cypress help fill this gap
  - link on module page

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")



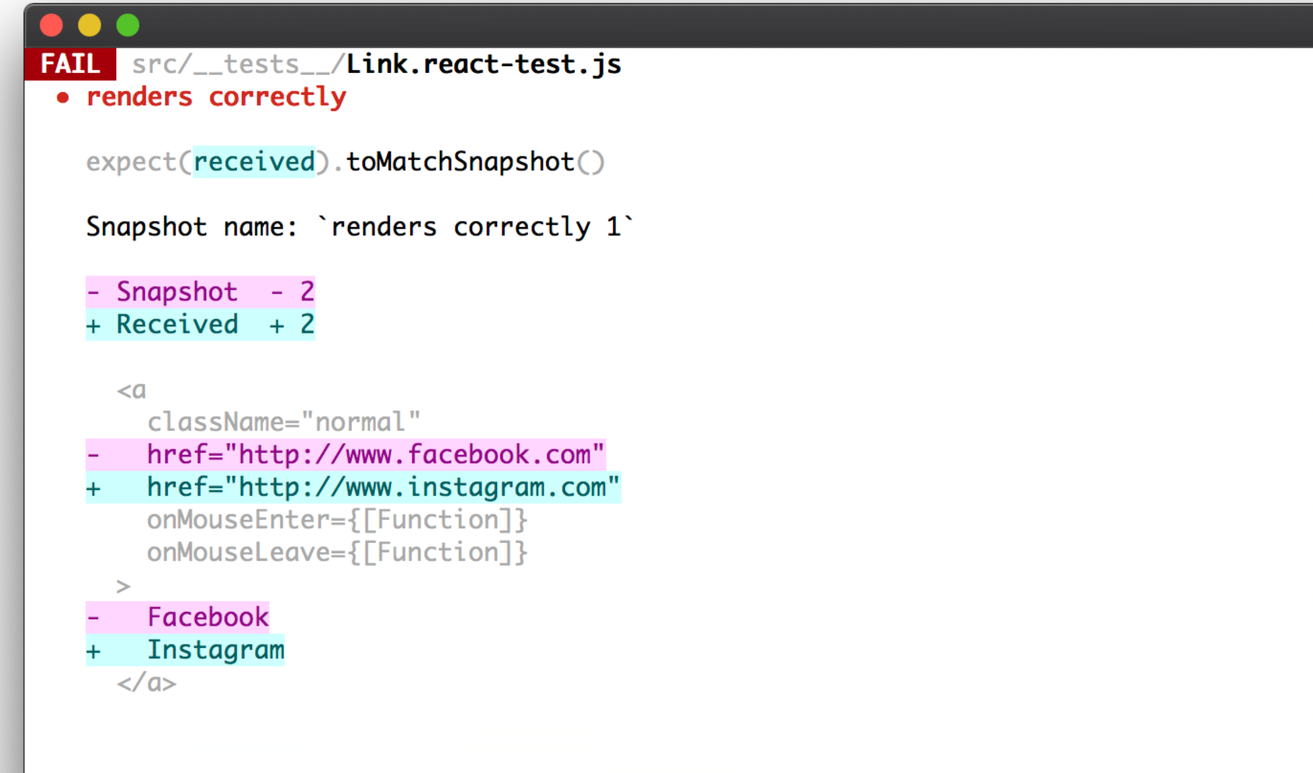
https://www.tradeweb.com/our-markets/data--reporting/replay-service/

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

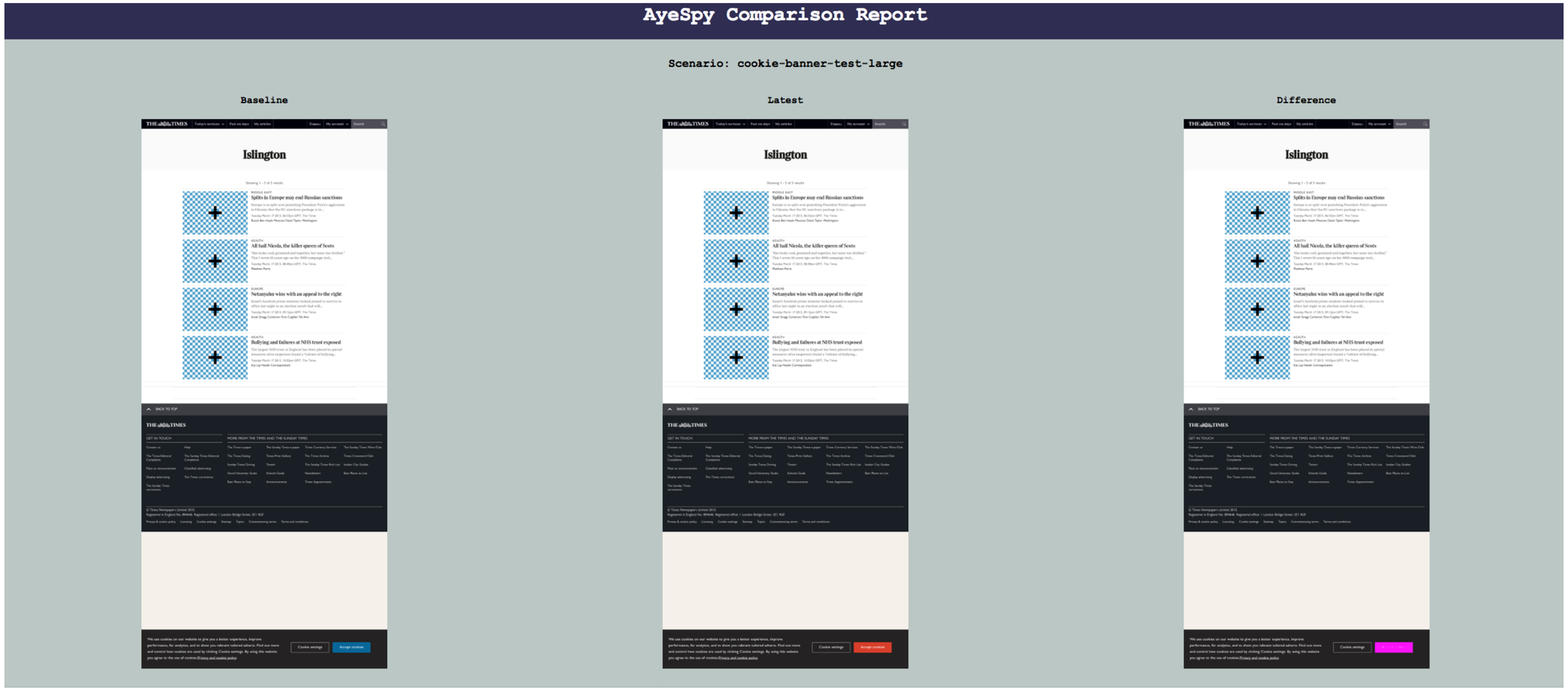
```
import renderer from 'react-test-renderer';
import Link from '../Link';

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



Product Owners can Assess Visual Snapshot Tests

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



https://github.com/newsuk/AyeSpy

Learning Objectives for this Lesson

- You should now be prepared to:
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  - 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