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

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?

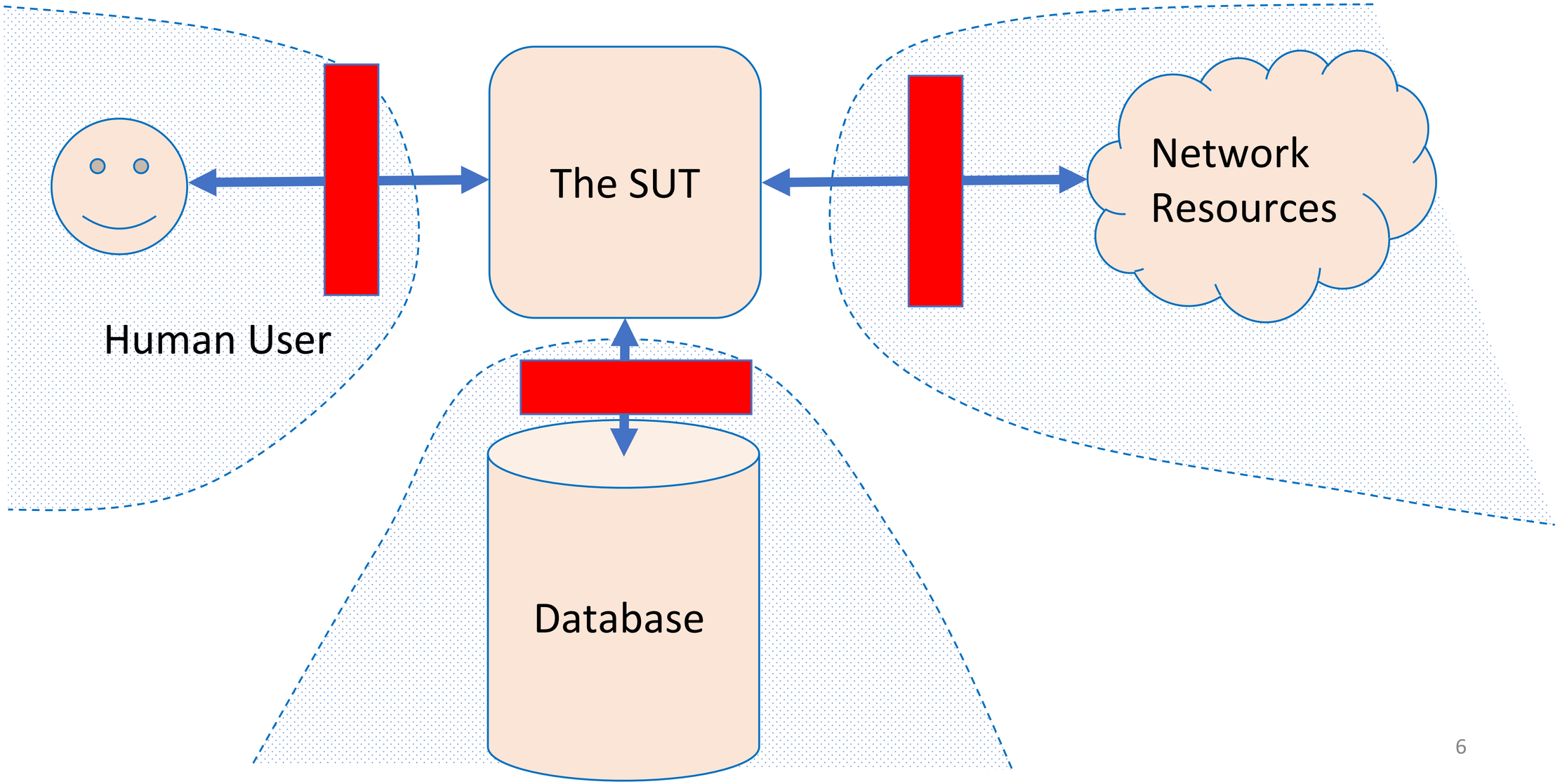
clockWithObserverPattern.test.ts

```
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” 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



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

clockWithObserverPattern.test.ts

```
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)
    })
})
```

Fake Listener: Discussion

- 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")
});
```

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);
});
```

Mock Classes and Interfaces with 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 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);
    });
});
```

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).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

Let’s mock the http client from the async module

echo.ts

```
import axios from 'axios'

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*

echo.test.ts

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

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);
        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)
    })
```

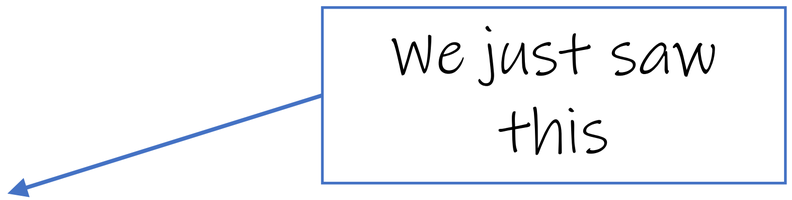
This pattern creates close coupling between the SUT and the test

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)
    })
```

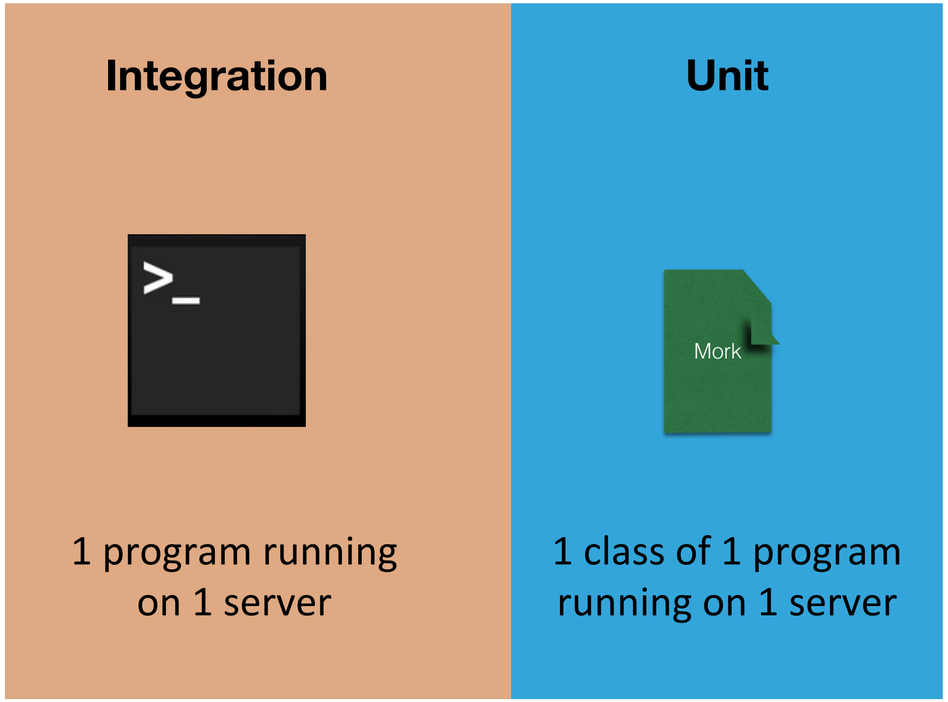
Test Doubles Have Weaknesses

- 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.



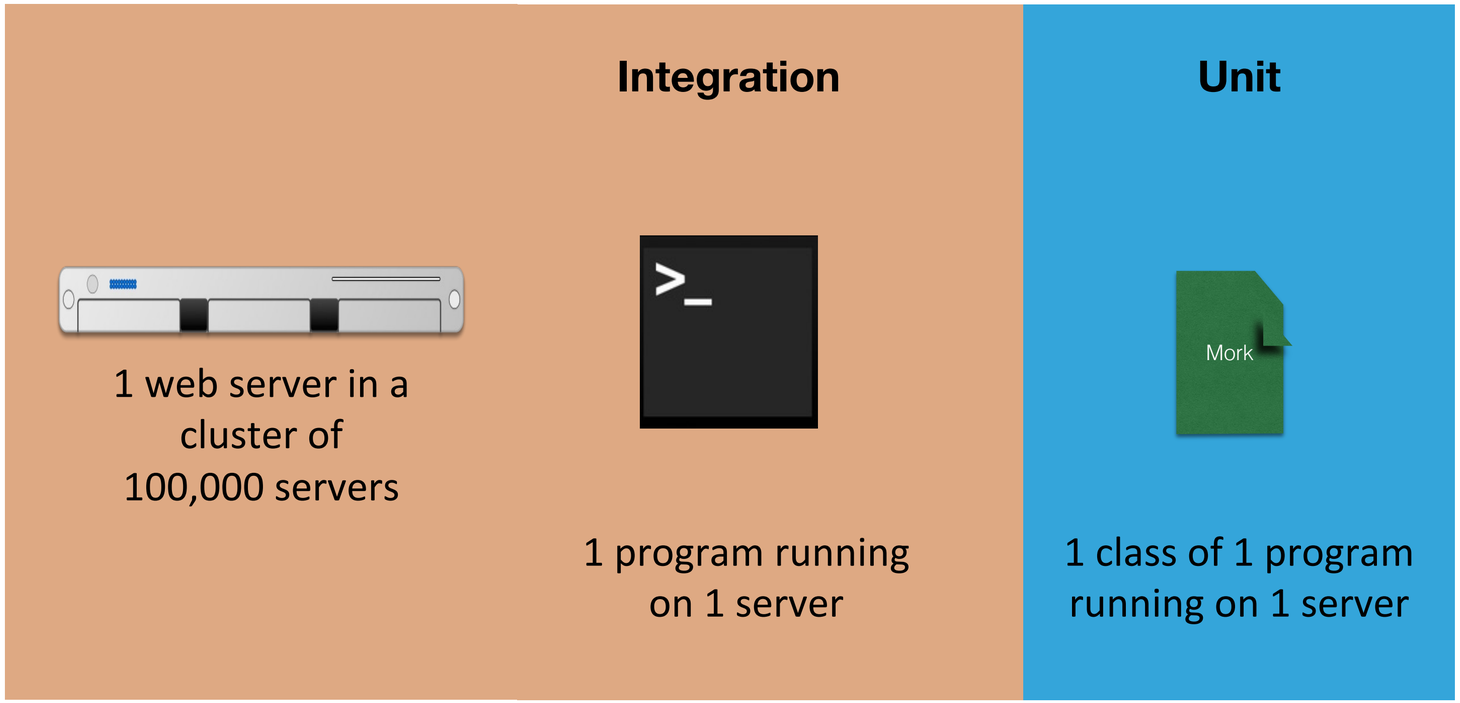
But some bugs are observable only when multiple components interact.

- 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

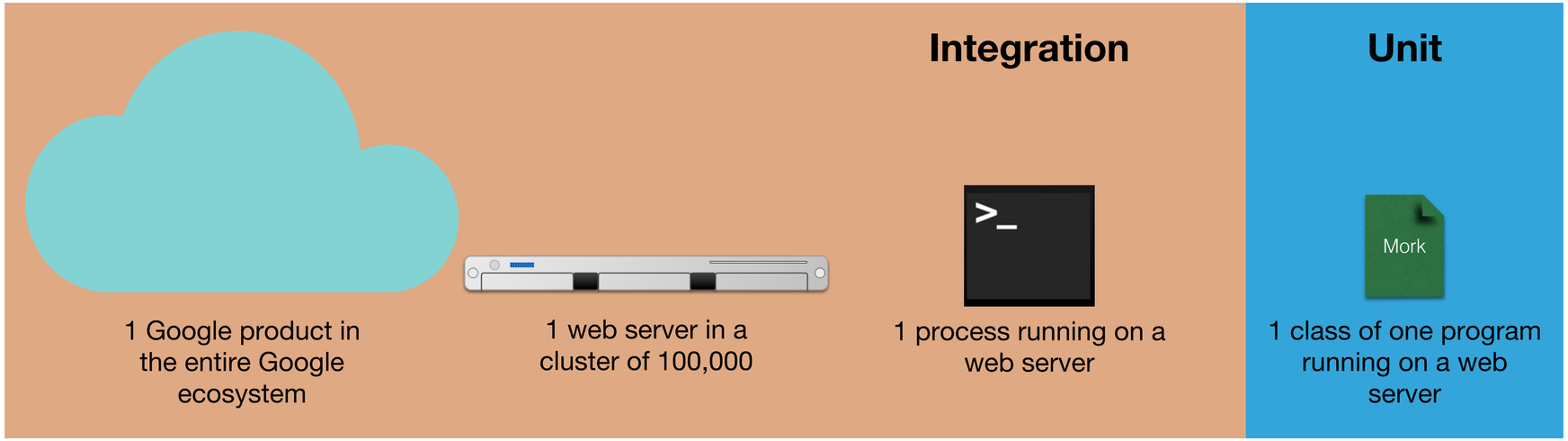


Integration tests may be larger

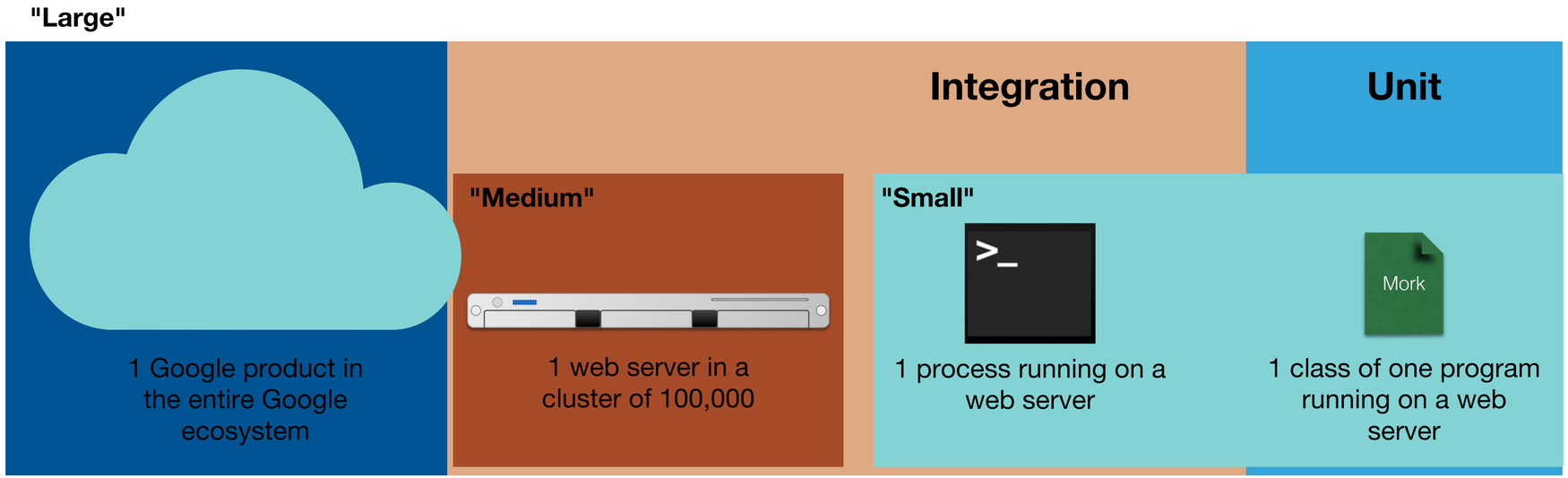
- Does the presence of other jobs on our server change the behavior of our program?
- Does the presence of the other servers change the behavior of our program?



Some Tests are Enormous



Google classifies tests by “size”



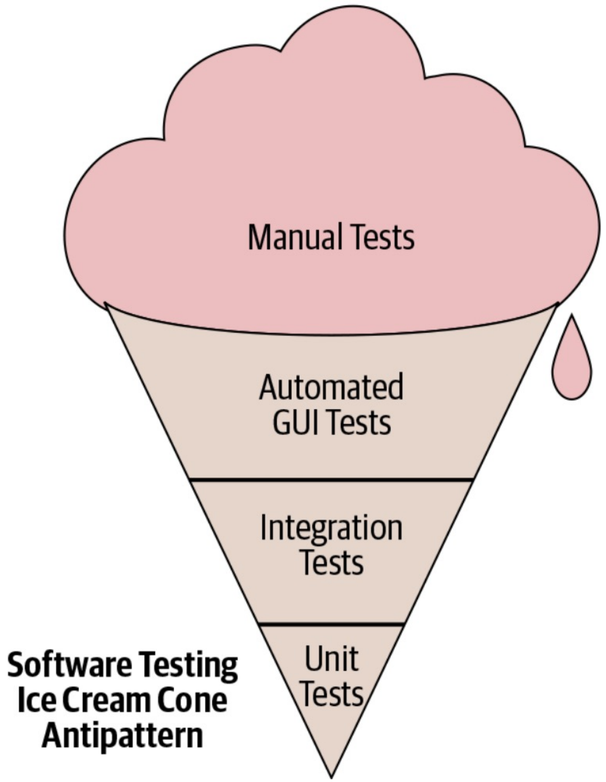
- “small” = single process
- “medium” = single machine
- “large” = bigger than that.

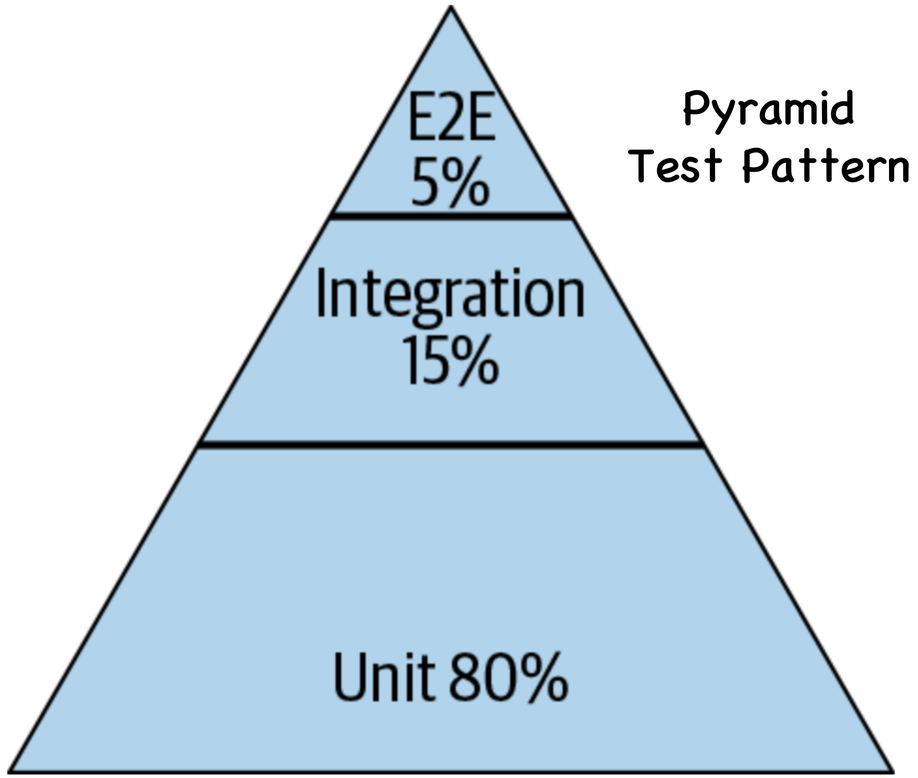
"Software Engineering at Google: Lessons Learned from Programming Over Time," Wright, Winters and Manshreck, 2020 (O’Reilly)

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?)

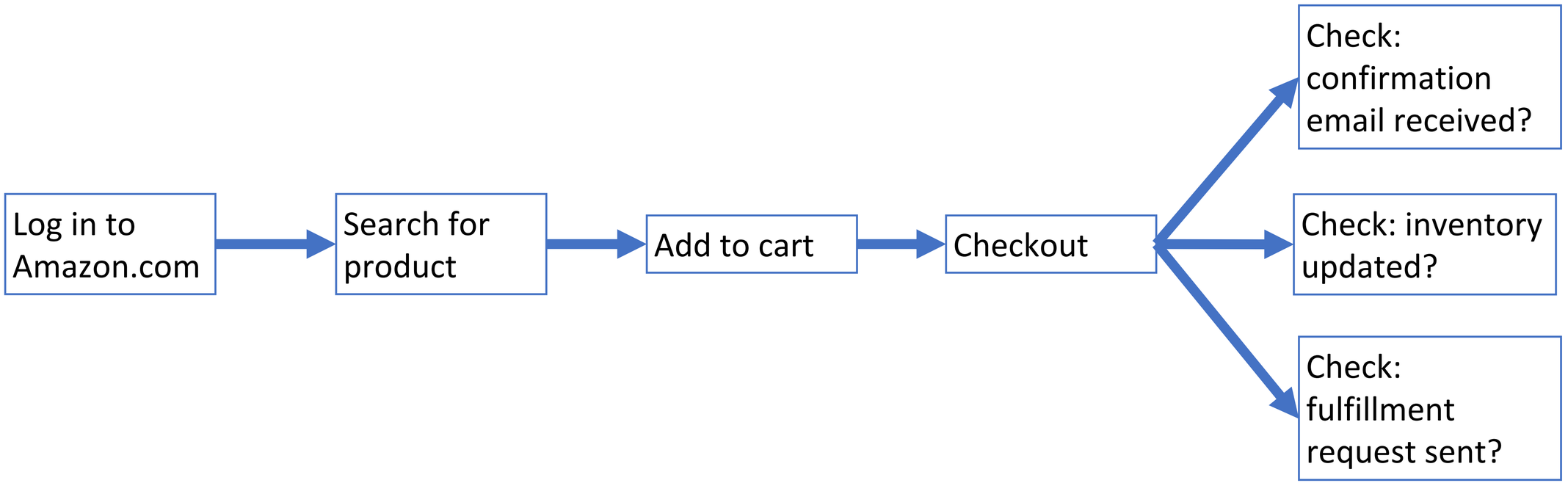




From SoftEng @ Google Chapter 11

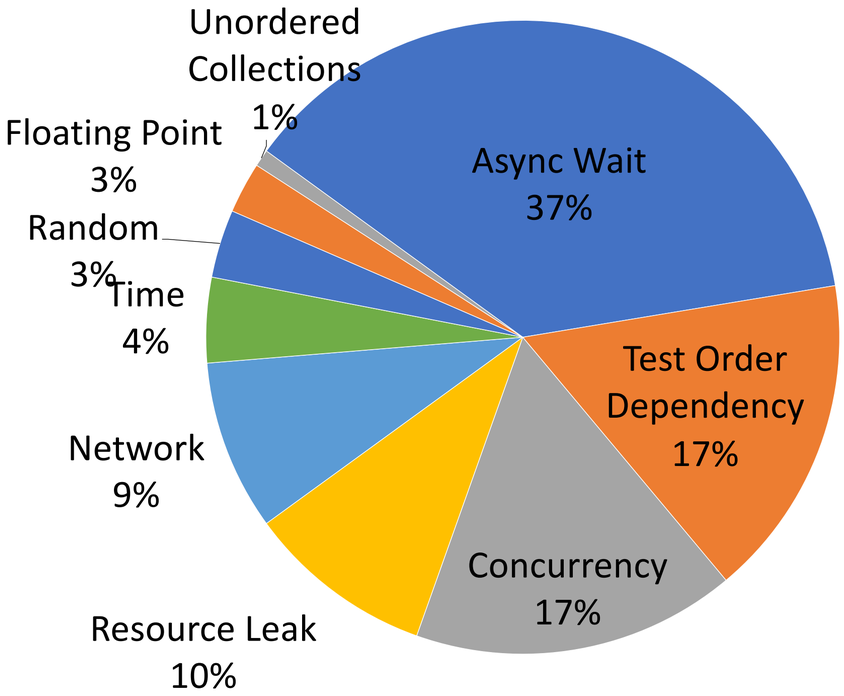
- https://learning.oreilly.com/library/view/software-engineering-at/9781492082781/ch11.html#testing_overview

“End-to-End” Tests are Enormous



Medium and Large Tests can be Flaky

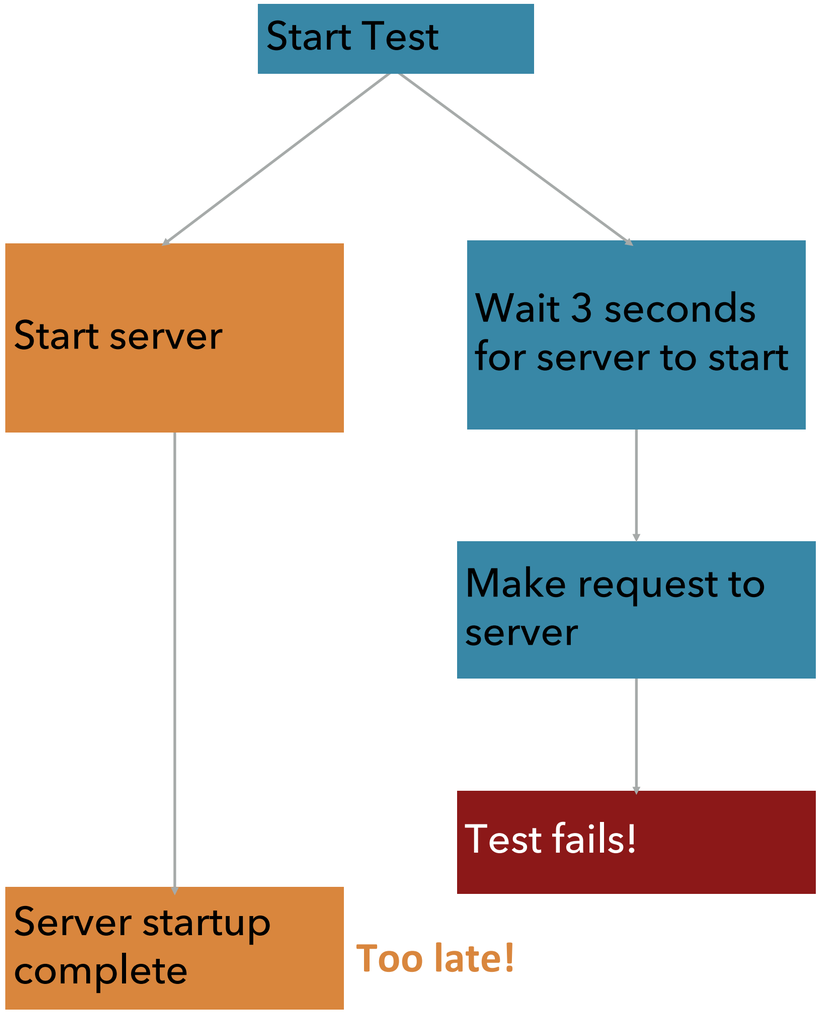
- Flaky test failures are false alarms
- Tests that are hermetic defend against “test order dependency” - failures due to tests running in other orders
- Most common cause of flaky test failures: “async wait” - tests that expect some asynchronous action to occur within a timeout
- Good tests avoid relying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

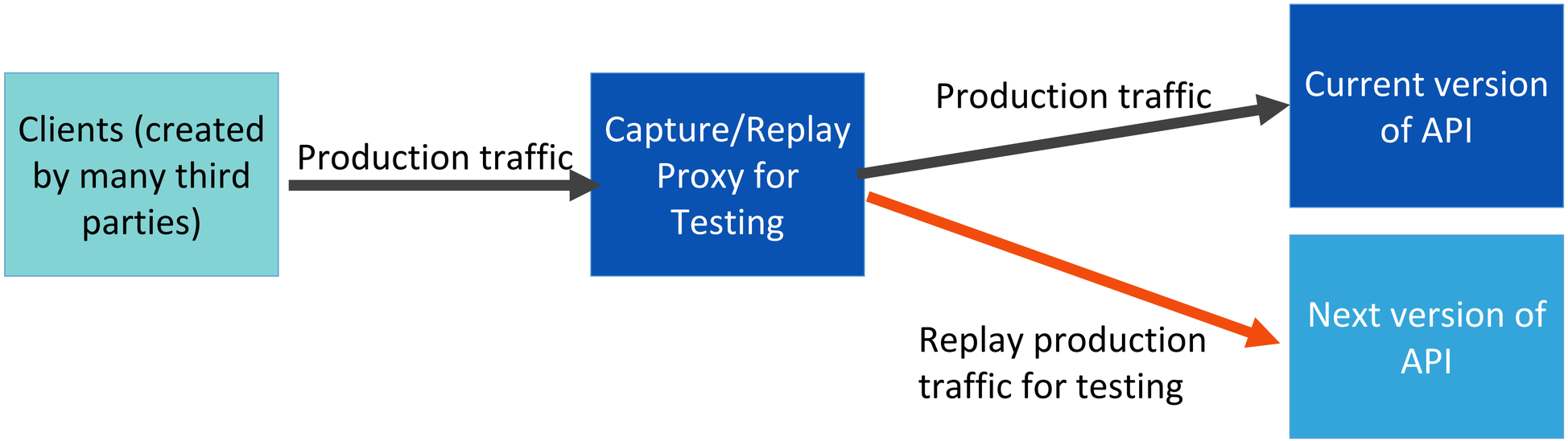


Deployed systems create even more testing challenges

- 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")



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

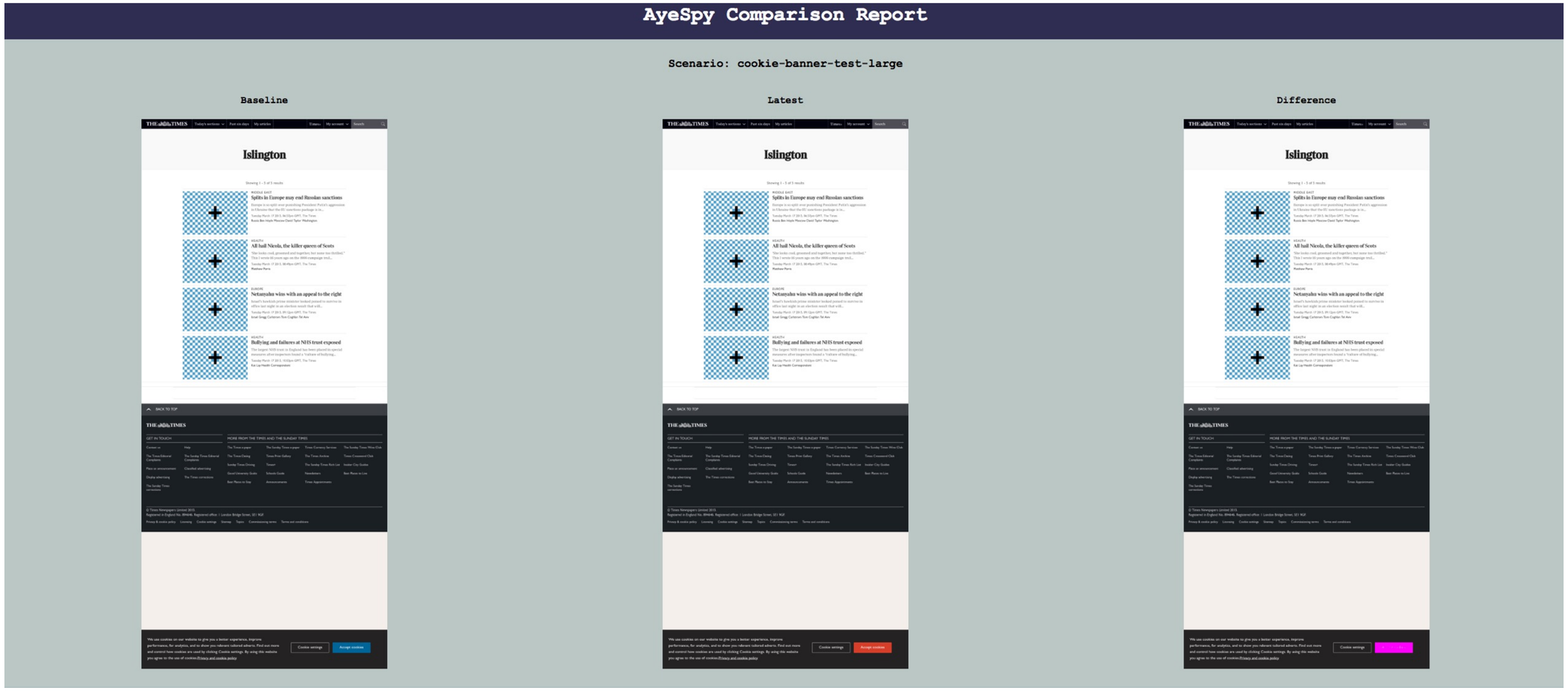
Snapshot Tests Can Detect GUI Changes

- 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 tests that are larger than unit tests
  - Explain how large, deployed systems lead to additional testing challenges