"Approaches and tools for Automated E2E testing of web applications"

A multi-perspective analysis during software evolution

Andrea Stocco
UBC
astocco@ece.ubc.ca

The World “Wild” Web

The World “Wild” Web

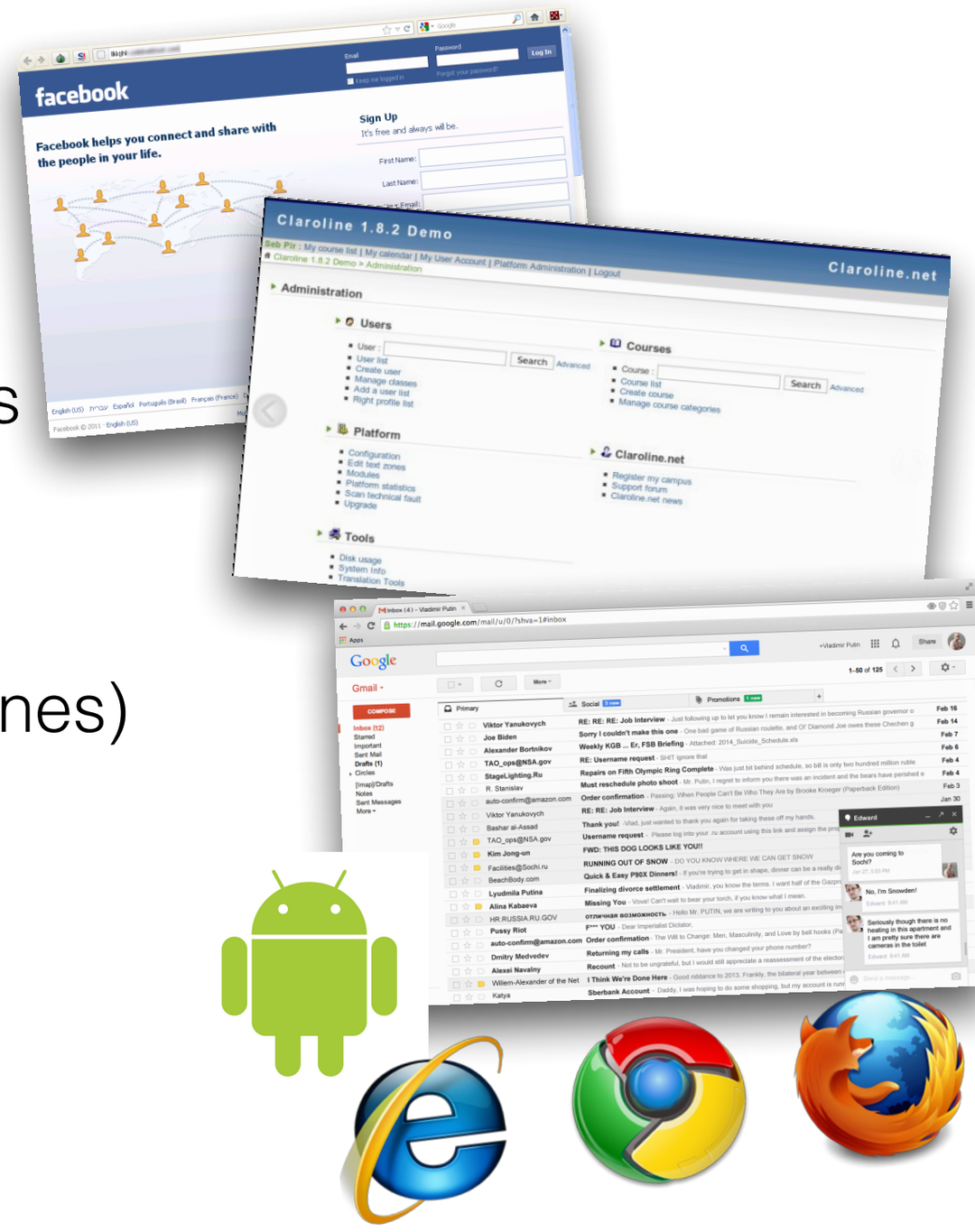
What does make a web application unique?

Is testing web apps different than testing a desktop app?

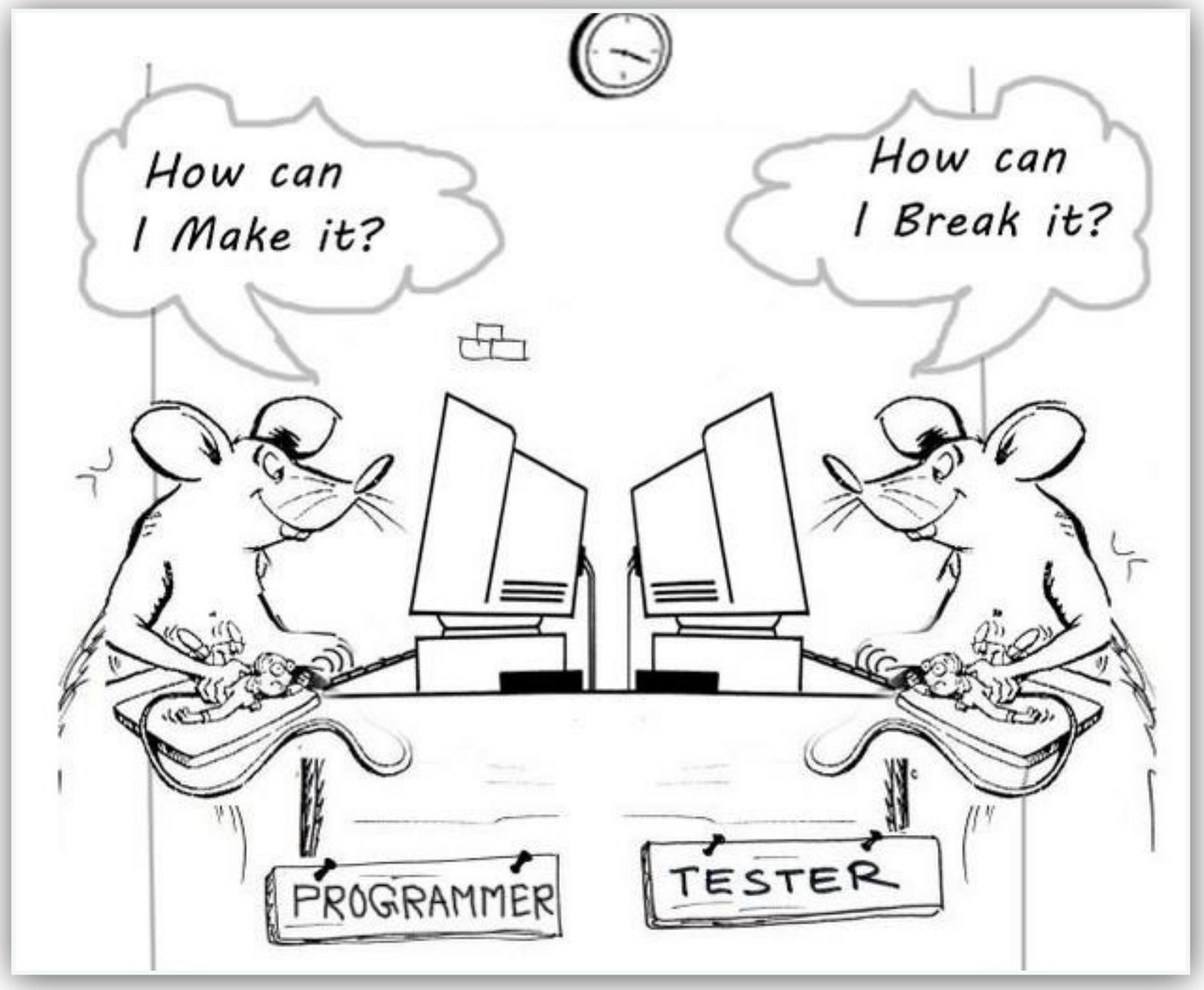
What makes testing web apps complex?

Modern Web Applications

- complex **infrastructure**
- integration of **different** technologies
- **asynchronous** interactions
- **different** platforms (web, smartphones)
- used by billions of people
- **ultra-rapid** evolution



Web Development vs Testing



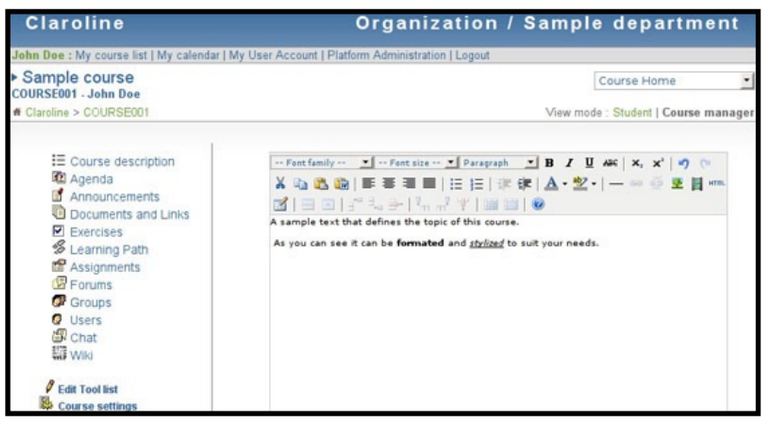
SELENIUM

- open-source web browser automation tool
- widely-used worldwide
- C#, Groovy, Java, Perl, PHP, Python, Ruby and Scala
- WebDriver protocol has become W3C standard

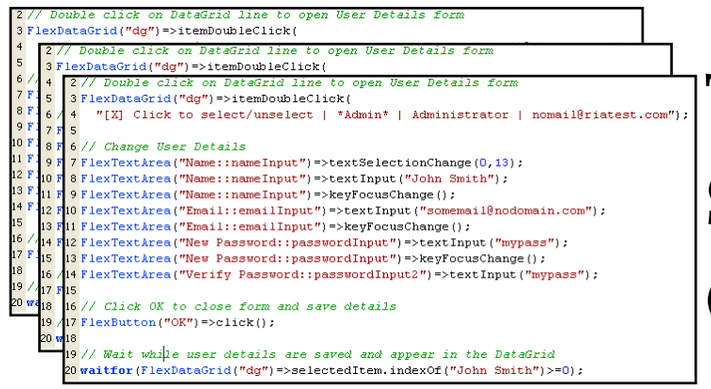
  https://www.w3.org/TR/webdriver1/

Functional Test Automation

Web App



Functional Requirements Analysis



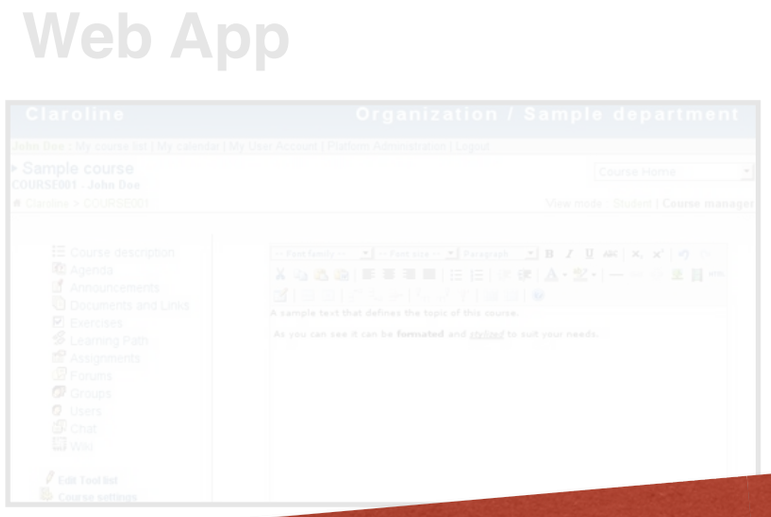
Test Scripts Creation

Test Scripts Automation

Test Results

Bug Reports

Functional Test Automation



Functional Requirements Analysis

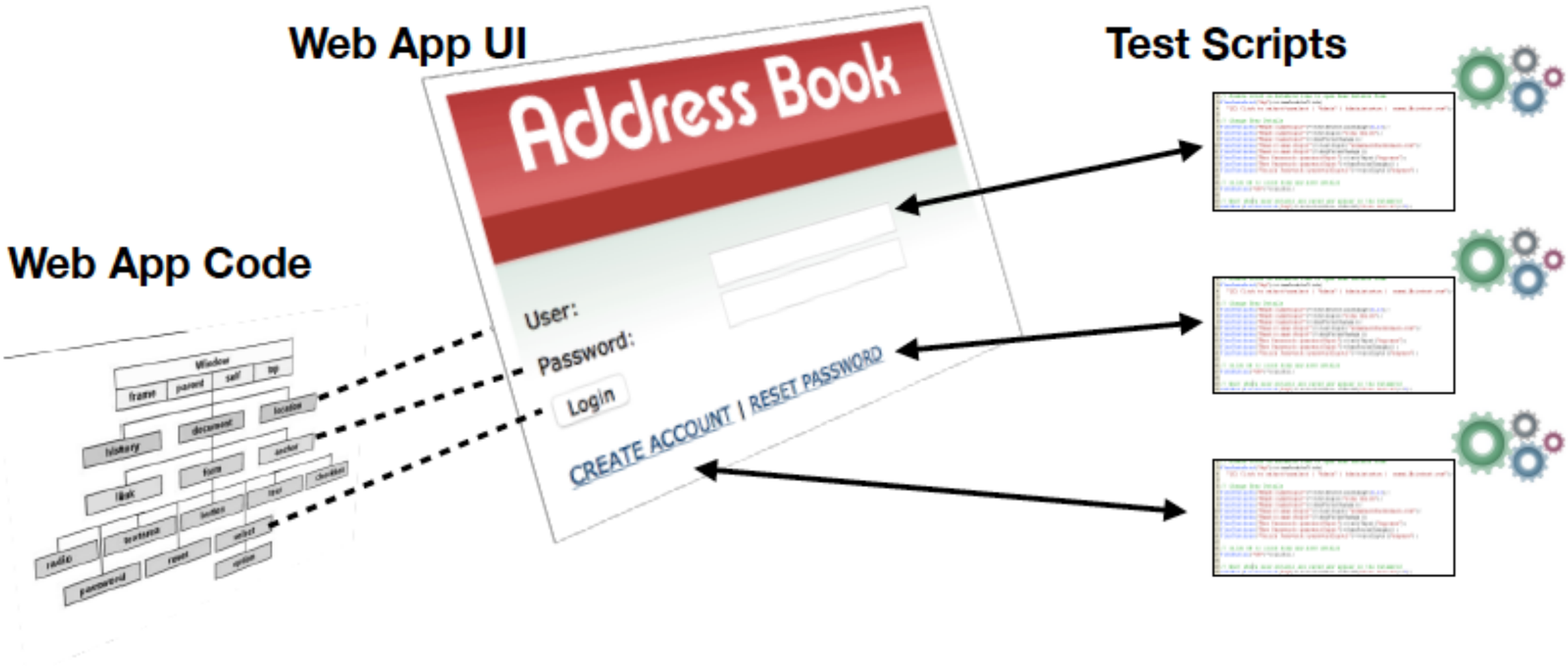
Test Scripts Automation

Test Results

Bug Reports

Why have such tools focused at the E2E (GUI) level?

E2E Test Automation



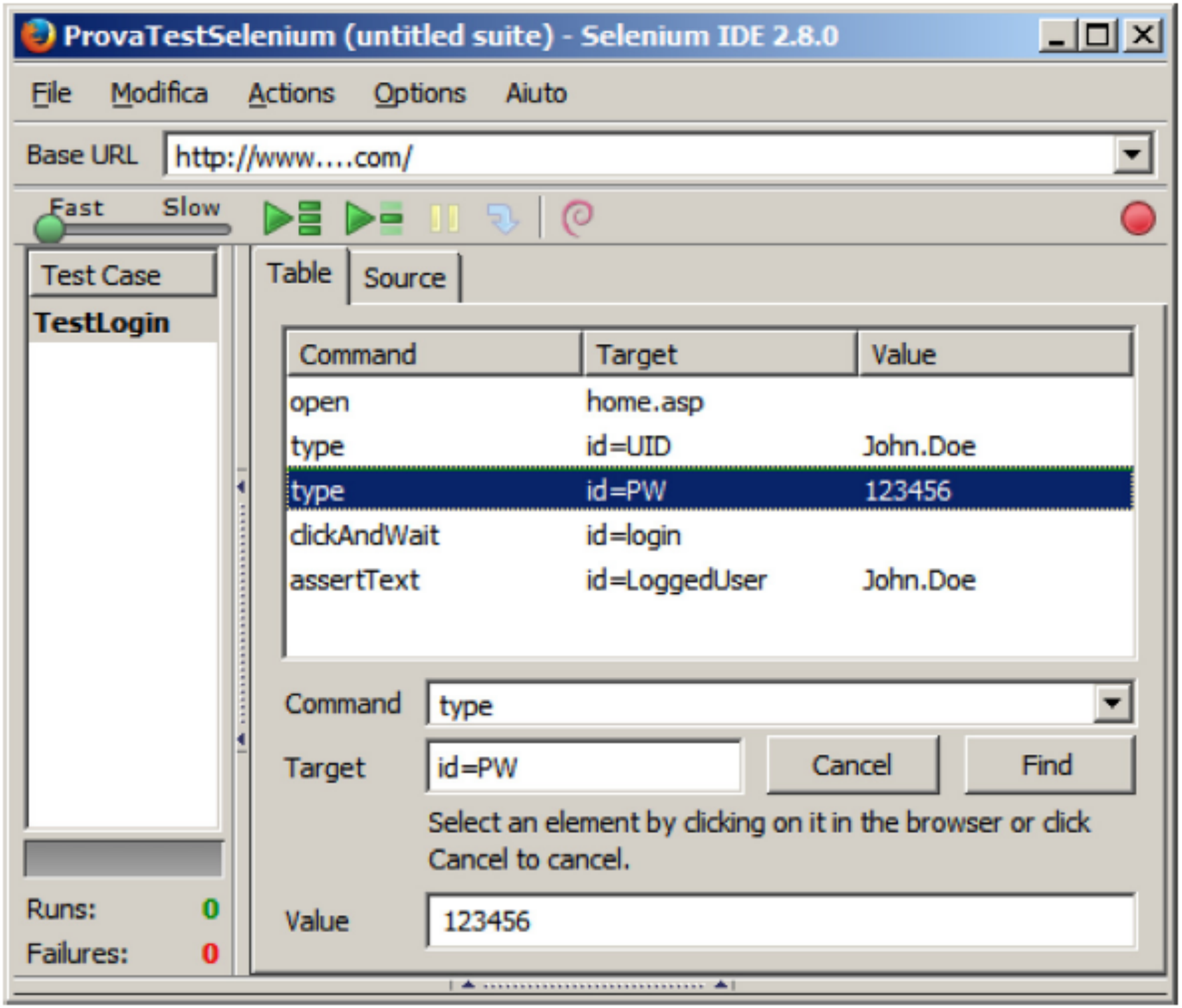
Approaches to E2E Test Automation

		Development of test cases	
		Capture & Replay	**Programmable**
Element Localization	**coordinates (1st gen)**	-	-
	DOM-based (2nd gen)	Selenium IDE	Selenium WebDriver
	Visual (3rd gen)	SikuliX, JAutomate	SikuliDriver

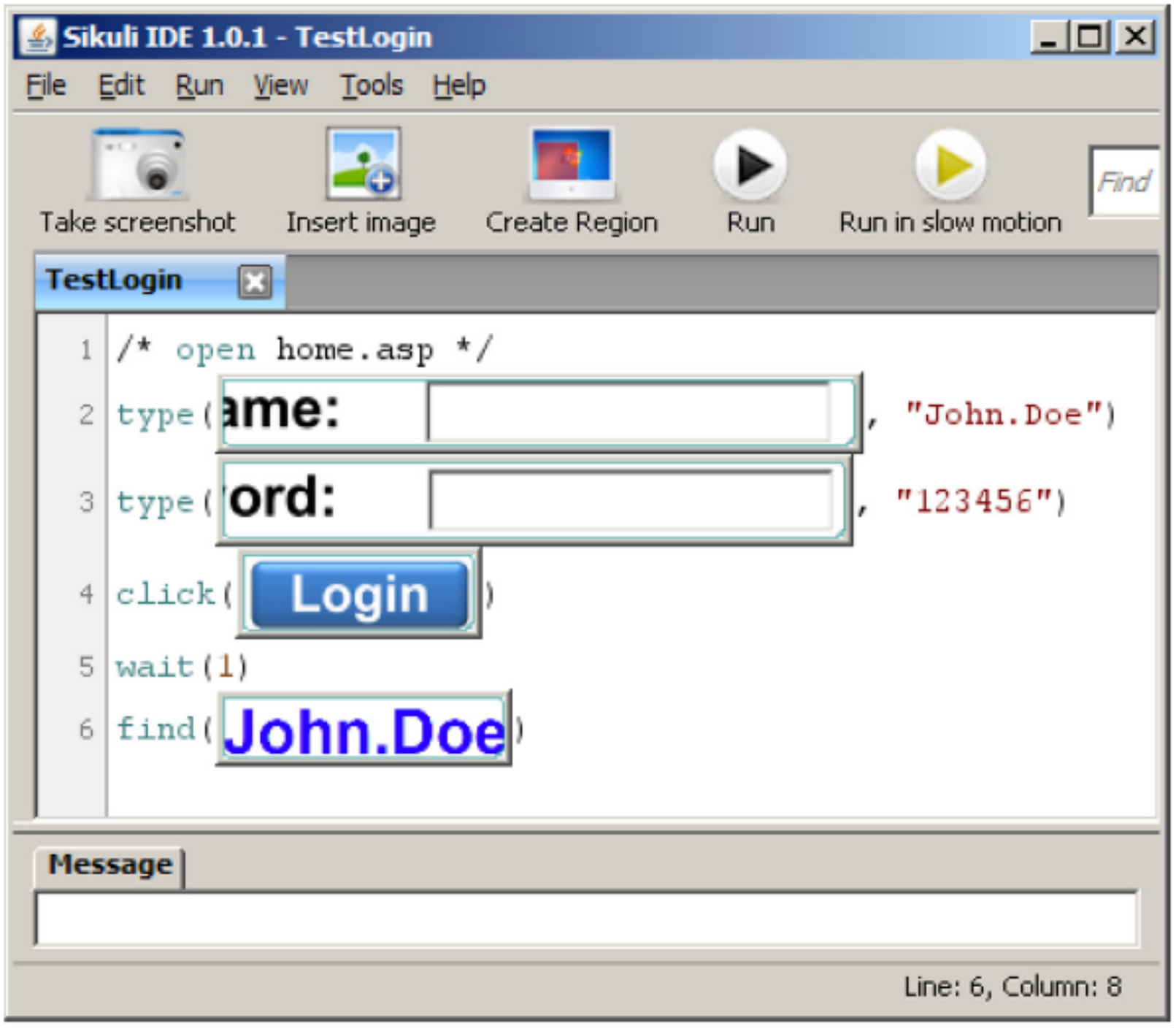
Approaches to E2E Test Automation

Element Localization	Development of test cases: Capture & Replay	Development of test cases: Programmable
coordinates (1st gen)	-	-
DOM-based (2nd gen)	Selenium IDE	Selenium WebDriver
Visual (3rd gen)	SikuliX, JAutomate	SikuliDriver

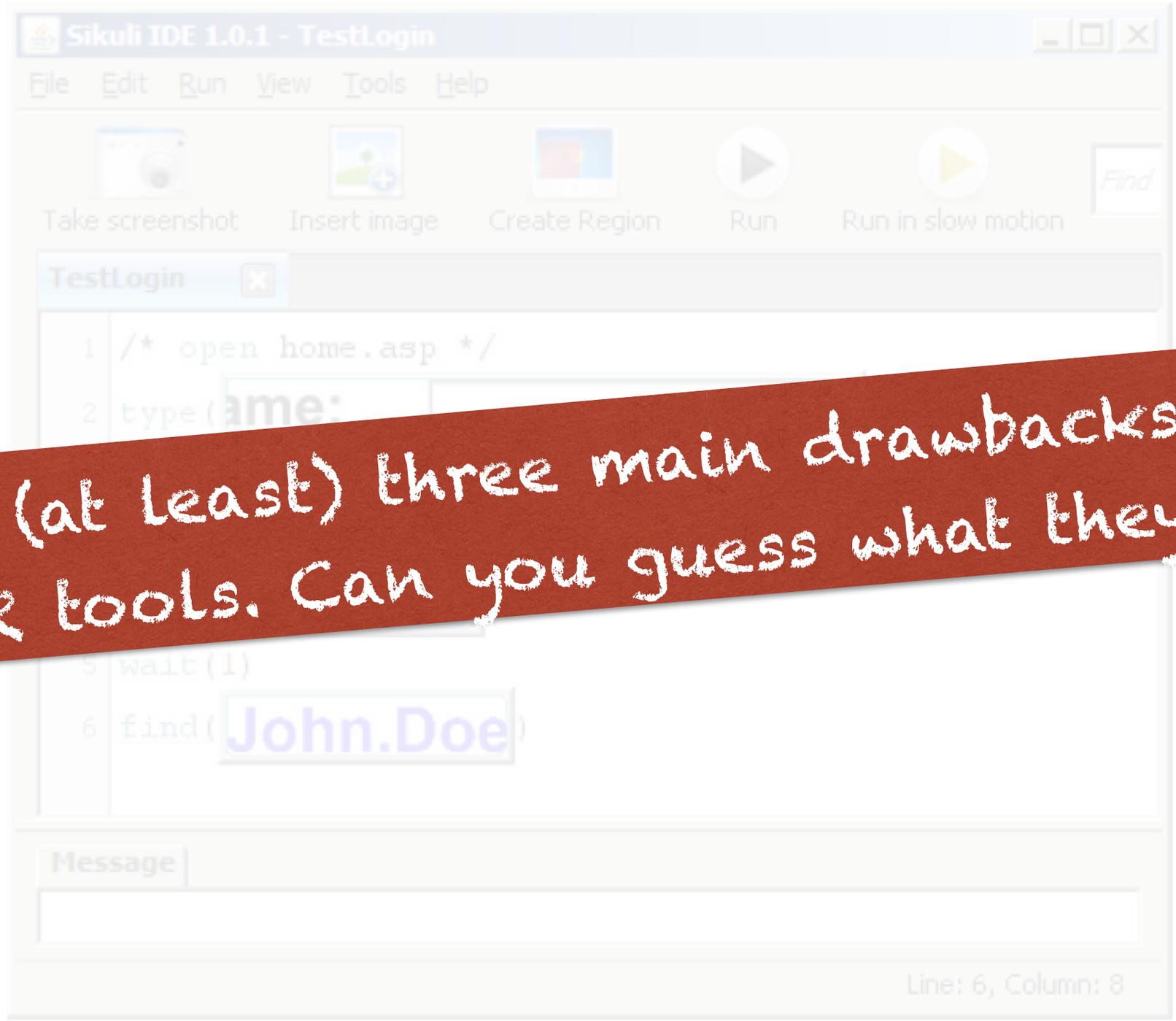
(DOM) Capture & Replay



(Visual) Capture & Replay



(Visual) Capture & Replay



There are (at least) three main drawbacks related to C&R tools. Can you guess what they are?

Capture & Replay Drawbacks

Hard-code values

open	home.asp	
type	id=UID	John.Doe
type	id=PW	123456
clickAndWait	id=login	
assertText	id=LoggedUser	John.Doe

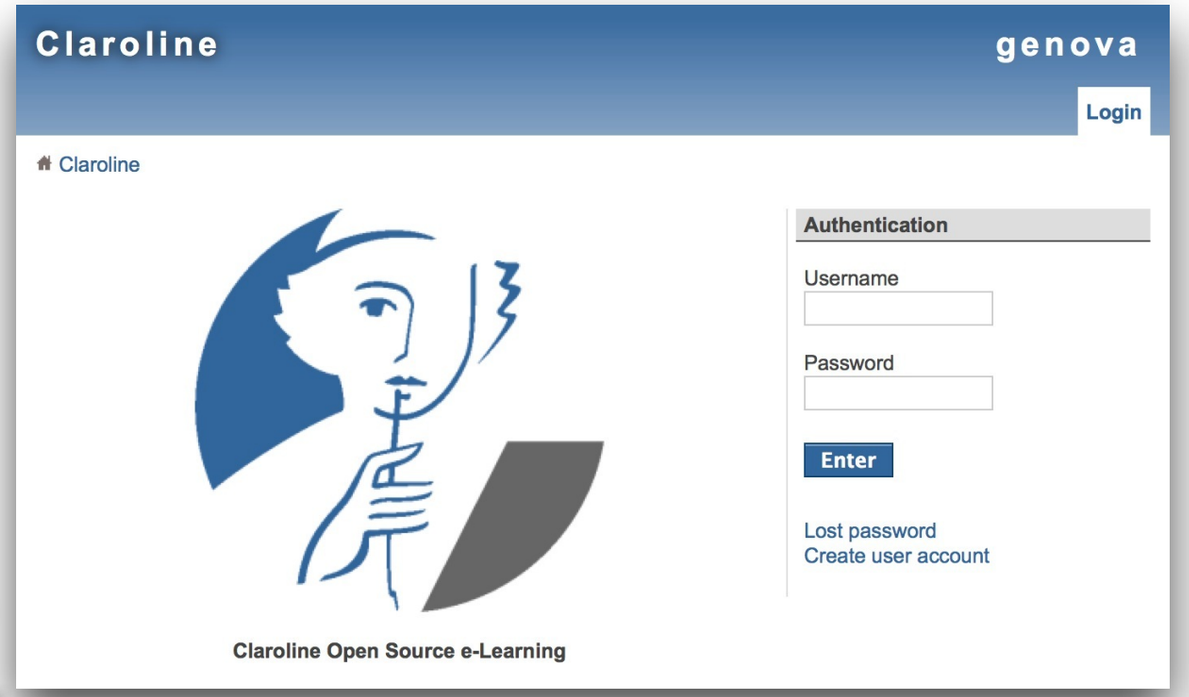
Strong coupling

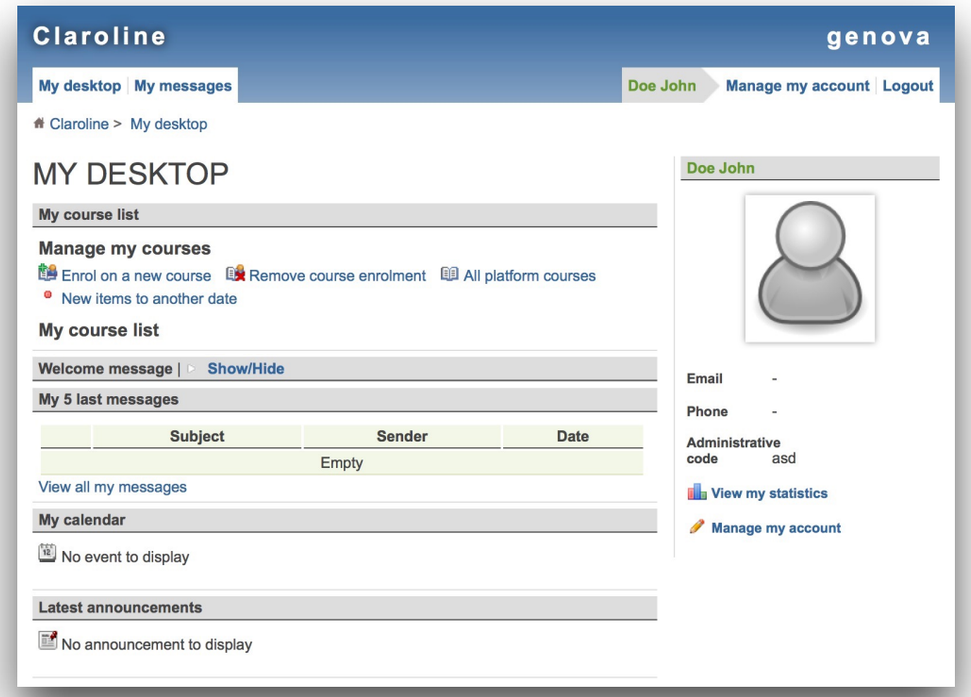
Duplicated code

Approaches to E2E Test Automation

Element Localization	Development of test cases: Capture & Replay	Development of test cases: Programmable
coordinates (1st gen)	-	-
DOM-based (2nd gen)	Selenium IDE	Selenium WebDriver
Visual (3rd gen)	SikuliX, JAutomate	SikuliDriver

(DOM) Programmable





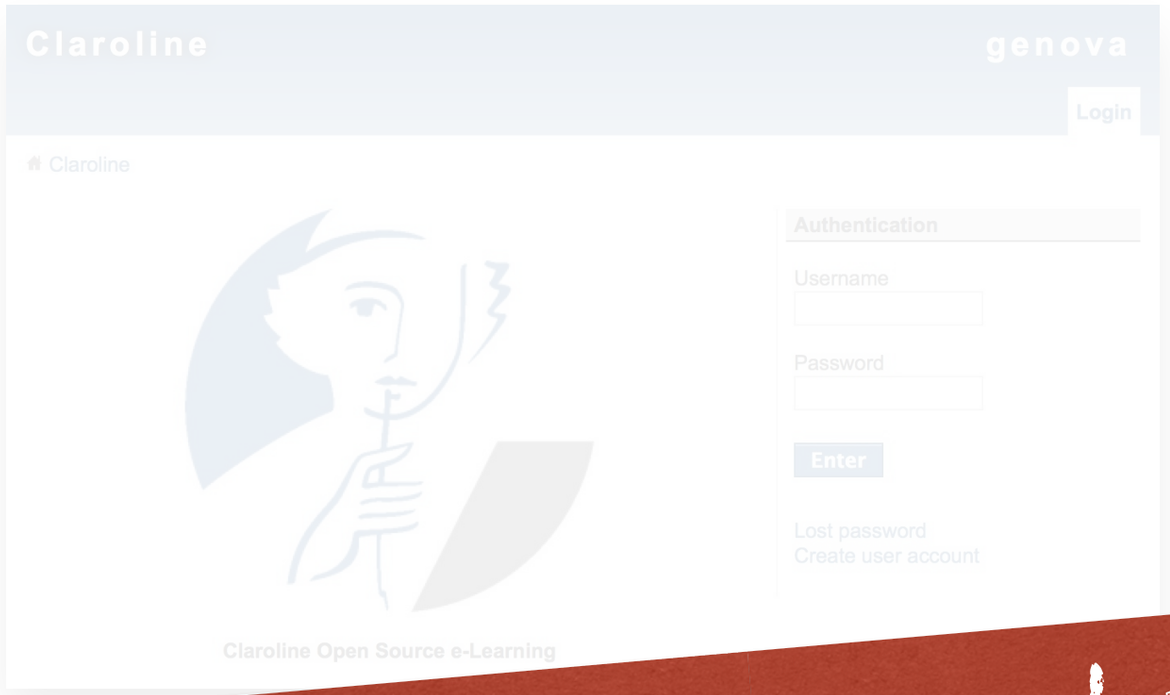

```
public class Login {
  @Test
  public void testLogin() {
    WebDriver driver = new FirefoxDriver();
    driver.get("http://localhost/claroline1115/index.php");
    driver.findElement(By.Id(id="user")).sendKeys("John Doe");
    driver.findElement(By.XPath("xpath="//form/input[2]")).sendKeys("securepassword");
    driver.findElement(By.LinkText(linkText="Enter")).click();
    Assert.assertEquals(driver.findElement(By.Id("John Doe")), "Login was successful");
   }
}
```

Browser specific

UI specific

Manipulation specific

(DOM) Programmable



What are the main advantages brought by programmable tools w.r.t. C&R tools?

```
public
  @Tes
  public                                    () {
    WebDriver driver = new FirefoxDriver();
    driver.get("http://localhost/claroline1115/index.php");
    driver.findElement(By.Id(id="user")).sendKeys("John Doe");
    driver.findElement(By.XPath("xpath="//form/input[2]")).sendKeys("securepassword");
    driver.findElement(By.LinkText(linkText="Enter")).click();
    Assert.assertEquals(driver.findElement(By.Id("John Doe")), "Login was successful");
  }
}
```

UI specific

Manipulation specific

Advantages of Programmable tools

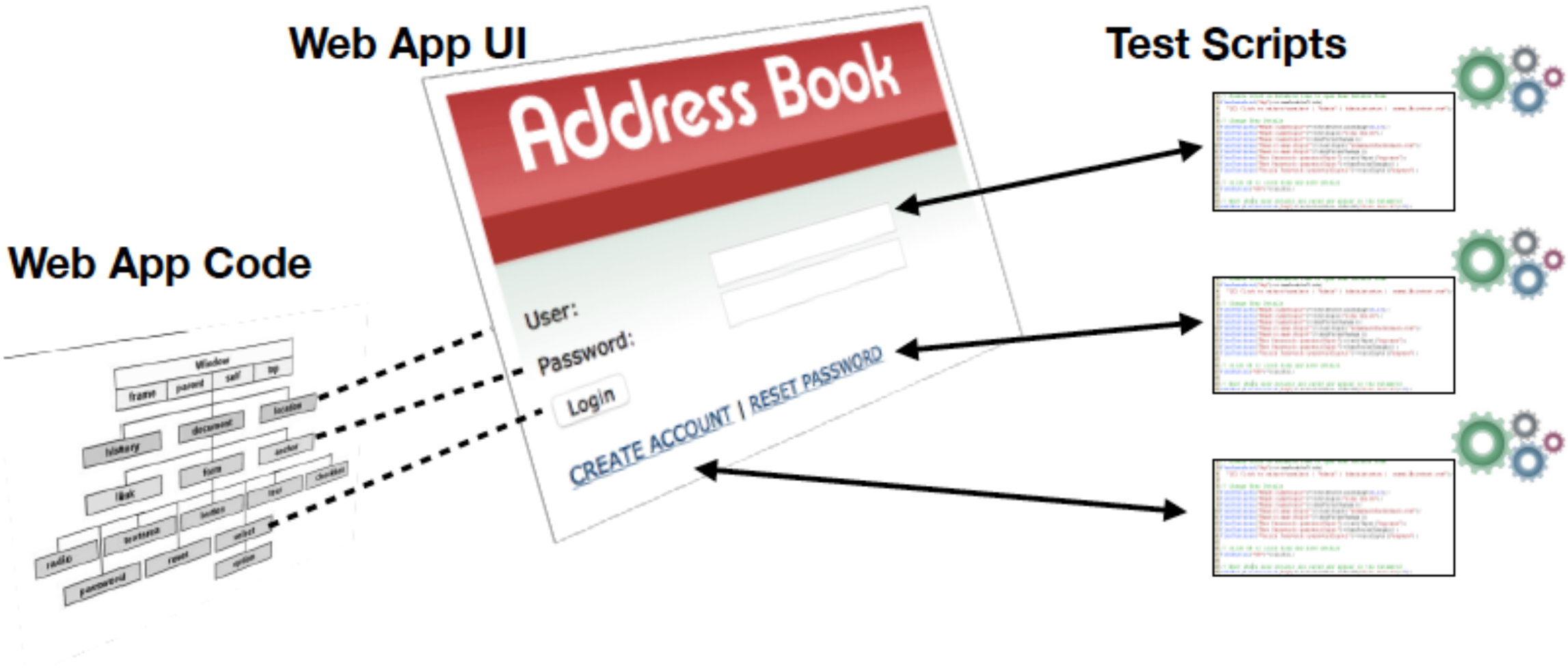
~~Hard-code values~~ **Data-driven**

~~Strong coupling~~

Design Patterns

~~Duplicated~~ code

Naïve web testing



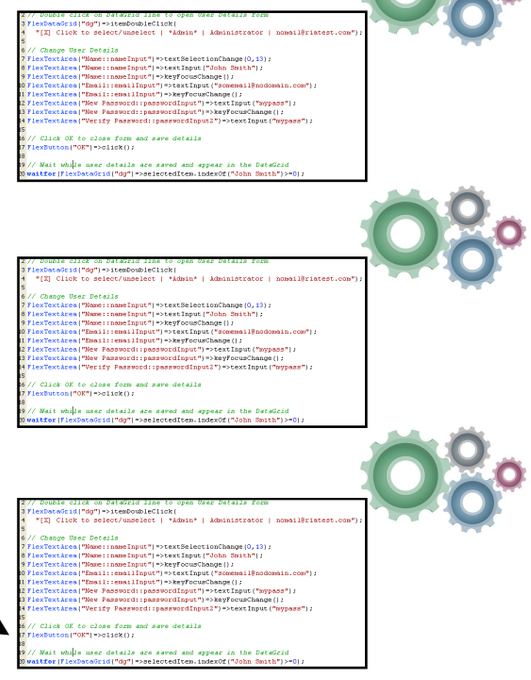
Use Page Objects!

Web App UI

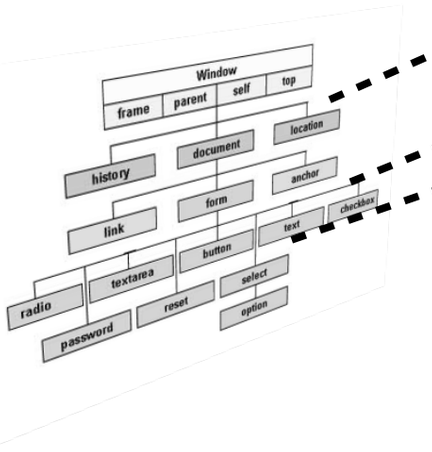
Page Object

```
public class Index {

    @FindBy(xpath = "/HTML[1]/BODY[1]/DIV[1]/DIV[4]/A[1]")
    private WebElement a_CreateAccount;
    @FindBy(xpath = "/HTML[1]/BODY[1]/DIV[1]/DIV[4]/A[2]")
    private WebElement a_Createaccount;
    @FindBy(css = "#LoginForm > input:nth-child(2)")
    private WebElement input_user;
    @FindBy(css = "#LoginForm > input:nth-child(5)")
    private WebElement input_pass;
    @FindBy(css = "#LoginForm > input:nth-child(7)")
    private WebElement input_Accesso;
    private WebDriver driver;

    public Index(WebDriver driver) {
        this.driver = driver;
        PageFactory.initElements(driver, this);
    }

    public User_Add goToUser_Add() {
        a_CreateAccount.click();
        return new User_Add(driver);
    }

    public Email_Password goToEmail_Password() {
        a_Createaccount.click();
        return new Email_Password(driver);
    }

    public Index1 goToIndex1() {
        input_Accesso.click();
        return new Index1(driver);
    }

    public void LoginForm(String args0, String args1) {
        input_user.sendKeys(args0);
        input_pass.sendKeys(args1);
        input_Accesso.click();
    }
}
```

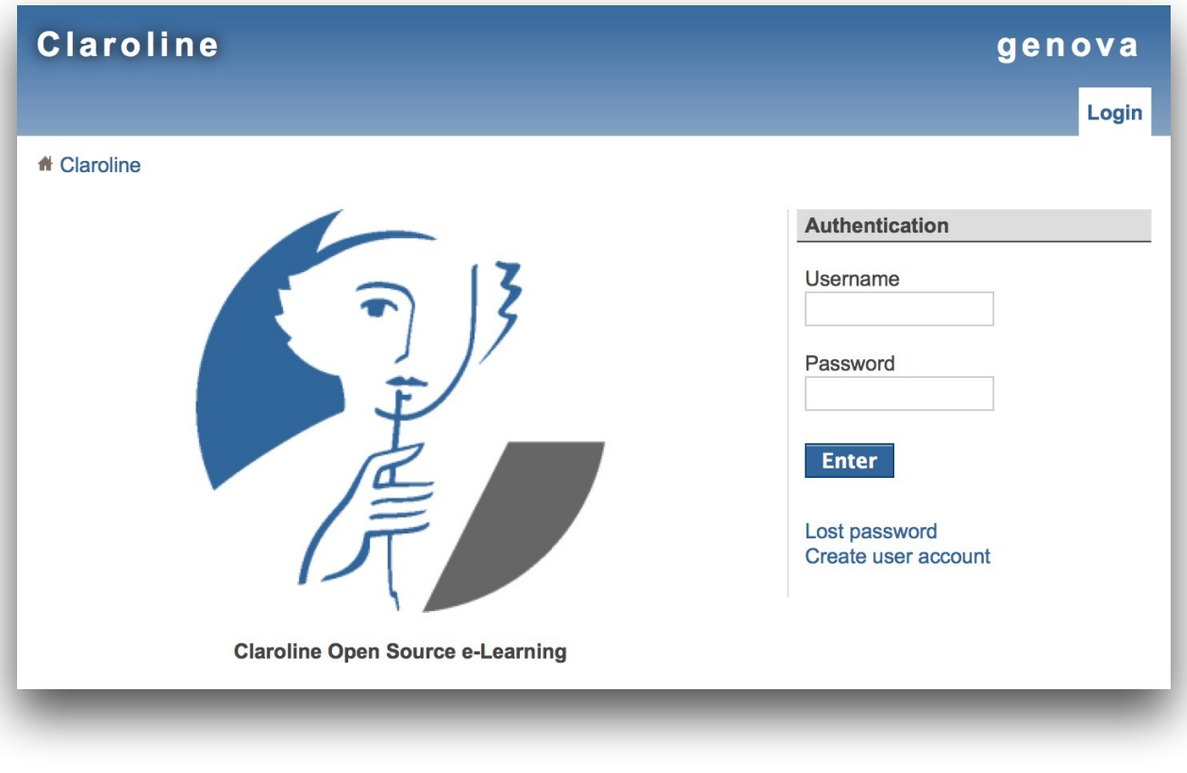
Test Scripts



Web App Code

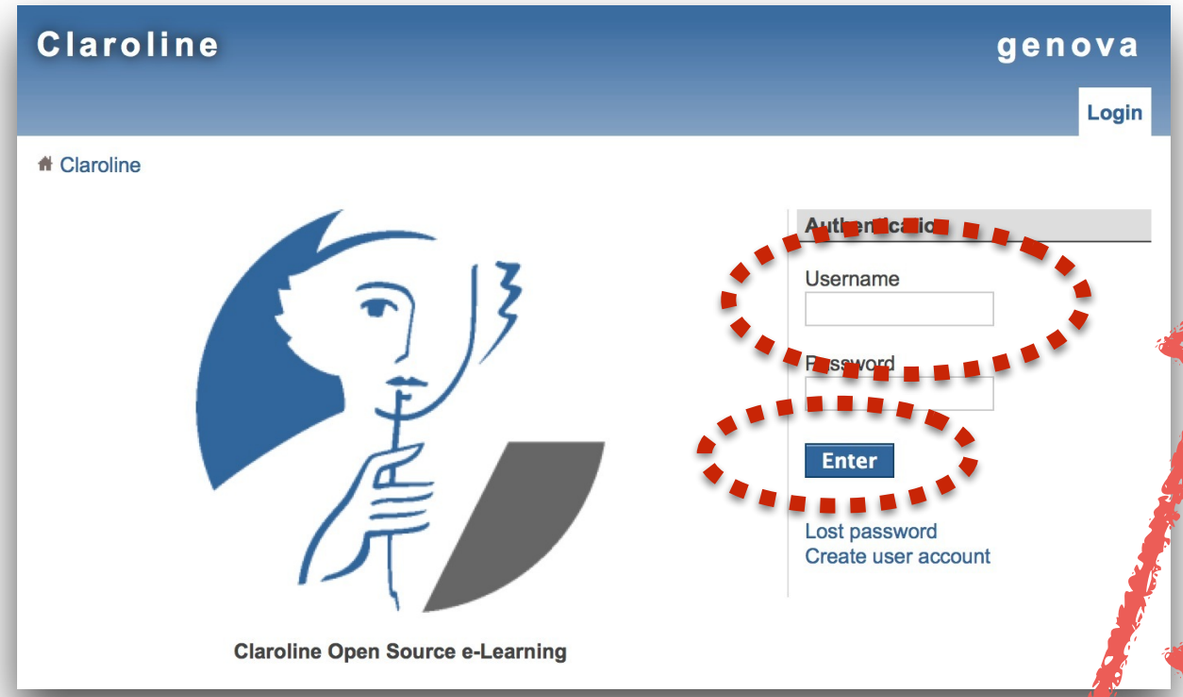


Page Object Pattern: An Example




```
public class IndexPage {
  private final WebDriver driver;

  @FindBy(id="user")
  private WebElement username;

  @FindBy(xpath="//form/input[2]")
  private WebElement password;

  @FindBy(linkText="Enter")
  private WebElement login;

  @FindBy(id="loggedUser")
  private WebElement loggedUser;

  public UserAccount goToCreateAccount(){
    createUserAccount.click();
    return new UserAccount(driver);
  }

  public HomePage login(String usr, String pwd) {
    username.sendKeys(usr);
    password.sendKeys(pwd);
    login.click();
    return new HomePage(driver);
  }
}
```

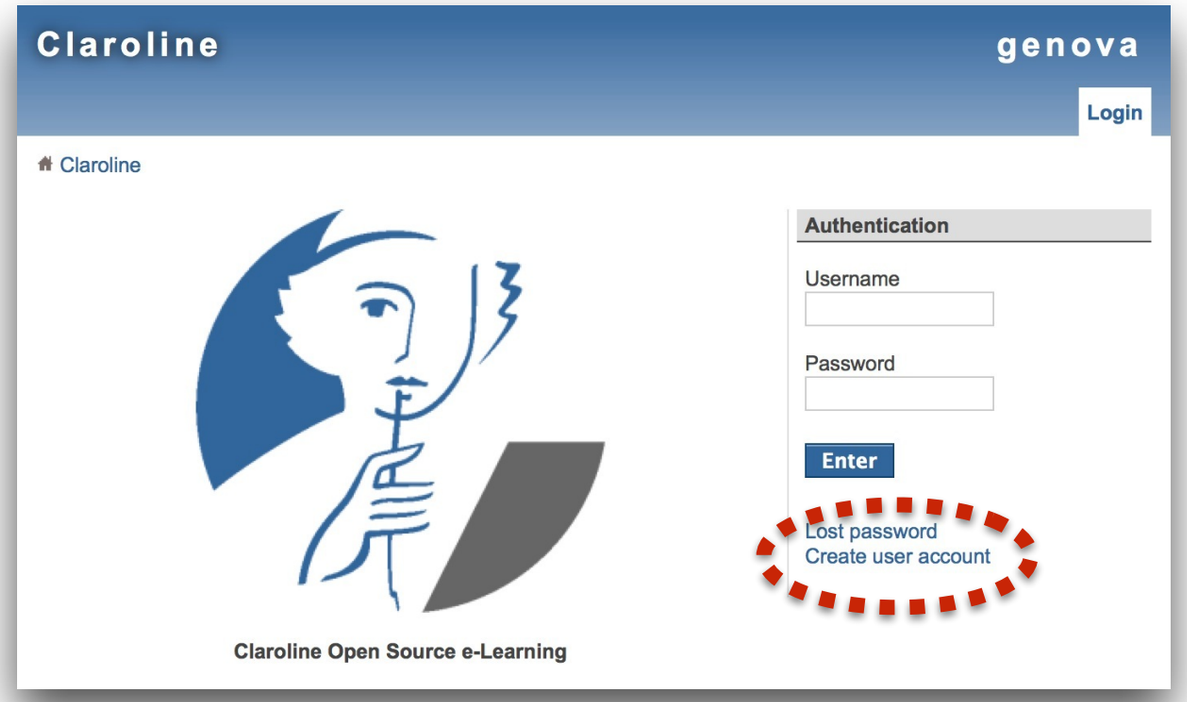
Page Object Pattern: An Example



WebElements

```
public class IndexPage {
  private final WebDriver driver;

  @FindBy(id="user")
  private WebElement username;

  @FindBy(xpath="//form/input[2]")
  private WebElement password;

  @FindBy(linkText="Enter")
  private WebElement login;

  @FindBy(id="loggedUser")
  private WebElement loggedUser;

  public UserAccount goToCreateAccount(){
    createUserAccount.click();
    return new UserAccount(driver);
  }

  public HomePage login(String usr, String pwd) {
    username.sendKeys(usr);
    password.sendKeys(pwd);
    login.click();
    return new HomePage(driver);
  }
}
```

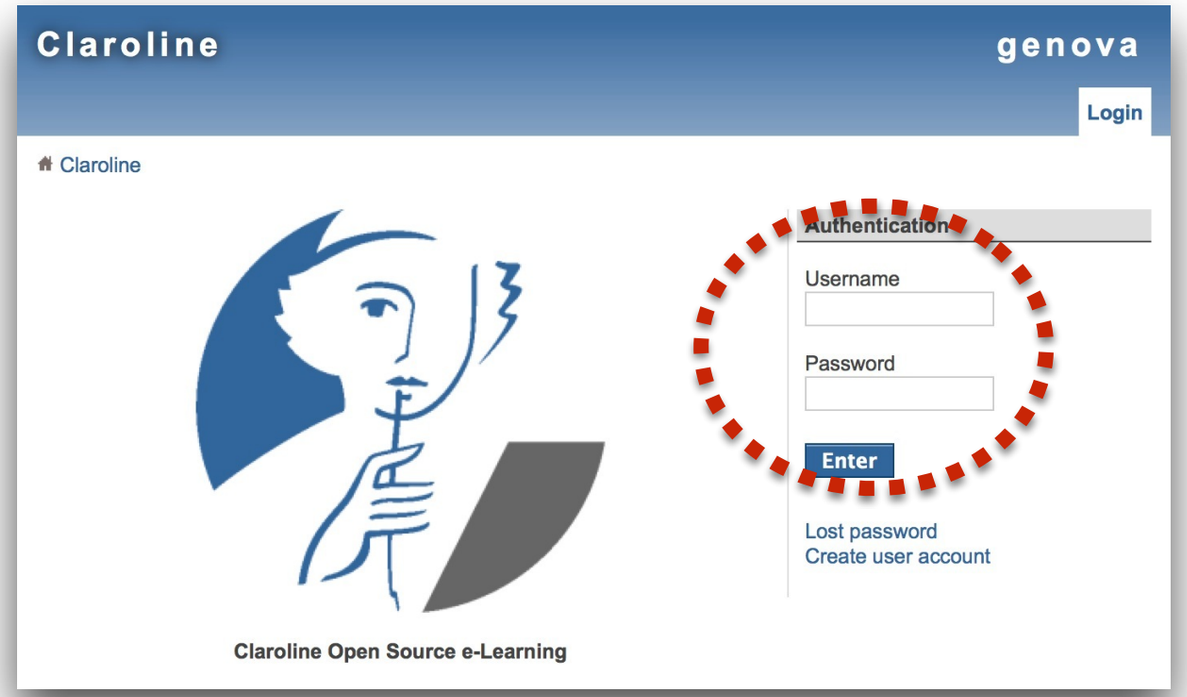
Page Object Pattern: An Example



Navigations

```
public class IndexPage {
  private final WebDriver driver;

  @FindBy(id="user")
  private WebElement username;

  @FindBy(xpath="//form/input[2]")
  private WebElement password;

  @FindBy(linkText="Enter")
  private WebElement login;

  @FindBy(id="loggedUser")
  private WebElement loggedUser;

  public UserAccount goToCreateAccount(){
    createUserAccount.click();
    return new UserAccount(driver);
  }

  public HomePage login(String usr, String pwd) {
    username.sendKeys(usr);
    password.sendKeys(pwd);
    login.click();
    return new HomePage(driver);
  }
}
```

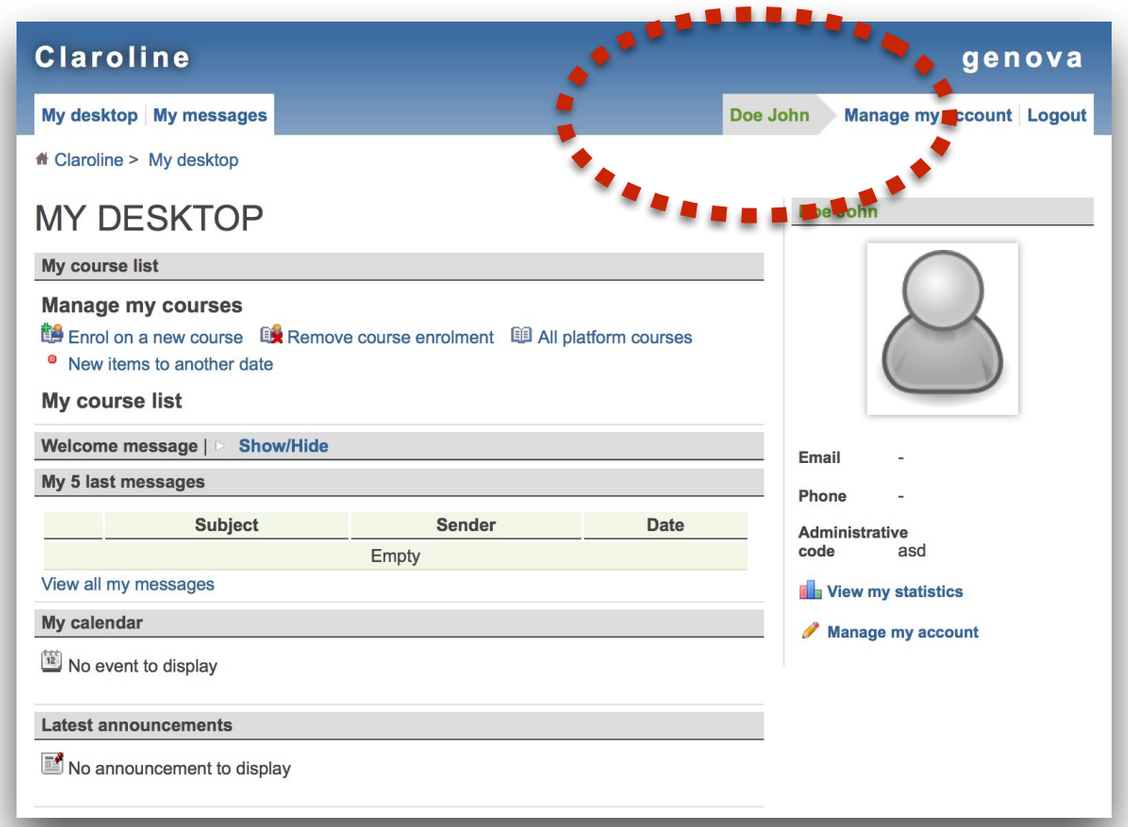
Page Object Pattern: An Example



Actions

```
public class IndexPage {
  private final WebDriver driver;

  @FindBy(id="user")
  private WebElement username;

  @FindBy(xpath="//form/input[2]")
  private WebElement password;

  @FindBy(linkText="Enter")
  private WebElement login;

  @FindBy(id="loggedUser")
  private WebElement loggedUser;

  public UserAccount goToCreateAccount(){
    createUserAccount.click();
    return new UserAccount(driver);
  }

  public HomePage login(String usr, String pwd) {
    username.sendKeys(usr);
    password.sendKeys(pwd);
    login.click();
    return new HomePage(driver);
  }
}
```

Page Object Pattern: An Example



Getters

```
public class HomePage {
  private final WebDriver driver;

  @FindBy(xpath="//li/a[1]")
  private WebElement myDesktop;

  @FindBy(xpath="//li/a[2]")
  private WebElement myMessages;

  @FindBy(linkText="Enrol")
  private WebElement enrolACourse;

  @FindBy(id="loggedUser")
  private WebElement loggedUser;

  public CoursePage goToEnrol(){
    enrolACourse.click();
    return new CoursePage(driver);
  }
...
  public String getLoggedUser() {
    return loggedUser.getText();
  }
}
```

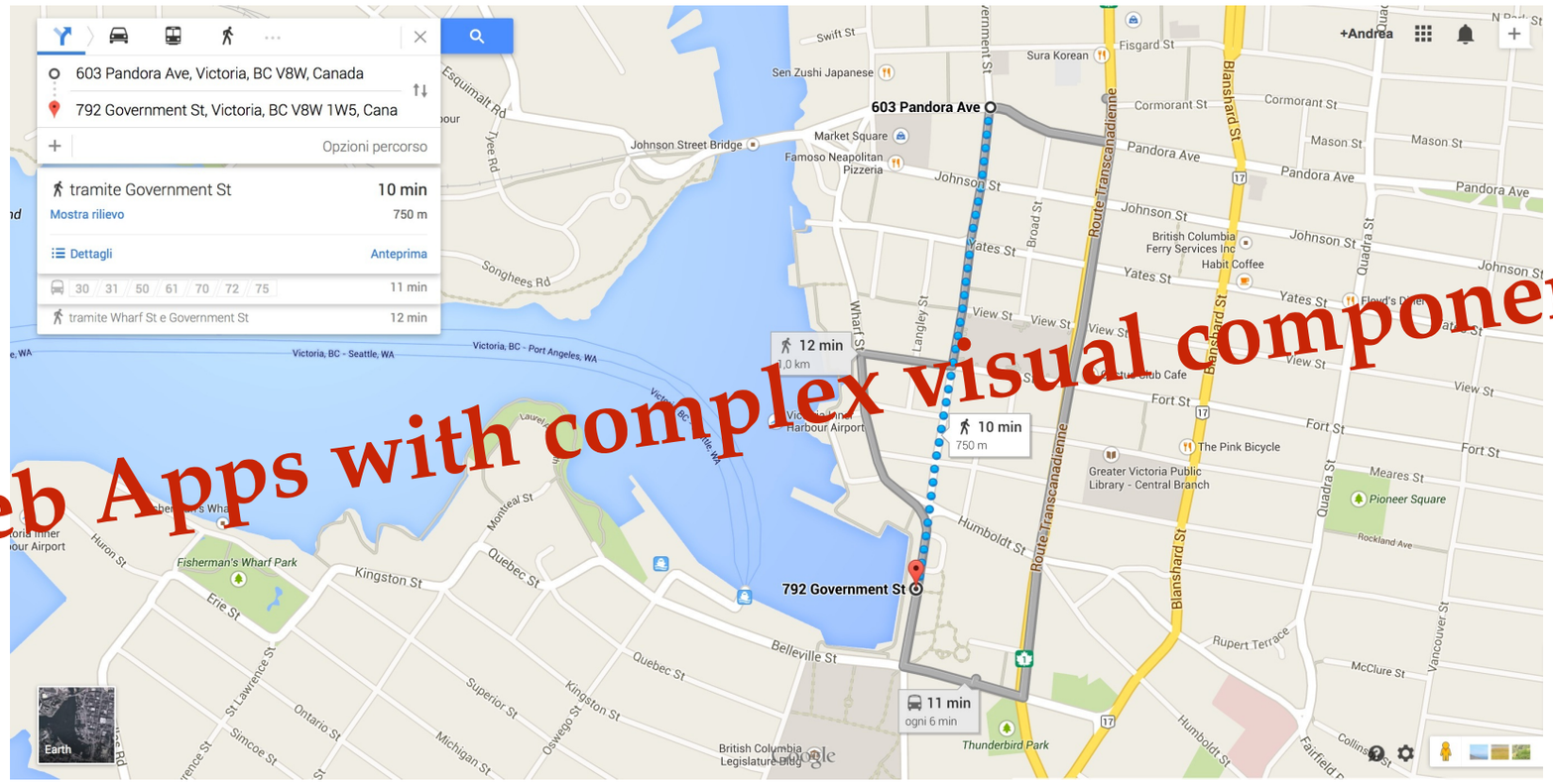
Test without abstraction

```
public class Login {
  @Test
  public void testLogin() {
    WebDriver driver = new FirefoxDriver();
    driver.get(“http://localhost/claroline1115/index.php”);
    driver.findElement(By.Id(id=“user”)).sendKeys(“John Doe”);
    driver.findElement(By.XPath(“xpath=“//form/input[2]”)).sendKeys(“securepassword”);
    driver.findElement(By.LinkText(linkText=“Enter”)).click();
    Assert.assertEquals(driver.findElement(By.Id(“John Doe”)), "Login was successful”);
   }
}
```

Test with Page Object abstraction

```
public class Login {
  @Test
  public void testLogin {
    Utils.connectToWebAppUnderTest();

    IndexPage ip = new IndexPage(driver);

    HomePage hp = ip.login("John Doe", "securepassword");

    assertEquals(hp.getLoggedUser(), "Doe John");
  }
}
```

Visual Test Automation



Web Apps with complex visual components

3rd generation: **image-recognition**

sikuli

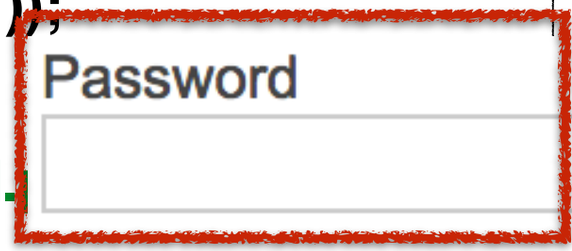
JAutomate

(Visual) Programmable

sikuli

```
public class Login {
  @Test
  public void testLogin() {
     WebDriver driver = new FirefoxDriver();
     driver.get(“http://localhost/claroline1115/index.php”);

     ImageTarget user = new ImageTarget(new File(path+"username.png"));
     sendKeys(user, “John Doe”);

     ImageTarget password = new ImageTarget(new File(path+”password.
     sendKeys(password, “thenameofmycat”);

    ImageTarget login = new ImageTarget(new File(path+"login.png"));
    click(login);

    …
  }
}
```

Visual Locators



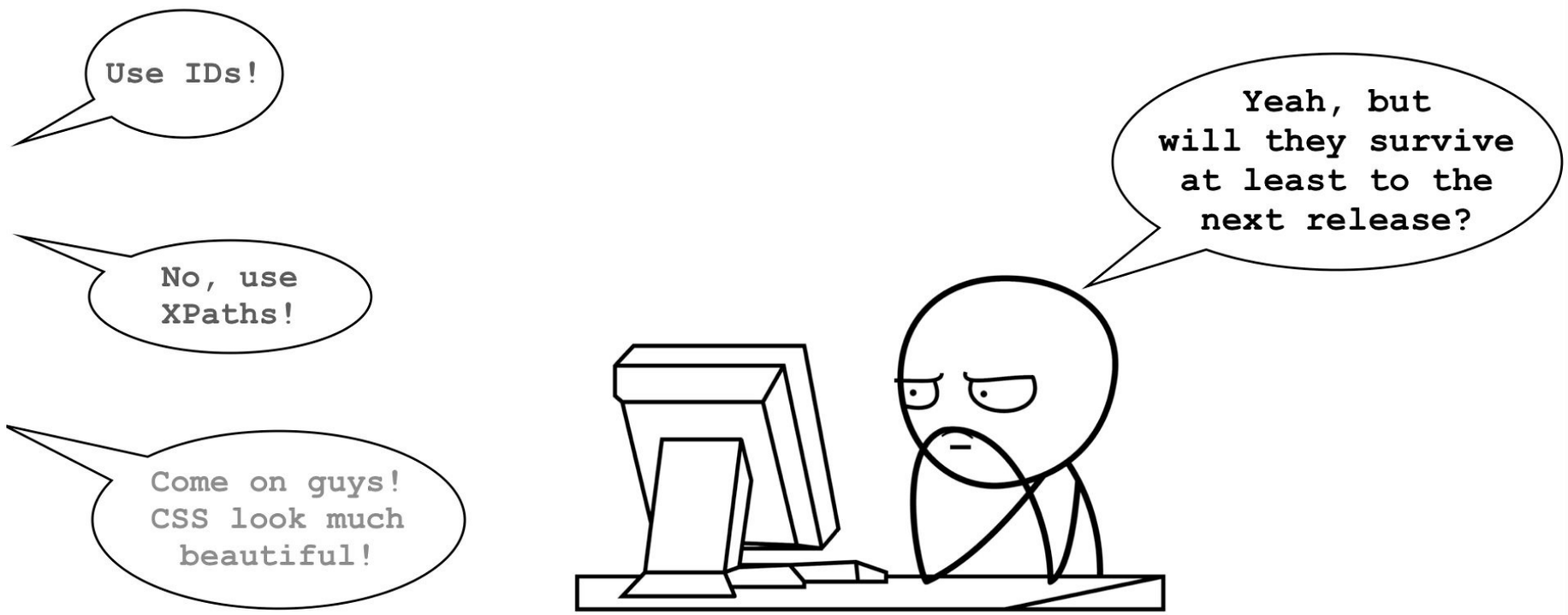
Approaches to E2E Test Automation

Element Localization	Development of test cases: Capture & Replay	Development of test cases: Programmable
coordinates (1st gen)	-	-
DOM-based (2nd gen)	Selenium IDE	Selenium WebDriver
Visual (3rd gen)	SikuliX, JAutomate	SikuliDriver

DOM-based locators

- **id**
- **css**
- **name**
- **linkText**
- **XPath**

DOM Locators and SW Evolution



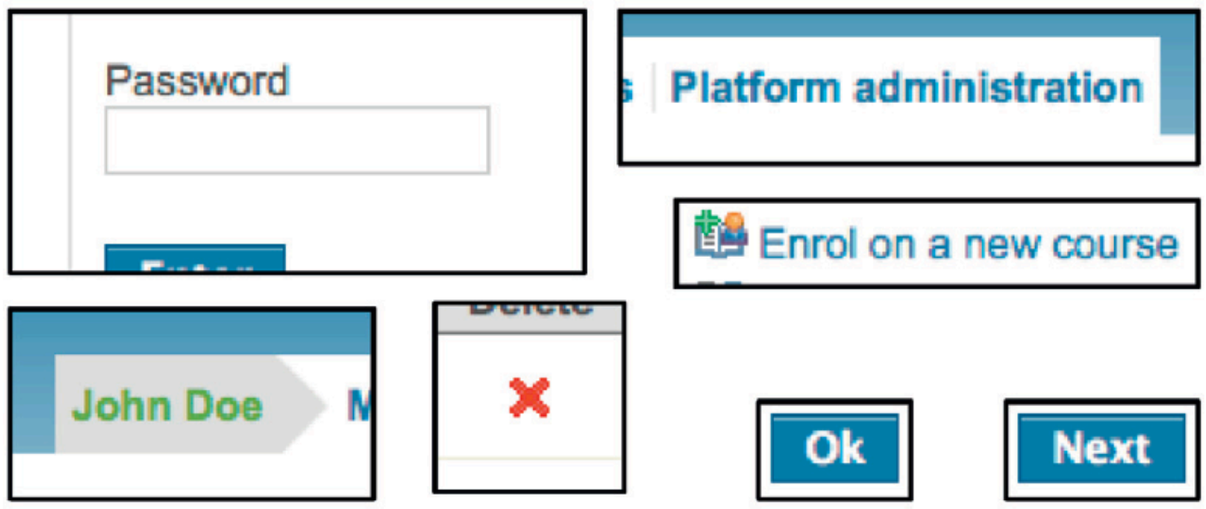
- **ids** are preferable but *(i)* not present *(ii)* auto-generated *(iii)* not unique
- other strategies are applicable **only** in **specific** contexts
- XPath **complex** and brittle but **powerful** and flexible
- a **careful** choice of locators can save you precious time (and headache)

Approaches to E2E Test Automation

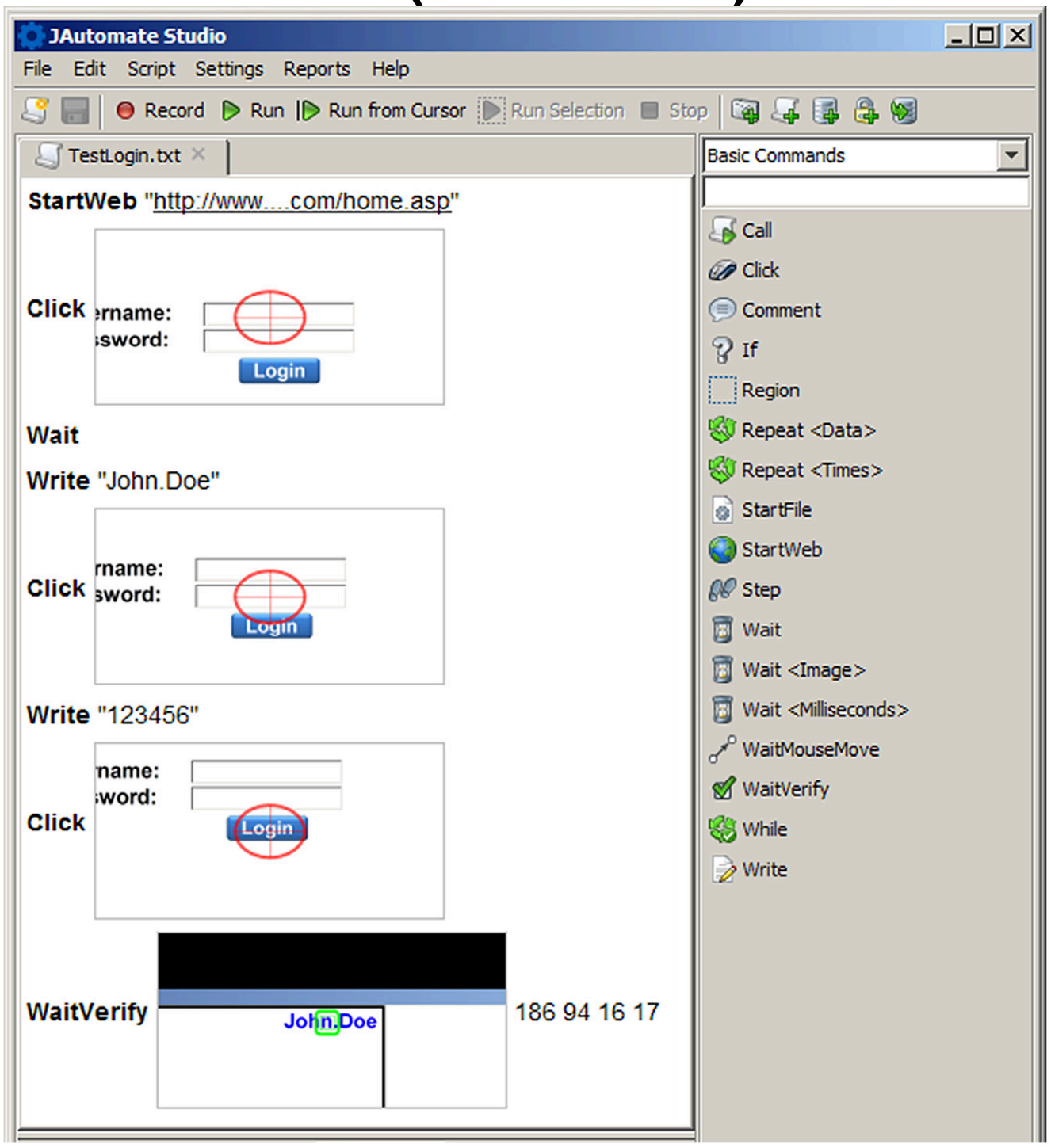
		Development of test cases	
		Capture & Replay	**Programmable**
Element Localization	**coordinates (1st gen)**	-	-
	DOM-based (2nd gen)	Selenium IDE	Selenium WebDriver
	Visual (3rd gen)	SikuliX, JAutomate	SikuliDriver

Visual locators

manually crafted (SikuliX and SikuliAPI)

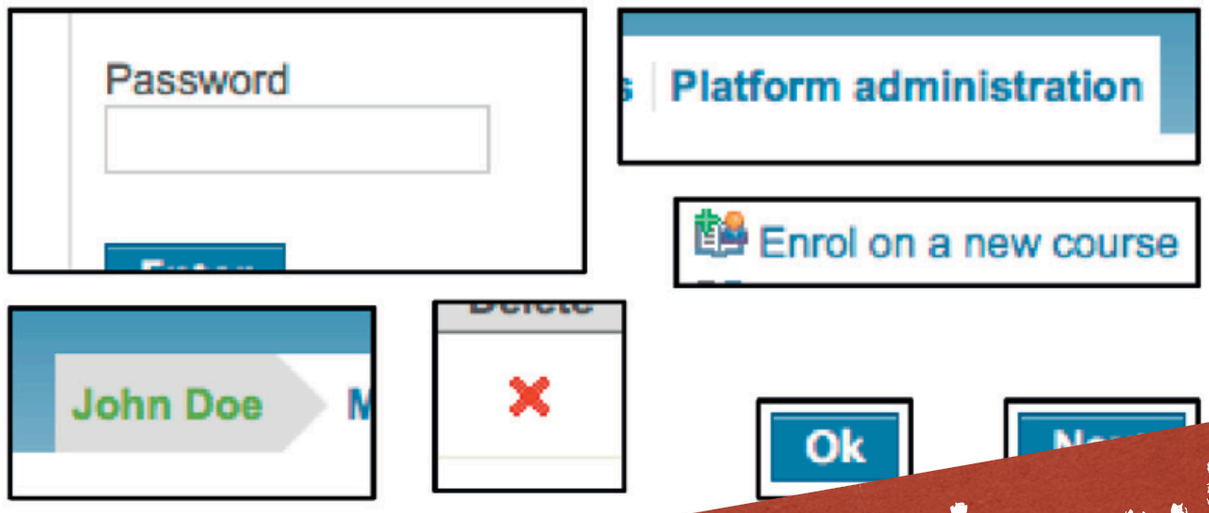


auto-generated (JAutomate)

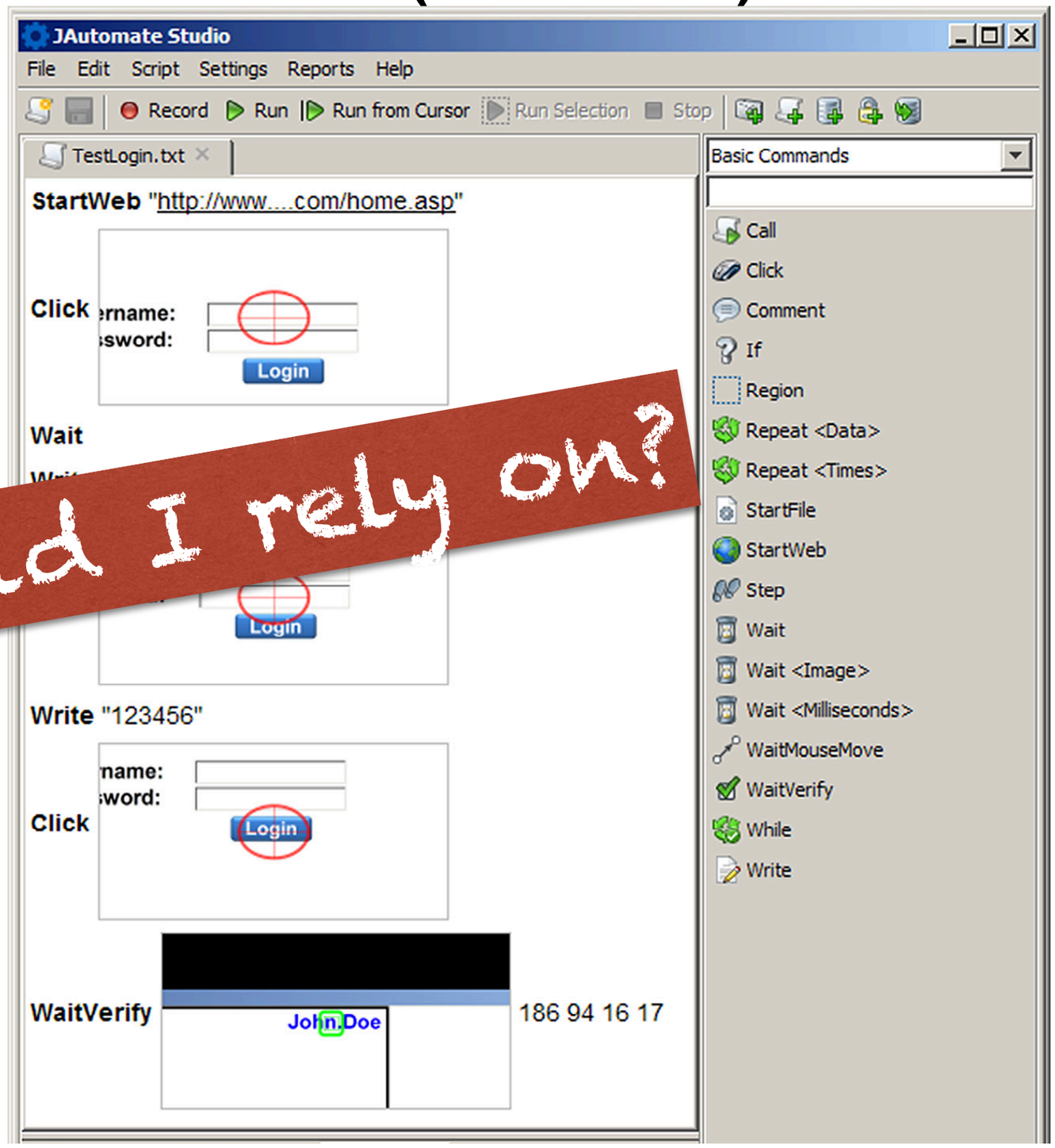


Visual locators

manually crafted (SikuliX and SikuliAPI)



auto-generated (JAutomate)



Which one should I rely on?

Test Case Evolution

Issues with Test Automation

Test Scripts

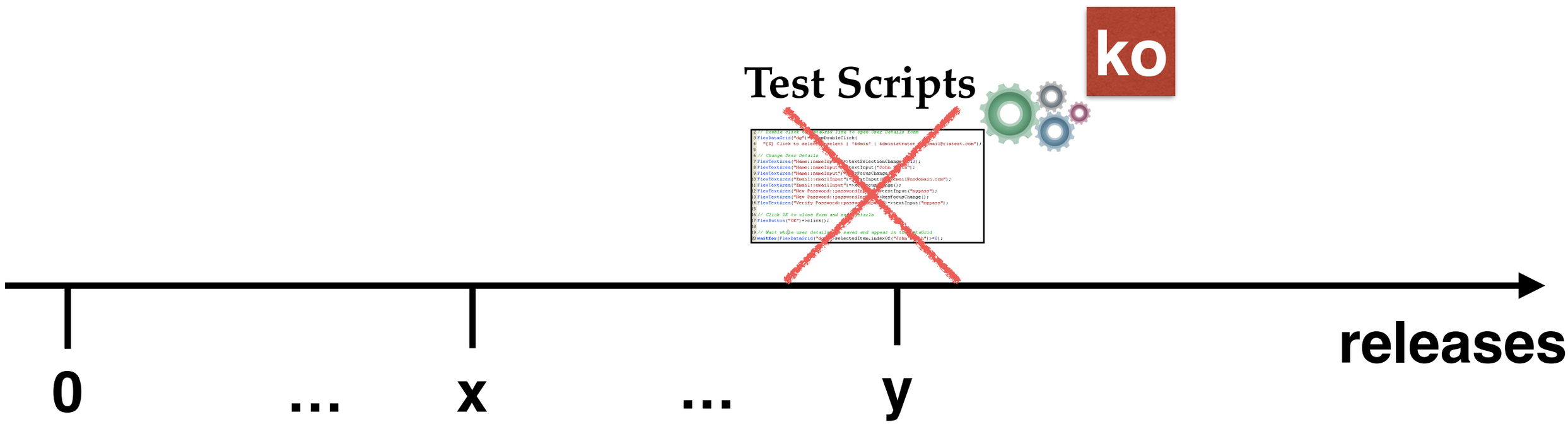
```
// Double click on DataGrid line to open User Details Form
FlexDataGrid("dg")=>itemDoubleClick(
  "{X} Click to select/unselect | *Admin* | Administrator | nomail@riatest.com");

// Change User Details
FlexTextArea("UName::nameInput")=>textSelectionChange(0,13);
FlexTextArea("UName::nameInput")=>textInput("John Smith");
FlexTextArea("UName::nameInput")=>keyFocusChange();
FlexTextArea("Email::emailInput")=>textInput("fromemail@nodomain.com");
FlexTextArea("Email::emailInput")=>keyFocusChange();
FlexTextArea("New Password::passwordInput")=>textInput("mypass");
FlexTextArea("New Password::passwordInput")=>keyFocusChange();
FlexTextArea("Verify Password::passwordInput2")=>textInput("mypass");

// Click OK to close form and save details
FlexButton("OK")=>click();

// Wait while user details are saved and appear in the DataGrid
waitfor(FlexDataGrid("dg")=>selectedItem.indexOf("John Smith")>=0);
```

releases

0

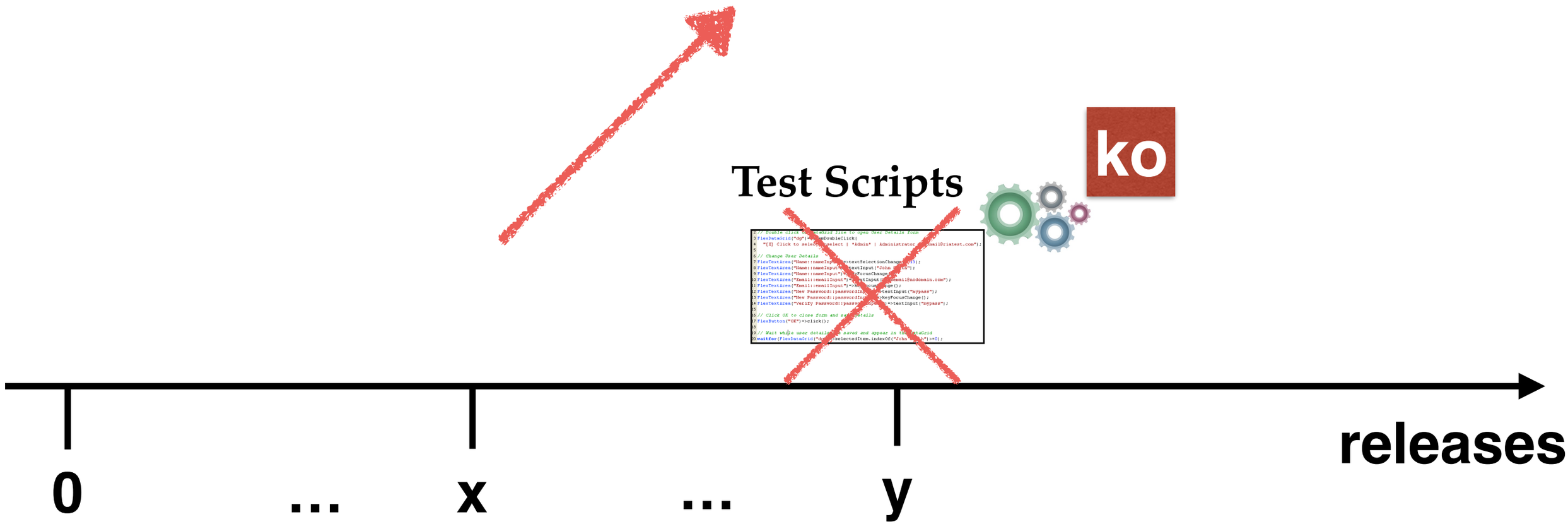
Issues with Test Automation

Issues with Test Automation



Issues with Test Automation

in web development, the releases are frequent!



Test Scripts Maintenance

- Even **minor changes of the GUI** layout can lead most of the test cases to fail. The repair activity costs e.g., the Accenture company $120 million per year

  [Grechanick et al., *"Maintaining and evolving GUI-directed test scripts,"* ICSE 2009]

- A study on Adobe's Acrobat Reader found that **74%** of its test scripts get broken between **two successive releases**

  [Memon and Soffa, "*Regression Testing of GUIs,*" SIGSOFT Software Engineering Notes 28, 2003]

- The **main source** for web test cases **fragility** are the web elements **locators**

  [Leotta et al., "*Comparing the Maintainability of Selenium WebDriver Test Suites Employing Different Locators: A Case Study.,*" JAMAICA 2013]

  [Christophe et al., "*Prevalence and Maintenance of Automated Functional Tests for Web Applications,*" ICSME 2014]

Test Evolution Patterns

Structural Change

Release N


```
<form name="loginform" action="homepage.asp" method="post">
     Username : <input type="text" id="userid" name="user"><br>
     Password : <input type="text" id="pw" name="password"><br>
     <a href="javascript:loginform.submit()" id="login">Login</a>
</form>
```

Release N+1


```
<form name="loginform" action="homepage.asp" method="post">
 Username : <input type="text" id="userid" name="user"><br>
 Password : <input type="text" id="pw" name="password"><br>
 <a href="javascript:loginform.submit()" id="login">Login Now!</a>
</form>
```

Test Evolution Patterns

Logical Change

Release N

Auth1.php

Username

Password

Login!

Release N+1

Auth1.php

Username

Birthday

Submit

Auth2.php

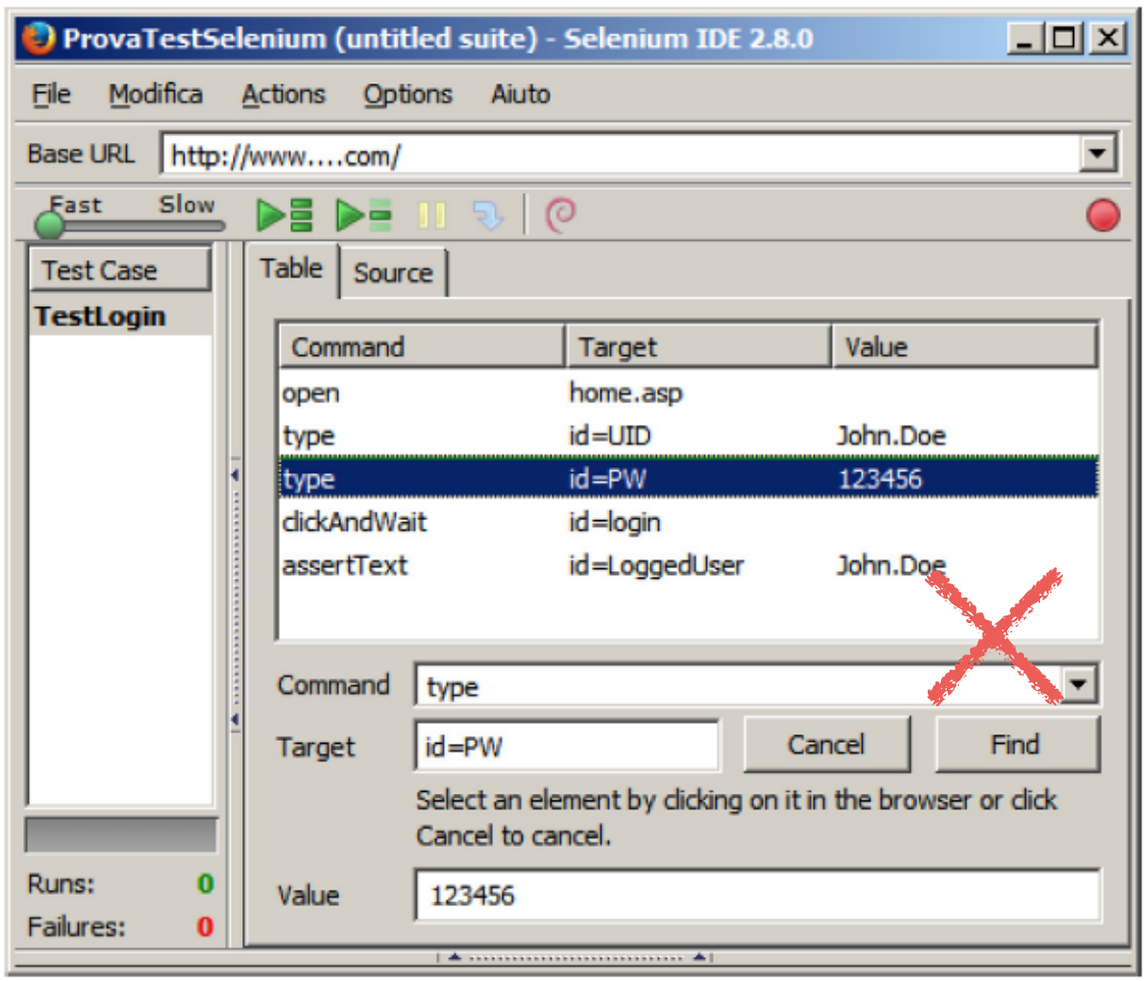
Password

Login!

Tasks

Scenario1 : C&R Approach + logical change

Q: What's the maintenance activity in this case?



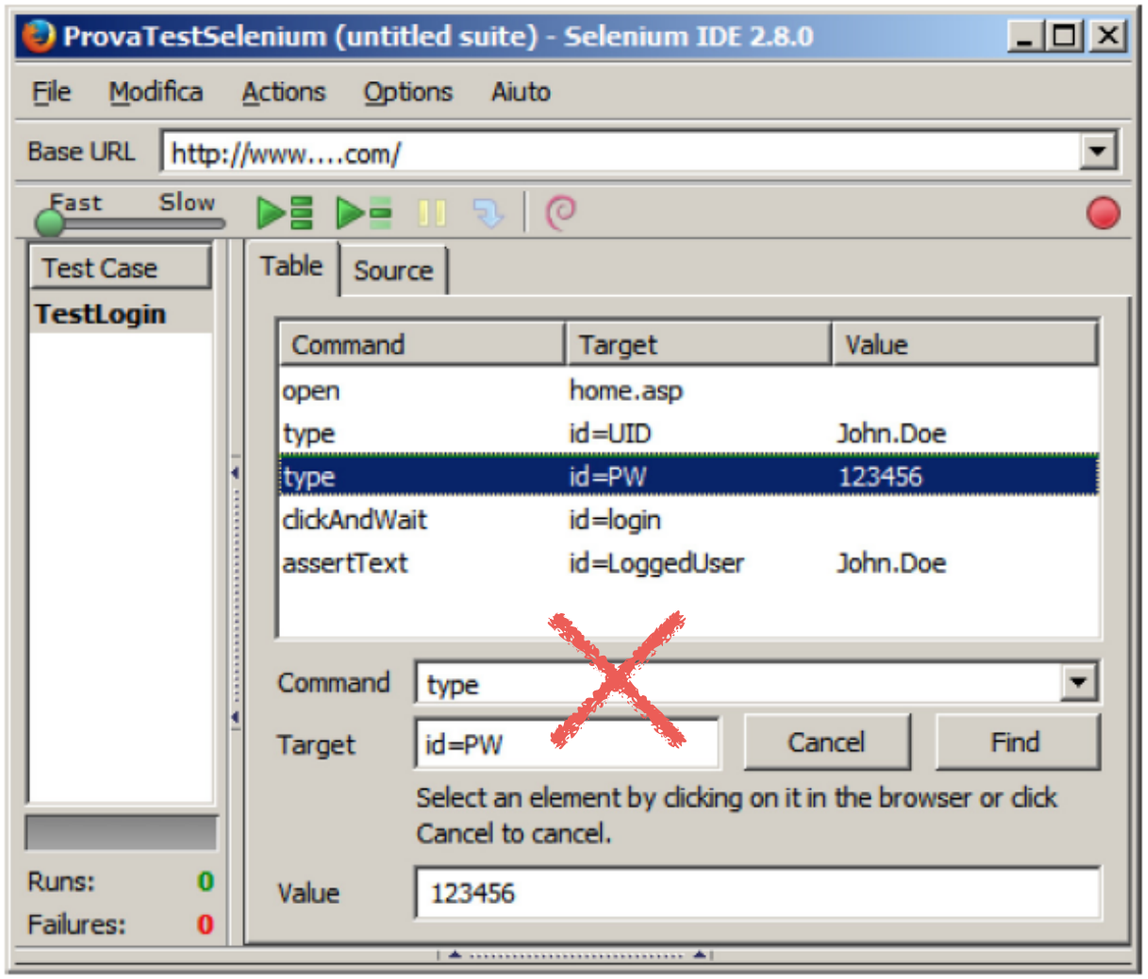
Answer:

Keep the portion of the script up to the broken command.

Re-capture the execution scenario by starting from the last working command.

Scenario2 : C&R Approach + structural change

Q: What's the maintenance activity in this case?



Answer:

Modify all the broken locators, actions, or values.

Scenario3 : Programmable Approach + logical change

Q: What's the maintenance activity in this case?

```
public class Login {
  @Test
  public void testLogin() {
    WebDriver driver = new FirefoxDriver();
    driver.get("http://localhost/claroline1115/index.php");
    driver.findElement(By.Id(id="user")).sendKeys("John Doe");
    driver.findElement(By.XPath("xpath="//form/
   input[2]")).sendKeys("securepassword");
    driver.findElement(By.LinkText(linkText="Enter")).click();
    Assert.assertEquals(driver.findElement(By.Id("John Doe")),
   "Login was successful");
   }
}
```

```
public class IndexPage {
   private final WebDriver driver;
   @FindBy(id="user")
   private WebElement username;
   @FindBy(xpath="//form/input[2]")
   private WebElement password;
   @FindBy(linkText="Enter")
   private WebElement login;
   @FindBy(id="loggedUser")
   private WebElement loggedUser;

    public UserAccount goToCreateAccount(){
       createUserAccount.click();
       return new UserAccount(driver);
    }

   public HomePage login(String usr, String pwd) {
      username.sendKeys(usr);
      password.sendKeys(pwd);
      login.click();
      return new HomePage(driver);
   }
}
```

Answer:

Modify the page object actions and, eventually, the tests.

Scenario4 : Programmable Approach + structural change

Q: What's the maintenance activity in this case?

```
public class Login {
  @Test
  public void testLogin() {
    WebDriver driver = new FirefoxDriver();
    driver.get("http://localhost/claroline1115/index.php");
    driver.findElement(By.Id(id="user")).sendKeys("John Doe");
    driver.findElement(By.XPath("xpath="//form/
   input[2]")).sendKeys("securepassword");
    driver.findElement(By.LinkText(linkText="Enter")).click();
    Assert.assertEquals(driver.findElement(By.Id("John Doe")),
   "Login was successful");
   }
}
```

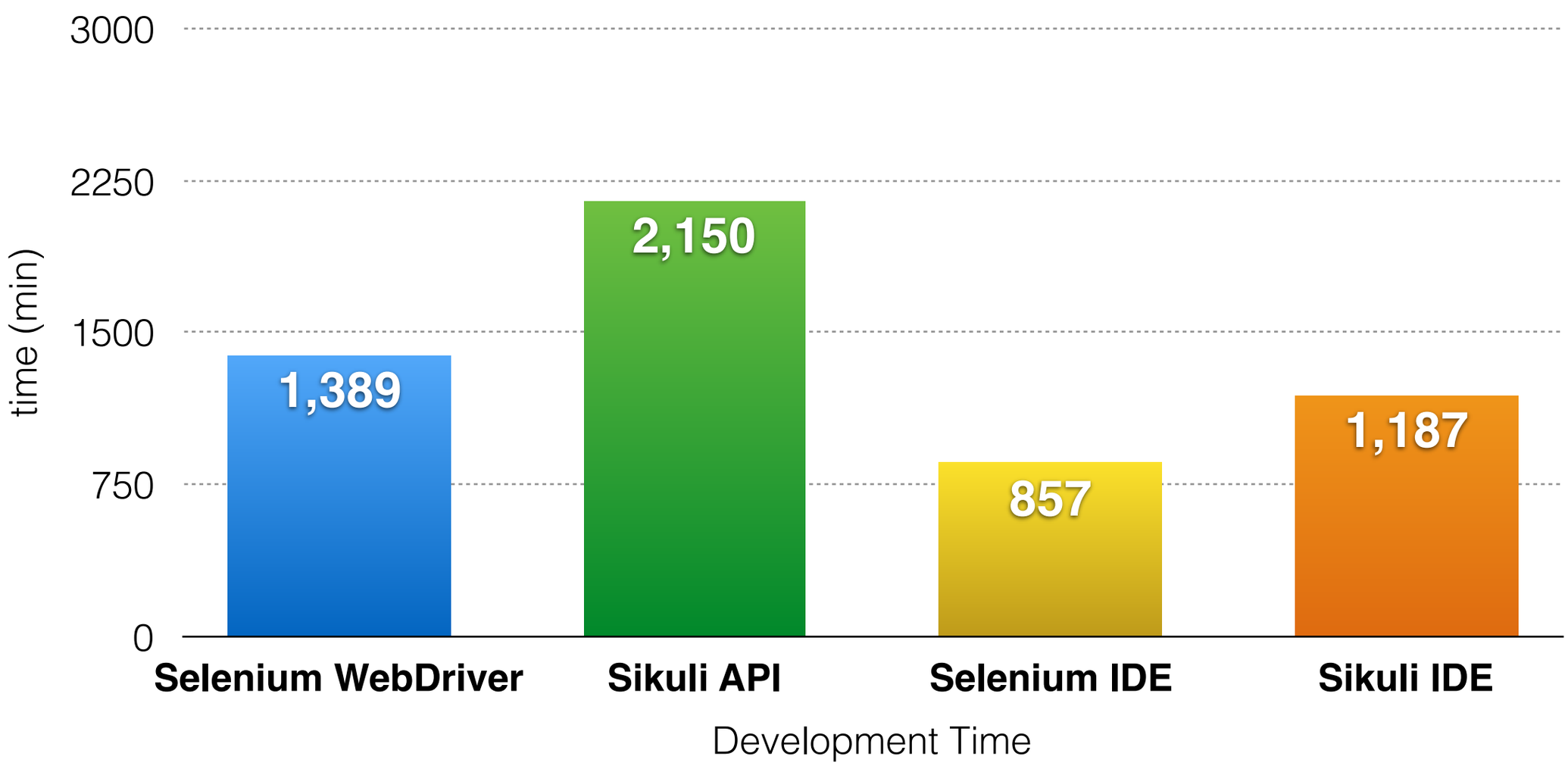
```
public class IndexPage {
  private final WebDriver driver;
  @FindBy(id="user")
  private WebElement username;
  @FindBy(xpath="//form/input[2]")
  private WebElement password;
  @FindBy(linkText="Enter")
  private WebElement login;
  @FindBy(id="loggedUser")
  private WebElement loggedUser;

   public UserAccount goToCreateAccount(){
     createUserAccount.click();
     return new UserAccount(driver);
   }

  public HomePage login(String usr, String pwd) {
    username.sendKeys(usr);
    password.sendKeys(pwd);
    login.click();
    return new HomePage(driver);
  }
}
```

Answer:

Modify only the page object(s). No modifications to the tests needed!!!

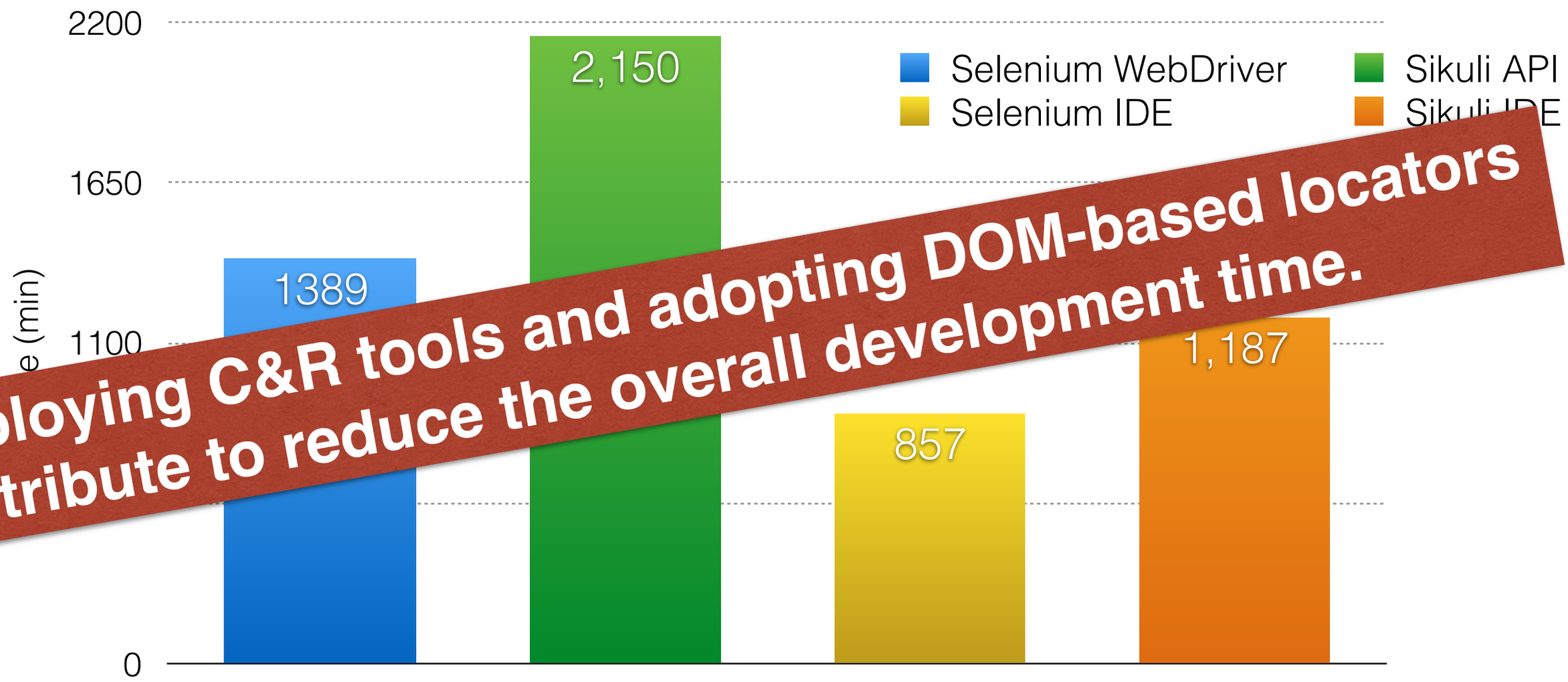
Test Suite Development Cost

Q: In practice, which one is more convenient?



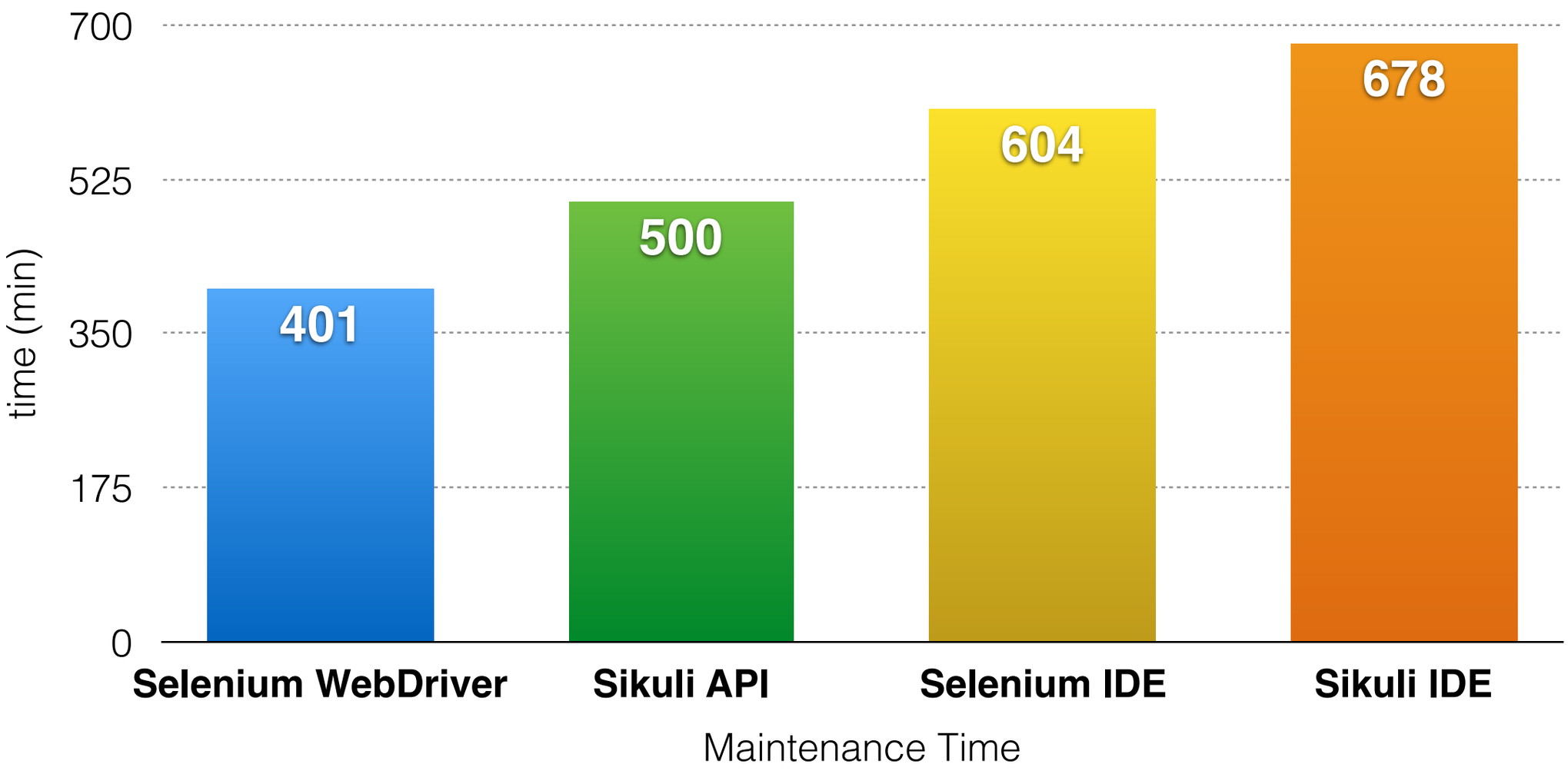
[Leotta et al., *"Approaches and Tools for Automated End-to-End Web Testing,"* Advances in Computers, Volume 101:5 (2016)]

Test Suite Development Cost



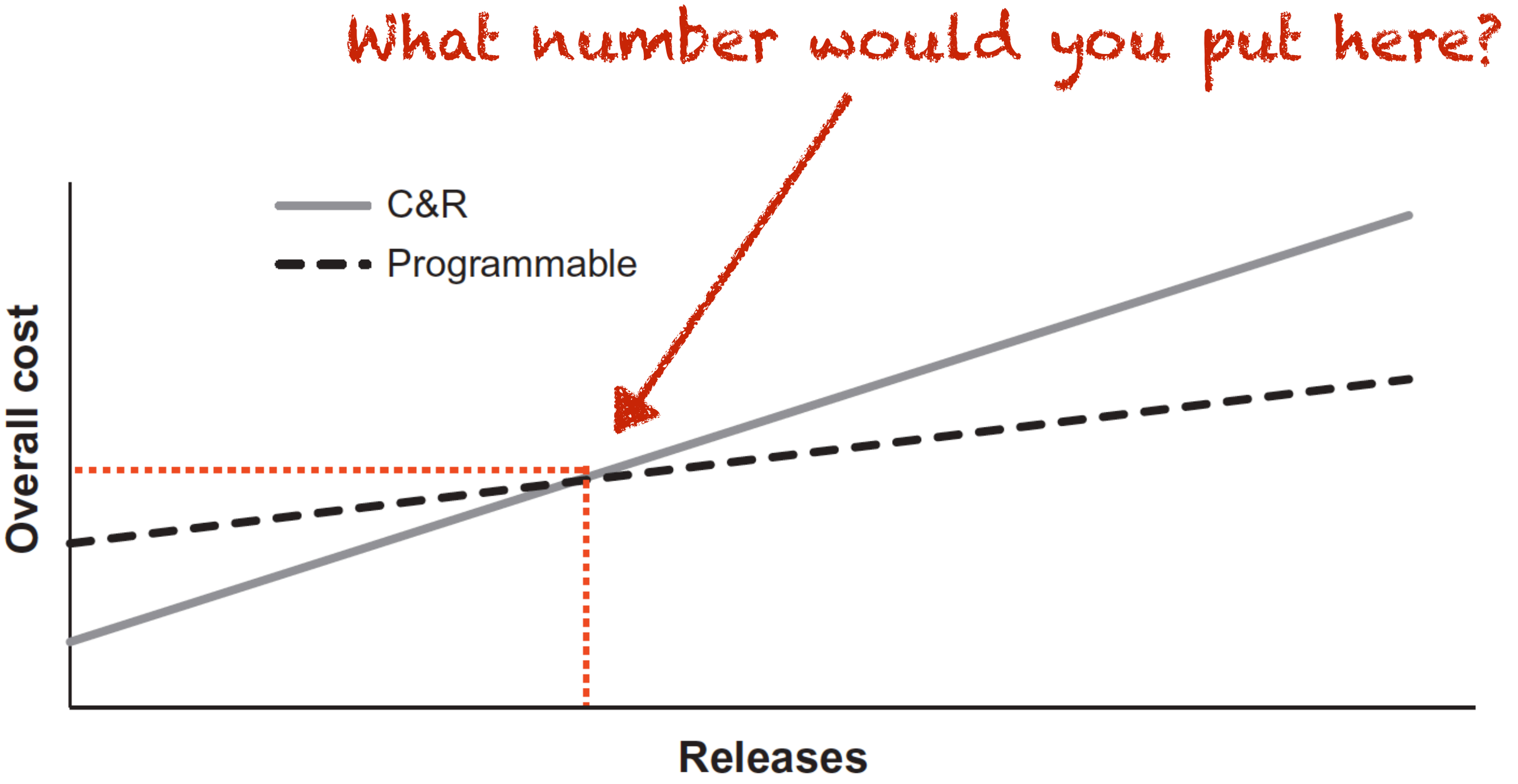
[Leotta et al., *"Approaches and Tools for Automated End-to-End Web Testing,"* Advances in Computers, Volume 101:5 (2016)]

Test Suite Maintenance Cost



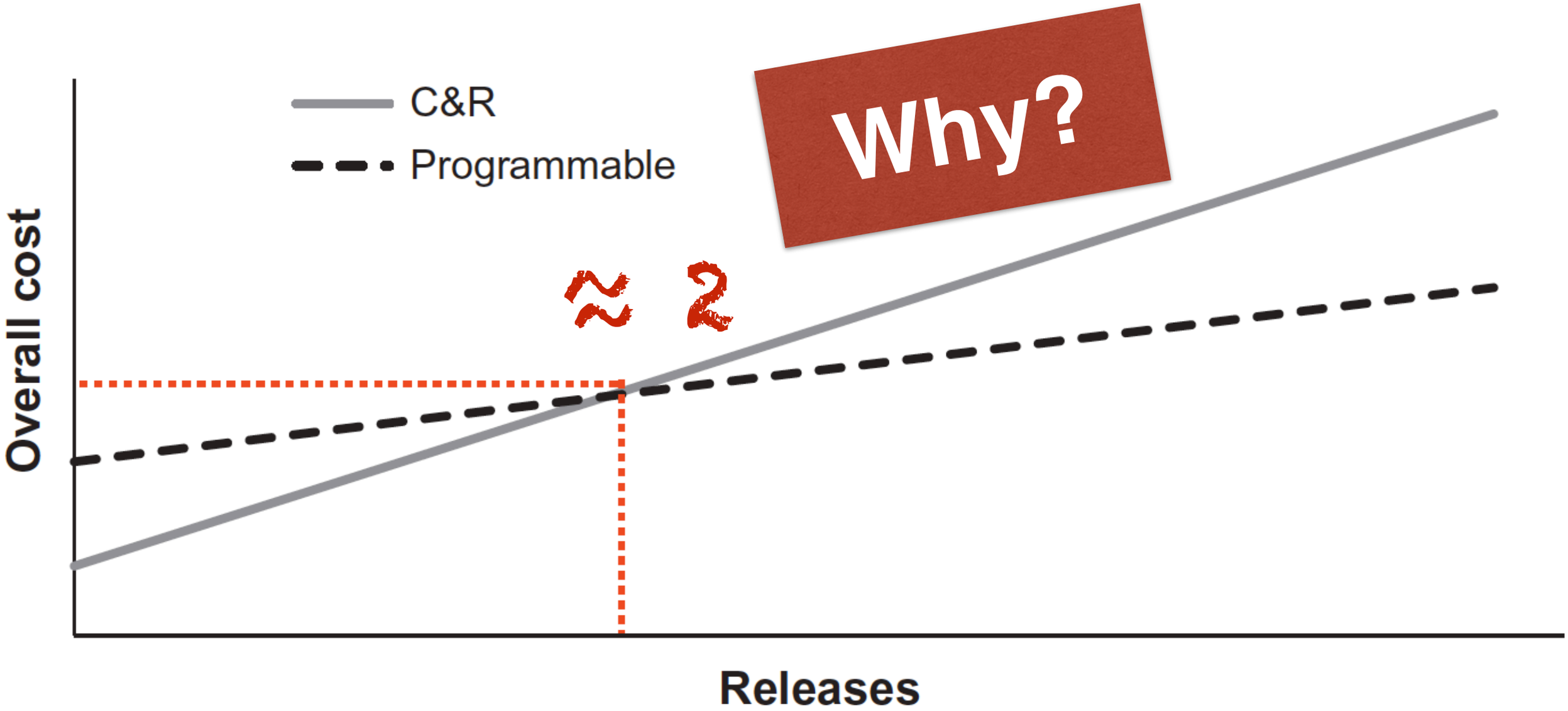
[Leotta et al., *"Approaches and Tools for Automated End-to-End Web Testing,"* Advances in Computers, Volume 101:5 (2016)]

When do they become convenient?



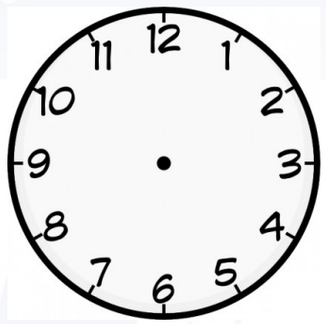
[Leotta et al., *"Approaches and Tools for Automated End-to-End Web Testing,"* Advances in Computers, Volume 101:5 (2016)]

When do they become convenient?



[Leotta et al., "*Approaches and Tools for Automated End-to-End Web Testing,*" Advances in Computers, Volume 101:5 (2016)]

Augmented Maintainability



3x

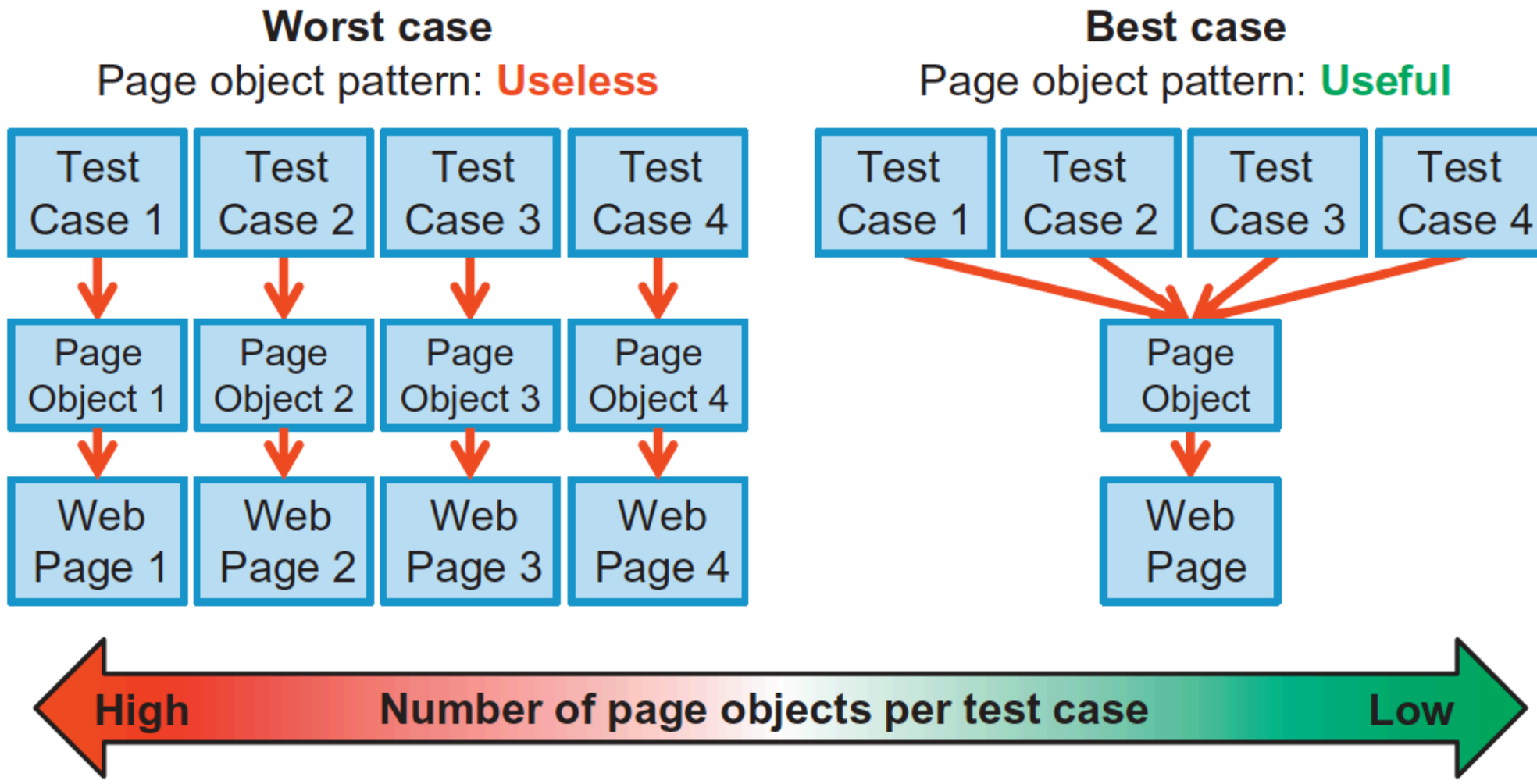
8x

[Leotta et al., *"Improving Test Suites Maintainability with the Page Object Pattern: An Industrial Case Study,"* ICSTW 2013]

```
// A simple Page Object class with Selenium WebDriver
public class IndexPage {
        private final WebDriver driver;

        @FindBy(id="user")
        private WebElement username;

        @FindBy(xpath="//form/input[2]")
        private WebElement password;

        @FindBy(linkText="Enter")
        private WebElement login;

        @FindBy(id="loggedUser")
        private WebElement loggedUser;

        public HomePage login(String usr, String pwd) {
                username.sendKeys(usr);
                password.sendKeys(pwd);
                login.click();
                return new HomePage(driver);
        }
}
```

```
@Test
public void testLogin {
        Utils.connectToWebAppUnderTest();
        IndexPage IP = new IndexPage(driver);
        HomePage hp = IP.login("John Doe", "securepassword");
        assertTrue(hp.checkLoggedUser("Doe John"));
}
```

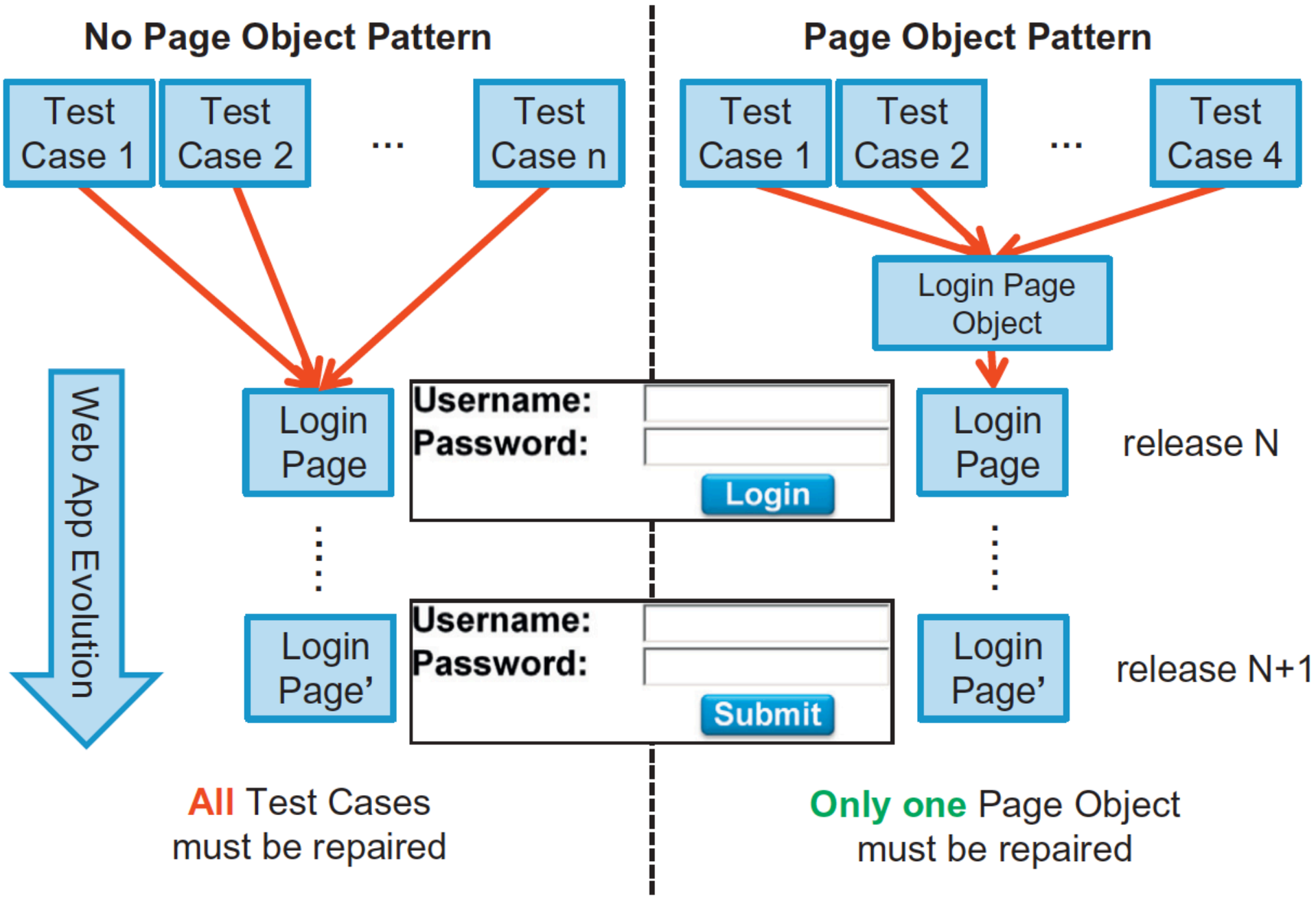
Factor 1 : Test cases vs Page objects



The web page modularity of the web application under test affects the benefits of programmable test cases.

Reusable pages objects are maintained less during software evolution.

Factor 2 : Page objects and repair effort



eg, in Selenium WebDriver the repair is:

`@FindBy(linkText="Login")` becomes `@FindBy(linkText="Submit")`

Factor 3 : Number of Locators

Elements with complex visual interaction

Add Car Test Case: Select the car manufacturer

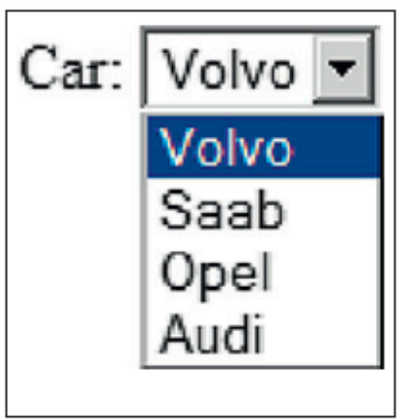
DOM-based approach
one locator needed

```
(driver.findElement(By.id("carList")))
    .selectByVisibleText("Saab");
```

Visual approach
two locators needed

Locate the Select Web Element + Click to Open

Locate the Option Value



Factor 3 : Number of Locators

Multistate Elements

Add Car Test Case
Check the Box and Submit

Remove Car Test Case
Uncheck the Box and Submit

I have a car
Submit

I have a car
Submit

The Target Web Element is always the same

(ie, the Box)

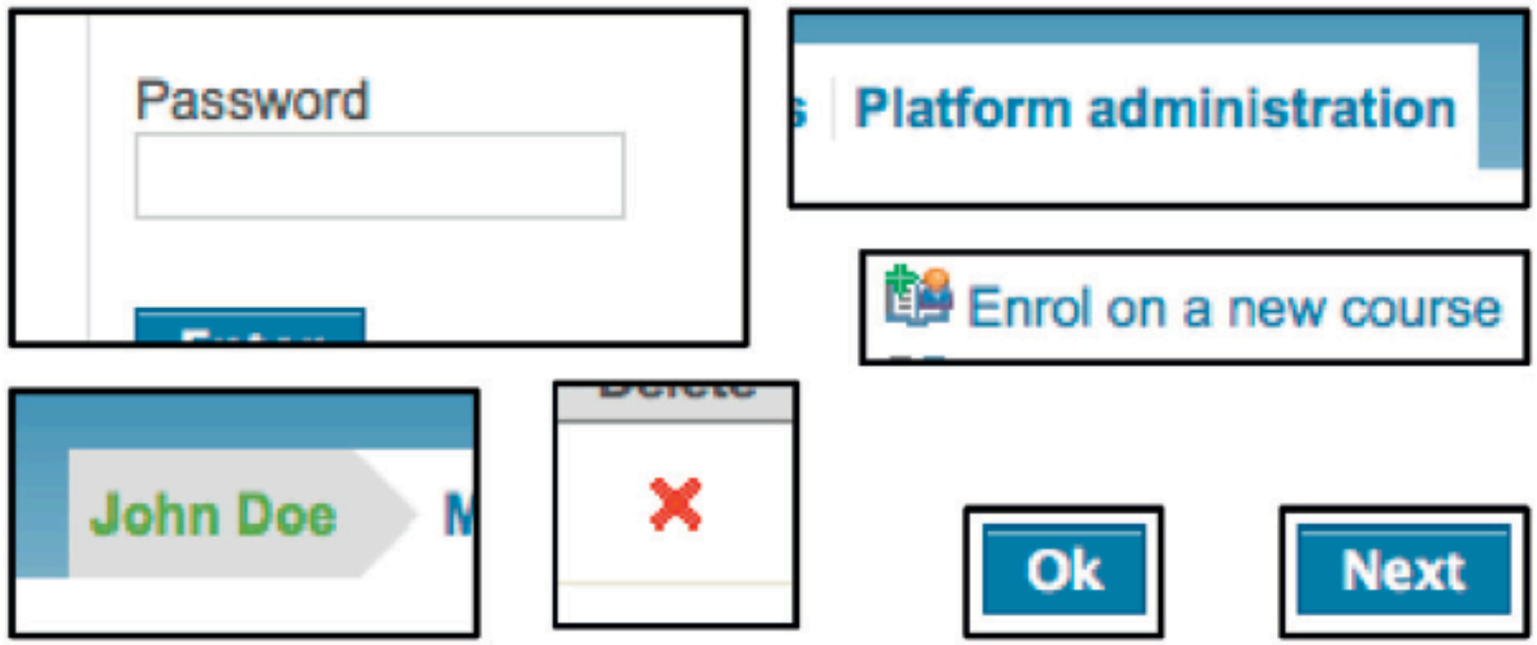
Visual approach
two locators needed

DOM-based approach
one locator needed

//input[@name="vehicle"]

Factor 3 : Number of Locators

Data Driven Test Cases



Examples of DOM-based Locators

```
//input[2]
linkText = Platform administration
//td[contains(text(),'John Doe')]
//img[@src="/web/img/edit.png?1232379976"]
//*[@id='body']/table[2]/tbody/tr/td[4]/a/img[4]
```

Other Factors

Robustness favours the DOM based

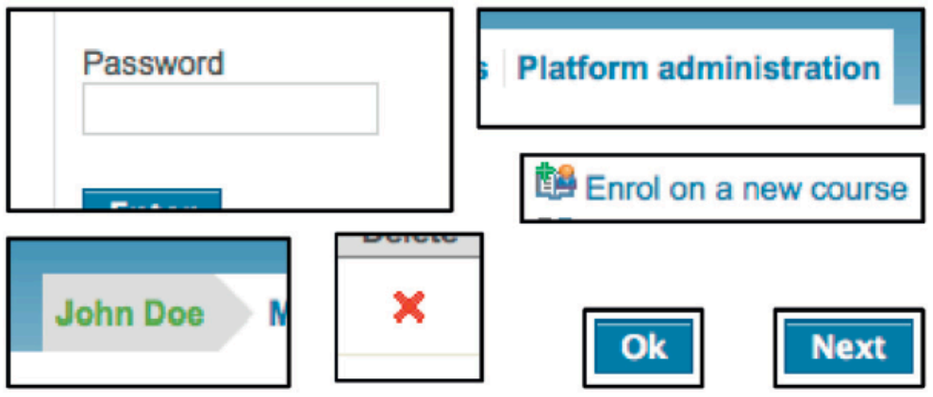
Execution Time: almost the same

Multiple Instances of the same web element

Invisible/Hidden elements

Web page loading/**synchronization**

Comprehensibility



Examples of DOM-based Locators

```
//input[2]
linkText = Platform administration
//td[contains(text(),'John Doe')]
//img[@src="/web/img/edit.png?1232379976"]
//*[@id='body']/table[2]/tbody/tr/td[4]/a/img[4]
```

Can we do better?

Hybrid Testing
join the advantages of visual and DOM-based tools
in a single testing framework

Contextual Clues
write the test script in natural language

Much still needs to be done!!!

"Approaches and tools for Automated E2E testing of web applications"

A multi-perspective analysis during software evolution

Questions?

Andrea Stocco
UBC
astocco@ece.ubc.ca