# Does Research Support the Effectiveness of Test Driven Development?

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*DISI, Università di Genova*

# Agenda

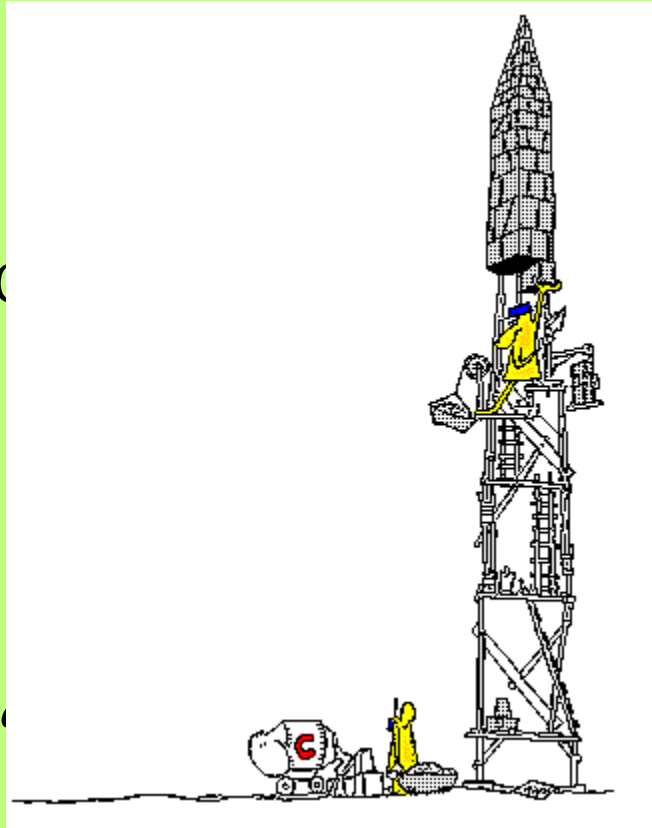
- What is TDD?
- A little bit of History!
- TDD vs. TLD (Test Last Development)
- (Supposed) Benefits and drawbacks of TDD
- TDD in action with JUnit
  - Current/Bank account
- Empirical evidence on TDD

# What is TDD?

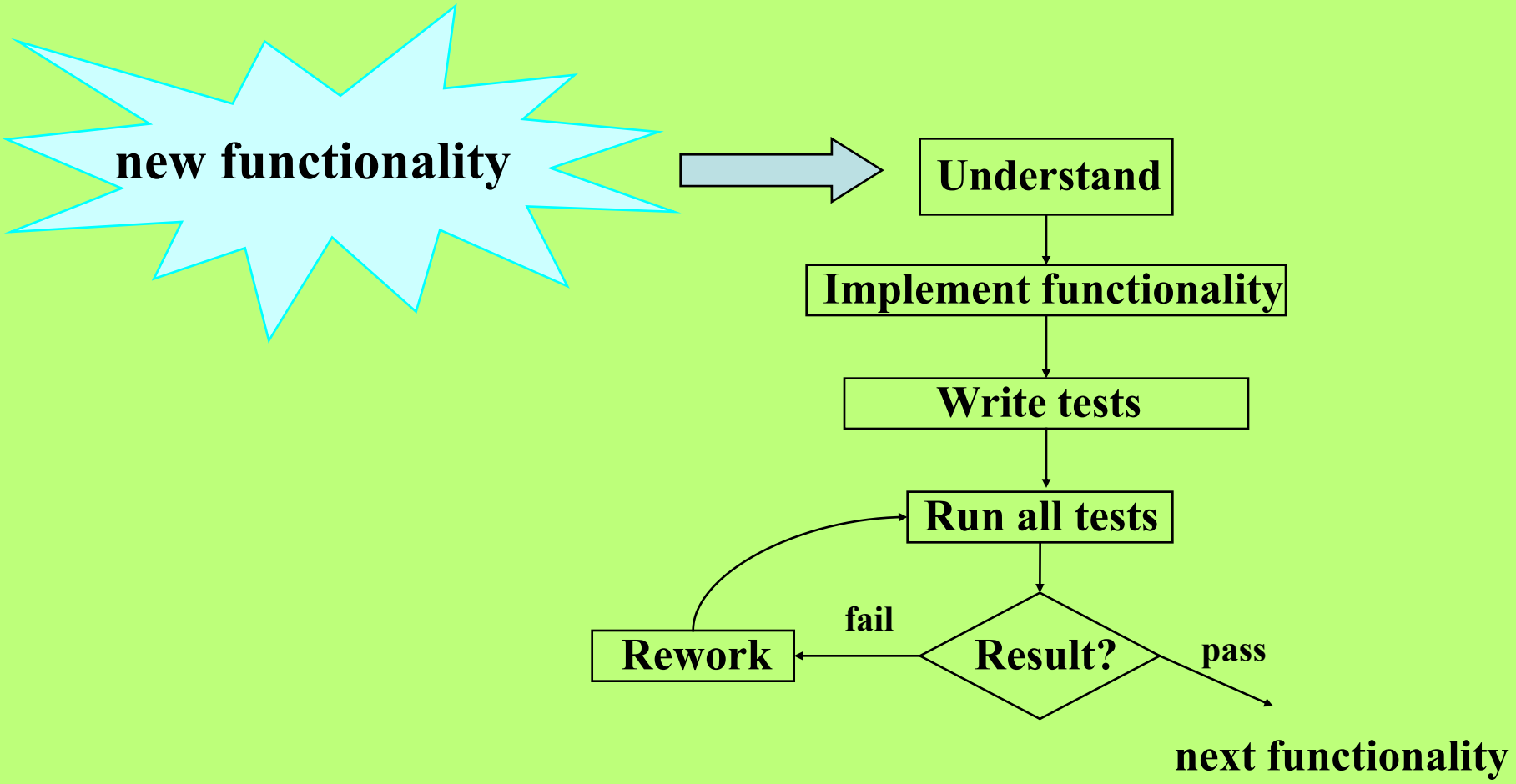
- **TDD is not**
  - a testing technique
  - all that new
    - used in the 1960's
      - NASA project
- **TDD is**
  - (micro) development and design technique
    - Test first
    - Refactoring
  - cornerstone of XP

# A little bit of History

- **In the early 1960s**
  - TDD used in NASA's Project Mercury
- **In 1996**
  - K. Beck "rediscovered" TDD during the C project
    - C3 = payroll system
    - C3 was never fully implemented!
    - C3 was eventually shut down!
- **In 1999**
  - *K. Beck, Extreme Programming Explained, Addison Wesley*
- **In 2003**
  - *K. Beck, Test-Driven Development by Example, Addison Wesley*

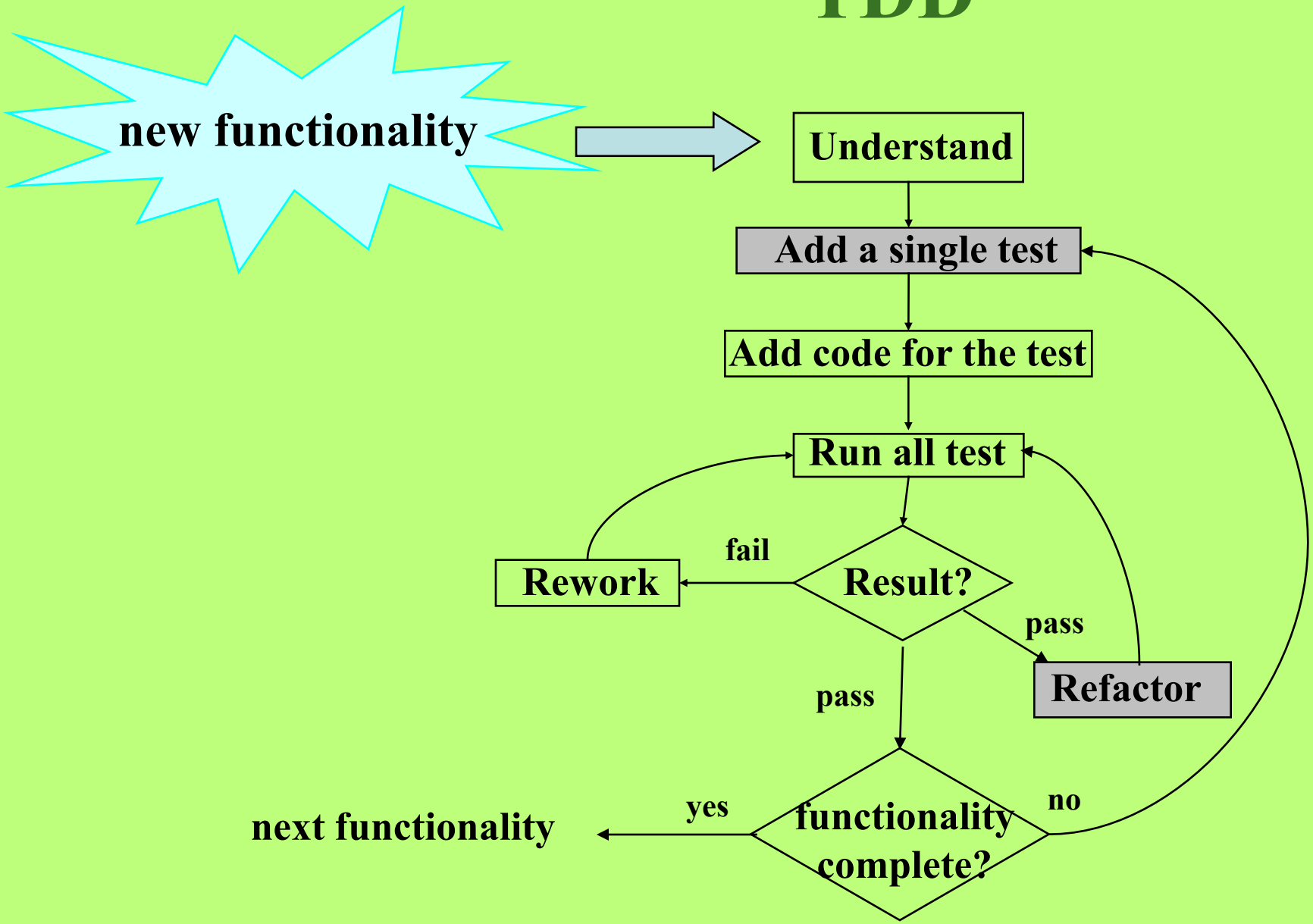


# Test last development




"new functionality" = class with methods

# TDD


new functionality
Understand
Add a single test
Add code for the test
Run all test
Result?
fail
Rework
pass
Refactor
pass
functionality complete?
yes
next functionality
no

# (Supposed) Benefits of TDD

- Code more cohesive and less coupled
- Simplify the design
- Improve software quality
  - in terms of decreased fault rates
- Improve testability
- Augment the test coverage
- Improve documentation
- Simplify maintenance/restructuring
  - Regression suite

Is it true?

If yes, direct consequence or indirect of TDD?

# (Supposed) Drawbacks of TDD

- Limited by “skill&experience” of developers
  - No upfront design
- Some codes are hard to test with TDD
  - GUIs
  - Effort to write mock objects
- Effort required is high
  - in terms of time
- “Tight Coupling” with automatic testing tools
  - JUnit

# JUnit

- JUnit is a **unit test environment** for Java
  - Writing test cases
  - Executing test cases
    - Pass/fail? (red/green bar)
- Developed by *Eric Gamma* and *Kent Beck*
- **Framework** providing all the tools for testing
  - Framework=set of Java classes and conventions to use them
- Integrated into **Eclipse**

# Stack example: main

JUnit tests "substitute the use of **main**"

```
public class Stack {
   …
      public static void main (String[] args) {
         Stack aStack = new Stack();
         if (!aStack.isEmpty()) {
               System.out.println ("Stack should be empty!");
         }
         aStack.push(10);
         aStack.push(-4);
         System.out.println("Last element:" + aStack.pop());
         System.out.println("First element: " + aStack.pop());
      }
}
```

```
public class Stack {
   isEmpty()
   pop()
   push(...)
}
```

-4

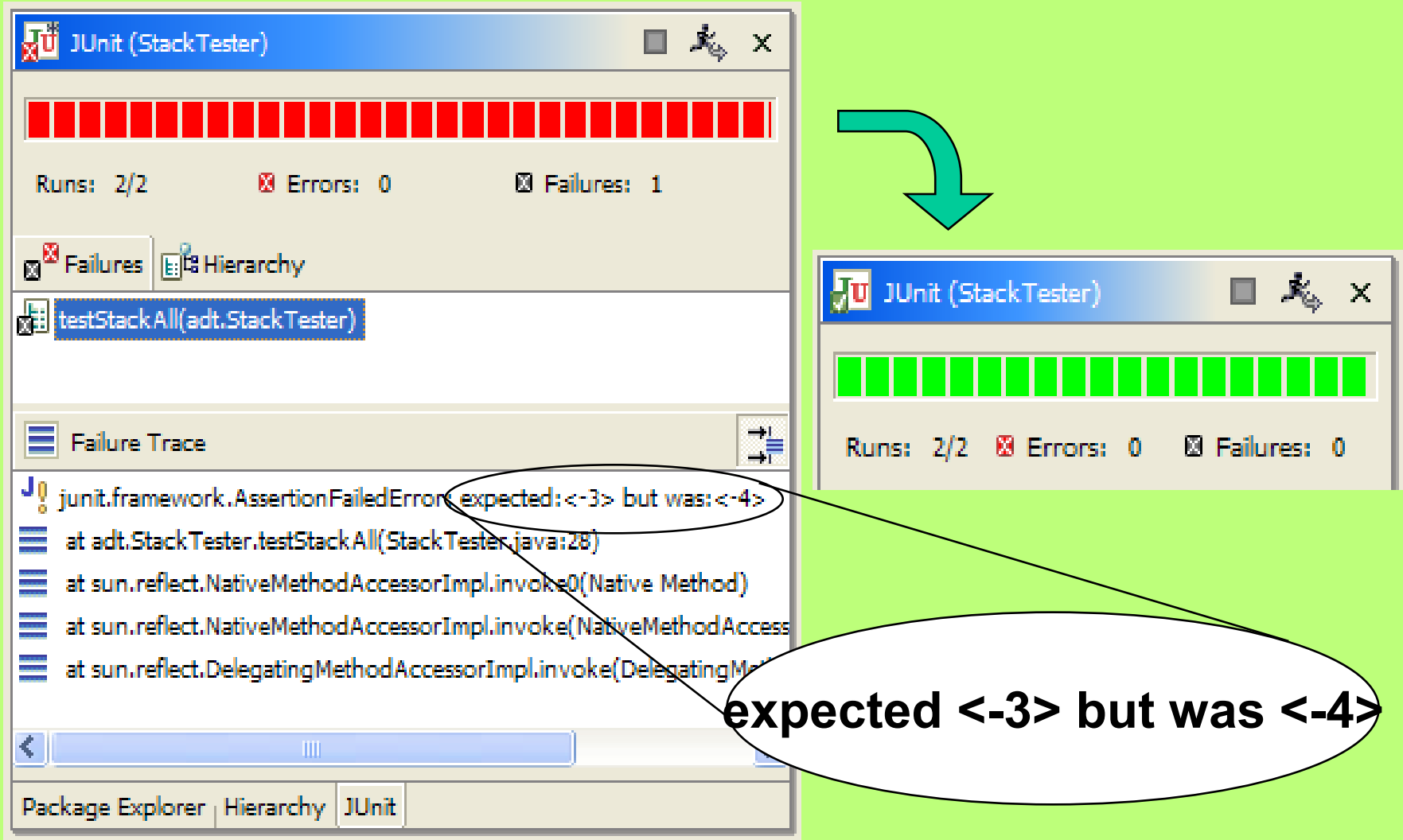
10

# Stack example: JUnit

```
public class Stack {
   isEmpty()
   pop()
   push(...)
}
```

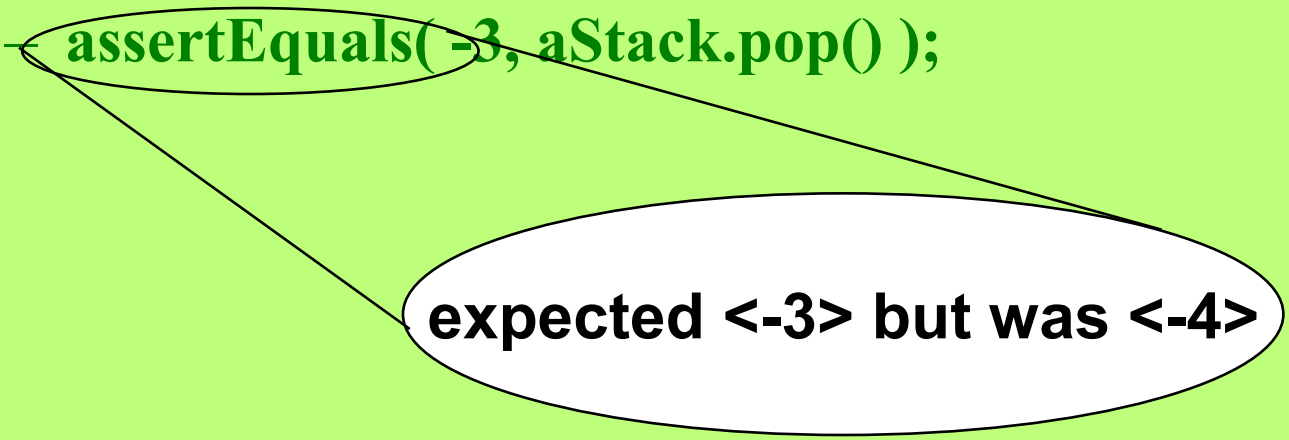
```
import junit.framework.TestCase;

public class StackTester extends TestCase {

 …

  public void testStack() {
    Stack aStack = new Stack();
    assertTrue("Stack should be empty!", aStack.isEmpty());
    aStack.push(10);
    assertTrue("Stack should not be empty!",!aStack.isEmpty());
    aStack.push(-4);
    assertEquals(-4, aStack.pop());
    assertEquals(10, aStack.pop());
  }
}
```

# Red / Green Bar



# Failures vs. Errors

- **Failure**: assertion not satisfied
  - **assertEquals( -3, aStack.pop() );**



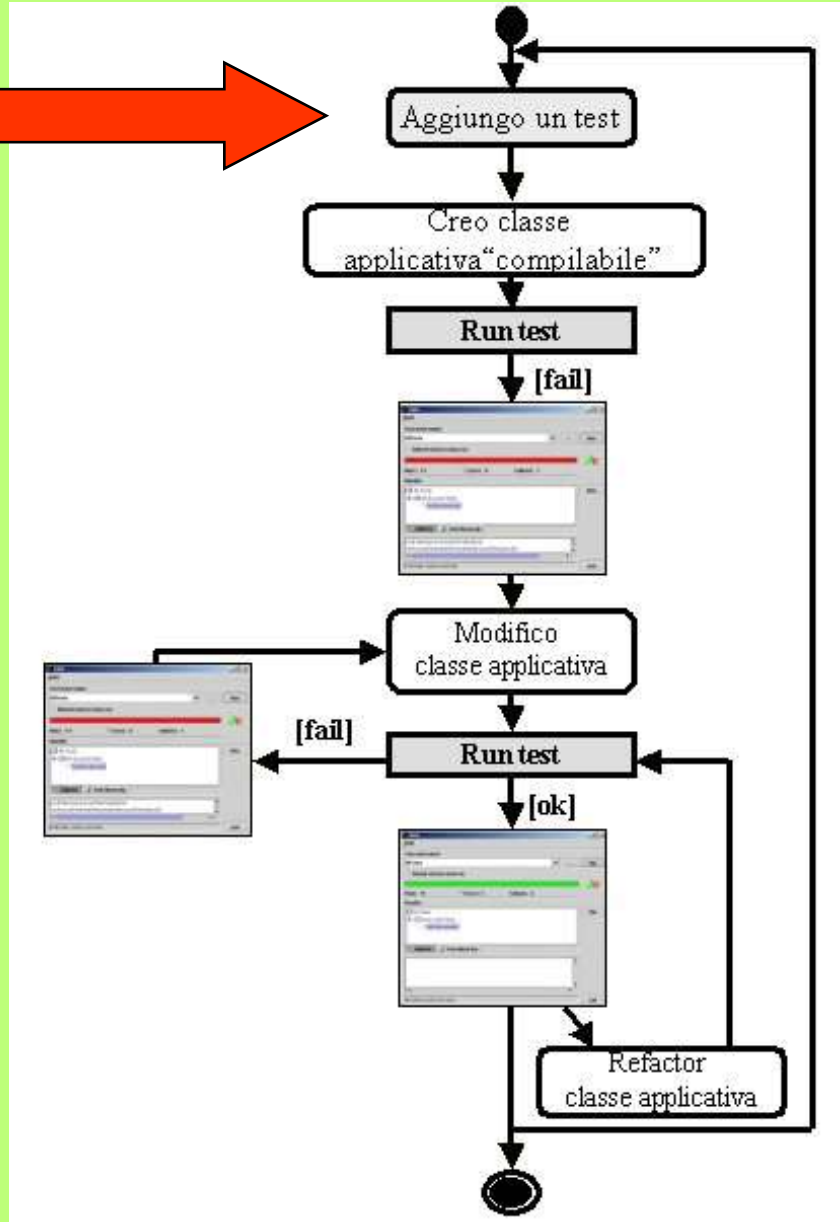

- **Error**: run time error
  - **assertEquals( -3, saldo.getSaldo() );**

java.lang.ArrayIndexOutOfBoundsException …

# TDD in practice …

- **New Functionality:**
  - Create a class current account (bank account)
    - deposit (*deposito*)
    - withdraw (*prelievo*)
    - settlement (*saldo*)

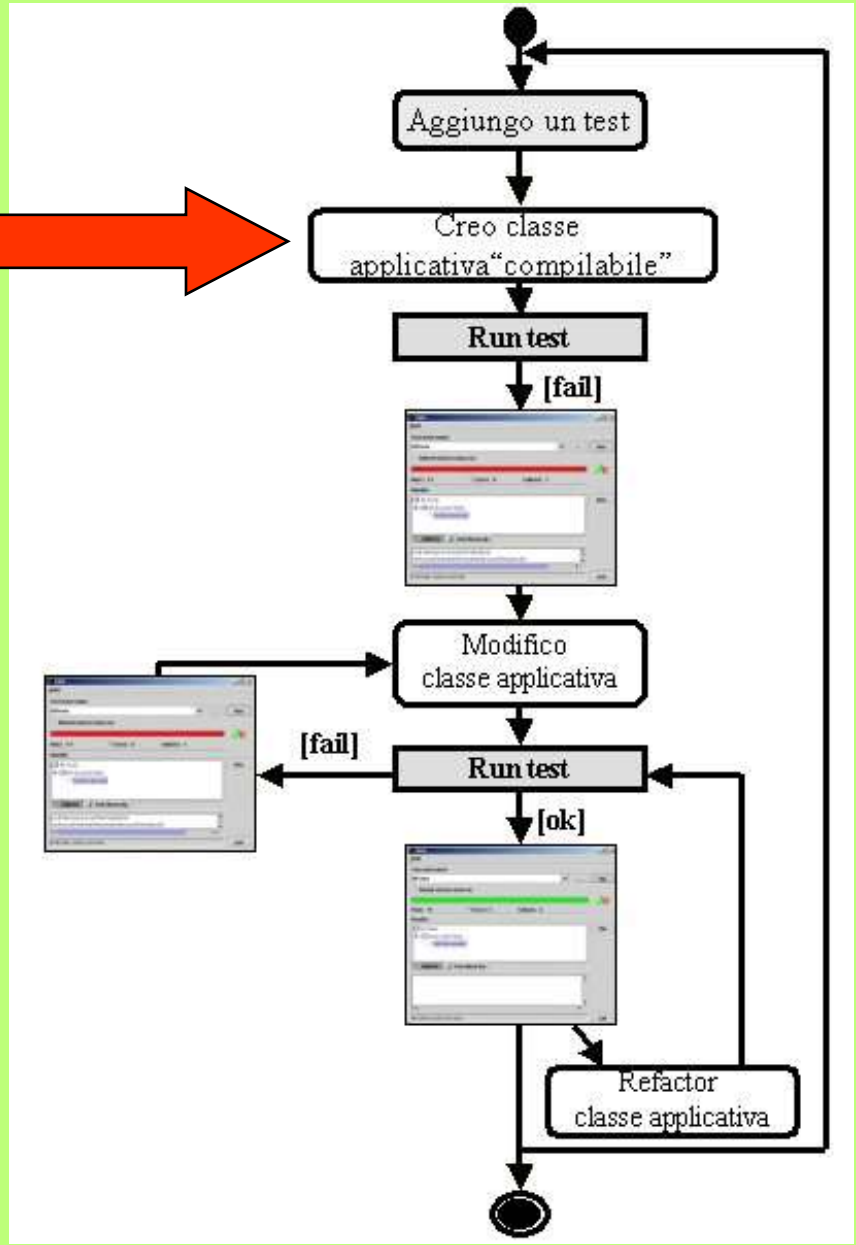
**Example:**


Aggiungo un test
Creo classe applicativa"compilabile"
Run test
[fail]
Modifico classe applicativa
[fail]
Run test
[ok]
Refactor classe applicativa

# Add a single test

```
import junit.framework.TestCase;

public class Test_account extends TestCase {

    public void testSettlement() {
        CAccount c = new CAccount();
        c.deposit(12);
        c.draw(-8);
        c.deposit(10);
        assertTrue(c.settlement() == 14);
    }
}
```

*"assertion"* 

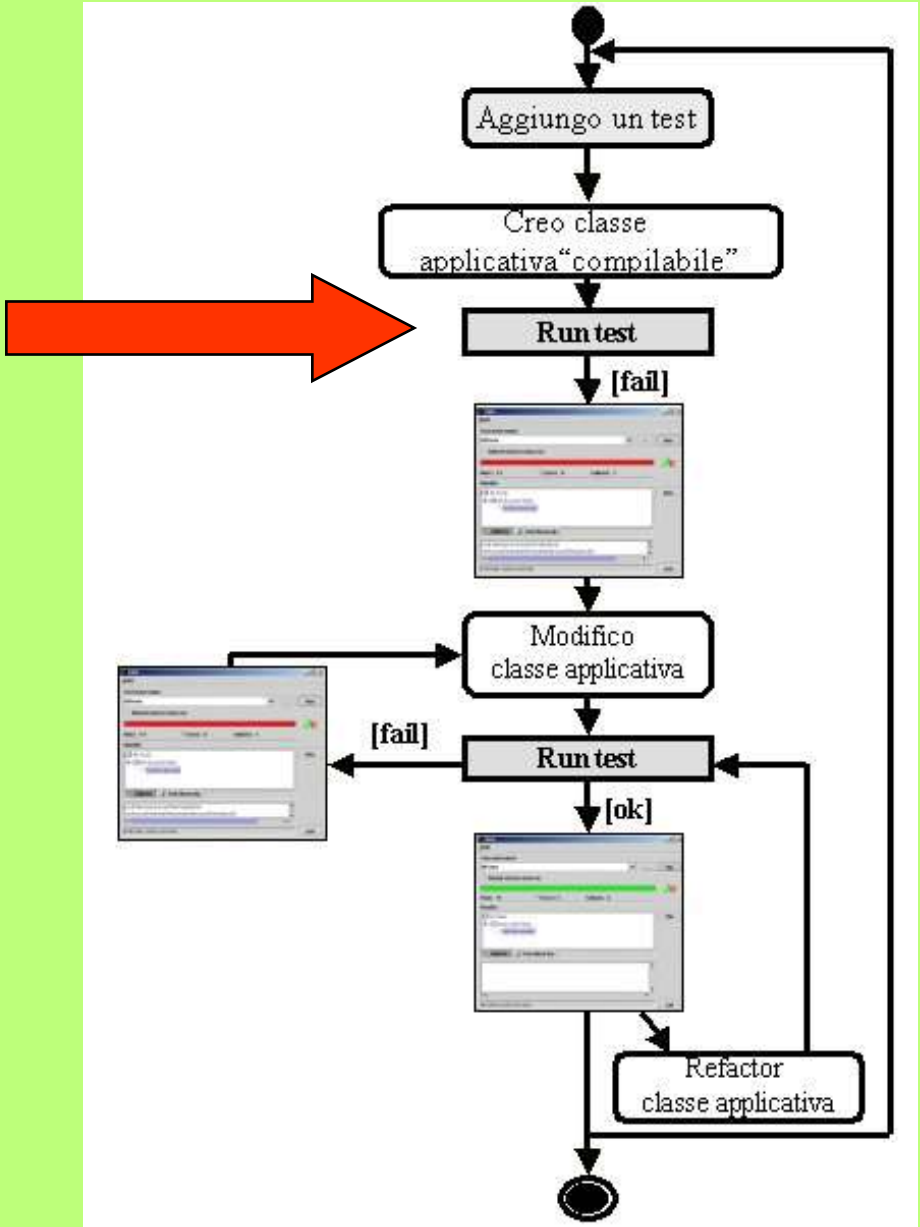

Aggiungo un test
Creo classe applicativa"compilabile"
Run test
[fail]
Modifico classe applicativa
[fail]
Run test
[ok]
Refactor classe applicativa

# Add the skeleton of class

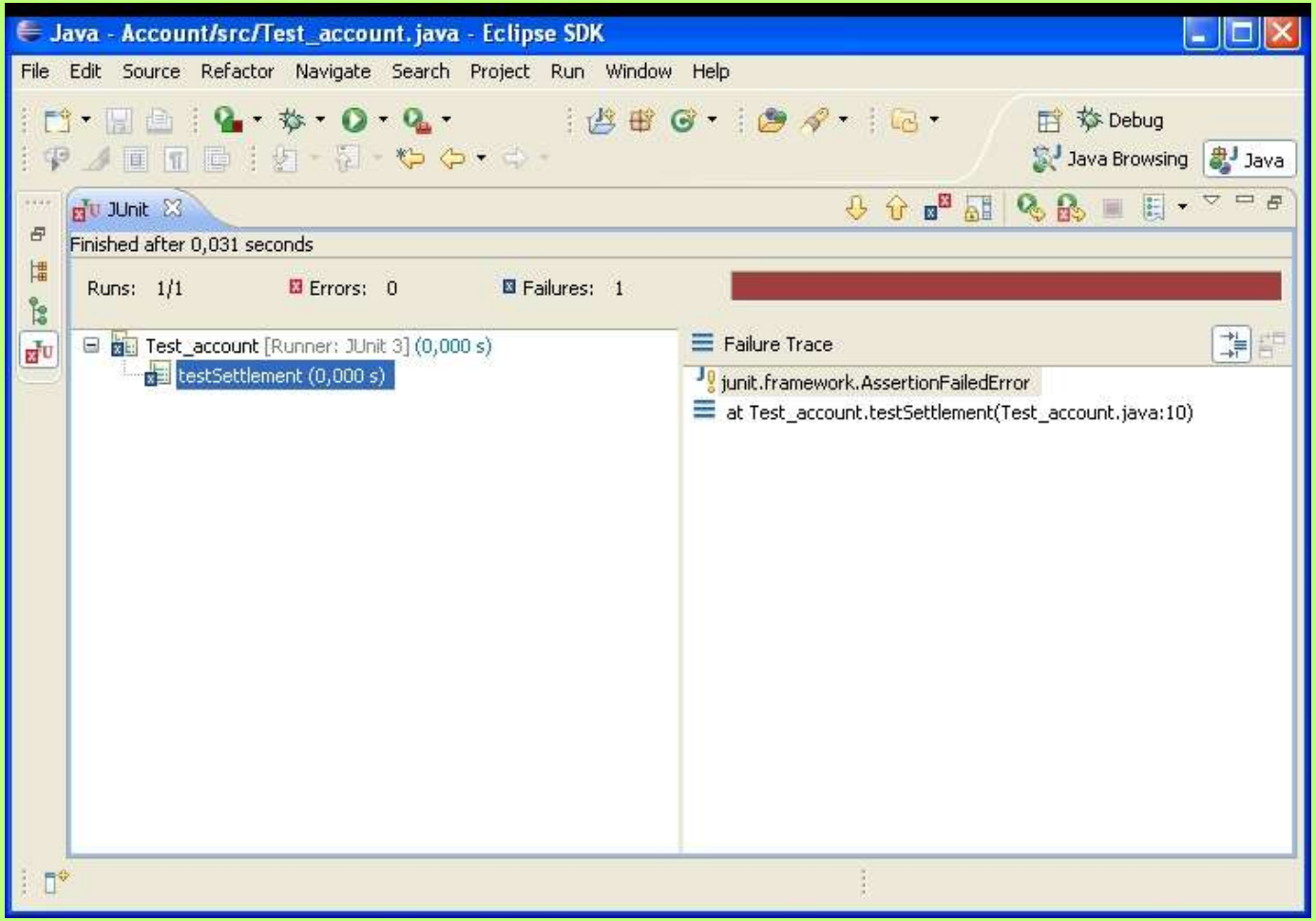
```
public class CAccount {

  public void deposit(int i) {
    // Auto-generated method stub
  }
  public void draw(int i) {
    // Auto-generated method stub
  }
  public int settlement() {
    // Auto-generated method stub
  return 0;
  }
}
```

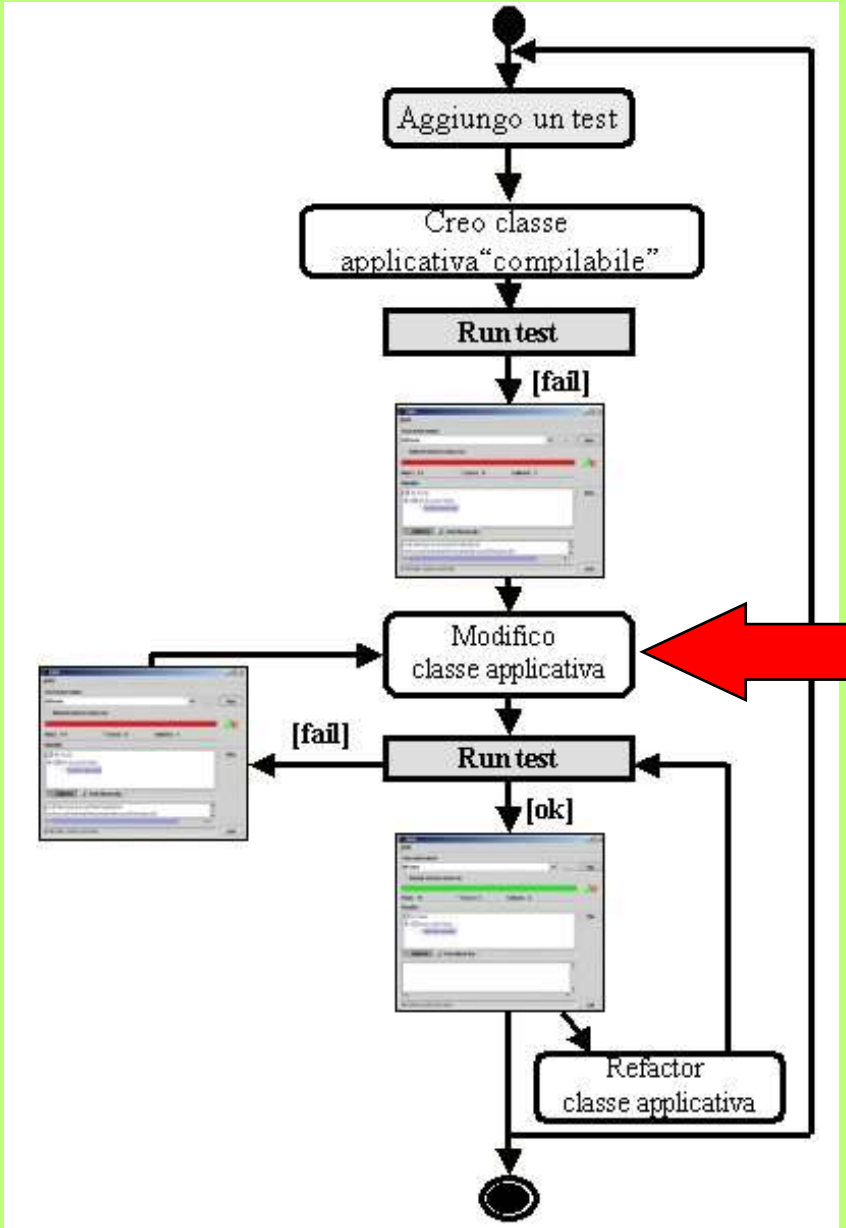
```
import junit.framework.TestCase;

public class Test_account extends TestCase {

    public void testSettlement() {
        CAccount c = new CAccount();
        c.deposit(12);
        c.draw(-8);
        c.deposit(10);
        assertTrue(c.settlement() == 14);
    }
}
```

*"Eclipse auto-completion"*


Aggiungo un test
Creo classe applicativa"compilabile"
Run test
[fail]
Modifico classe applicativa
[fail]
Run test
[ok]
Refactor classe applicativa

# Run JUnit (1)

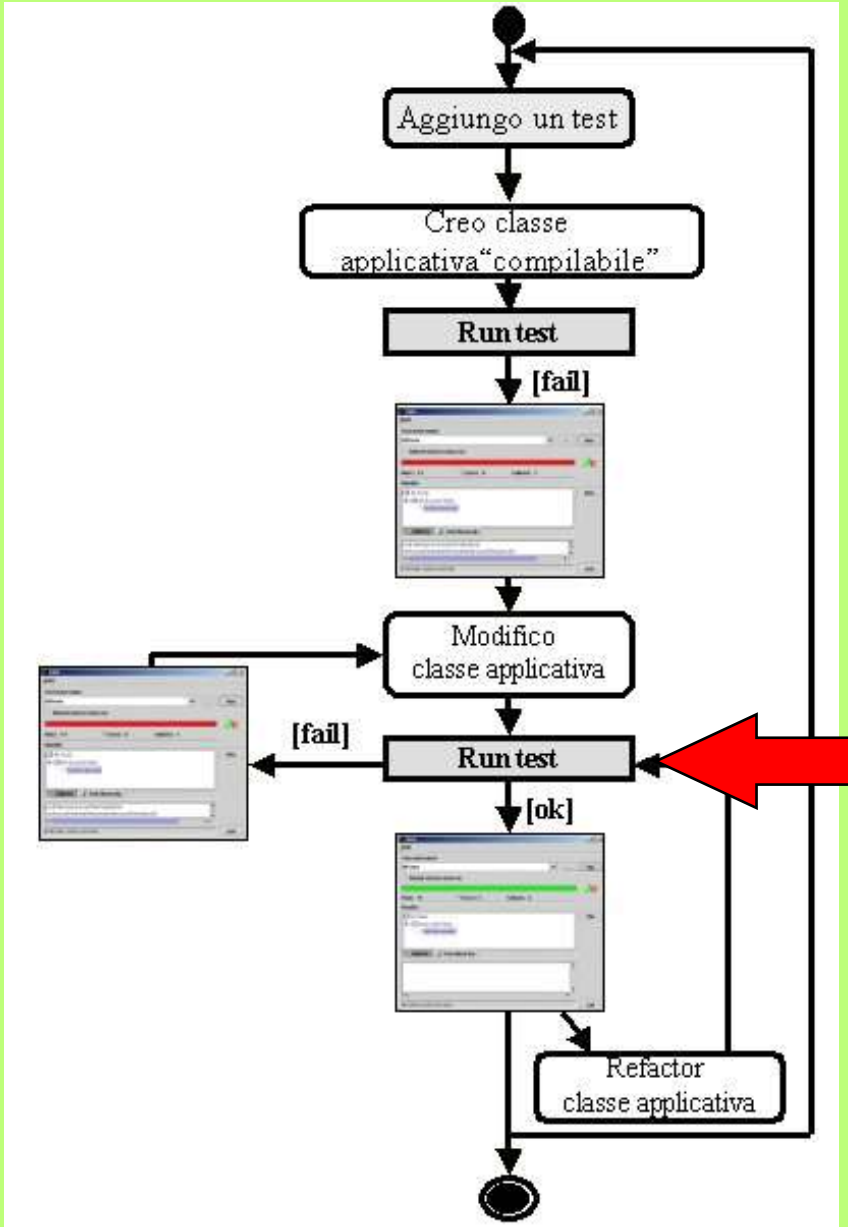

Java - Account/src/Test_account.java - Eclipse SDK
File Edit Source Refactor Navigate Search Project Run Window Help
Debug
Java Browsing
Java
JUnit
Finished after 0,031 seconds
Runs: 1/1
Errors: 0
Failures: 1
Test_account [Runner: JUnit 3] (0,000 s)
testSettlement (0,000 s)
Failure Trace
junit.framework.AssertionFailedError
at Test_account.testSettlement(Test_account.java:10)


Aggiungo un test
Creo classe applicativa"compilabile"
Run test
[fail]
Modifico classe applicativa
[fail]
Run test
[ok]
Refactor classe applicativa

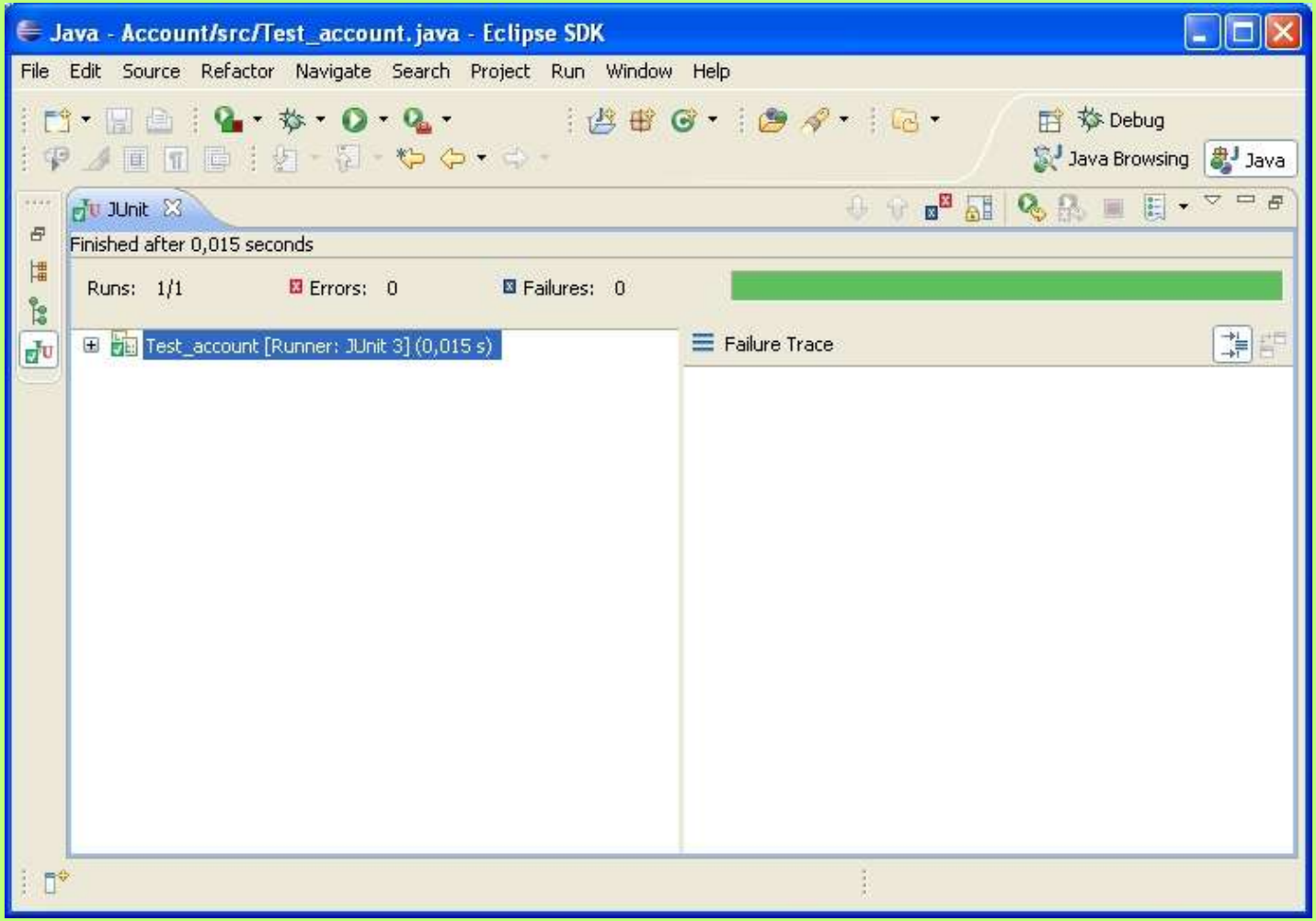
```
public class CAccount {

int account[]; int lastMove;

public CAccount(){
   lastMove=0; account=new int[10];}

public void deposit(int value){
   account[lastMove]=value;
   lastMove++;
}

public void draw(int value) {
   account[lastMove]=value;
   lastMove++;
}

public int settlement() {
  int result = 0;
  for (int i=0; i<account.length; i++) {
      result = result + account[i];
   }
  return result;
 }
}
```

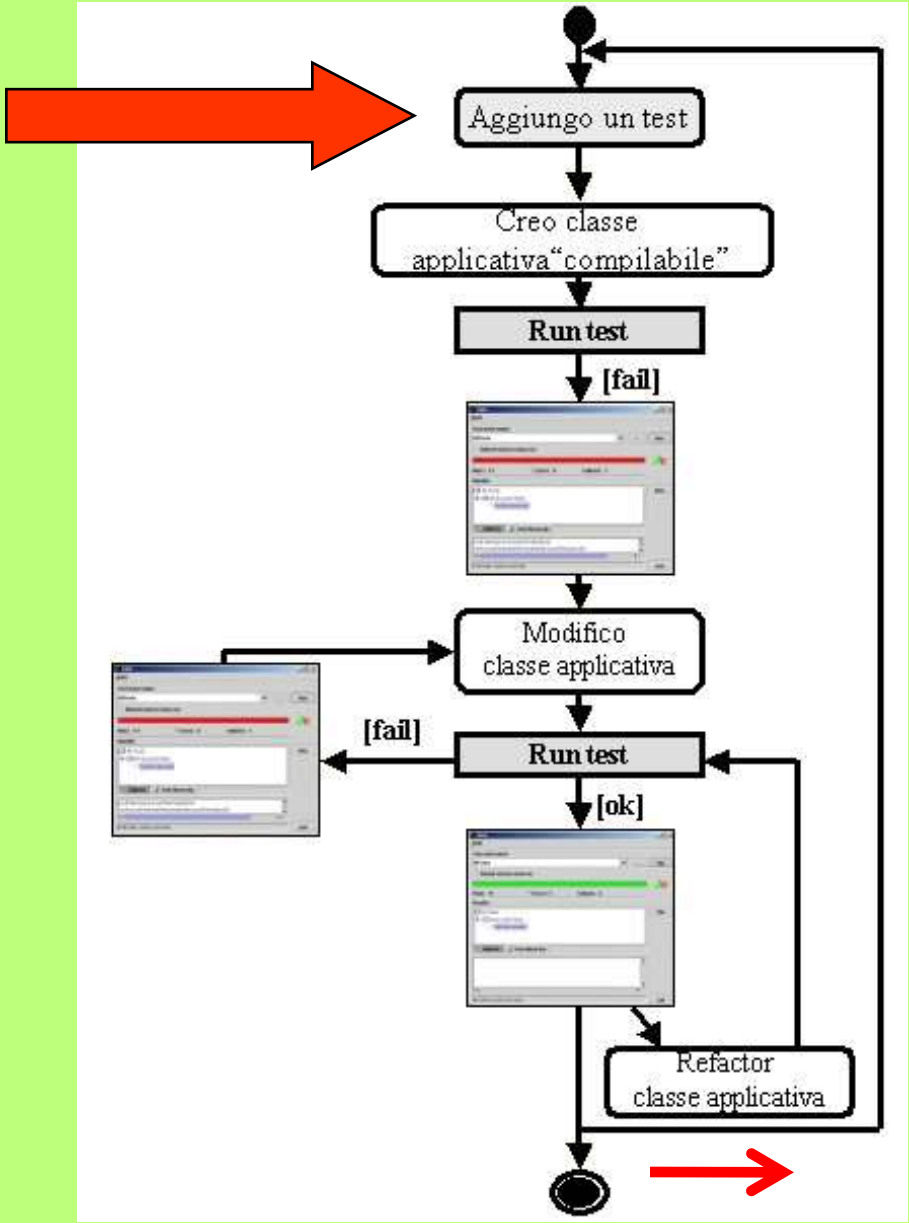
# Rework

```
import junit.framework.TestCase;

public class Test_account extends TestCase {

   public void testSettlement() {
     CAccount c = new CAccount();
      c.deposit(12);
      c.draw(-8);
      c.deposit(10);
      assertTrue(c.settlement() == 14);
   }
}
```


Aggiungo un test
Creo classe applicativa"compilabile"
Run test
[fail]
Modifico classe applicativa
[fail]
Run test
[ok]
Refactor classe applicativa

# Run JUnit (2)

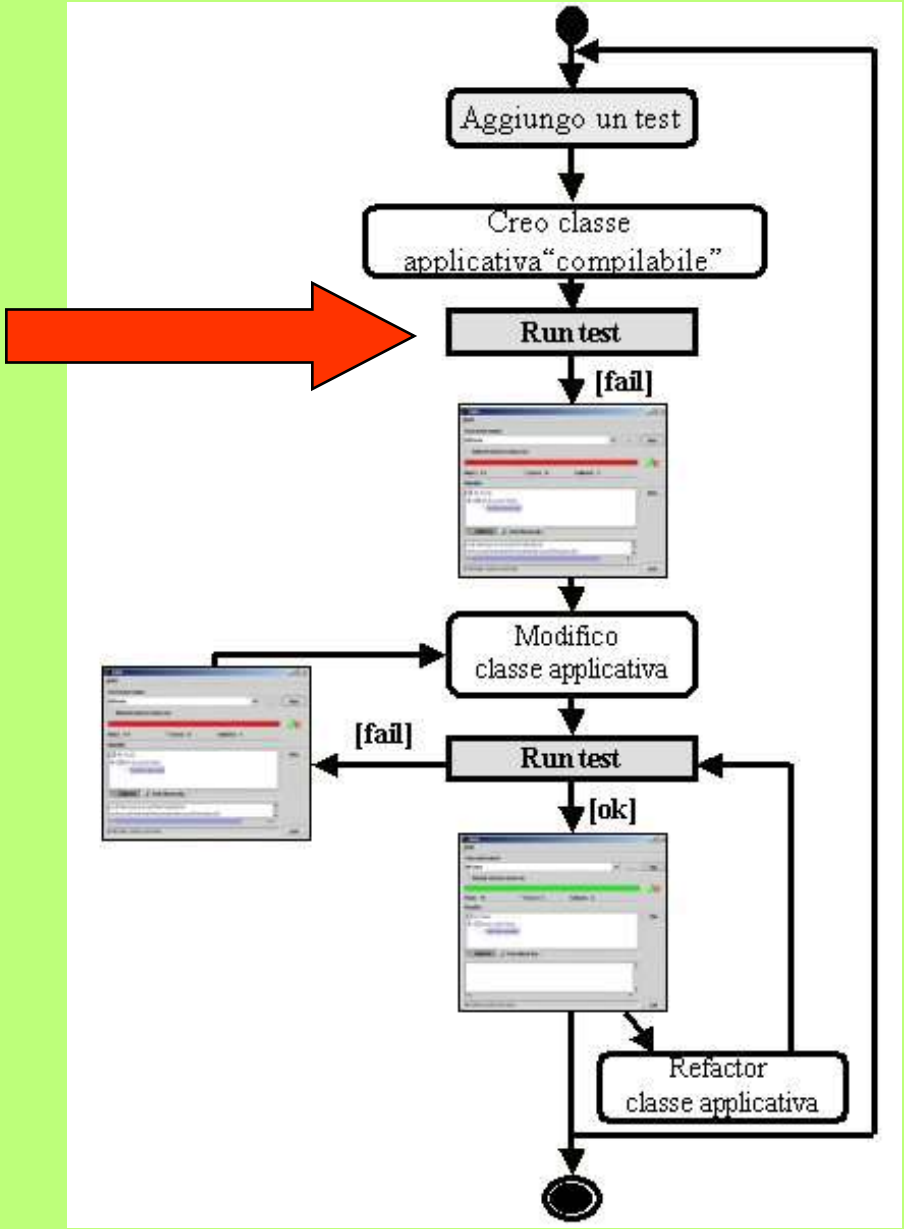

Java - Account/src/Test_account.java - Eclipse SDK
File Edit Source Refactor Navigate Search Project Run Window Help
Debug
Java Browsing
Java
JUnit
Finished after 0,015 seconds
Runs: 1/1
Errors: 0
Failures: 0
Test_account [Runner: JUnit 3] (0,015 s)
Failure Trace


Aggiungo un test
Creo classe applicativa"compilabile"
Run test
[fail]
Modifico classe applicativa
[fail]
Run test
[ok]
Refactor classe applicativa

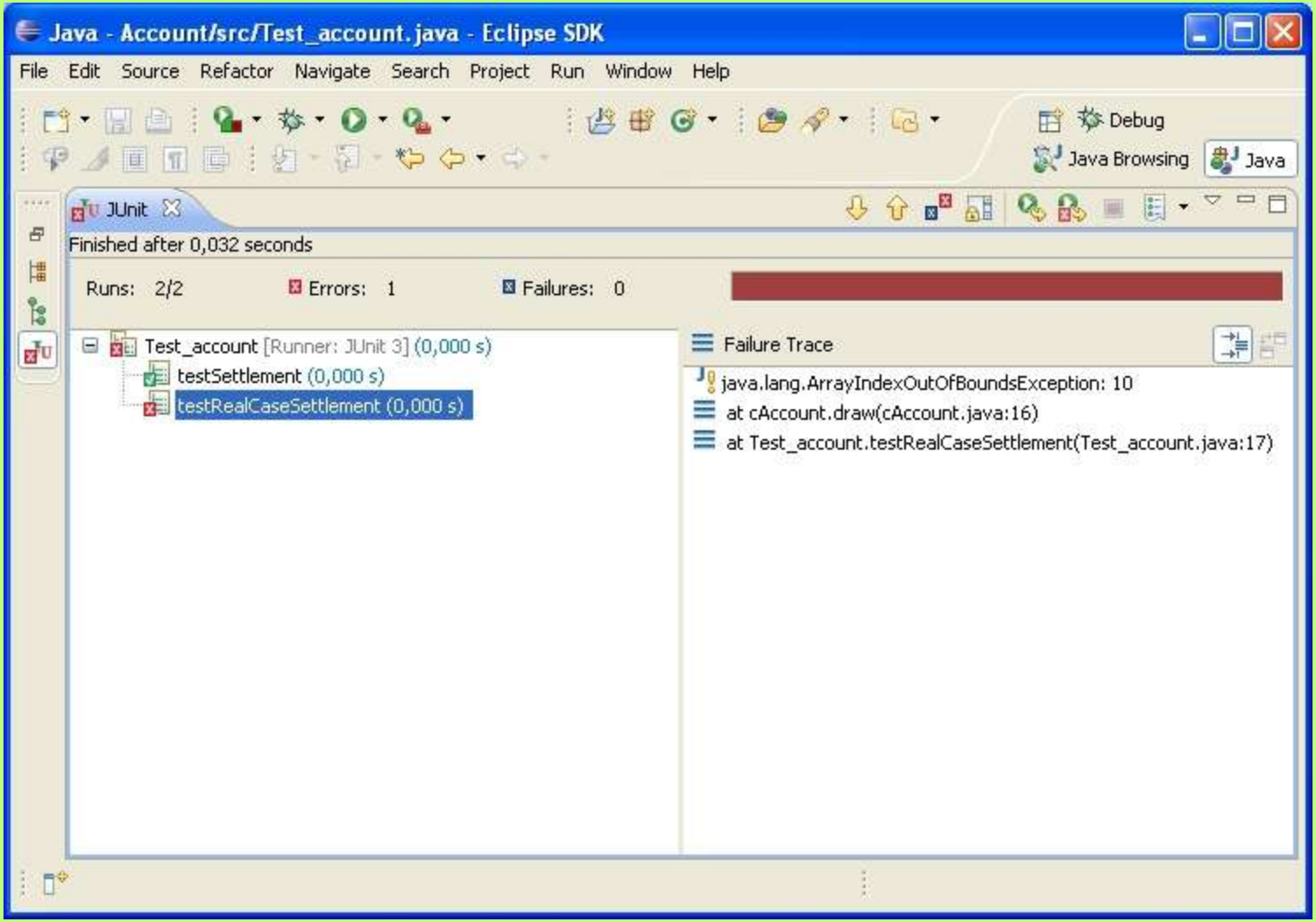
```
public class CAccount {

int account[]; int lastMove;

public CAccount(){
   lastMove=0; account=new int[10];}

public void deposit(int value){
   account[lastMove]=value;
   lastMove++;
}

public void draw(int value) {
   account[lastMove]=value;
   lastMove++;
}

public int settlement() {
  int result = 0;
  for (int i=0; i<account.length; i++) {
      result = result + account[i];
   }
  return result;
 }
}
```

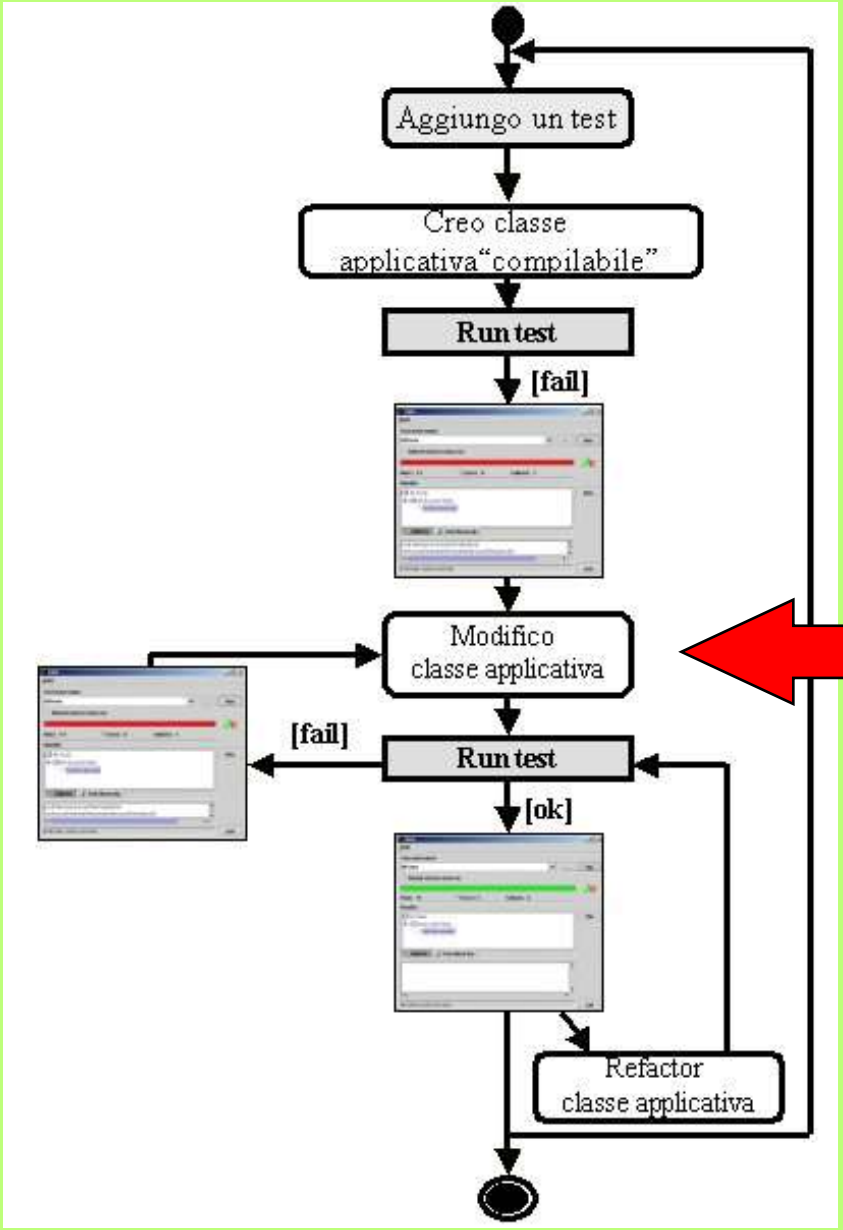
# Add a new test

```
public class Test_account extends TestCase {

public void testSettlement() {
     …..
}

public void testRealCaseSettlement() {
  CAccount c = new CAccount();
  for (int i=0; i <10 ; i++)
        c.deposit(1);
  c.draw(-10);
  assertTrue(c.settlement() == 0);
 }
}
```


Aggiungo un test
Creo classe applicativa"compilabile"
Run test
[fail]
Modifico classe applicativa
[fail]
Run test
[ok]
Refactor classe applicativa

# Run JUnit (3)

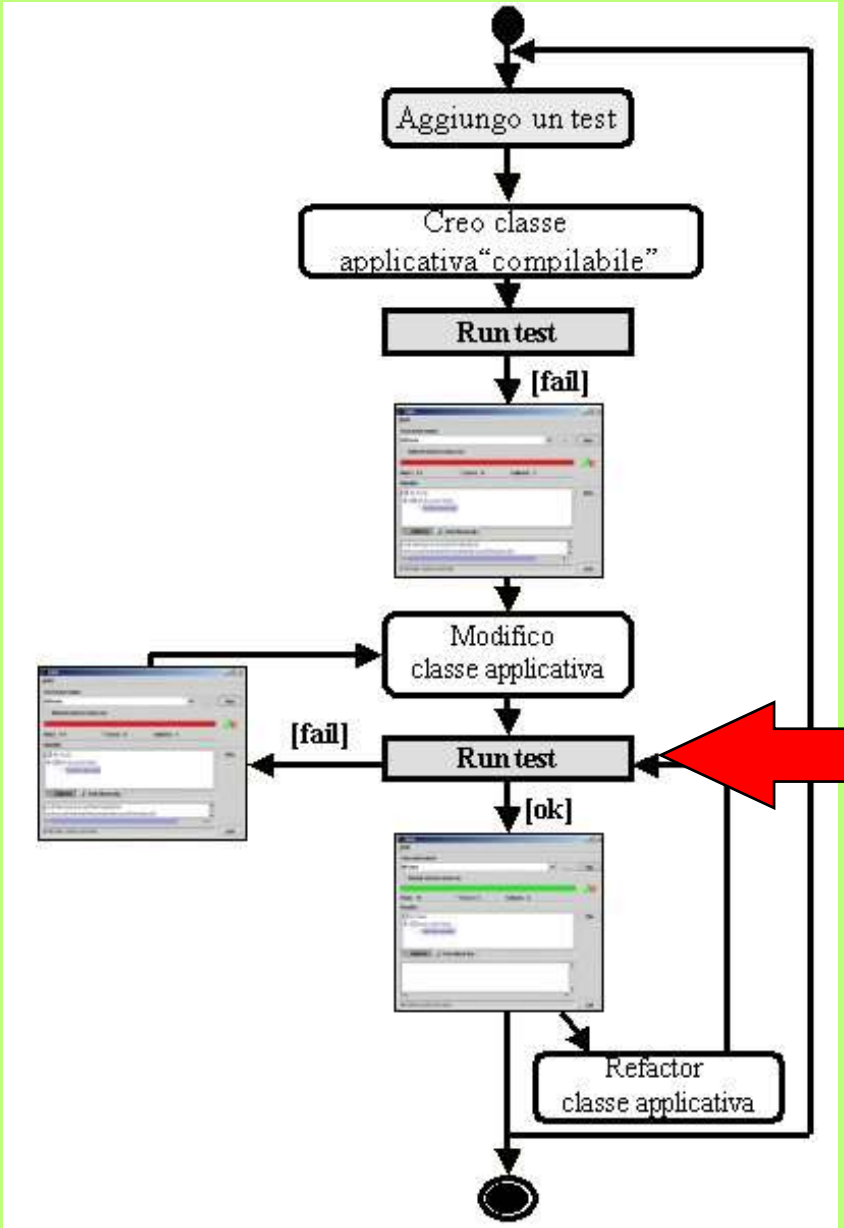

Java - Account/src/Test_account.java - Eclipse SDK
File Edit Source Refactor Navigate Search Project Run Window Help
Debug
Java Browsing
Java
JUnit
Finished after 0,032 seconds
Runs: 2/2
Errors: 1
Failures: 0
Test_account [Runner: JUnit 3] (0,000 s)
testSettlement (0,000 s)
testRealCaseSettlement (0,000 s)
Failure Trace
java.lang.ArrayIndexOutOfBoundsException: 10
at cAccount.draw(cAccount.java:16)
at Test_account.testRealCaseSettlement(Test_account.java:17)


Aggiungo un test
Creo classe applicativa"compilabile"
Run test
[fail]
Modifico classe applicativa
[fail]
Run test
[ok]
Refactor classe applicativa

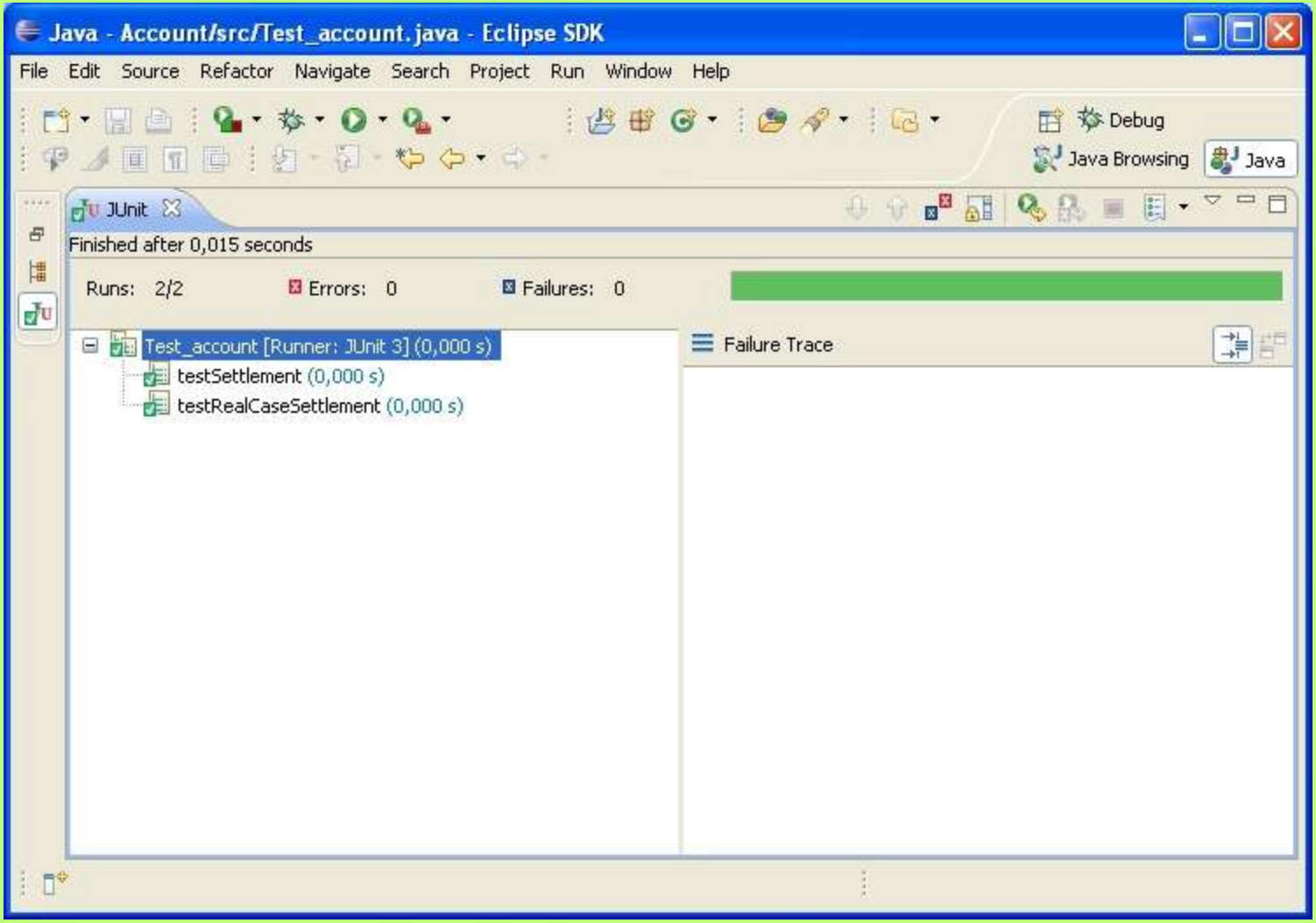
```
public class CAccount {
  List account = new LinkedList();
  public void deposit(int value){
    account.add(new Integer(value));
  }
  public void draw(int value){
    account.add(new Integer(value));
  }
  public int settlement() {
    int result = 0;
    Iterator it = account.iterator();
    while (it.hasNext()) {
      Integer valueI = (Integer)it.next();
      int val = valueI.intValue();
      result = result + val;
    }
    return result;
  }
}
```

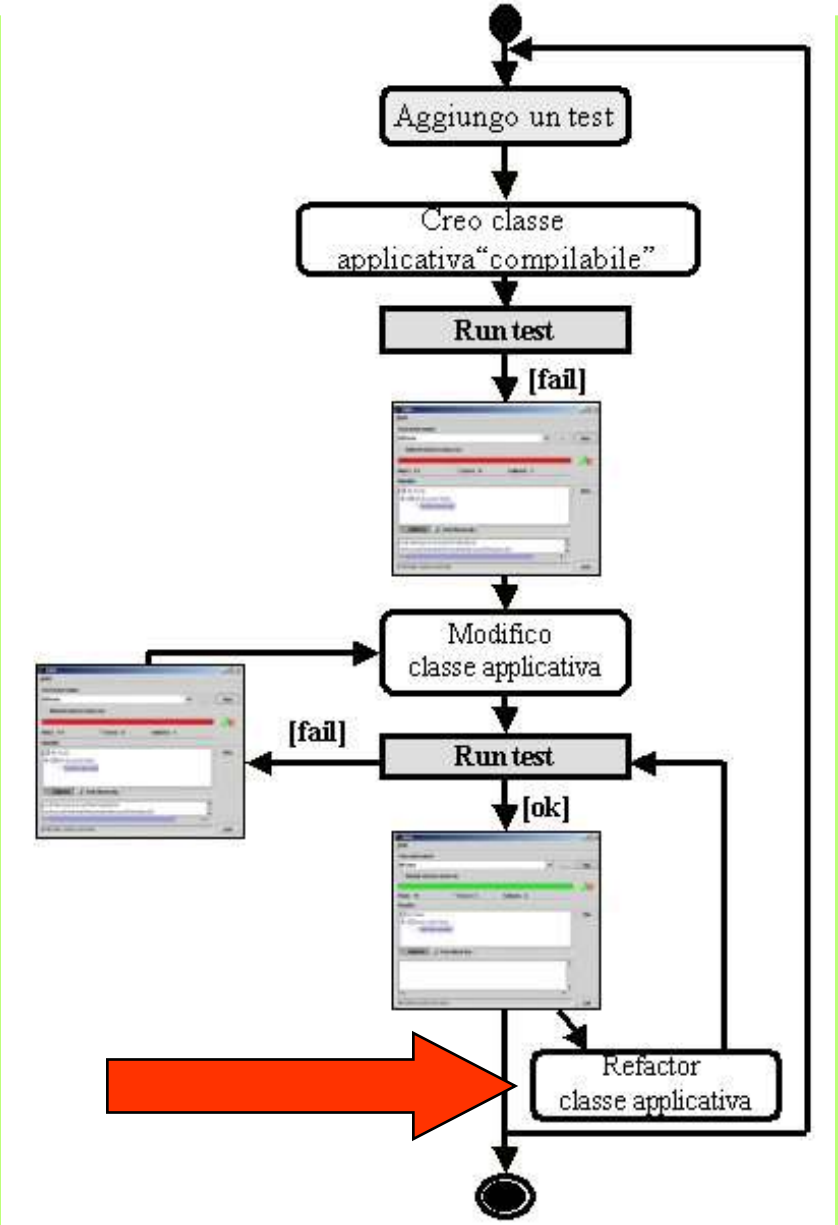
# Rework

```
public class Test_account extends TestCase {

public void testSettlement() {
      …..
}

public void testRealCaseSettlement() {
  CAccount c = new CAccount();
  for (int i=0; i <10 ; i++)
        c.deposit(1);
  c.draw(-10);
  assertTrue(c.settlement() == 0);
 }
}
```


Aggiungo un test
Creo classe applicativa"compilabile"
Run test
[fail]
Modifico classe applicativa
[fail]
Run test
[ok]
Refactor classe applicativa

# Run JUnit (4)


Java - Account/src/Test_account.java - Eclipse SDK
File Edit Source Refactor Navigate Search Project Run Window Help
Debug
Java Browsing
Java
JUnit
Finished after 0,015 seconds
Runs: 2/2
Errors: 0
Failures: 0
Test_account [Runner: JUnit 3] (0,000 s)
testSettlement (0,000 s)
testRealCaseSettlement (0,000 s)
Failure Trace

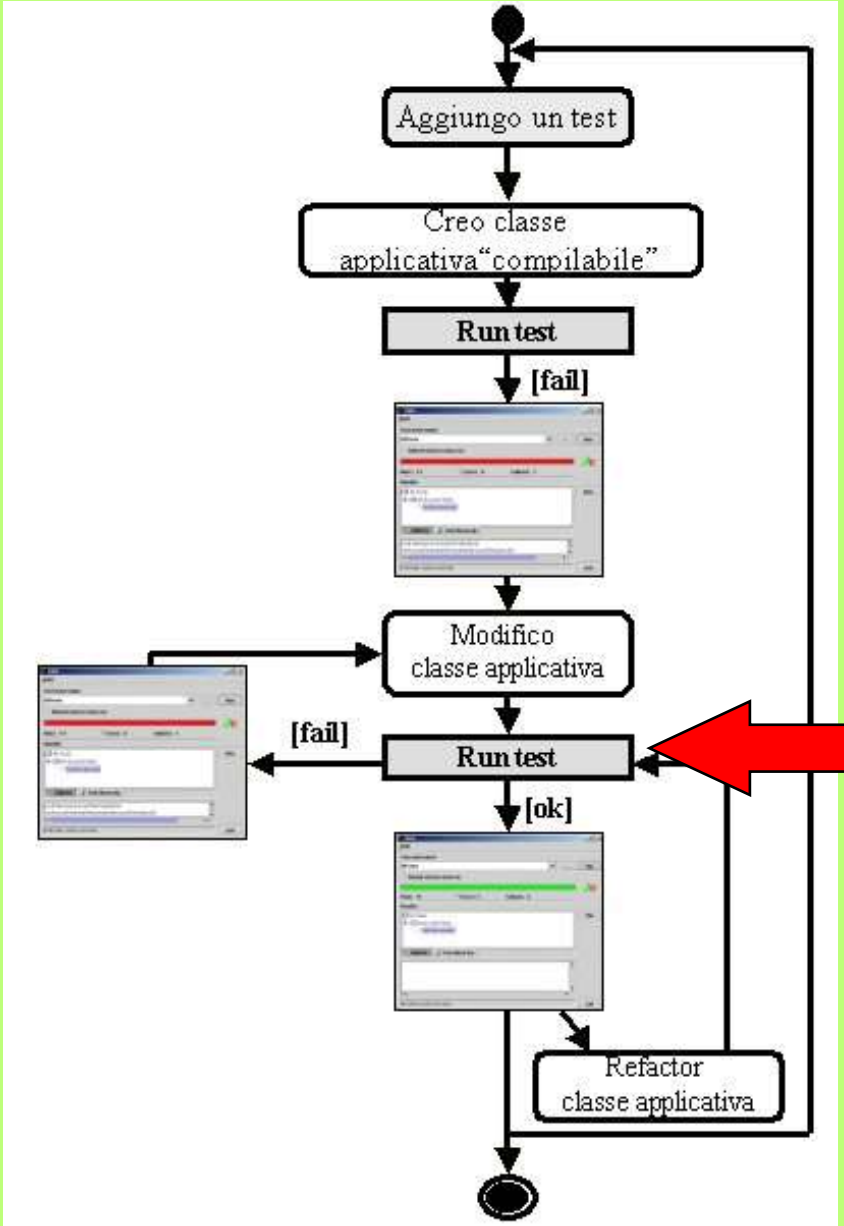



*"I can refactoring the program without anxiety. I have the testcases ..."*

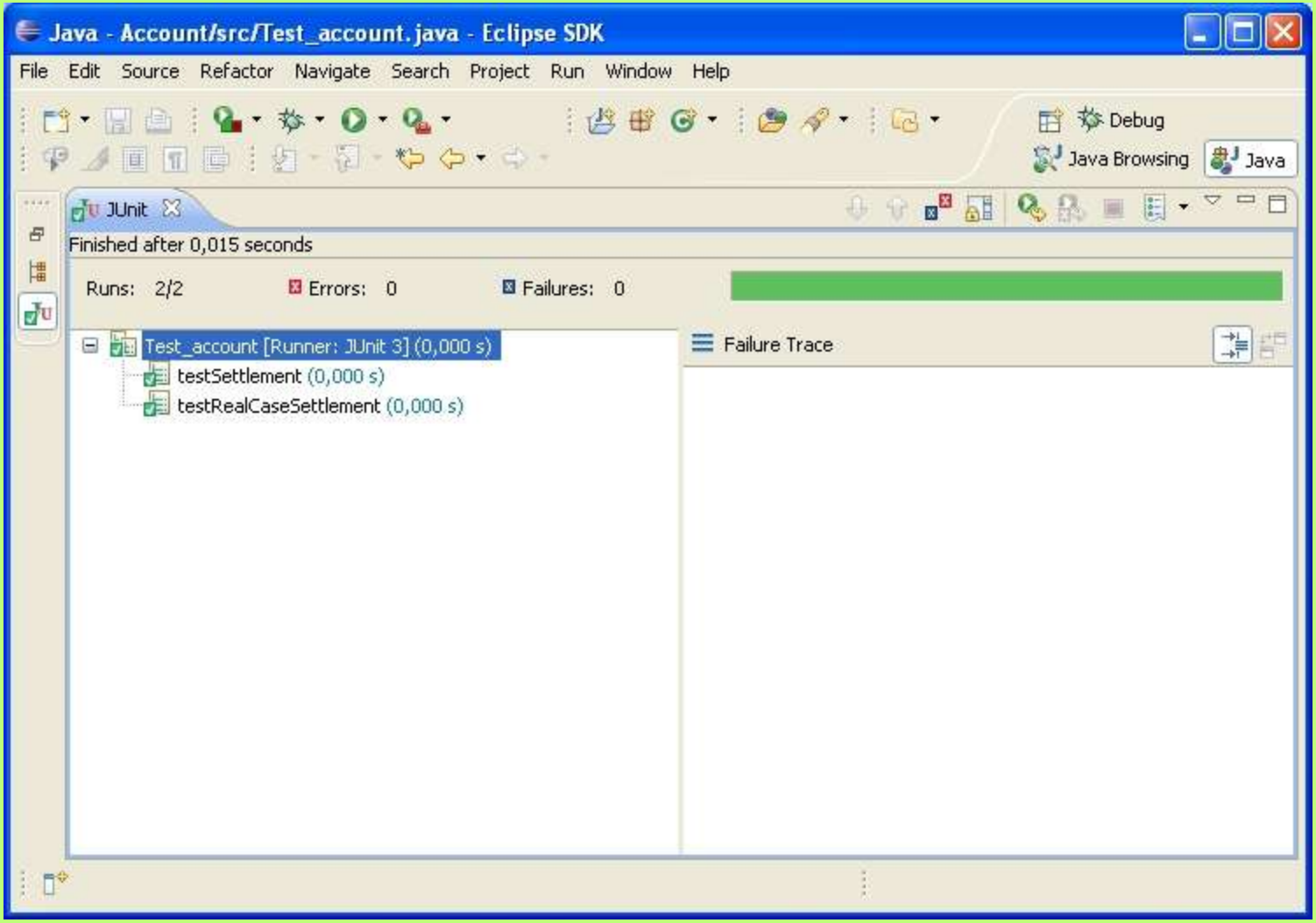
```
public class CAccount{
  List<Integer> account= new
     LinkedList<Integer>();
  public void deposit(int value){
    account.add(value);
   }
  public void draw(int value){
    account.add(value);
  }
  public int settlement() {
      int result = 0;
      for(int val: account) {
            result = result + val;
       }
  return result;
  }
}
```

# Refactor
## (Java generics)

```
public class Test_account extends TestCase {

public void testSettlement() {
      …..
}

public void testRealCaseSettlement() {
  CAccount c = new CAccount();
  for (int i=0; i <10 ; i++)
         c.deposit(1);
  c.draw(-10);
  assertTrue(c.settlement() == 0);
 }
}
```


Aggiungo un test
Creo classe applicativa"compilabile"
Run test
[fail]
Modifico classe applicativa
[fail]
Run test
[ok]
Refactor classe applicativa

# Run JUnit (5)


Java - Account/src/Test_account.java - Eclipse SDK
File Edit Source Refactor Navigate Search Project Run Window Help
Debug
Java Browsing
Java
JUnit
Finished after 0,015 seconds
Runs: 2/2
Errors: 0
Failures: 0
Test_account [Runner: JUnit 3] (0,000 s)
testSettlement (0,000 s)
testRealCaseSettlement (0,000 s)
Failure Trace

# Does Research Support the Effectiveness of Test Driven Development?

# Empirical studies

**Long list …**

| | |
|---|---|
| Madeyski [56] | CE |
| George, Williams [8] | QCE |
| Bhat, Nagappan [17] | CS |
| Erdogmus [3] | CE |
| Flor, Schneider [32] | QCE |
| Gupta, Jalote [57] | CE |
| Huang, Holcombe [4] | CE |
| Janzen, Saiedian [55] | QCE,CS |
| Janzen, Saiedian [24] | CE |
| Crispin [54] | CS |
| Geras et al. [16] | QCE |
| Pančur et al. [7] | CE |
| Siniaalto [21] | CS |
| Mueller, Hagner [5] | QCE |
| Madeyski [58] | CE |

…

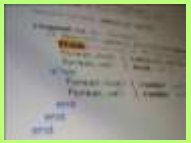
**CE = Controlled Exp**
**QCE = Quasi-Controlled Exp**
**CS = Case Study**

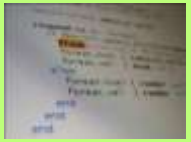
**Industrial Context**
**With professionals (toy example)**
**Academic Context**

# Experiment

TLD

implement





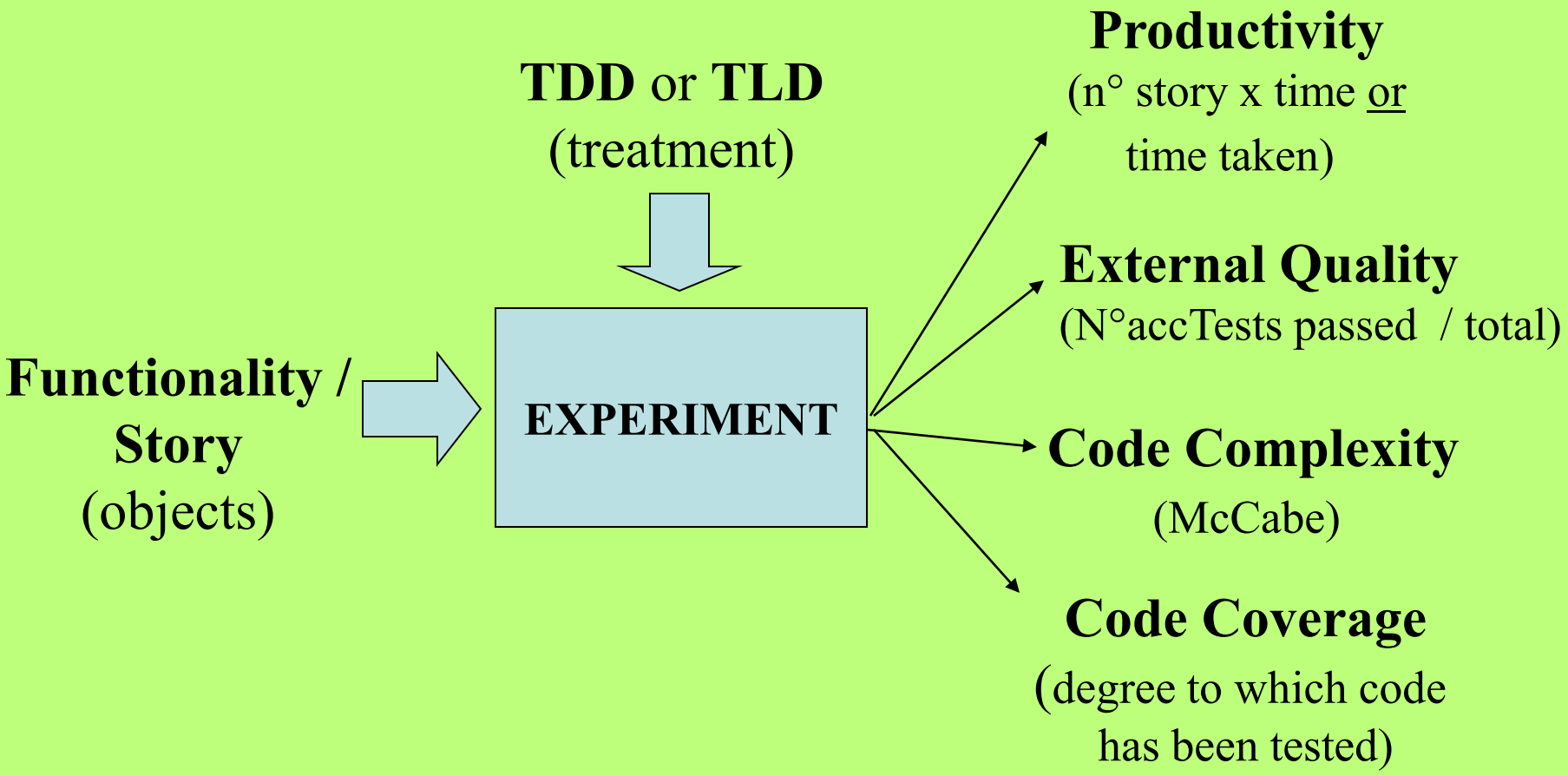
TDD

implement

?

2 Groups

# Variables


TDD or TLD
(treatment)
Functionality / Story
(objects)
EXPERIMENT
Productivity
(n° story x time or time taken)
External Quality
(N°accTests passed / total)
Code Complexity
(McCabe)
Code Coverage
(degree to which code has been tested)

Information and Software Tecnology 2011

Impact of test-driven development on productivity, code and tests: a controlled experiment

Matjaž Pančur[1] and Mojca Ciglarič

# Effects of TDD

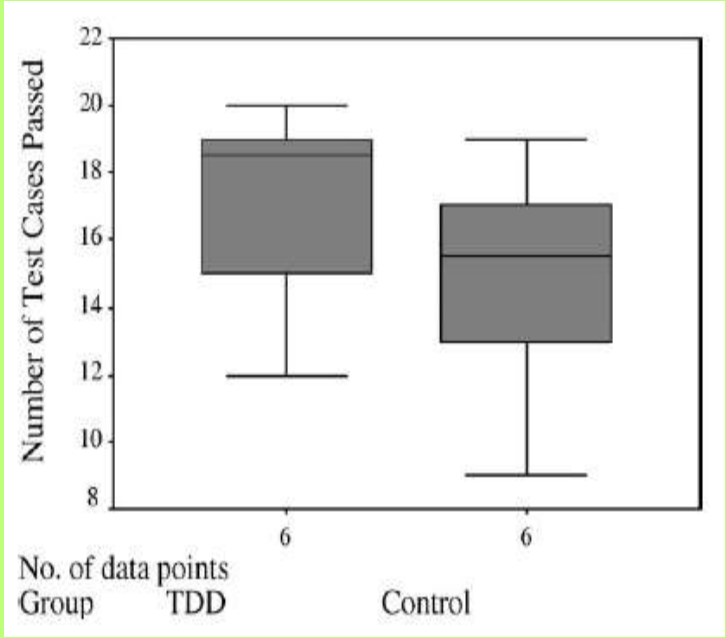
| | Study type | Productivity | External Quality | Complexity | Code Coverage |
|---|---|---|---|---|---|
| Madeyski [56] | CE | < | < | | > |
| George, Williams [8] | QCE | < | > | | |
| Bhat, Nagappan [17] | CS | < | | | > |
| Erdogmus [3] | CE | > | o | | |
| Flor, Schneider [32] | QCE | > | | | < |
| Gupta, Jalote [57] | CE | > | > | | |
| Huang, Holcombe [4] | CE | > | o | | |
| Janzen, Saiedian [55] | QCE,CS | | | > | |
| Janzen, Saiedian [24] | CE | | > | | |
| Crispin [54] | CS | | > | | |
| Geras et al. [16] | QCE | | o | | |
| Pančur et al. [7] | CE | | < | | < |
| Siniaalto [21] | CS | | | | > |
| Mueller, Hagner [5] | QCE | | | | < |
| Madeyski [58] | CE | | < | | |
| | | 4-3 | 4-3 | 1-0 | 3-3 |

15

(>) positive (<) negative (o) null

# George, Williams [8]

- Result:
  - TDD devs passed 18% more tests
  - TDD devs took 16% more time
- Threats to validity
  - Results are not statistically significant
  - Sample very small (24 subjects)
  - Pair programming
  - Application very small
    - 200 LOC
  - Different experience devs




**With professionals (toy example)**

# Conclusion

- Several supposed benefits of TDD
- Currently research **seems not support TDD** effectiveness
  - Overall result is not clear-cut
- But more replications are needed!
  - "Building Knowledge through Families of Experiments"
    - Victor R. Basili et alt., IEEE Trans. Software Eng. 25(4): 456-473 (1999)
- But a "serious" systematic review is needed!
  - Meta-analysis

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# Questions?