



Code Defenders

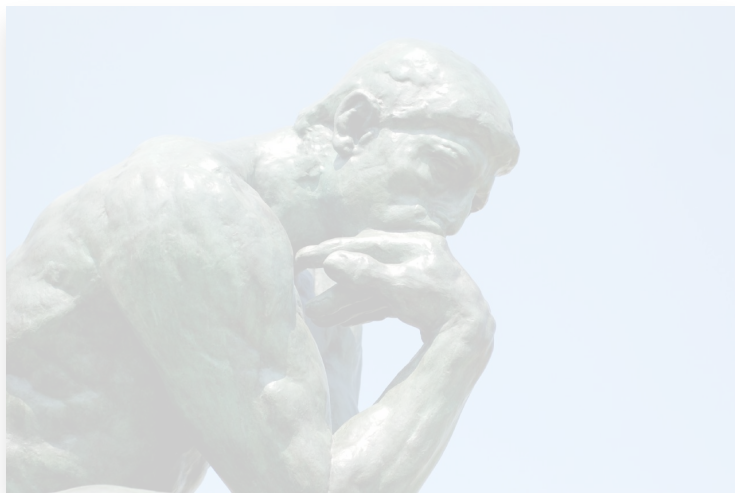
Crowdsourcing Effective Tests and Subtle Mutants
with a Mutation Testing Game

José Miguel Rojas, Thomas White, Benjamin Clegg, Gordon Fraser





On Fault-revealing Tests



by Brian Hillegas (Flickr)

Manual Testing

Writing good tests is difficult and time-consuming.

EVASUITE



Randoop

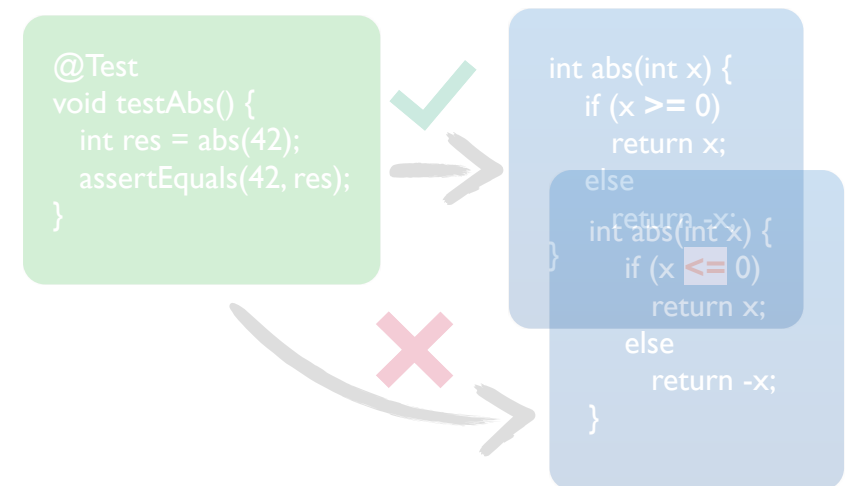
Automatic unit test generation

AgitarOne

PUTTING JAVA TO THE TEST

Test Generation

High coverage, but weak assertions.

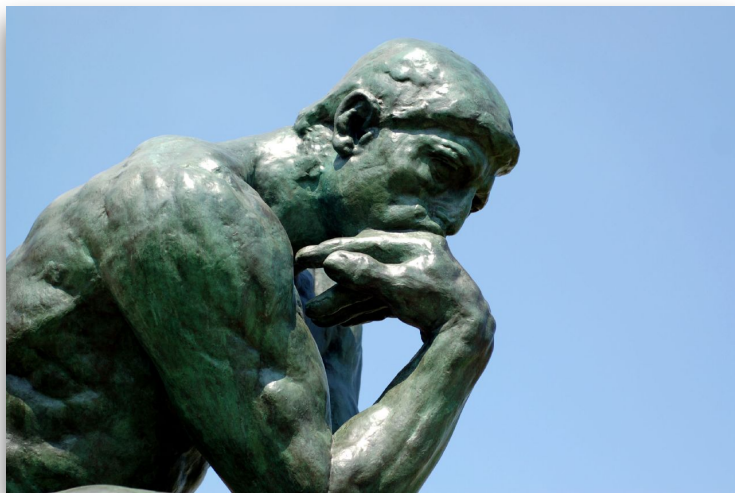


Mutation Testing

Too many mutants, often trivial, redundant or equivalent.



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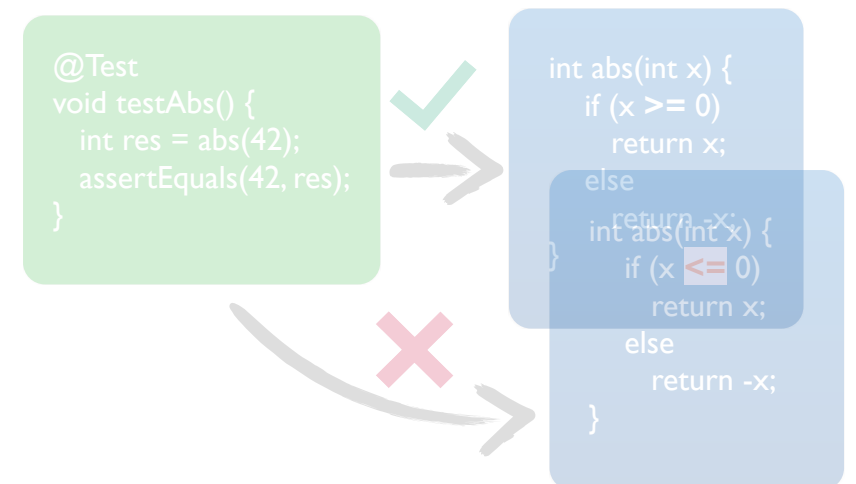
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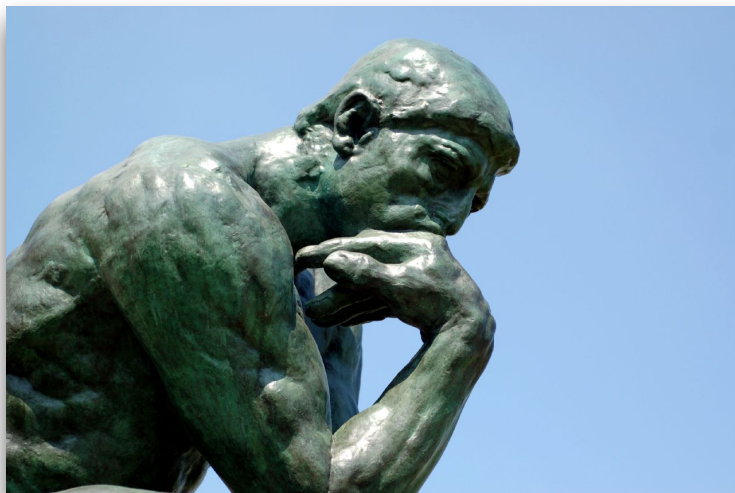


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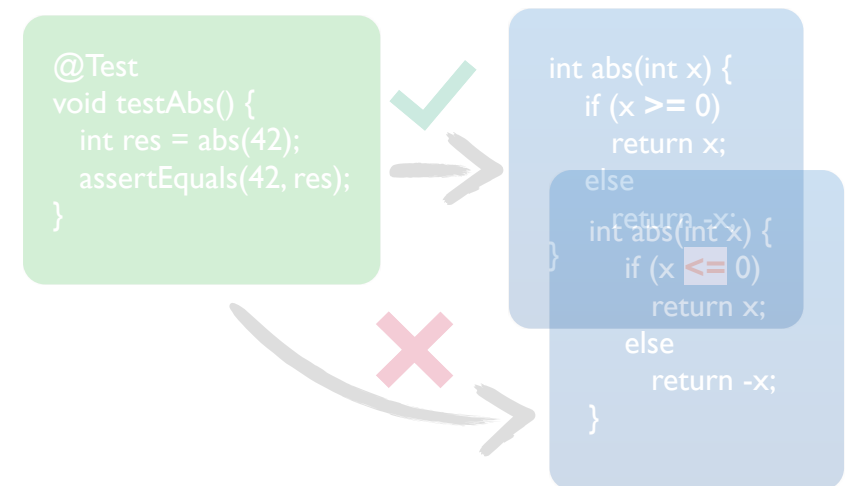
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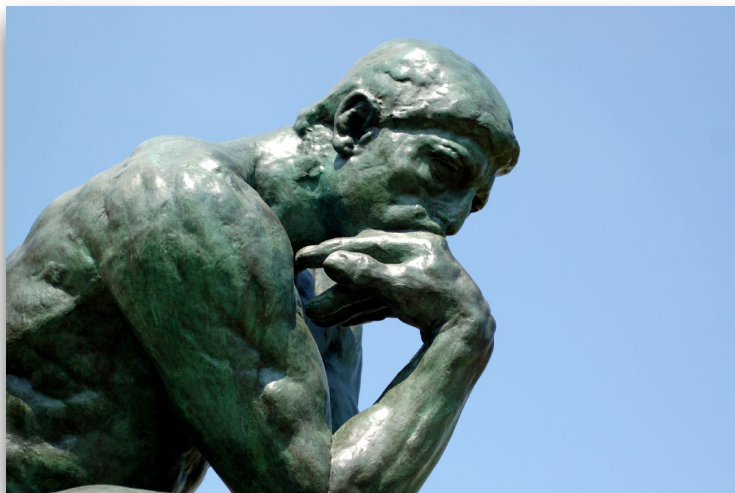


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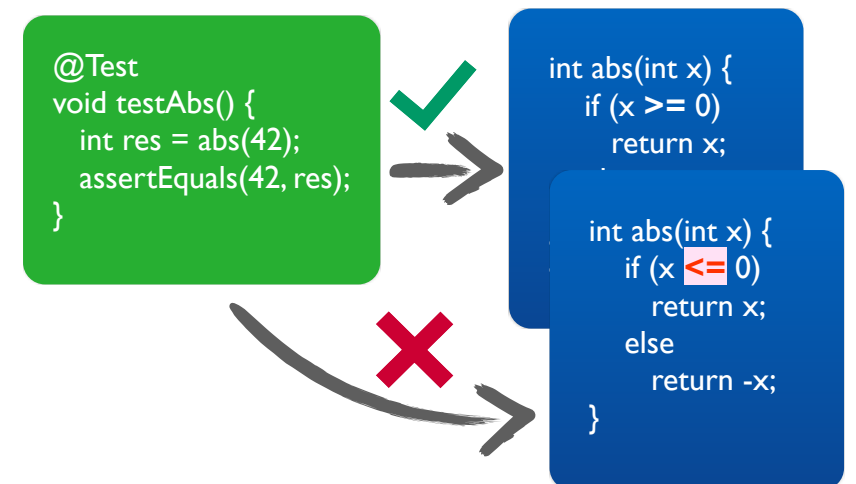
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Code Defenders



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Software Testing
Gamification



Supporting software
testing education



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Crowdsourcing
tests and mutants



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Code Defenders

Class Under Test

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public class Arithmetics {  
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Attackers



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Attackers



Defenders



Code Defenders

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Attackers



Defenders

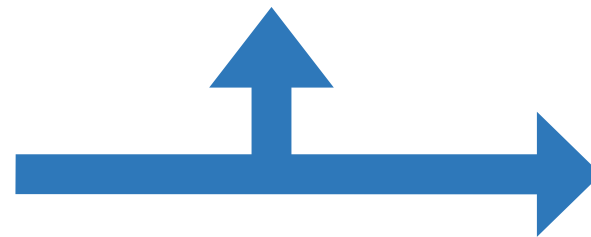


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Defenders



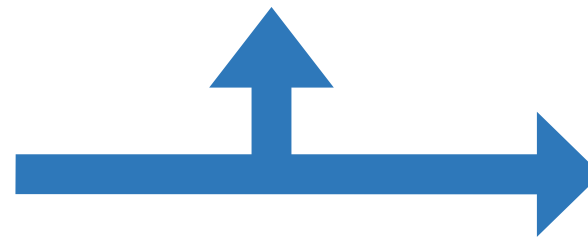
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Attackers



Defenders



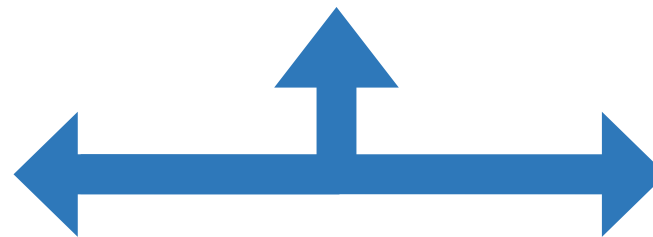
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Attackers



Defenders



Code Defenders

Score points for
surviving mutants

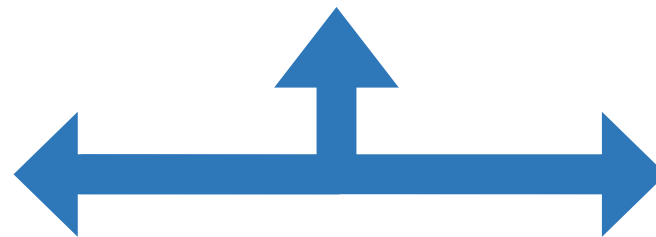
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Attackers

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Defenders



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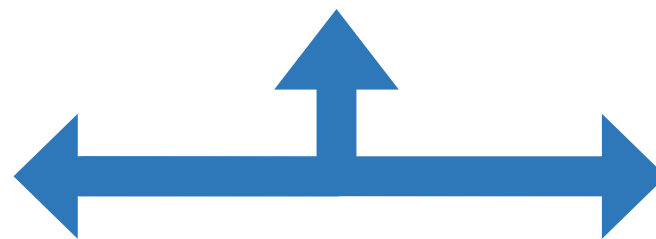
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Attackers

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Defenders



Code Defenders

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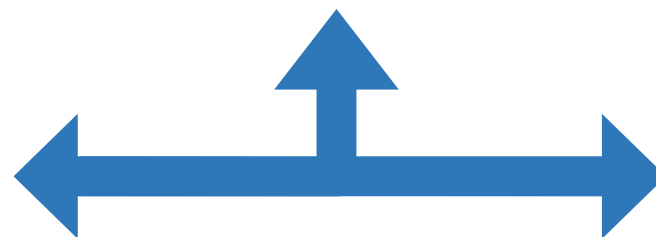
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Attackers

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Defenders

Equivalent Mutant Duels



Code Defenders

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Attackers

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Defenders

equivalent!

Equivalent Mutant Duels



Code Defenders

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no way! here is
a killing test!

equivalent!



Attackers



Defenders

Equivalent Mutant Duels



Code Defenders

Class Under Test

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Attackers

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Defenders

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Equivalent Mutant Duels



Code Defenders

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oh no! :(

equivalent!



Attackers



Defenders

Equivalent Mutant Duels



Code Defenders

Code Defenders - Game 2260 x

code-defenders.org/multiplayer/play?id=2260

Code Defenders

games upload class leaderboard help neilwalkinshaw

DEFENDER::ACTIVE SparseIntArray Show Scoreboard

Class Under Test

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47     } else {  
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Write a new JUnit test here Defend!

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1 /* no package name */  
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3 import org.junit.*;  
4 import static org.junit.Assert.*;  
5  
6 public class TestSparseIntArray {  
7     @Test(timeout = 4000)  
8     public void test() throws Throwable {  
9         // test here!  
10  
11  
12     }  
13 }  
14
```

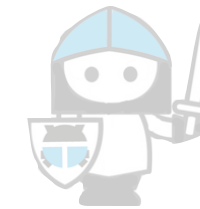
Existing Mutants

alive (35)	killed (68)	equivalent (5)
Search...		
Mutant 5838 Creator: amin [UID: 428]		
Modified line 244		Claim Equivalent
Mutant 5855 Creator: abrahamc2 [UID: 432]		
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Mutant 5823 Creator: gregory [UID: 426]		
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Mutant 5886 Creator: gregory [UID: 426]		
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JUnit tests

Test 4034 | Creator: alessiogambi [UID: 433]

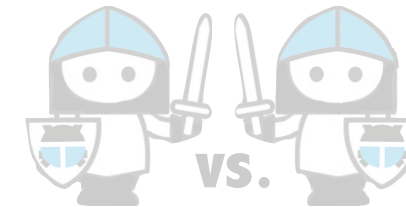
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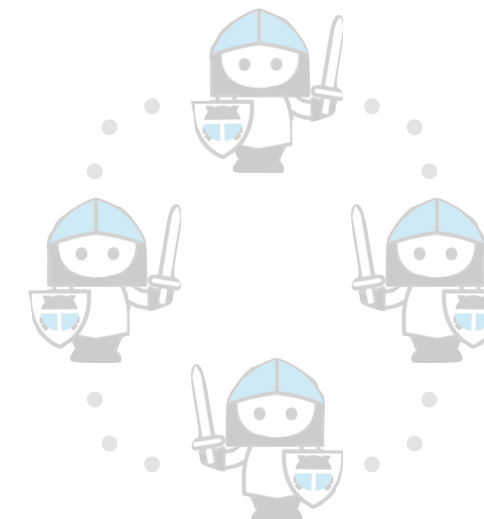
Single-player

vs.

EVASUITE / MAJOR



Two-player



Multi-player



Code Defenders

Code Defenders - Game 2260 x

code-defenders.org/multiplayer/play?id=2260

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games upload class leaderboard help neilwalkinshaw

DEFENDER::ACTIVE SparseIntArray Show Scoreboard

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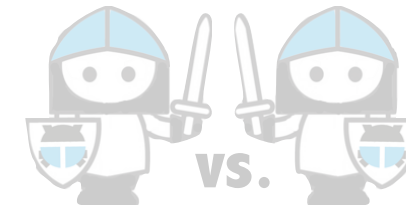
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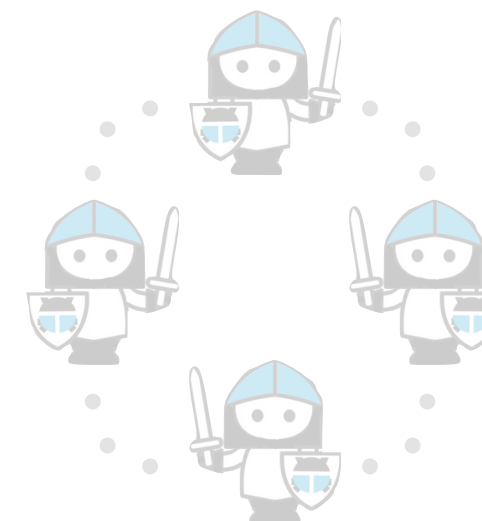
Single-player

vs.

EVASUITE / MAJOR



Two-player



Multi-player



Code Defenders

Code Defenders - Game 2260 x

code-defenders.org/multiplayer/play?id=2260

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games upload class leaderboard help neilwalkinshaw

DEFENDER::ACTIVE SparseIntArray Show Scoreboard

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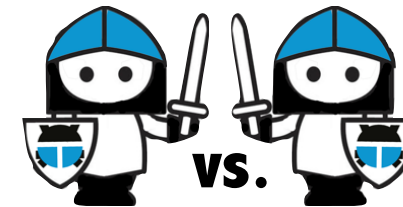
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Single-player

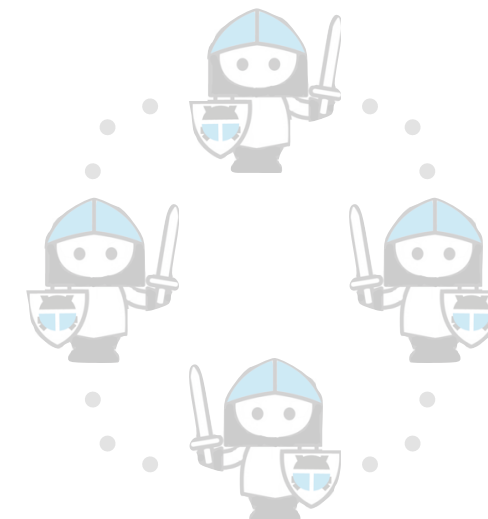
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EVASUITE / MAJOR



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Code Defenders

Code Defenders - Game 2260 x

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DEFENDER::ACTIVE SparseIntArray Show Scoreboard

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45         mKeys = SparseIntArray.EMPTY_INT_ARRAY;  
46         mValues = SparseIntArray.EMPTY_INT_ARRAY;  
47     } else {  
48         mKeys = new int[initialCapacity];  
49         mValues = new int[mKeys.length];  
50     }  
51     mSize = 0;  
52 }  
53 /**  
54  * Given the current size of an array, returns an ideal size to which the array should grow  
55  * This is typically double the given size, but should not be relied upon to do so in the  
56  * future.  
57  */  
58 public static int growSize(int currentSize) {  
59     return currentSize <= 4 ? 8 : currentSize + (currentSize >> 1);  
60 }  
61
```

Write a new JUnit test here

```
1 /* no package name */  
2  
3 import org.junit.*;  
4 import static org.junit.Assert.*;  
5  
6 public class TestSparseIntArray {  
7     @Test(timeout = 4000)  
8     public void test() throws Throwable {  
9         // test here!  
10  
11  
12     }  
13 }  
14
```

Existing Mutants

alive (35)	killed (68)	equivalent (5)
Search...		
Mutant 5838 Creator: amin [UID: 428]		
Modified line 244		Claim Equivalent
Mutant 5855 Creator: abrahamc2 [UID: 432]		
Modified line 211		Claim Equivalent
Mutant 5823 Creator: gregory [UID: 426]		
Modified line 178		Claim Equivalent
Mutant 5886 Creator: gregory [UID: 426]		
Modified line 190		Claim Equivalent

JUnit tests

Test 4034 | Creator: alessiogambi [UID: 433]

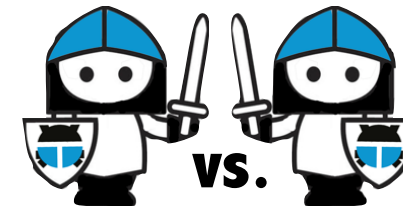
```
1 /* no package name */  
2  
3 import org.junit.*;  
4 import static org.junit.Assert.*;  
5  
6 public class TestSparseIntArray {  
7     @Test(timeout = 4000)  
8     public void test() throws Throwable {  
9         SparseIntArray sia = new SparseIntArray(0);  
10        sia.put(0, 7);  
11        sia.put(1, 8);  
12        sia.delete(0);  
13        assertEquals(1, sia.size());  
14        assertEquals(8, sia.get(1));  
15    }  
16 }
```



Single-player

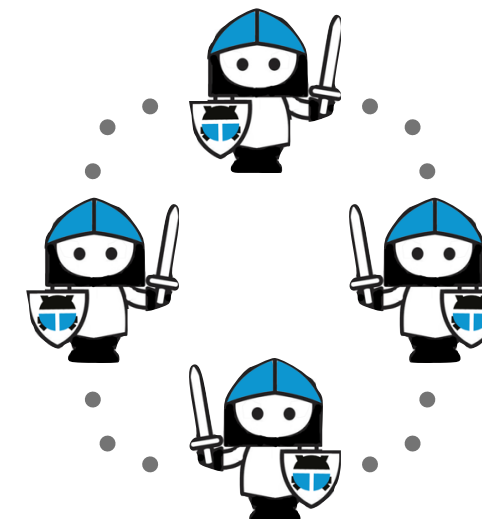
vs.

EVASUITE / MAJOR



Two-player

vs.



Multi-player



Code Defenders

DEFENDER::ACTIVE

SparseIntArray

Class Under Test

Write a new JUnit test here

```
35  /**
36   * Creates a new SparseIntArray containing no mappings that will not
37   * require any additional memory allocation to store the specified
38   * number of mappings. If you supply an initial capacity of 0, the
39   * sparse array will be initialized with a light-weight representation
40   * not requiring any additional array allocations.
41   */
42  public SparseIntArray(int initialCapacity) {
43      if (initialCapacity == 0) {
44          mKeys = SparseIntArray.EMPTY_INT_ARRAY;
45          mValues = SparseIntArray.EMPTY_INT_ARRAY;
46      } else {
47          mKeys = new int[initialCapacity];
48          mValues = new int[mKeys.length];
49      }
50      mSize = 0;
51  }
52
53  /**
54   * Given the current size of an array, returns an ideal size to which the array should grow.
55   * This is typically double the given size, but should not be relied upon to do so in the
56   * future.
57   */
58  public static int growSize(int currentSize) {
59      return currentSize <= 4 ? 8 : currentSize + (currentSize >> 1);
60  }
61
```

```
1  /* no package name */
2
3  import org.junit.*;
4  import static org.junit.Assert.*;
5
6  public class TestSparseIntArray {
7      @Test(timeout = 4000)
8      public void test() throws Throwable {
9          // test here!
10         |
11     }
12 }
```

Existing Mutants

JUnit tests



Code Defenders

games upload class leaderboard help demoattacker

ATTACKER::ACTIVE headstart.Elevator Show Scoreboard

Existing Mutants

alive (1)	killed (0)	equivalent (0)
Search...		
Mutant 4815 Creator: demoattacker [UID: 318]		
Modified line 11		
View Diff		

First Previous 1 Next Last

Create a mutant here

Attack!

```
1 package headstart;
2
3 public class Elevator {
4
5     private int topFloor;
6     private int currentFloor = 0; // default
7     private int capacity = 10;    // default
8     private int numRiders = 0;    // default
9
10    public Elevator(int highestFloor) {
11        topFloor = highestFloor;
12    }
13
14    public Elevator(int highestFloor, int maxRiders) {
15        this(highestFloor);
16        capacity = maxRiders;
17    }
18
19    public int getTopFloor() {
20        return topFloor;
21    }
22
23    public int getCurrentFloor() {
24        return currentFloor;
25    }
26 }
```

Attacking

ICST'17 Best Tool Demo Award



Code Defenders

games upload class leaderboard help demoattacker

ATTACKER::ACTIVE headstart.Elevator Show Scoreboard

Existing Mutants

alive (1)	killed (0)	equivalent (0)
Search...		
Mutant 4815 Creator: demoattacker [UID: 318]		
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First Previous 1 Next Last

Create a mutant here

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9
10    public Elevator(int highestFloor) {
11        topFloor = highestFloor;
12    }
13
14    public Elevator(int highestFloor, int maxRiders) {
15        this(highestFloor);
16        capacity = maxRiders;
17    }
18
19    public int getTopFloor() {
20        return topFloor;
21    }
22
23    public int getCurrentFloor() {
24        return currentFloor;
25    }
26 }
```

Attacking

ICST'17 Best Tool Demo Award



Code Defenders - x

code-defenders.org/multiplayer/play?id=...

games

ATTACKER::ACT

Existing Mutants

alive (1)

Mutant 4815 | Creator: demoattacker [UID: 318]

Modified line 11

Attack

Scoreboard

93  78

Attackers	Mutants	Alive / Killed / Equivalent	Total Points
a.alsharif	3	0 / 3 / 0	0
jose.campos	29	0 / 27 / 2	29
mat_	20	0 / 13 / 7	30
Ignatius	5	1 / 1 / 3	34
Attacking Team	57	1 / 44 / 12	93
Defenders	Tests	Mutants Killed	Total Points
Shaunyprawn	2	4	4
sina	47	33	73
nasser86	1	1	1
Defending Team	50	38	78

Close

Show Scoreboard

Attack!







Does Gamification Work?



Does Gamification Work?

Does Crowdsourcing Work?



Does Gamification Work?

Controlled Study

Does Code Defenders lead to better tests than regular unit testing? Is it fun to play?



Does Gamification Work?

Controlled Study

Does Code Defenders lead to better tests than regular unit testing? Is it fun to play?



41



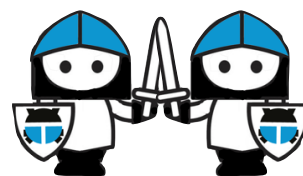
Does Gamification Work?

Controlled Study

Does Code Defenders lead to better tests than regular unit testing? Is it fun to play?



41



2-player



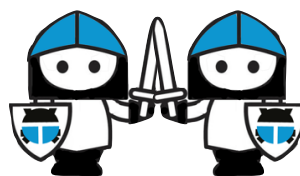
Does Gamification Work?

Controlled Study

Does Code Defenders lead to better tests than regular unit testing? Is it fun to play?



41



2-player



1



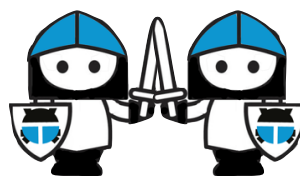
Does Gamification Work?

Controlled Study

Does Code Defenders lead to better tests than regular unit testing? Is it fun to play?



41



2-player



1



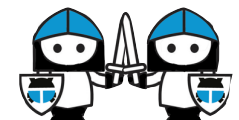
2



Does Gamification Work?



41



2-player



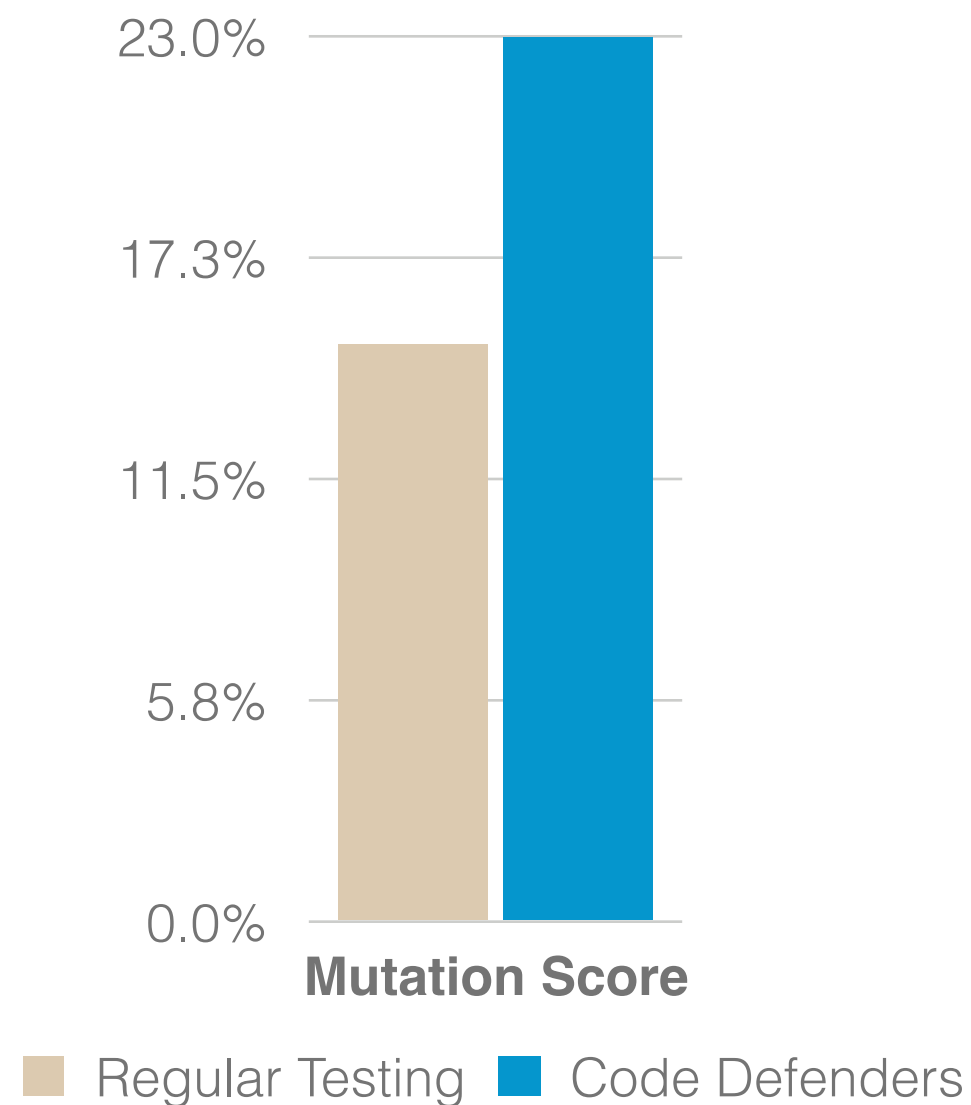
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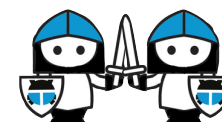
2



Does Gamification Work?



41



2-player



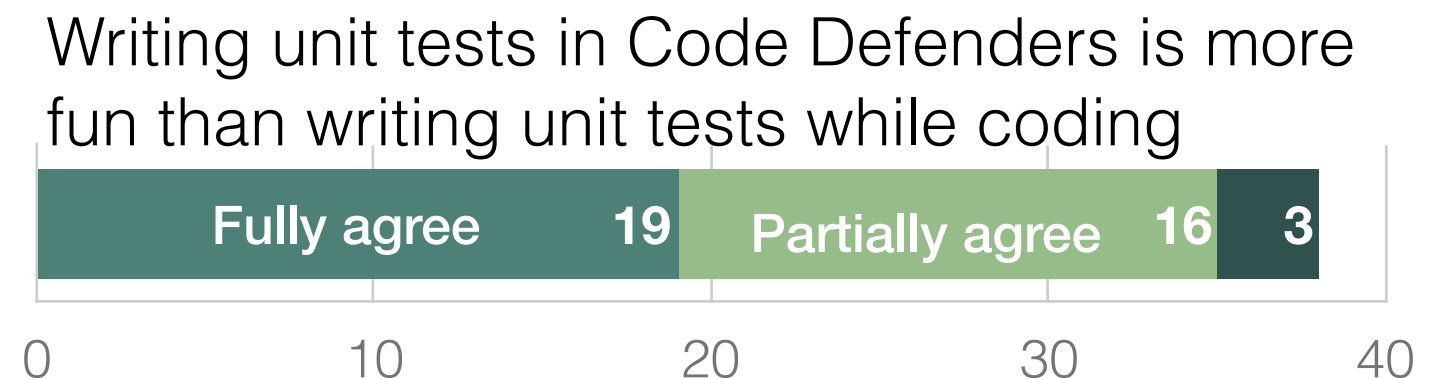
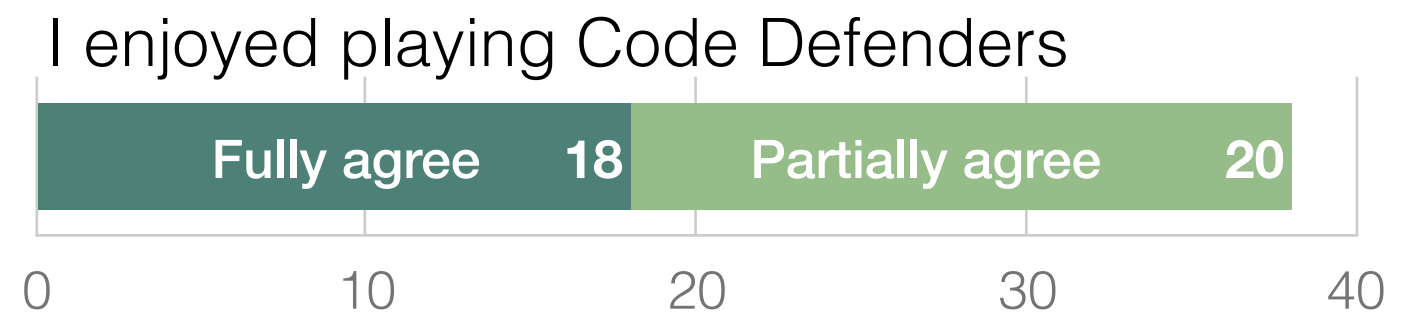
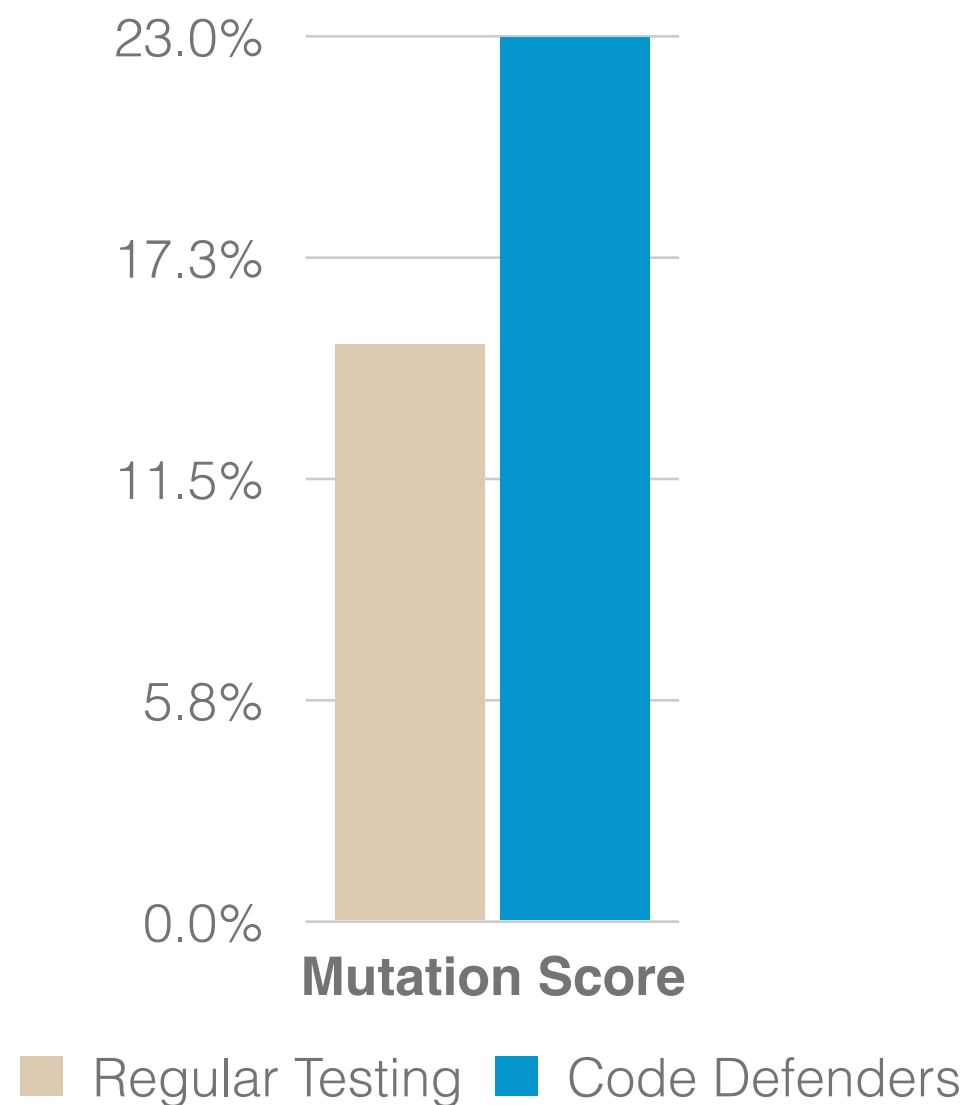
1



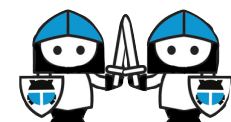
2



Does Gamification Work?



41



2-player



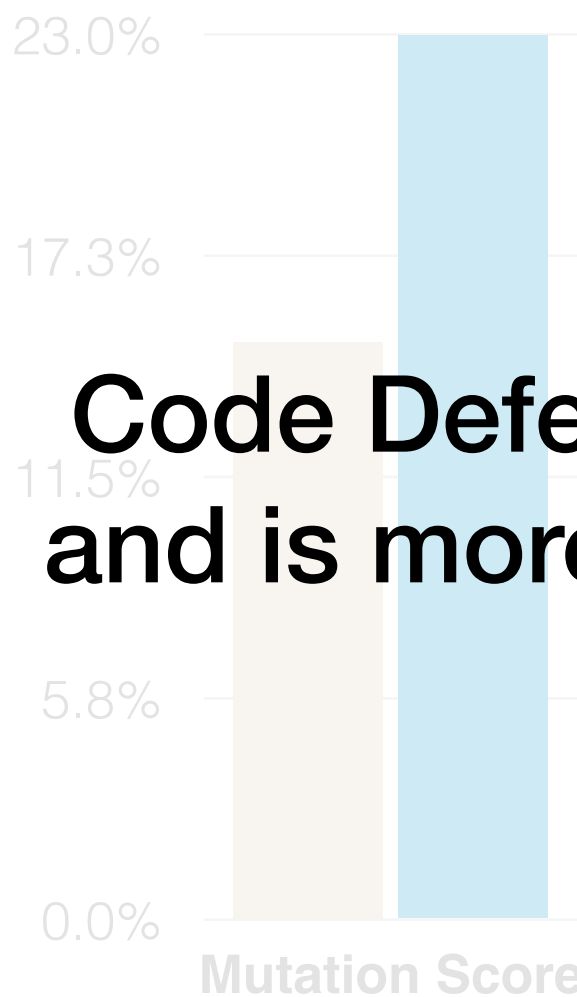
1



2

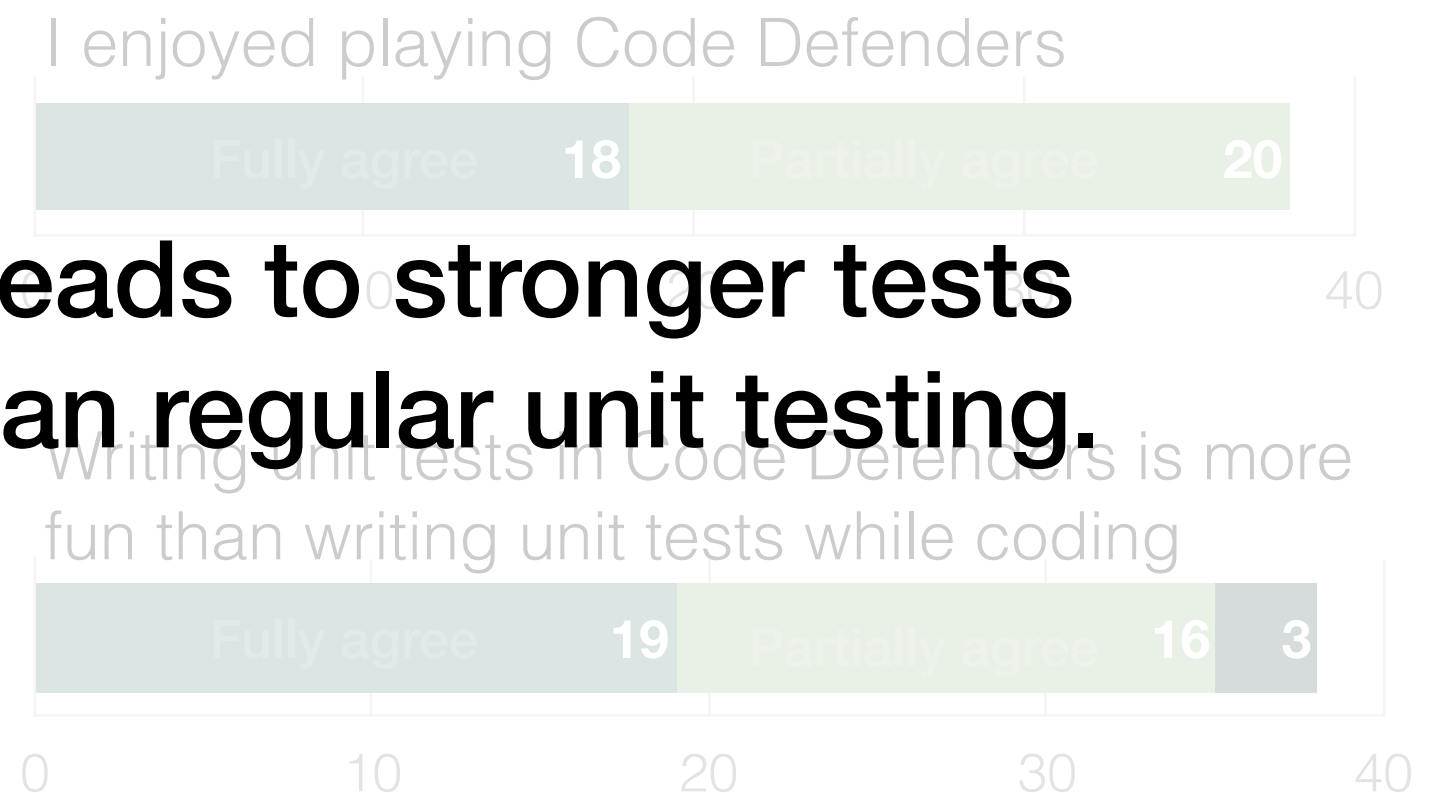


Does Gamification Work?

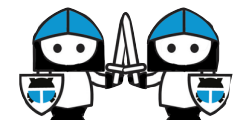


Regular Testing Code Defenders

Code Defenders leads to stronger tests and is more fun than regular unit testing.



41



2-player



1



2



Does Crowdsourcing Work?

Online Study

Does using Code Defenders in a crowdsourcing scenario lead to better tests and mutants than those generated by test generation and mutation testing tools?



Does Crowdsourcing Work?

Online Study

Does using Code Defenders in a crowdsourcing scenario lead to better tests and mutants than those generated by test generation and mutation testing tools?



35



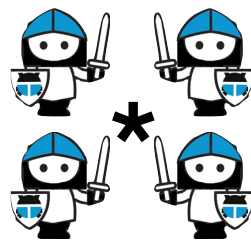
Does Crowdsourcing Work?

Online Study

Does using Code Defenders in a crowdsourcing scenario lead to better tests and mutants than those generated by test generation and mutation testing tools?



35



6-10



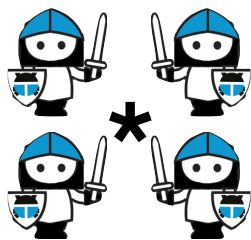
Does Crowdsourcing Work?

Online Study

Does using Code Defenders in a crowdsourcing scenario lead to better tests and mutants than those generated by test generation and mutation testing tools?



35



6-10



24



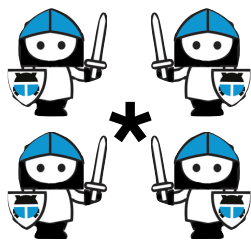
Does Crowdsourcing Work?

Online Study

Does using Code Defenders in a crowdsourcing scenario lead to better tests and mutants than those generated by test generation and mutation testing tools?



35



6-10



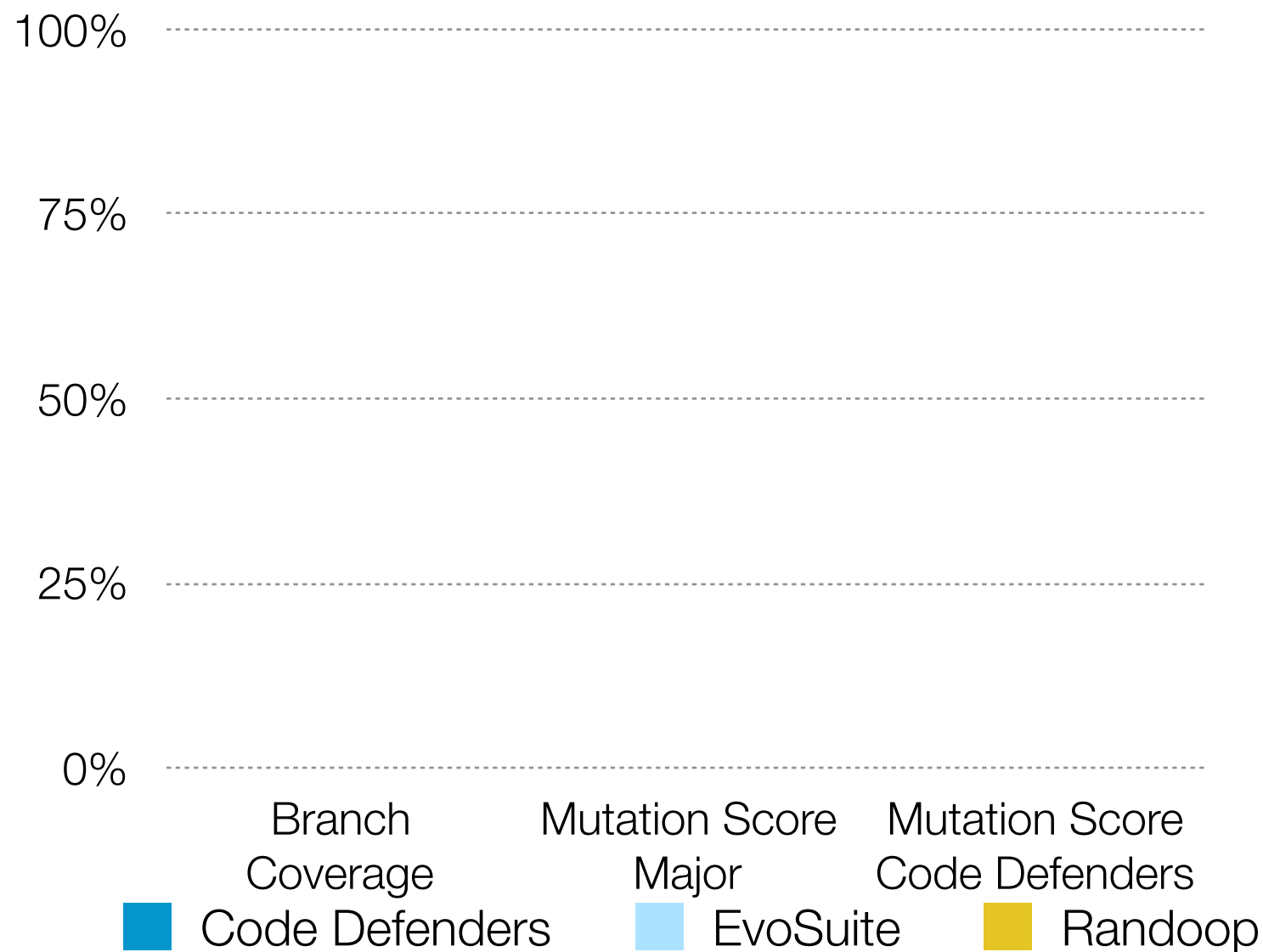
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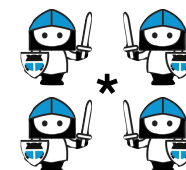
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Does Crowdsourcing Work?



35



6-10



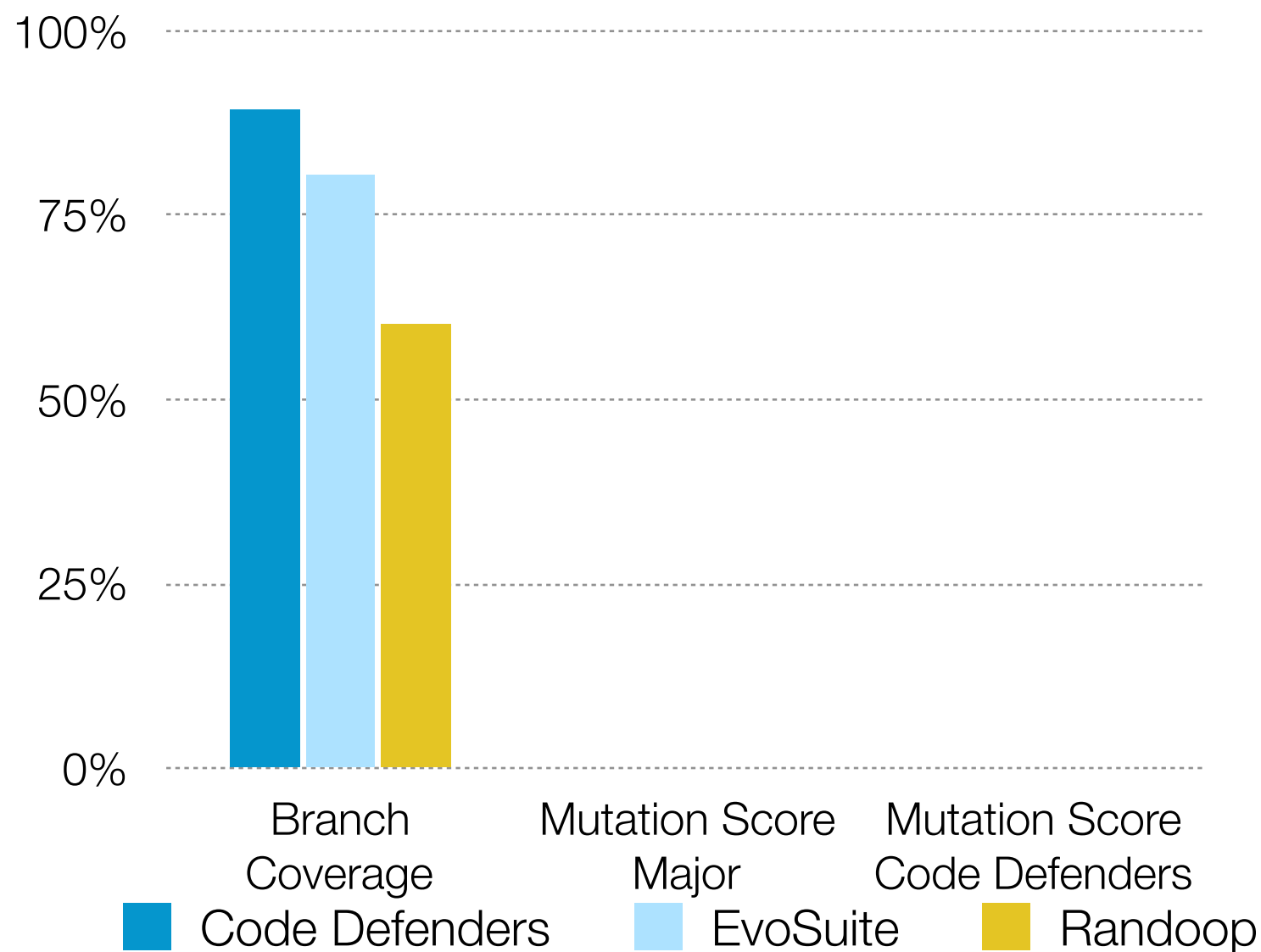
24



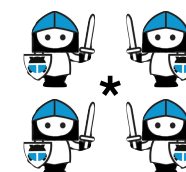
20



Does Crowdsourcing Work?



35



6-10



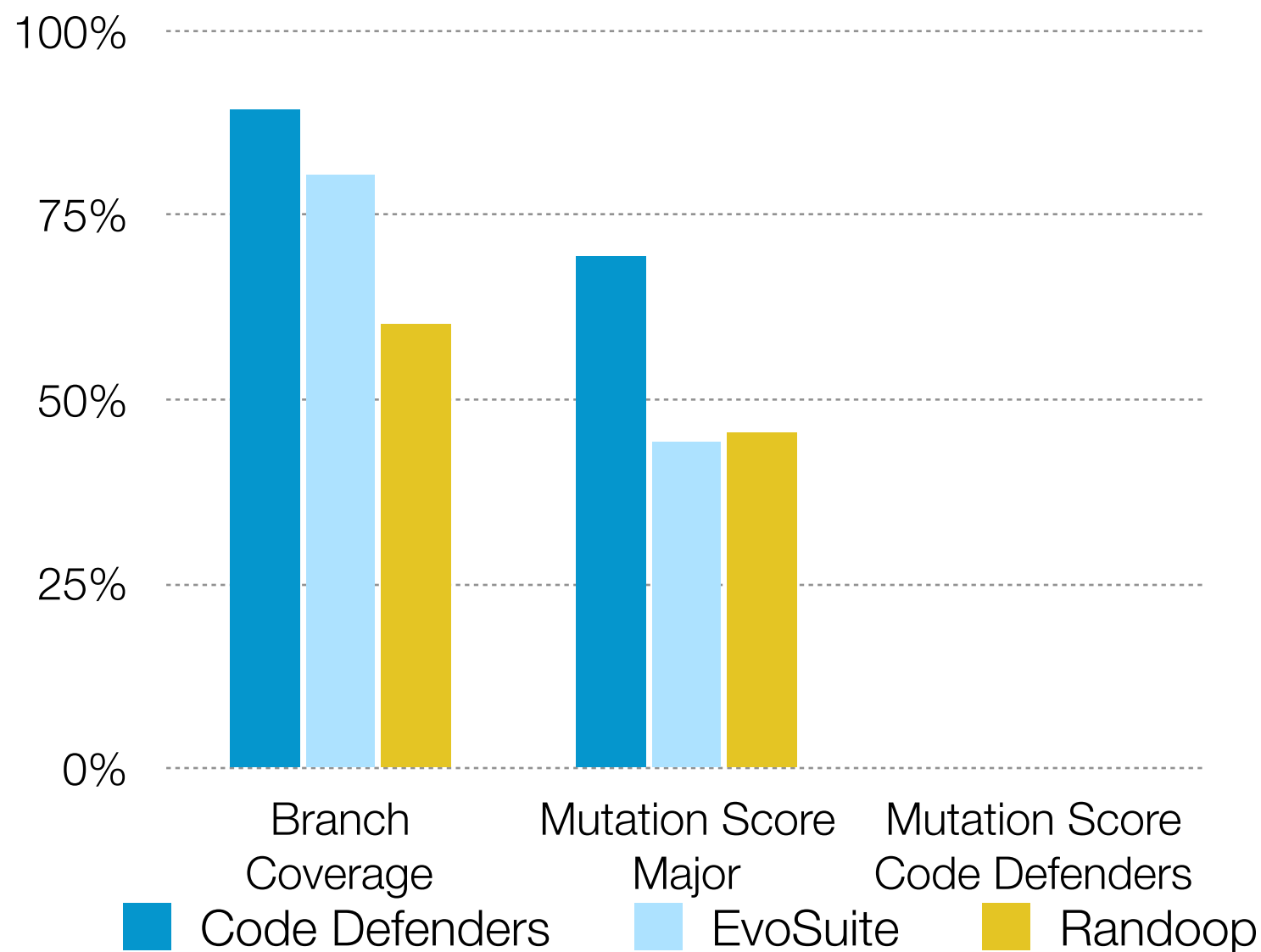
24



20

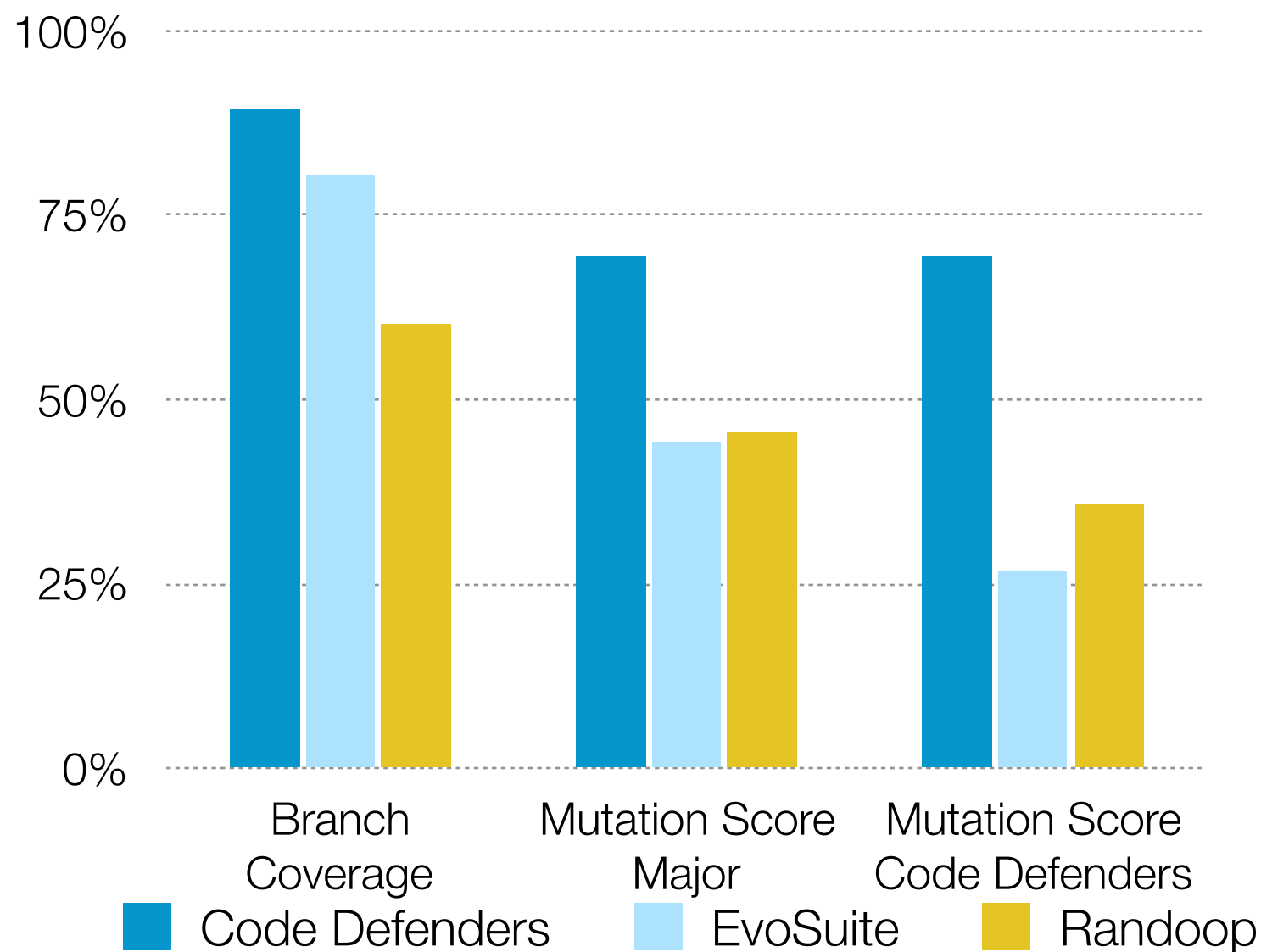


Does Crowdsourcing Work?

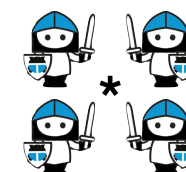




Does Crowdsourcing Work?



35



6-10



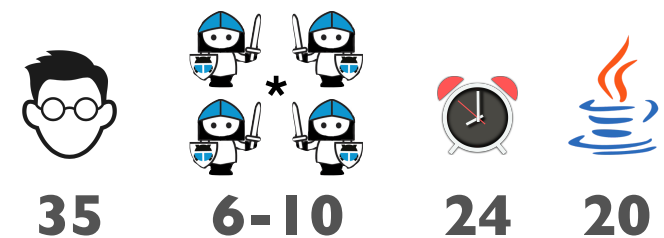
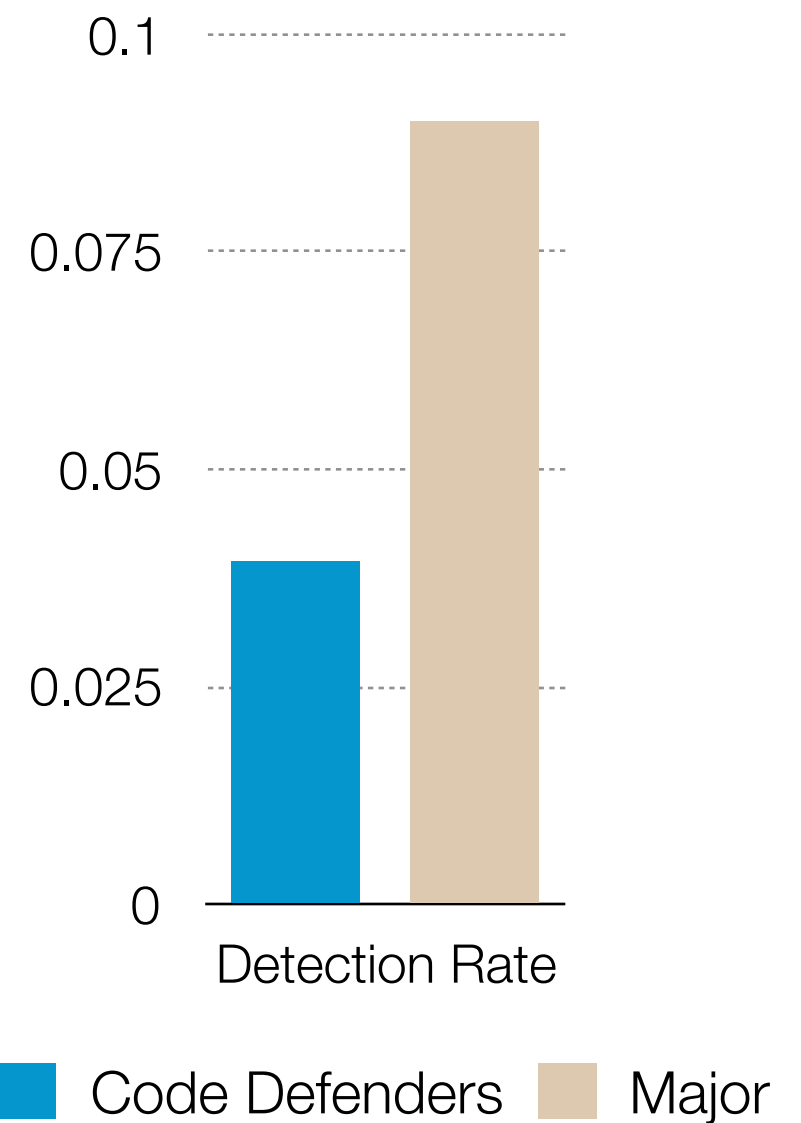
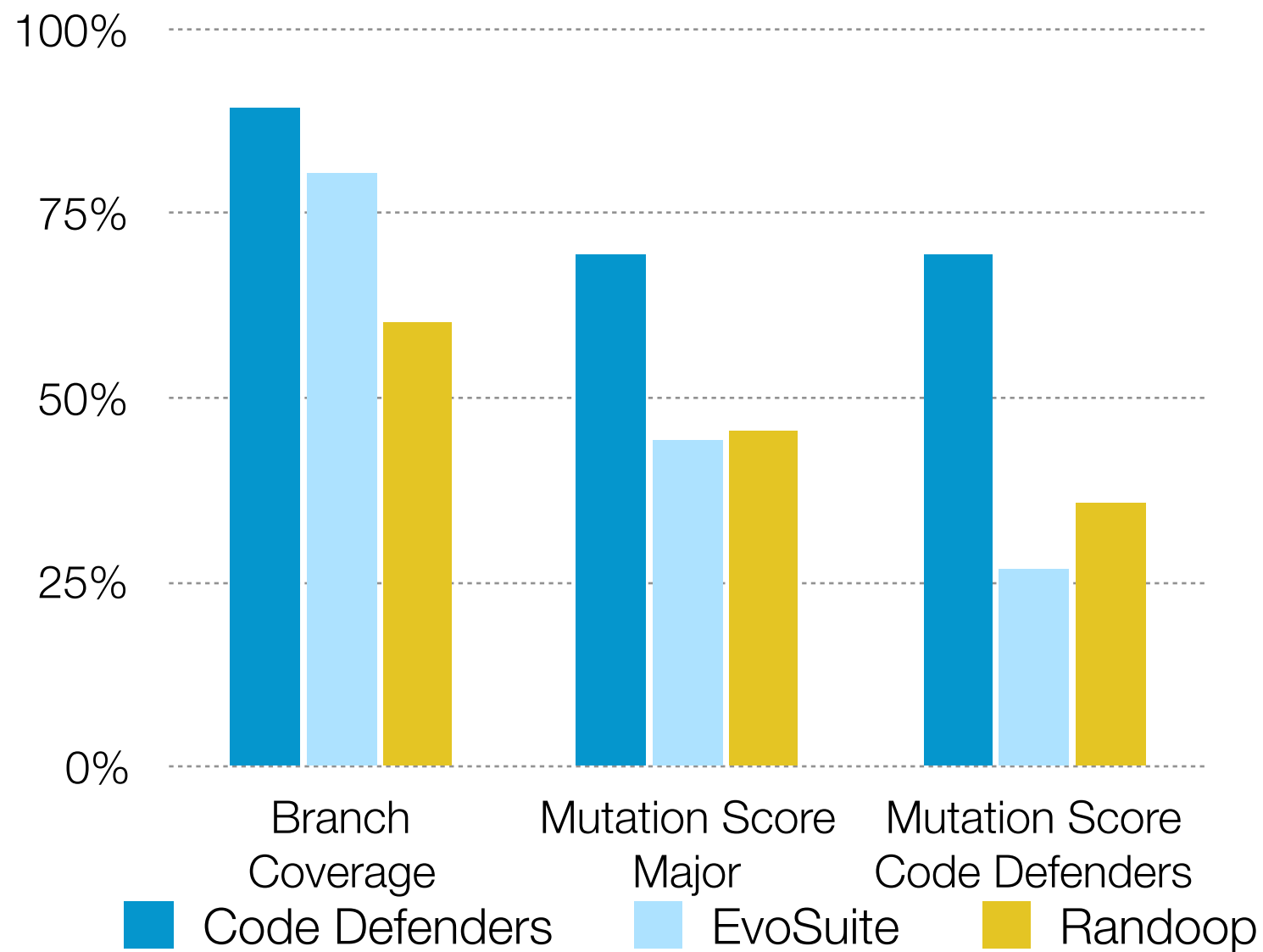
24



20

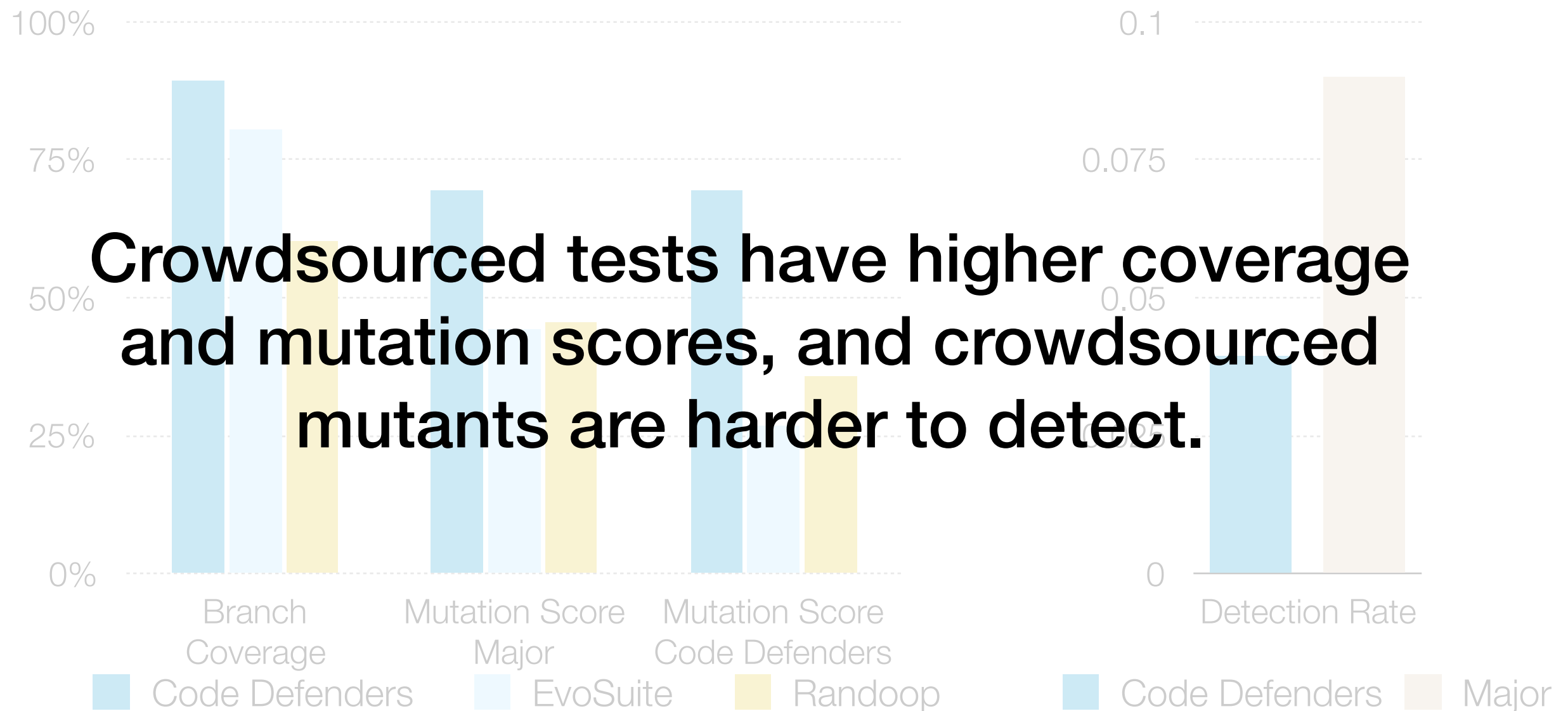


Does Crowdsourcing Work?





Does Crowdsourcing Work?





Challenges



Challenges

Cheating

```
public int abs(int x) {  
    if (x == 8273482675) return -1;  
    if (x >= 0)  
        return x;  
    else  
        return -x;  
}
```



Challenges

Cheating

```
public int abs(int x) {  
    if (x == 8273482675) return -1;  
    if (x >= 0)  
        return x;  
    else  
        return -x;  
}
```

Profanity

```
@Test(timeout = 4000)  
public void test() throws Throwable {  
    XmlElement anus = new XmlElement();  
    XmlElement poo = anus.addSubElement("shit", "fuck");  
    assertEquals(anus, poo.getParent());  
    assertEquals("shit", poo.name);  
}
```



Challenges

Narrative and other gamification elements





CodeGame



press F5 to refresh
press F9 to preview code

ATTACKER: 0

DEFENDER: 0

It is YOUR move!
You are an attacker. make a mutation!





CodeGame

press F5 to refresh
press F9 to preview code

ATTACKER: 0

DEFENDER: 0

It is YOUR move!
You are an attacker. make a mutation!

Mutation Editor.

cancel

Create Mutation

```
1 public class Lift {  
2  
3     private int topFloor;  
4     private int currentFloor = 0; // default  
5     private int capacity = 10;    // default  
6     private int numRiders = 0;   // default  
7  
8     public Lift(int highestFloor) {  
9         topFloor = highestFloor+1;  
10    }  
11  
12    public Lift(int highestFloor, int maxRiders) {  
13        this(highestFloor);  
14        capacity = maxRiders;  
15    }  
16  
17    public int getTopFloor() {  
18        return topFloor;  
19    }  
20
```




CodeGame



press F5 to refresh
press F9 to preview code

ATTACKER: 5

DEFENDER: 1

It is YOUR move!
You are a defender. make some tests!

METHOD: void goDown()

Hits: [52, 52]

! 52

! 52





Other Plans



Other Plans





Other Plans





Other Plans





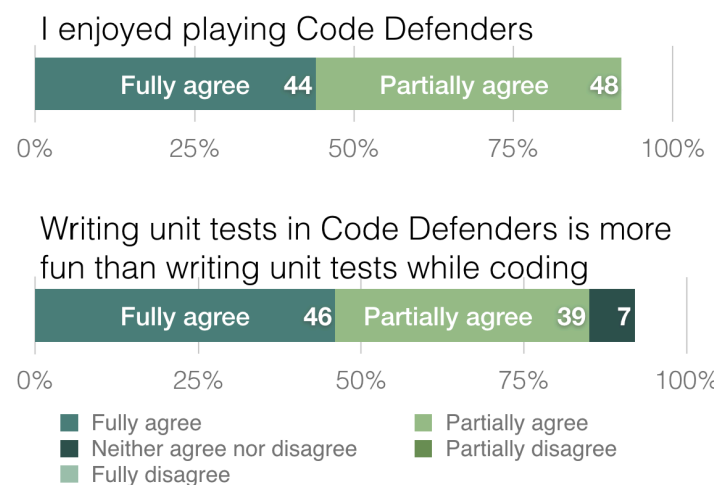
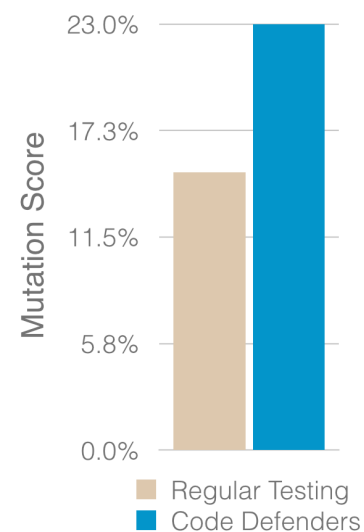
Other Plans







Does Gamification Work?

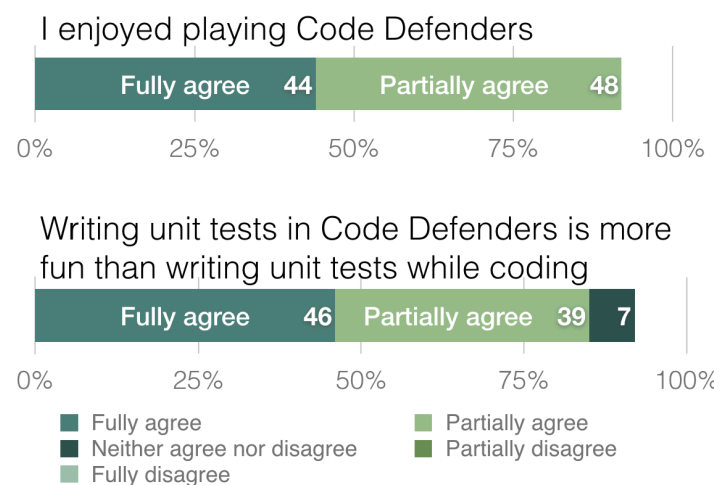
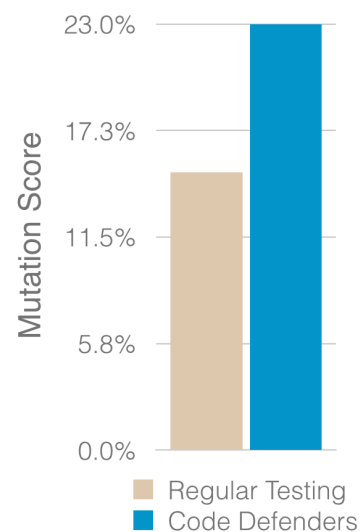


**Code Defenders leads to stronger tests
and is more fun than regular unit testing.**





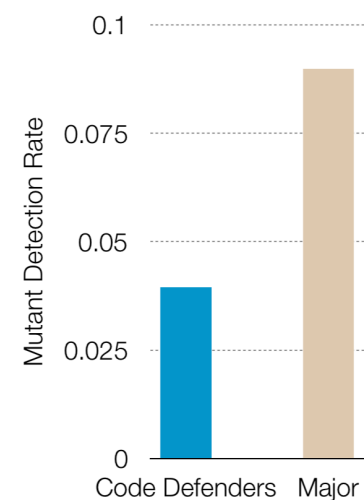
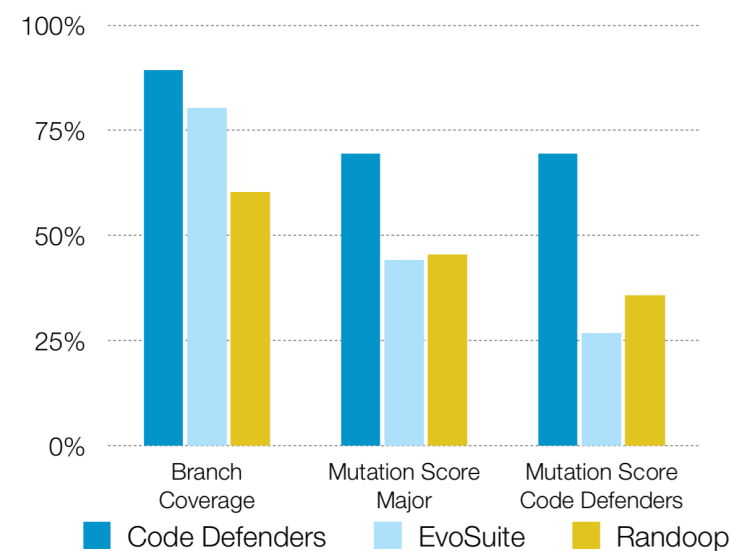
Does Gamification Work?



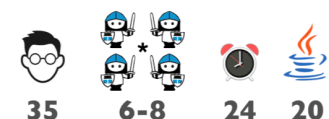
Code Defenders leads to stronger tests and is more fun than regular unit testing.



Does Crowdsourcing Work?

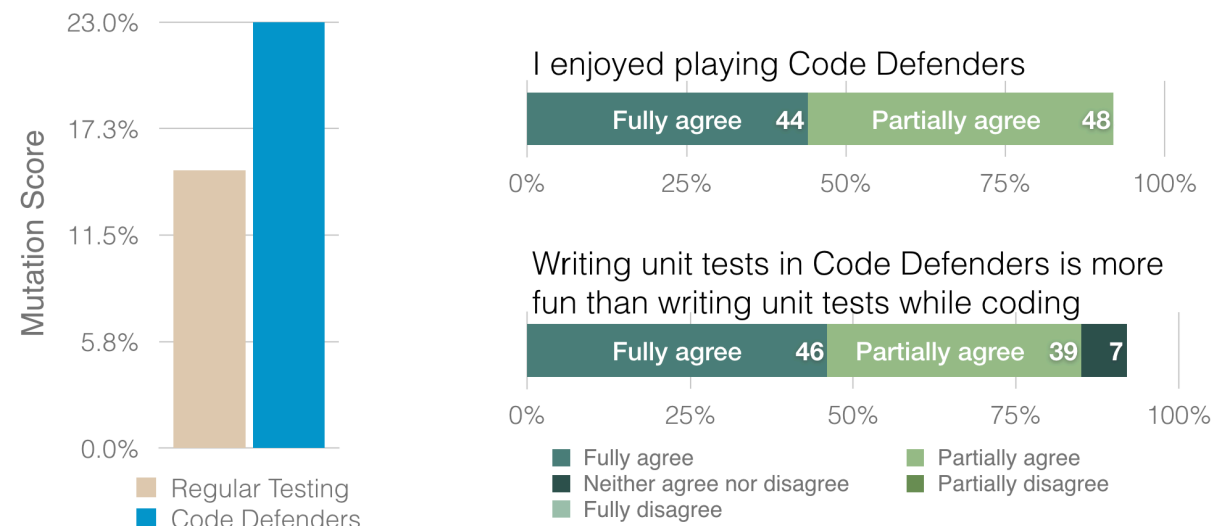


Crowdsourced tests have higher coverage/mutation scores, and crowdsourced mutants are harder to detect.

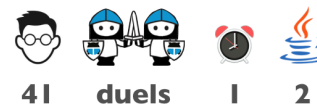




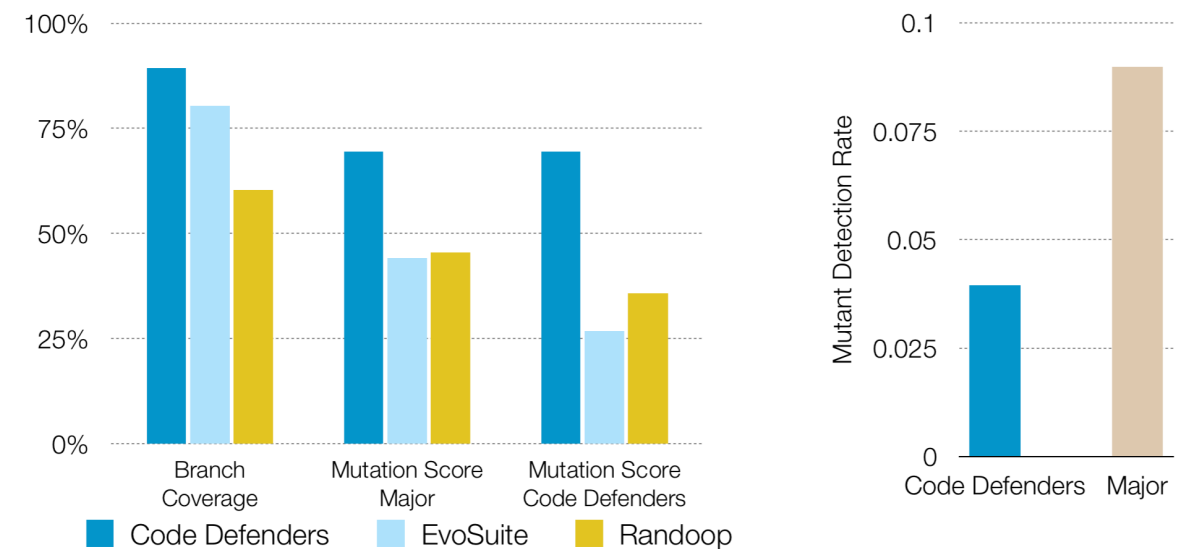
Does Gamification Work?



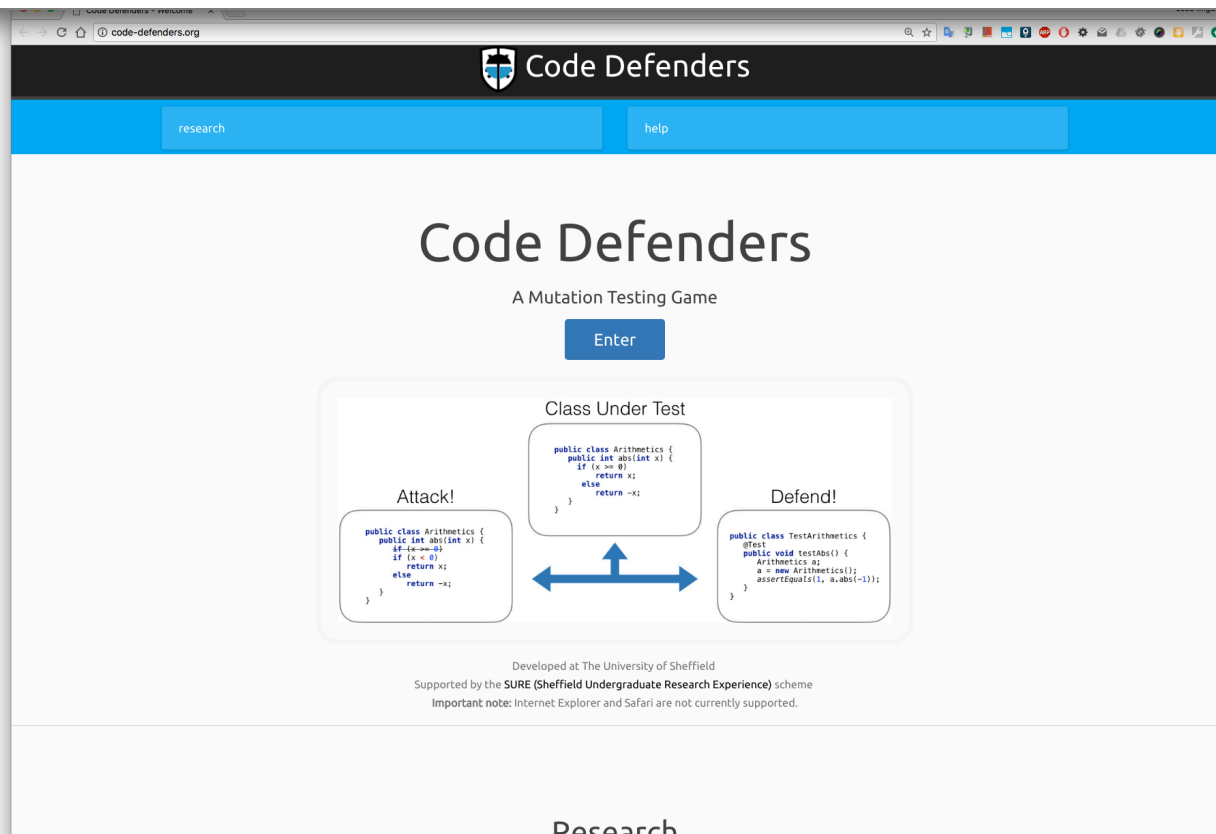
Code Defenders leads to stronger tests and is more fun than regular unit testing.



Does Crowdsourcing Work?



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code-defenders.org