Kill all mutants with Stryker

Mutation testing workshop

15-11-2022

infoSupport Solid Innovator

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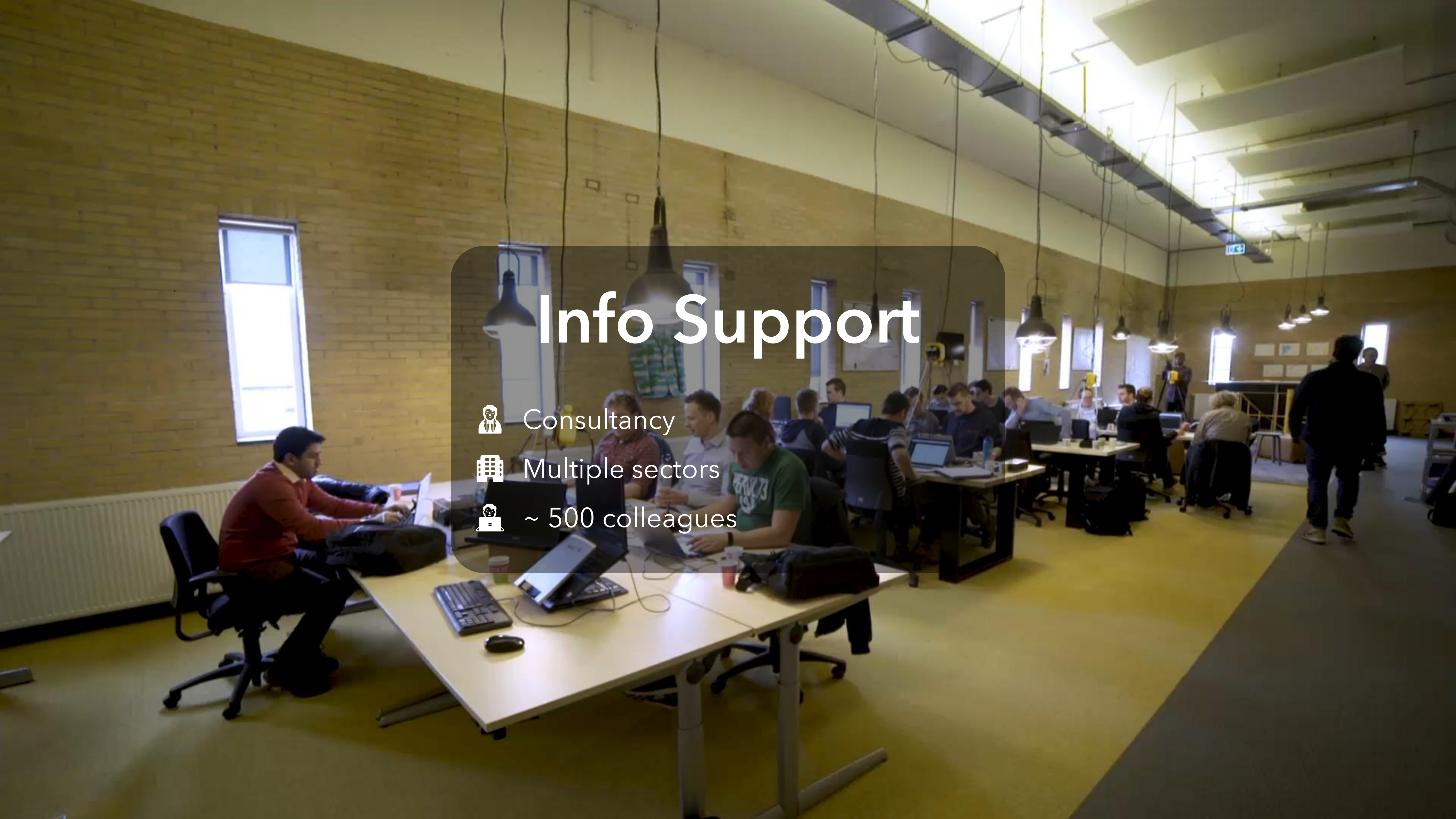
SCAN ME

Agenda



Info Support

- Consultancy
- Multiple sectors
- ~ 500 colleagues

Focus themes

Software & Architecture

- Cloud Architecture
- Observability
- Domain Driven Design

Way of Working

- DevOps
- (Agile) Project beheersing

Data & Artificial Intelligence

- AI
- Explainable AI
- Modern Data Architectures

Work & Internships

- Dirk Spanbroek
  https://www.linkedin.com/in/dirkspanbroek/

- Or visit our website
  https://carriere.infosupport.com/

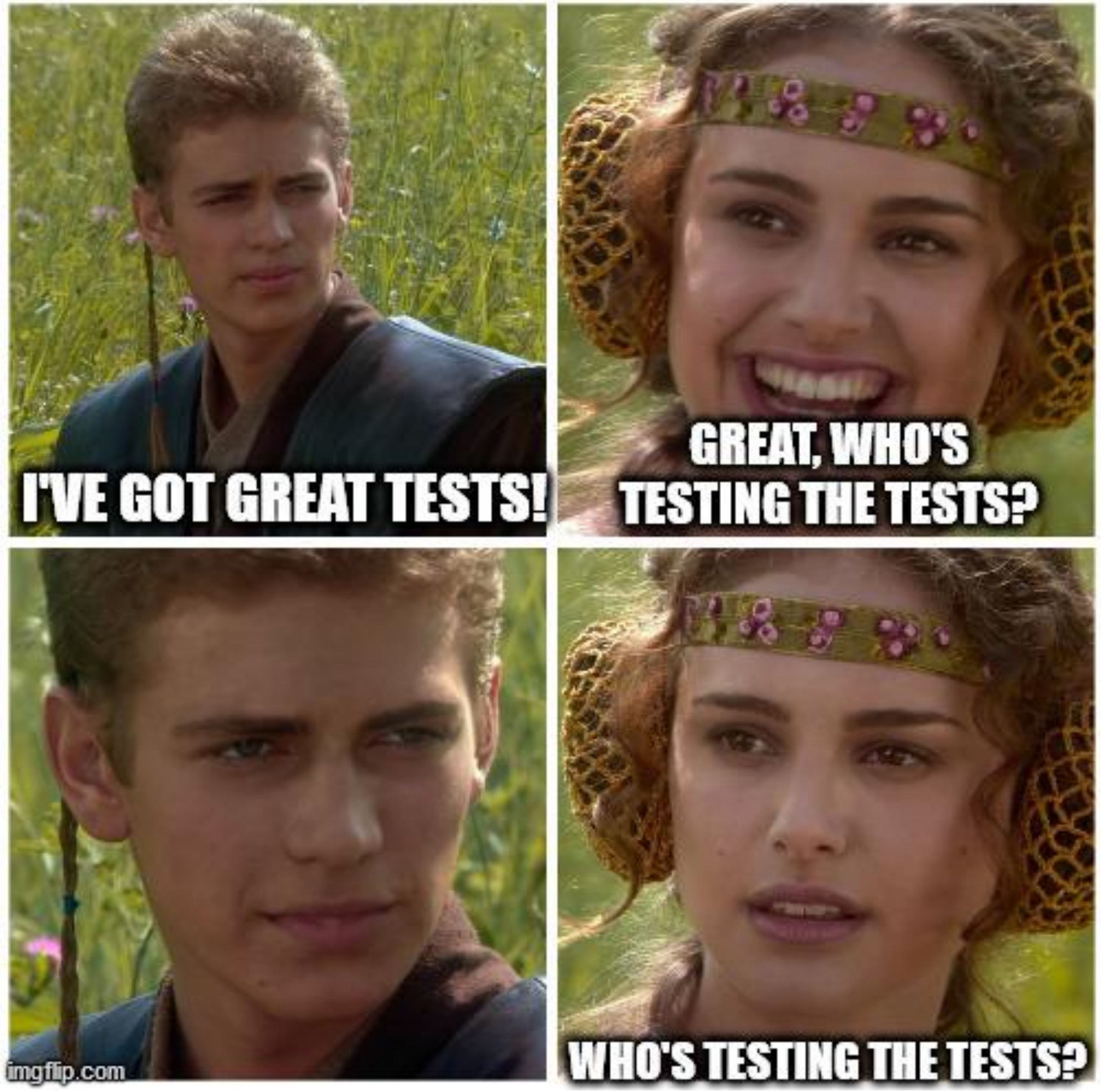
(I would appreciate it if you mention me!)

Unit Testing

When are my unit tests good?

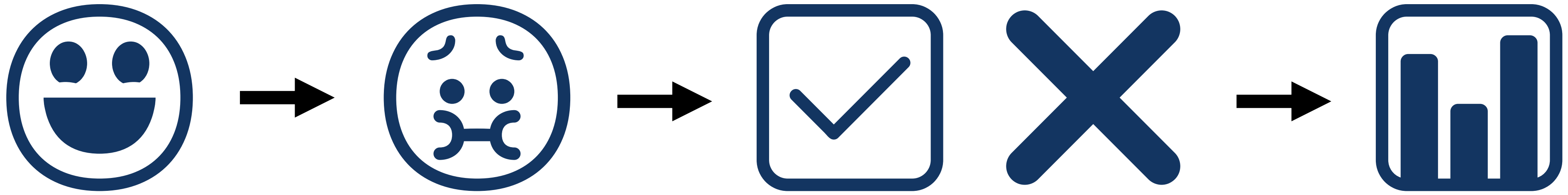
📖 Testing patterns
☑ All tests are green
📝 > 80% code coverage

🥳 I have great tests


I'VE GOT GREAT TESTS!
GREAT, WHO'S TESTING THE TESTS?
WHO'S TESTING THE TESTS?
imgflip.com

Mutation testing

Mutation testing process



1. Source code
2. Introduce mutant
3. Test (killed / survived)
4. Report

Mutating code

```
// Production Code
public static bool IsAllowedToBuyAlcohol(Customer customer) {
    return customer.Age >= 18;
    // ☑ Test succeeds
}

// Test
[TestMethod]
public void CustomerIsOlderThan18_ReturnTrue() {
    Customer customer = new Customer("Professor X", 96);
    Assert.IsTrue(Store.IsAllowedToBuyAlcohol(customer));
}
```

Mutating code

```
// Production Code
public static bool IsAllowedToBuyAlcohol(Customer customer) {
    return customer.Age < 18;
    // ❌ Test fails, mutant KILLED
}

// Test
[TestMethod]
public void CustomerIsOlderThan18_ReturnTrue() {
    Customer customer = new Customer("Professor X", 96);
    Assert.IsTrue(Store.IsAllowedToBuyAlcohol(customer));
}
```

Mutating code

```
// Production Code
public static bool IsAllowedToBuyAlcohol(Customer customer) {
    return customer.Age > 18;
    // ✓ Test succeeds, mutant SURVIVED
}

// Test
[TestMethod]
public void CustomerIsOlderThan18_ReturnTrue() {
    Customer customer = new Customer("Professor X", 96);
    Assert.IsTrue(Store.IsAllowedToBuyAlcohol(customer));
}
```

Mutating code

```
// Production Code
public static bool IsAllowedToBuyAlcohol(Customer customer) {
    return true;
    // ☑ Test succeeds, mutant SURVIVED
}

// Test
[TestMethod]
public void CustomerIsOlderThan18_ReturnTrue() {
    Customer customer = new Customer("Professor X", 96);
    Assert.IsTrue(Store.IsAllowedToBuyAlcohol(customer));
}
```

Common mutations

Original	Mutated
`a + b`	`a - b`
`a / b`	`a * b`
`a < b`	`a > b`
`a == b`	`a != b`
`a && b`	`a || b`
`string drink = "Cola"`	`string drink = ""`
`int[] list = {1, 2, 3, 4}`	`int[] list = {}`
`if (a > b) { ... }`	`if (true) { ... }`
`public void fn() { ... }`	`public void fn() { /* EMPTY */ }`

Mutant states

- ✅ Killed
- 👽 Survived
- 🙈 No coverage
- ⌛ Timeout
- 💥 Runtime error
- 💥 Compile error
- 🤥 Ignored

Mutant metrics

- Detected
  `killed + timeout`
- Undetected
  `survived + no coverage`
- Covered
  `detected + survived`
- Valid
  `detected + undetected`
- Invalid
  `Runtime Error + Compile Error`
- Mutation score
  `detected / valid * 100`
- Mutation score based on covered code
  `detected / covered * 100`

Question: what different conclusions can we derive from the 2 scores?

Frameworks

Language	Framework
JavaScript & TypeScript	StrykerJS
Scala	Stryker4s
C#	Stryker.NET
Java	PITest
PHP	InfectionPHP
Ruby	Mutant
Python	Cosmic Ray
C/C++	Mull

Disadvantages

- Slower
- Configuration
- Project support

Improving performance

$$T_{total} \mathrel{!}= T_{test} * N$$

- ⏩ Do faster
- ▶️ Do fewer
- 🤔 Do smarter

A. Pizzoleto, F. Ferrari, J. Offutt, L. Fernandes, and M. Ribeiro, “A systematic literature review of techniques and metrics to reduce the cost of mutation testing,” Journal of Systems and Software, vol. 157, Jul. 2019. DOI: 10.1016/j.jss.2019.07.100 (cit. on pp. 15, 18).

Do faster

"Reduce execution time by using novel algorithms, tool improvements, or special-purpose hardware"

~ 30 papers

Do fewer

“The objective is to reduce the number of mutants that will be executed, preferably without reducing effectiveness”

~ 65 papers

🤔 Do smarter

“The objective is either to find smaller test sets that are still as effective at killing mutants, or to identify groups of similar mutants to reduce the number of test runs”

~ 15 papers

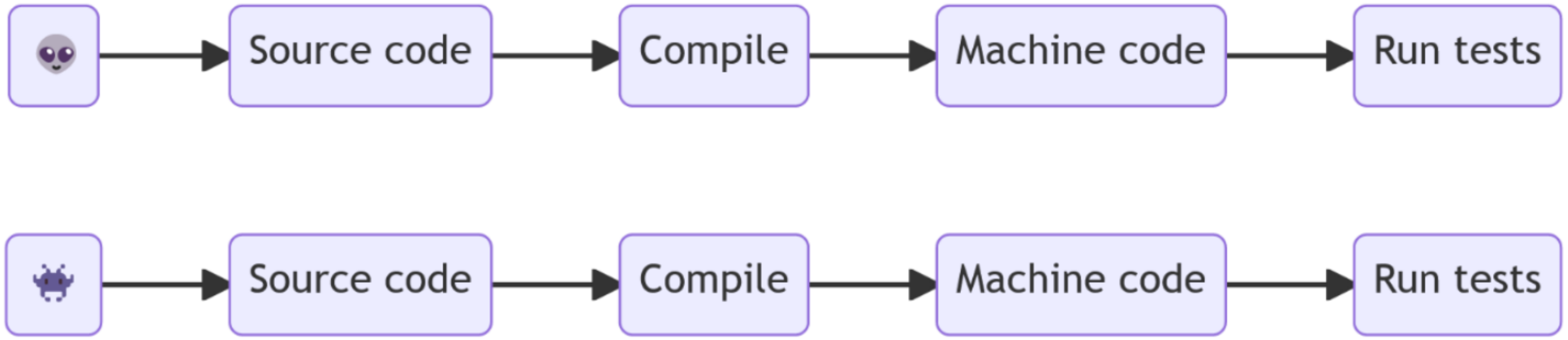
Mutating strategies

How to place the mutations into the code

2 obvious candidates

1. Source code mutation
2. Byte code mutation

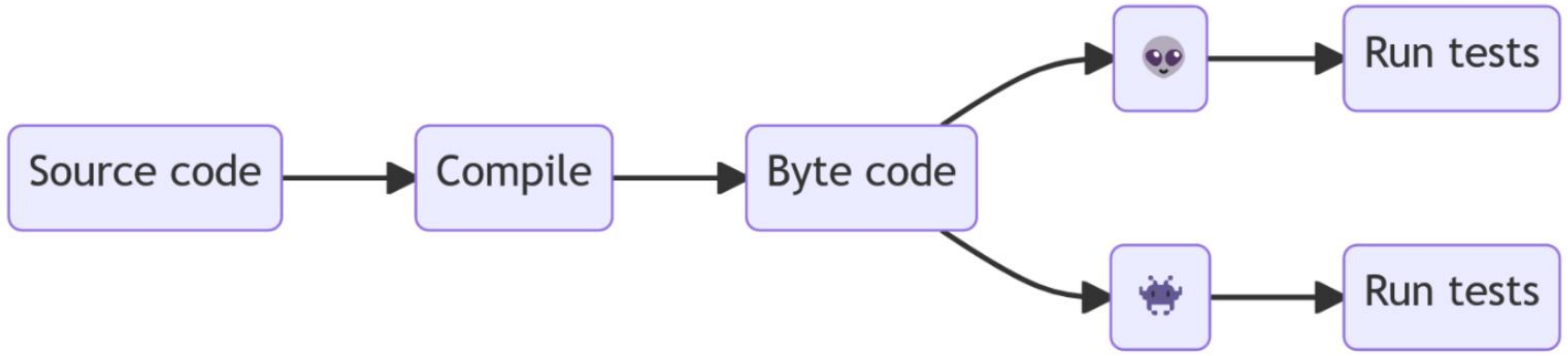
Source code mutation



- Generate mutants based on source code

☑ Precise
☑ Easy
✗ Slow

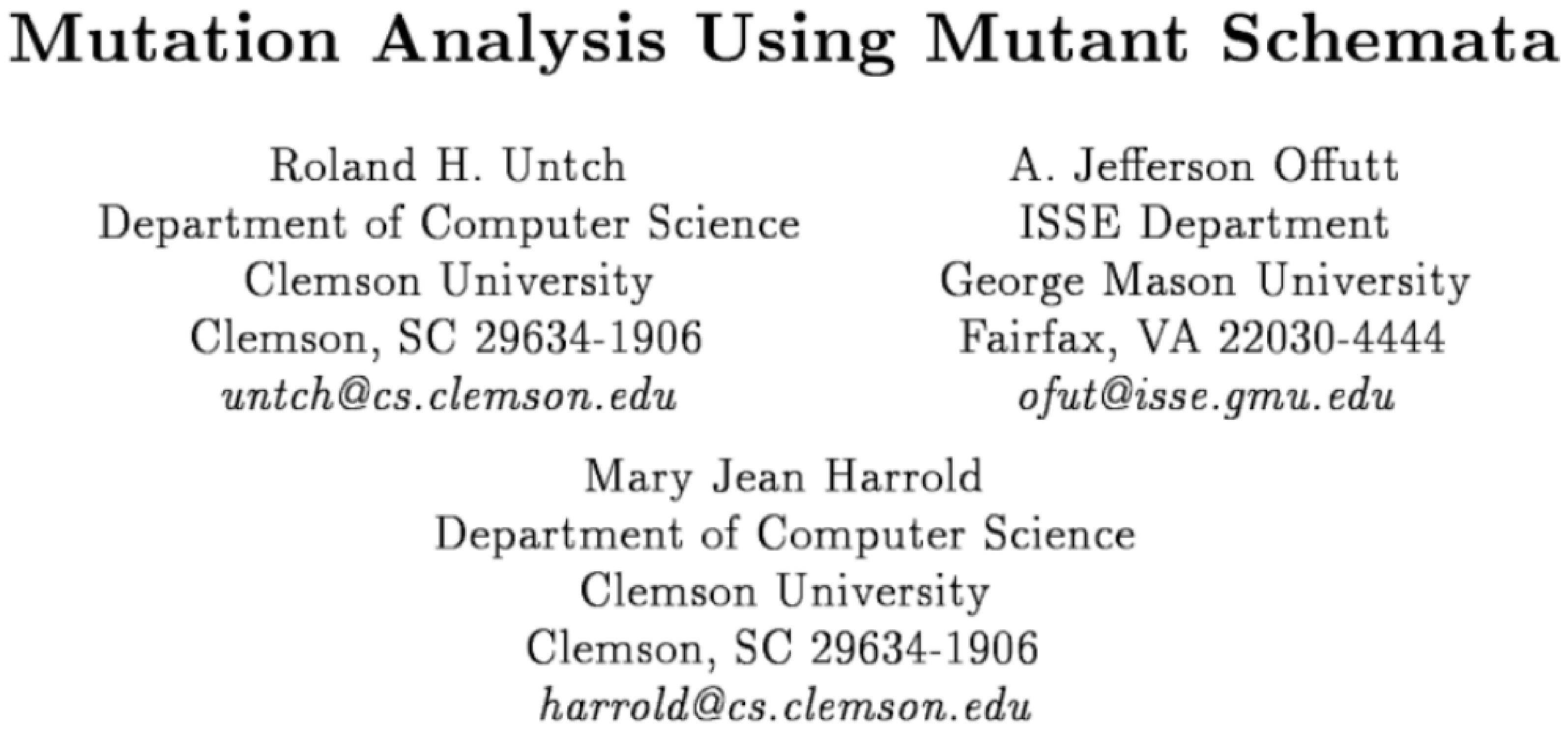
Byte code mutation



- Generate mutants based on compiled code

☑ Fast…ish
✗ False positives
✗ Complicated

Mutant schemata



Mutation Analysis Using Mutant Schemata

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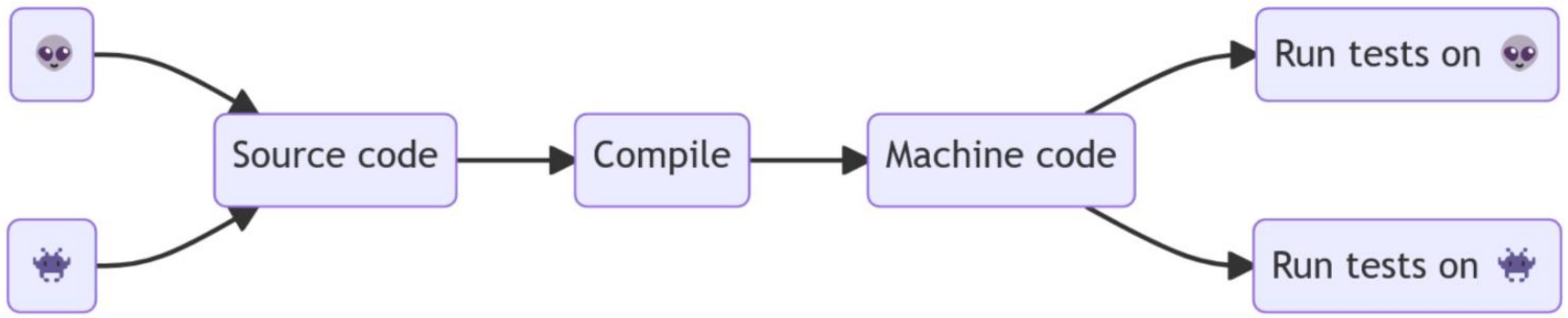
Mutant schemata process



- Generate mutants based on source code, but compile once

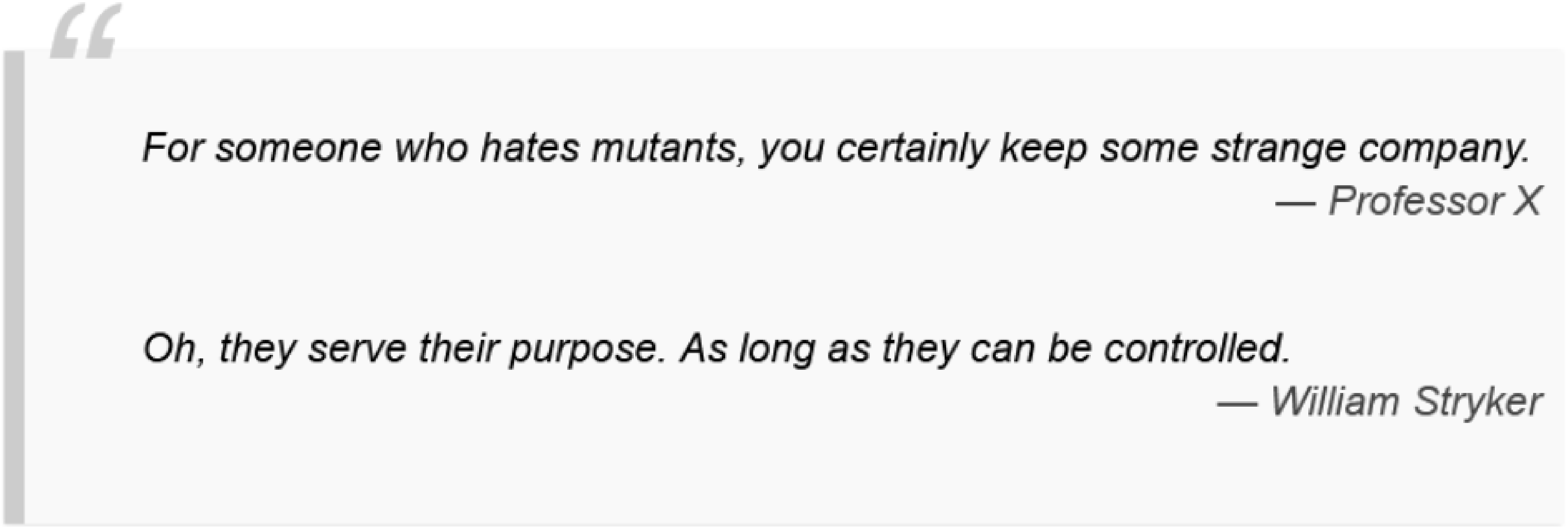
☑ Precise
☑ Fast
▨ Complicated (but manageable)

Mutation testing conclusion

- Testing the tests
- Mutation score: how many mutants were detected
- Framework support is broad
- A lot of research on performance
- There are 3 mutation strategies
  - Mutant schemata is generally the best approach

STRYKER
KILL THE MUTANTS

Stryker
Mutation testing



For someone who hates mutants, you certainly keep some strange company.

— Professor X

Oh, they serve their purpose. As long as they can be controlled.

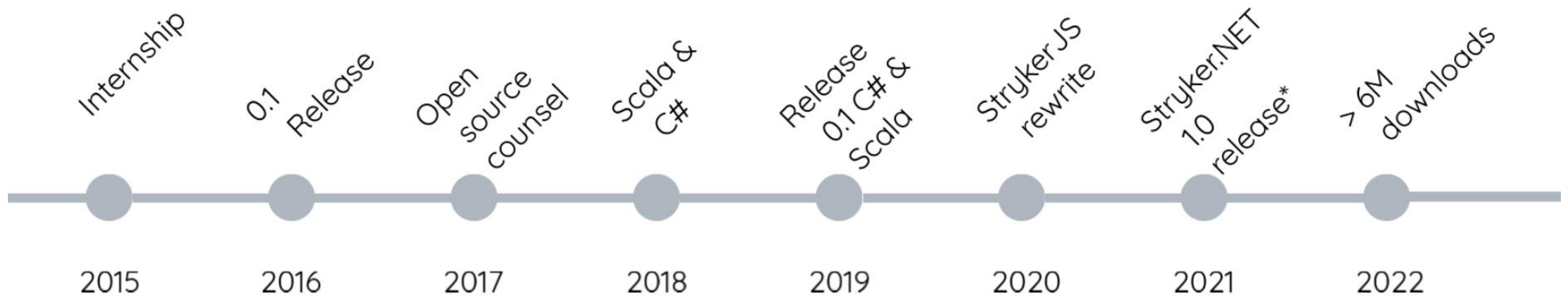
— William Stryker

JavaScript
and friends

C#

Scala

Origin story



Some highlights

- StrykerJS
  - More than 5m total downloads
  - 60.654 downloads a week
- Stryker.NET and Stryker4s
  - More than 0.5m total downloads each
- Shared projects
  - `mutation-testing-elements`: HTML report for mutation testing
  - `stryker-dashboard`: Dashboard for mutation testing reports
  - `weapon-regex`: Regex mutations for Scala & JavaScript

Stryker.NET Mutators

Arithmetic Operators

Original	Mutated
+	-
-	+
*	/
/	*
%	*

Equality Operators

Original	Mutated
>	<
>	>=
>=	<
>=	>
<	>
<	<=
<=	>
<=	<
==	!=
!=	==

Logical Operators

Original	Mutated
&&	||
||	&&
^	==

Boolean Literals

Original	Mutated
true	false
false	true
!person.IsAdult()	person.IsAdult()
if(person.IsAdult())	if(!person.IsAdult())
while(person.IsAdult())	while(!person.IsAdult())

Assignment Statements

Original	Mutated
+=	-=
-=	+=
*=	/=
/=	*=
%=	*=
<<=	>>=
>>=	<<=
&=	|=
&=	^=
|=	&=
|=	^=
^=	|=
^=	&=

Initialization

Original	Mutated
new int[] { 1, 2 };	new int[] { };
int[] numbers = { 1, 2 };	int[] numbers = { };
new List<int> { 1, 2 };	new List<int> { };
new Collection<int> { 1, 2 };	new Collection<int> { };
new Dictionary<int, int> { { 1, 1 } };	new Dictionary<int, int> { };
new SomeClass { Foo = "Bar" };	new SomeClass { };

Removal mutators

Original	Mutated
void Function() { Age++; }	void Function() {} (block emptied)
int Function() { Age++; return Age; }	void Function() { return default; } (block emptied)
return;	removed
return value;	removed
break;	removed
continue;	removed
goto;	removed
throw;	removed
throw exception;	removed
yield return value;	removed
yield break;	removed
MyMethodCall();	removed

Unary Operators

Original	Mutated
-variable	+variable
+variable	-variable
~variable	variable

Update Operators

Original	Mutated
Original	Mutated
variable++	variable--
variable--	variable++
++variable	--variable

Checked Statements

Original	Mutated
checked(2 + 4)	2 + 4

Linq Methods

Original	Mutated
SingleOrDefault()	Single()
Single()	SingleOrDefault()
FirstOrDefault()	First()
First()	FirstOrDefault()
Last()	First()
All()	Any()
Any()	All()
Skip()	Take()
Take()	Skip()
SkipWhile()	TakeWhile()
TakeWhile()	SkipWhile()
Min()	Max()

Original	Mutated
Max()	Min()
Sum()	Max()
Count()	Sum()
Average()	Min()
OrderBy()	OrderByDescending()
OrderByDescending()	OrderBy()
ThenBy()	ThenByDescending()
ThenByDescending()	ThenBy()
Reverse()	AsEnumerable()
AsEnumerable()	Reverse()
Union()	Intersect()
Intersect()	Union()

String Literals and Constants

Original	Mutated
"foo"	""
""	"Stryker was here!"
$"foo {bar}"	$""
@"foo"	@""
string.Empty	"Stryker was here!"

Bitwise Operators

Original	Mutated
<<	>>
>>	<<
&	|
|	&
a^b	~(a^b)

Regular Expressions

Types
Common tokens
Anchors
Quantifiers
Group constructs

Static mutants

Stryker.NET Internals

Choosing the mutation strategy

👽 Mutant schemata

However, this is not possible…

- Mutating constant values
- Mutating method names
- Mutating access modifiers

rosλyn

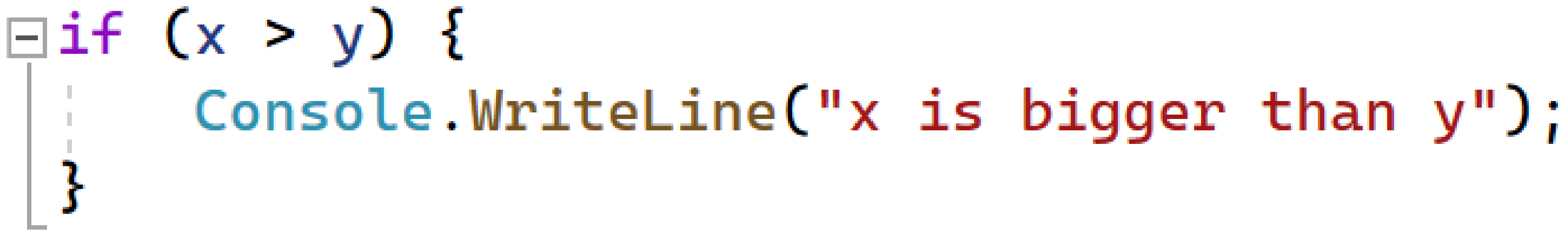
Roslyn API

🔎 Analyzers (code smells, compile errors, etc.)
🏗 Code fixes (find and correct code)

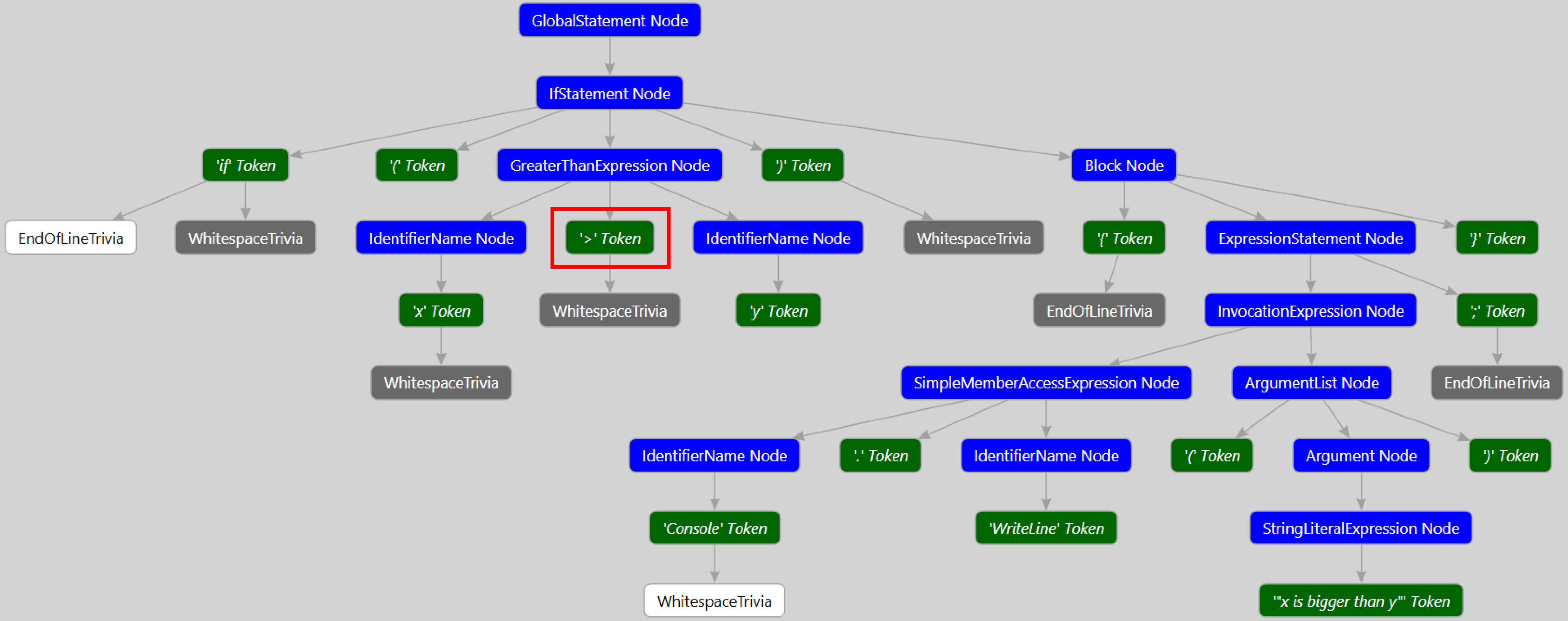
Use cases:
☑ Code completion (IntelliSense)
❓ Inline parameter & type hints
🔃 Code refactoring's
🧪 Mutation testing

Syntax Trees

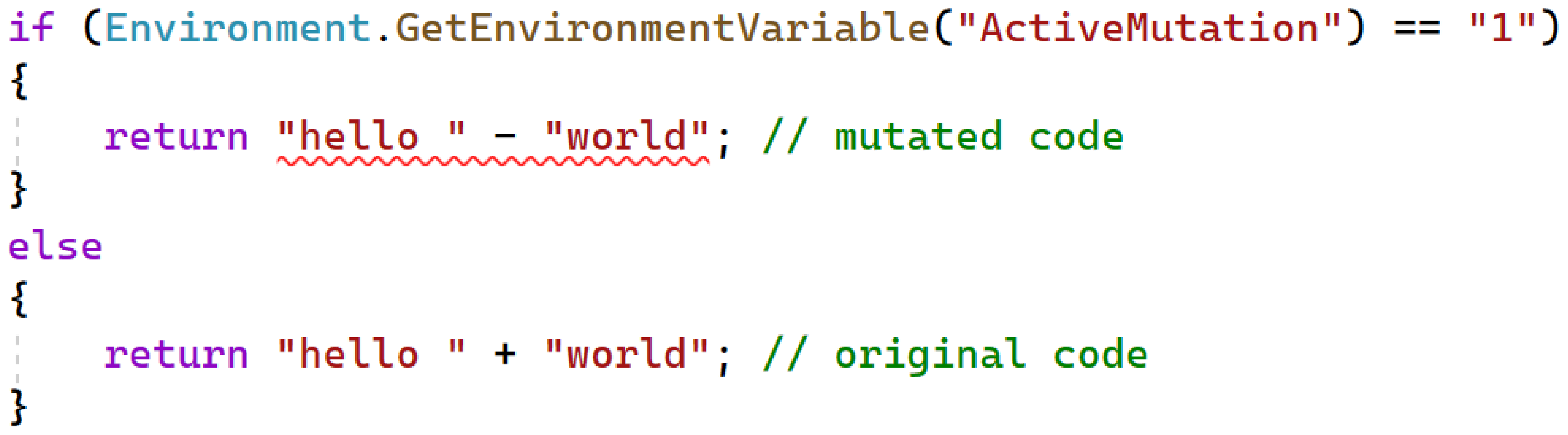
- Data structure used by the compiler
- 4 Primary building blocks:
  1. Syntax tree (an instance of which represents an entire parse tree)
  2. Syntax node (declarations, statements, clauses, and expressions)
  3. Syntax Token (individual keyword, identifier, operator, or punctuation)
  4. Syntax Trivia (white space between tokens, preprocessing directives, and comments.)



```
if (x > y) {
    Console.WriteLine("x is bigger than y");
}
```


GlobalStatement Node
IfStatement Node
'if' Token
'(' Token
GreaterThanExpression Node
')' Token
Block Node
EndOfLineTrivia
WhitespaceTrivia
IdentifierName Node
'>' Token
IdentifierName Node
WhitespaceTrivia
'{' Token
ExpressionStatement Node
'}' Token
'x' Token
WhitespaceTrivia
'y' Token
EndOfLineTrivia
InvocationExpression Node
';' Token
WhitespaceTrivia
SimpleMemberAccessExpression Node
ArgumentList Node
EndOfLineTrivia
IdentifierName Node
'.' Token
IdentifierName Node
'(' Token
Argument Node
')' Token
'Console' Token
'WriteLine' Token
StringLiteralExpression Node
WhitespaceTrivia
'"x is bigger than y"' Token

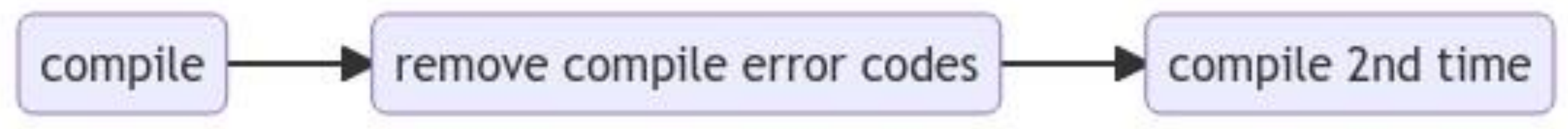
Compile errors



```
if (Environment.GetEnvironmentVariable("ActiveMutation") == "1")
{
    return "hello " - "world"; // mutated code
}
else
{
    return "hello " + "world"; // original code
}
```

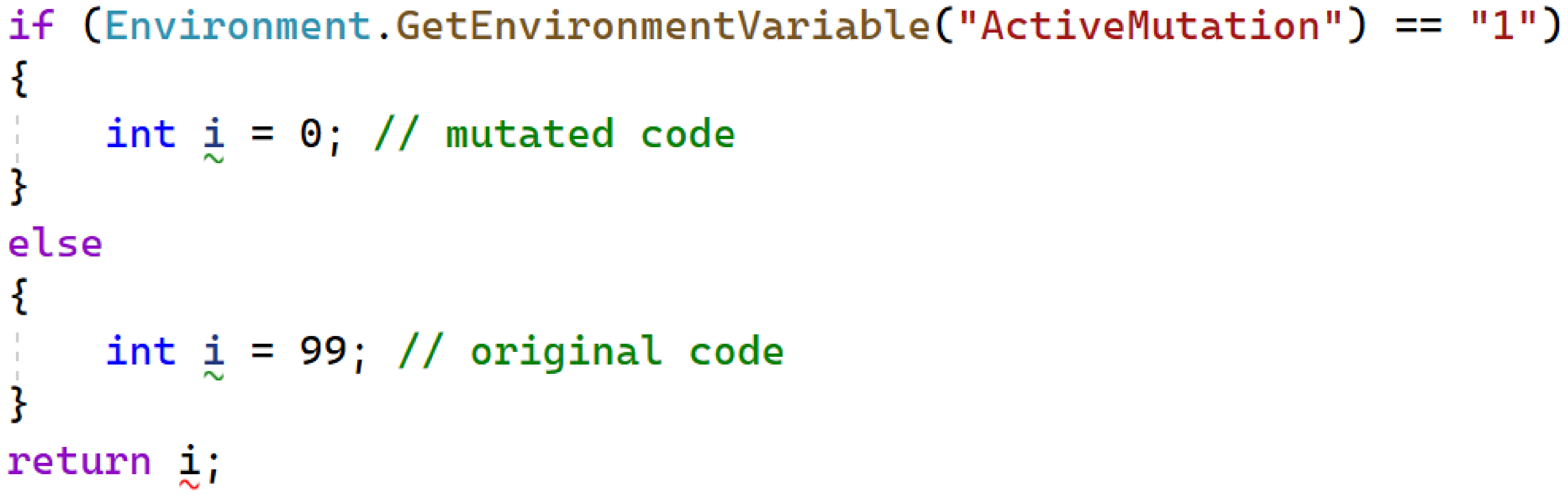
✗ Not all mutations can be compiled

Rollback



- 🔁 Rollbacking all mutations that result in compile errors
- 🔂 Repeat process until we compile the code
- 👽 Mutant gets status build error

Scope



```
if (Environment.GetEnvironmentVariable("ActiveMutation") == "1")
{
    int i = 0; // mutated code
}
else
{
    int i = 99; // original code
}
return i;
```

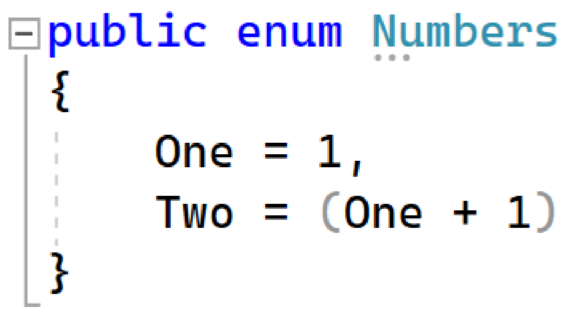
✗ Cannot be compiled because the scope of the variables can change when places inside an if statement

Using conditional statements

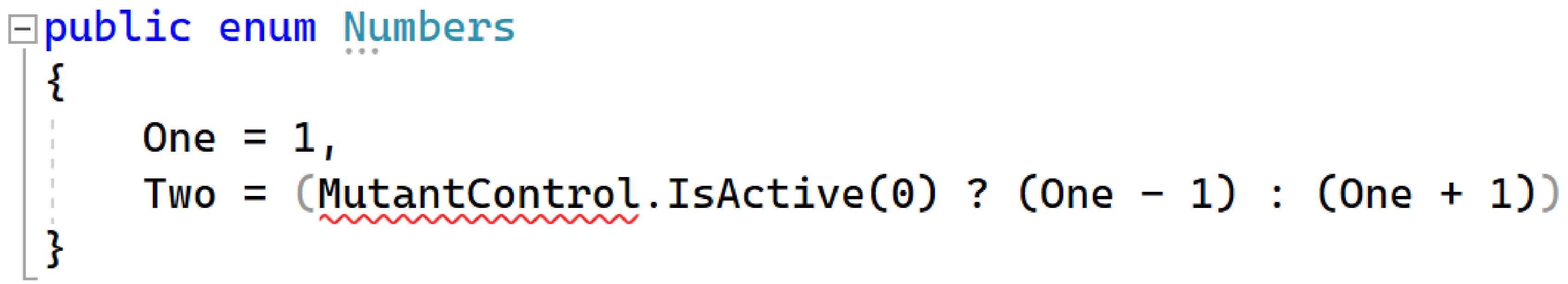
- Rollback is not possible
- Use conditional statements instead of if statements

```
int i = Environment.GetEnvironmentVariable("ActiveMutation") == "1" ? 0 : 99;
return i;
```

Constant values



```
public enum Numbers
{
    One = 1,
    Two = (One + 1)
}
```



```
public enum Numbers
{
    One = 1,
    Two = (MutantControl.IsActive(0) ? (One - 1) : (One + 1))
}
```

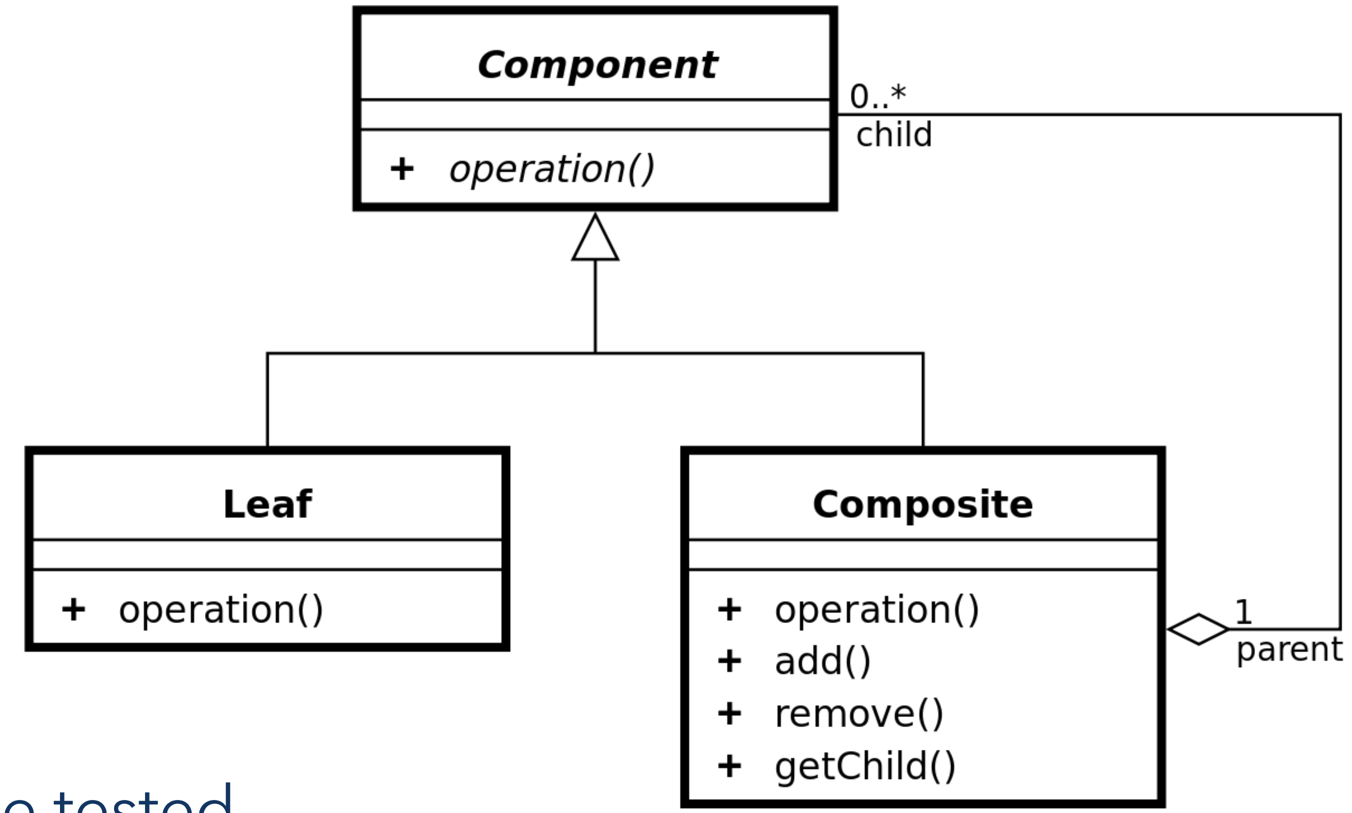
✗ This cannot compile since `MutantControl.IsActive(0)` is not a constant value.

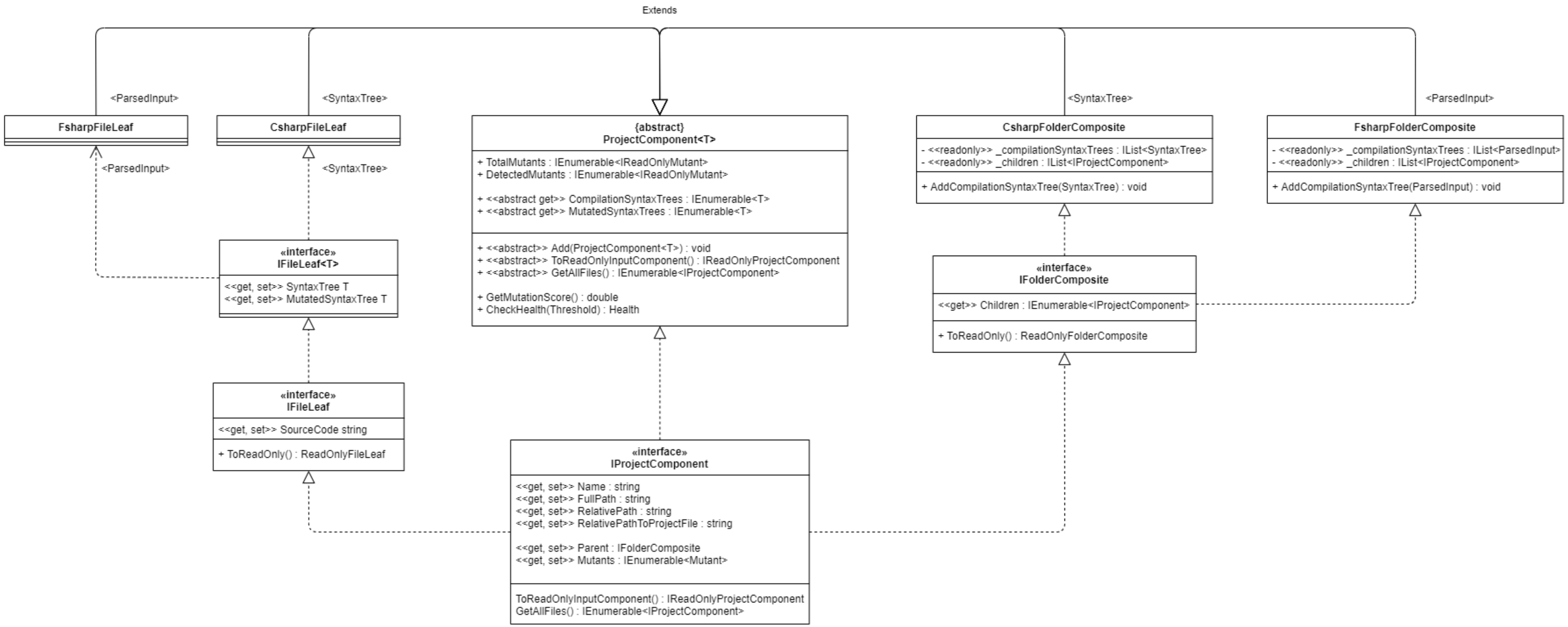
Project components

- Project component
- Folder composite
- File leaf

- ✗ F# syntax tree
- Differentiate C# & F#

- ✗ Not everything needs to be tested
- Read only



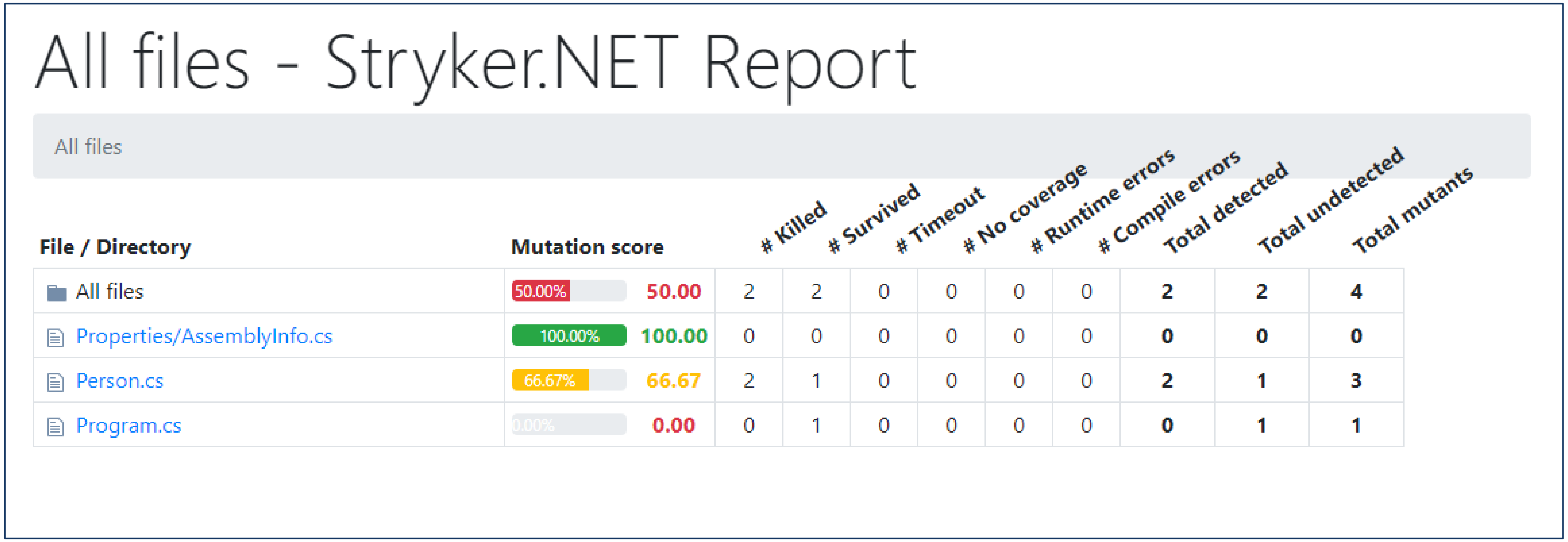

Extends
<ParsedInput>
<SyntaxTree>
<SyntaxTree>
<ParsedInput>
FsharpFileLeaf
CsharpFileLeaf
{abstract}
ProjectComponent<T>
+ TotalMutants : IEnumerable<IReadOnlyMutant>
+ DetectedMutants : IEnumerable<IReadOnlyMutant>
+ <<abstract get>> CompilationSyntaxTrees : IEnumerable<T>
+ <<abstract get>> MutatedSyntaxTrees : IEnumerable<T>
+ <<abstract>> Add(ProjectComponent<T>) : void
+ <<abstract>> ToReadOnlyInputComponent() : IReadOnlyProjectComponent
+ <<abstract>> GetAllFiles() : IEnumerable<IProjectComponent>
+ GetMutationScore() : double
+ CheckHealth(Threshold) : Health
CsharpFolderComposite
- <<readonly>> _compilationSyntaxTrees : IList<SyntaxTree>
- <<readonly>> _children : IList<IProjectComponent>
+ AddCompilationSyntaxTree(SyntaxTree) : void
FsharpFolderComposite
- <<readonly>> _compilationSyntaxTrees : IList<ParsedInput>
- <<readonly>> _children : IList<IProjectComponent>
+ AddCompilationSyntaxTree(ParsedInput) : void
<ParsedInput>
<SyntaxTree>
«interface»
IFileLeaf<T>
<<get, set>> SyntaxTree T
<<get, set>> MutatedSyntaxTree T
«interface»
IFolderComposite
<<get>> Children : IEnumerable<IProjectComponent>
+ ToReadOnly() : ReadOnlyFolderComposite
«interface»
IFileLeaf
<<get, set>> SourceCode string
+ ToReadOnly() : ReadOnlyFileLeaf
«interface»
IProjectComponent
<<get, set>> Name : string
<<get, set>> FullPath : string
<<get, set>> RelativePath : string
<<get, set>> RelativePathToProjectFile : string
<<get, set>> Parent : IFolderComposite
<<get, set>> Mutants : IEnumerable<Mutant>
ToReadOnlyInputComponent() : IReadOnlyProjectComponent
GetAllFiles() : IEnumerable<IProjectComponent>

VSTest

🏃‍♀️ Running tests
🎒 Collect diagnostics
👮‍♀️ Report results (we use our own)

💁‍♂️ Supports:
- XUnit
- NUnit
- MSTest

HTML Reporter



All files - Stryker.NET Report

All files

File / Directory	Mutation score		# Killed	# Survived	# Timeout	# No coverage	# Runtime errors	# Compile errors	Total detected	Total undetected	Total mutants
All files	50.00%	50.00	2	2	0	0	0	0	**2**	**2**	**4**
Properties/AssemblyInfo.cs	100.00%	100.00	0	0	0	0	0	0	**0**	**0**	**0**
Person.cs	66.67%	66.67	2	1	0	0	0	0	**2**	**1**	**3**
Program.cs	0.00%	0.00	0	1	0	0	0	0	**0**	**1**	**1**

Conclusion

- Stryker is a family of mutation testing frameworks
- Open source and maintained by InfoSupport
  - View our issues board if you want to contribute as well! https://github.com/stryker-mutator/stryker-net/issues

Exercise 1 – Make it work

1. Install Stryker.NET (globally or check docs for local)

```
.NET CLI
dotnet tool install -g dotnet-stryker
```

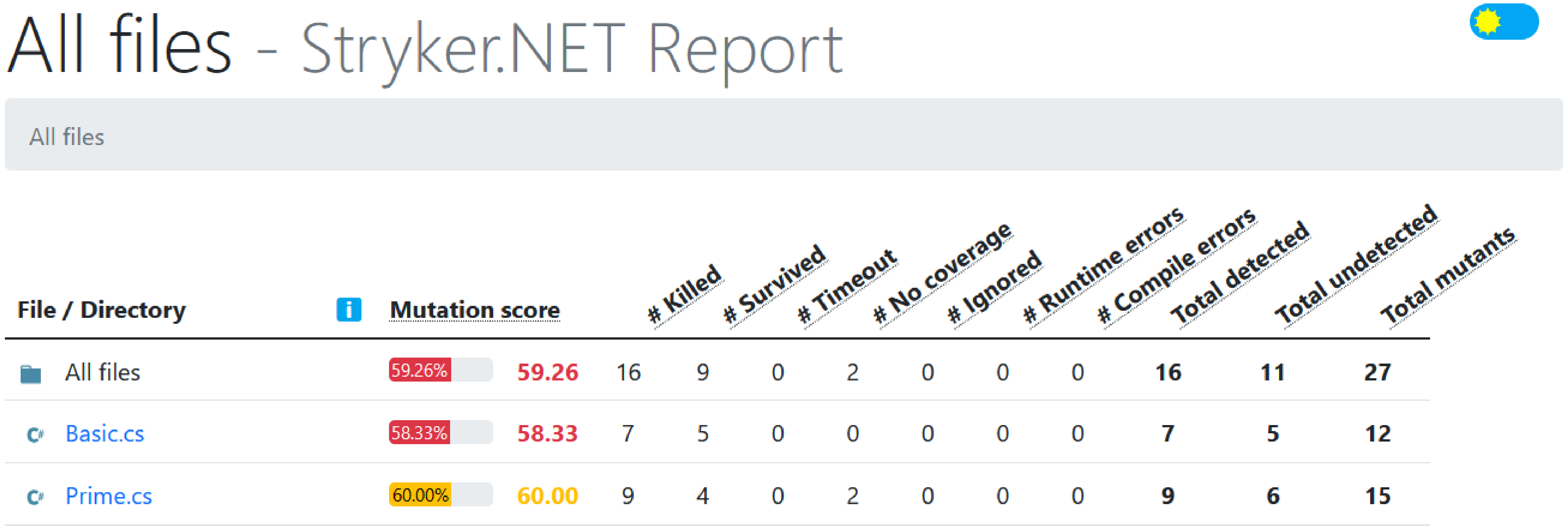
2. Navigate to your test folder

3. Run Stryker.NET and inspect the report

```
.NET CLI
dotnet stryker -o
```

Exercise 2 – Improve mutation score

1. Fix the tests to improve your mutation score



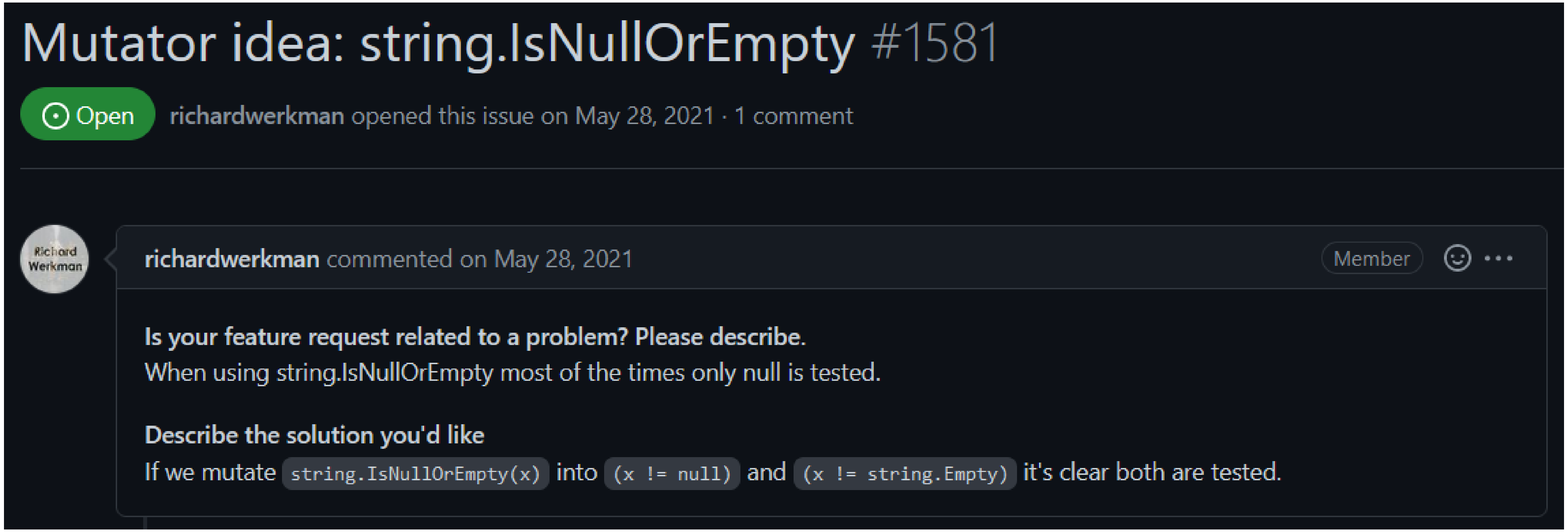
All files - Stryker.NET Report

All files

File / Directory	Mutation score		# Killed	# Survived	# Timeout	# No coverage	# Ignored	# Runtime errors	# Compile errors	Total detected	Total undetected	Total mutants
All files	59.26%	59.26	16	9	0	2	0	0	0	16	11	27
Basic.cs	58.33%	58.33	7	5	0	0	0	0	0	7	5	12
Prime.cs	60.00%	60.00	9	4	0	2	0	0	0	9	6	15

Exercise 3 - Help me create a mutant

1. Fork Stryker.NET and inspect the project
2. Work out the mutator idea



Mutator idea: string.IsNullOrEmpty #1581

Open richardwerkman opened this issue on May 28, 2021 · 1 comment

richardwerkman commented on May 28, 2021 Member

Is your feature request related to a problem? Please describe.
When using string.IsNullOrEmpty most of the times only null is tested.

Describe the solution you'd like
If we mutate `string.IsNullOrEmpty(x)` into `(x != null)` and `(x != string.Empty)` it's clear both are tested.

- You can also find us @

01001001 01000011 01010100

MEET YOUR FUTURE

01001001 01000011 01010100

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