Property based testing in practice

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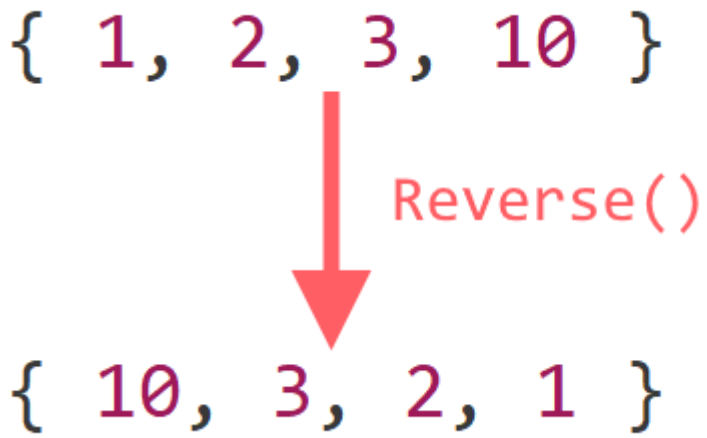
Automated tests…

- … are fast to execute.
- … prevent regression.
- … don’t forget about specific use-cases.
- … serve as documentation.

Example based testing

1. Define some input values.
2. Define expected output values.
3. Execute code and check the result is as expected.

Example - List Reverse



Test with a collection of integer values

```
[Test]
public void ReversalOfListOfIntsWorks()
{
    var list = new List<int> { 1, 2, 3, 10 };
    var reversedList = Reverse(list);
    CollectionAssert.AreEqual(
        expected: new List<int> { 10, 3, 2, 1 },
        actual: reversedList
    );
}
```

+ Test with an empty collection

```
[Test]
public void ReversalOfListOfIntsWorks()
{
    var list = new List<int> { 1, 2, 3, 10 };
    var reversedList = Reverse(list);
    CollectionAssert.AreEqual(
        expected: new List<int> { 10, 3, 2, 1 },
        actual: reversedList
    );
}

[Test]
public void ReversalOfEmptyListOfIntsWorks()
{
    var list = new List<int>();
    var reversedList = Reverse(list);
    CollectionAssert.AreEqual(
        expected: new List<int>(),
        actual: reversedList
    );
}
```

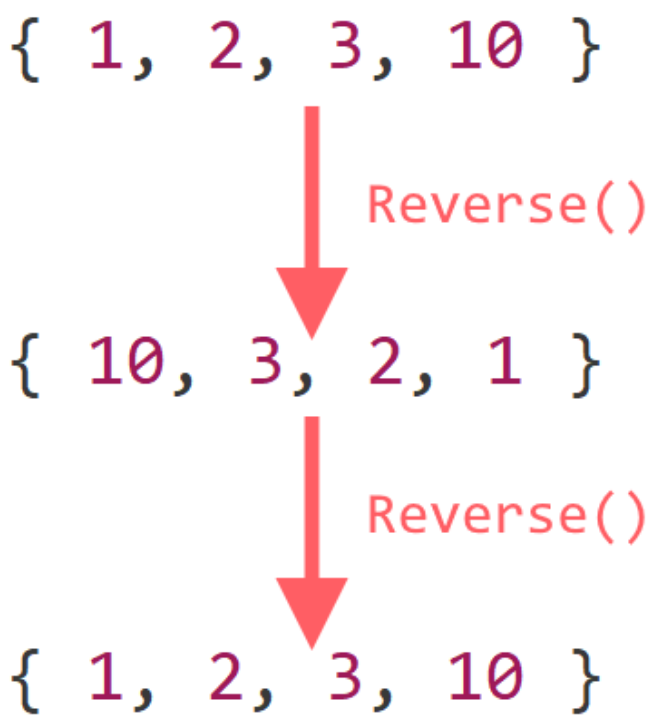
Refactoring

```
[Test]
public void ReversalOfListOfIntsWorks()
{
    TestListReversal(
        list: new List<int> { 1, 2, 3, 10 },
        expected: new List<int> { 10, 3, 2, 1 }
    );
}

[Test]
public void ReversalOfEmptyListOfIntsWorks()
{
    TestListReversal(
        list: new List<int>(),
        expected: new List<int>()
    );
}

2 usages
private void TestListReversal<T>(List<T> list, List<T> expected)
{
    var reversedList = Reverse(list);
    CollectionAssert.AreEqual(
        expected: expected,
        actual: reversedList
    );
}
```

Property based testing

1. Describe the input.
2. Describe the properties of the output.
3. Run test with randomly generated values and check the properties.

Reverse(Reverse(list)) = list



First generative test

```
[Test]
public void DoubleReversalOfListReturnsOriginalList()
{
    var random = new Random();
    for (var i = 0; i < 100; i++)
    {
        var list =
            Enumerable.Range(0, random.Next(1000))
            .Select(_ => random.Next())
            .ToList();
        var reversedList = Reverse(list);
        var doubleReverseList = Reverse(reversedList);
        CollectionAssert.AreEqual(
            expected: list,
            actual: doubleReverseList
        );
    }
}
```

First generative test

```
DoubleReversalOfListReturnsOriginalList (.NETCoreApp,Version=v3.1) [34 ms] System.ArgumentOutOfRangeException : Index was out of range. Must be non-negative and less than the size of the collection. (Parameter 'index')
PropertyBasedTesting.ListReverse.DoubleReversalOfListReturnsOriginalList

System.ArgumentOutOfRangeException : Index was out of range. Must be non-negative and less
 than the size of the collection. (Parameter 'index')
   at System.Collections.Generic.List`1.get_Item(Int32 index)
   at PropertyBasedTesting.ListReverse.Reverse[T](List`1 input) in
 C:\Users\marek\OneDrive\mews\prezentace\property-based-testing\samples
 \PropertyBasedTesting\PropertyBasedTesting\ListReverse.cs:line 18
   at PropertyBasedTesting.ListReverse.DoubleReversalOfListReturnsOriginalList() in
 C:\Users\marek\OneDrive\mews\prezentace\property-based-testing\samples
 \PropertyBasedTesting\PropertyBasedTesting\ListReverse.cs:line 71
```

Different flavors of QuickCheck

1. C
2. C++
3. Chicken
4. Clojure
5. Common Lisp
6. Coq
7. D
8. Elm
9. Elixir
10. Erlang
11. F#
12. C#
13. Visual Basic .NET
14. Factor
15. Go
16. Io
17. Java
18. JavaScript
19. Julia
20. Logtalk
21. Lua
22. Mathematica
23. Objective-C
24. OCaml
25. Perl
26. Prolog
27. PHP
28. Pony
29. Python
30. R
31. Racket
32. Ruby
33. Rust
34. Scala
35. Scheme
36. Smalltalk
37. Standard ML
38. Swift
39. TypeScript
40. Whiley

Generative test using the library

```
[Test]
public void DoubleReversalOfListReturnsOriginalList()
{
    Prop.ForAll<List<int>>(list =>
    {
    });
}
```

Generative test using the library

```
[Test]
public void DoubleReversalOfListReturnsOriginalList()
{
    Prop.ForAll<List<int>>(list =>
    {
    });
}
```

```
Output (.NETCoreApp,Version=v3.1) [173 ms]
97:
seq [0; 0; 0; 0; ...]
98:
seq [3; 0; -3; -5; ...]
99:
seq [0; 1; 34; 0; ...]
```

Generative test using the library

```
[Test]
public void DoubleReversalOfListReturnsOriginalList()
{
    Prop.ForAll<List<int>>(list =>
    {
        var reversedList = Reverse(list);
        var doubleReversedList = Reverse(reversedList);
        return list.SequenceEqual(doubleReversedList);
    });
}
```

Generative test using the library

```
[Test]
public void DoubleReversalOfListReturnsOriginalList()
{
    Prop.ForAll<List<int>>(list =>
    {
        var reversedList = Reverse(list);
        var doubleReversedList = Reverse(reversedList);
        return list.SequenceEqual(doubleReversedList);
    }).QuickCheckThrowOnFailure();
}
```

Generative test using the library

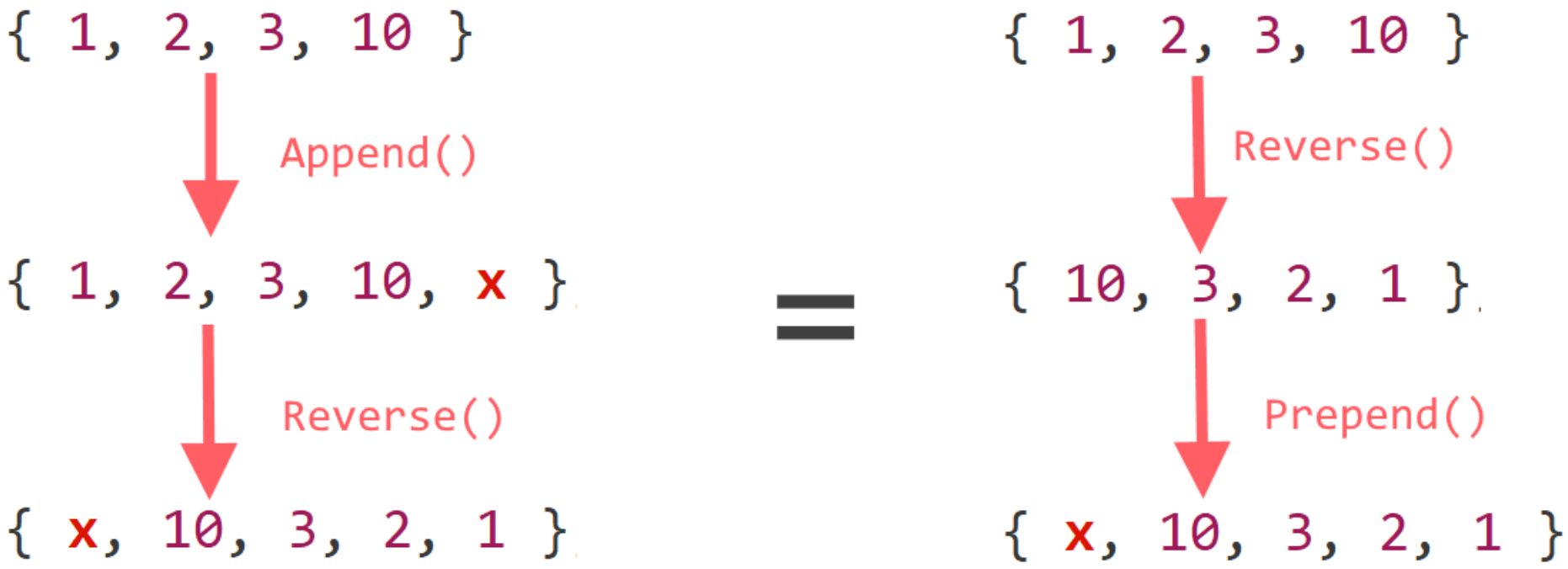
```
[Test]
public void DoubleReversalOfListReturnsOriginalList()
{
    Prop.ForAll<List<int>>(list =>
    {
        var reversedList = Reverse(list);
        var doubleReversedList = Reverse(reversedList);
        return list.SequenceEqual(doubleReversedList);
    }).QuickCheckThrowOnFailure();
}
```

Implementation of Reverse()

```
private List<T> Reverse<T>(List<T> input)
{
    return input;
}
```

✔ DoubleReversalOfListReturnsOriginalList [173 ms] Success

Reverse(Append(list)) = Prepend(Reverse(list))



Multiple auto-generated values

```
[Test]
public void AppendThenReverseIsEqualToReverseThenPrepend()
{
    Prop.ForAll(Arb.From<int>(), Arb.From<List<int>>(), (element, list) =>
    {
    });
}
```

Test Reverse(Append) = Prepend(Reverse)

```
[Test]
public void AppendThenReverseIsEqualToReverseThenPrepend()
{
    Prop.ForAll(Arb.From<int>(), Arb.From<List<int>>(), (element, list) =>
    {
        var appendThenReverse = Reverse(Append(list, element));
        var reverseThenPrepend = Prepend(Reverse(list), element);
        return appendThenReverse.SequenceEqual(reverseThenPrepend);
    }).QuickCheckThrowOnFailure();
}
```

Test Reverse(Append) = Prepend(Reverse)

```
[Test]
public void AppendThenReverseIsEqualToReverseThenPrepend()
{
    Prop.ForAll(Arb.From<int>(), Arb.From<List<int>>(), (element, list) =>
    {
        var appendThenReverse = Reverse(Append(list, element));
        var reverseThenPrepend = Prepend(Reverse(list), element);
        return appendThenReverse.SequenceEqual(reverseThenPrepend);
    }).QuickCheckThrowOnFailure();
}
```

AppendThenReverseIsEqualToReverseThenPrepend [203 ms] Failed: System.Exception : Falsifiable

Working implementation of Reverse()

```
private List<T> Reverse<T>(List<T> input)
{
    var output = new List<T>(input);
    output.Reverse();
    return output;
}
```

✔ AppendThenReverseIsEqualToReverseThenPrepend [130 ms] Success

✔ DoubleReversalOfListReturnsOriginalList [71 ms] Success

Test Reverse(Append) = Prepend(Reverse)

```
AppendThenReverseIsEqualToReverseThenPrepend (.NETCoreApp,Version=v3.1) [199 ms] System.Exception : Falsifiable, after 3 tests (3 shrinks) (427708154167105 7,14413507071265457431)
PropertyBasedTesting.ListReverse.AppendThenReverseIsEqualToReverseThenPrepend

System.Exception : Falsifiable, after 3 tests (3 shrinks) (4277081541671057107,
 14413507071265457431)
Last step was invoked with size of 4 and seed of (8928640929221858429,
 1429398716816633359):
Original:
-3
seq [0]
Shrunk:
1
seq [0]
```

Shrinker

```
AppendThenReverseIsEqualToReverseThenPrepend (.NETCoreApp,Version=v3.1) [199 ms] System.Exception : Falsifiable, after 3 tests (3 shrinks) (4277081541671057107,1441350707126545743 1)
PropertyBasedTesting.ListReverse.AppendThenReverseIsEqualToReverseThenPrepend

System.Exception : Falsifiable, after 3 tests (3 shrinks) (4277081541671057107,
 14413507071265457431)
Last step was invoked with size of 4 and seed of (8928640929221858429,
 1429398716816633359):
Original:
-3
seq [0]
Shrunk:
1
seq [0]
```

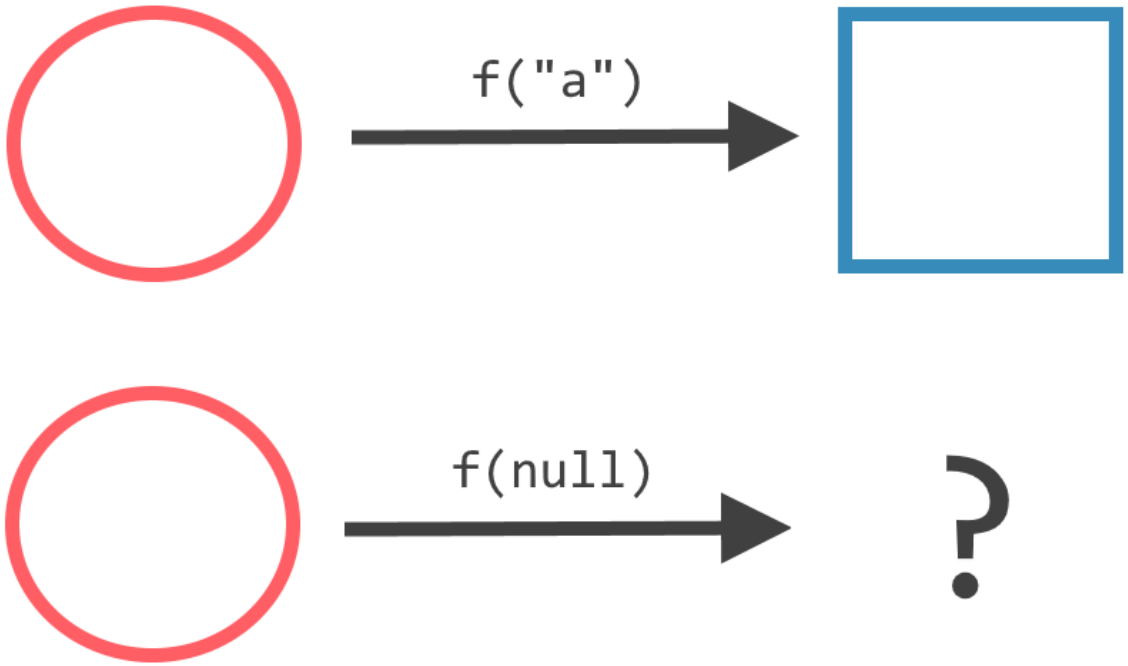
Seed

```
AppendThenReverseIsEqualToReverseThenPrepend (.NETCoreApp,Version=v3.1) [199 ms] System.Exception : Falsifiable, after 3 tests (3 shrinks) (4277081541671057107,1441350707126545743 1)
PropertyBasedTesting.ListReverse.AppendThenReverseIsEqualToReverseThenPrepend

System.Exception : Falsifiable, after 3 tests (3 shrinks) (4277081541671057107,
 1441350707126545743 1)
Last step was invoked with size of 4 and seed of (8928640929221858429,
 1429398716816633359):
Original:
-3
seq [0]
Shrunk:
1
seq [0]
```

Useful testing patterns

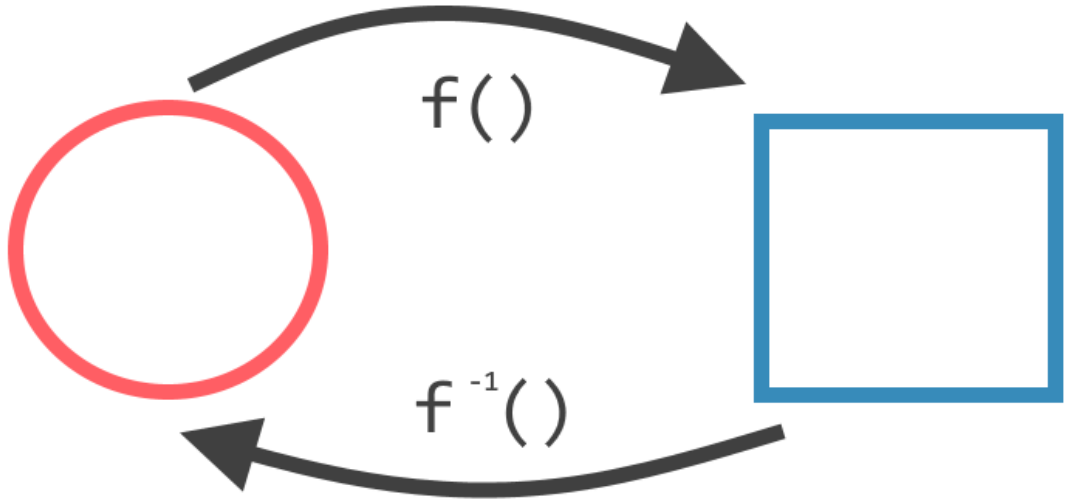
Fuzz testing

- Checking that the code doesn't crash.



Inverse function

- Encode / Decode
- Serialize / Deserialize
- Write / Read

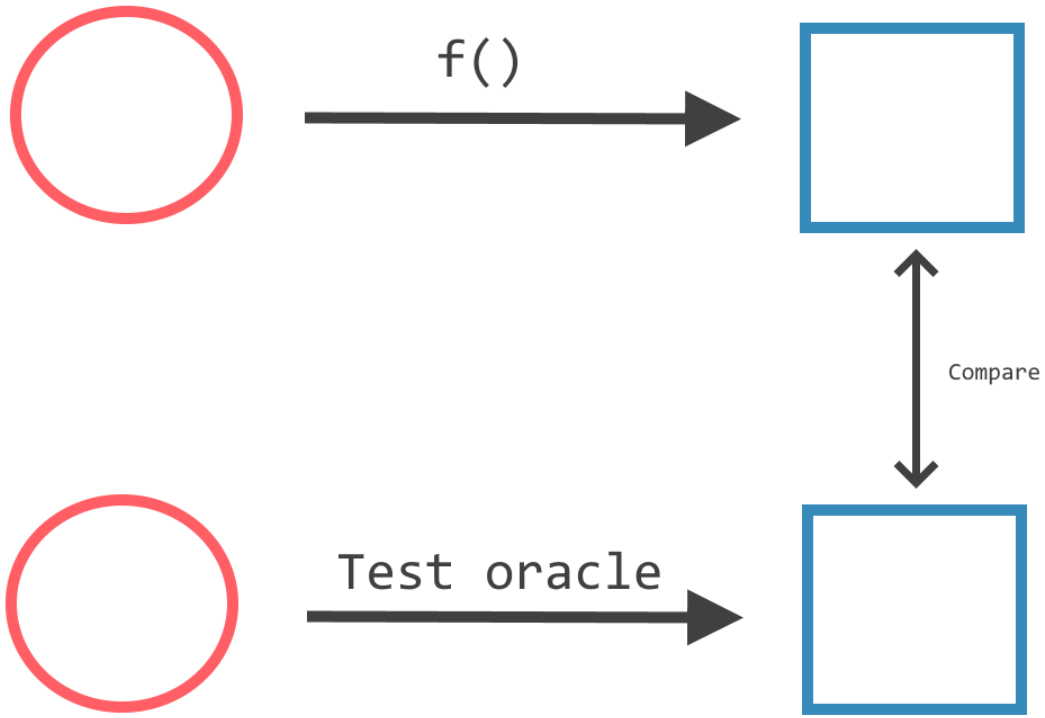


Idempotence

- List.Distinct()
- String.Trim()

Test oracle

- New vs old implementation.
- Naive vs optimized implementation.



Summary

- It’s often beneficial to combine EBT and PBT.
- Example based tests are usually easier to understand.
- Few generative test can replace many example based tests.
- Generative tests are more likely to discover edge-cases.

Useful resources

- FSharpForFunAndProfit.com
- en.wikipedia.org/wiki/QuickCheck
- github.com/marektresnak/talks

Questions?

- marek.tresnak@outlook.com
- github.com/MewsSystems/developers

MEWS