Computer Systems Modeling and Verification
(USEEN1)

Part II: PBT with Hypothesis

This tutorial is taken from the introduction of the "Property Based Testing" series (adapted to Python and Hypothesis).

Choosing properties for property-based testing

Or, I want to use PBT, but I can never think of any properties to use

But here's a common problem. Everyone who sees a property-based testing tool like QuickCheck[1] thinks that it is amazing... but when it comes time to start creating your own properties, the universal complaint is: "what properties should I use? I can't think of any!"

The goal of this tutorial is to show some common patterns that can help you discover the properties that are applicable to your code.

Categories for properties

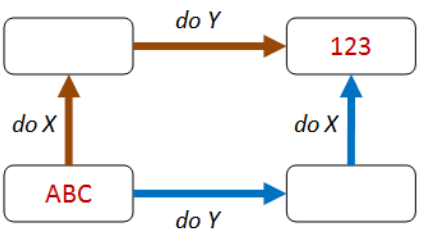
In my experience, many properties can be discovered by using one of the seven approaches listed below.

- "Different paths, same destination"
- "There and back again"
- "Some things never change"
- "The more things change, the more they stay the same"
- "Solve a smaller problem first"
- "Hard to prove, easy to verify"
- "The test oracle"

This is by no means a comprehensive list, just the ones that have been most useful to me. For a different perspective, check out the list of patterns that the Pex team at Microsoft have compiled.

"Different paths, same destination"

These kinds of properties are based on combining operations in different orders, but getting the same result. For example, in the diagram below, doing `X` then `Y` gives the same result as doing `Y` followed by `X`.



In category theory, this is called a *commutative diagram*.

1. QuickCheck: a lightweight tool for random testing of Haskell programs

Addition is an obvious example of this pattern. For example, the result of adding `1` then adding `2` is the same as the result of adding `2` followed by adding `1`.

This pattern, generalized, can produce a wide range of useful properties. We'll see some more uses of this pattern later.

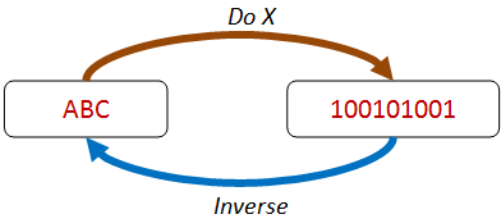
Exercise 1. Check the simple property given for the addition.

Exercise 2. Check that `map` commutes with `reversed` (these functions were implemented in previous assignments.

"There and back again"

These kinds of properties are based on combining an operation with its inverse, ending up with the same value you started with.

In the diagram below, doing `X` serializes `ABC` to some kind of binary format, and the inverse of `X` is some sort of deserialization that returns the same `ABC` value again.



In addition to `serialization/deserialization`, other pairs of operations can be checked this way: `addition/subtraction`, `write/read`, `setProperty/getProperty`, and so on.

Other pair of functions fit this pattern too, even though they are not strict inverses, pairs such as `insert/contains`, `create/exists`, etc.

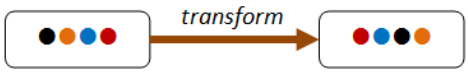
Exercise 3. Check that `chr` and `ord` on `ascii` characters are inverses.

Exercise 4. Check that `reversed` is its own inverse.

"Some things never change"

These kinds of properties are based on an invariant that is preserved after some transformation.

In the diagram below, the transform changes the order of the items, but the same four items are still present afterwards.



Common invariants include size of a collection (for `map` say), the contents of a collection (for `sort` say), the height or depth of something in proportion to size (e.g. balanced trees).

Exercise 5. Check that `map` and `reversed` do not change the length of the list.

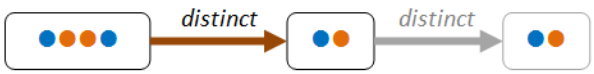
Exercise 6. Check that `reversed` do not change the contents of the list (using `sorted` for instance).

Exercise 7. Check that `sorted` do not change the contents of the list (for instance, by first converting a list into a dictionary mapping each value onto its multiplicity).

"The more things change, the more they stay the same"

These kinds of properties are based on "idempotence" – that is, doing an operation twice is the same as doing it once.

In the diagram below, using `distinct` to filter the list returns two items, but doing `distinct` twice returns the same list again.



Idempotence properties are very useful, and can be extended to things like database updates and message processing.

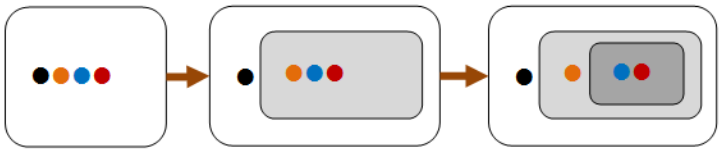
> **Exercise 8.** Define function `distinct` as follows: turn the list into a dictionary and back again into a list (note that dictionaries preserve insertion order, but not sets). Check that `distinct` is idempotent.

> **Exercise 9.** Check that `sorted` is idempotent.

"Solve a smaller problem first"

These kinds of properties are based on "structural induction" – that is, if a large thing can be broken into smaller parts, and some property is true for these smaller parts, then you can often prove that the property is true for a large thing as well.

In the diagram below, we can see that the four-item list can be partitioned into an item plus a three-item list, which in turn can be partitioned into an item plus a two-item list. If we can prove the property holds for two-item list, then we can infer that it holds for the three-item list, and for the four-item list as well.



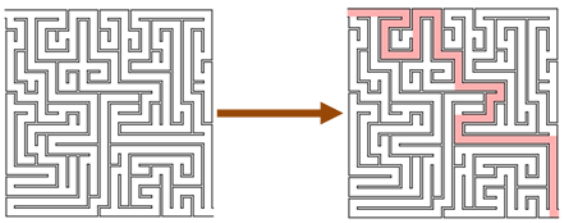
Induction properties are often naturally applicable to recursive structures such as lists and trees.

> **Exercise 10.** Check the defining equations of a few functions on lists (these equations were given in previous assignments).

"Hard to prove, easy to verify"

Often an algorithm to find a result can be complicated, but verifying the answer is easy.

In the diagram below, we can see that finding a route through a maze is hard, but checking that it works is trivial!



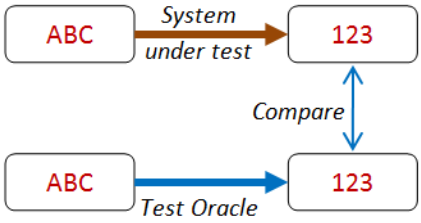
Many famous problems are of this sort, such as prime number factorization. But this approach can be used for even simple problems.

For example, you might check that a string tokenizer works by just concatenating all the tokens again. The resulting string should be the same as what you started with.

> **Exercise 11.** Define a function `is_sorted` that tests whether a list of integers is already sorted. Check that `sorted` returns a list which is sorted.

"The test oracle"

In many situations you often have an alternate version of an algorithm or process (a "test oracle") that you can use to check your results.



For example, you might have a high-performance algorithm with optimization tweaks that you want to test. In this case, you might compare it with a brute force algorithm that is much slower but is also much easier to write correctly.

Similarly, you might compare the result of a parallel or concurrent algorithm with the result of a linear, single thread version.

> **Exercise 12.** For a few functions on lists, check the imperative version against the functional version (these versions were given in previous assignments).

Summary

So that covers some of the common ways of thinking about properties.

Here are the seven ways again, along with a more formal term, if available.

- "Different paths, same destination" – *a diagram that commutes*
- "There and back again" – *an invertible function*
- "Some things never change" – *an invariant under transformation*
- "The more things change, the more they stay the same" – *idempotence*
- "Solve a smaller problem first" – *structural induction*
- "Hard to prove, easy to verify"
- "A test oracle"