# Mutation Testing: Determining The Robustness of QuickCheck Tests Generated with agda2hs

## 1. Background

**Mutation testing** is a way of checking a strength of a test suite by modifying the code tested in an automated manner, and checking that the tests report a failure.

**Agda** is a dependently typed language that allows to write formal proofs of correctness about properties of functions.

**agda2hs** [1] is a compiler that allows to convert Agda modules into clean and readable Haskell modules that can be used in that ecosystem.

**Property testing** is a testing strategy where some required property about a function is postulated, and then a framework tries to generate tests to disprove it in an automated manner. The original and most prominent library for this in Haskell is **QuickCheck**.

**Core idea**: proving properties in Agda can be hard. Try to bring Agda module into Haskell and create traditional tests first, to catch early some of the incorrect implementations, only prove afterwards.

## 2. Research Questions

How can mutation testing be applied to determine the robustness of QuickCheck tests derived from Agda type signatures?

- How is mutation testing already being used in Haskell and other languages for more general use?
- How to extract Haskell's Abstract Syntax Tree of functions we wish to test with mutations?
- What functions are fit for being mutated, and how can the programmer impact and tweak which parts of the code undergo mutation?
- Can the resulting mutations help identify too lenient properties that allow incorrect code to slip through?

## 3. Implementation

**MuCheck** [2] is a proof-of-concept Haskell implementation of mutation testing, based on **haskell-src-exts** and **hint** libraries. I used it as a base to implement the following additional features:

- **QuickCheck** properties adapted into the framework
- Per-test tested function annotation for improving where the framework performs tests
- Marking functions that had all their necessary properties proven on Agda side as “Proven”.

Example annotated test

```
prop_LenPreserved :: [Int] → Bool
prop_LenPreserved xs = length xs == (length . qsort) xs
{-# ANN prop_LenPreserved "Test qsort" #-}
```

Example of a function marked as “Proven”

```
dropWhileNeq :: Char → String → String
dropWhileNeq c = dropWhile (/=c)
{-# ANN dropWhileNeq "Proven" #-}
```

### Function mutation example

Example input function

```
qsort :: [Int] → [Int]
qsort [] = []
qsort (x : xs) = qsort l ++ [x] ++ qsort r
    where l = filter (< x) xs
          r = filter (≥ x) xs
```

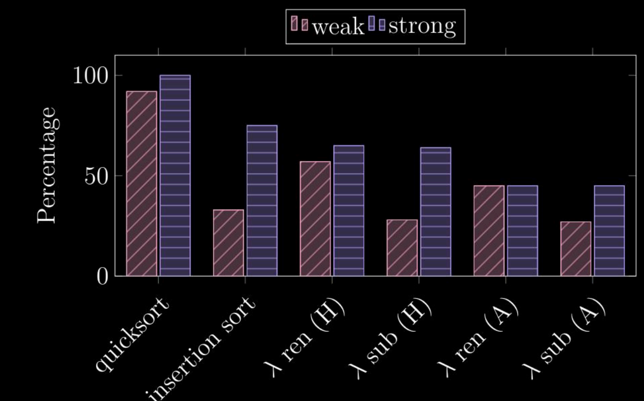
Example output mutants

```
qsort :: [Int] → [Int]
qsort [] = []
qsort (x : xs) = qsort l ++ [x] ++ qsort r
  where l = filter (< x) xs
        r = filter (== x) xs

qsort :: [Int] → [Int]
qsort [] = []
qsort (x : xs) = qsort l ++ [x] ++ qsort r
  where l = filter (< x) xs
        r = filter (> x) xs

qsort :: [Int] → [Int]
qsort (x : xs) = qsort l ++ [x] ++ qsort r
  where l = filter (< x) xs
        r = filter (≥ x) xs
```

## 4. Results and Conclusion

- There is a strong base for further development of the method in Haskell for this purpose
- Stronger test suites result in more killed mutants in almost every test case
- A lot of the mutations don’t change the functions outputs, thus skewing the results in unpredictable ways, meaning any given score is not very useful
- Haskell code created from idiomatic Agda results in fewer useful mutations with the current “generic” implementation
- A better implementation catching some of equivalent mutations and working better on code from Agda is needed if this technique is to be useful

### Raw test results comparison




While for the most cases killed mutants improvement is visible for stronger tests, the scores between modules investigated vary substantially. “ren”- renaming, “sub”- substitution. “H”- code written in Haskell, “A”- code generated with agda2hs.

## 5. References


[1] Jesper Cockx, Orestis Melkonian, Lucas Escot, James Chapman, and Ulf Norell. Reasonable Agda is correct Haskell: writing verified Haskell using agda2hs. In Proceedings of the 15th ACM SIGPLAN International Haskell Symposium, pages 108–122, Ljubljana Slovenia, September 2022. ACM.

[2] Duc Le, Mohammad Amin Alipour, Rahul Gopinath, and Alex Groce. MuCheck: an extensible tool for mutation testing of haskell programs. In Proceedings of the 2014 International Symposium on Software Testing and Analysis, pages 429–432, San Jose CA USA, July 2014. ACM.



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