Application of Metamorphic Testing to Mixed Signal Systems with Behavioral Models

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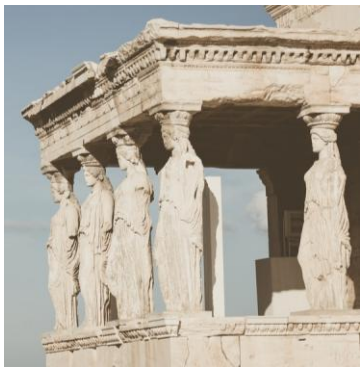
Verification:

Find the bugs!
Stimulus → Response

Test Oracle:



What was supposed to happen?
(*Bus Functional Model*)

Metamorphic Testing:

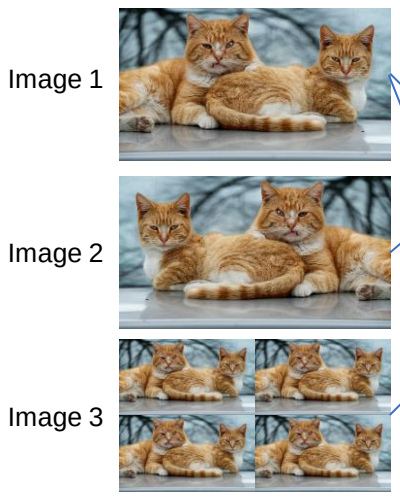
For cases where you do not have a good Test Oracle

Signs of a good Metamorphic Relation (MR):

- Easy to adjust stimulus
- Easy to measure response
- Relationship of stimuli ∝ Relationship of responses
- If the relation does not hold, the system is not performing as desired

Example from Machine Learning [1]

Image classifier reports the number of cats in a test image



count(2) = count(1)

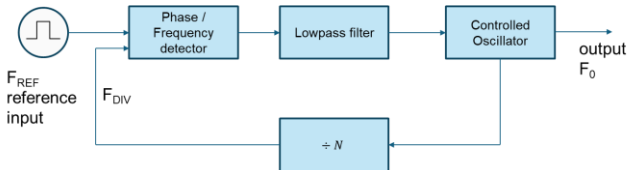
count(3) = count(1)x4

No apriori knowledge of image content is required

That is, no test oracle needed.

Mixed Signal Example [2]

Industrial Phase Locked Loop

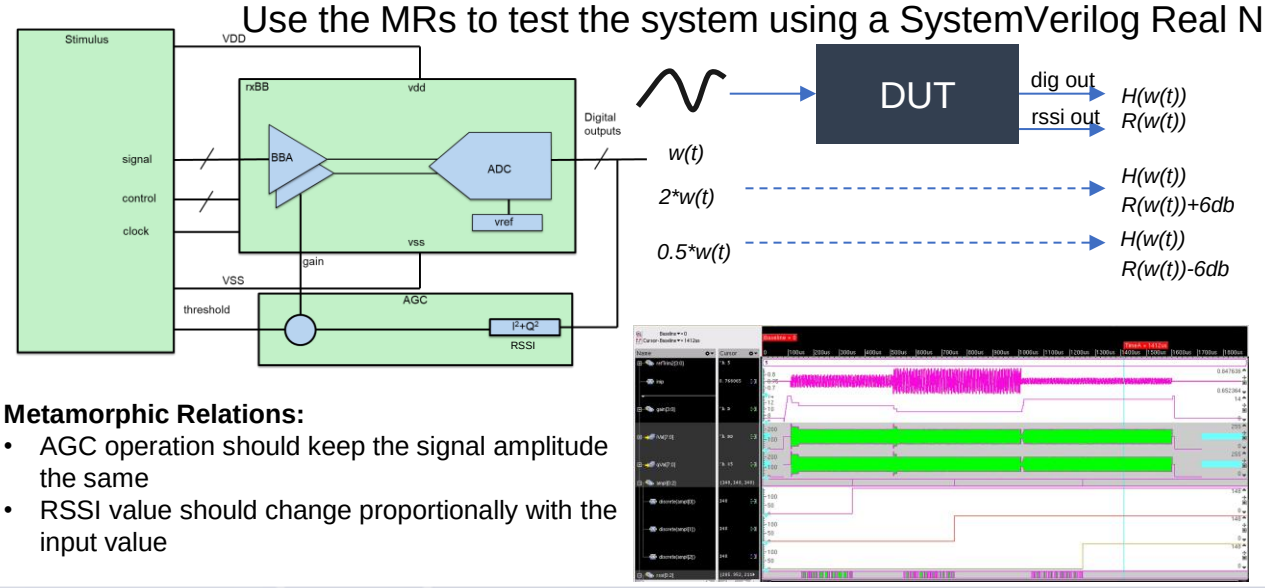


Test 1: F_{REF} = F1
Test 2: F_{REF} = F2 = C x F1
MR: At lock, $F_{DIV,PLL(F2)} = C \times F_{DIV,PLL(F1)}$

Result: With C = 1.01, the PLL frequency locked to a very low subharmonic of F_{REF}. The authors investigated and found a dead-zone bug in the phase-frequency detector.

This Work: Derive MRs for a receiver baseband with Automatic Gain Control (AGC)

Use the MRs to test the system using a SystemVerilog Real Number Model



Metamorphic Relations:

- AGC operation should keep the signal amplitude the same
- RSSI value should change proportionally with the input value

Use your favorite SystemVerilog tricks!

- Constrained random stimulus
- Assertions, coverage
- Measurement modules

```
******* Measurement Report *******
Peak-to-peak magnitudes
Measurement            0                148
Measurement            1                148
Measurement            2                148
******* TEST PASSED         *******
*******  ******* *******    *******
RSSI Values
Measurement            0          205.952
Measurement            1          211.989
Measurement            2          199.947
******* TEST PASSED         *******
```

Download all simulation files at https://support.cadence.com/apex/ArticleAttachmentPortal?id=a1OPP000001scZB2AY

[1] X. Xie, Z. Zhang, T. Y. Chen, Y. Liu, P.-L. Poon, and B. Xu, "METTLE: A METamorphic Testing Approach to Assessing and Validating Unsupervised Machine Learning Systems," *IEEE Transactions on Reliability*, vol. 69, no. 4, pp. 1293–1322, Dec. 2020.

[2] M. Hassan, D. Große and R. Drechsler, "System Level Verification of Phase-Locked Loop using Metamorphic Relations," *2021 Design, Automation & Test in Europe Conference & Exhibition (DATE)*, Grenoble, France, 2021, pp. 1378-1381.

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