Testing the Temporal Behavior of Real-Time Software Modules using Extended Evolutionary Algorithms

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1 Motivation

Costs for development and test of embedded systems

→ 50 % implementation, 30 % unit testing, 20 % system testing

⇒ 50 % of development costs spent for testing

Objectives of testing real-time systems

→ finding errors in functional behavior

→ finding errors in temporal behavior

→ building up confidence in the correct functioning of the test object by executing the system under test with selected inputs

2 Testing temporal behavior

Testing temporal system behavior

→ find violations of specified timing constraints (find the inputs with longest and shortest execution time)

→ check whether they produce a temporal error (outputs are produced prematurely or their computation takes too long)

⇒ testing temporal behavior is a complex task

Problem:

→ lack of appropriate test procedures

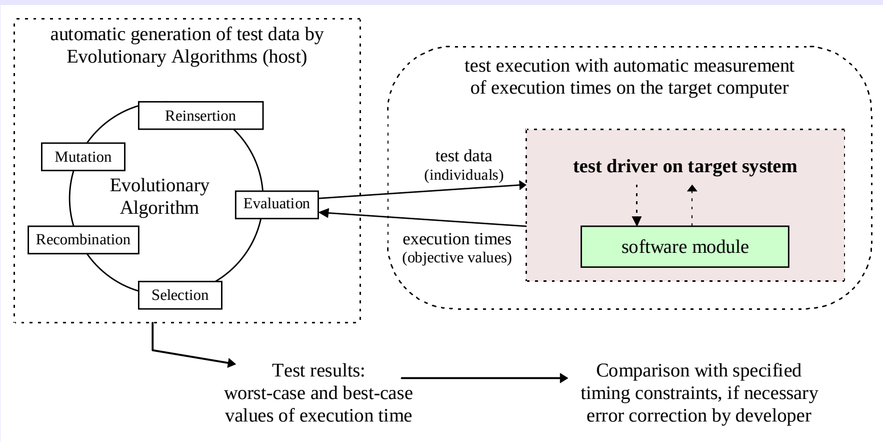
→ tester uses conventional test methods

Evolutionary Testing

Use of Evolutionary Optimization to determine longest and shortest execution times automatically.

3 Evolutionary Testing

Integration of Evolutionary Algorithm and time measurement equipment



- each individual represents a test datum
- execution time for each test datum determines its objective value
- when looking for worst-case execution time: test data with long execution time obtain high fitness values and vice versa

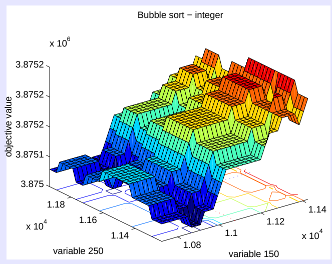
employed tools:

- GEATbx: Genetic and Evolutionary Algorithm Toolbox for Matlab (www.geatbx.com)
- QUANTIFY by Rational Software Corp. (www.rational.com)

4 Search space analysis

- temporal behavior forms a very complex multi-dimensional search space
- many plateaus, local minima and discontinuities
  - several input data executing the same program path are identical
  - different program paths lead to irregular changes of the exec. times
- two analysis examples provided
  - bubblesort modul (benchmark)
  - feature extraction ME (real world)

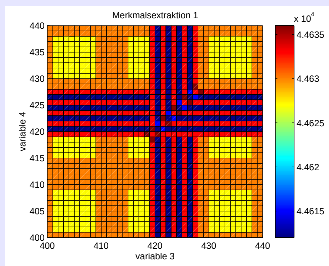
Analysis of bubblesort modul



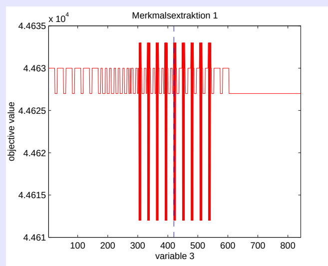
3-D variation plot (execution time of bubblesort modul): variable 150 and 250 in a small area (0.6%) of the search space

- list of 500 variables, each variable in range [-32768, 32767]
- bubble sort variables
- analysis results:
  - many plateaus
  - many local minima
  - correlation between variables

Analysis of feature extraction modul (ME)



2-D color quilt variation plot (execution time of feature extraction): toggle brightness (min/max variable value) at 2 variable positions (400-440)

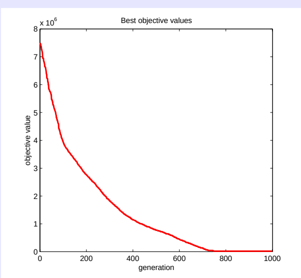


2-D variation plot (execution time of feature extraction): toggle 1 brightness value over all variable positions

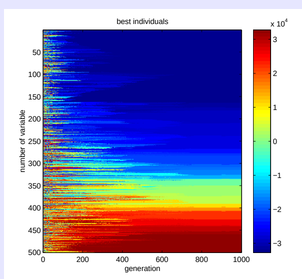
- 843 variables in [0, 4095]
- defining a 29x29 pixel matrix out of an 287x1200 pixel picture
- analysis results:
  - large steps in objective values even for small changes in variable values
  - large plateaus without change of objective value

5 Experiments

Optimization of bubblesort modul



Optimization of bubblesort modul (minimal execution time): best objective value over 1000 generations, optimum found in generation 746



Optimization of bubblesort modul (same run as left): variables of best individual per generation over 1000 generations ("sorting of variables")

- execution time measured by QUANTIFY (Rational)
- Evolutionary Algorithm for integer/permutation variables:
  - 6 subpopulations (regional model), each 50 indiv., 1000 generations
  - different strategies per subpopulation
  - discrete recombination / order crossover
  - integer mutation and swap mutation
  - competition between subpopulations

Optimization of motor control software modules

- results were compared to the times determined by the developers with systematic testing

module name	max. exec. time in µs: evolutionary testing	max. exec. time in µs: developer test	lines of code	para-meters
zr2	69,6 µs	67,2 µs	41	18
t1	120,8 µs	108,4 µs	119	18
mc1	112,0 µs	108,4 µs	98	17
mr1	68,8 µs	64,0 µs	81	32
k1	59,6 µs	57,6 µs	39	14
zk1	58,4 µs	54,0 µs	56	9

- exec. time measured on target system
- Evolutionary Algorithm for integer variables (parameter optimization):
  - 3 subpopulations (regional model), each 20 individuals over 100 generations
  - use of different strategies per subpopulation
  - discrete and double point recombination
  - integer mutation (different mutation range)
  - competition between subpopulations
- Evolutionary Testing found longer execution times for all given modules

6 Summary

New approach:

Testing temporal behavior by Evolutionary Testing

Advantages:

+ automatic search for the longest and shortest execution times
+ suited for discontinuous target functions
+ suited for complex input domains with many parameters
+ can escape local optima (search by multiple individuals)
+ direct assessment of objective value: execution time of individual

But:

– finding the extreme execution times is **not** guaranteed

- Combination of systematic testing and Evolutionary Optimization opens up further potential for improvement

  → perform systematic test to examine functional correctness

  → use systematically produced test data to inoculate initial population of Evolutionary Algorithm

  → apply Evolutionary Testing to find extreme execution times

References

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[4] *Wegener, J., and Pitschinetz, R.*: TESSY - Yet Another Computer–Aided Software Testing Tool? Proceedings of the Second European International Conference on Software Testing, Analysis & Review EuroSTAR '94, 1994.