Beyond Feasibility

CP Usage in Constrained-Random Functional Hardware Verification

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Functional Verification

Verification Environment

Stimulus Scenarios

Random Stimulus Generation

Physical Layer

Device

Data and Assertion Checkers

Generation

Constraint Solver

Coverage Monitor

Self Checking

Distribution

Coverage
Random testing and constraints

• Random stimuli is used to find bugs in the device
  – Diversity of tests is needed so all scenarios will be tested
  – Constraints are used to define the injected data’s properties

• Verification environments can be huge
  – Many separate constraint problems
  – Some of the problems are solved many times
  – Some are solved only once
  – The problems are not necessarily hard to solve

• Debug is a crucial matter
  – Tests need to be reproduced
  – The verification engineers are not constraint experts
IntelliGen

• Part of Cadence Specman tool
  – Introduced in 2007
  – Works with the e verification language

• Suitable for large verification environments
  – Splits the environment to many separate problems
  – Uses a reusable and low cost solver

• Various kinds of constraints
  – Word-level (arithmetic) and bit-level constraints
  – Global constraints (sum, count, all-different)
  – Soft constraints
  – Distribution constraints

• Provides interactive generation debugger
IntelliGen: Gen Debugger
IntelliGen’s High Level Solving

• Propagation-based solver
• Based on the standard backtrack flow
• Variable selection
  – Based on the ‘first-fail’ principle
  – Involves randomization between variables with similar domains
• Value selection
  – Uniform randomization from the variable’s domain
  – Variable domains represent the word-level and the bit-level
Distribution of Random Tests

• “...we want the tests to be distributed as uniformly as possible among all possible tests that conform to the CSP. Essentially, we want to reach a significantly different solution each time we run the solver on the same CSP” (Y. Naveh et. al., 2007)

• A good distribution means:
  – All ‘interesting’ test scenarios are sampled
  – The scenarios are chosen randomly
  – No repetitions of solutions in consecutive runs
  – No bias towards specific cases
Uniform Distribution

• The intuitive solution for generation of random stimuli
  – Part of the SystemVerilog IEEE standard
  – Also suggested by various academic papers
  – Not so easy to achieve:
    – BDD solvers might explode
    – Solving performance might be damaged

• Is uniform distribution really desired?
  – The desired behavior if the problem is symmetric
  – Highly undesired in asymmetric problems

• Uniformity over the set of scenarios, and not over the solution space
Uniform distribution- Example

x is a variable with domain {1..4}
y is a variable with domain {1..2^32}
x=1 -> y=2

- Uniform distribution scenario:
  - (x=1, y=2) has 1/(3*2^32+1) chance to occur
  - The value x=1 will almost never occur
Uniform distribution- Example

x is a variable with domain \{1..4\}
y is a variable with domain \{1..2^{32}\}
x=1 \rightarrow y=2

- IntelliGen’s behavior (much better):
  - x is generated first (smallest domain), and its value is randomized uniformly
  - All four values of x are sampled in equal shares
Distribution – Biased values

• Biased values are values which are repeated more than their theoretical chances
  – May cause duplicate tests
  – Requires much longer coverage filling

• Can be caused by randomization of Boolean expressions
  – An expression (e.g. ‘x+y=100’) may be satisfied even when unneeded
  – An example of improved efficiency which harms distribution

• SMT solvers are especially prone to this, assuming:
  – Boolean expressions are translated to the SAT layer
  – Randomization starts with the SAT variables
Biased Values - Example

x, y and z are variables with domain \{1..2^{32}\}

x=1 -> y!=1
false -> z=1

- If the Boolean expressions are randomized:
  - x=1 or y=1 will occur in most tests
  - z=1 will occur in half the tests!

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Biased Values - Example

x, y and z are variables with domain \( \{1..2^{32}\} \)
x=1 \rightarrow y \neq 1
false \rightarrow z=1

- IntelliGen’s behavior:
  - x, y and z are generated freely
  - The cases x=1, y=1, z=1 (almost) never occur
The Global Sum Propagator

- Demonstrates failure of the default CP randomization
- Required specific randomization process

\[ L.\text{sum}() = 1000 \]
\[ (L[0] + L[1] + \ldots = 1000) \]

Older IntelliGen

Newer IntelliGen
Reproducibility

• Reproducibility is a crucial matter for functional verification
• The same test may run several times and in different modes
  – Inside a regression (batch mode)
  – During a debug session (interactive mode, breakpoints, etc.)
  – As a validation of a bug fix (code might have changed)
• Cases which are prone to produce irreproducible tests
  – Non-deterministic algorithms (e.g. parallel search/propagation)
  – Learning solvers: test behavior may be influenced by exact timing of
    garbage collection
  – Additional of irrelevant code
• More information in the paper…
Summary

• Efficient finding of a feasible solution is not enough
  – Solvers which can handle huge verification environment
  – Handle both single solving and multiple solving of the same problem
  – Randomization which distribute well over the solution space
  – Reproducibility of the solving process
  – Ability for the verification engineer to debug the solving

• Why CP?
  – Light and reusable solvers
  – Flexibility in generation of diverse tests – not just uniform distribution
  – Adapted better to Reproducibility
  – Solving can be explained easier to the users