Scenario Sampling for Cyber Physical Systems using Combinatorial Testing

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Abstract—Physical and continuous aspects are inevitable in
cyber physical systems like automated driving systems. De-
spite the success of combinatorial testing on discrete systems,
there is a fundamental challenge in applying combinatorial
testing techniques when continuous parameters are involved.
This extended abstract presents an initial step towards applying
combinatorial testing to systems in which discrete and continuous
parameters are mixed. We define a generic XML-based language
for describing the test space of such systems and provide a
prototype implementation to generate test cases, using externally
the combinatorial test tool PICT.

Index Terms—Cyber physical systems, Combinatorial testing,
Random testing

I. MOTIVATION

When testing cyber physical systems such as automated
driving systems, it is inevitable to choose real values for phys-
ic quantities. Consider an oversimplified automated driving
system, where ego vehicle is given an initial position \(x\) and
velocity \(v\) (which are real numbers) and there are several
obstacles in some positions, possibly static or moving forward
or backward at some velocity. An exhaustive testing of such
a physical system is not just infeasible but impossible: one
will need uncountably many test cases (scenarios) to cover
the possibility of any real-valued parameter.

Random testing [4] provides an obvious way of choosing
(i.e., sampling) real values from bounded real intervals and,
under a well-chosen distribution, from unbounded continuous
spaces. For the purpose of the quality assurance of safety-
critical systems, however, the “random” nature of random
testing might be undesirable; in particular, there is no agreed
notion of coverage that the random testing literature provides.

Combinatorial testing [5], on the other hand, provides a
well-defined quantitative coverage criterion—the combinator-
ial coverage—when the systems under test have only discrete
input parameters. We expect combinatorial coverage to be still
a useful criterion for cyber physical systems when continuous
parameters are appropriately partitioned; for instance, Fig. 1
shows four out of nine test cases covering all pairwise com-
binations of obstacles which can be in front or in back, static
or moving forward or backward.

In this work, we propose a general language for describing
test scenarios with discrete and continuous parameters mixed,
and provide a prototype implementation that generates con-
crete test cases from such a scenario description, by combining
both the combinatorial testing approach and random testing
approach. We have implemented a prototype scenario sam-
ples, available at https://github.com/ERATOMMSD/scenario-
sampler. This implementation externally calls the combi-
natorial testing tool PICT [3] for generating pairwise covering
test suites. In collaboration with our industry partner, we
actually used the scenario sampler for testing a prototype
implementation of a simulator of an automotive system.

II. SYNTAX AND SEMANTICS

Here we define the language of the Scenario Sampling
Script. The language constitutes of the following three layers:

\[
\ell_1 ::= \text{text} | \langle \text{text} \rangle \langle \text{text} \rangle \\
| \langle \text{random min} = \text{real} \ max = \text{real} \rangle \\
\ell_2 ::= \ell_1 | \langle \text{choice} \rangle \ell_1^+ \langle \text{choice} \rangle \\
\ell_3 ::= \ell_2 | \langle \text{repeat} \rangle \ell_3^+ \langle \text{repeat} \rangle
\]

By a layer-\(k\) script we mean a sequence of elements from
the corresponding layer. In the following, we describe the role
of each layer.

Layer 1: The first layer allows \langle \text{random} \rangle tags, which
represent real values taken from the range specified by at-
tributes \text{min} and \text{max}, as well as plain text, which may be
enclosed in \langle \text{text} \rangle...\langle \text{text} \rangle tags in order to clarify the
structure. The structure of text is voluntarily kept ambiguous.
many different numbers of repetition should be tested.

III. CONCLUSION AND FUTURE WORK

In this extended abstract, we proposed a language to describe scenarios where both continuous real-valued parameters and discrete parameters are involved. We provide a prototype implementation of a tool that inputs such a scenario description and outputs a set of concrete scenarios by combining random testing and combinatorial testing. This preliminary work opens up a vast field for further exploration.

- How effective is combinatorial testing for cyber physical systems in terms of failure detection?
- What kind of combinatorial coverage should we focus on? For instance, it seems redundant to distinguish obstacle 1 and obstacle 2 in our example. Also when considering a scenario with time stages, intuitively we would like to consider a mixed-strength coverage concerning only combinations of adjacent time stages.
- How do we handle constraints which, on cyber physical systems, are naturally about real variables and real functions. It is nontrivial how to turn real constraints into discrete constraints on the combinatorial testing level.
- How should we systematically sample from \( \ell 1 \) and \( \ell 3 \) scripts? We plan to incorporate adaptive random testing \([2]\) and regular language sampling \([1]\).

REFERENCES