FBDScenaGen+: GA-based High-Quality Scenario Generator for FBD Simulation

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   (GA-based High-Quality Simulation Scenario Generator)

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## Introduction

- **FBDScenaGen+**: GA-based High-Quality Scenario Generator for FBD Simulation
  - **Objective**
    - High-Quality Scenario generation for FBD program simulation
  - **Target system:**
    - PLC-based software system in nuclear plants
    - Typical development process: SRS – FBD – C – executable SW

### Software Development Process for PLC

<table>
<thead>
<tr>
<th>Requirements Analysis</th>
<th>Design</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRS</td>
<td>FBD / LD Programs</td>
<td>C Programs</td>
</tr>
<tr>
<td>Manual Programming</td>
<td>Automatic Translation</td>
<td>C Compiler</td>
</tr>
<tr>
<td>FBD Unit Testing</td>
<td></td>
<td>Executable Code for PLC</td>
</tr>
</tbody>
</table>

![Diagram of Software Development Process for PLC](image)
Introduction

• Q. How Adequately the Testing has been Performed?
  – Test Done = Test Plan Executed and All Codes Executed

• Q. How much efforts is needed to accomplish some coverages?
  – Our Issue: **FBD Coverage + GA Techniques** → High-quality scenarios
1. FBD Structural Coverage
2. Genetic Algorithm

BACKGROUND
FBD Structural Coverage

• A metric for measuring simulation effectiveness
  – To help determine when a system is adequately tested

• Two coverage
  – Toggle coverage
  – MC/DC coverage

Ex) 1-to-0 and 0-to-1 → 100% toggle coverage
FBD Structural Coverage

• A metric for measuring simulation effectiveness
  – To help determine when a system is adequately tested

• Two coverage
  – Toggle coverage
  – MC/DC coverage
Genetic Algorithm

- Genetic algorithm (GA)
  - A metaheuristic inspired by the process of natural selection.
  - Belongs to the larger class of evolutionary algorithms (EA).
  - High-quality solutions to optimization and search problems

Best scenarios

Many scenario set
Genetic Algorithm

- Genetic algorithm (GA)
  - A metaheuristic inspired by the process of natural selection.
  - Basic process: 1) selection, 2) crossover, 3) mutation

Many scenario set ➔ Many scenario set ➔ Best scenarios
FBD Simulation Framework

- FBD Editor
- FBDSceanaGen
- FBDSim
- FBDCover
FBDSenaGen+  
(GA-based High-Quality Simulation Scenario Generator)

1. Initialization
2. Selection
3. Crossover
4. Mutation
5. Simulation
6. Evaluation (Fitness function)
7. Progress?

Evolution!
A genetic representation of scenario

- A chromosome = Sequence of Input value change
Selection operator

- Select good chromosome for new generation (t+1)
- Roulette wheel selection for gene diversity
Roulette wheel selection

<table>
<thead>
<tr>
<th>Fitness Score</th>
<th>Generation (T)</th>
<th>Generation (T+1)</th>
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<tbody>
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<td>- ↑5 ↓7 ... -</td>
<td>- ↑1 ↓8 ... -</td>
</tr>
<tr>
<td>4</td>
<td>- ↑1 ↓8 ... ↓1</td>
<td>- ↓12 ↑1 ... -</td>
</tr>
<tr>
<td>5</td>
<td>- ↓2 ↑1 ... -</td>
<td>- - ↑3 ... -</td>
</tr>
<tr>
<td>6</td>
<td>- - ↑3 ... ↑9</td>
<td>- - ↓8 ... -</td>
</tr>
<tr>
<td>2</td>
<td>- - ↓8 ... ↑1</td>
<td>- - ↓4 ... -</td>
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<td>0</td>
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<tr>
<td>1</td>
<td>- ↑1 ↓2 ... ↑2</td>
<td>- ↑1 ↓2 ... ↑2</td>
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</table>

Population

chromosome 1 ≠ chromosome 2
chromosome 3 ≠ chromosome 4
Crossover operator

- Crossover with good chromosomes for new generation (t+1)
- Single point crossover

One Point Crossover

```
0 1 2 3 4 5 6 7 8 9
5 8 9 4 2 3 5 7 5 8
```

```
0 1 2 3 4 3 5 7 5 8
5 8 9 4 2 5 6 7 8 9
```

Multi Point Crossover

```
0 1 2 3 4 5 6 7 8 9
5 8 9 4 2 3 5 7 5 8
```

```
0 1 2 4 2 3 6 7 8 9
5 8 9 3 4 5 5 7 5 8
```

Uniform Crossover

```
0 1 2 3 4 5 6 7 8 9
5 8 9 4 2 3 5 7 5 8
```

```
5 1 9 4 4 5 5 7 5 9
0 8 2 3 2 3 6 7 8 8
```

## Single point crossover

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</table>

**Population**
Mutation operator

- Mutate a chromosome for gene diversity

**Bit Flip Mutation**

\[
\begin{array}{cccccccc}
0 & 0 & 1 & 1 & 0 & 1 & 0 & 0 & 1 & 0 \\
0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 & 0 \\
\end{array}
\]

**Swap Mutation**

\[
\begin{array}{cccccccc}
1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 0 \\
1 & 6 & 3 & 4 & 5 & 2 & 7 & 8 & 9 & 0 \\
\end{array}
\]

**Scramble Mutation**

\[
\begin{array}{cccccccc}
0 & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\
0 & 1 & 3 & 6 & 4 & 2 & 5 & 7 & 8 & 9 \\
\end{array}
\]
Swap mutation
Fitness function

- fitness for toggle coverage:
  \[ f_T = \frac{(\text{number of toggled blocks and output variables})}{(\text{number of boolean blocks and output variable})} \times 2 \]

- fitness for MC/DC coverage:
  \[ f_M = \frac{(\text{number of simulated important combinations of conditions})}{(\text{all important combinations of conditions for all boolean function blocks})} \]

- fitness function:
  \[ f = f_T \times f_M \]
Case Study

• Target: an example replicating a KNICS APR-1400 RPS BP

• We used our tool-set of
  – FBD Editor
  – FBDScenaGen+
  – FBDSim
  – FBDCover

1. Initialization
   1. Initialization
      loop
      2. Selection
      3. Crossover
      4. Mutation
      5. Simulation
      6. Evaluation (Fitness function)
      7. Progress?

Evolution!
Uncovered points
Conclusions

• We applied basic **GA techniques** to the scenario generation
  – for a **high-quality scenarios for FBD simulation**

• The prime objective
  – check a **feasibility** and efficiency of applying **GA techniques**

• We developed **FBDScenaGen+**
  – it can automatically generates high-quality scenarios
  – The result (**quality of scenarios**) is increased during repetition.

• Future work
  – Using High-level AI techniques
  – Adapting various fields in NPP
- Thank you –

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