Diagnostics and Strategic Plan for Advancing the SAPHIRE Engine

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Changing the World's Energy Future

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INL Idaho National Laboratory

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Reliability, Risk and Resilience Sciences (R3S)

Diagnostics and Strategic Plan for Advancing the SAPHIRE Engine

Benchmarking, Performance Analysis, and Upgrading the SAPHIRE Engine

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CONTENT

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MOTIVATION

👉**FACTS**:

  👉PRA applications exhibit high computational demands.

  👉Many PRA tools, including SAPHIRE, were developed during the 1980s and 1990s.

  👉While SAPHIRE has undergone numerous enhancements, a comprehensive analysis of its quantification engine is still pending.

👉**NEEDS**:
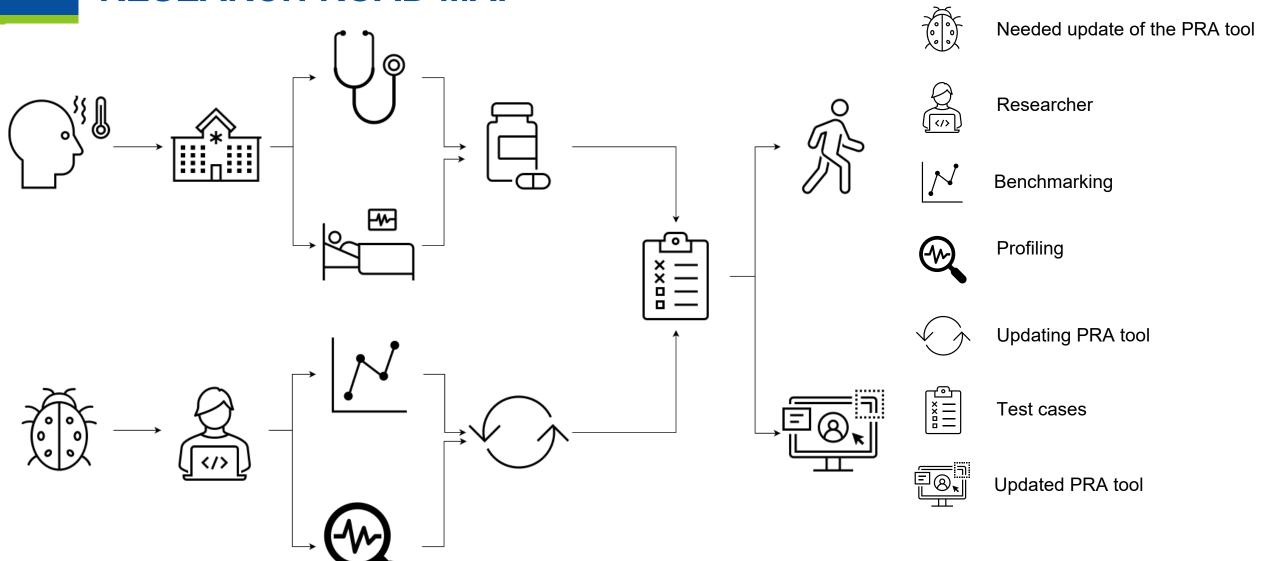
  👉**Integration with Modern Technologies**:

    👉Optimize SAPHIRE for parallel and distributed computing.

  👉**Enhanced Efficiency:**

    👉Accelerate evaluations, minimizing memory usage.

  👉**Incorporating Multi-Hazard Models**

    👉Seamlessly integrate multi-hazard models into traditional ones.

  👉**Seamless Model Exchange:**

    👉Enable smooth model exchange between SAPHIRE and other tools.

👉**SOLUTION**:

  👉Upgrade the SAPHIRE engine.

👉**RESEARCH ROAD MAP**:

  👉See next slide!

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RESEARCH ROAD MAP

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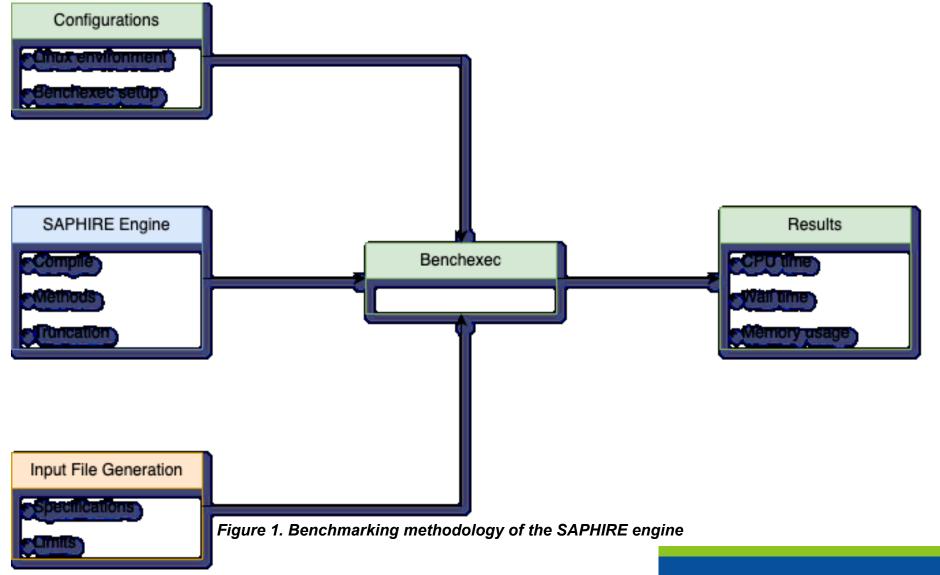
SAPHIRE

👉 **Systems Analysis Programs for Hands-on Integrated Reliability Evaluations (SAPHIRE):**

   👉 SAPHIRE is the successor of Integrated Reliability and Risk Analysis System (IRRAS) for reliability assessment.

   👉 IRRAS was a comprehensive tool for risk assessment.

   👉 IRRAS released its first version in February 1987.

   👉 The latest version of the SAPHIRE is 8.2.8.0.

SAPHIRE

BENCHMARKING

Figure 1. Benchmarking methodology of the SAPHIRE engine

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BENCHMARKING

Table 1. Generated fault tree arguments

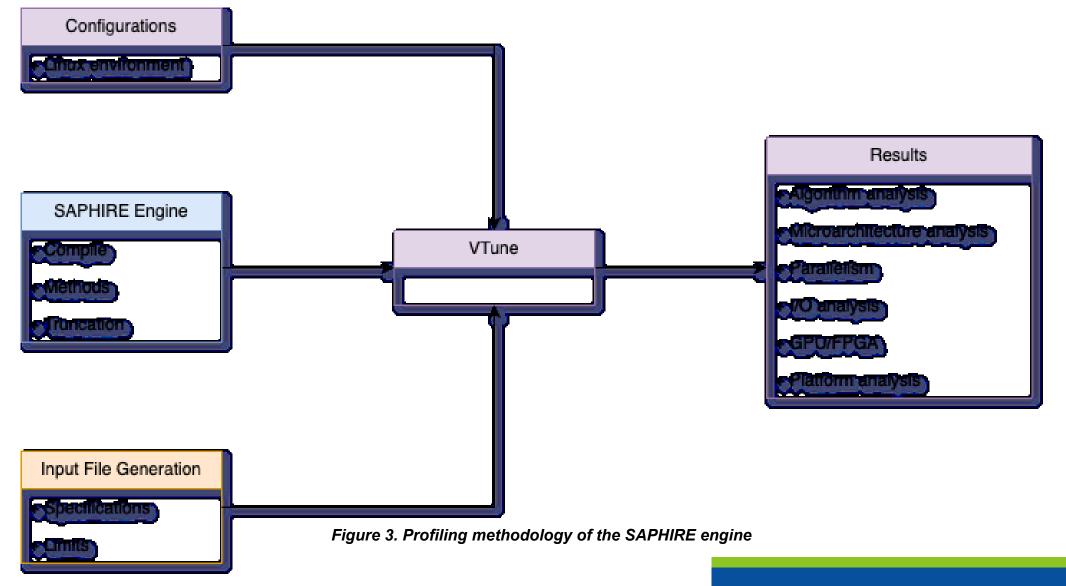| #	Argument	Options	Analyzed
1	Name for fault tree	--ft-name	Autogenerated
2	Name for the root gate	--root	Root
3	Seed for PRNG	--seed	123
4	# of basic events	-b or –num-basic	100:50:5000
5	Avg.# of gate arguments	-a or –num-args	3.0
6	Weights for [AND, OR, K/N, NOT, XOR] gates	--weights-g	[1,1,1,0,0]
7	Avg. %% of common basic events per gate	--common-b	0.3
8	Avg. %% of common gates per gate	--common-g	0.1
9	Avg.# of parents for common basic events	--parents-b	2
10	Avg. # of parents for common basic events	--parents-g	2
11	# of gates (discards parents -b/g and common-b/g	-g or –num-gate	0
12	Maximum probability for basic events	--max-prob	0.05
13	Minimum probability for basic events	--min-prob	0.01
14	# of house events	--num-house	0
15	# of ccf groups	--num-ccf	0
16	A file to write the fault tree	-o or –out	ft-####.JSInp
17	Apply the Aralia format to the output	--aralia	-
18	Nest NOT connectives in Boolean formulae	--nest	-

```
<!DOCTYPE benchmark PUBLIC "+//IDN sosy-lab.org//DTD BenchExec
benchmark 2.3//EN" "https://www.sosy-lab.org/benchexec/benchmark-2.2.3dtd">
<benchmark tool= "saphsolve"
        timelimit="30min"
        memlimit= "16 GB"
        cpuCores= "1"
        threads= "1">
  <option name="">/dev/fd/1</option>
  <rundefinition name="saphsolve">
  </rundefinition>
  <tasks name= "saphsolve.mocus.trunc.mcub.no-limit">
    <includesfile>/home/egemen-ubuntu/benchmarking/saphsolve/input-
jsinp/saphsolve.txt</includesfile>
  </tasks>
</benchmark>
```

Figure 2. BENCHEXEC configuration file for SAPHIRE

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PROFILING

Figure 3. Profiling methodology of the SAPHIRE engine

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PROFILING

☞ **Preparing SAPHIRE for Profiling :**
  ☞ Compiled in release mode with debug information.
  ☞ map2pd is used to transform the MAP files generated by Delphi compilers into Microsoft PDB files

☞ **Input File Determination :**
  ☞ Fault tree with parameters from Table 1.
  ☞ 310 basic events with truncation size of 16, 18, and 20.
  ☞ No probability truncation.
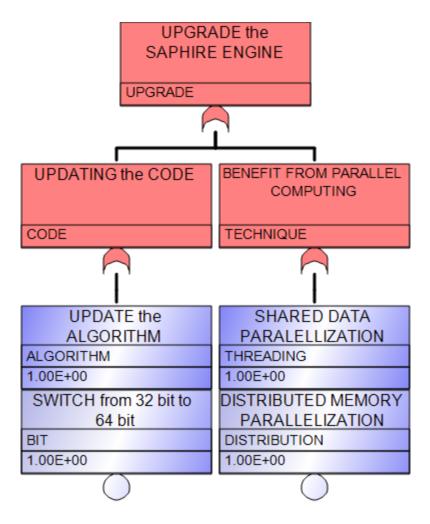
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Figure 4. Success Tree (optimizing methodology) for Upgrading the SAPHIRE engine

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RESULTS - BENCHMARKING

Table 2. Benchmarking results for the given probability truncations

#	Number of Basic Events	Truncation Probability of e-14	Truncation Probability of e-20	SCRAM Results w/o Probability Truncation	Parameter
2	4850	1800	1800	187	CPU Time [sec]
		51.8	48.8	8,890	Memory Usage [MB]
		-	-	10,814,607	Number of Cutsets
		-	-	3.1094×10^{-11}	Probability
4	5000	1.05	0.98	2.10	CPU Time [sec]
		52.1	48.9	48.2	Memory Usage [MB]
		4	74	734	Number of Cutsets
		6.6724×10^{-14}	8.3155×10^{-4}	8.3155×10^{-4}	Probability

☞ **Observations :**

☞ Windows outperforms Linux in solver capabilities.

☞ Linux version struggles with time limit for certain cases.

☞ Engine excels in assessing most fault trees except large ones.

☞ Efficient memory management with consumption under 50 MB.

☞ SCRAM inclusion allows comparison for SAPHIRE upgrades.

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RESULTS - PROFILING

Table 3. Profiling results for the given probability truncations

#	Truncation Size	CPU Time [sec]	Number of Cutsets / Probability	SCRAM Number of Cutsets / Probability
2	18	3,828.795	102,444	-
			1.3388×10^{-11}	-

Table 4. Top hot spots in the code of the SAPHIRE engine

Truncation Size	Function	CPU Time [sec]	Percentage of CPU Time [%]
	InternalSetIntersectionEmpty	52.284	14.7
	InternalSetIntersectionEmpty	1,648.130	43.0
18			
	WriteFile	209.027	5.5
	InternalSetAssignComplement	3929.234	6.5
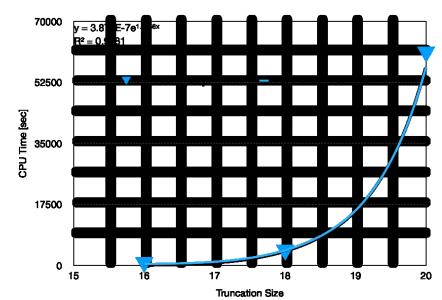
Figure 4. Trendline estimation for the CPU time for different truncation size

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RESULTS - UPGRADE

Table 5. Gain by achieved by upgrading from 32 bit to 64 bit for SetLib module of the SAPHIRE engine

#	Truncation Size	SetLib-32bit [sec]	SetLib-64bit [sec]	Percentage Enhancement [%]
2	16	259.35	179.03	31
4	18	4,497.45	2,963.55	34
6	20	82,783.48	56,220.37	32

On average : 29%

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CONCLUSION & FUTURE WORK

👉**What we did so far:**

👉Diagnostics and strategic plan for advancing the SAPHIRE engine is accomplished.

👉The strategy is applicable to any PRA tool with a minimum effort.

👉Limitations are determined.

👉Bottle necks in the code are identified.

👉29% speed up is already gained.

👉**What we will do:**

👉Parallel computing and algorithm update if necessary and if possible.

👉Benchmarking environment transition to Windows environment.

👉Examine other quantification algorithms.

👉Incorporate common cause failures (CCF).

👉Validate our findings on real models.

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