Architecturally Speaking, Are We Cool?

Effectiveness of Qualifying C/C++ Hardware Model and Simulator Environment Using Certitude C++

A Gutmann

Analog Devices Inc.

September 11, 2014

SNUG Boston

SNUG Paper

Based on “Architecturally Speaking, Are We Cool? Effectiveness of Qualifying C/C++ Hardware Model and Simulator Environment Using Certitude C++”, paper by

A Gutmann, John Hayden, David Brownell, and Marty Rowe

Why are we here?

Architect and Design Engineers' Challenges

Verification Environment Is Difficult

Importance of Verification Effectiveness and Measuring Verification methodologies in C/C++

Exploring Functional Qualification Certitude C++ and Results

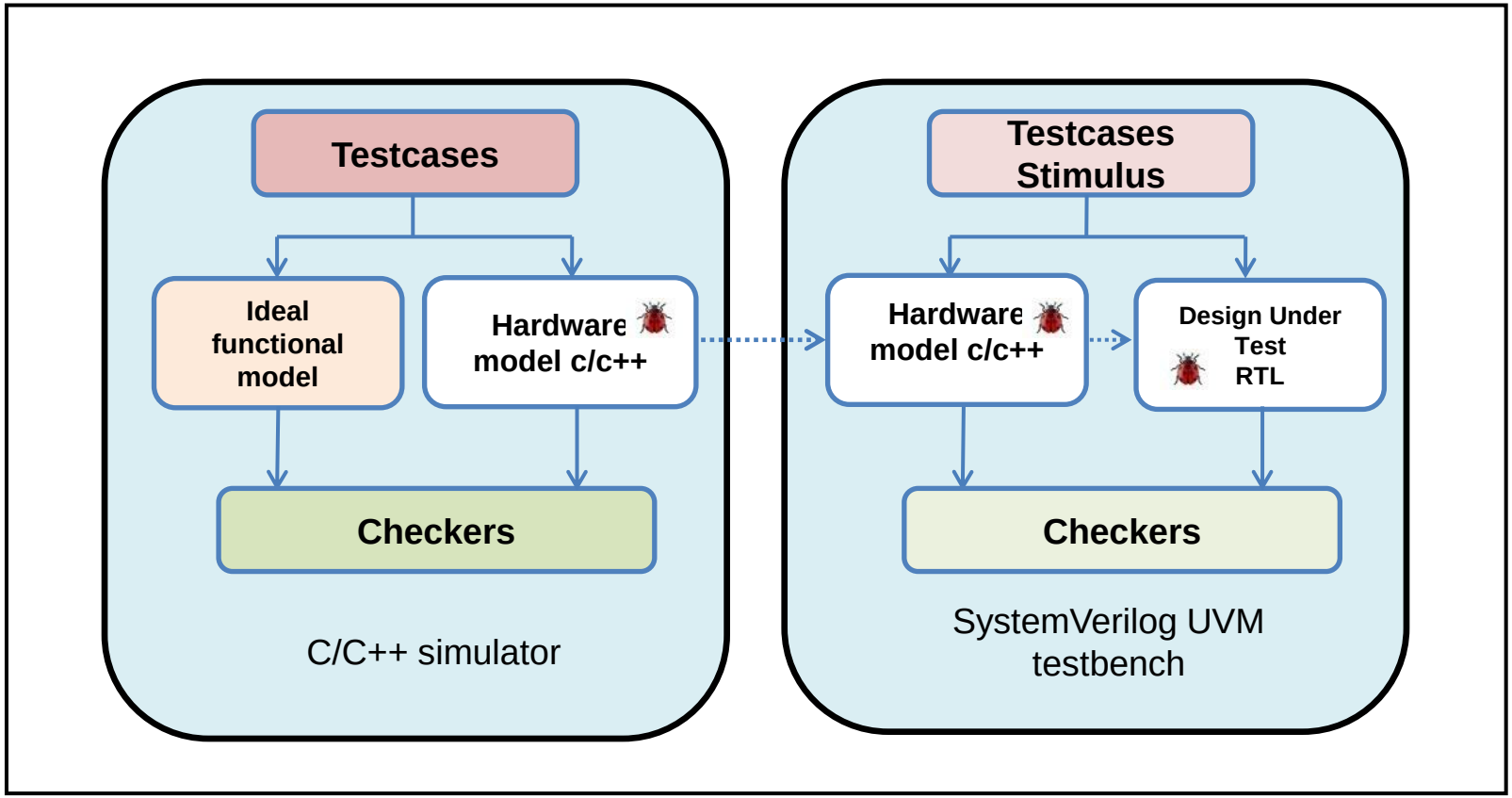
Advantage of Using Functional Qualification tool

Architect and Design Engineers' Challenge

Importance of Verification Effectiveness and Measuring Verification methodologies in C/C++

- *Faster Tapeout*
- *Reduce number of respins.*
  (i.e. Eliminate bugs in our design)
- *Better software and memory utilization.*
  (i.e. Better and more efficient coding style.)
- *Good Quality in our software and system verification before the Chip arrives*

Typical C/C++ Simulator vs. SystemVerilog UVM Testbench



Certitude C/C++

Certitude for RTL

Verification Environment Is Difficult

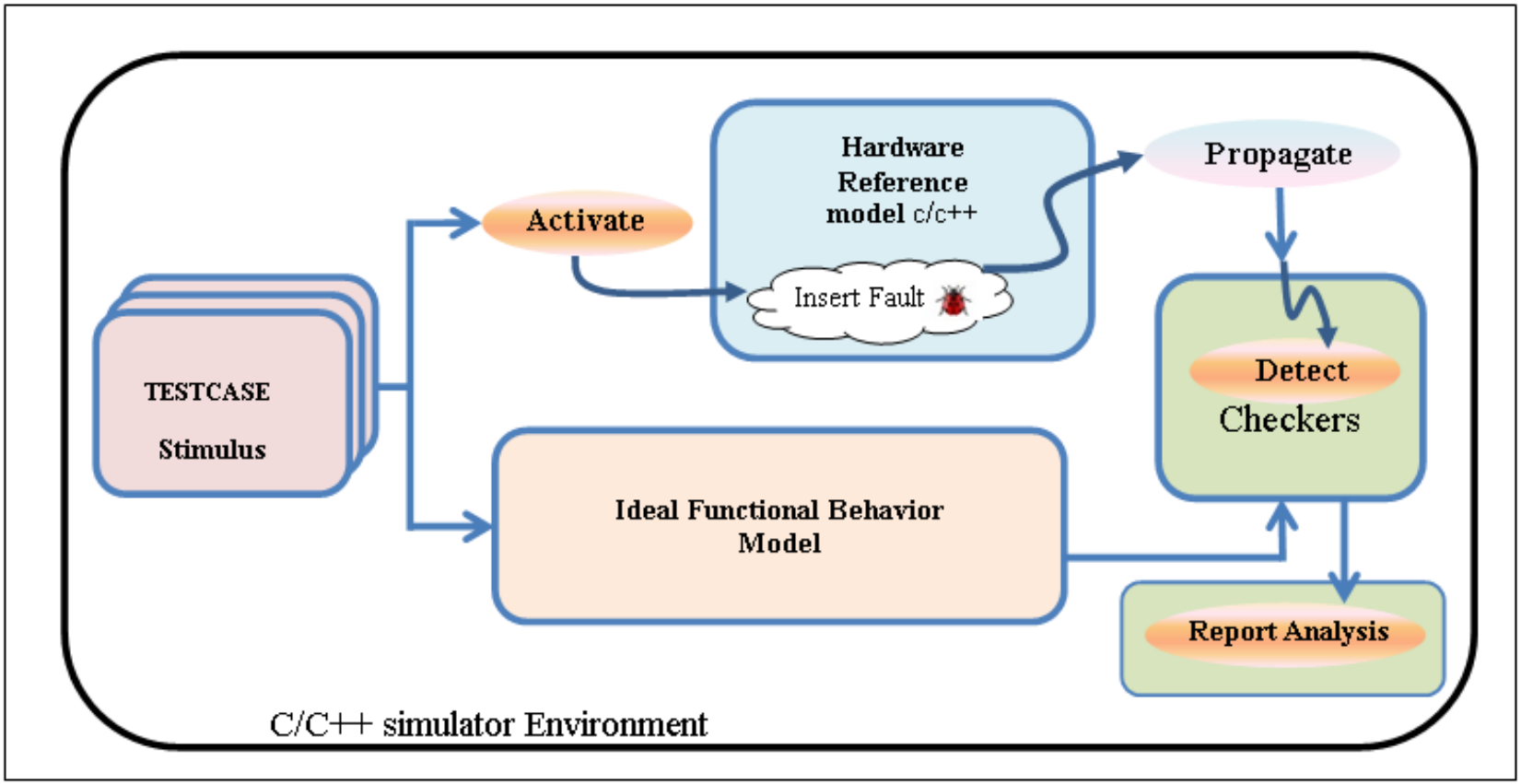
- C/C++ Simulator must cover all scenarios
- Every single functionality should be monitored, checked, and confirmed
- C/C++ testbench infrastructure reports all errors without any false positive
- Everything that is IMPORTANT should be checked!!!

Effective Verification in C/C++

Detecting a bug, the C/C++ testbench must be able to:

- **Activate** the bug
- An effect of the bug must **Propagate** to an "output" of the program/model
- The C/C++ testbench infrastructure must **Detect** the behavior difference if bugs exist
- The C/C++ testbench must process and report failures properly

Qualification Steps with C/C++



*Effective Verification must be able to **activate**, **propagate**, and **detect** faults !!!*

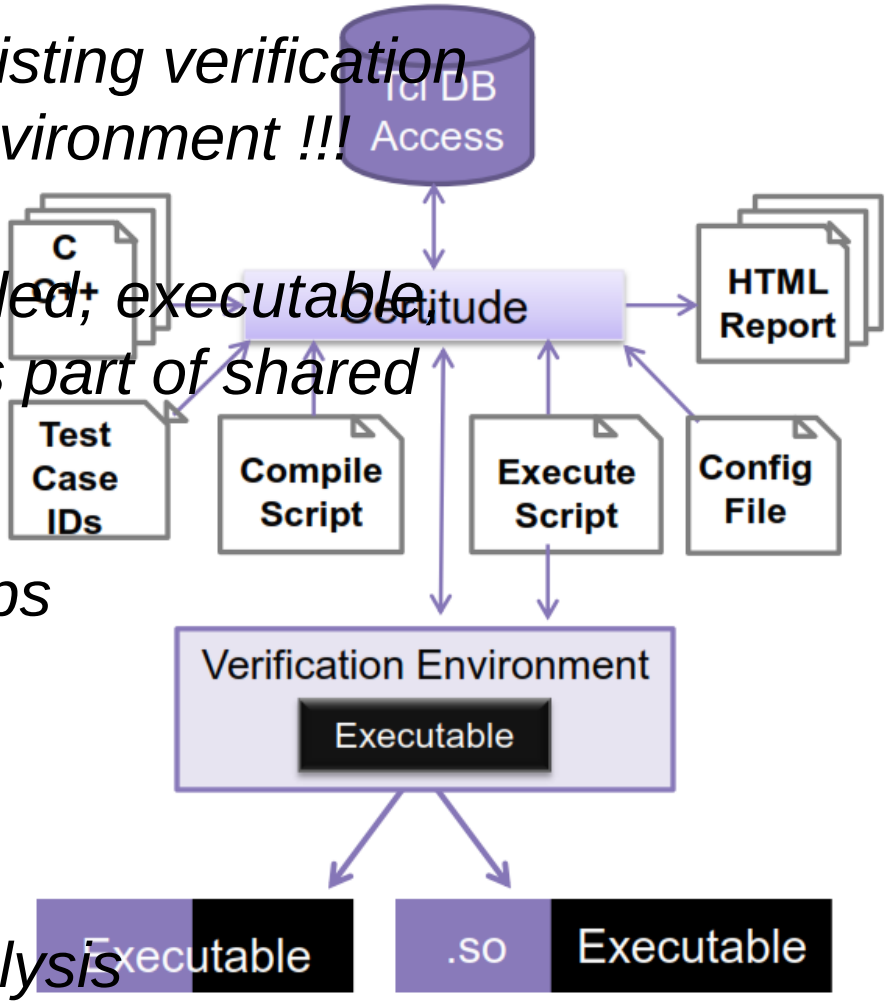
Certitude C/C++ Process and Flow Diagram

Leverages existing verification regression environment !!!

DUT is compiled, executable, and linked as part of shared object

Certitude Steps

- *Model*
- *Activate*
- *Detect*
- *Report analysis*



How Fault Injection Works in Certitude C/C++?

- *Locally modified c/c++ code to insert fault*

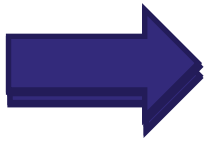
```
a = b | c  →  a = b & c   // fault changes operator
```

- *Simulates broken c/c++ code in verification environment*
  - Test failed == **GREAT!!!**
  - **If not, something is wrong in our c/c++ code or in our verification environment**

Types of Inserted Faults in C/C++

Fault Types	Fault Insertion
Condition Faults	Condition True, Condition False, Negated
Dead Faults	Dead Assign, Dead Call, Dead operator, Dead Assignment
Variable/Array Faults	ValueAtZero, ValueAtMax
Operator Faults	Swap Operators including prefix to postfix

Operation Fault:

a = b + c;  a= b - c;

Fault Classification

- ***Non-Activated fault*** *: No testcase capable of activating fault*
- ***Non-Propagated (Weak)*** *: Fault is activated, but no testcase has propagated it to detection phase.*
  E.g. an if-statement which is always false.
- ***Detected:*** *At least one testcase has activated, propagated, and detected the fault*
- ***Non-Detected****: The fault has been activated but no testcase has detected it. This fault is propagated to the boundary of the output of hardware reference.*
- ***Not Yet Qualified****: The fault has not been fully processed yet.*

Certitude C/C++
Example of Fault Injection for a single line of code

1st : If (0) { C += 8; D >>1; }

2nd: If (1) { C += 8; D >>1; }

3rd: If (!(A == 0 && B > -2)) { C += 8; D >>1; }

If (A == 0 && B > -2) { C += 8; D >>1; }

4th: If (A != 0 && B > -2) { C += 8; D >>1; }

5th: If (A == 0 || B > -2) { C += 8; D >>1; }

6th: If (A == 0 && B < -2) { C += 8; D >>1;

7th: If (A == 0 && B >= -2) { C += 8; D >>1; }

Certitude C/C++
Example of Fault Injection

```
If (A == 0 && B > -2) { C += 8; D >>1; }
```

8th: `If (A == 0 && B > +2) { C += 8; D >> 1; }`

9th: `If (A == 0 && B > -2) { C; D >> 1; }`

10th: `If (A == 0 && B > -2) { C -= 8;  D >> 1; }`

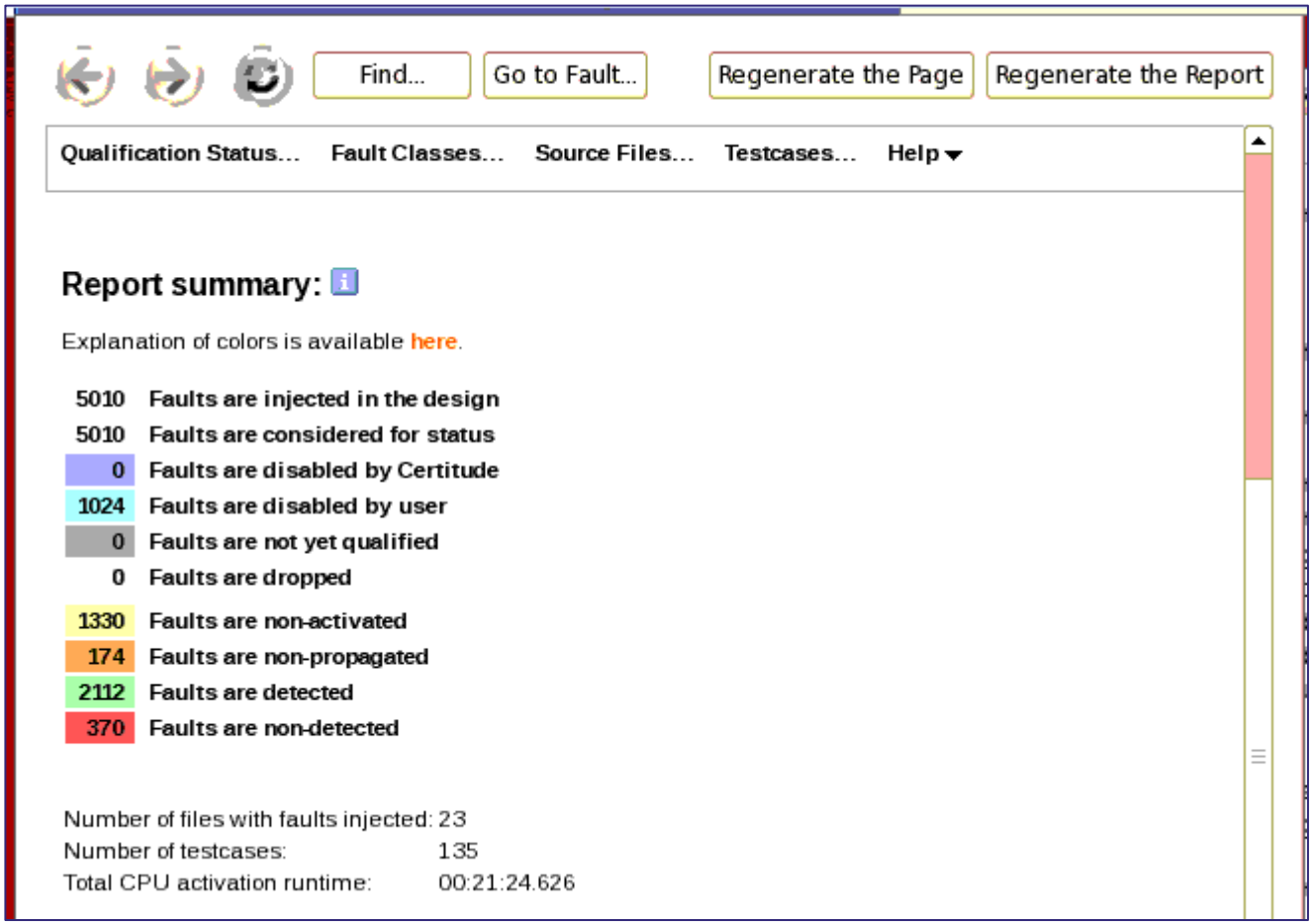
11th: `If (A == 0 && B > -2) { C += 8; D << 1; }`

Certitude C/C++
Example of Fault Injection

```
function_helloWorld();
```

Fault injection: /* code removed */ // function_helloWorld()

Certitude C/C++ Internal HTML report example : Summary



Fault Type Color coded report

- ***Yellow*** *represents non-activated faults.*
- ***Orange*** *represents non-propagated (weak) faults.*
- ***Green*** *represents detected faults.*
- ***Red*** *represents non-detected faults.*

Certitude C/C++ Testcase Report

Synopsys Users Group

Testcase statistics for 'DSP Accelerator'

All durations are expressed using hh:mm:ss.milliseconds

This report was generated on: 2014-08-15 at 17:06:47

Group	Testcase	Id	Runtime	Activated Faults	# Run for Detection	Propagated Faults	Detected Faults
All Testcases (135)			**00:21:24.626**	**2656**	**18945**	**0**	**2112**
	dsp_acc001	1	00:00:00.508	453	106	0	0
	dsp_acc002	2	00:00:00.553	465	105	0	0
	dsp_acc003	3	00:00:00.764	456	101	0	0
	dsp_acc004	4	00:00:00.653	443	104	0	0
	dsp_acc005	5	00:00:00.848	537	101	0	0
	dsp_acc006	6	00:00:01.104	534	101	0	0

Certitude C/C++ Source Files Report

Synopsys Users Group

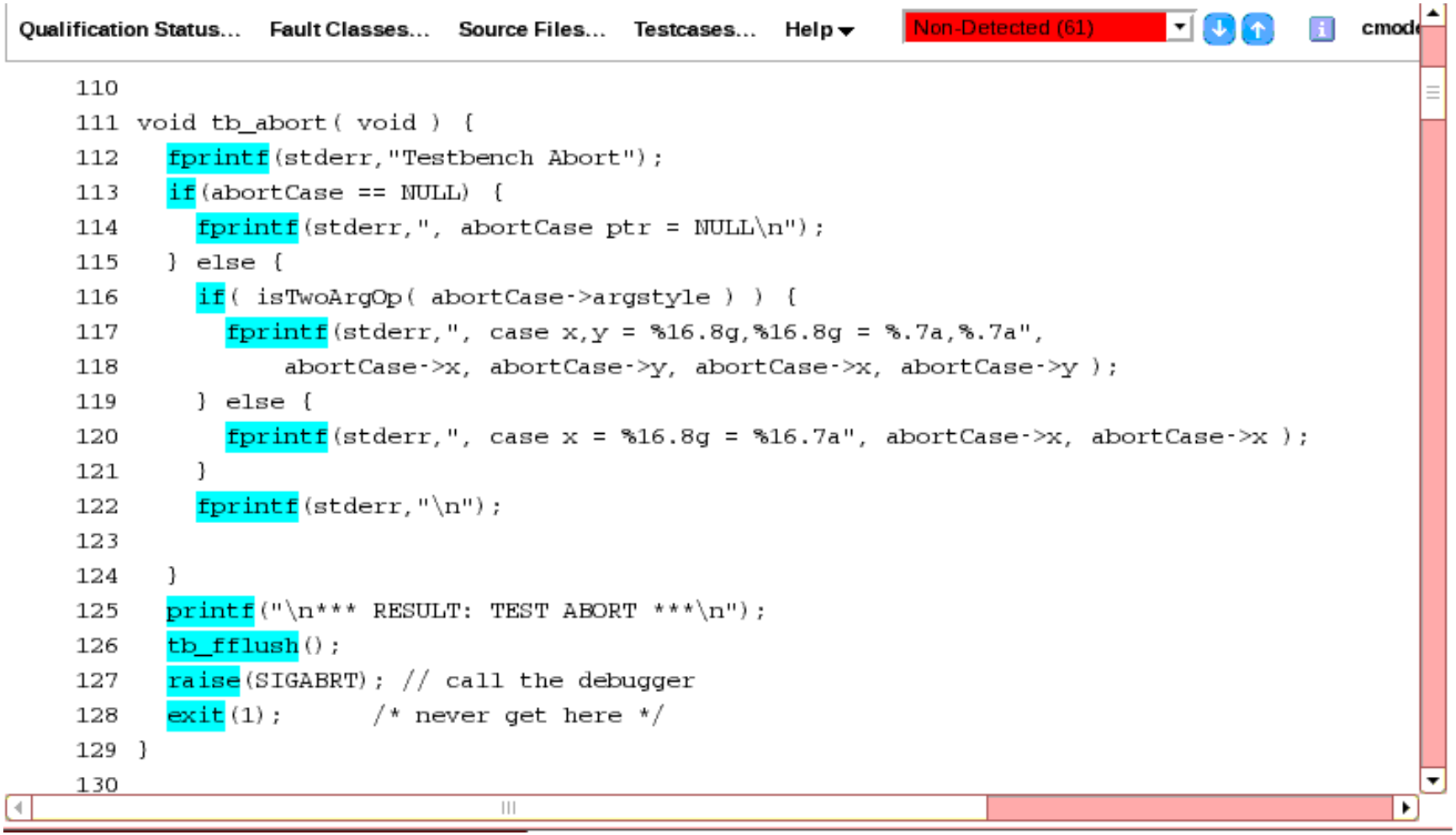
Source file statistics for 'DSP Accelerator'

Find... | Go to Fault... | Regenerate the Page | Regenerate the Report

Qualification Status... | Fault Classes... | Source Files... | Testcases... | Help | Non-Propagated (20)

```
363       //
364       //  width
365       //       0    1-1
366       //    1    2-3
367       //    2    4-7
368       //    3    8-15
369       //    4    16-31
370       //    5    32-63
371       //    6    63-127
372       //    7    127-255 (149 is max attainable value)
373       if( etmp & 0xFF00 ) { r1_w += 8; etmp >>= 8; }
374       if( etmp & 0xF0   ) { r1_w += 4; etmp >>= 4; }
375       if( etmp & 0xC    ) { r1_w += 2; etmp >>= 2; }
376       if( etmp & 0xE    ) { r1_w += 1; etmp >>= 1; }
377       if( etmp != 0     ) { r1_w += 1; }
378
379
380
```

Certitude C/C++ Source Files Report




```
110
111 void tb_abort( void ) {
112   fprintf(stderr,"Testbench Abort");
113   if(abortCase == NULL) {
114     fprintf(stderr,", abortCase ptr = NULL\n");
115   } else {
116     if( isTwoArgOp( abortCase->argstyle ) ) {
117       fprintf(stderr,", case x,y = %16.8g,%16.8g = %.7a,%.7a",
118           abortCase->x, abortCase->y, abortCase->x, abortCase->y );
119     } else {
120       fprintf(stderr,", case x = %16.8g = %16.7a", abortCase->x, abortCase->x );
121     }
122     fprintf(stderr,"\n");
123
124   }
125   printf("\n*** RESULT: TEST ABORT ***\n");
126   tb_fflush();
127   raise(SIGABRT); // call the debugger
128   exit(1);       /* never get here */
129 }
130
```

Experience with Functional Qualification Certitude C/C++ and Results

Certitude C/C++ Easy Integration

Setting up simulator environment in Certitude C/C++ was approximately 2 hours by updating the following files, compile, and run.

- ***certitude_config.cer*** *(setup config)*
- ***certitude_compile*** *(environment compilation step)*
- ***certitude_batch*** *(lsf job command)*
- ***certitude_execute*** *(script capturing “pass” or “fail”)*
- ***certitude_testcases.cer*** *(testcase names)*
- ***certitude_hdl_files.cer*** *(reference model and waivers)*
- ***cert_testlist*** *(testcase list).*

****Certitude C/C++ License was required*

Simulator Environment Qualified Statistic

- *16 different algorithms*
- *Bit-accurate Hardware Reference model*
- *4 different accuracy models*

Source Code	Line Count
C/C++ Hardware Reference Model	9658
C/C++ Ideal Reference Model and Testbench	9,642
RTL in SystemVerilog	12,808
SystemVerilog UVM Testbench	17,313

Runtime and Data Volume

$$Activate\ Runtime = \frac{\#tests\ *\ test\_time}{Number\ of\ Servers}$$

$$Detect\ Runtime = \frac{\#\ faults\ *\ \#tests\ *\ test\_time}{Number\ of\ servers}$$

Phase	Short Regression Runtime
Model	1 minute
Activate	45 minutes
Detect	21 hours

Objective Goal and Certitude C/C++ Result

- *Plan ahead:*
  - When to run Certitude C/C++?
  - Who should run it?
- *Resource: Runtime, disk volume, and Result Analysis*
  - Analyzing your result... Prioritize to use your time wisely
  - Runtime and disk volume can be large
- *Level of severities matter*
  - Non-Detect faults are the highest priority
  - Non-Activated faults are the next high priority

Certitude C/C++ Report example … Detected Fault

Synopsys Users Group

Find... | Go to Fault... | Regenerate the Page | Regenerate the Report

Qualification Status... | Fault Classes... | Source Files... | Testcases... | Help | Non-Detected (43)

```
373       //    6    63-127
374       //    7    127-255 (149 is max attainable value)
375       if( etmp & 0xF000 ) { r1_w += 8; etmp >>= 8; }
376       if( etmp & 0xF0   ) { r1_w += 4; etmp >>= 4; }
```

Certitude faults 4207 detail

Fault detail

Action	Fault ID	Fault Type	Status	Detected By Test
Disable	4207	ConditionTrue	Detected	121
Disable	4208	ConditionFalse	Detected	121
Disable	4209	NegatedCondition	Detected	121

With the fault 4207 of type 'ConditionTrue', the code:

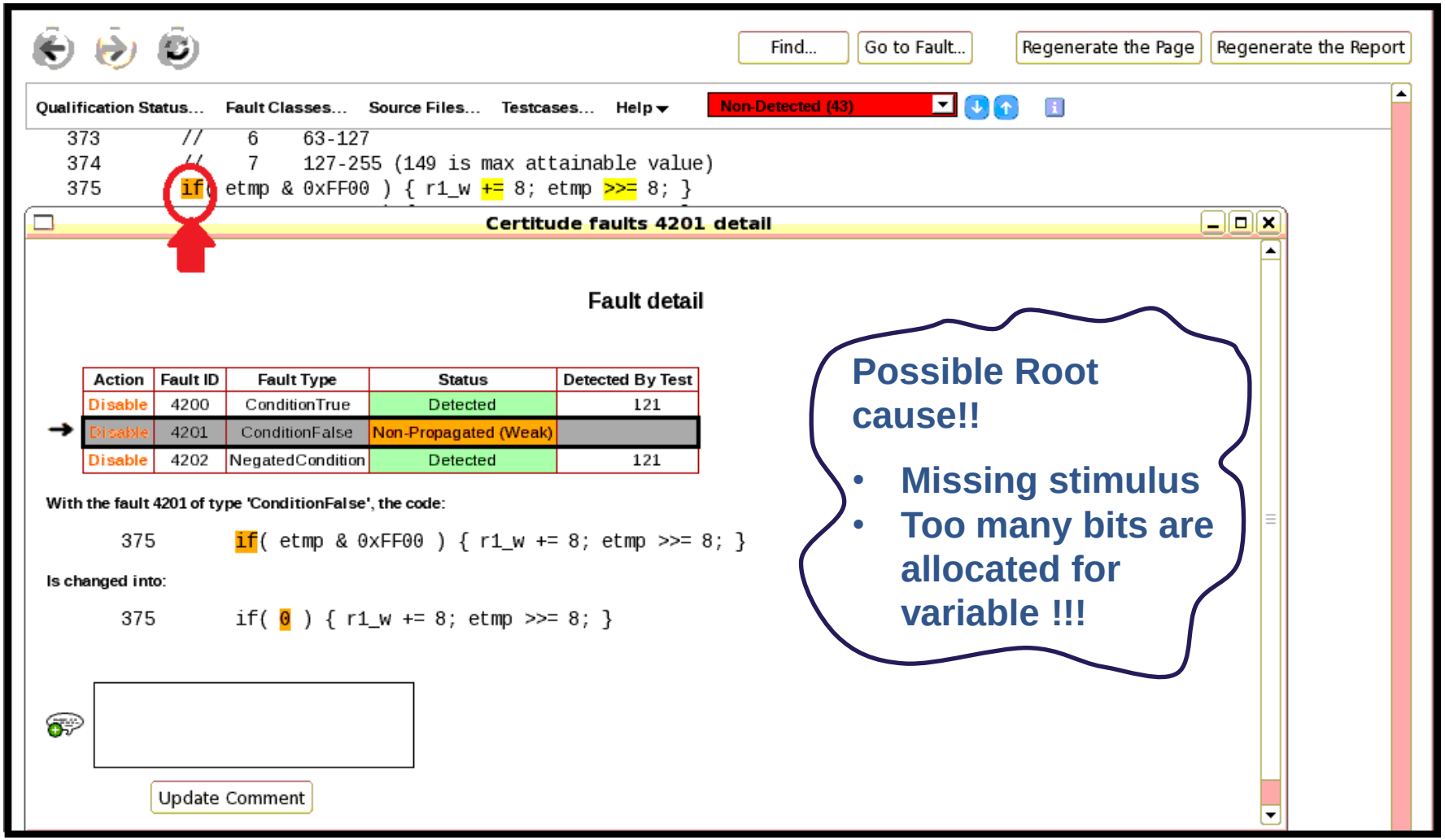
```
376       if( etmp & 0xF0   ) { r1_w += 4; etmp >>= 4; }
```

Is changed into:

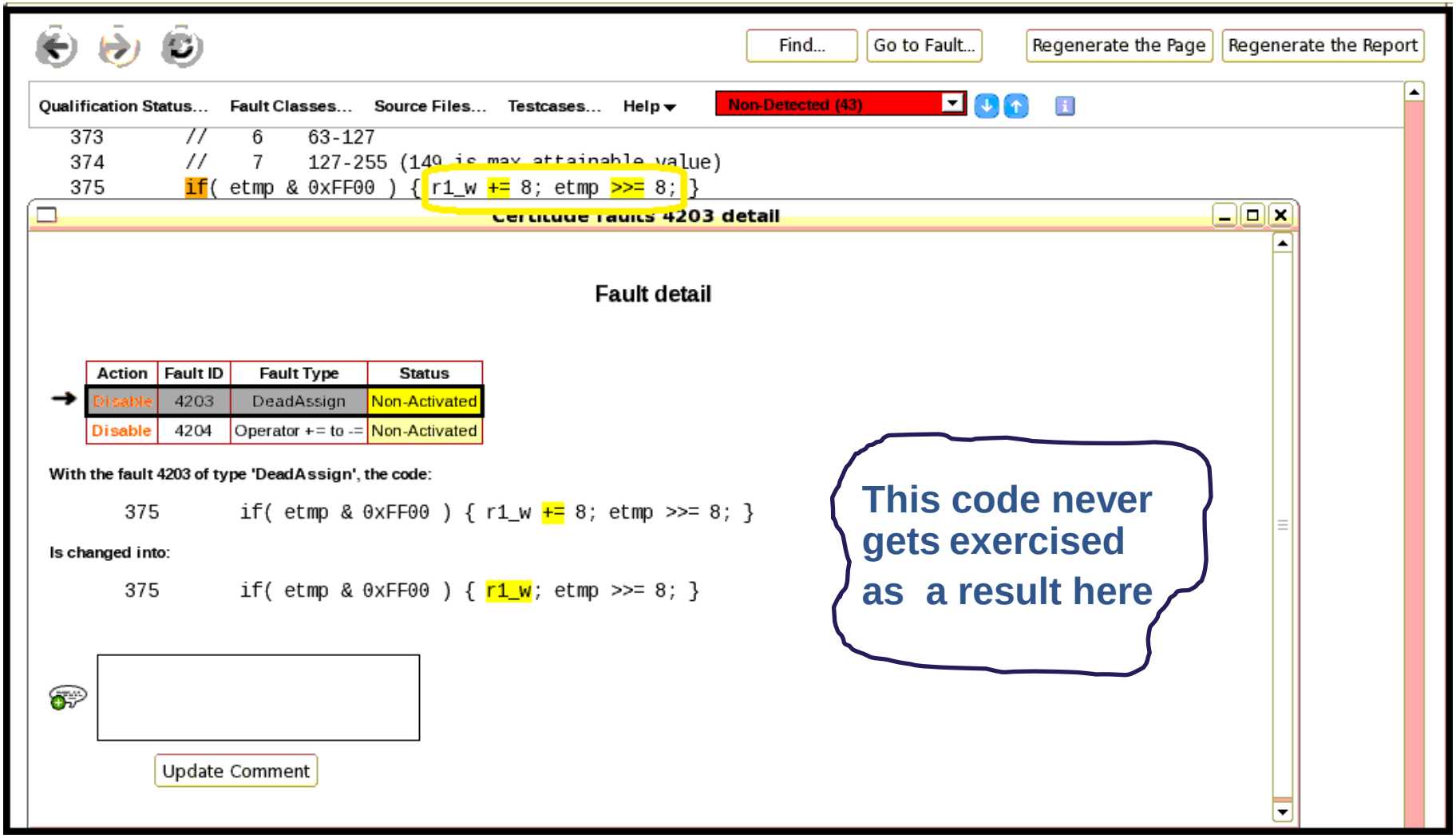
```
376       if( 1    ) { r1_w += 4; etmp >>= 4; }
```

Update Comment

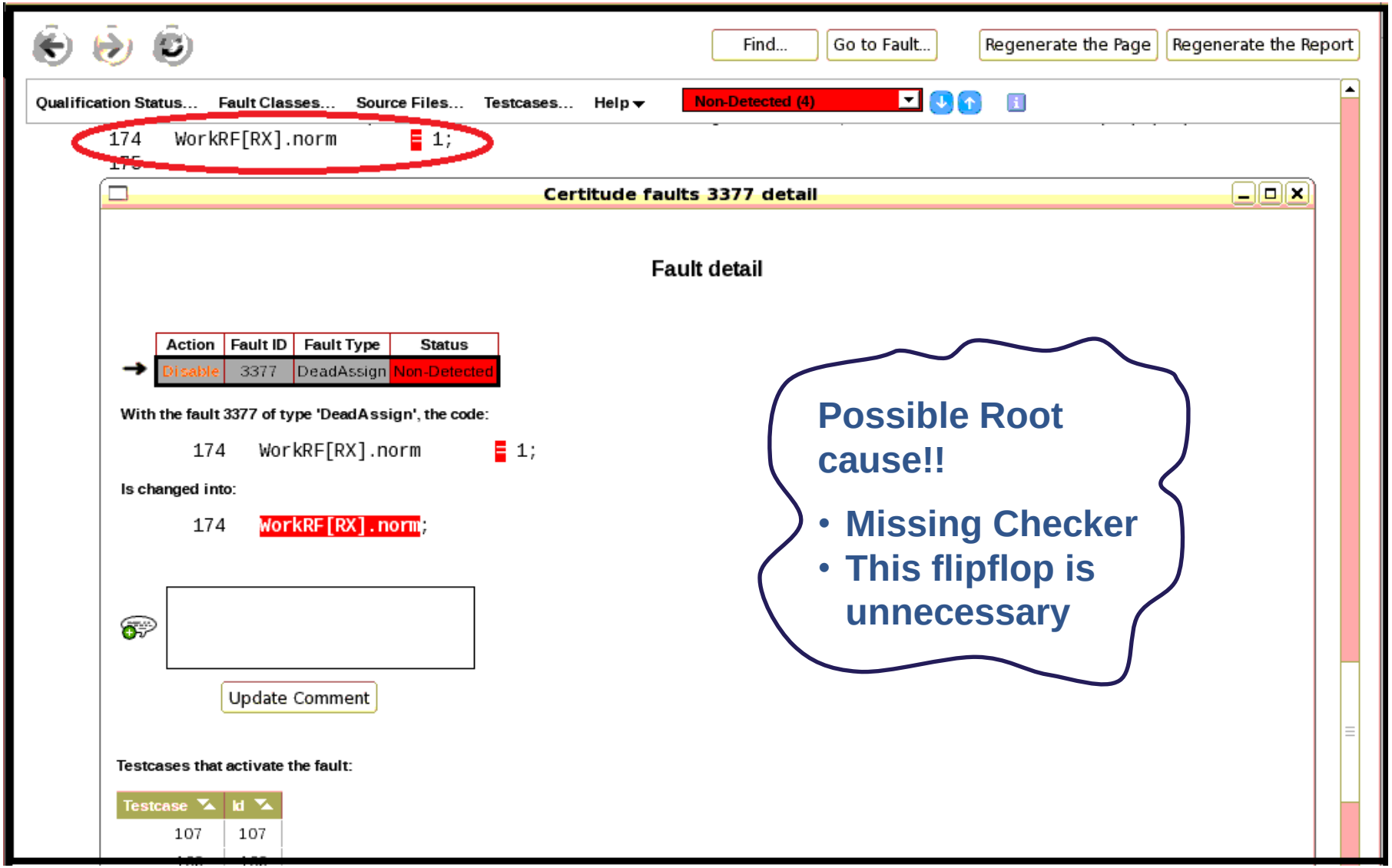
Certitude C/C++ Report example… Non-Propagated Fault (Weak)



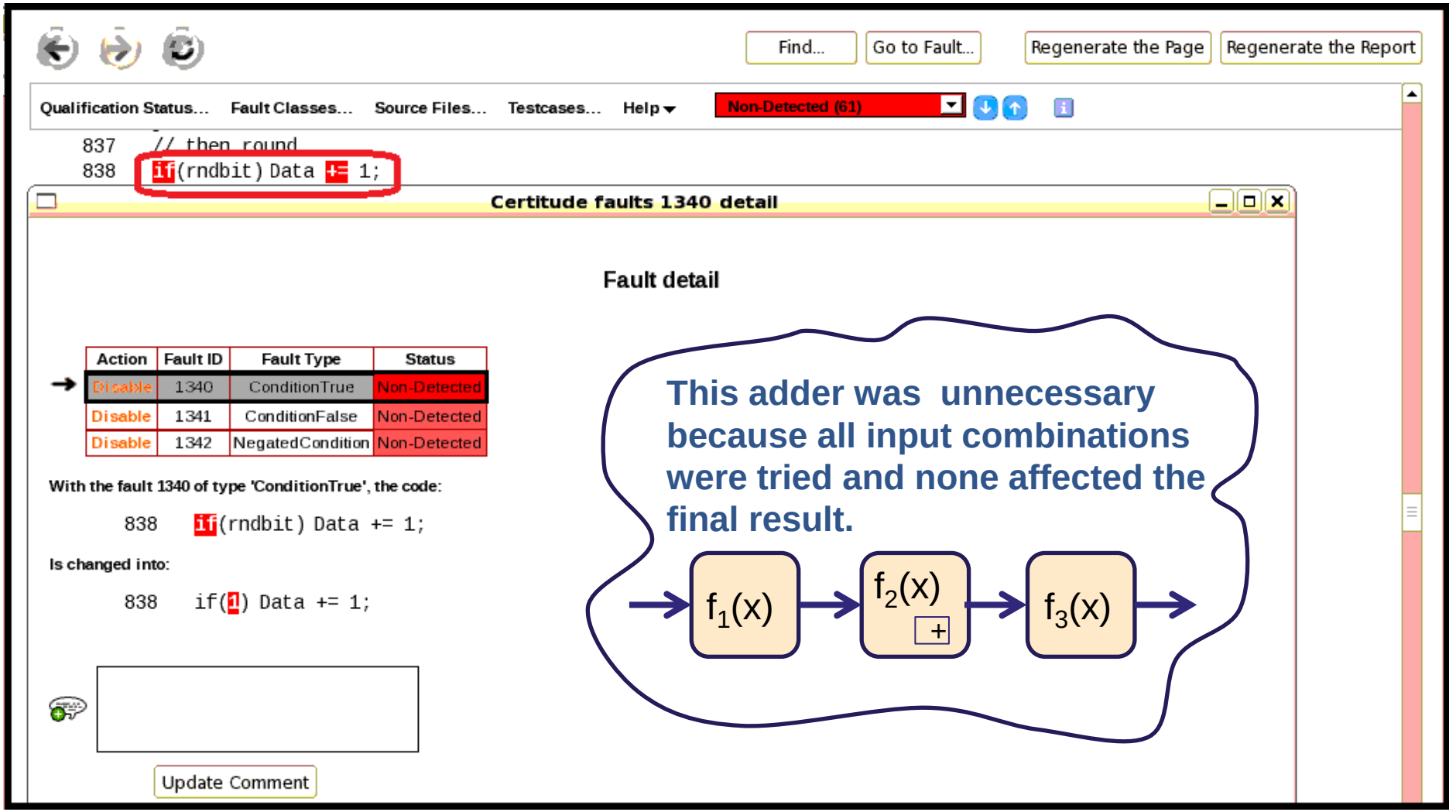
Certitude C/C++ Report example… Non-Activated Fault



Certitude C/C++ Report example… Non-Detected Fault



Certitude C/C++ Report example… Non-Detected Fault

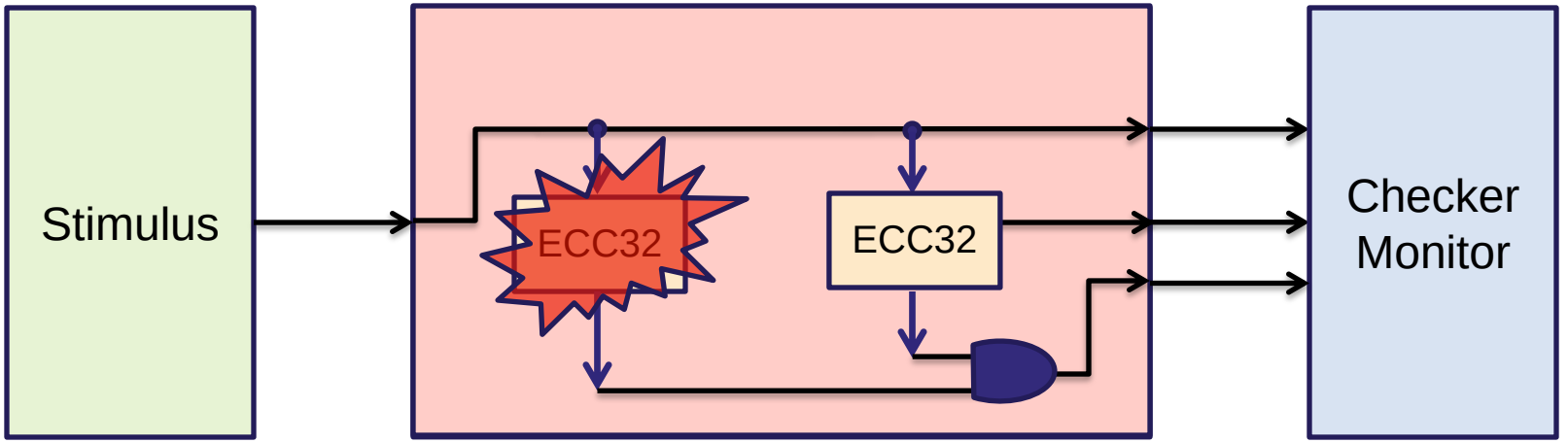


Another example of Certitude C/C++ Finding Design issues

A hardware reference model or software code:

Alarm2 = ECC32_calc(input, corrected_data2);
Alarm1 = ECC32_calc(input, corrected_data1);
IRQ = Alarm1 && Alarm2;

Output = corrected_data1;



If you run Certitude C/C++, You will find this.

Advantage of Using Functional Qualification tool

The Good, The Bad, and The Ugly

Sometimes the unexpected happens,
and we are human after all !!!

The Bad and The Ugly :

BE SMART….

(Don’t start the engine and throw the key away!!)

The Good!!!!
That is why we are here…

- You will find (many) things that aren't perfect in your design and verification environment
  - Low Power design
  - Software memory critical code/program
- Detect bad coding style or deadcode that weren't intended to be in the design
- You can get a good list of tests for Short Regression. Critical for design change, feature adding, and a quick respin.

Why should you run Certitude C/C++ too?

- *You can walk away feeling more confident as your design code is thoroughly interrogated and examined.*

  "There is a checker for every single line of code or logic"
- *Improved C/C++ code results in higher quality RTL or software*
- *Objectively measure critical software code or Hardware model as well as your verification environment*
- *Find bugs earlier rather than waiting for device to come back*

Recommendation for Future Certitude C/C++ features

Acknowledgement
“Who We Should Thank!!!”

John Hayden, David Brownell, Marty Rowe, ADI Norwood and IPDC team, Synopsys, and Technical committees

Always Have Fun !!

Thank You

Get It Done !!