Formal Fault Tolerance Analysis of Algorithms for Redundant Systems in Early Design Stages

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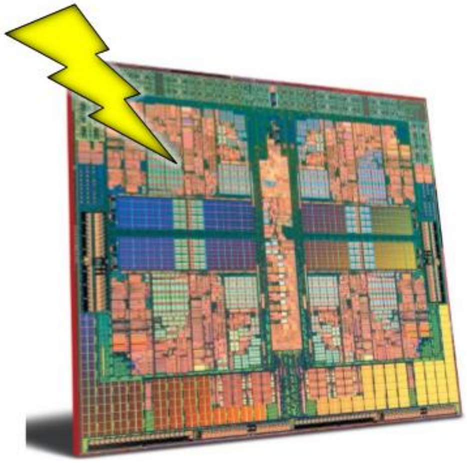
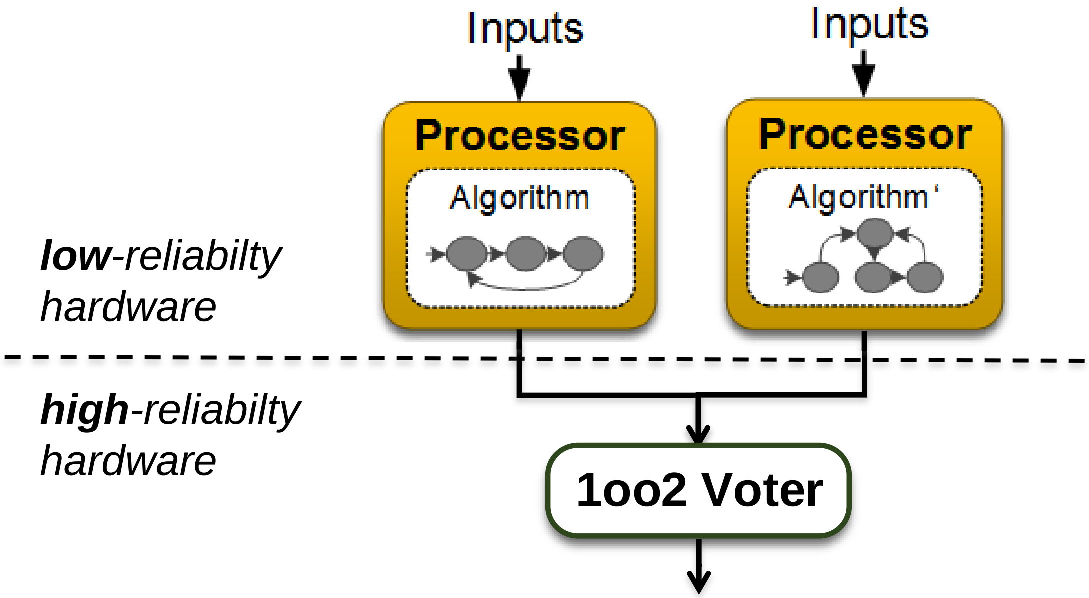
Hardware Fault Tolerance is a Challenge

- Trend to use COTS-hardware components for safety-critical systems
- Increasing number of soft erros
- High level of fault tolerance required
- Hardware redundancy



Hardware Redundancy

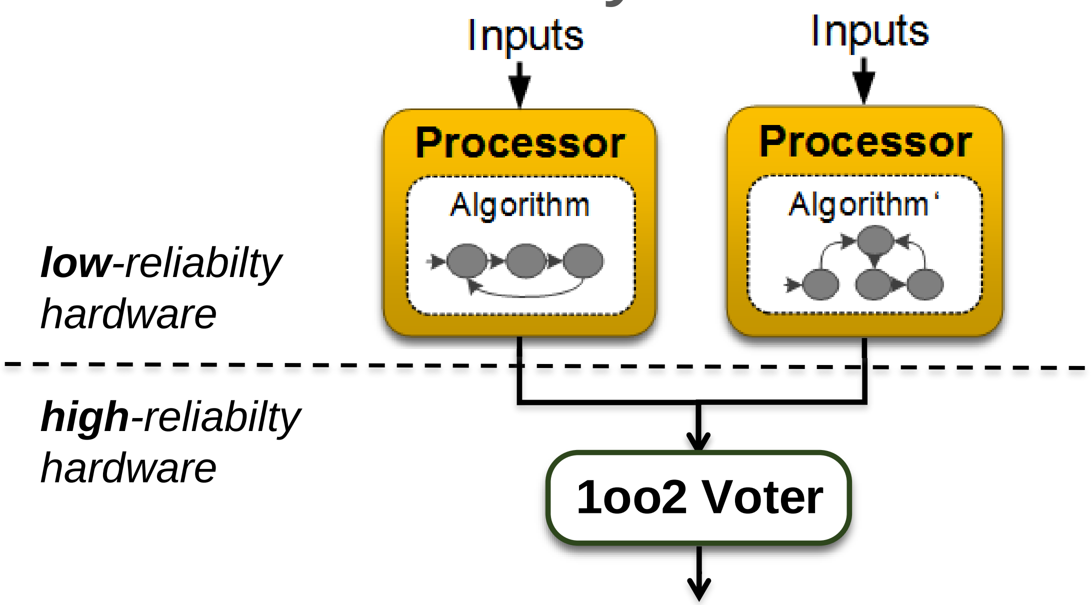


Which algorithms should be chosen to efficiently exploit the redundancy?

- Diversity to tolerate ...
  - systematic faults
  - random faults
- Inherent fault masking at algorithm-layer
  - Example: stuck-at-1 fault

1 OR 0 = 1 1 AND 0 = 0

Hardware Redundancy



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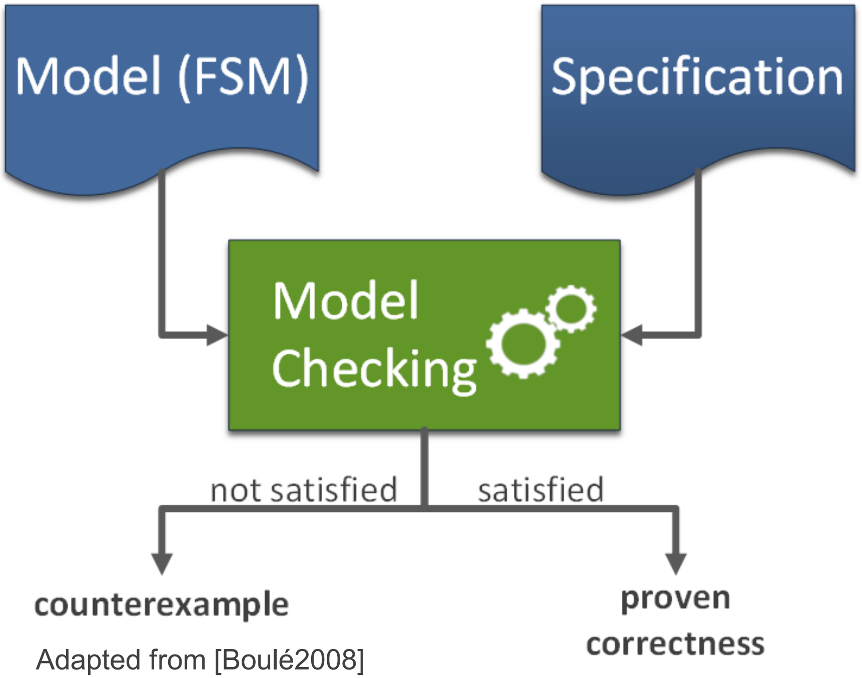
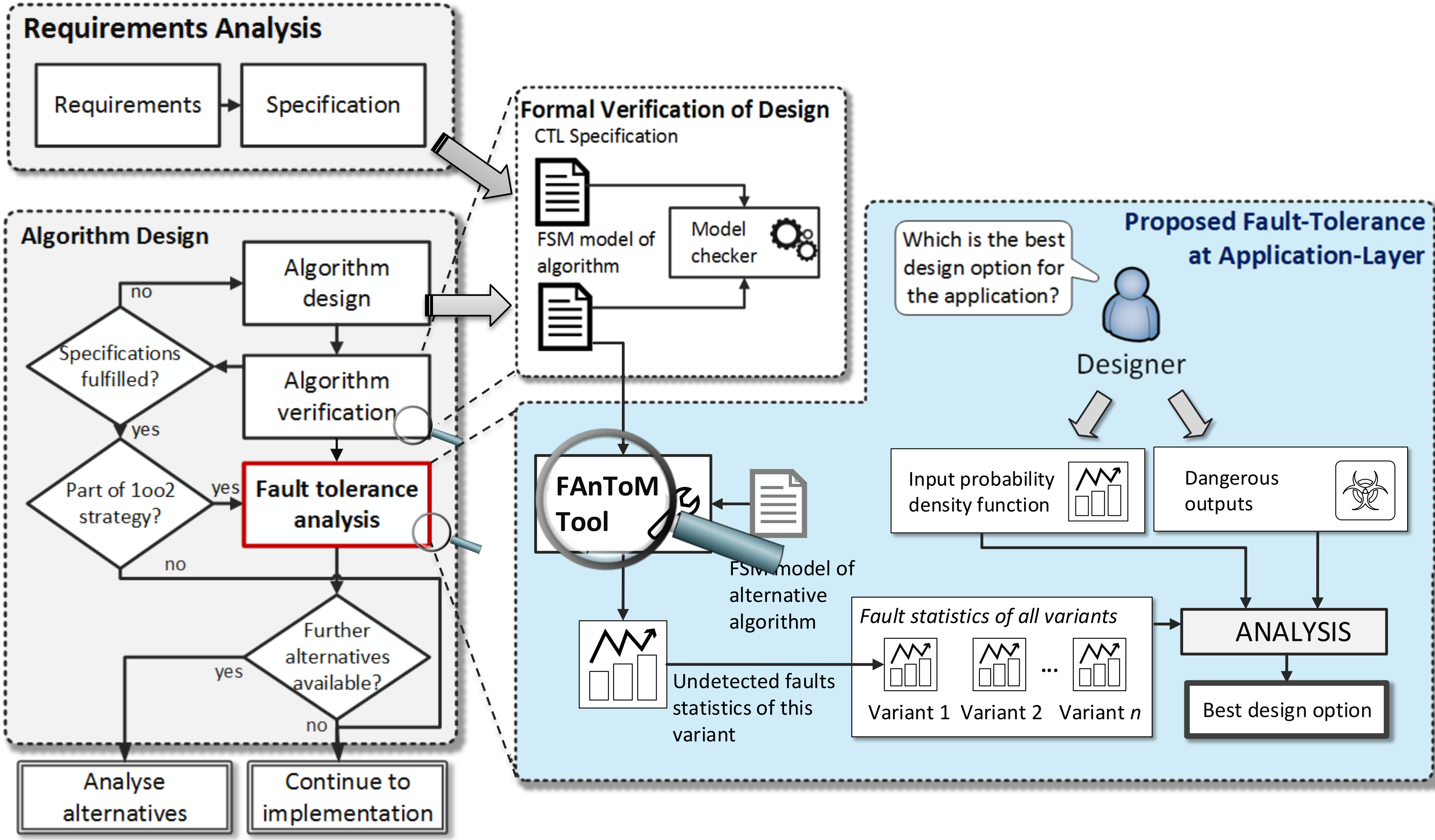
1 OR **1** = **1** 1 AND **1** = **1**

Model Checking



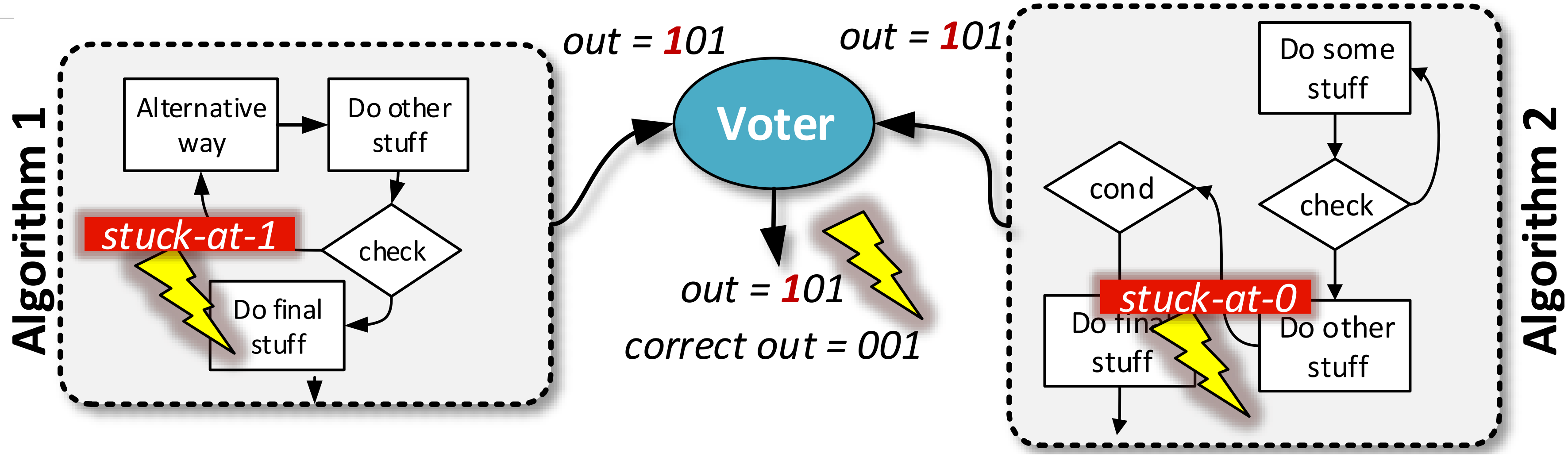
- NuSMV Tool
- Related work: Qualitative fault tolerance analysis [Huth2006, Krautz2006, Ezkiel2009]

Fault Tolerance Analysis in Early Design Stages



High-Level Evaluation of diverse Algorithms

→ Find all non-detected dual fault combinations



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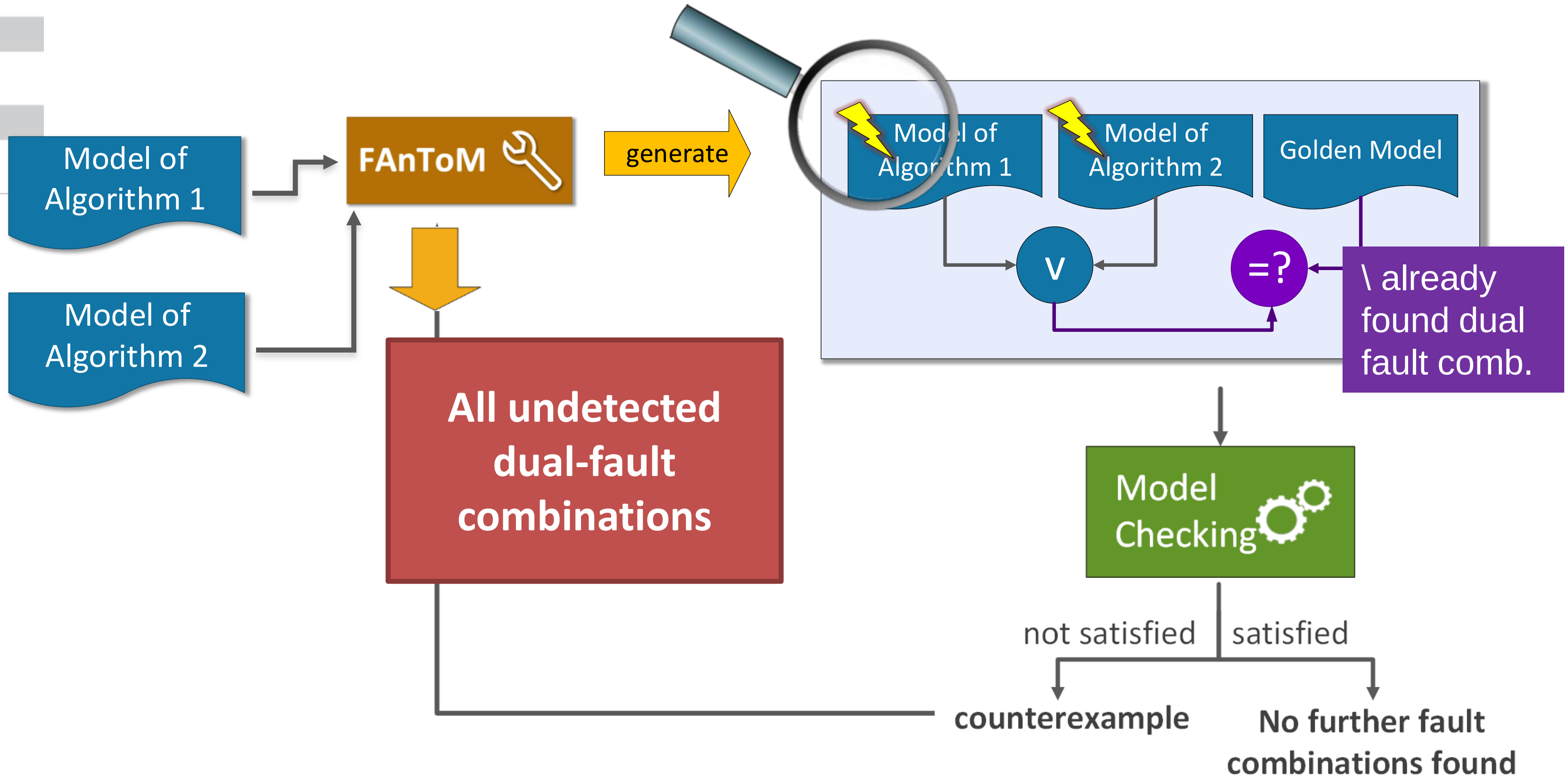


Fault Modeling

```
-- len…length of data variable, fi…should a fault be injected?
MODULE WORD(input, len, fi, my_var) --Data word with fault injection
 DEFINE     MAX_BIT_INJ := len - 1;
            fi_type     := my_var.fi_type; --fi-type of variant
 FROZENVAR inj_bit      := 0..MAX_BIT_INJ; --target bit of fi
 DEFINE out:= case
        fi & fi_type = stuck_at_0 : input & !(1 << inj_bit);
        fi & fi_type = stuck_at_1 : input |  (1 << inj_bit);
        fi & fi_type = bit_flip & my_var.fi_state = my_var.state :
                                                  input xor (1 << inj_bit);
         TRUE : input;    esac;
```

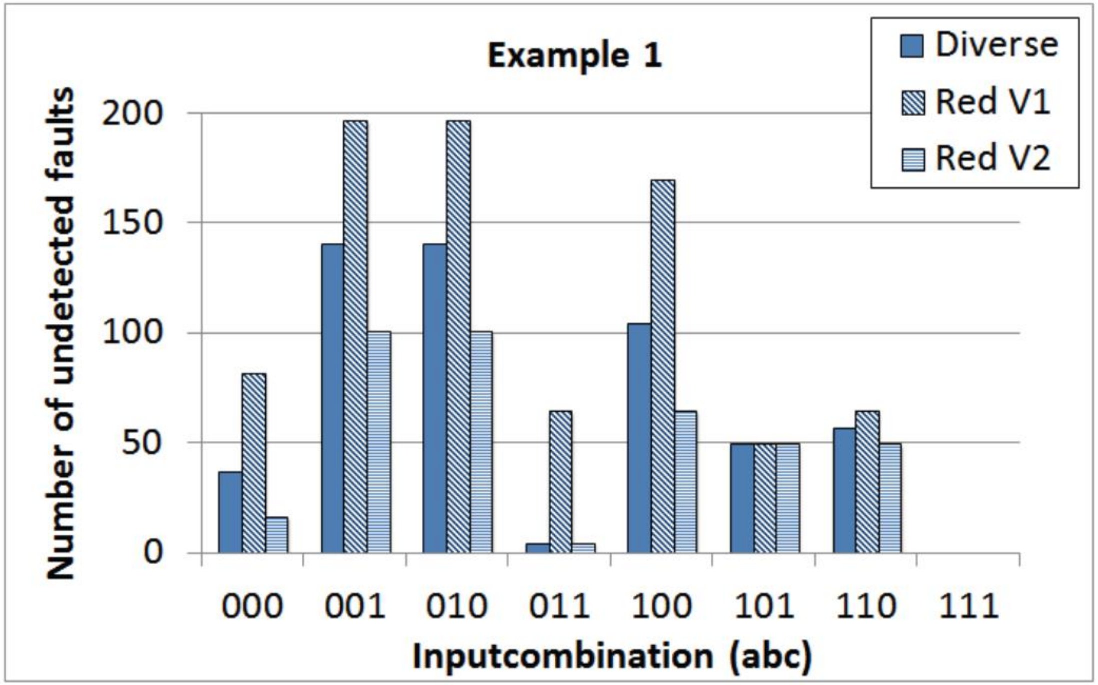
- Data faults
  - Stuck-at-x faults
  - Bit-flips
- Input variables to model random faults
  - Target signal
  - Fault type
  - Triggering time

Experimental Results

- Hydro-electrical power plant controller
- Simple boolean calculations
  - Example 1

$$\text{Variant 1}: (A \wedge B) \vee (C \wedge B) \vee (A \wedge C) \vee (B \wedge C)$$

$$\text{Variant 2}: B \wedge (A \vee C) \vee C \wedge (A \vee B)$$

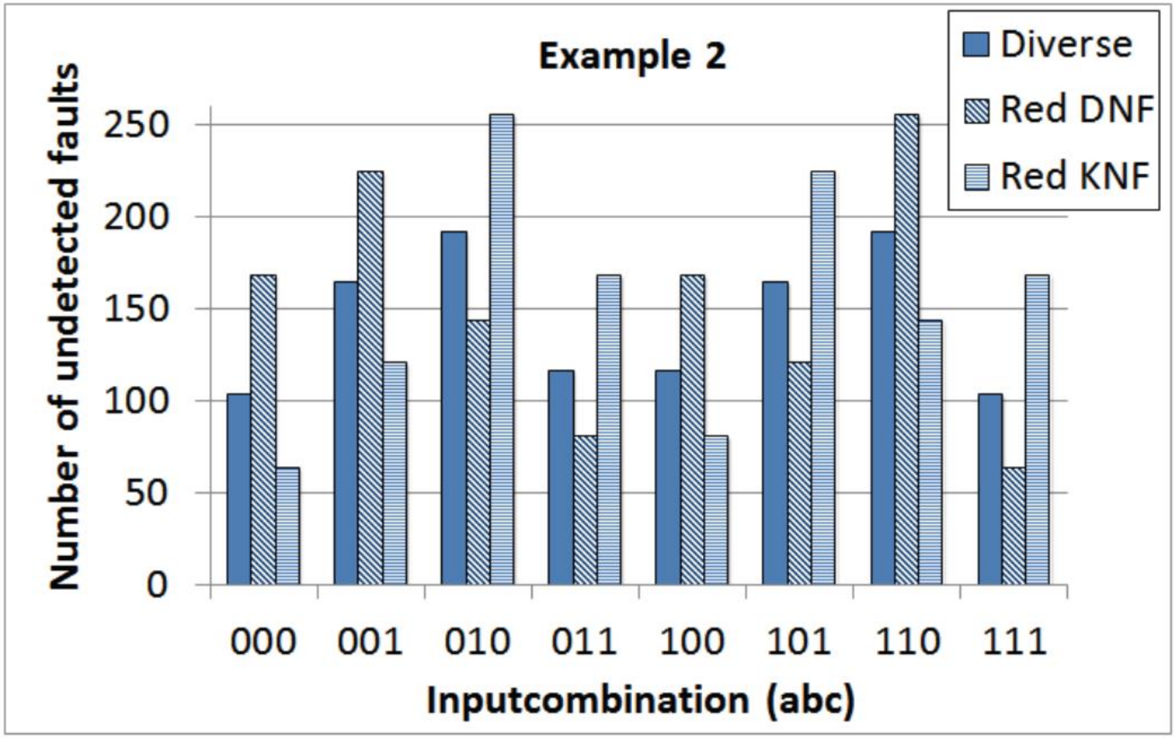


Experimental Results

- Simple boolean calculations
  - Example 2

$$\mathrm{DNF}: (\bar{A} \wedge B \wedge \bar{C}) \vee (\bar{A} \wedge B \wedge C) \vee (A \wedge \bar{B} \wedge C) \vee (A \wedge B \wedge C)$$

$$\mathrm{CNF}: (A \vee B \vee C) \wedge (A \vee B \vee \bar{C}) \wedge (\bar{A} \vee B \vee C) \wedge (\bar{A} \vee \bar{B} \vee C)$$



Conclusion

- Formal quantitative fault tolerance analysis
- Applicable in early design stages
- Understanding of algorithm-specific fault tolerance
  - Influence of input
  - Probability of certain errorneous output value
- Scalability issues
- Future work
  - Application for control-flow analysis and security
  - Handle more complex designs

Thank you very much for your attention!

Any questions?

References

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