Critical Variable Identifications using Register Vulnerability for Selective Protections

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Agenda

- Motivation
- Related works
- Problem definition
- Method Proposal
- Experiments
- Conclusions

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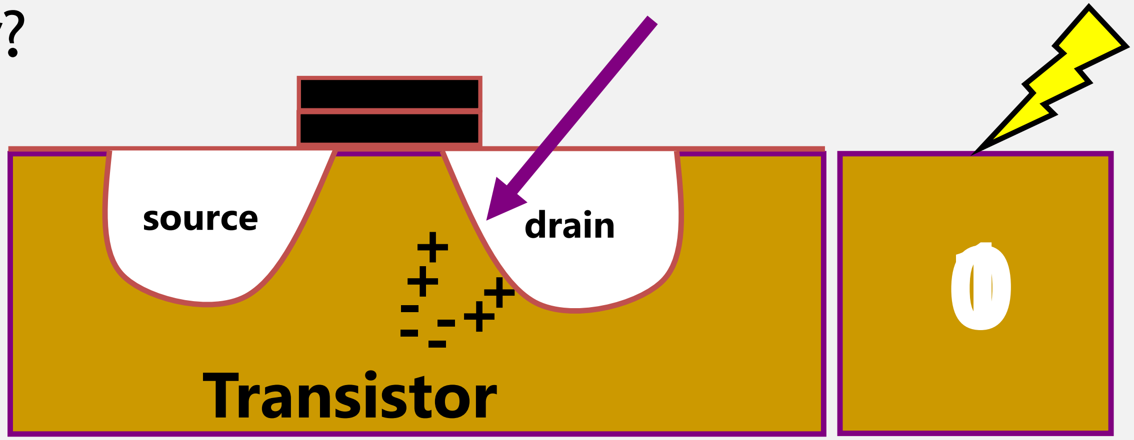
What is soft error?

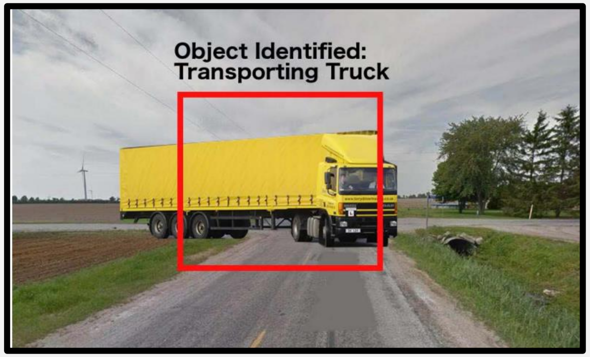
- Soft Error?



  - A phenomenon that the bit of the transistor is temporarily reversed
    - Assume that this transistor contains bit value 0
    - This transistor is attacked by external radiation
    - The external radiation makes some charges
    - The extra charges make the bit value to 1
  - Soft error rate exponentially increase with technology scaling and near-threshold computing

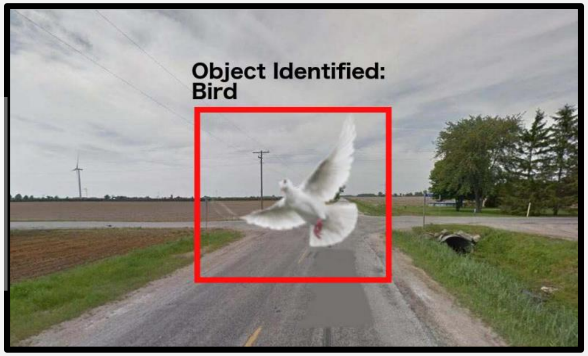
Soft error is important

- Soft error is an increasing concern
  - Soft error is a major threat to system reliability
  - As computer systems are used more and more in industry and life, soft error is becoming important
- If soft error occurs in auto-driving car [2017, Li]
  - Only 1 bit of soft error can lead to misclassification of objects in DNN based vision technique
  - Misclassification can result in the wrong action



action = brake

Soft error makes misclassification (truck → bird)



action = keep driving (collision)

Soft error protection technique is required

- The progress of soft error protection
  - Detect soft error occurrence
  - Execute fault tolerance policy (correction, restart, rollback, etc..)
  - Make the system to operate normally

- Implement soft error protection

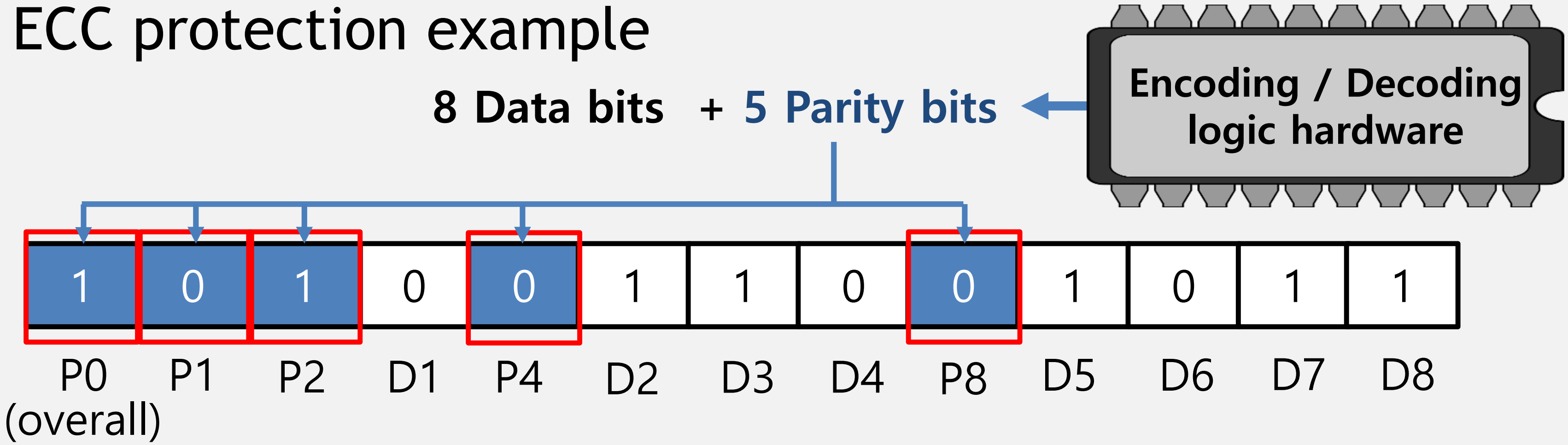
H/W based technique

S/W based technique

Hardware based technique

- Hardware based protection technique
  - Redundant H/W to detect or correct errors
    - Requires additional hardware costs
  - ECC(Error Correction Code) block on L1D (SEC-DED) [2006, chibani]
    - 215% increase runtime than unprotected one
    - 20% additional area occupancy and 300% more power consumption

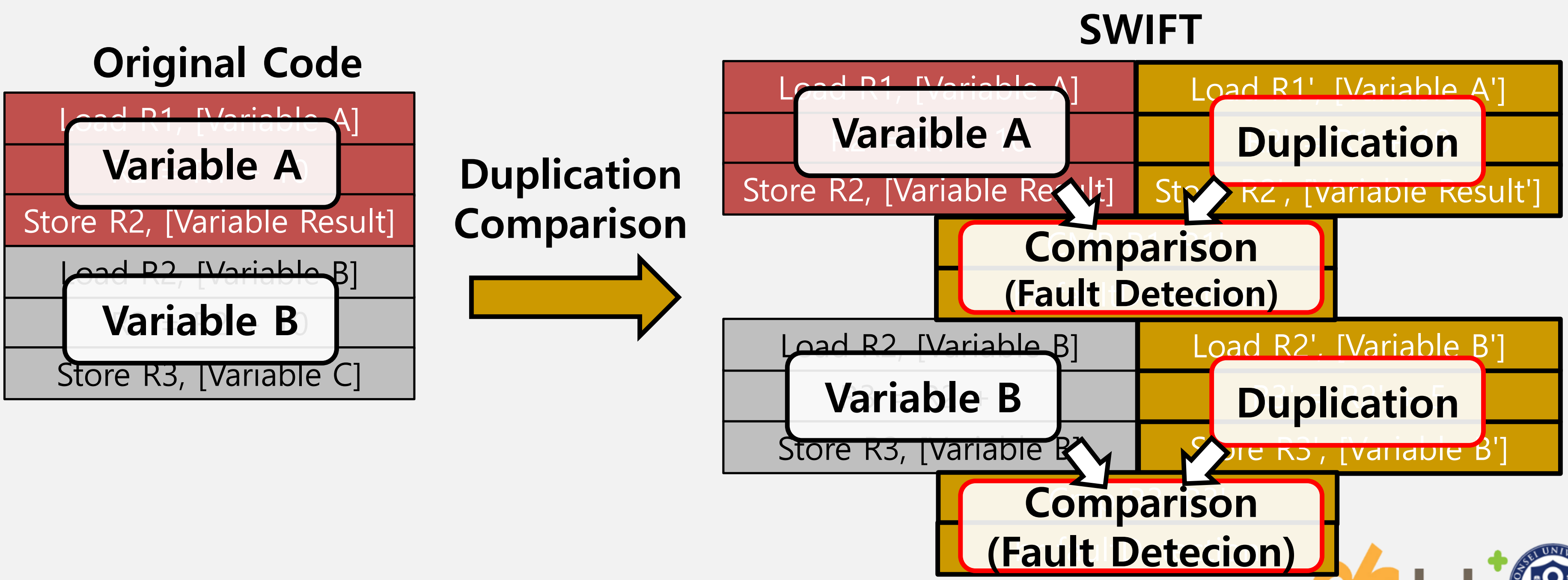
- ECC protection example



1 bit error correction = **P0** will be **wrong, P1,2,4,8** will be **index of error**
2 bit error detection = **P0** will be **correct**

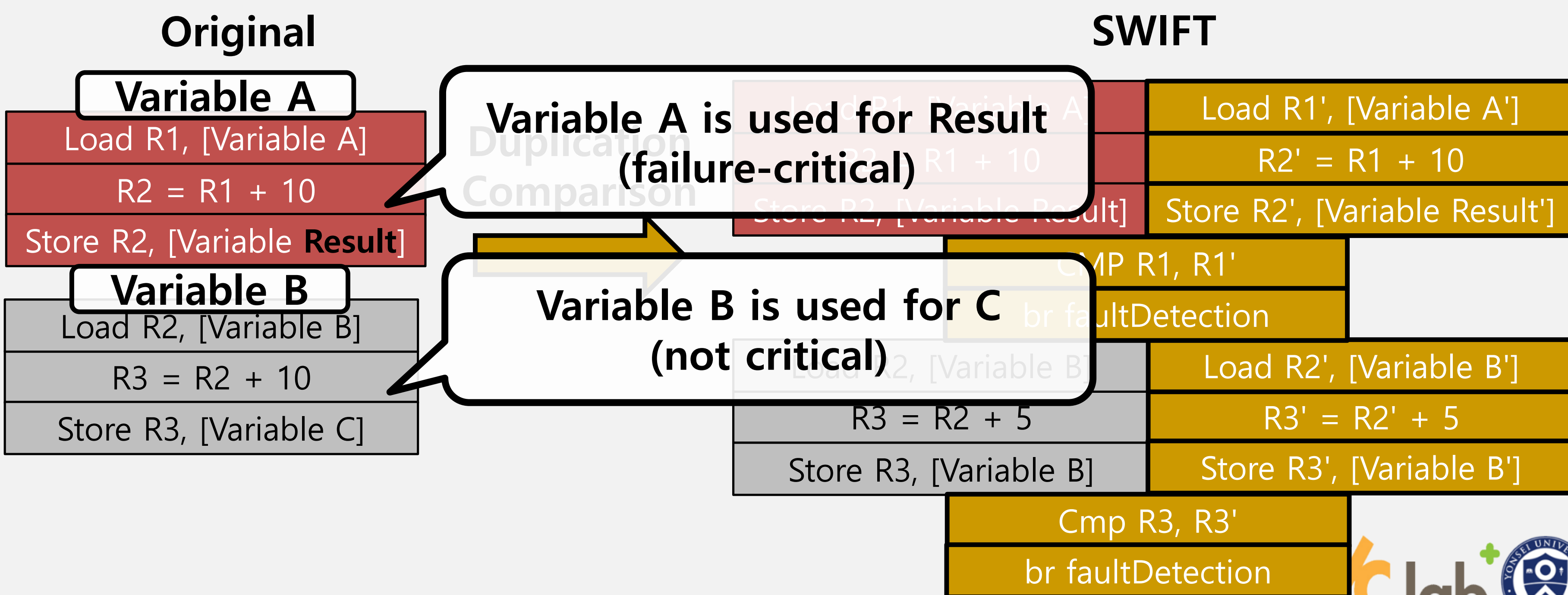
Software based technique

- Software based protection technique
  - No additional hardware costs, flexible to apply and change
  - SWIFT : Insert error detection code on program by duplicating instructions [2005, reis]
    - ◆ 70% of errors detection coverage, 400% increase runtime
- SWIFT (Software Implemented Fault Tolerance) example



Full protections are highly expensive

- H/W and S/W full protection are highly expensive
  - Runtime overhead : at least 2 times slower
  - May not be suitable for modern computer systems (low-power, IoT)
- Selective protection
  - All variable protection is expensive
  - Only few variables are important, i.e., failure-critical



Selective protection : a cost effective way

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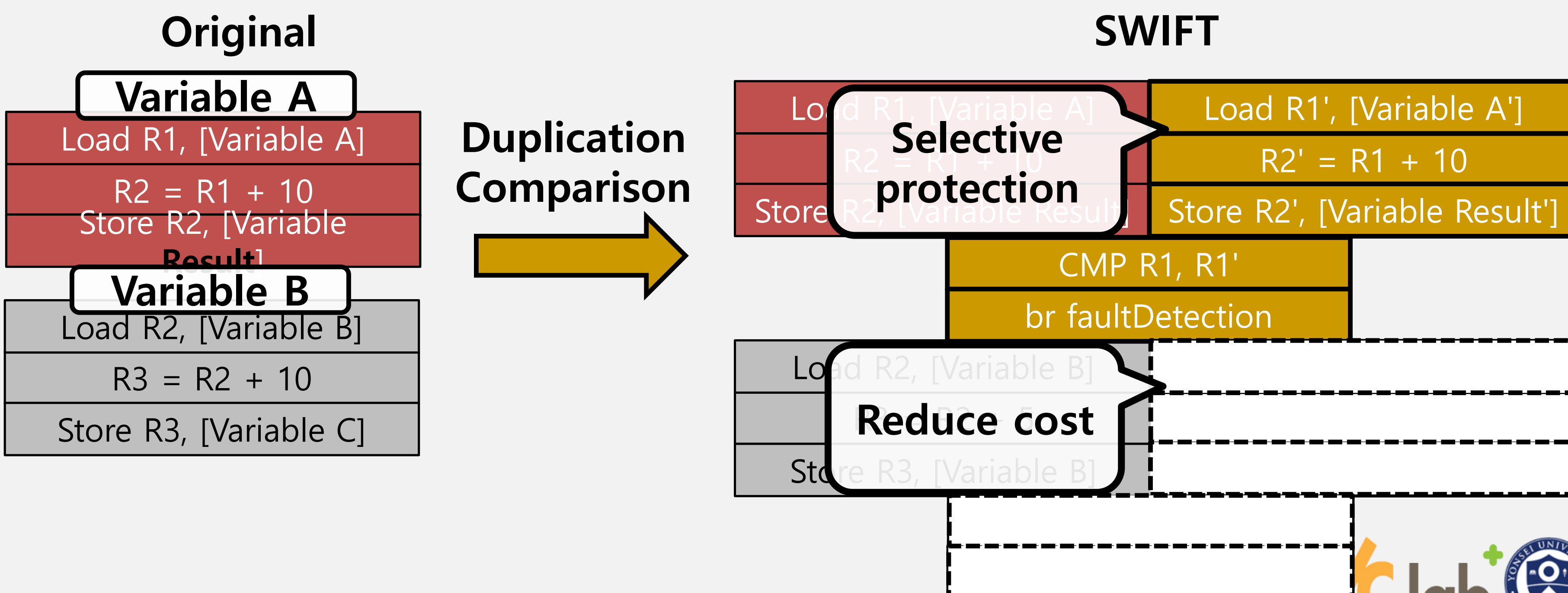

Selective protection : a cost effective

- H/W and S/W technique are highly expensive
  - Runtime overhead : at least 2 times slower
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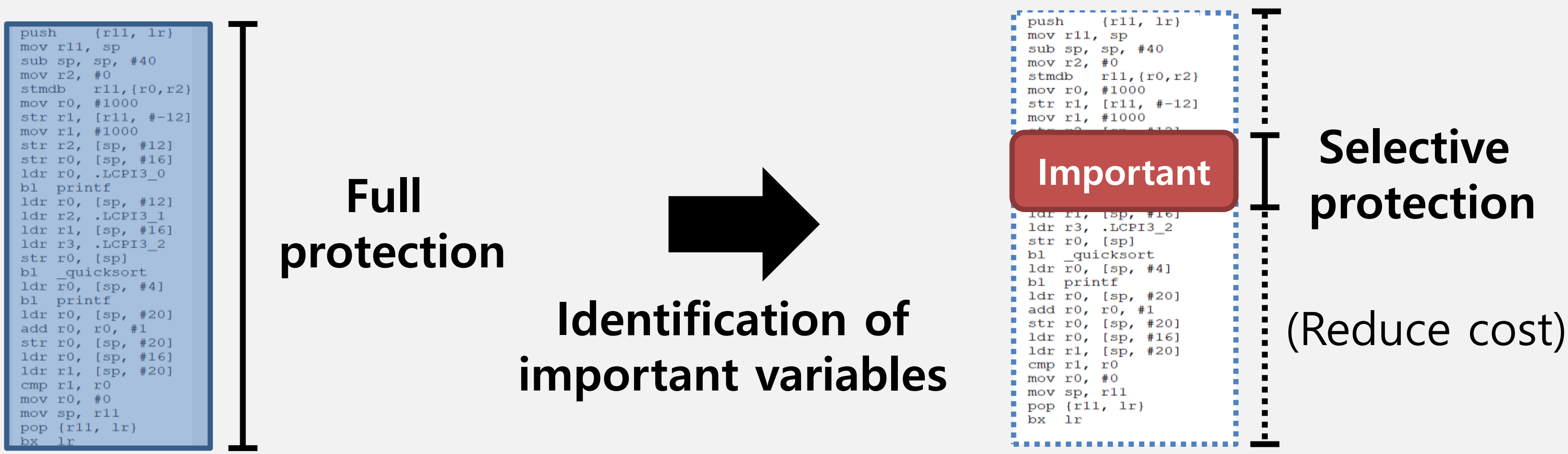
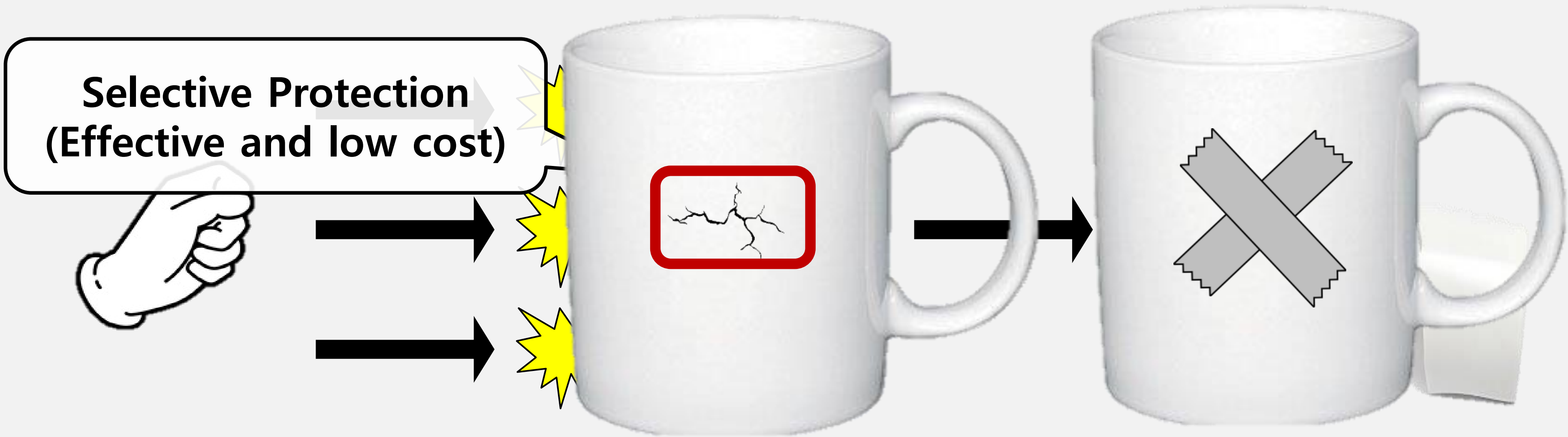
- Selective protection
  - All variable protection is expensive
  - Just some of them are important, i.e., failure-critical



Selective protections on important variables can be cost effective

Selective protection : a cost effective

- Selective protection example
  - Mug cup with an invisible crack
  - The cup will be broken if knock the cracked part
  - Attaching the tapes to the only crack can prevent broken



We need to figure out where to be protected

Agenda

- Motivation
- Related works
  - Method for finding where to protect in H/W
  - Method for finding where to protect in S/W (Critical variables)
- Problem definition
- Method Proposal
- Experiments
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H/W Vulnerability Measurement

- AVF(Architectural Vulnerability Factor) [2003, Mukherjee]
  - Vulnerability : possibility that a fault in that particular structure will result in an error

Fault is overwritten, not vulnerable

  - Before reading after writing (t2 ~ t7) is vulnerable
  - Weakness : accuracy (instruction unit), scalability (limited H/W)

- gemV toolset [2016, Tanikella]
  - Improve accuracy and scalability
  - Accuracy : CPU-cycle unit measurement (gem5 based)
  - Scalability : supports various hardware and components
  - Validation of vulnerability measurement by fault injection

H/W Vulnerability Measurement

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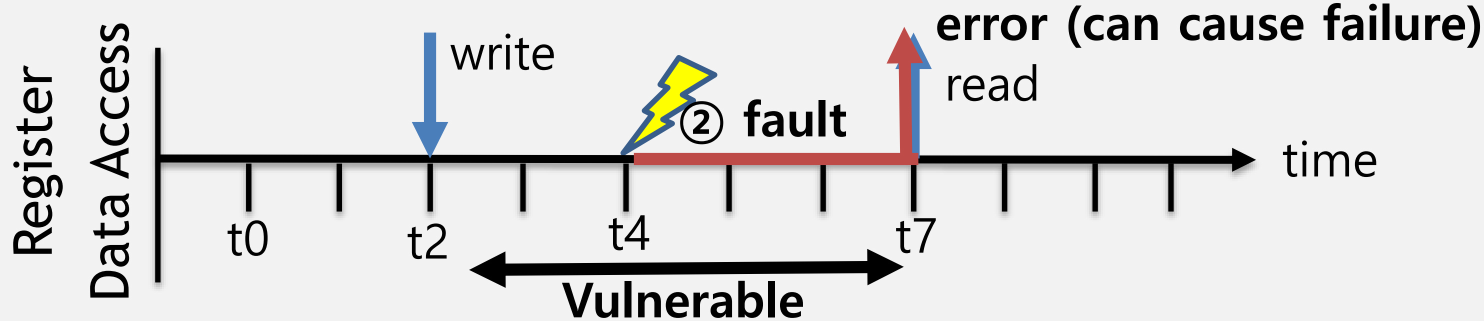

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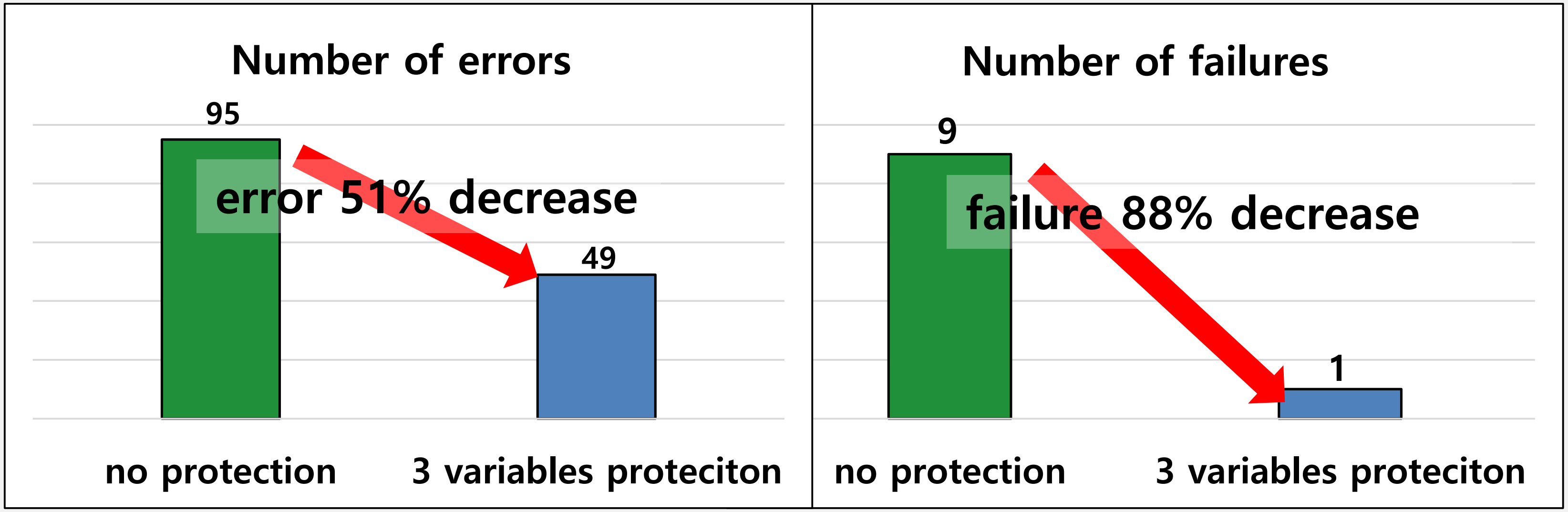
S/W Vulnerability Measurement

- Identification of Critical Variables using an FPGA-based Fault Injection Framework [Riefert, 2013]
  - **The Critical variable** : a variable that significantly affect on program **execution and calculation results** (frequently used)
  - In fault injection, critical variable will be highly injected
  - Experiment : protecting 3 variables (Runtime 18% increase)



  - However, Fault injection it takes large of time to run fault injection campaigns (at least 7,000 program run)

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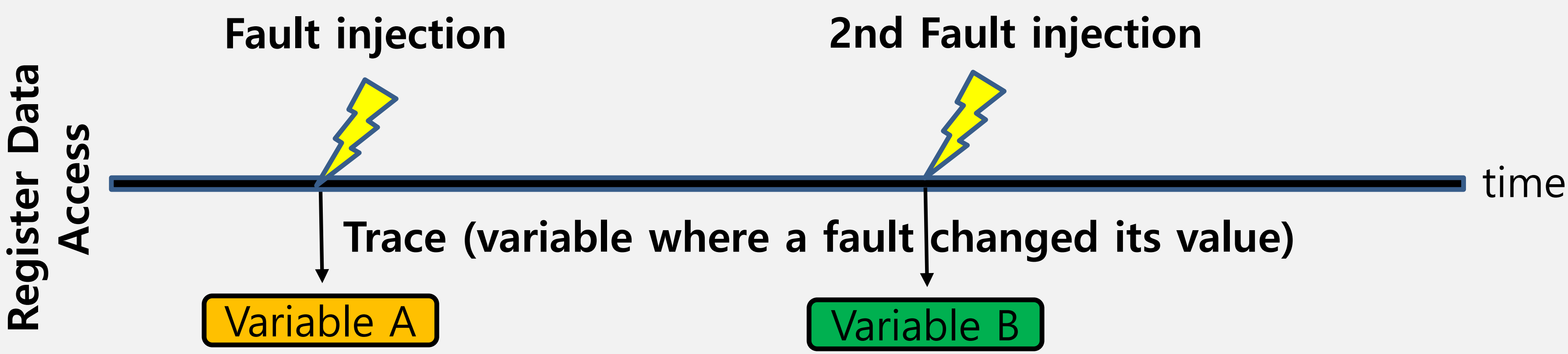
- Motivation
- Related works
- Problem definition
  - Finding critical variable(fault injection) takes a lot of time
- Method Proposal
- Experiments
- Conclusions

Fault Injection takes a lot of time

- Fault Injection method for finding critical variables
  - Fault injection is a good technique for finding critical variables
  - A large number of faults will be injected into the critical variables
  - Protecting critical variable, effective protection method at low cost
  - But, fault injection takes a lot of time



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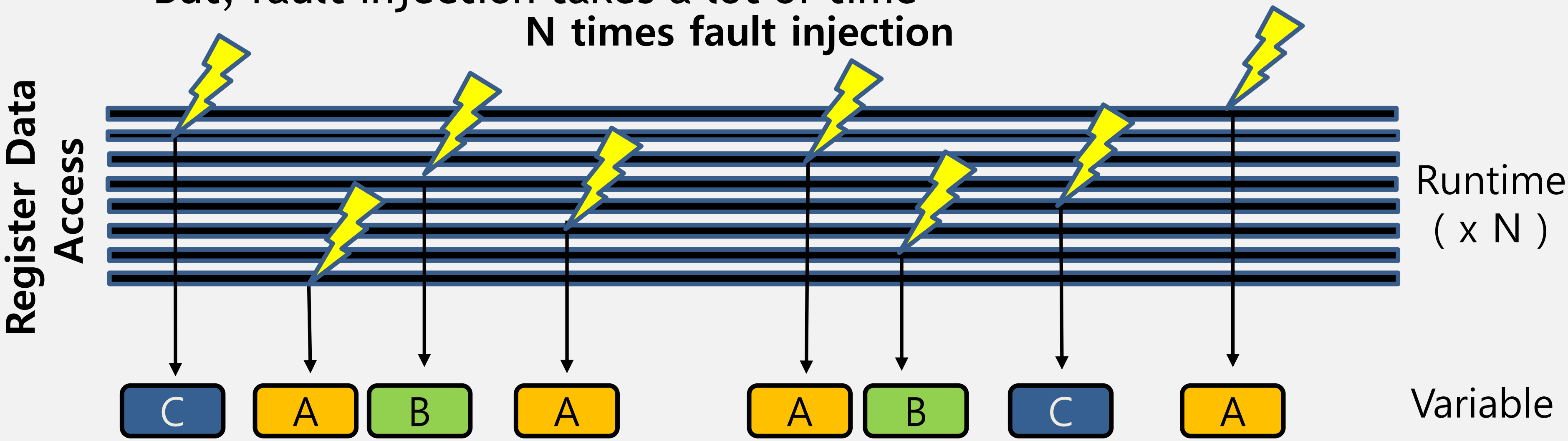


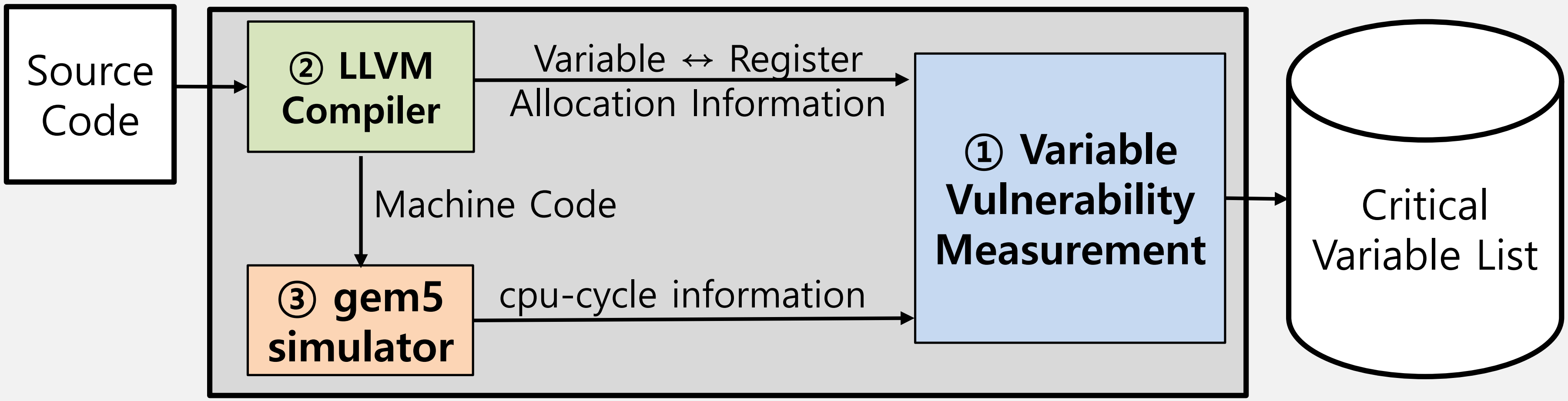
Count of faults = Variable A : 4 Variable B : 3 Variable C : 2

Agenda

- Motivation
- Related works
- Problem definition
- Method Proposal
  - Since fault injection take lots of time, we develop an alternative way to find out the critical variable
  - The framework of variable vulnerability measurement with LLVM compiler and gem5 simulator
- Experiments
- Conclusions

Overview of our proposed technique

- Variable vulnerability method for finding critical variables

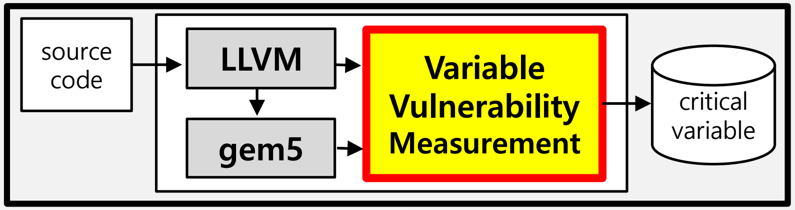


① Measures the vulnerability of variables that can cause an error

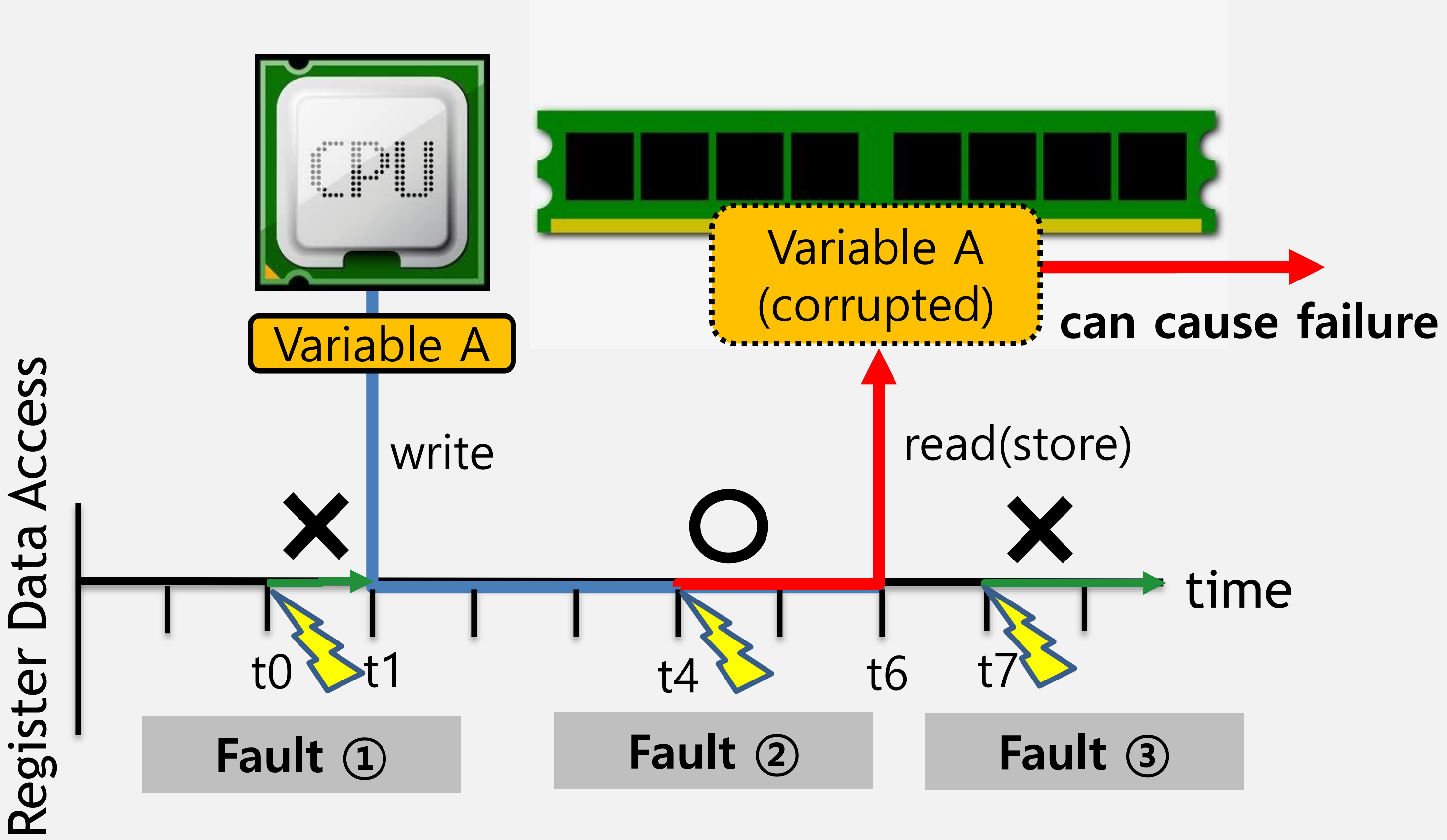
② LLVM maps variables and register

③ gem5 calculates actual CPU-cycle for vulnerability

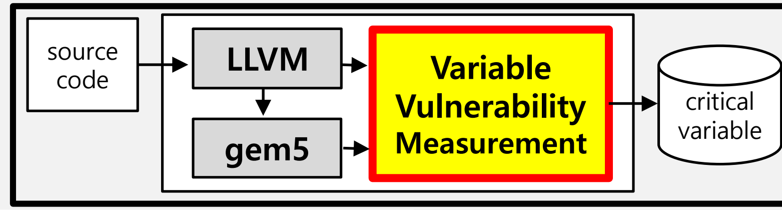
① Varaible Vulnerability Measurement



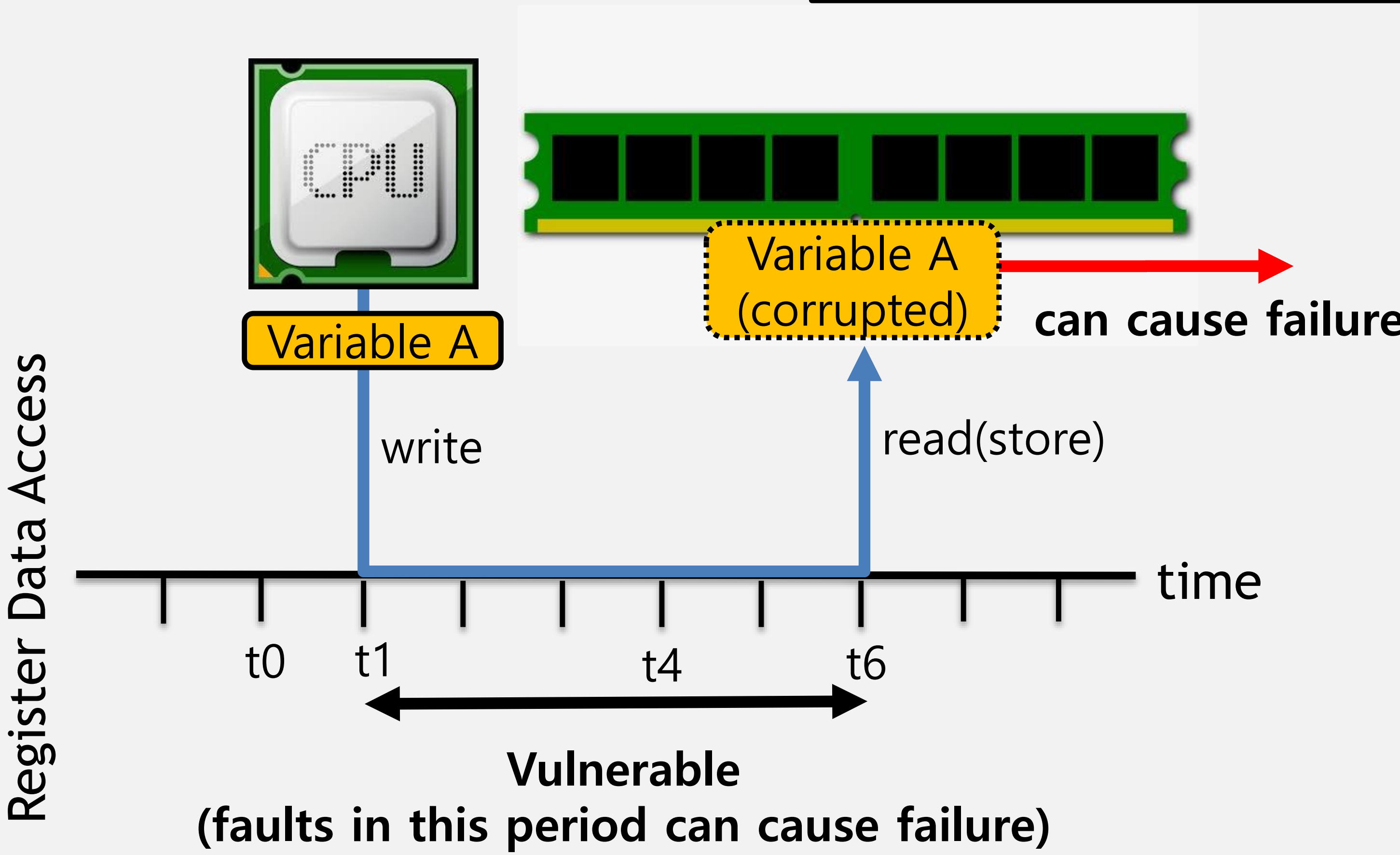
- Fault and Vulnerability



① Varaible Vulnerability Measurement



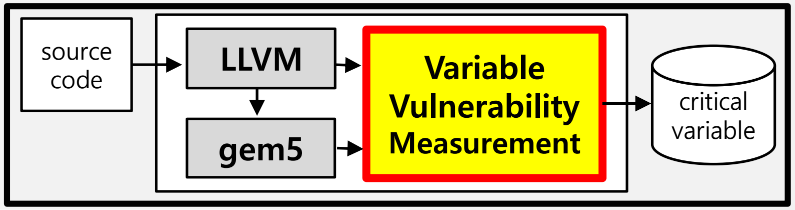
- Vulnerable Period

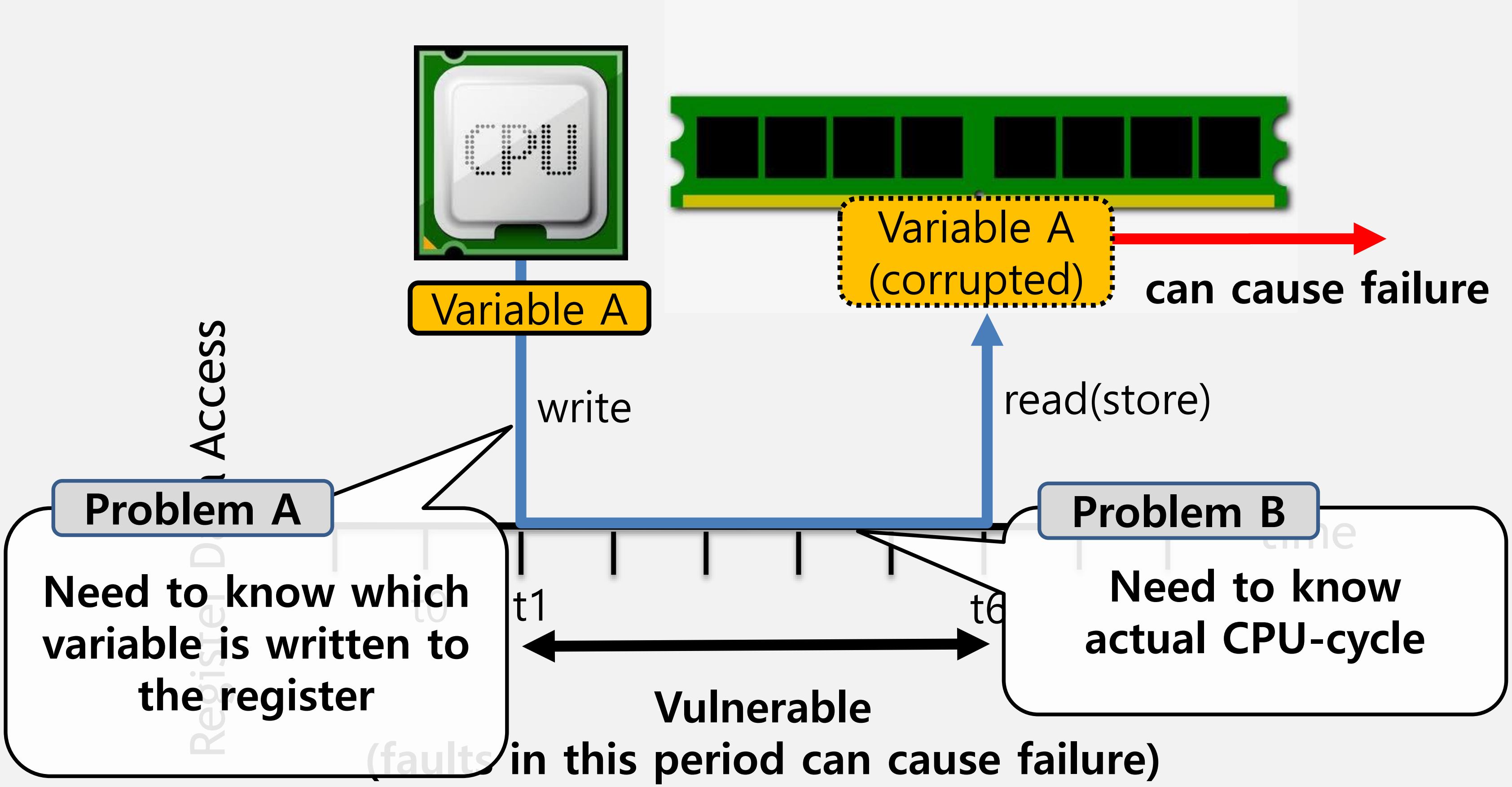


Variable A' Vulnerability = t6 - t1 = 5 time units

① Varaible Vulnerability Measurement

- Requirement for measurement

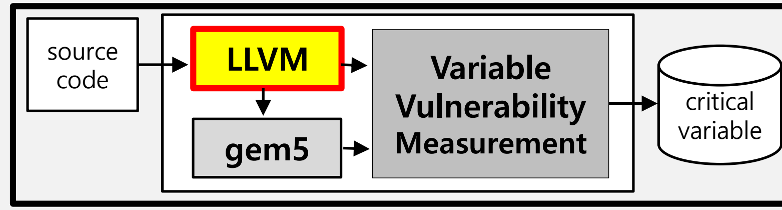




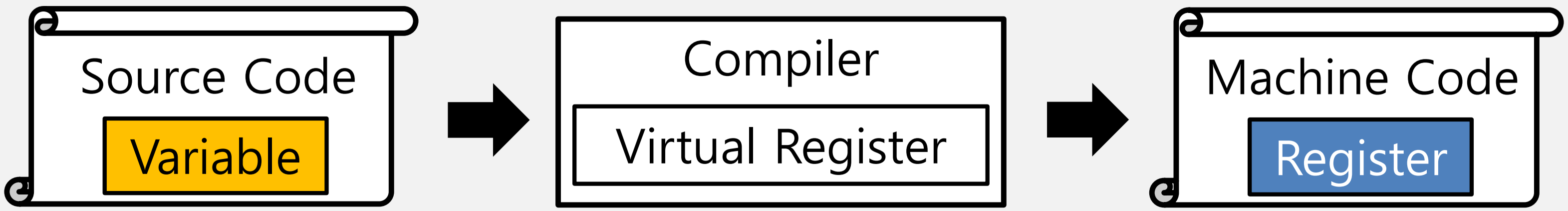
Variable A' Vulnerability = t6 - t1 = 5 time units

② Mapping Register ↔ Variables

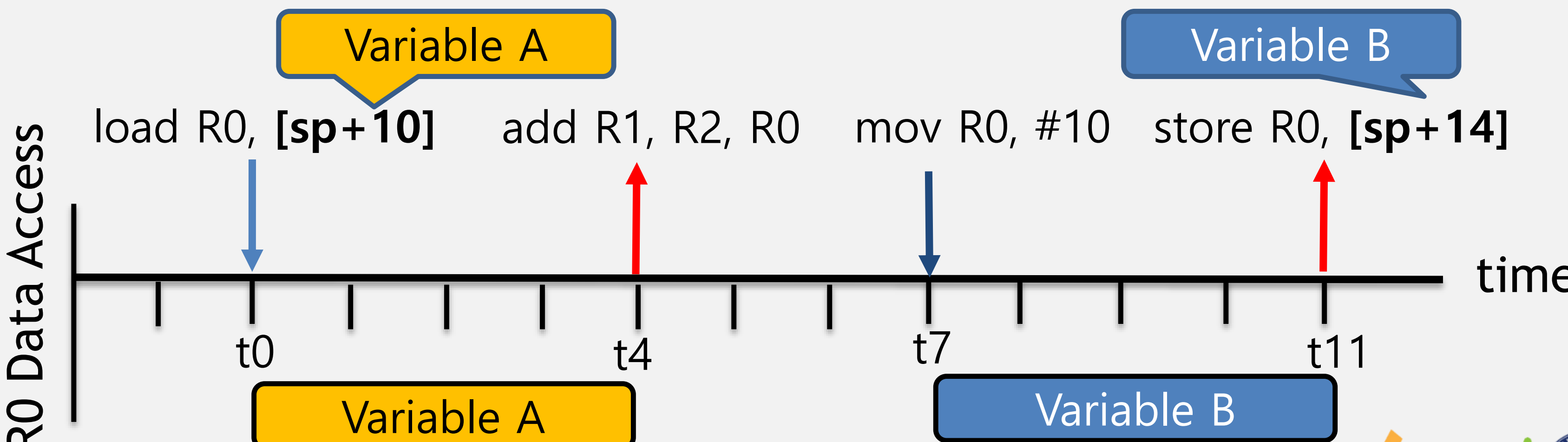
☞ **Answer to problem A**
(Which variable is written to the register)



- Modified LLVM Compiler
  - Variables are assigned to registers during compile

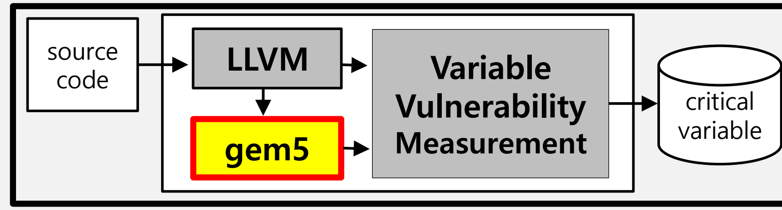


  - Modify compiler to output variable↔register allocation information
  - Machine code with variable name

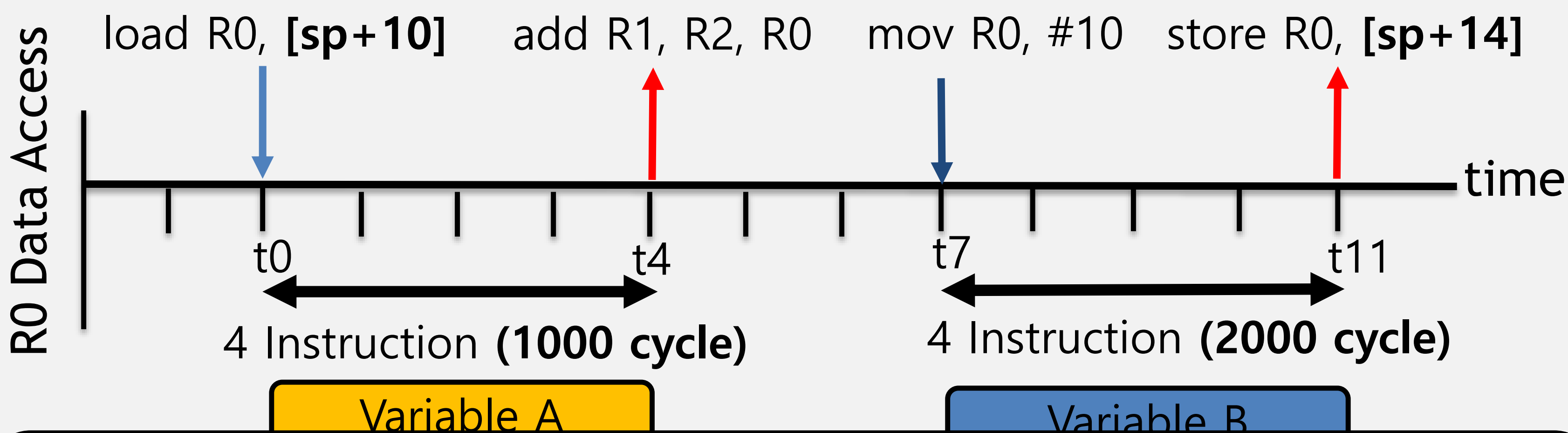


③ Actual vulnerable period cpu-cycle

☞ **Answer to problem B**
(need to know actual CPU-cycle)



- gem5 calculate CPU-cycle
  - Although the number of instructions is the same, the actual vulnerable time may be different



With our framework(vulnerability measurement with LLVM and gem5),
Now we can calculate variable vulnerability clearly

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  - Validate our vulnerability based framework with fault injection campaigns
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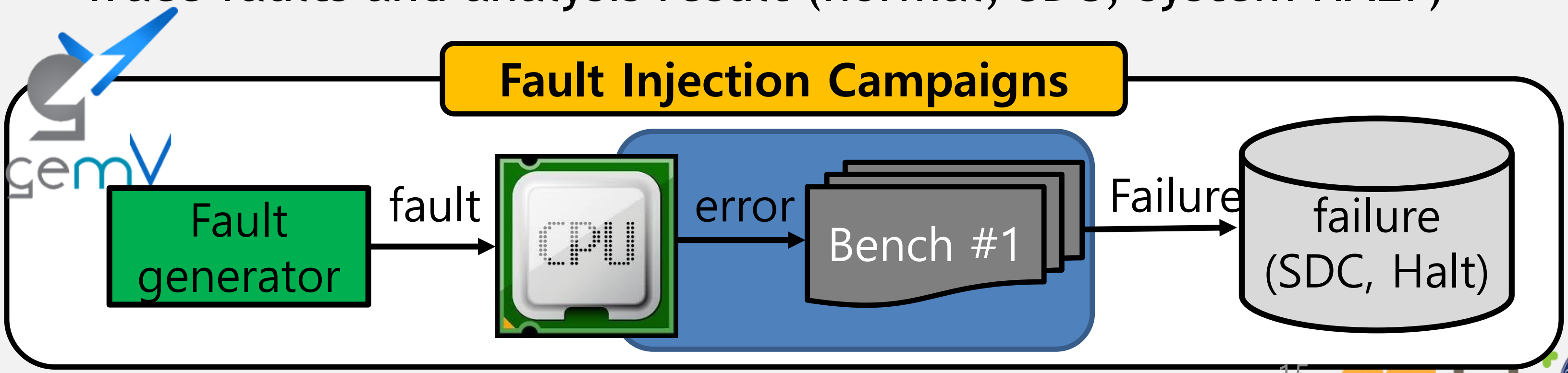
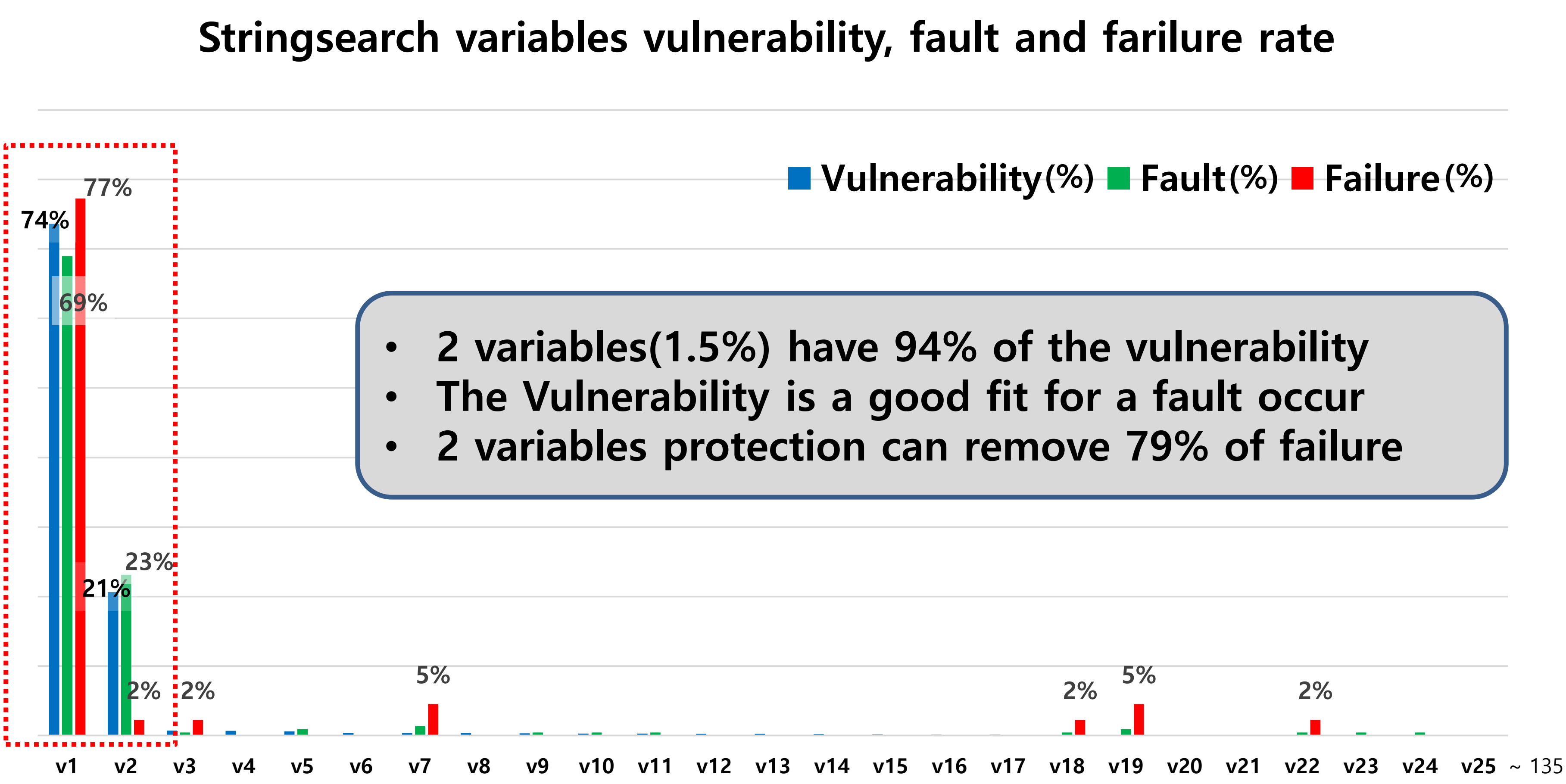
Experiments

- Validation
  - Are variables with high vulnerability be more fault injected?
  - Can assume variable with a high vulnerability is a critical variable?
- Fault injection experiment setup
  - Benchmark : 6 programs (MiBench version 1.0)
  - 4,000 times fault injection for each benchmark
  - gemV toolset is used for fault injection experiment
  - Trace faults and analysis result (normal, SDC, system HALT)

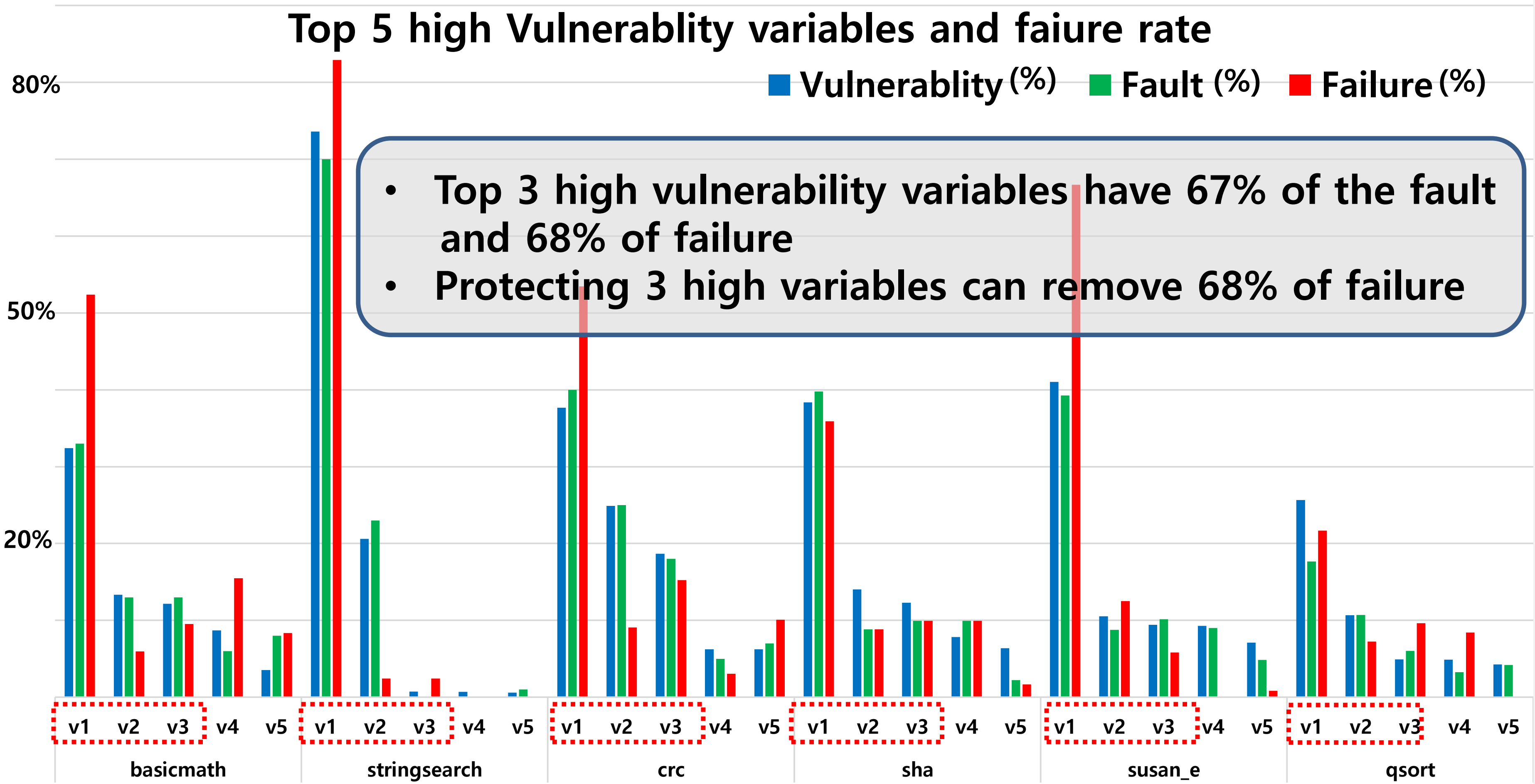


Result : Vulnerablity method fit a fault occur



* Variables are sorted in descending order of vulnerability.

Result : Find critical variable with vulnerablity



- Top 3 high vulnerability variables have 67% of the fault and 68% of failure
- Protecting 3 high variables can remove 68% of failure

* Variables are sorted in descending order of vulnerability.

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Conclusion

- Conclusion
  - Soft error is an important concern
  - H/W and S/W full protection is expensive
  - Need to identify the critical variables for selective protections
    - The higher the variable vulnerability, more faults are injected
  - We propose a framework for critical variable identifications with vulnerability measurement
    - Modeling vulnerability of variable
    - Early estimation of critical variables (without fault injection)
  - In the experiment, only protecting top 3 vulnerable variables, 68% failures can be removed (3 variable are critical variable)
  - Provide protection priority for selective technique

- Future work
  - There is a difference between variable vulnerability and failure (Masking effect : not all faults cause failure)
  - Research to minimize the difference caused by masking effect