Challenging Malicious Inputs with Fault Tolerance Techniques

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Agenda

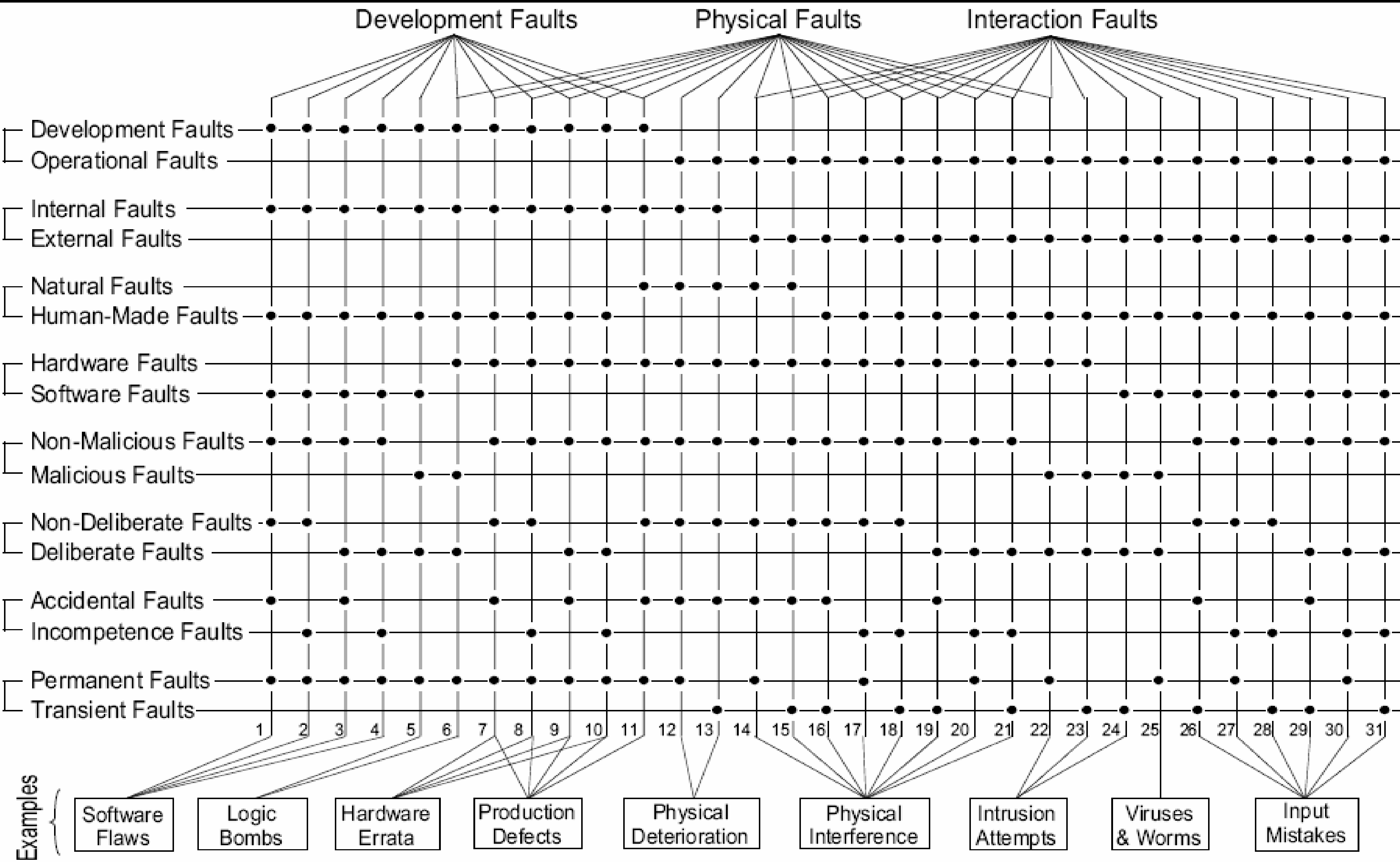
- Threats
- Fault Tolerance
  - Error Detection and Correction
  - Redundancy
  - Robust Software
  - Diversity
- Fault Injection for Fault Tolerance Assessment
- Basic and classic techniques
- Decision Mechanisms
- Implementation Methodology

Threats

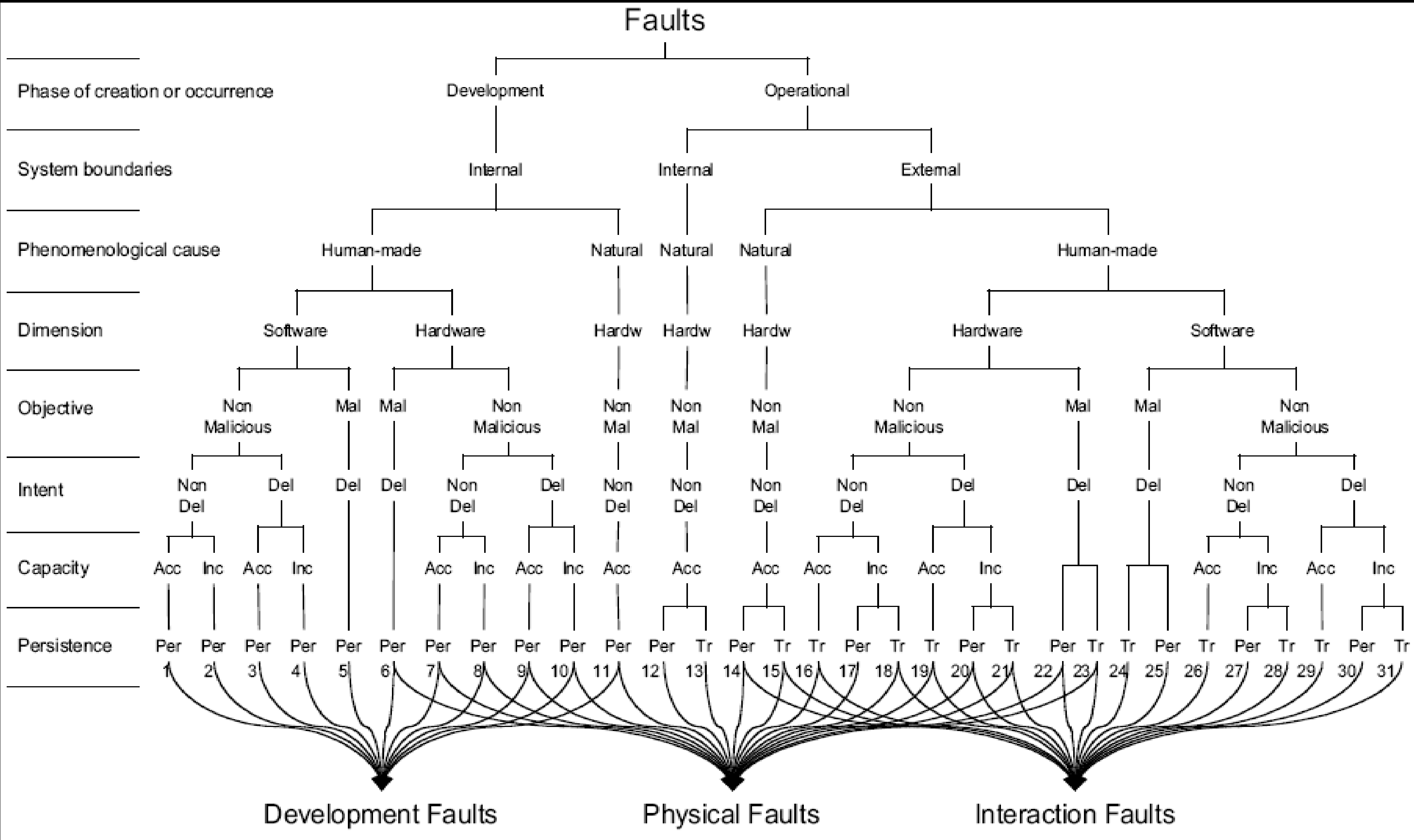
- Fault is the identifed or hypothesized cause of an error
- An error is part of the system state that is liable to lead to a failure
- A failure occurs when the service delivered by the system deviates from the specified service, otherwise termed an incorrect result

→ fault —activation→ error —propagation→ failure —causation→ fault →

The Classes of Faults



Tree Representation of Faults



Mal: Malicious Del: Deliberate Acc: Accidental Inc: Incompetence Per: Permanent Tr: Transient

Objective

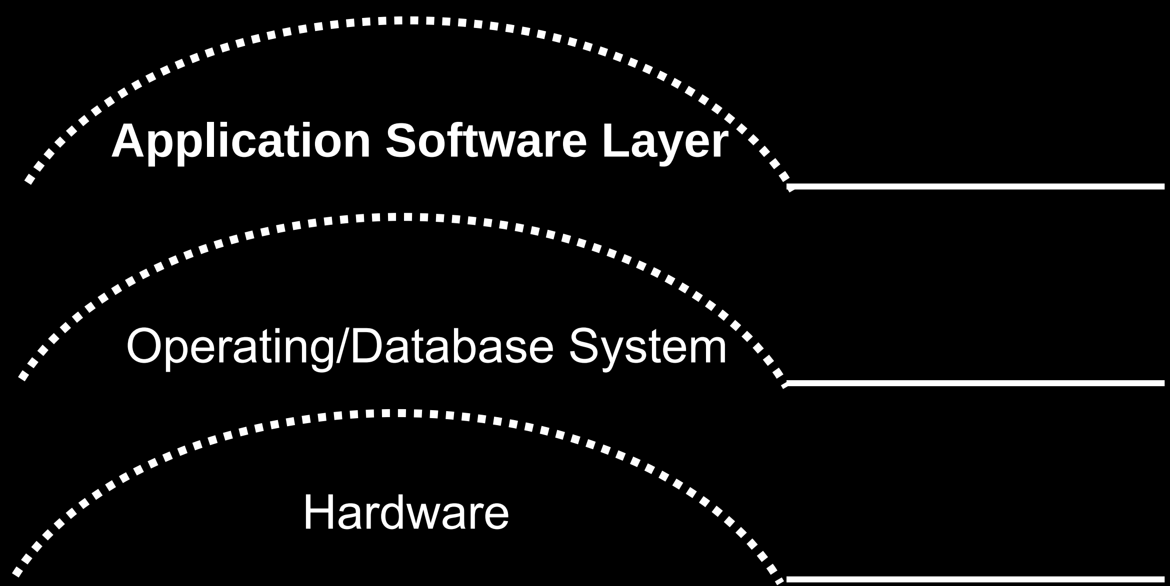
- **Malicious Faults** are introduced during either system development with the intent to cause harm to the system
  - They are grouped into two classes
    - Potentially harmful components
      - Trojan horses
      - Trapdoors
      - Logic or Timing bombs
    - Deliberately introduced software or hardware
      - Vulnerabilities or human-made faults
- **Non-malicious faults** are introduced without malicious objectives

Malicious Logic Faults

- That encompass development faults
  - Logic Bomb
  - Trojan horse
  - Trapdoor
  - Virus
  - Worm
  - Zombie

Intrusion Attempts

- Malicious Inputs
  - To disrupt or halt service
  - To access confidential information
  - To improperly modify the system



Vulnerabilities

- Development or operational faults
- Common feature of interaction faults
- Malicious or non-malicious faults
- Can be external fault that exploit them

Fault Tolerance

"The goal of fault tolerance methods is to include safety features in the software design or Source Code to ensure that the software will respond correctly to input data errors and prevent output and control errors"

Software faults are what we commonly call "bugs"

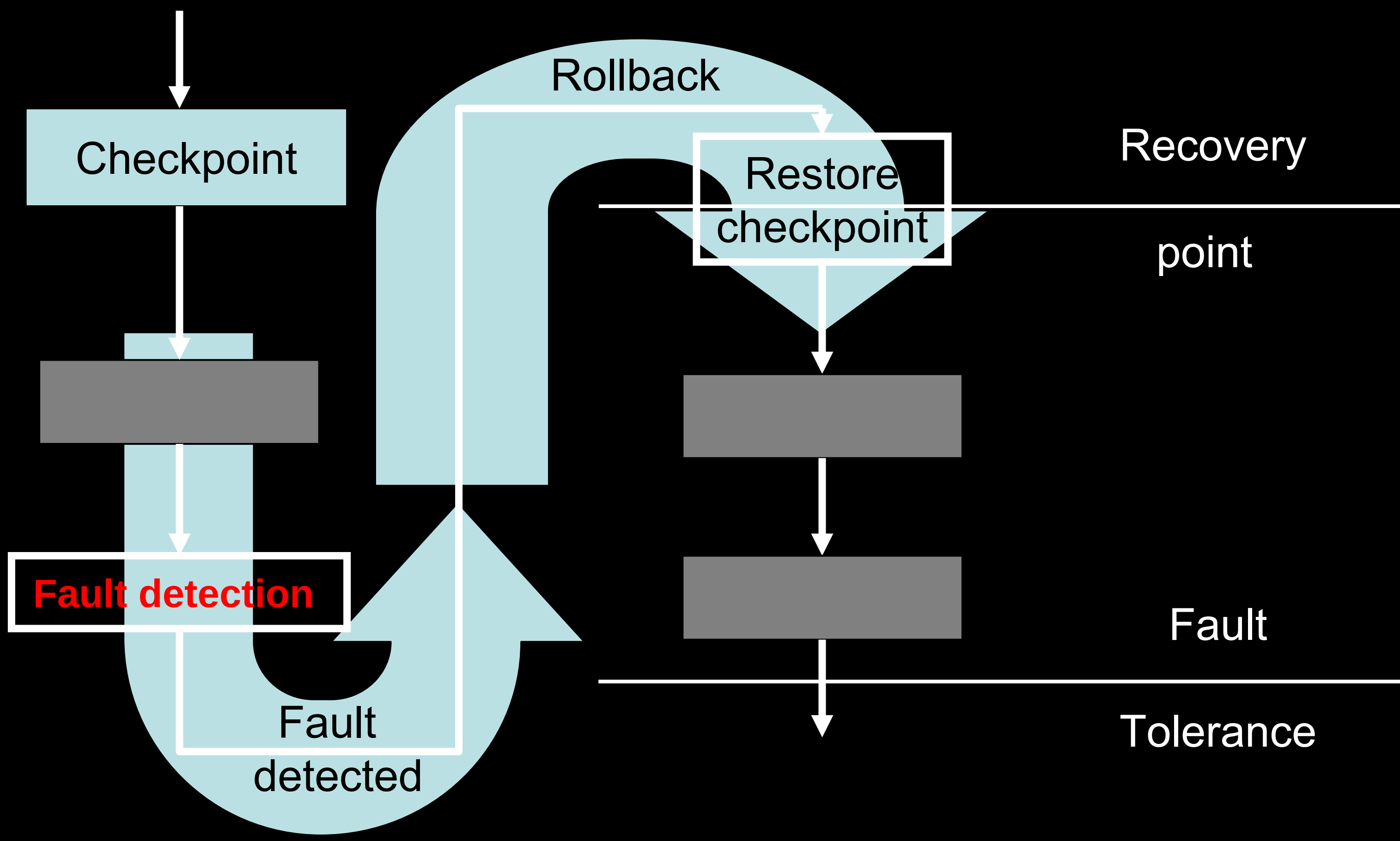
Fault Tolerance

- A characteristic of the software fault tolerance techniques is that they can, in principle, be applied at any level in a software system
  - Procedure
  - Process
  - Full application program
  - The whole system including the operating system
- These technologies are indeed economical and effective means to increase the level of fault tolerance in application software.
  - Watchd
  - libft
  - REPL

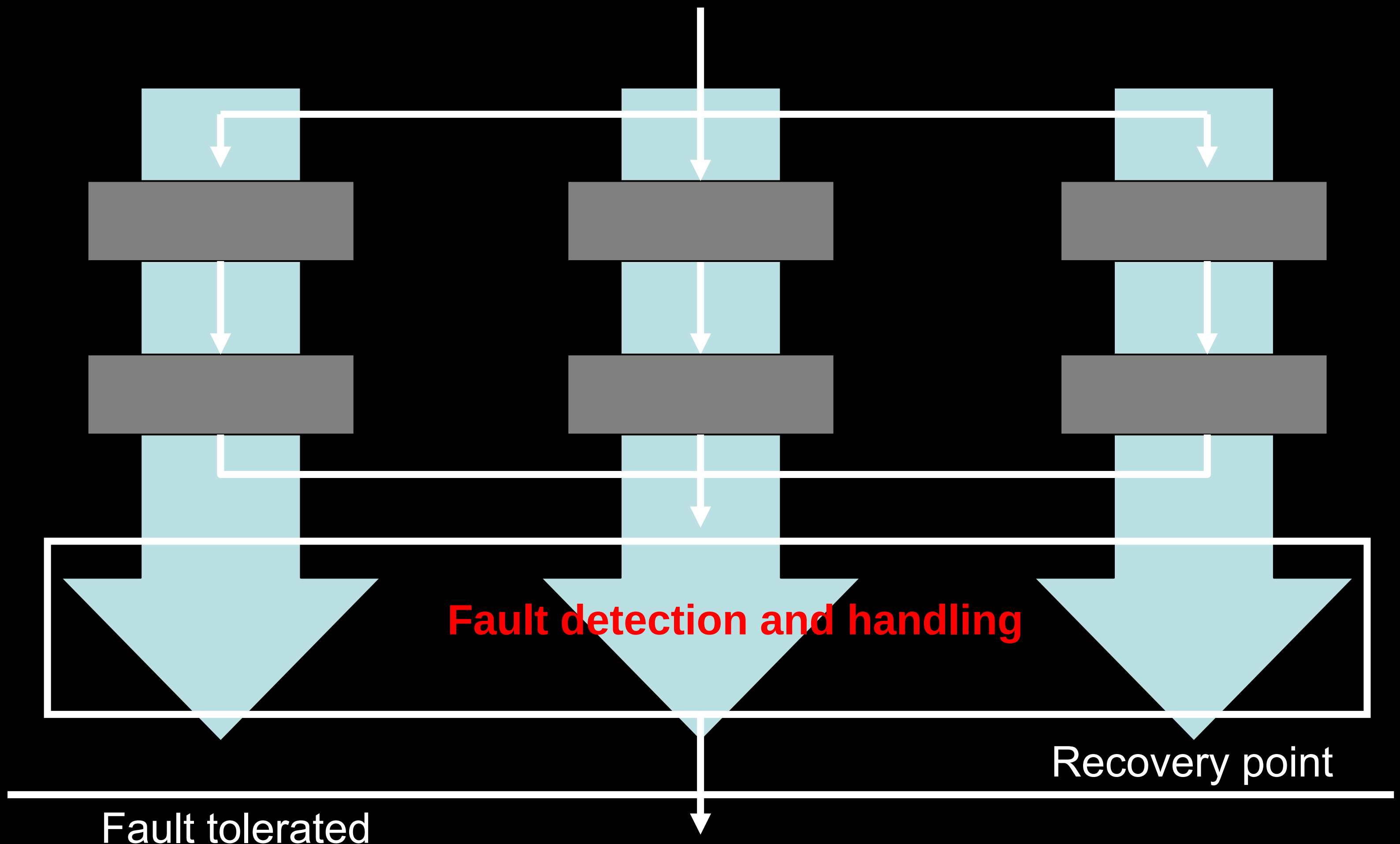
Error Detection and Correction

- Verification tests capable of detection of the errors
  - Replication
  - Temporal
  - Consistency
  - Diagnosis
- Once the error has been detected, the next step will be your elimination
  - Backward Recovery
  - Forward Recovery

Backward Recovery



Forward Recovery



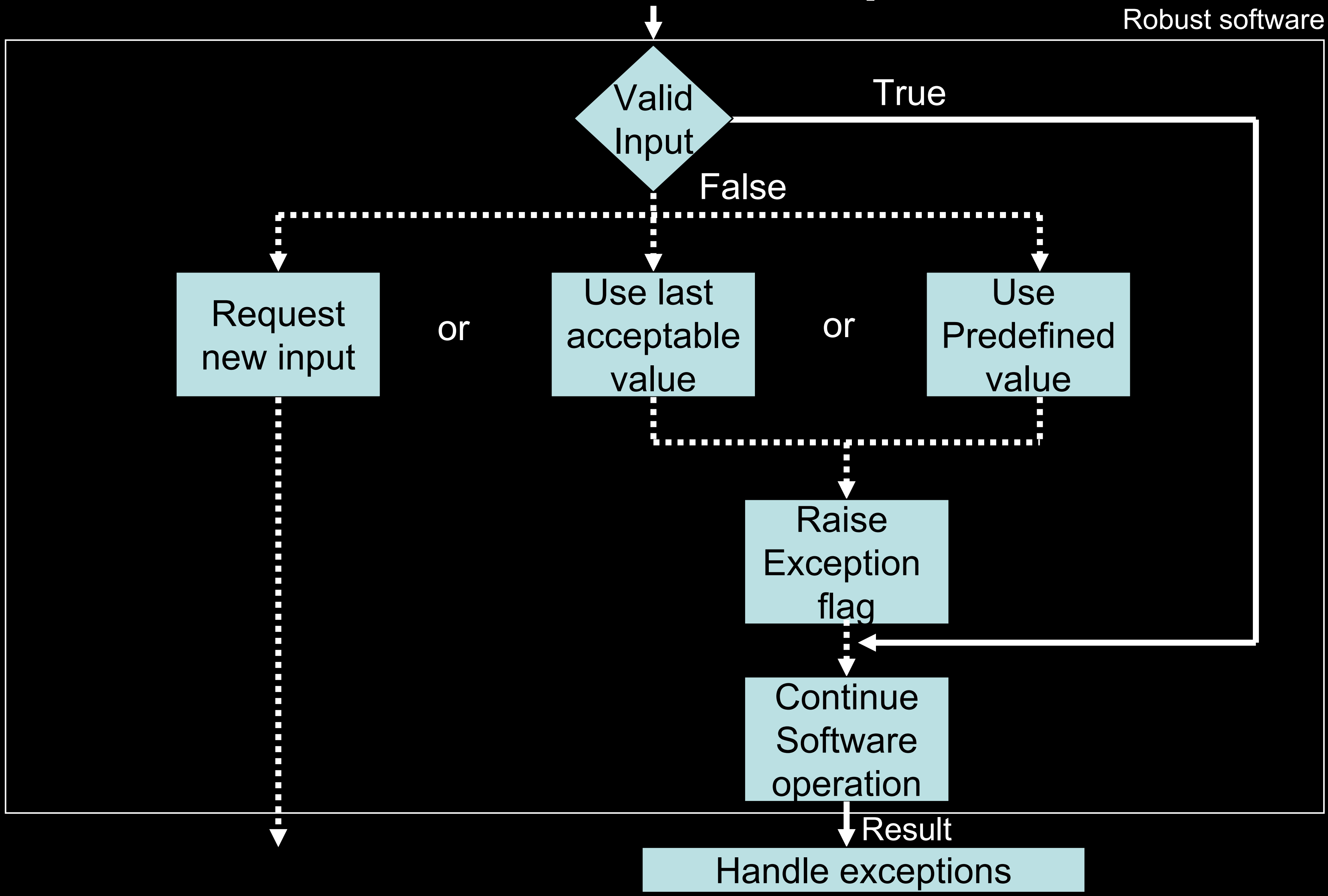
Redundancy

- Redundancy provides the additional capabilities and resources needed to detect and tolerate faults
- Types of Redundancy for Software Fault Tolerance
  - Software Redundancy
  - Information or Data Redundancy
  - Temporal Redundancy
- The selection of which type of redundancy to use is dependent on the application's requirements, its available resources, and available techniques

Robust Software

- The software property is defined as “the extent to which software can continue to operate correctly despite the introduction of invalid inputs”
  - Out of range inputs
  - Inputs of the wrong type
  - Inputs in the wrong format
- Self-checking software features
  - Testing the input data
  - Testing the control sequences
  - Testing the function of the process

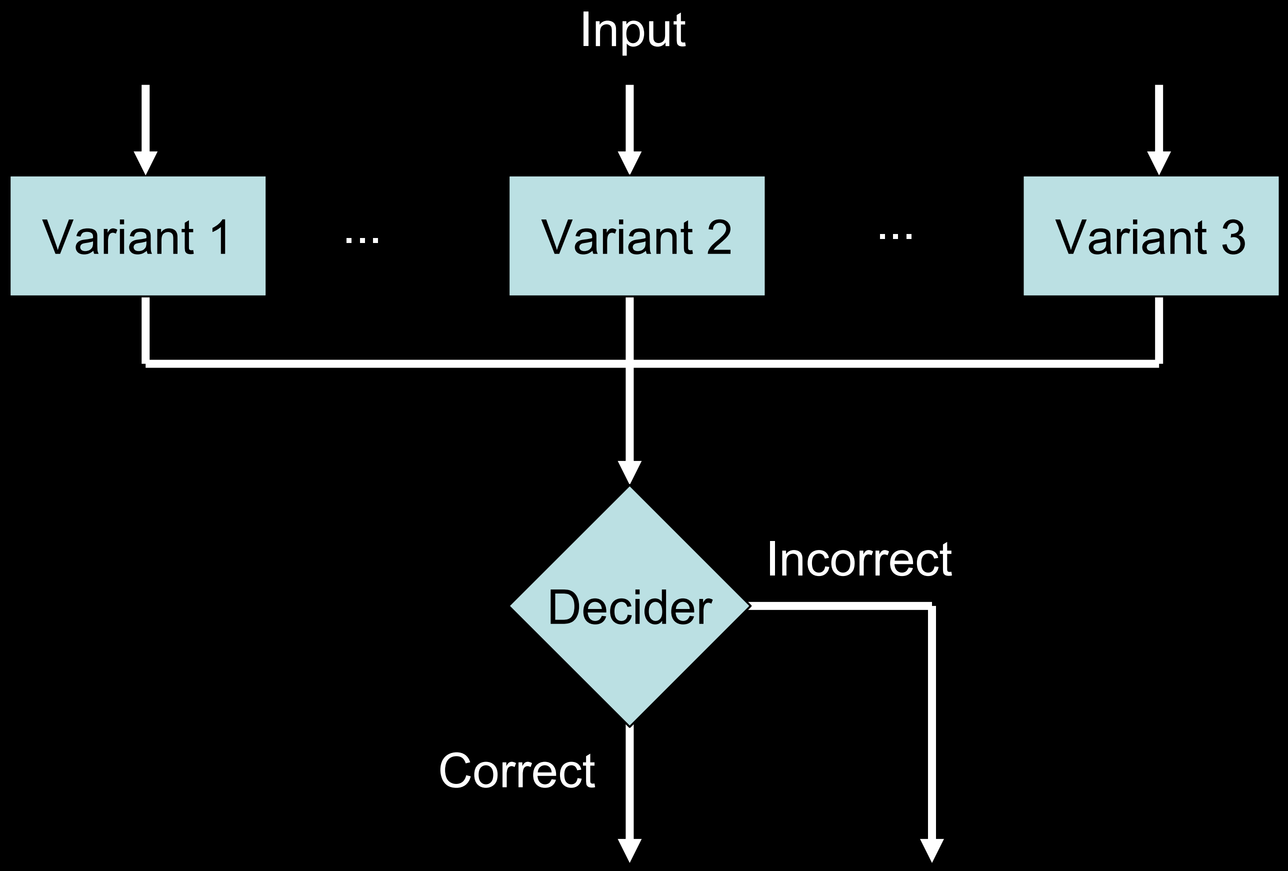
Robust software operation



Diversity

- Since redundancy alone is not sufficient to help detect and tolerate software design faults, some type of diversity must be present
- This diversity can be applied at several levels and in several forms
- Forms of diversity
  - Design diversity
  - Data diversity
  - Temporal diversity

Basic Design Diversity

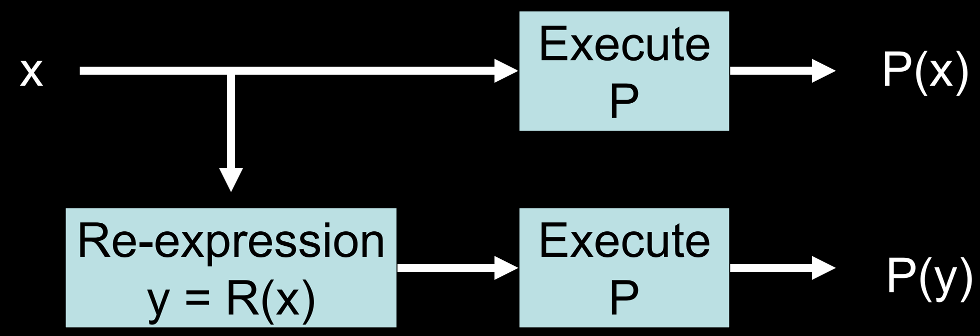


Data Diversity

- Is based on the provision of different input data to the program to avoid anomalous areas in the input data space that cause faults
- Use data re-expression algorithms (DRAs) to obtain their input data
- The performance of data diverse software tolerance techniques depends on the performance of the re-expression algorithm used
  - Input Data Re-Expression
  - Input Re-Expression with Post-Execution Adjustment
  - Re-Expression via Decomposition and Recombination

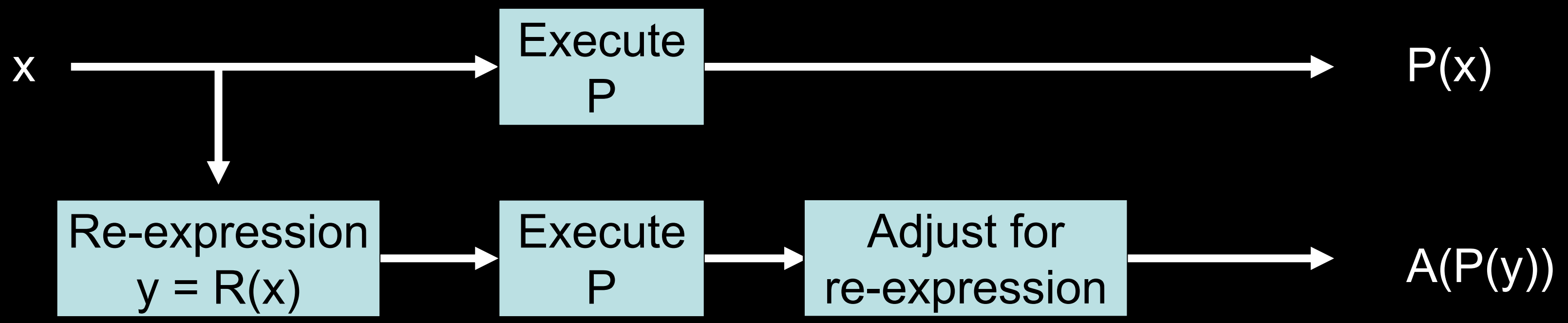
Overview of Data Re-Expression

- A re-expression algorithm, R, transforms the original input x to produce the new input, y = R(x)
- The input y may either approximate x or contain x's information in a different form



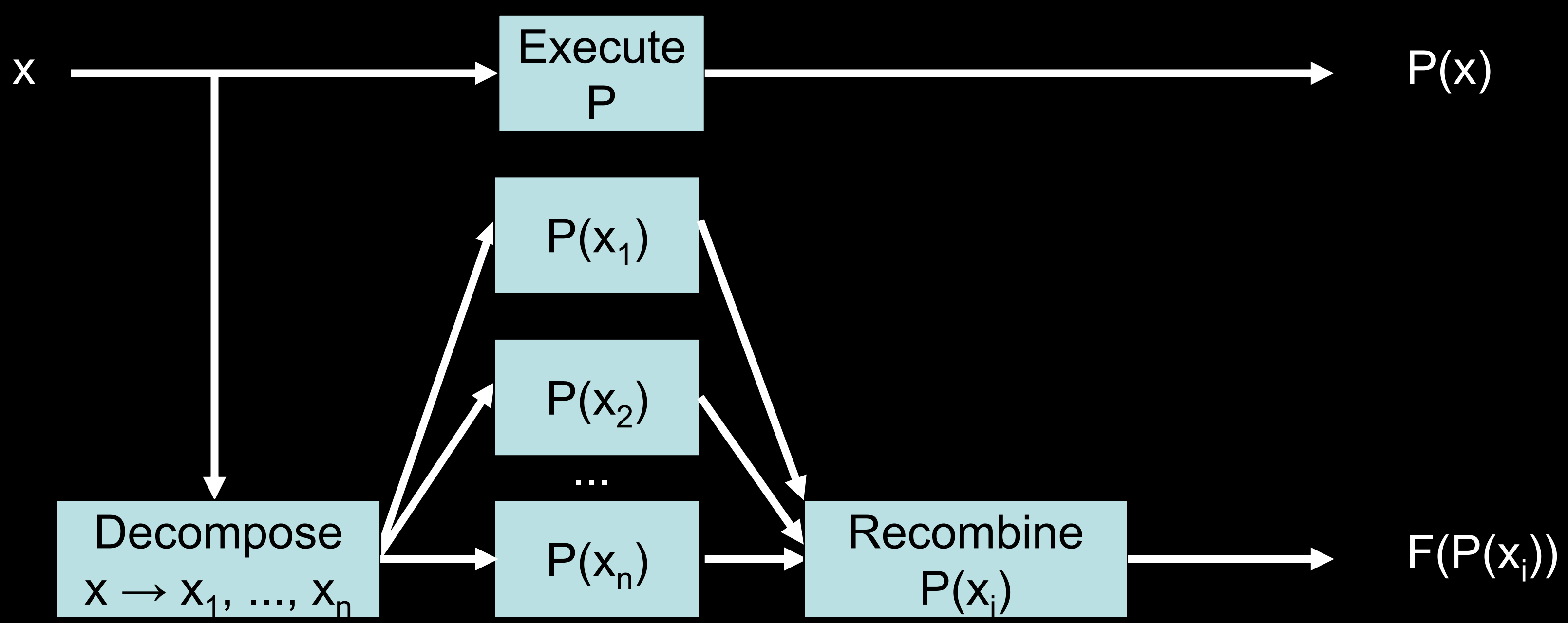
Data Re-Expression With Postexecution Adjustment

- A correction, A, is performed on P(y) to undo the distortion produced by the re-expression algorithm, R
- This approach allows major changes to the inputs



Data Re-Expression via Decomposition and Recombination

- An input x is decomposed into a related set of inputs
- Results are then recombined



Fault Injection for Fault Tolerance Assessment

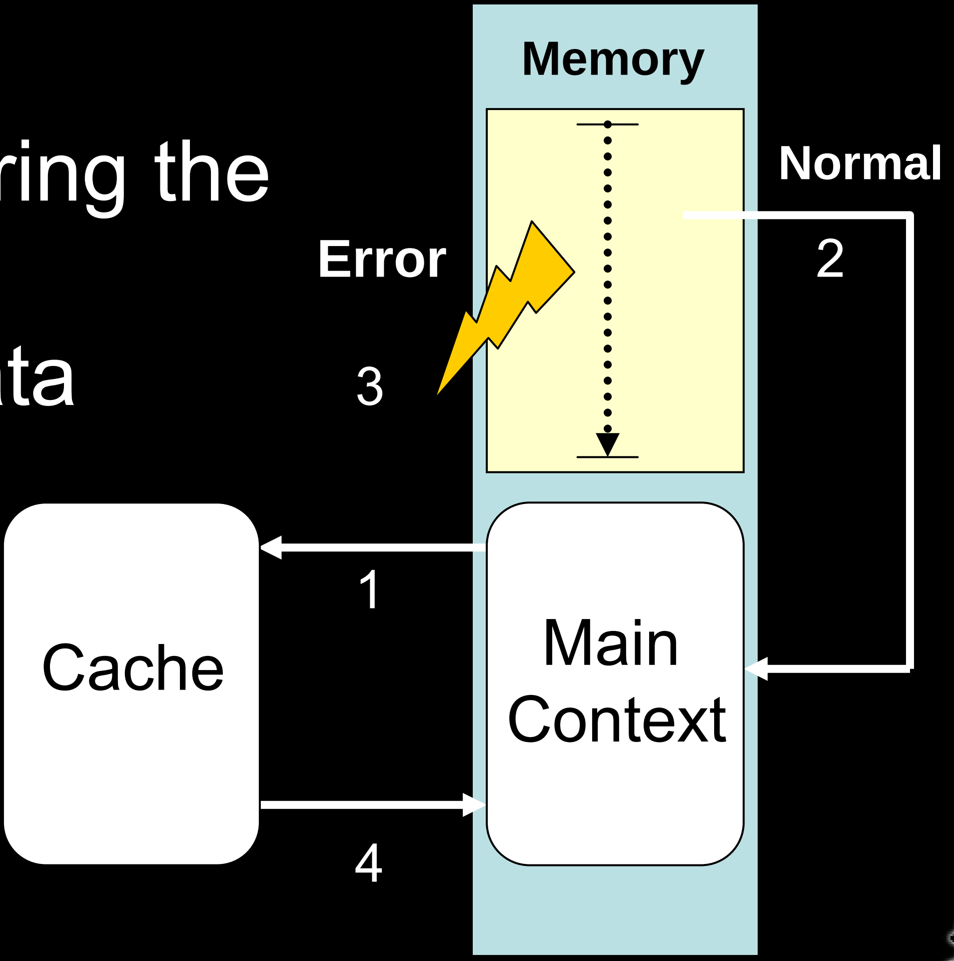
- Injecting Faults enables a performance estimate for the fault tolerance mechanisms
  - Fuzzing
    - Latency (the time from fault occurrence to error manifestation at the observation point)
  - Exploit vulnerability
    - Coverage (faults handled properly)

Fault Injection for Fault Tolerance Assessment

- Advantages of Fault Injection using fuzzing
  - Accelerating the failure rate
  - Able to better understand the behavior of that mechanism
    - Error propagation
    - Output response characteristics

Fault Injection for Fault Tolerance Assessment

- Advantages of Fault Injection using exploration
  - Saving and restoring the execution context
  - Integrity of the data during execution
  - Test backward recovery



Programming Techniques

- Assertions
- Checkpointing
- Atomic actions

Assertions

- Are a fairly common means of program validation and error detection
- In essence, they check whether a current program state to determine if it is corrupt by testing for out-of-range variable values
- Simplest form

```
if not assertion then action
```

Assertions

- Several modern programming languages include an assertion statement
- When an error does occur it is detected immediately and directly, rather than later through its often obscure side-effects

```
int *ptr = malloc(sizeof(int) * 10);
assert(ptr != NULL);
// use ptr
```

Assertions

- Simplify debugging
- Checked at runtime

```
int total = countNumberOfUsers();
if (total % 2 == 0)
{
      // total is even
} else
{
      // total is odd
      assert(total % 2 == 1);
}
```

Checkpointing

- Is used in error recovery, which we recall restores a previously saved state of the system when a failure is detected
- Saves a complete copy of the state when a recovery point is established
- The information saved by checkpoints includes
  - Values of variables in the process
  - Environment
  - Control information
  - Register values

Checkpointing

- Complex mechanism of restoring the stack and register state of the checkpointed process
- Save the state of data in memory, the processor context (register and instruction pointer) and the stack
    - User-level
    - Kernel-level

Checkpointing

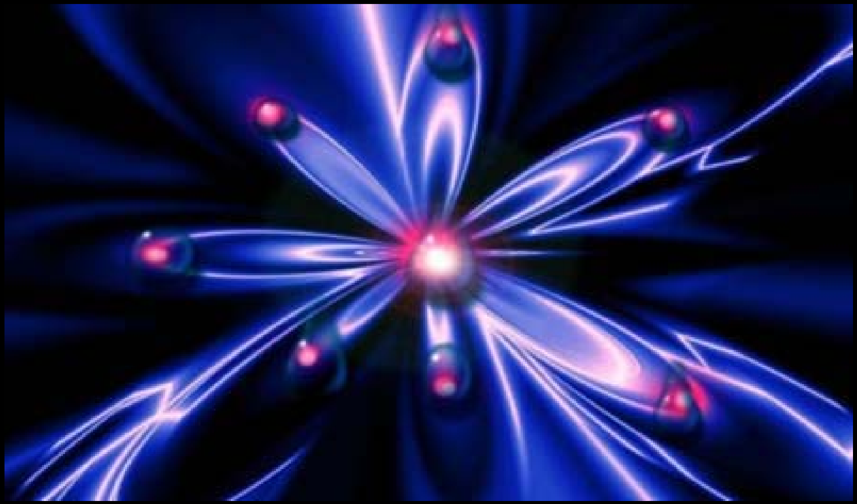
- Methods
  - Internal
    - Only be used by the process being checkpointed
    - Insert some code into the process to be checkpointed
  - External
    - May be used by any process
    - Examine the information published by the kernel through the /proc

Checkpointing

- Types
  - Static
    - Gathering kernel state information
    - Information can be acquired more or less directly from the kernel
  - Dynamic
    - Track all operations by a process
    - Replace C library functions with wrappers
- Existing systems
  - libckpt
  - condor
  - hector
  - icee
  - EPCKPT
  - CHPOX

Atomic Actions

- Are used for error recovery
- An atomic action is an action that is
  - Indivisible
  - Serializable
  - Recoverable



Basic and Classic Techniques

- Recovery Blocks
- N-Version Programming
- Retry Blocks
- N-Copy Programming

Recovery Blocks

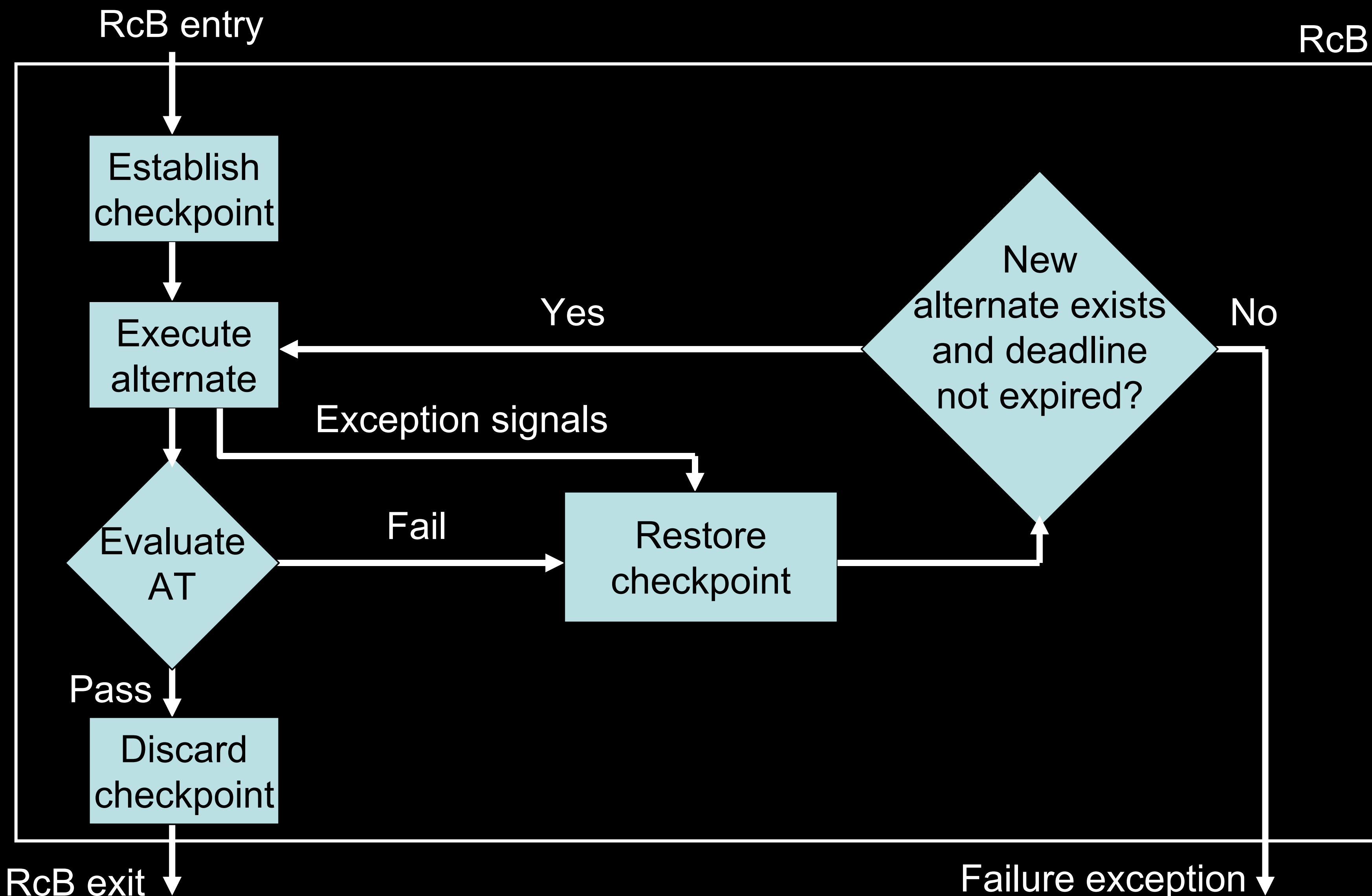
- Dynamic technique
- Uses an AT and backward recovery
- RcB scheme
  - Executive
  - Acceptance test
  - Primary and alternate blocks (variants)
  - Watchdog timer (WDT)

Recovery Block Operation

- General Syntax

```
ensure                        Acceptace Test
by                            Primary Alternate
else by                       Alternate 2
else by                       Alternate 3
...
else by                       Alternate n
else failure exception
```

Recovery Block Operation



N-Version Programming

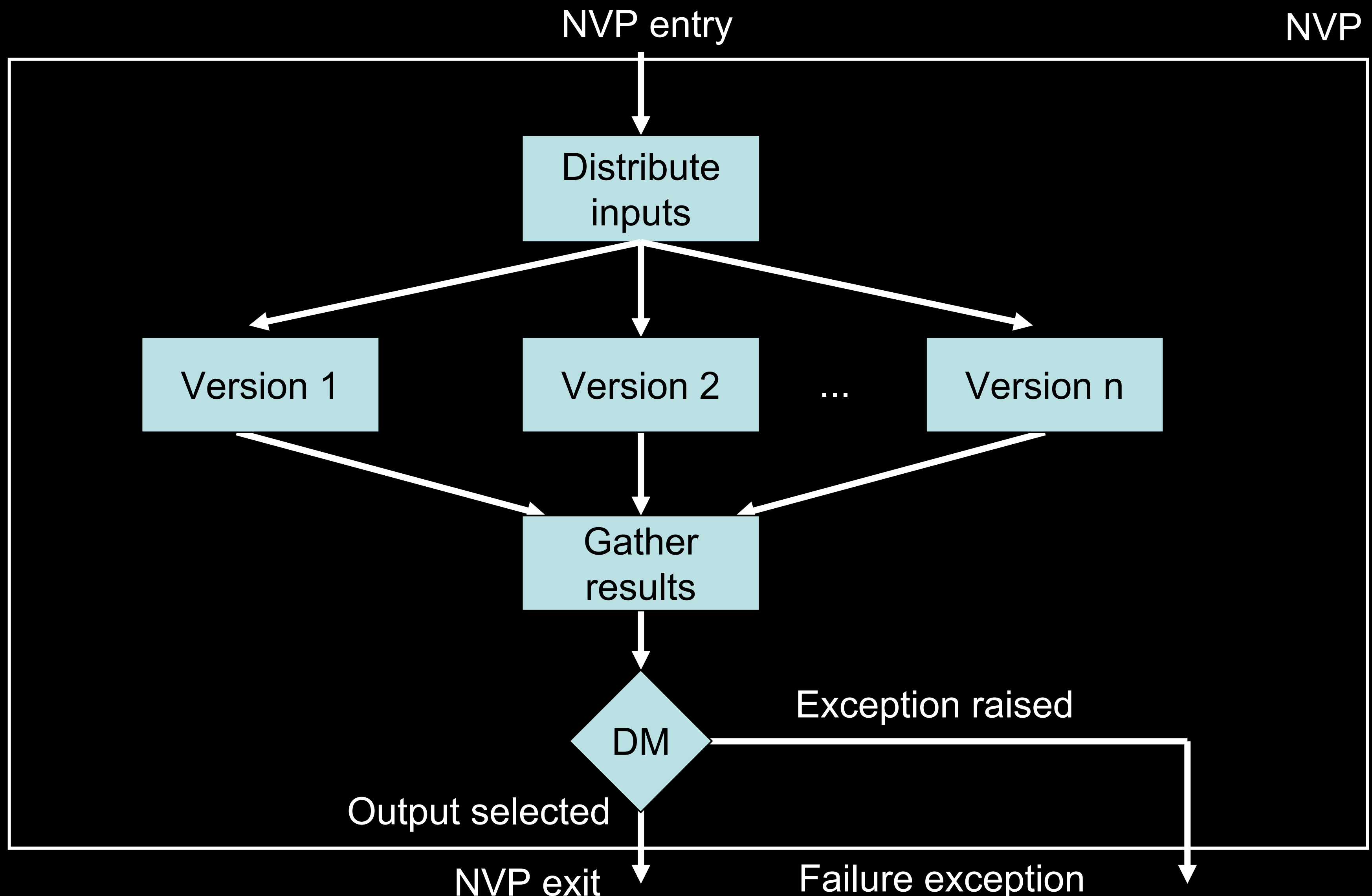
- Static technique
- Use a decision mechanism (DM) and forward recovery
- NVP technique consists
  - Executive
  - n variants
  - DM

N-Version Programming Operation

- General Syntax

```
Run Version 1, Version 2, ..., Version n
if (Decision Mechanism (Result 1, Result 2, ..., Result n))
   return Result
else failure exception
```

N-Version Programming Operation



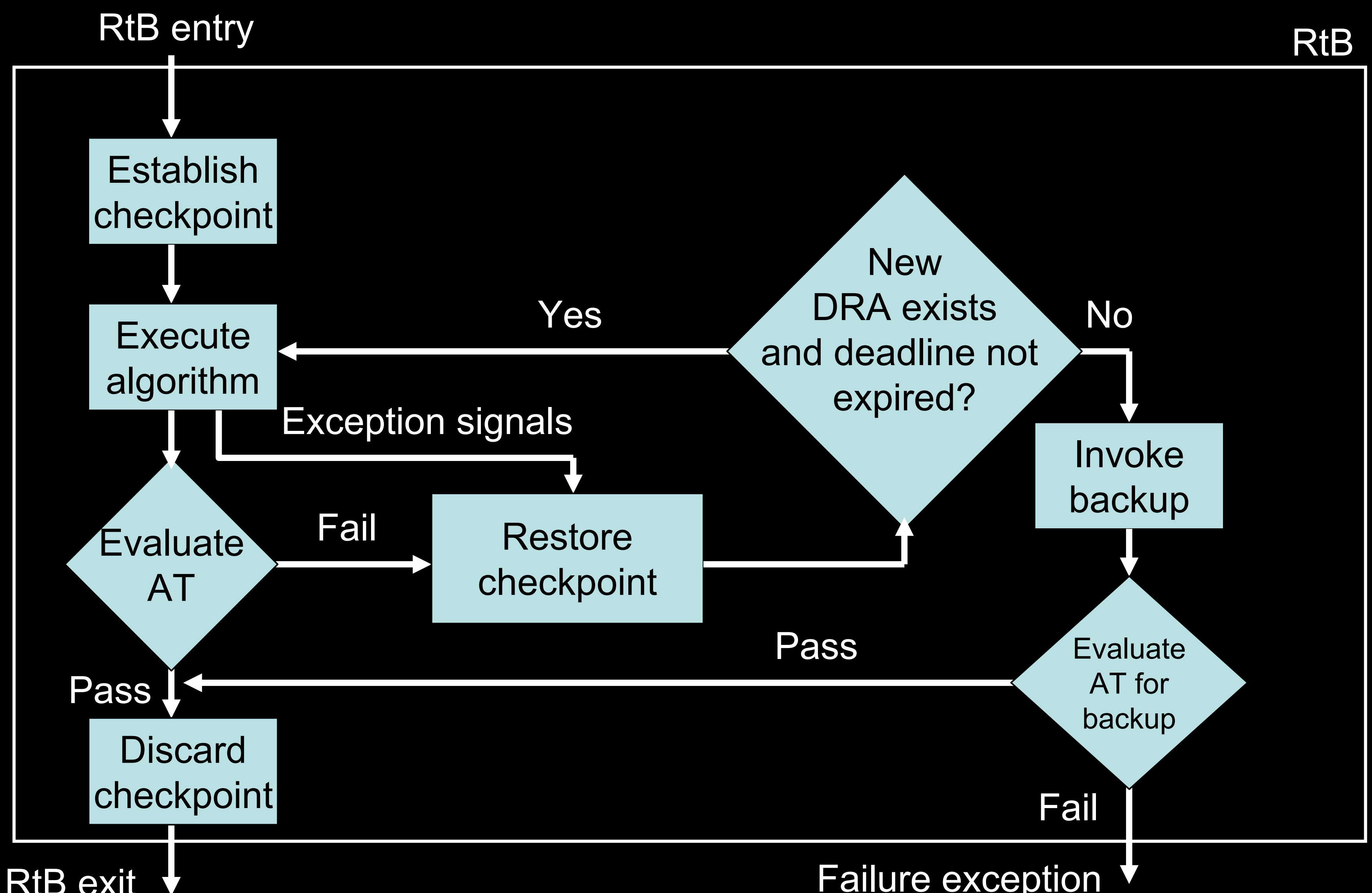
Retry Blocks

- RtB technique is the data diverse complement of the recovery block (RcB) scheme
- RtB technique consists
  - Executive
  - AT
  - DRA
  - WDT
  - Primary and backup algorithms

Retry Block Operation

```
Ensure                  Acceptace Test
by                      Primary Algorithm(Original Input)
else by                 Primary Algorithm(Re-expressed Input)
else by                 Primary Algorithm(Re-expressed Input)
...
...                     [Deadline Expires]
else by                 Backup Algorithm(Original Input)
else failure exception
```

Retry Block Operation



N-Copy Programming

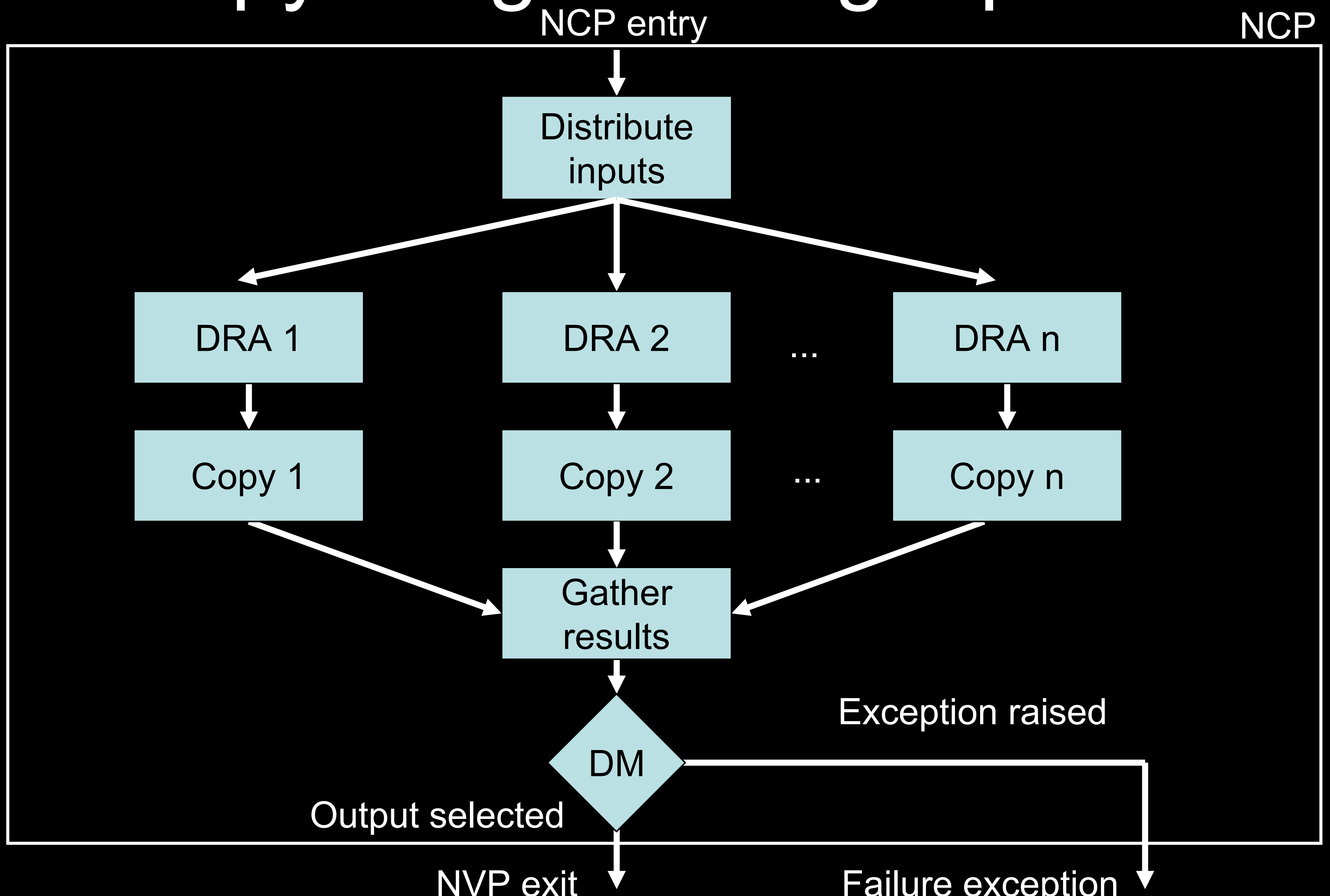
- NCP is the data diverse complement of N-version programming (NVP)
- Copies execute in parallel using the re-expressed data as input
- NCP technique consists
  - Executive
  - 1 to n DRA
  - n copies of the program or function
  - DM

N-Copy Programming Operation

- General Syntax

```
run DRA 1, DRA 2, ..., DRA n
Run Copy 1(result of DRA 1),
    Copy 2(result of DRA 2), ...,
    Copy n(result of DRA n)
if (Decision Mechanism (Result 1, Result 2, ...,
                        Result n))
    return Result
else failure exception
```

N-Copy Programming Operation



Decision Mechanisms

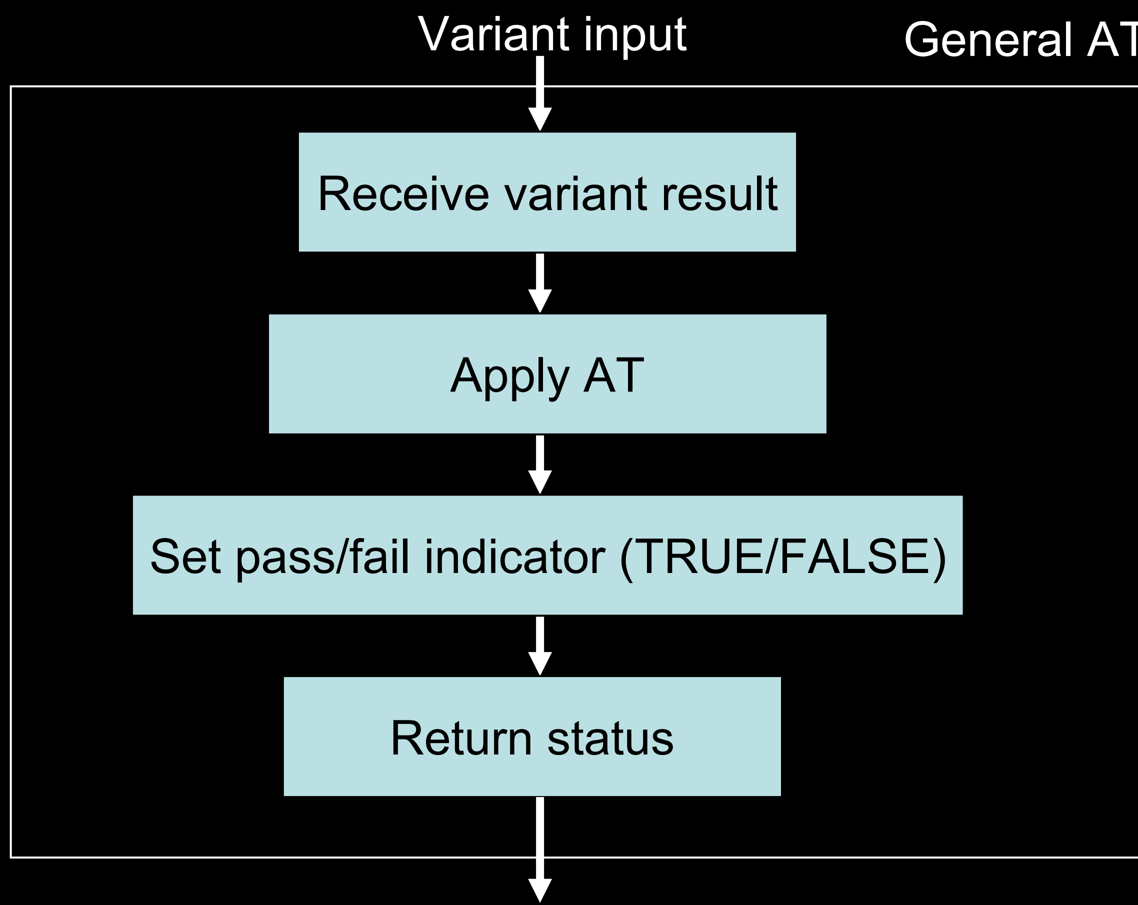
- Adjudicators determine if a “correct” result is produced by a technique
- Adjudicator would run its decision-making algorithm on the result
- Adjudicators generally come in two flavors
  - Voters
  - ATs

Adjudicator

- Acceptance Tests (ATs)
  - Reasonableness tests
  - Computer run-time tests

Acceptance Tests

- Basic approach to self-checking software



Reasonableness Tests

- Determine if the state of an object in the system is reasonable
  - Precomputed ranges
  - Expected sequences of program states
  - Other expected relationships

Range Bounds AT

- General Syntax

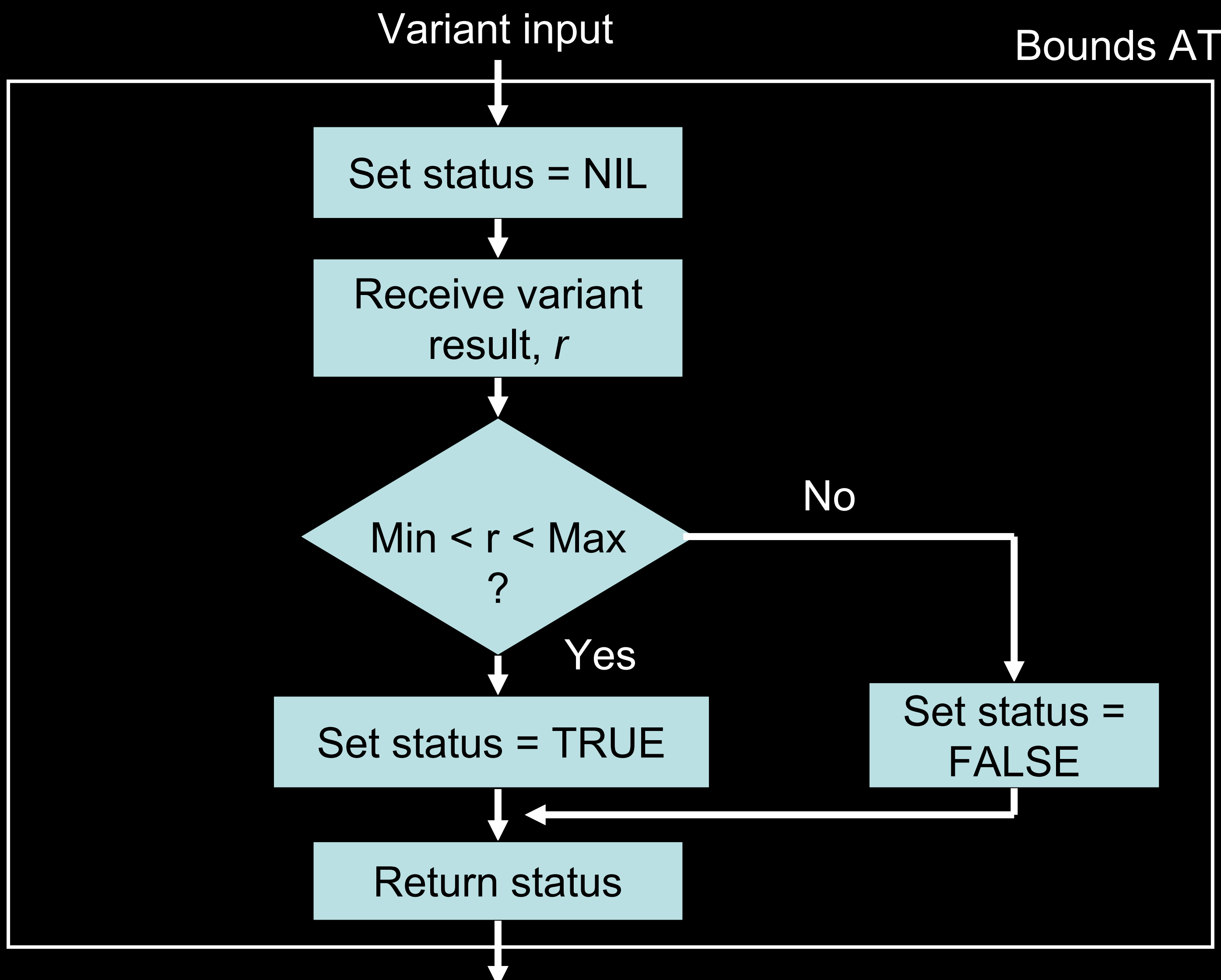
```
BoundsAT (input, Min, Max, Status)

Set Status = NIL
Receive algorithm result (input)
Retrieve bounds (Min < and < Max)

if input is whitin bounds (i.e., Min < input < Max)
then Set Status = TRUE
else Set Status = FALSE (Exception)
End

Return Status
```

Range Bounds AT Operation



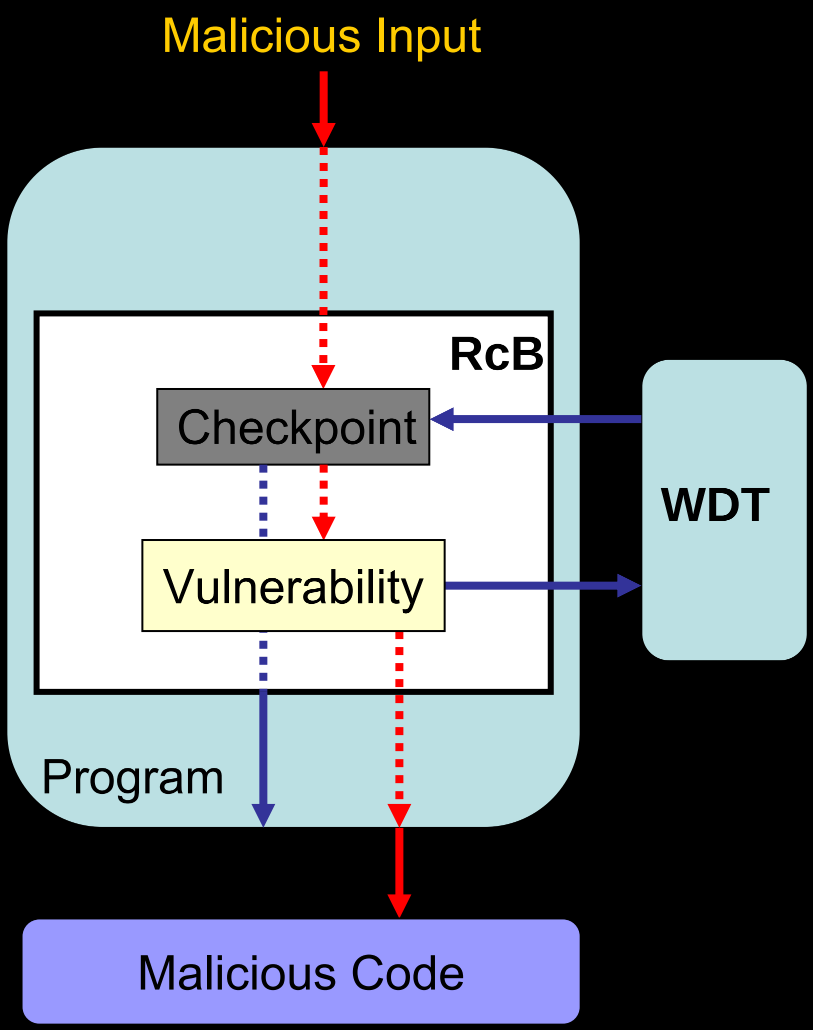
Computer Run-Time Tests

- Test only for anomalous states
- Detect anomalous states such as
  - Divide-by-zero
  - Overflow
  - Underflow
  - Undefined operation code
  - Write-protection violations

Recovering Exploration

- The recovering exploration technique uses RcB to accomplish fault tolerance.
- When a checkpoint is established the values of data in memory, the processor context (register and instruction pointer) and the stack are saved.
- Time-out via the watchdog occurs, resets the watchdog time, and restores the checkpoint

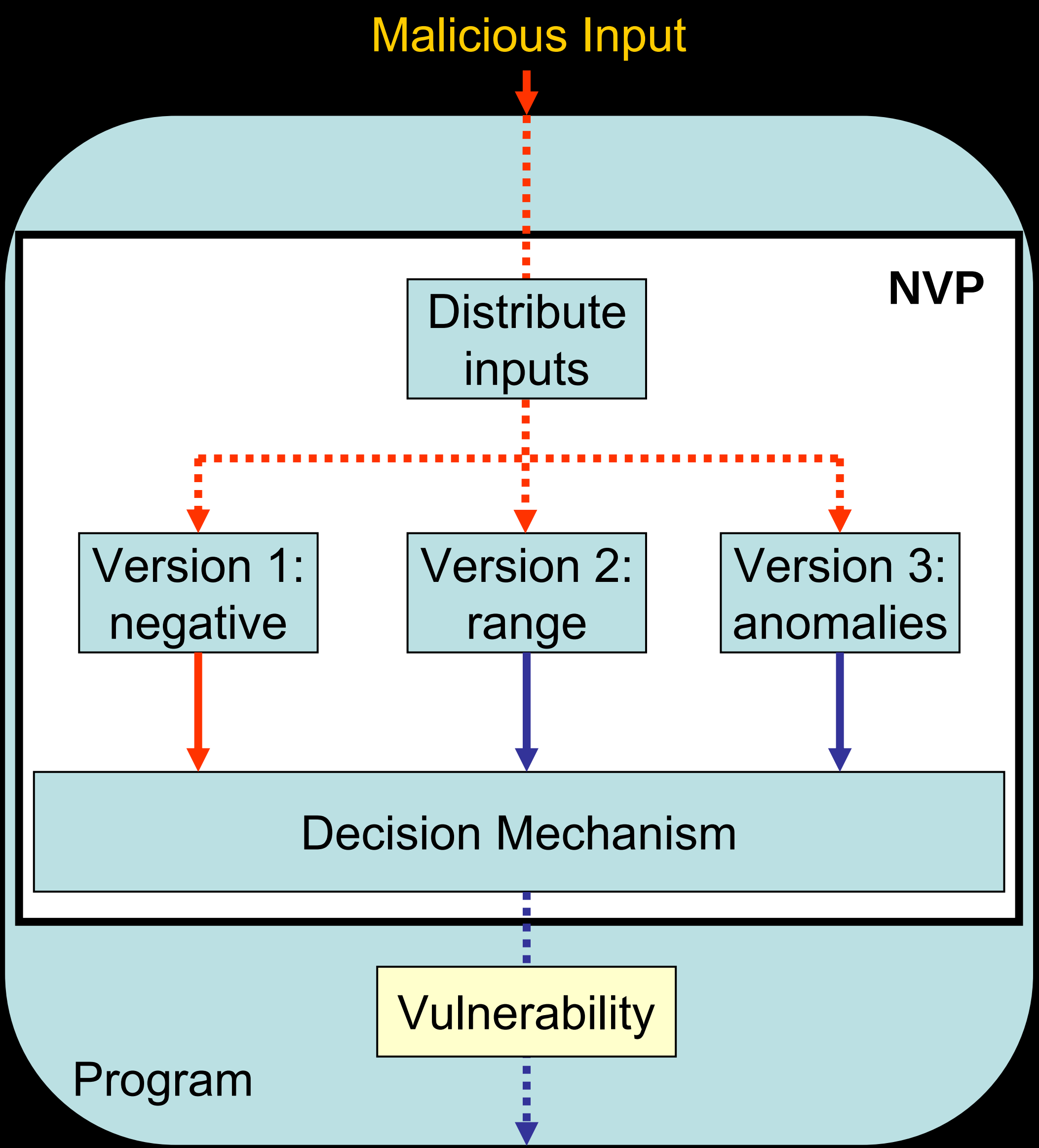
Recovering Exploration



Anti-Fuzzing

- Technique to prevent hacker discover zero day vulnerabilities in vendors
- The inputs are distributed for the modules and in case the results are divergentes a error is detected.
- Use N-Version Programming in which each version is an module.

Anti-Fuzzing



Implementation Methodology

1. It is defined an initial architecture and a technique for your implementation
2. They identify the classes of susceptible to flaws to happen, and that should be tolerated
3. They incorporate the mechanisms of detection of errors, necessary to the attendance of all the classes of important flaws
4. Recovery algorithms are defined that will be worked after the greeting of the originating from sign the detection mechanisms

Questions?

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