Silencing Hardware Backdoors

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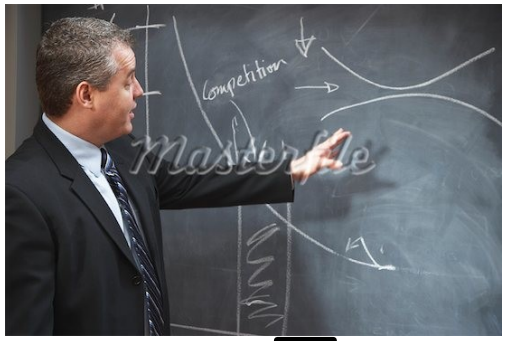
Idea

- Backdoor = Trigger + Payload
  - Triggers are necessary to bypass truthful design validators
  - Triggers need to be predictable by attackers
- Prior solution: Detects malicious actions of Payloads
  - Tamper-Evident Microprocessors [Oakland 2010]
  - Incomplete coverage because payload space is large
- This work: Disables Triggers
  - Alter inputs to defeat triggers
  - Fairly general-purpose
- Solution approach
  - Set of digital trigger types is finite
  - Find efficient methods to disable each trigger type

Backdoors in Hardware Design



Untrusted Designer
(Human/Insider)

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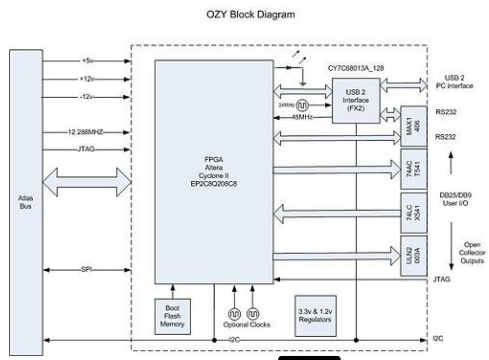
Hicks et al., 2010



Untrusted Compiler
(Software)

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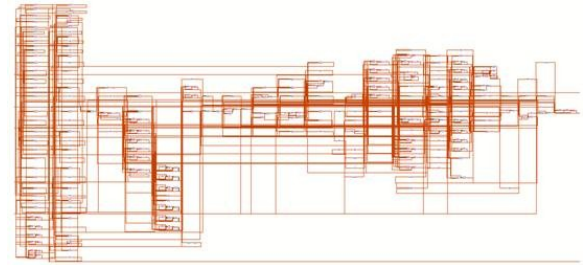

Untrusted
Fabrication
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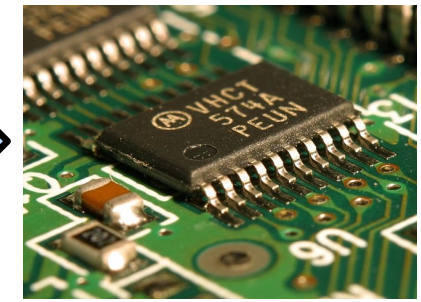

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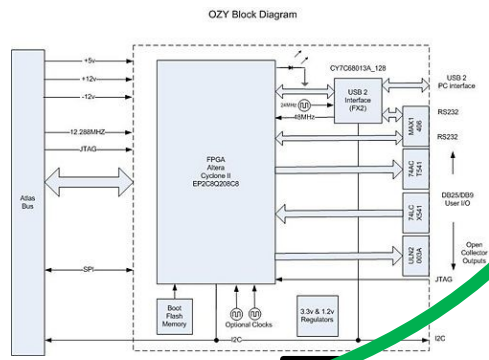

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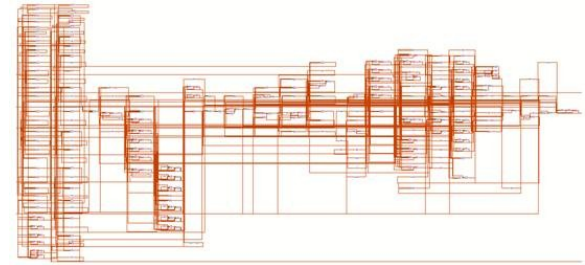

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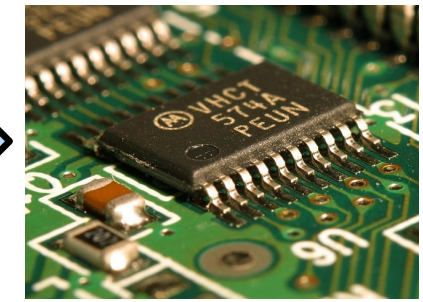
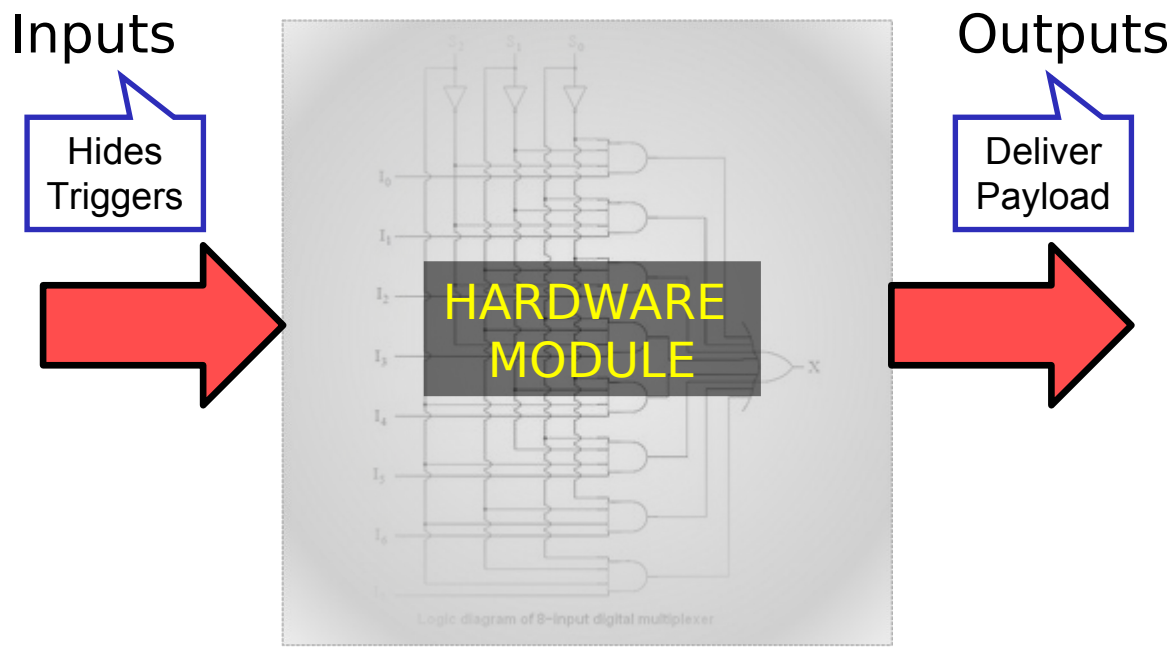


Solution: Obfuscation of Inputs

$$\text{Backdoor} = \text{Trigger} + \text{Payload}$$



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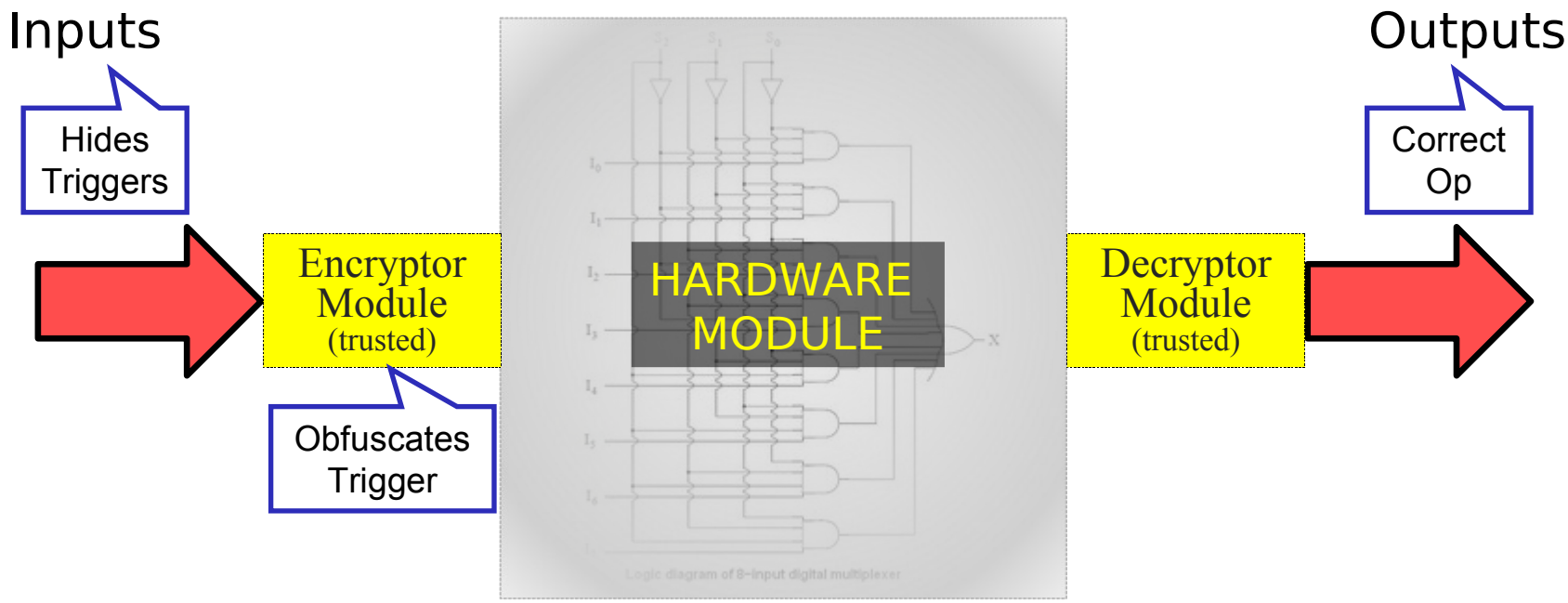
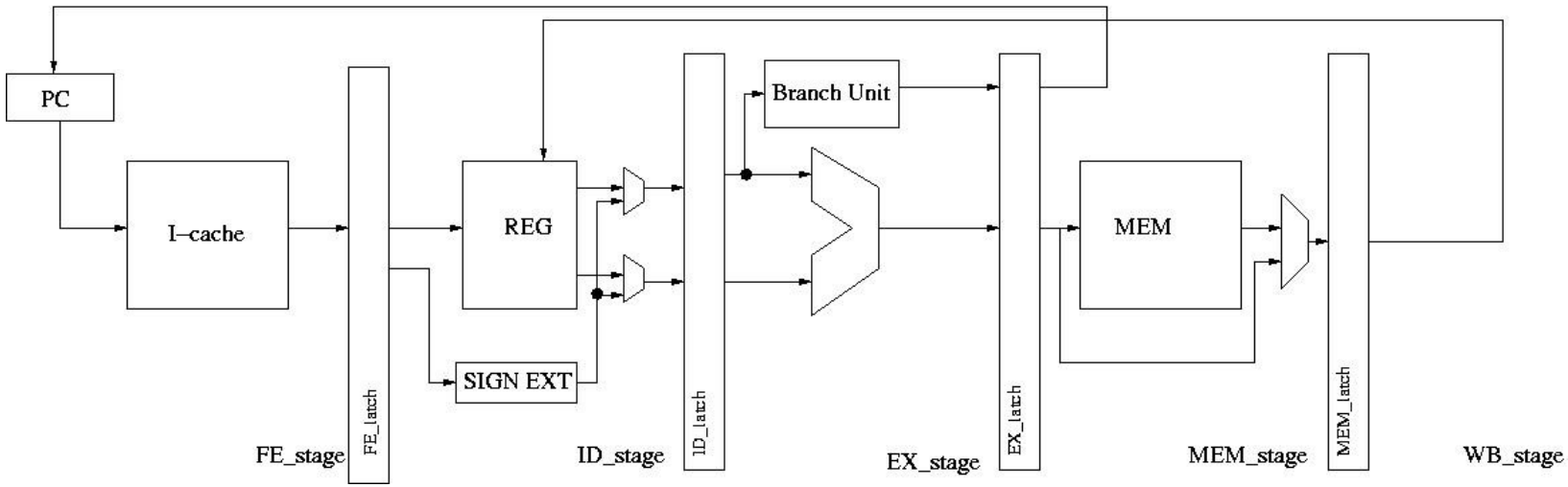


Outline

- Overview
- Framework for solving the backdoor problem
- Solutions and their theoretical strengths
  - Power Resets
  - Encrypted Computation
  - Reordering
  - “Catch all”
- Practical applicability
  - OpenSPARC case study
  - Performance Impacts
- Open problems

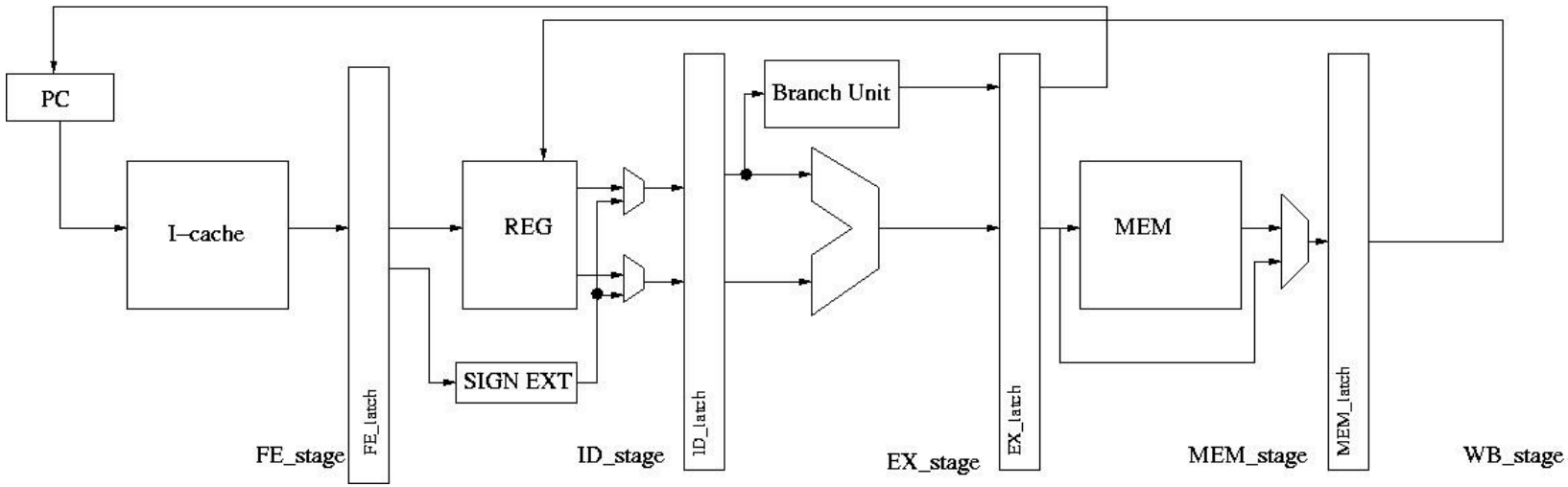
Hardware Design

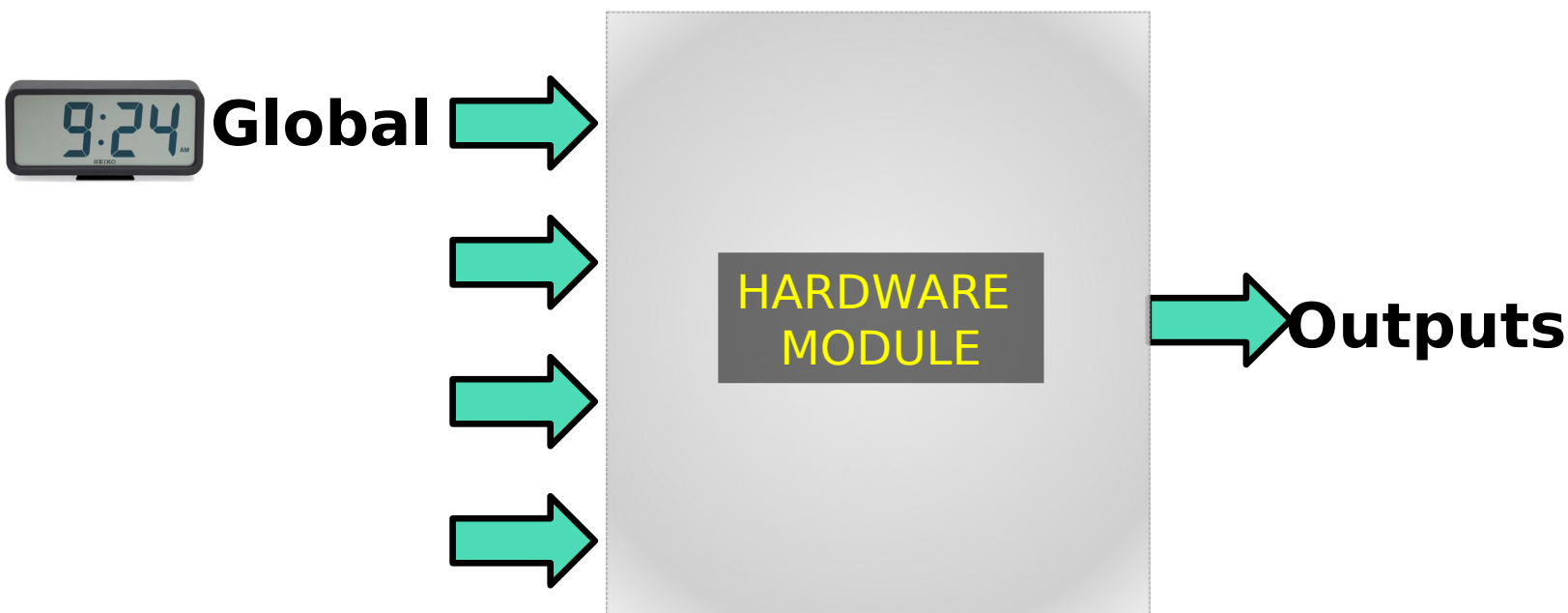


- A design is a connected set of modules
  - Modules connect to each other through interfaces

- In the picture above, each box is a module

Taxonomy of Interfaces





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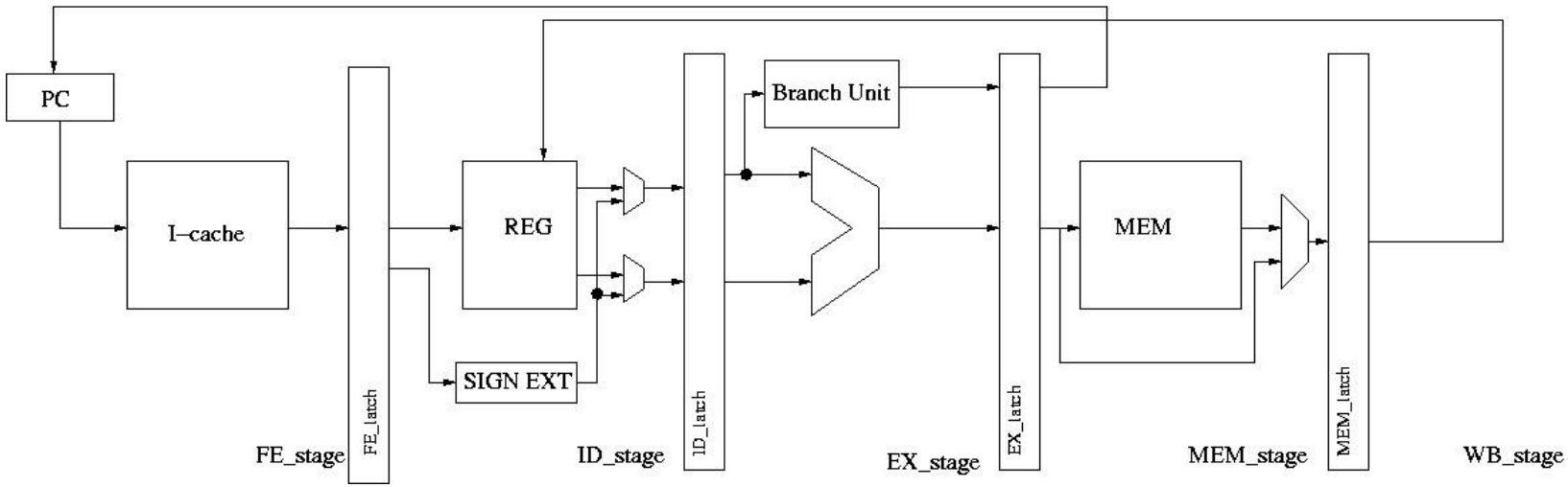

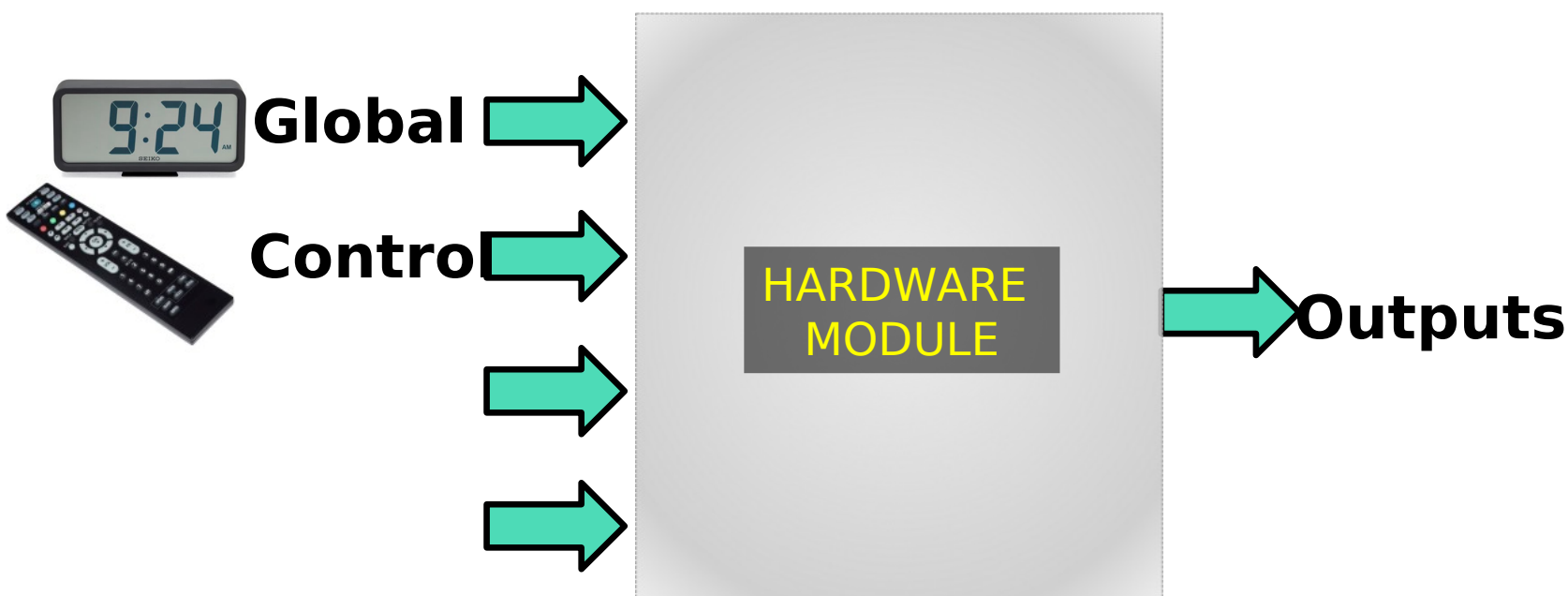

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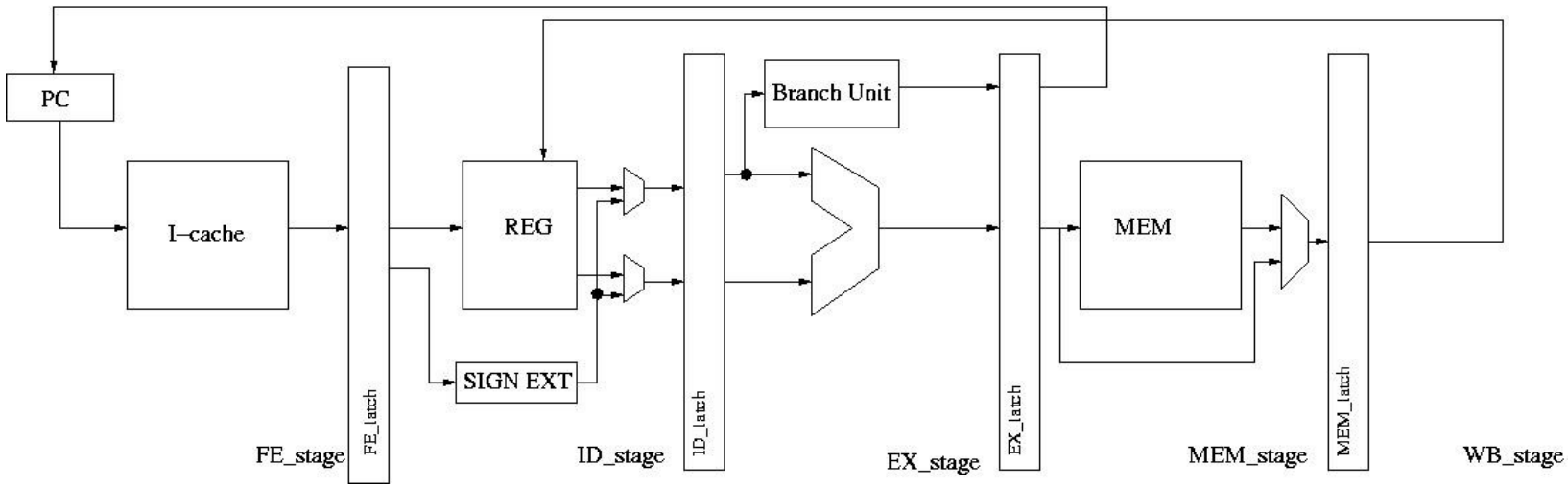


Global

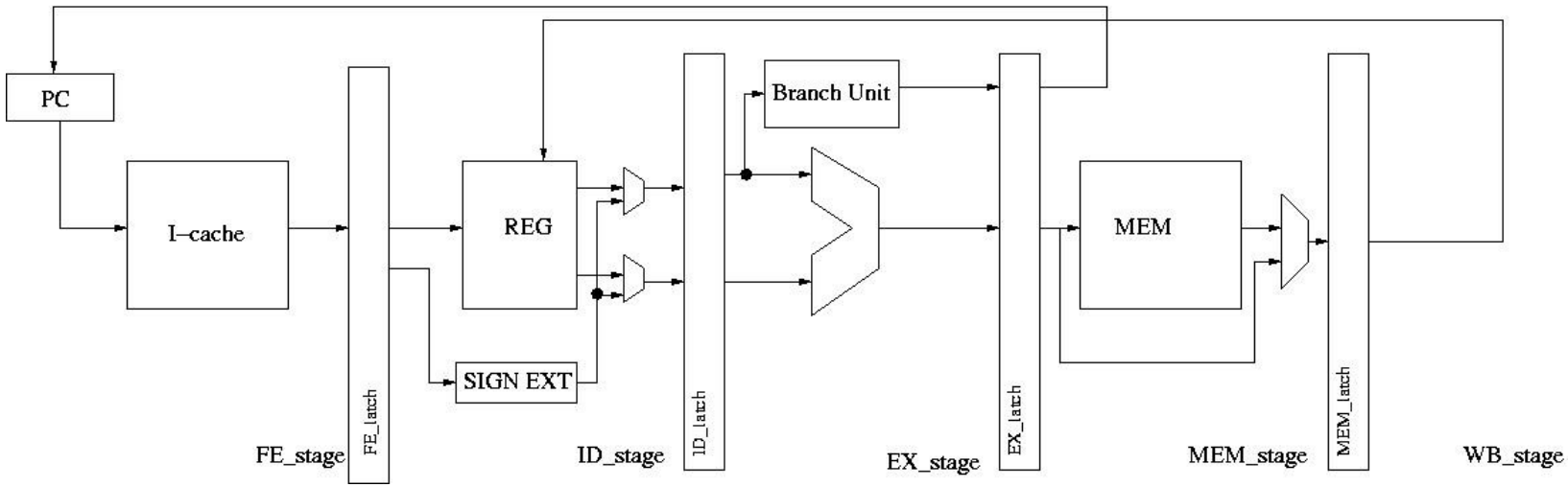
Control

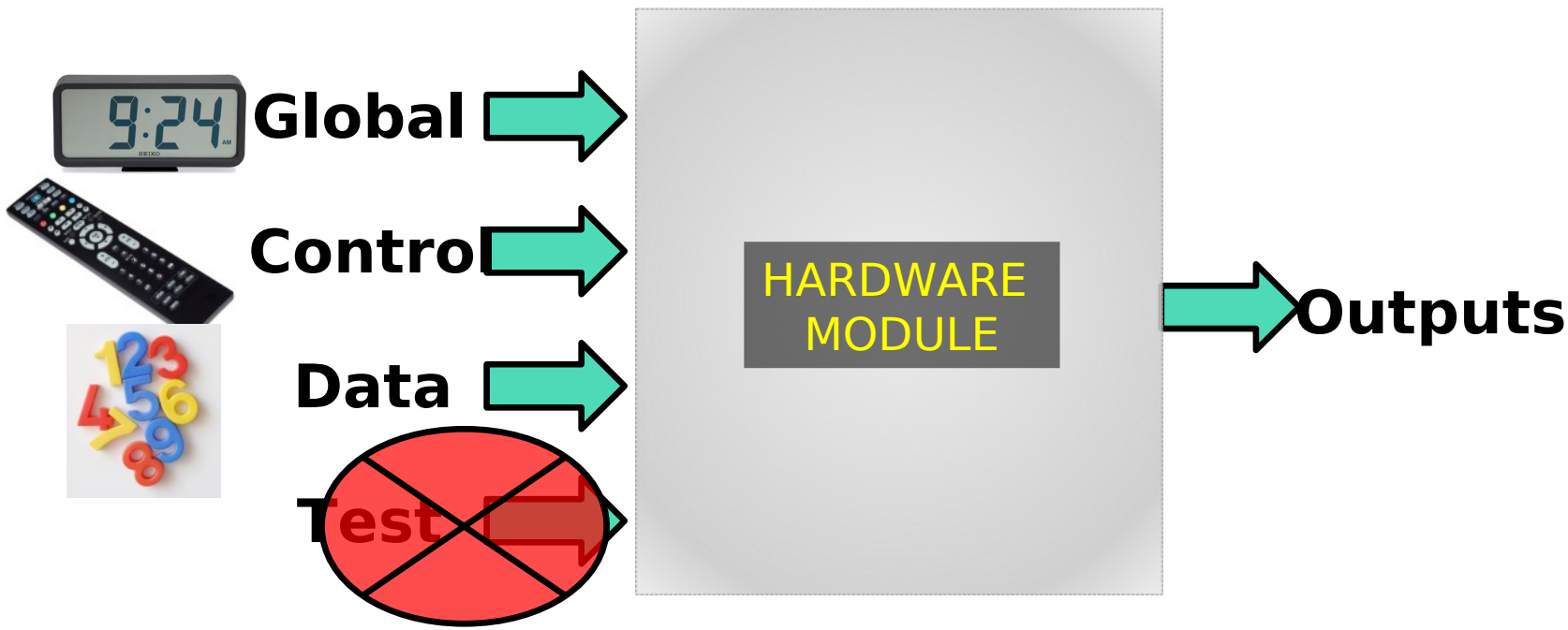
Data

HARDWARE MODULE

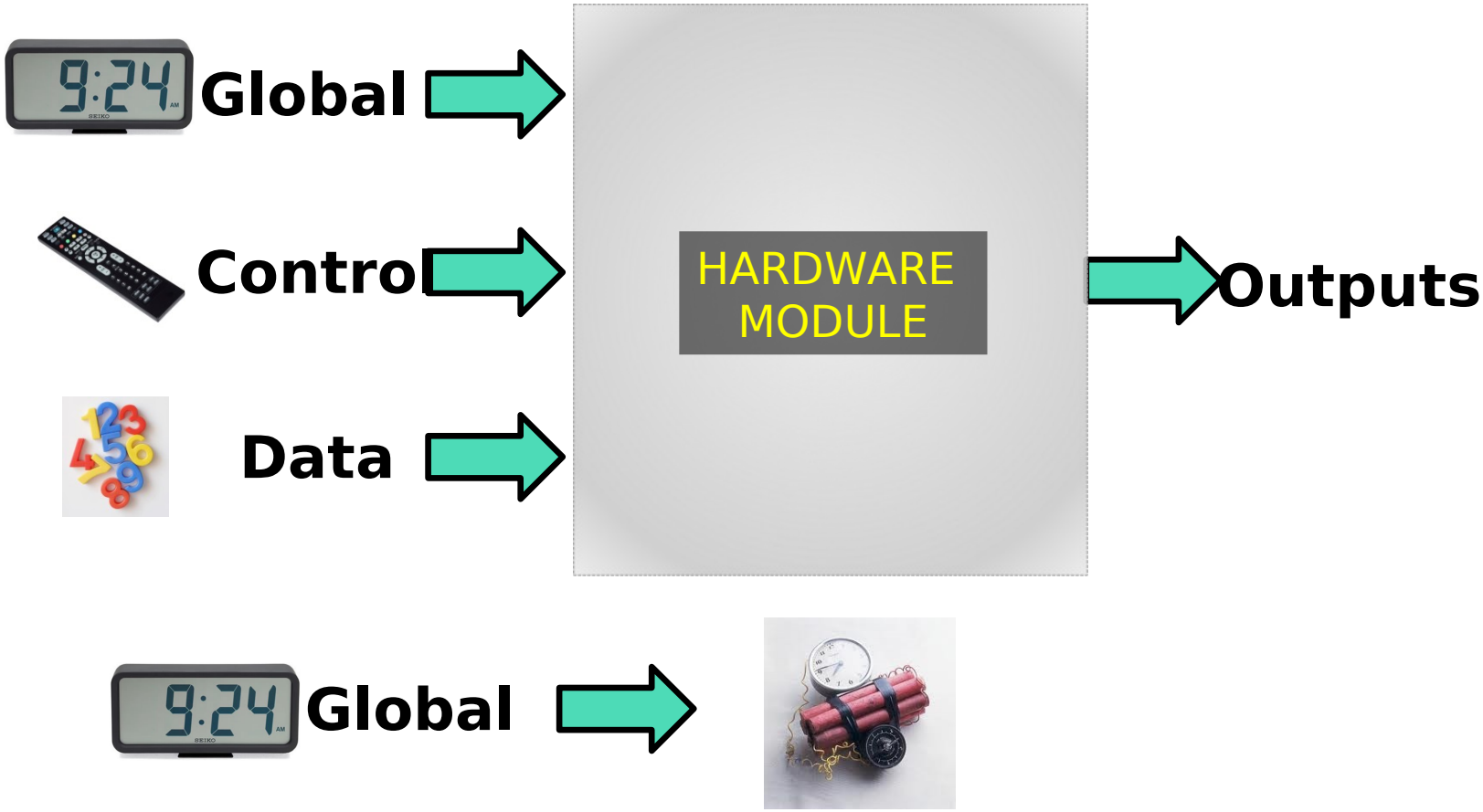
Outputs

Taxonomy of Interfaces





Three Kinds of Backdoor Triggers



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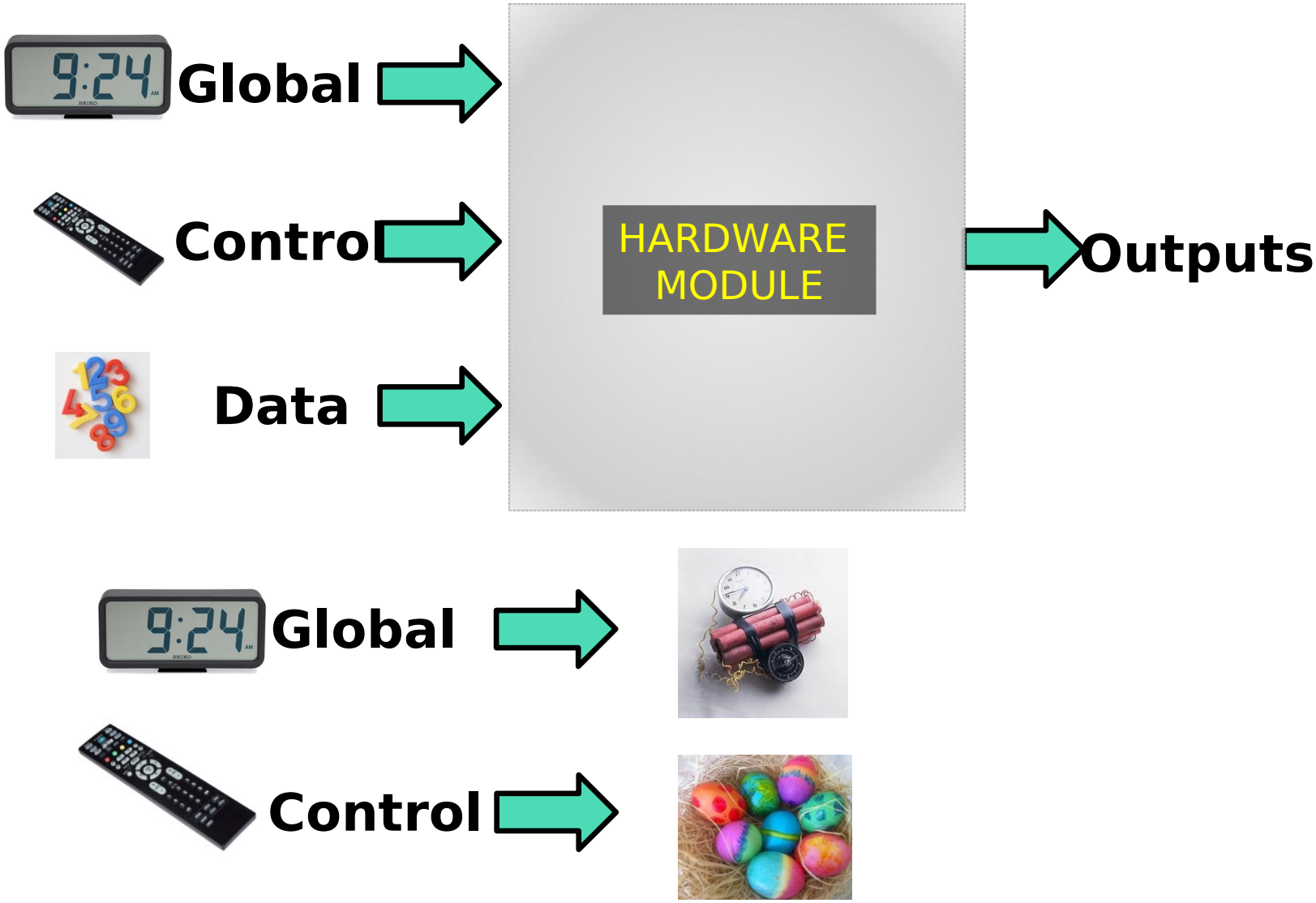

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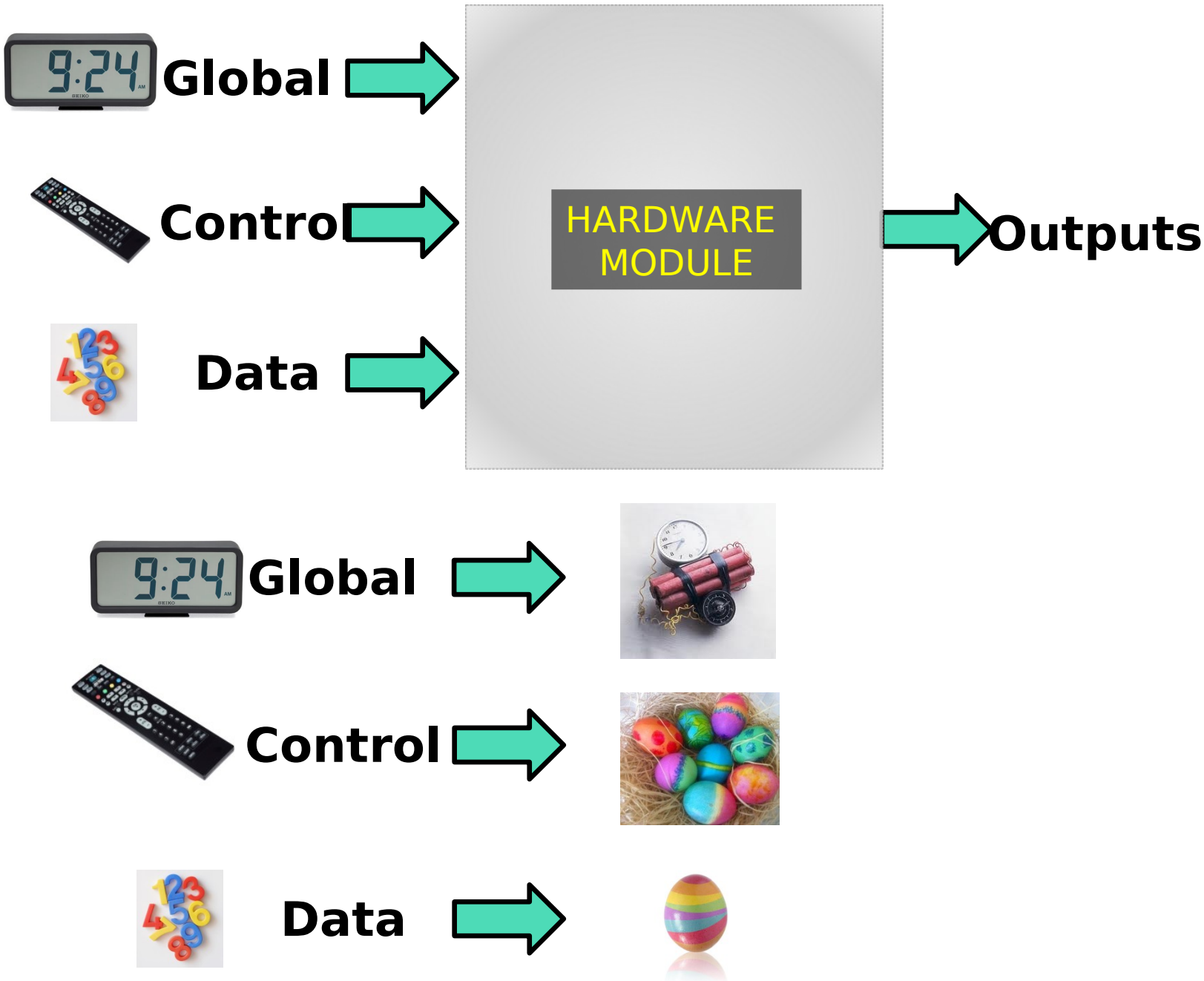

Three Interfaces, Three Triggers

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Ticking Timebombs

Control

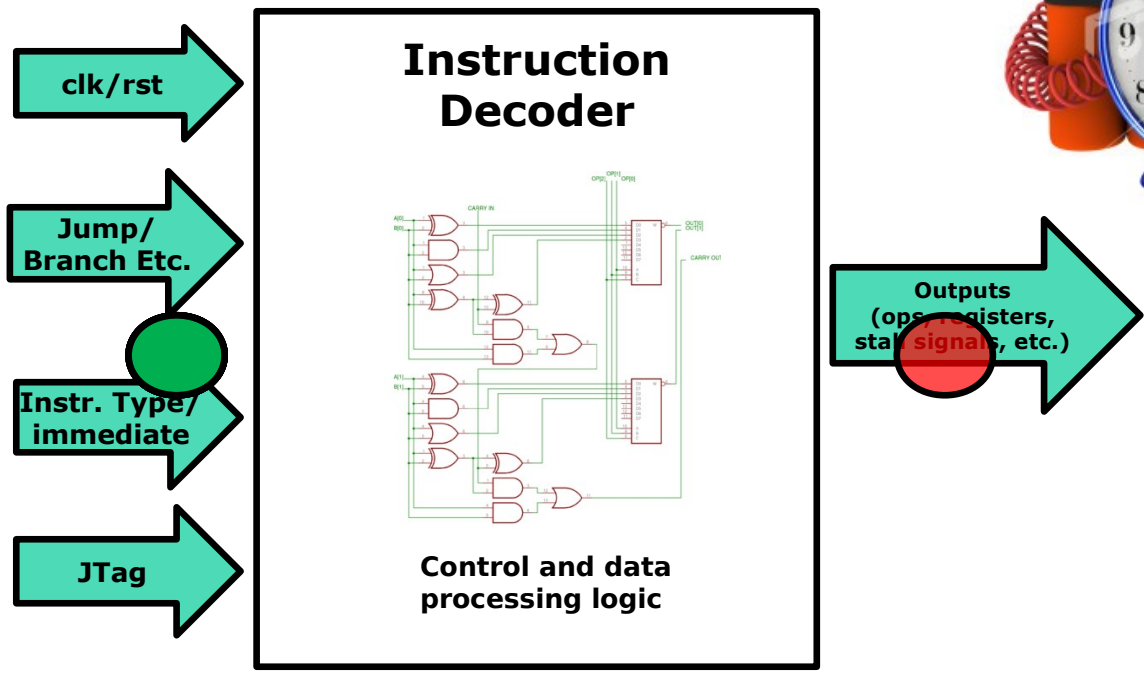
Cheatcodes
- **Single-shot**
- **Sequence**

Data

Cheatcodes
- **Single-shot**
- **Sequence**

Trigger #1: Ticking Timebomb

- After a fixed time, functionality changes



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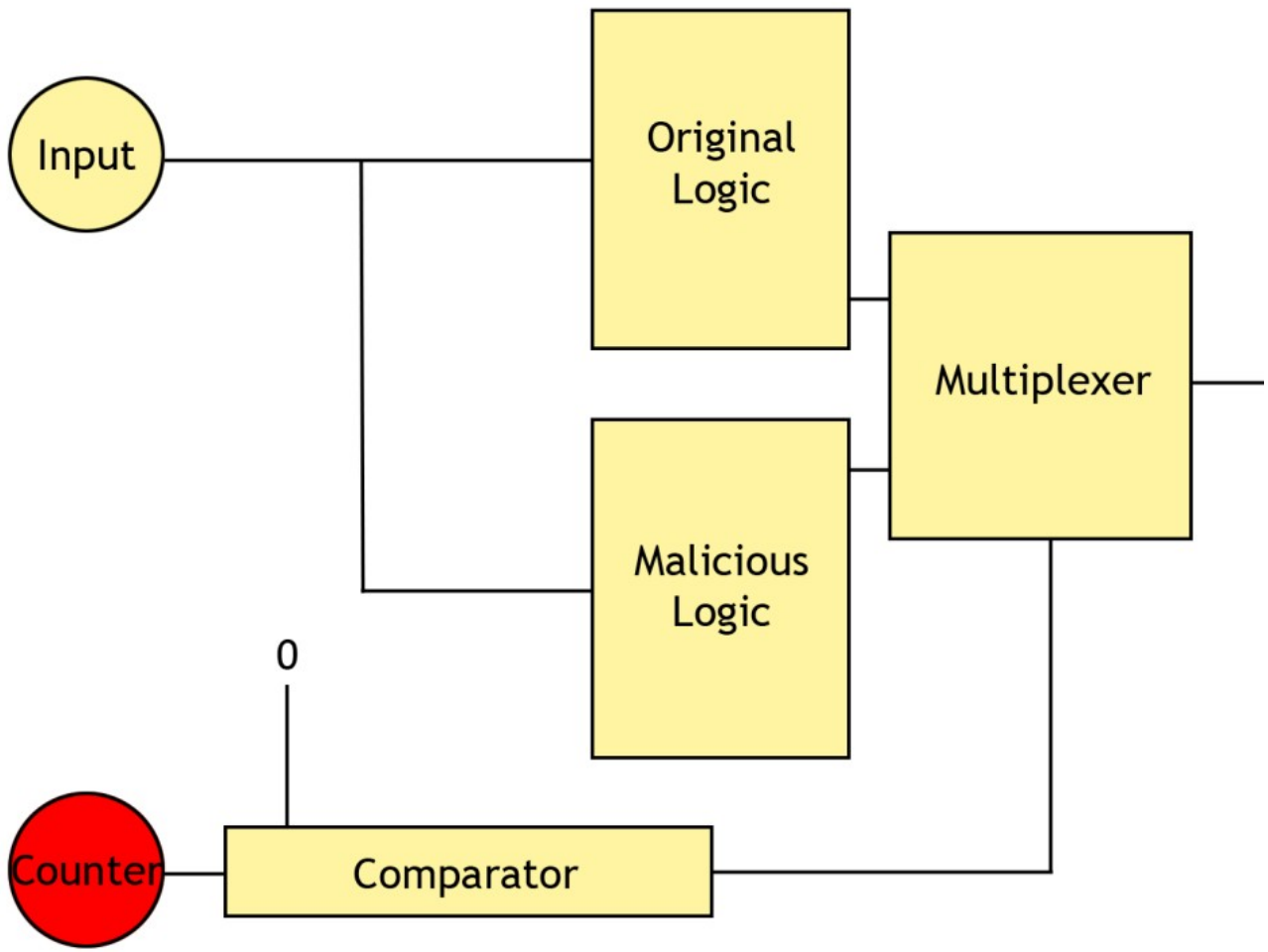
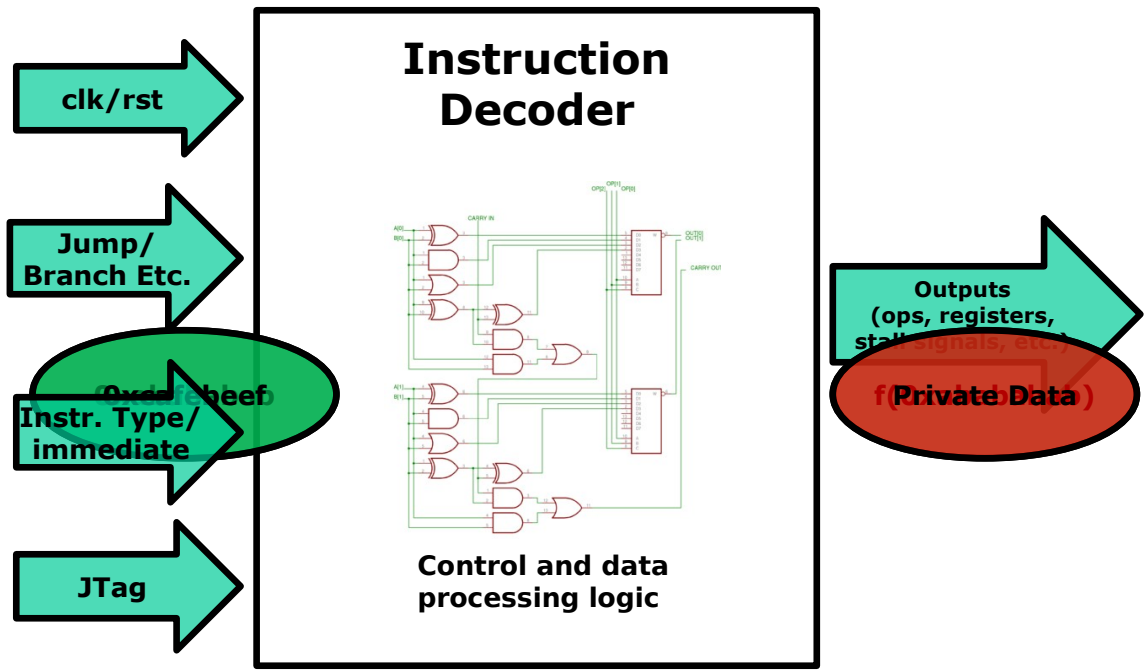


Trigger #2: Single-Shot Cheat Code

- A special value turns on malicious functionality
  - Example: 0xcafebeef



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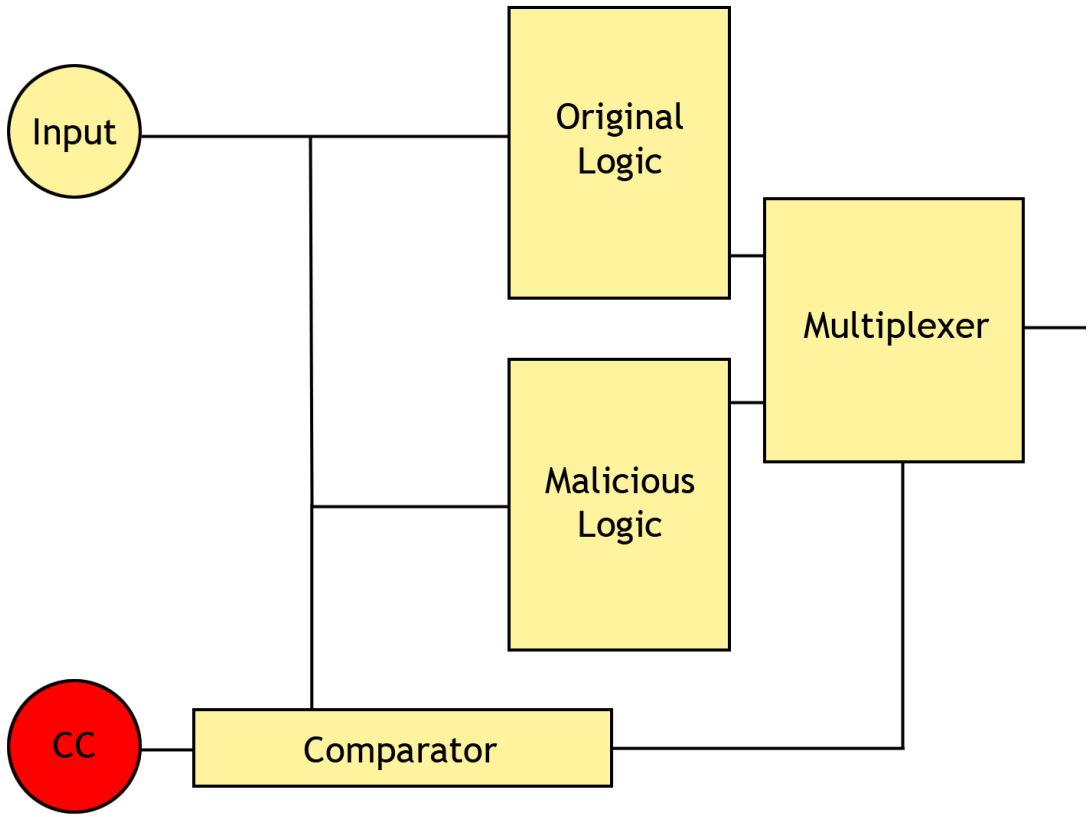
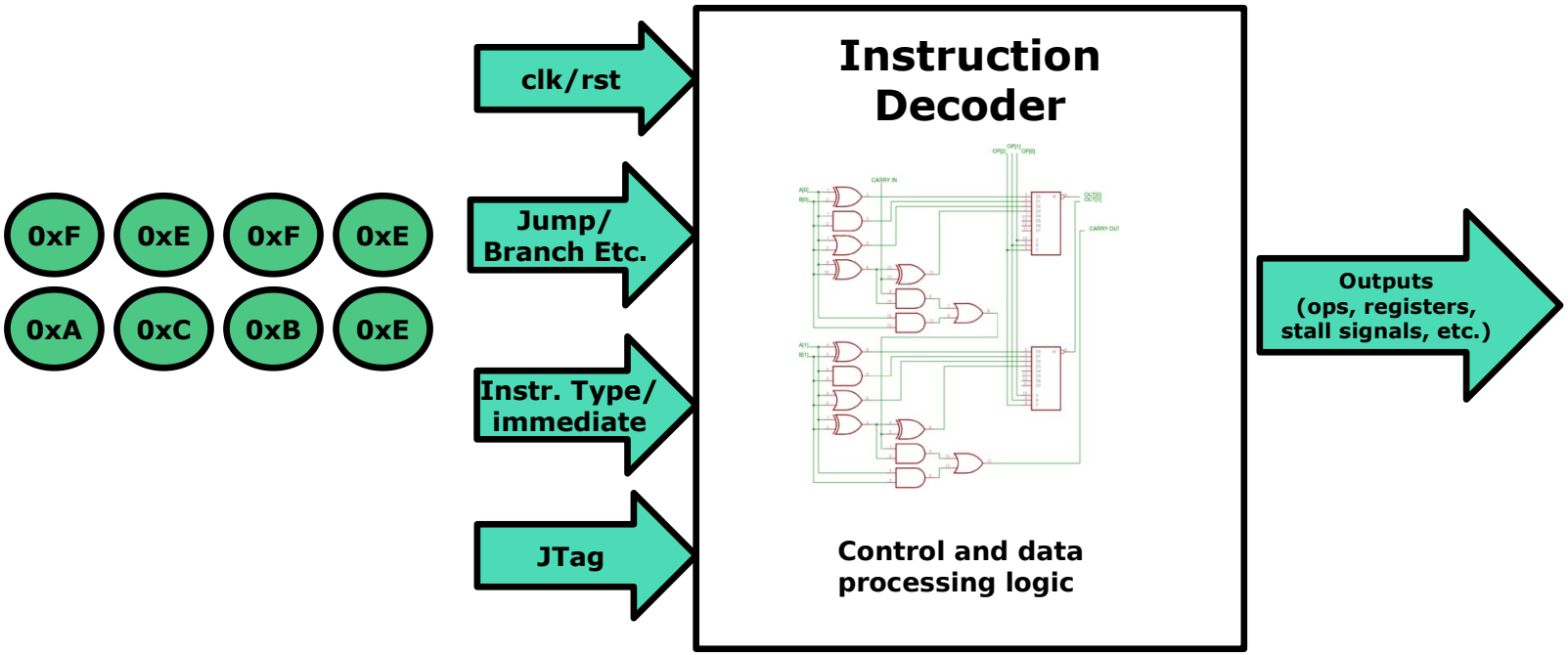


Trigger #3: Sequence Cheat Code

- A set of bits, events, or signals cause malicious functionality to turn on
  - Example: c, a, f, e, b, e, e, f



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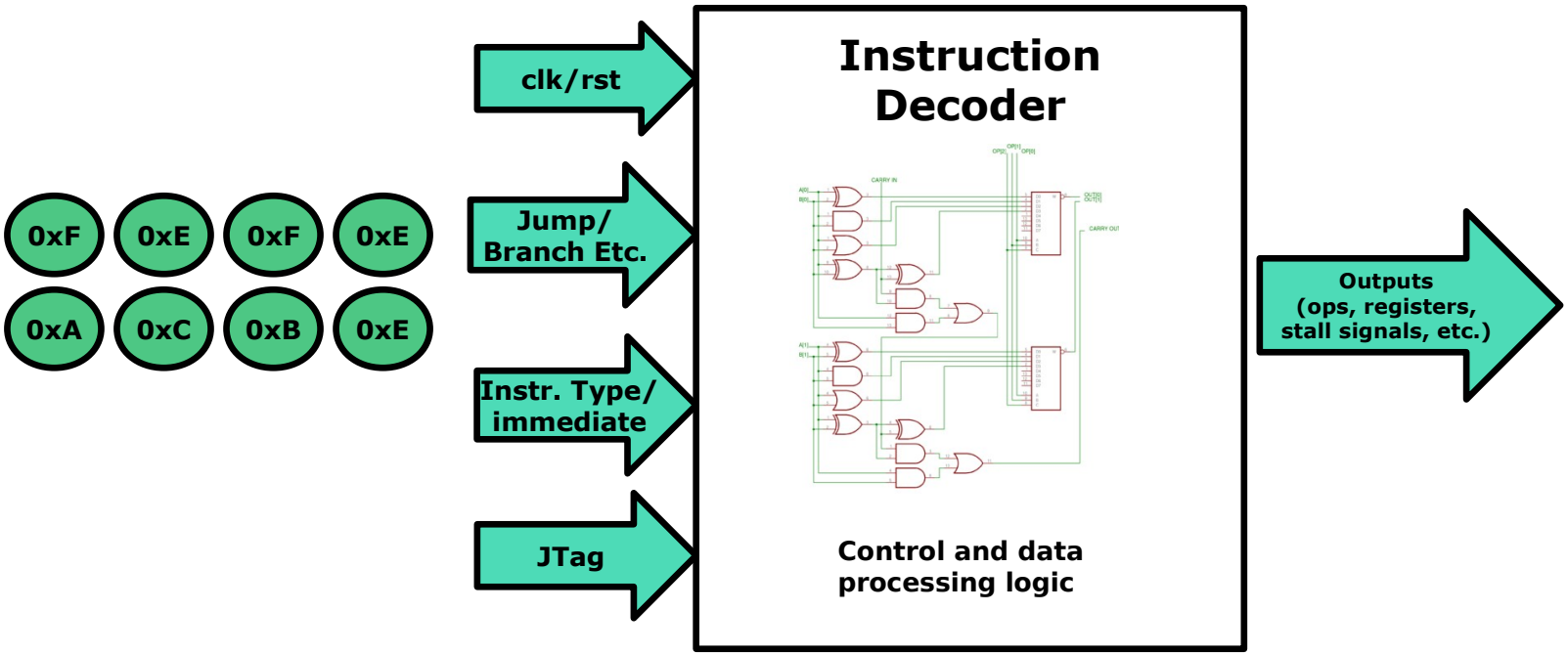

- Order and timing can vary

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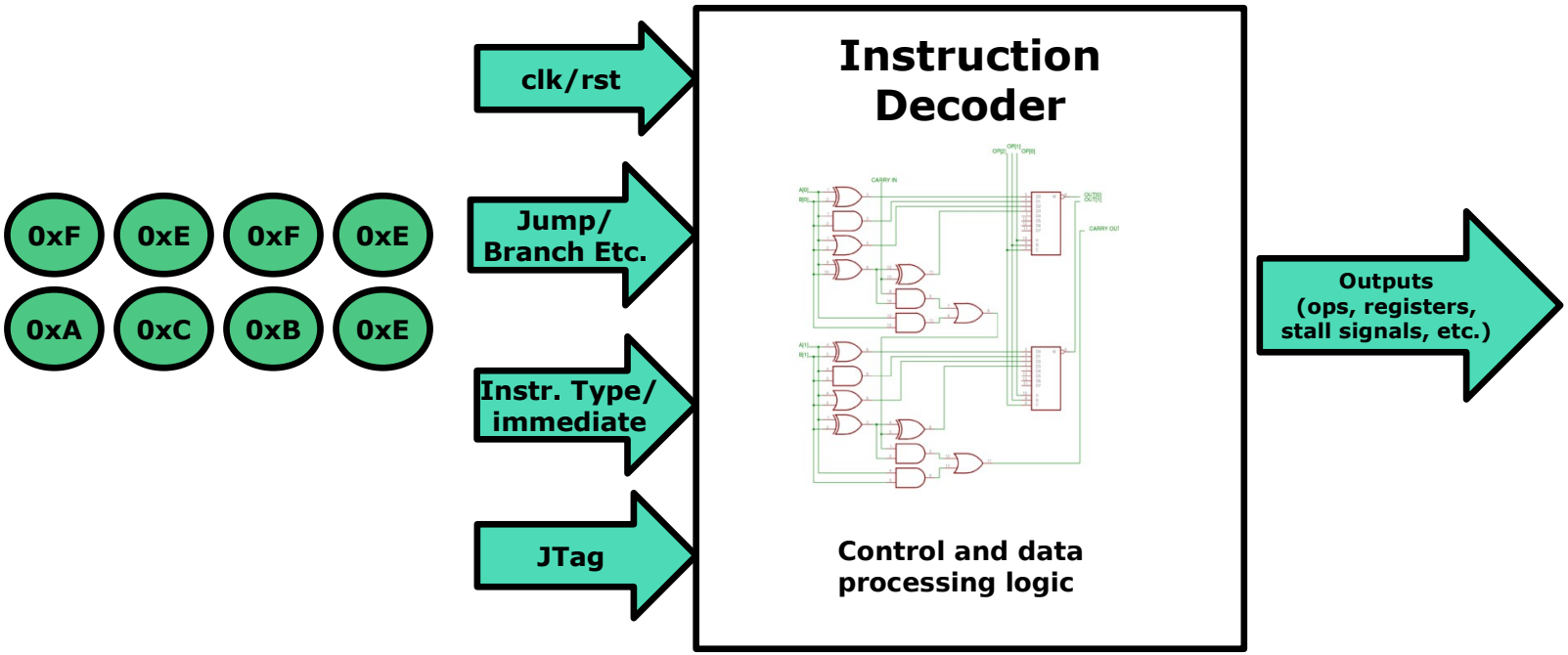

- Order and timing can vary
- Taxonomy is complete

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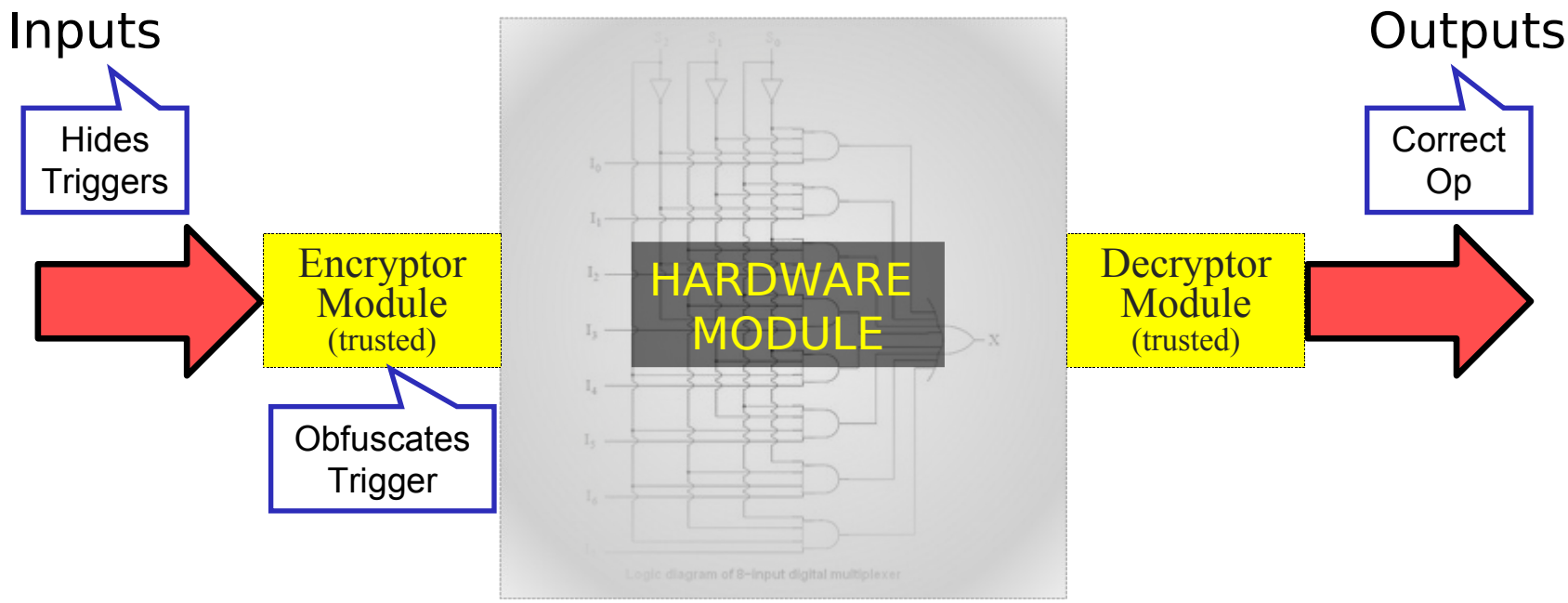


Three Solutions For Three Triggers

- Goal: Obfuscate information coming into each interface
  - Ticking timebombs
    - Periodically reset the power

  - Single-shot Cheatcodes
    - Encrypt data values

  - Sequence Cheatcodes
    - Reorder events or insert dummy events

Power Resets

- Power to modules is reset periodically
  - Time period = N – K cycles
  - N = Validation epoch
  - K = Time to restart module operation

- Forward progress guarantee
  - Architectural state must be saved and restored
  - Microarchitectural state can be discarded (low cost)
    - e.g., branch predictors, pipeline state etc.,

Power Resets: Security Analysis

Can trigger be stored to architectural state and restored later?

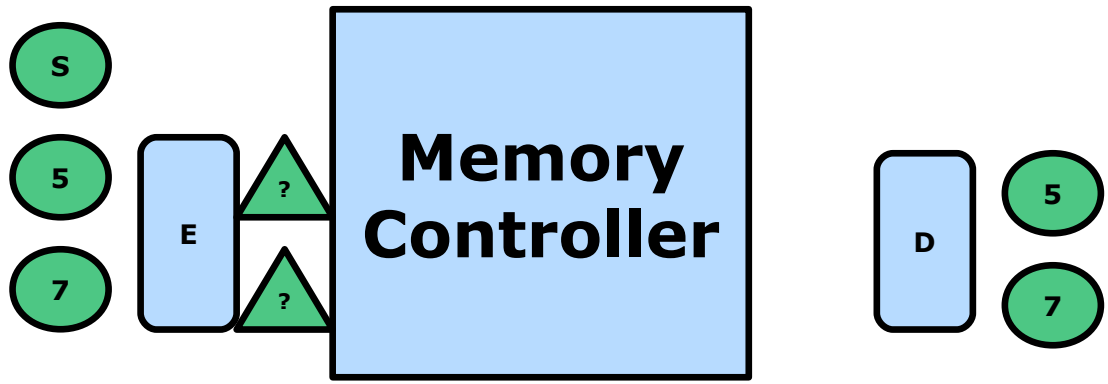
- No: Unit validation tests prevent this

- Reasons for trusting validation epoch
  - Large validation teams
  - Organized hierarchically

Can trigger be stored in non-volatile state internal to an unit?

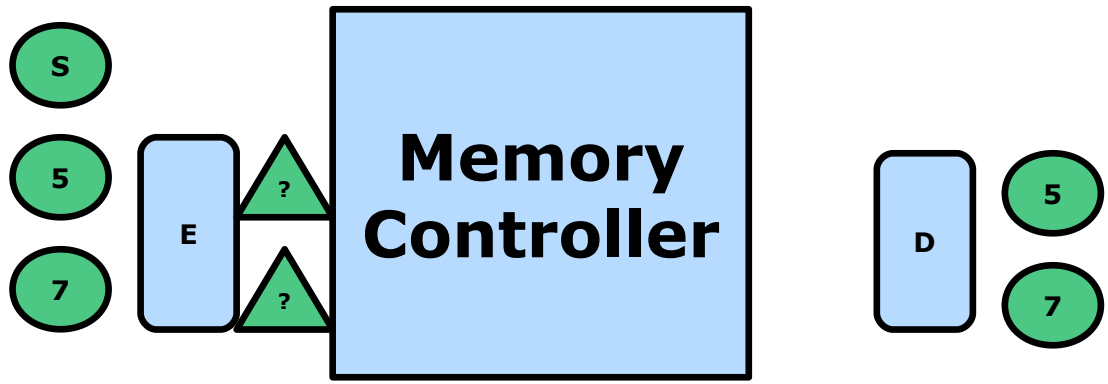
- Maybe, but non-volatile state can be detected
  - Details in the paper

Data Obfuscation



Data Obfuscation

- Homomorphic computation (Gentry 2009)
  - Data is operated on while encrypted



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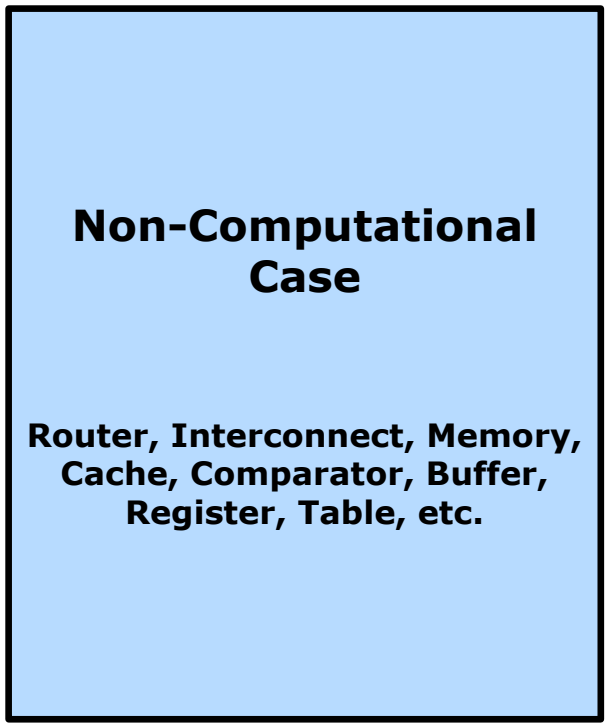

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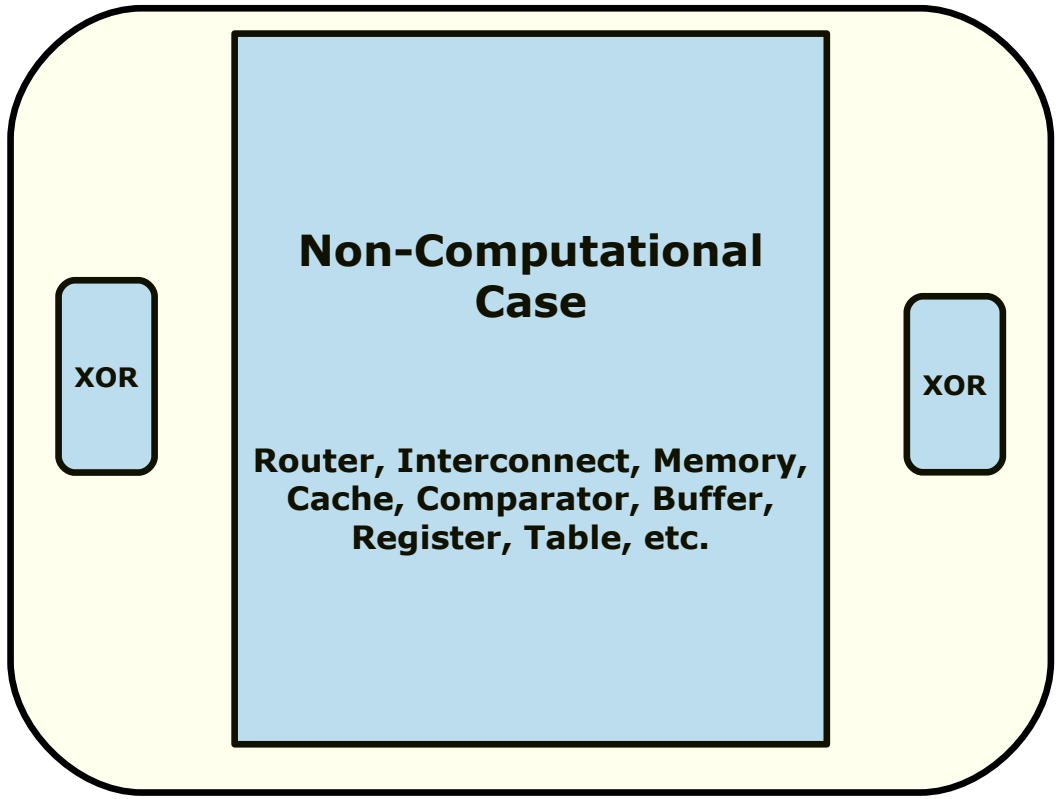

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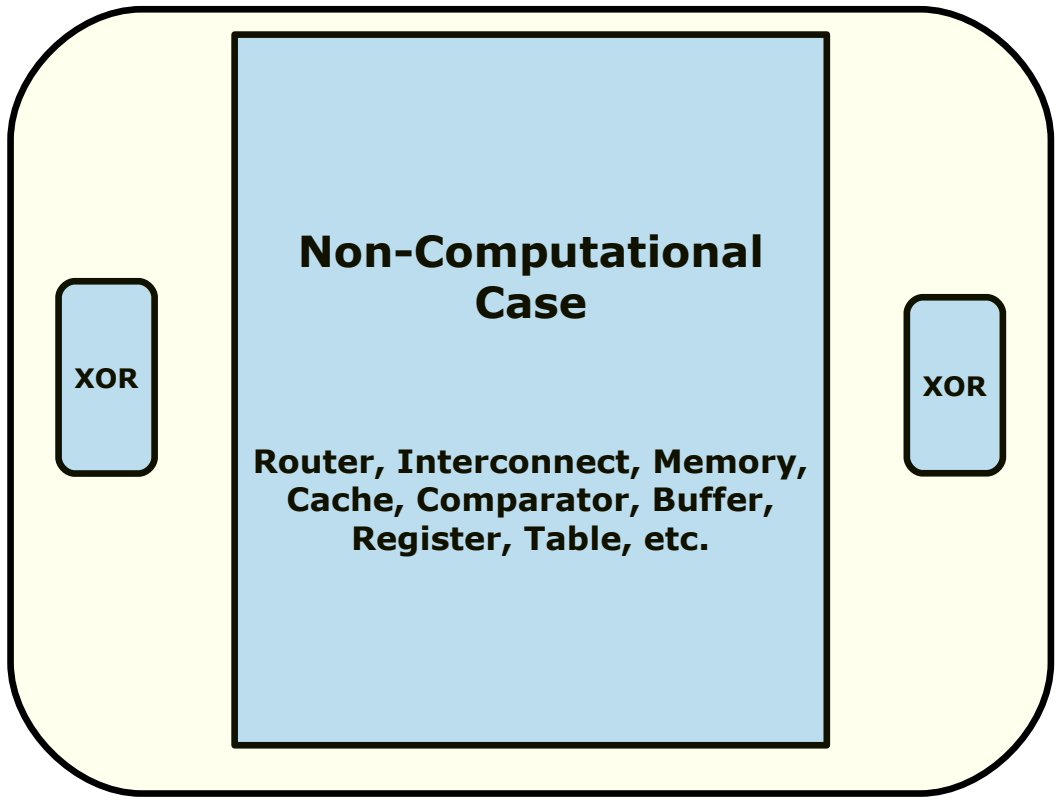
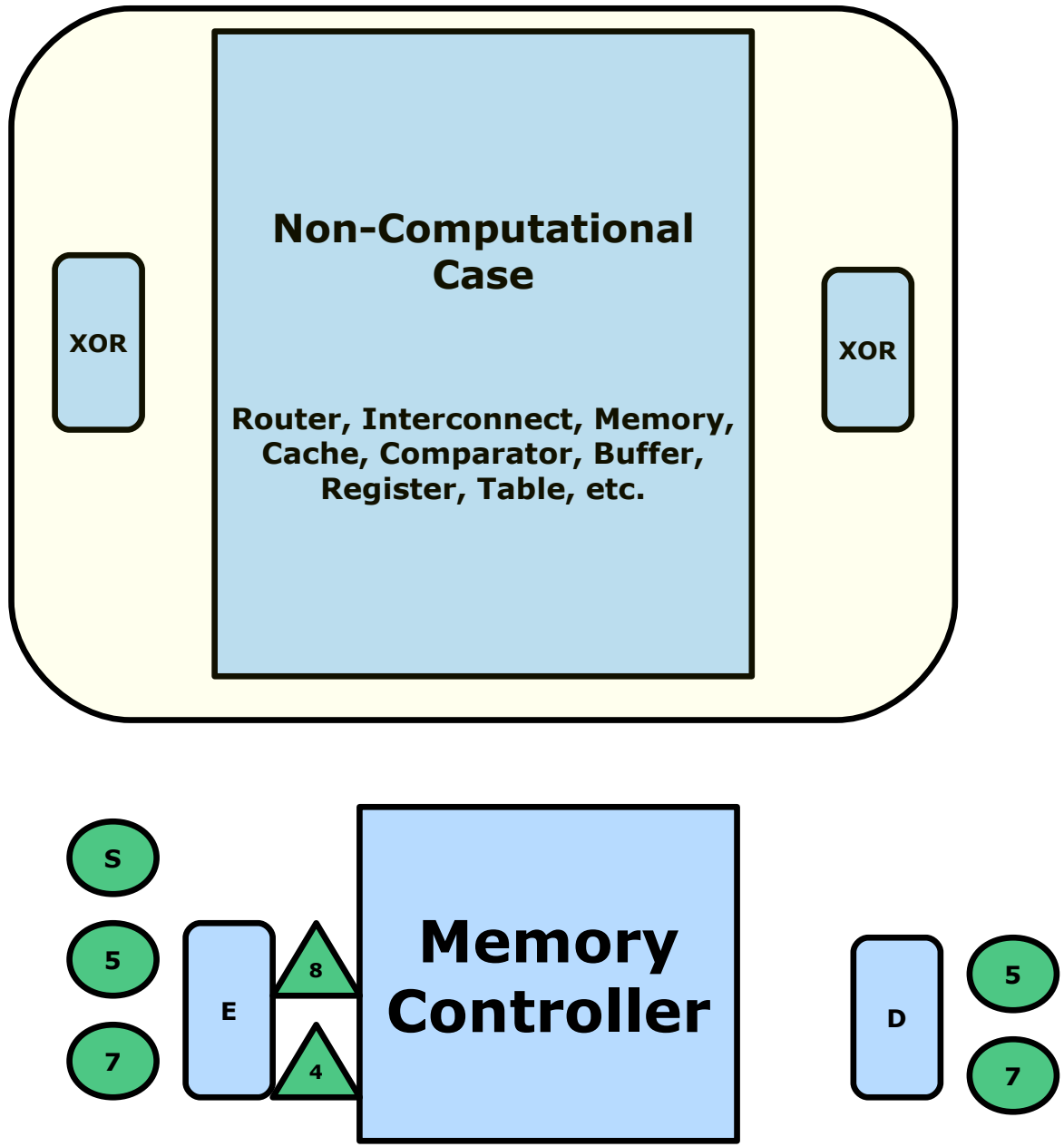


Store 5 to address 7

Memory Controller

Data Obfuscation: Simple Case



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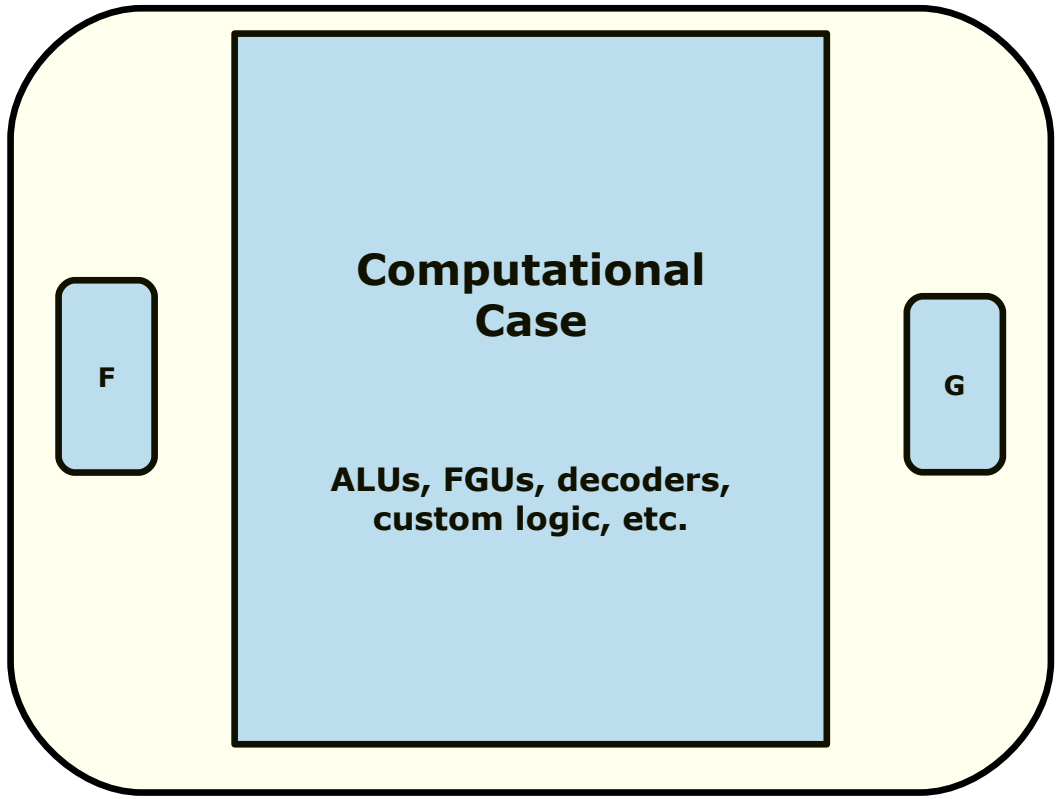

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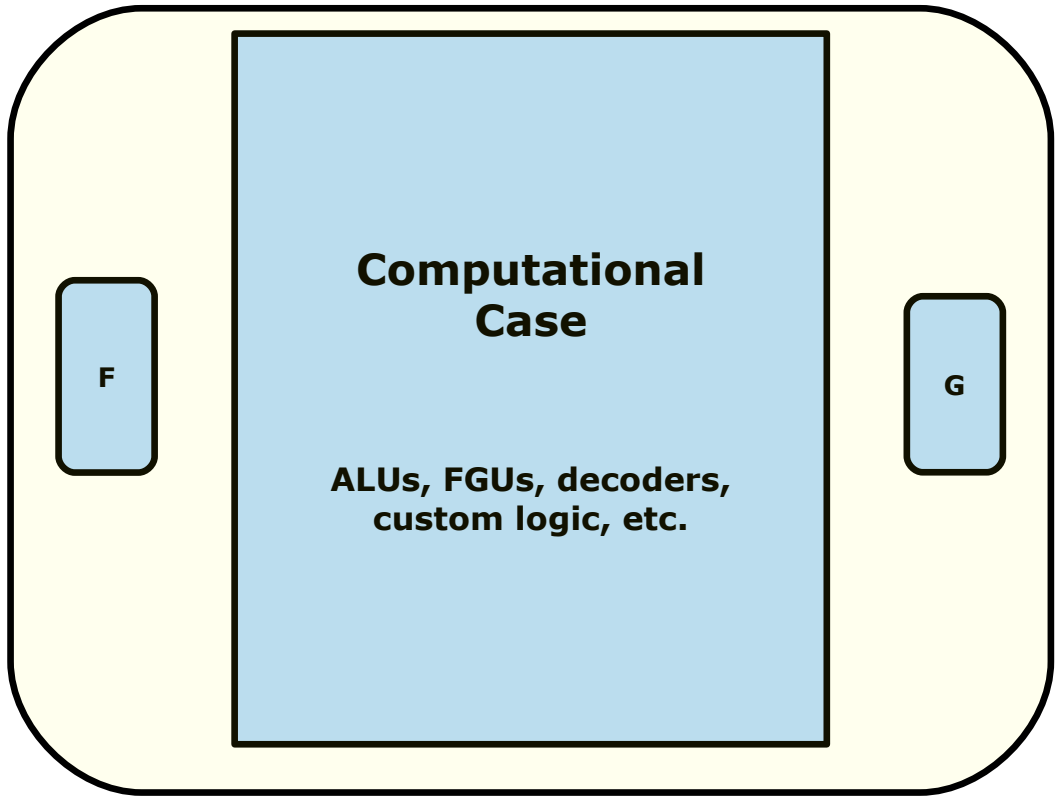
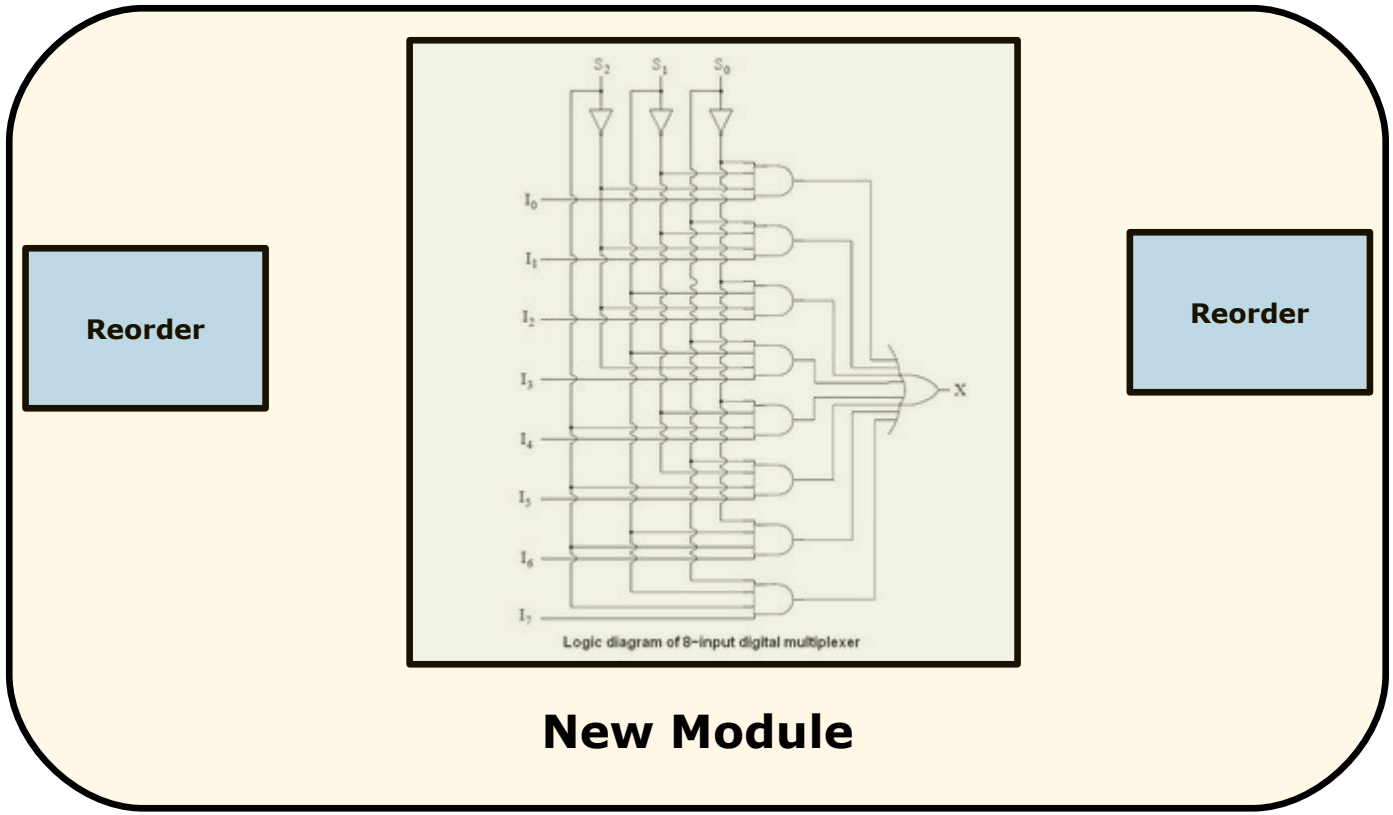


Sequence Breaking

- Prevent sequences from being predictable by the user
  - Pseudorandom reordering of events



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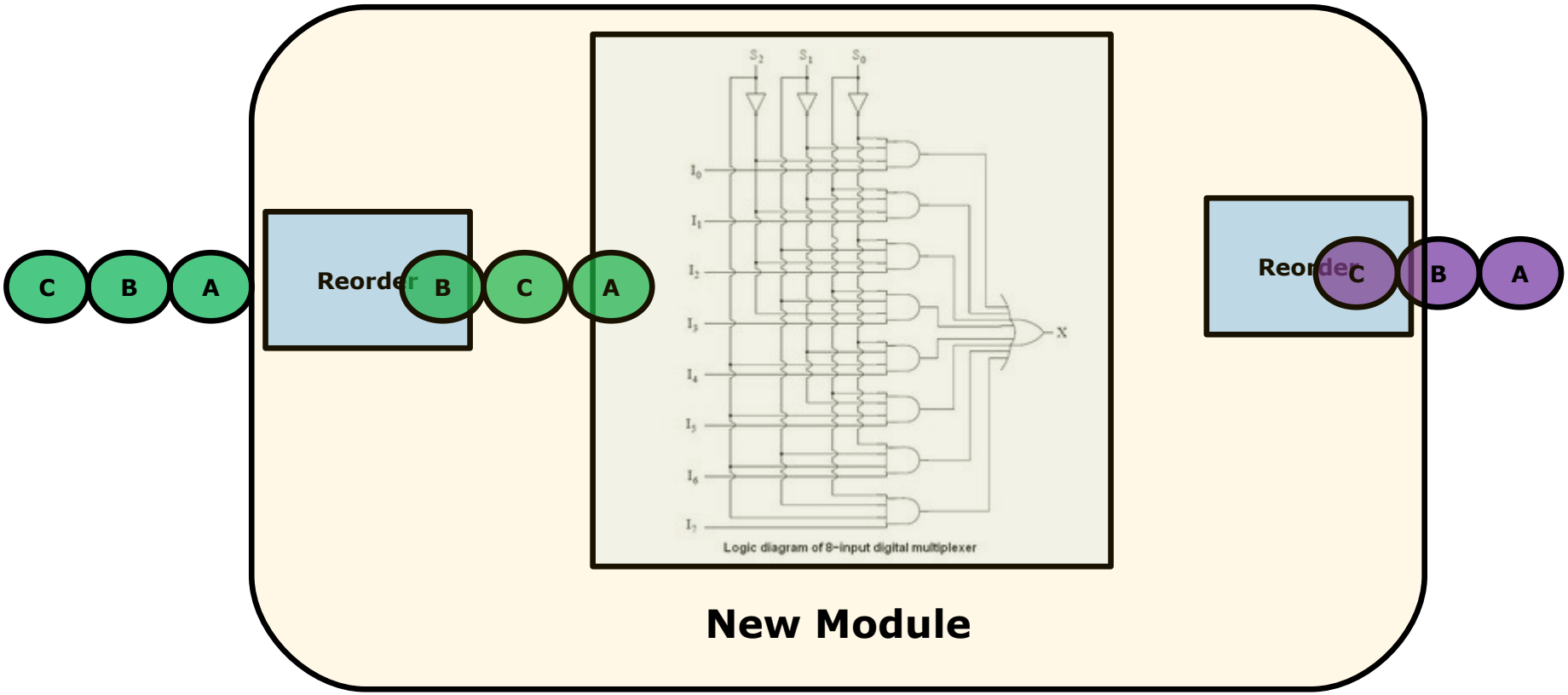

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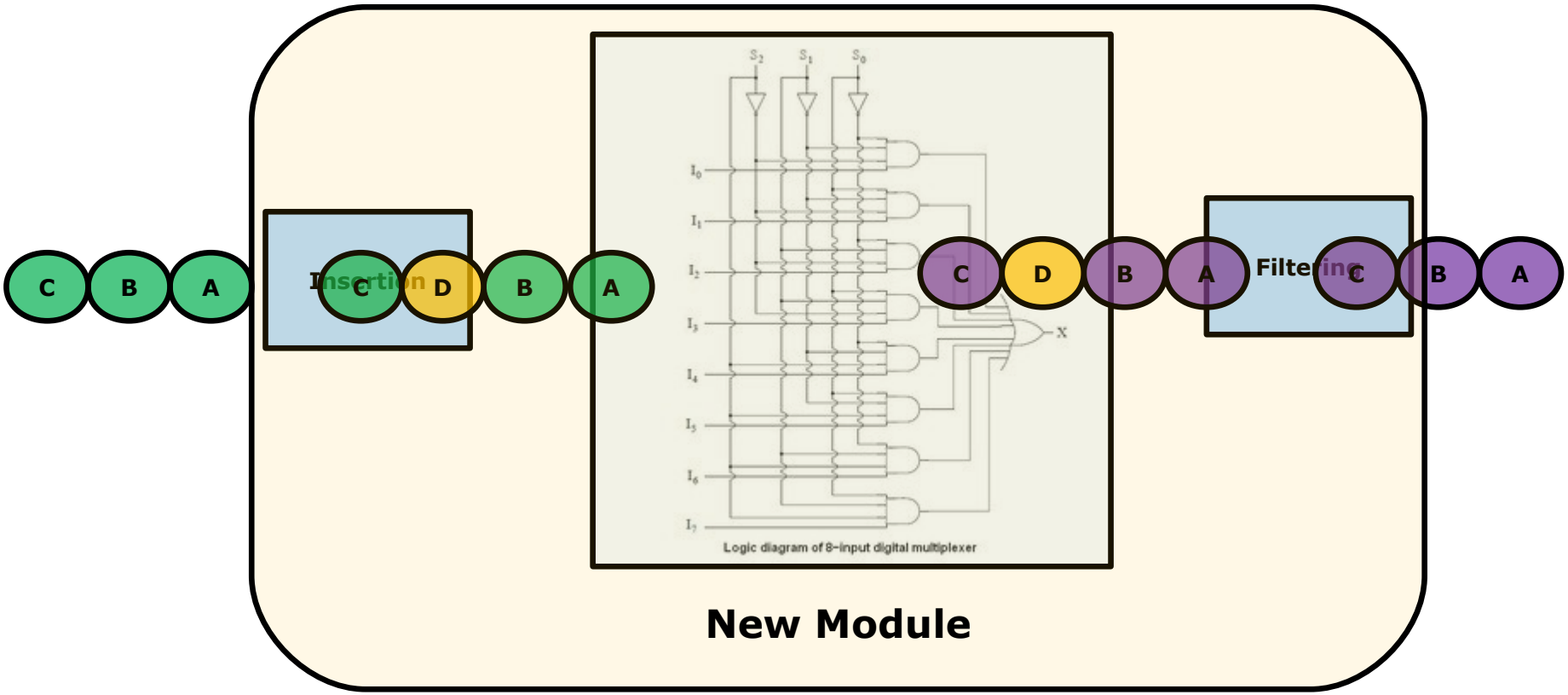

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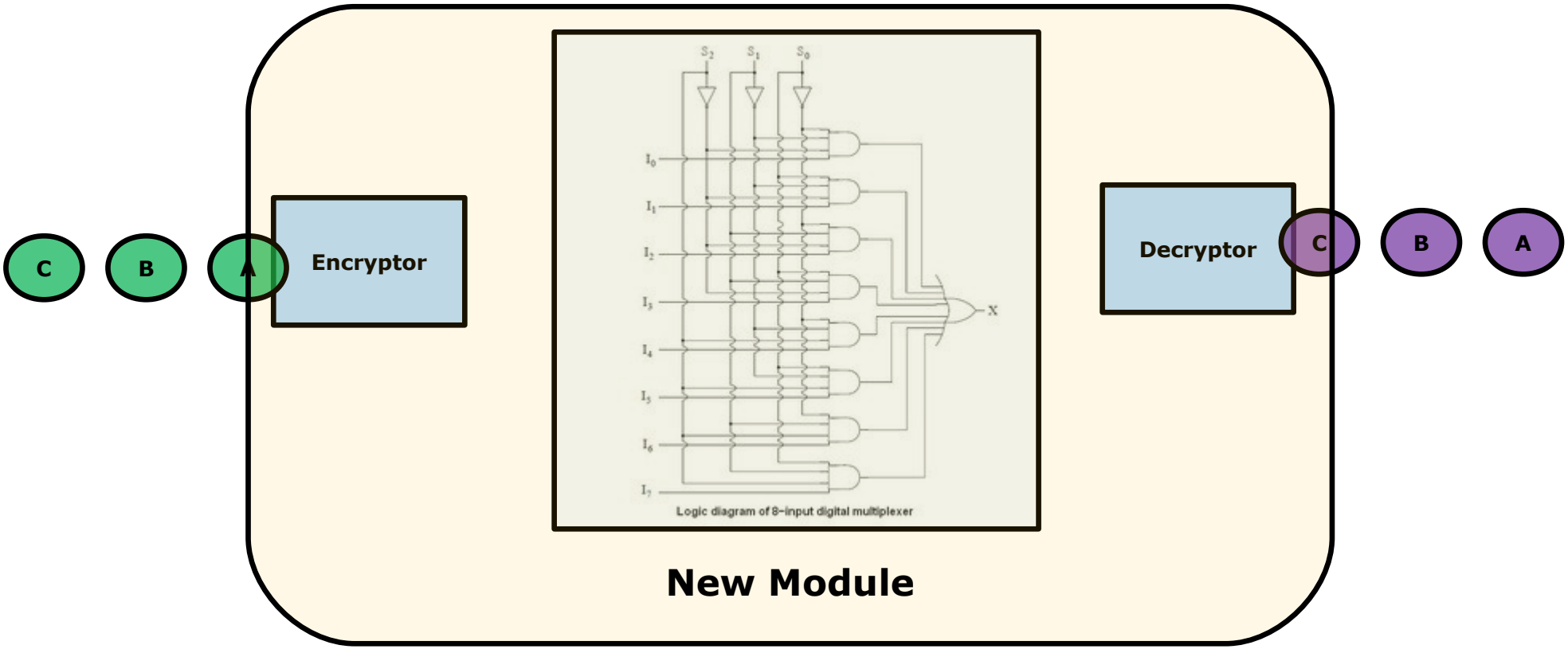
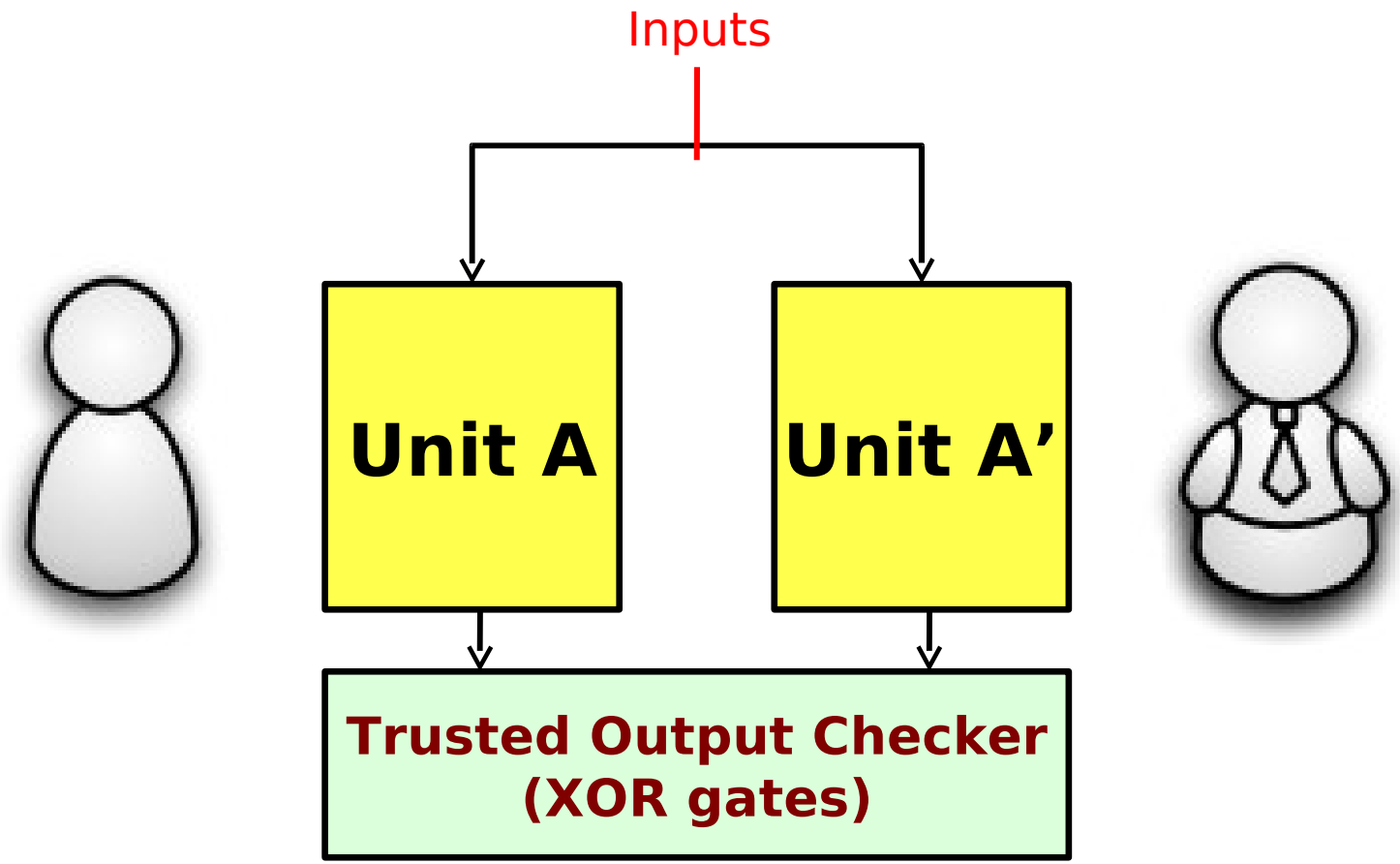


- Works for finite sets (not just ordered sequences)

Set is large enough for attacker to use ←→ Set is large enough for validation engineer to catch

(details in the paper)

Catch all: Duplication



- However, duplication is prohibitively expensive
  - Non-recurring design, verification costs due to duplication
  - Recurring power and energy costs

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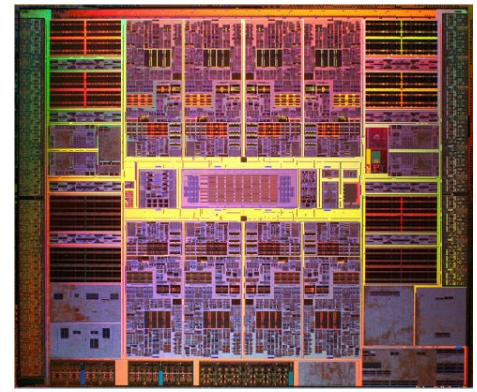
OpenSPARC Microprocessor Case Study

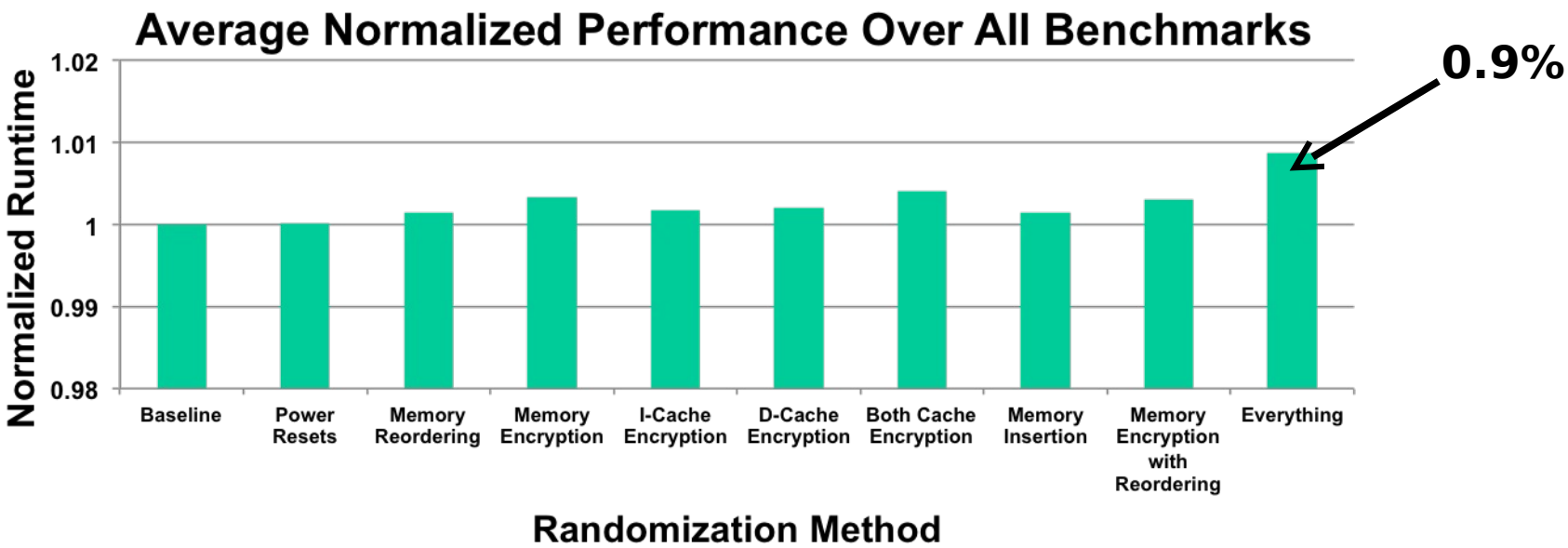
- Methodology
  - Manual analysis of modules in the design
  - Identified digital-only modules (nearly all)
- Power reset protection against ticking timebombs
  - Can be applied, can piggyback on power gating support
  - No non-volatile memories
- Obfuscation protection against single-shot cheatcodes
  - Data: > 3/4ths do not require non-trivial support
  - Control: Interfaces small enough to not be vulnerable
- Reordering protection against sequence cheatcodes
  - Must ensure that reordering does not violate memory reordering rules with respect to coherence and consistency
  - Most units, however, do not have these requirements

Performance Impacts

- OpenSPARC T2 microprocessor
  - Zesto X86 simulator



- Performance cost of all methods is < 1% on average
  - Precise breakdowns in the paper



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- Secure usage of non-volatile memory technologies
  - Incorporate non-volatile memory in a trusted way
    - Improvements to and increased use of Flash
    - PCM and other new technologies

Open Problems

- Secure design of performance counters
  - Provide information to users in a trusted way
    - Performance counters are increasingly used
    - Directly supply trigger-type information

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    - Units classified by type
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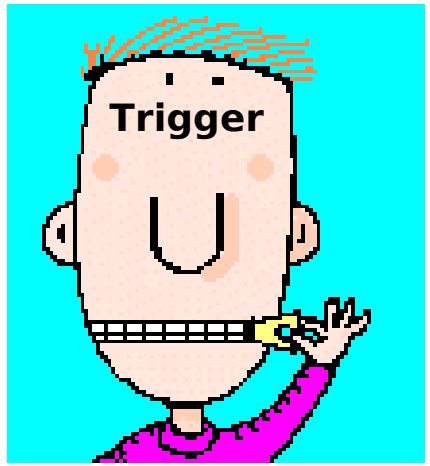
    - Units classified by type
    - Formal understanding of costs
- Automated implementation of backdoor protection
  - Compiler and/or language additions
    - Tools for designers
    - Simple language constructs for HDLs

Summary

- Prevent the triggering of hidden backdoors
  - Hardware-only solution
    - Low performance impact
    - Low power/area overhead
  - Prototyping required
  - Revealed new open problems
    - Challenges for processors/embedded systems
    - Linguistic challenges
- Vastly raises the bar against hardware backdoors



Thank You! Questions?