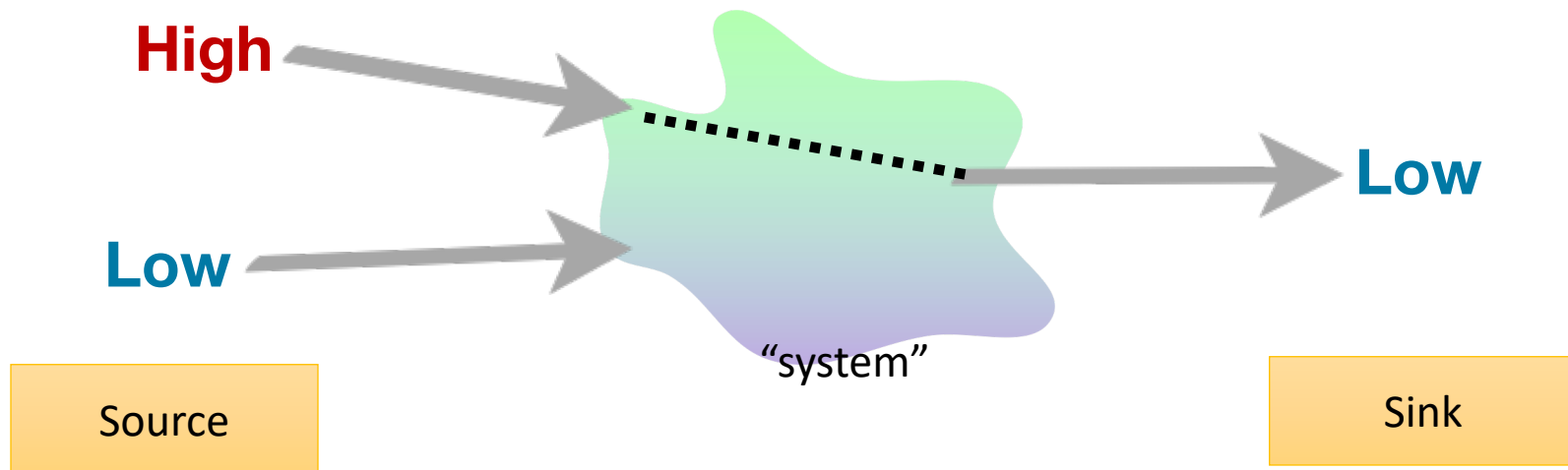# Complete Information Flow Tracking from Gates Up

Mohit Tiwari, Xun Li, Hassan M G Wassel, Frederic T Chong, Timothy Sherwood

Presented by Mengjia Yan
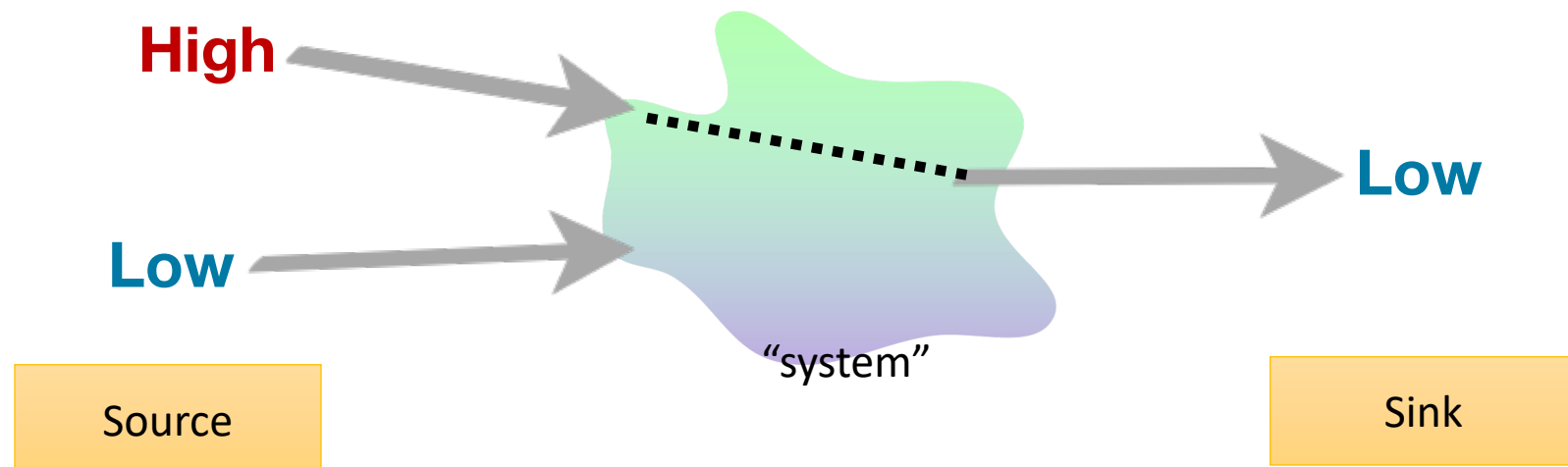
Based on slides from Mohit Tiwari
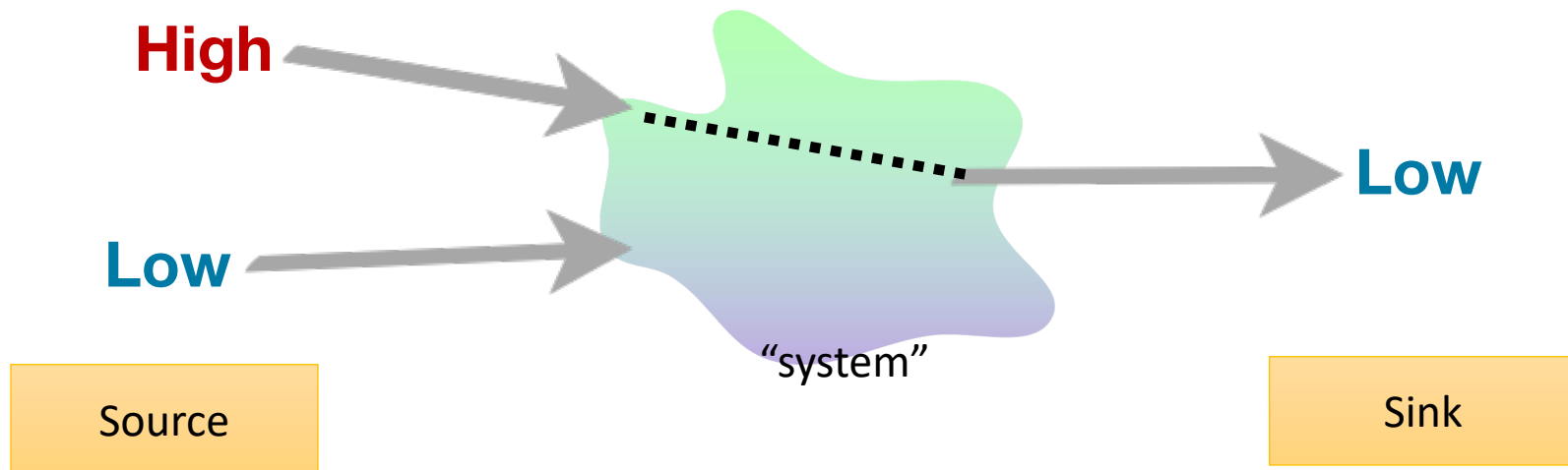
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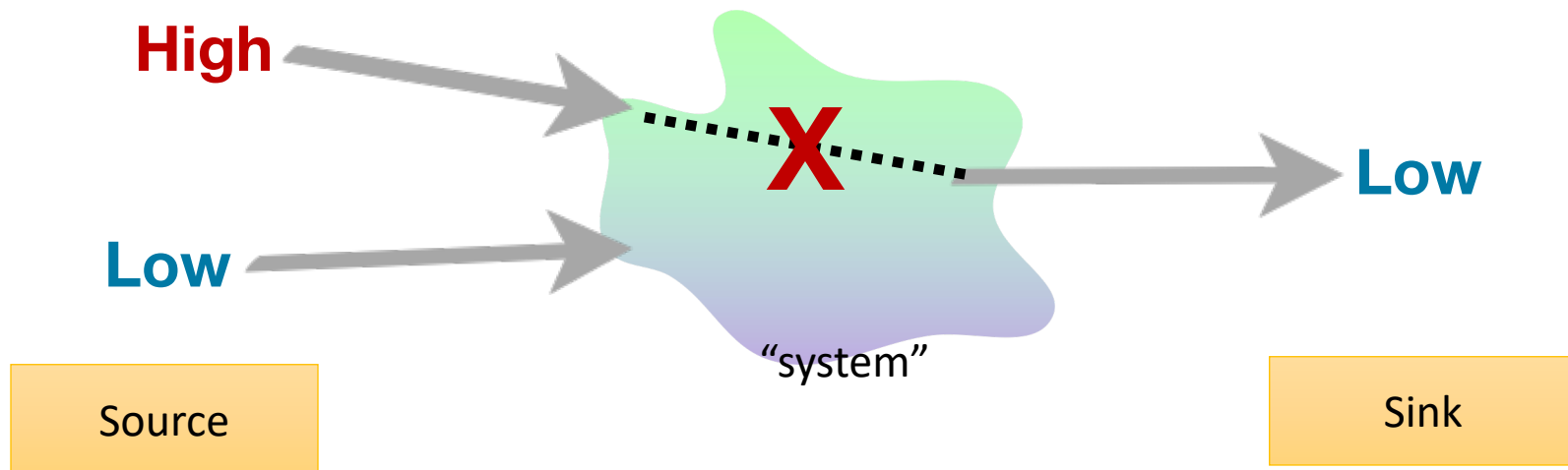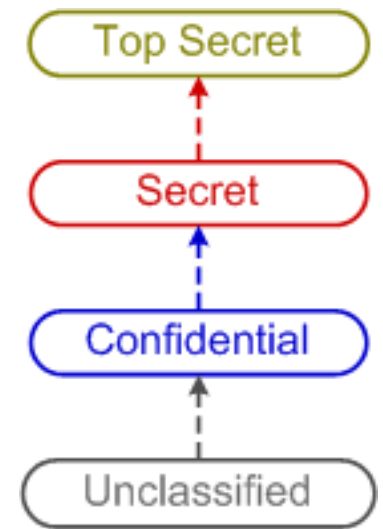
High

Low

Low

"system"

Source

Sink

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High

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X

"system"

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Information Flow for Privacy

- General lattice policies
- Secret vs. Unclassified Data
  - Secret: data with restricted access permission
 - Unclassified: data with unrestricted access

Information Flow for Privacy

- General lattice policies
- Secret vs. Unclassified Data
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- Enforce the property of non-interference:
  - Verify information never flows from high to low.
  - Secret information is never used to modify unclassified data
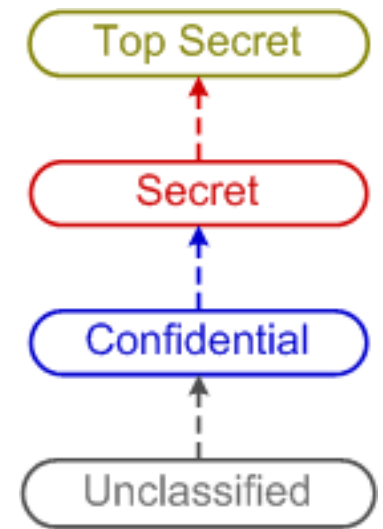
Information Flow for Integrity

- Trusted vs. Untrusted Tasks
  - Trusted: processes which are critical to the correct functionality of the space vehicle systems
  - Untrusted: mission processes, diagnostics, anything whose malfunction will not cause a vehicle loss

passenger → router →

avionics → X →
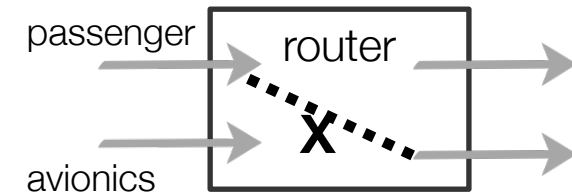
Information Flow for Integrity

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- Enforce the property of non-interference:
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  - Untrusted information is never used to make critical (trusted) decisions nor to determine the schedule (real-time)
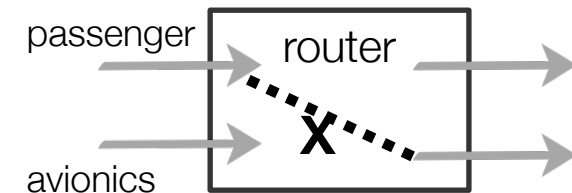
Threat Model

- Low output can include
  - Program output
  - Timing
  - Contention on system resources

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  - Program output
  - Timing
  - Contention on system resources

- Not include
  - Untrusted hardware component problem
  - Physical attacks that may tamper with memory
  - Non-digital side-channel attacks (power distribution and RF signals)

Highlights

- A secure SW/HW co-design **which is verifiable**

- Gate-level information flow tracking
  - More precise than conventional IFT

- ISA restrictions to prevent **taint explosion**
  - Handling conditional branch
  - Handling loops
  - Handling loads/stores

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A new way to look at IFT from a new perspective.

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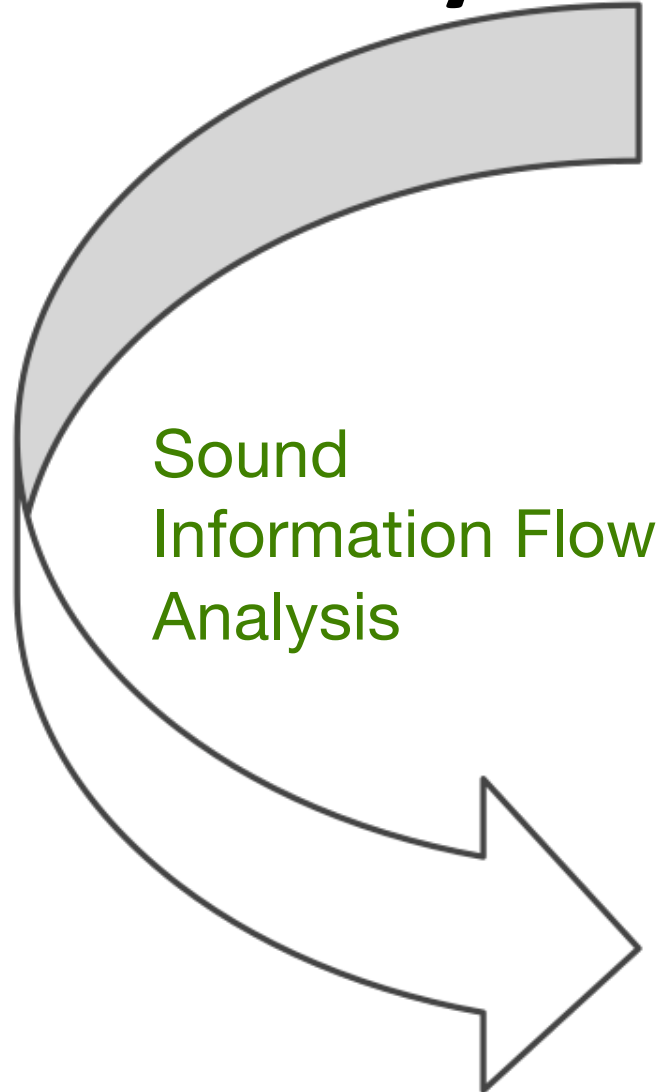A new way to look at IFT from a new perspective.

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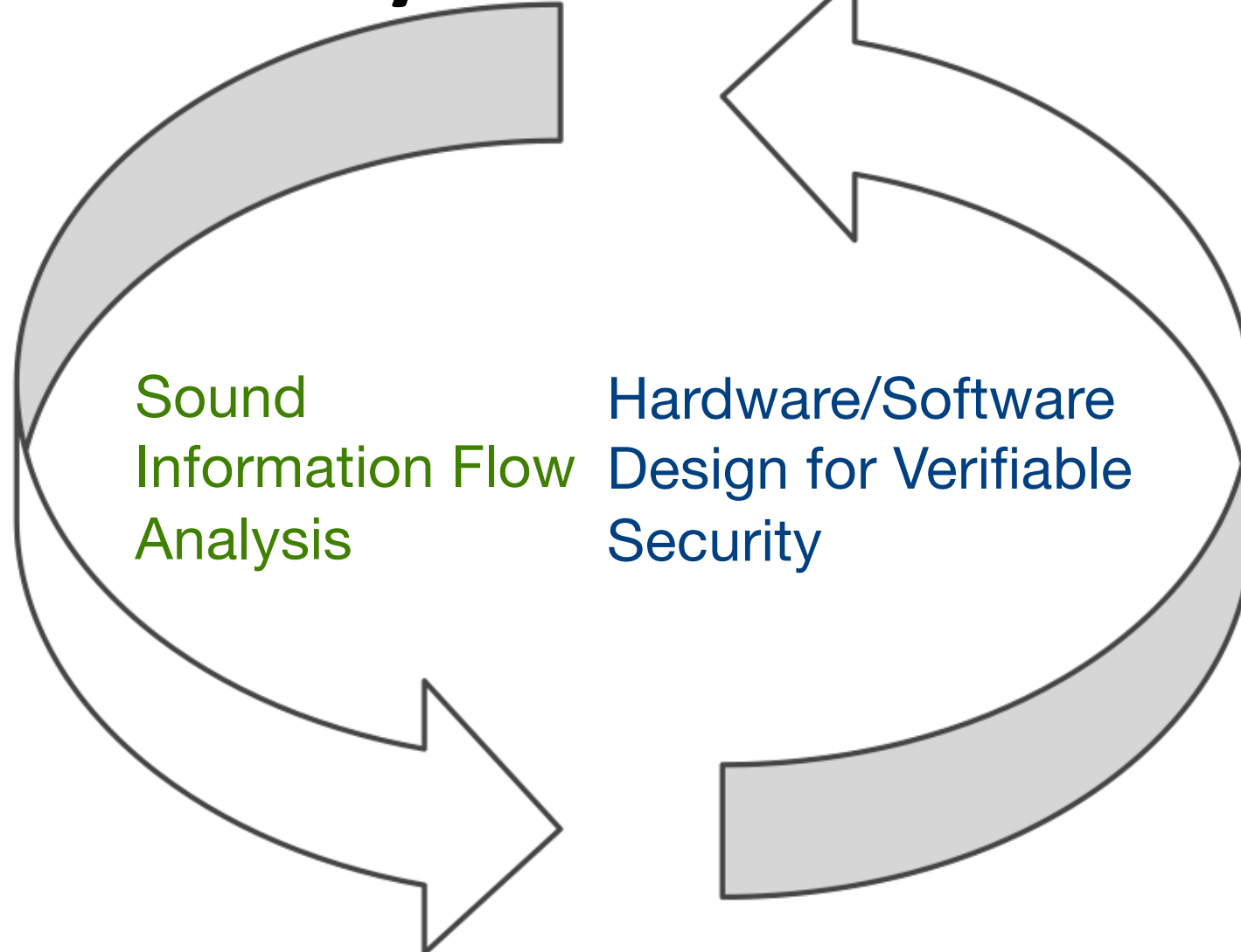
Usage: GLIFT + Information Flow Policy

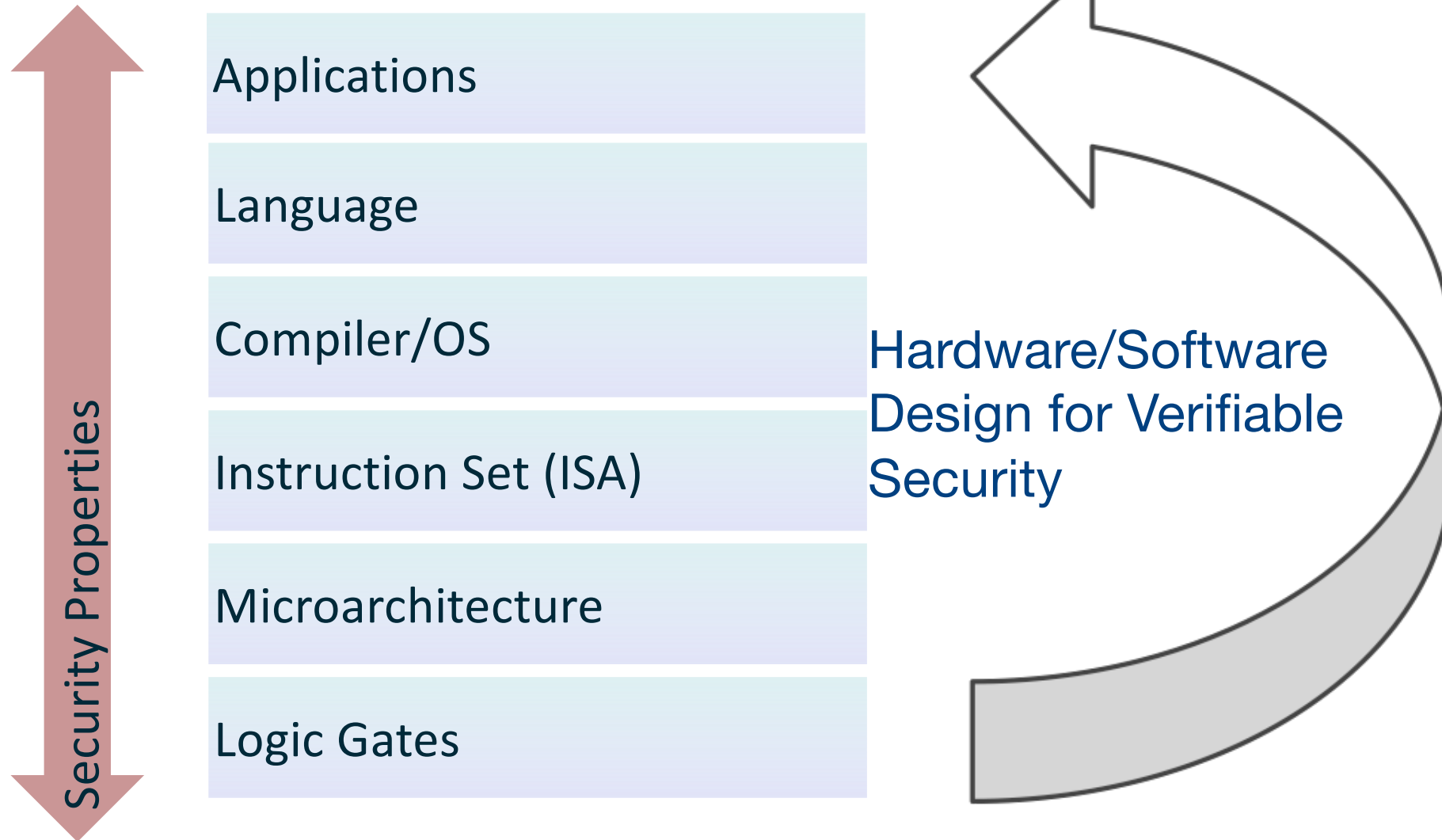# The Vision: Hardware Design for Software Security Verification

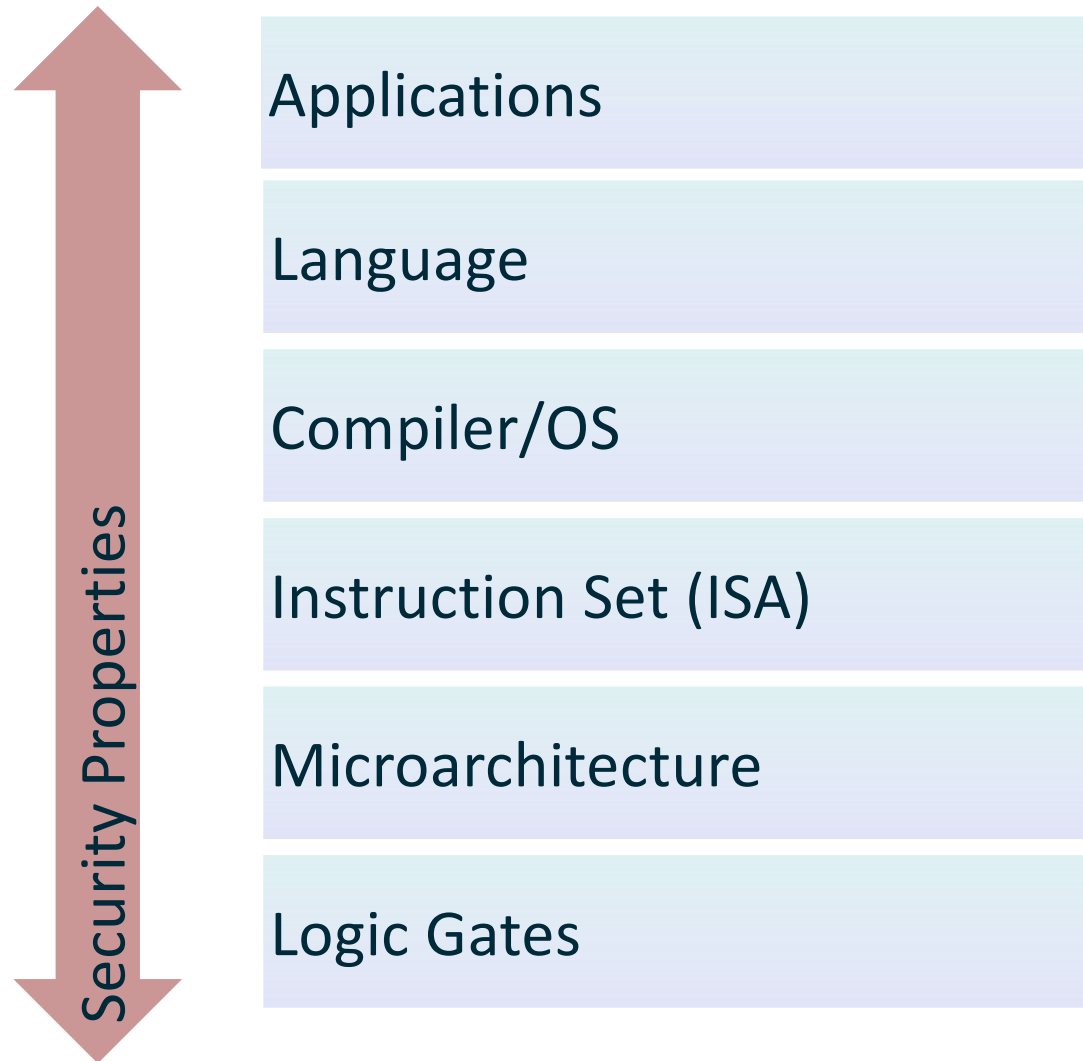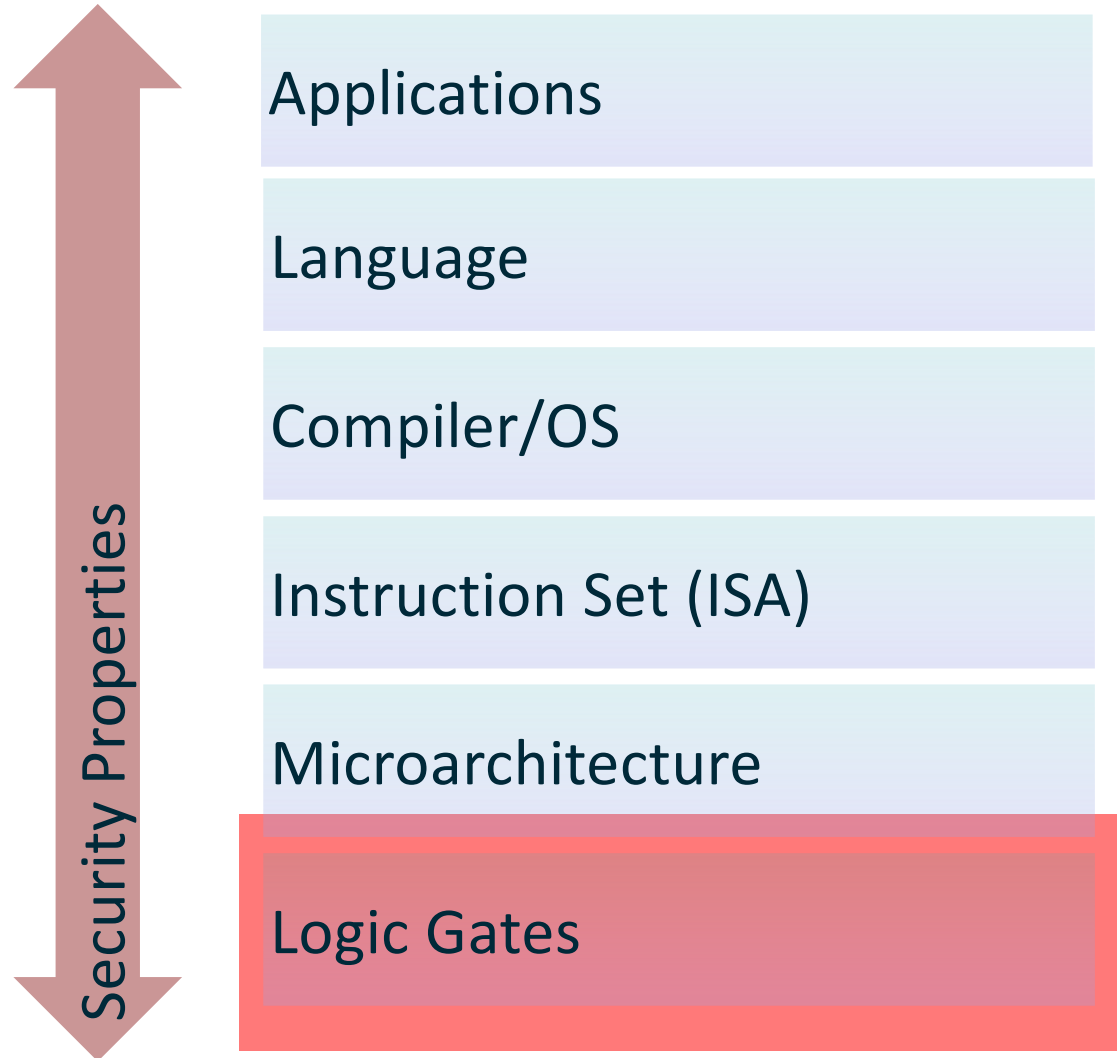# The Vision: Hardware Design for Software Security Verification

Sound Information Flow Analysis

The Vision: Hardware Design for Software Security Verification

Sound Information Flow Analysis

Hardware/Software Design for Verifiable Security

The Vision: Hardware Design for Software Security Verification

Security Properties

- Applications
- Language
- Compiler/OS
- Instruction Set (ISA)
- Microarchitecture
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$$
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&\text{if } (high == 1) \\
&\quad out1 = 1 \\
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\end{aligned}
$$

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Static and Dynamic Information Flow Tracking

out1 = ld(high)

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Static and Dynamic Information Flow Tracking

- Static analysis is conservative (need alias analysis for precise results)
- Dynamic analysis has difficulty in analyzing implicit flow

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Static and Dynamic Information Flow Tracking

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$$out1 = ld(high)$$

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out2 is tainted if the address or the memory value is tainted

(explicit flow)

if (high == 1)

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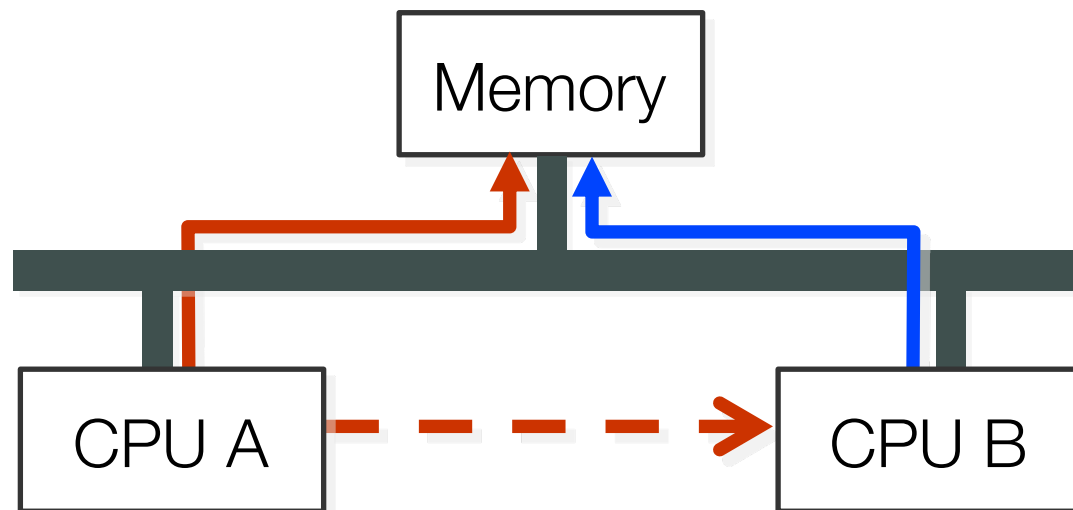
The paper addresses two challenges

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- How to account for all information flows in a system?
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- How to construct practical systems that won't leak?
  - → Use the concept of GLIFT to guide the design

High-level View: Track all flows
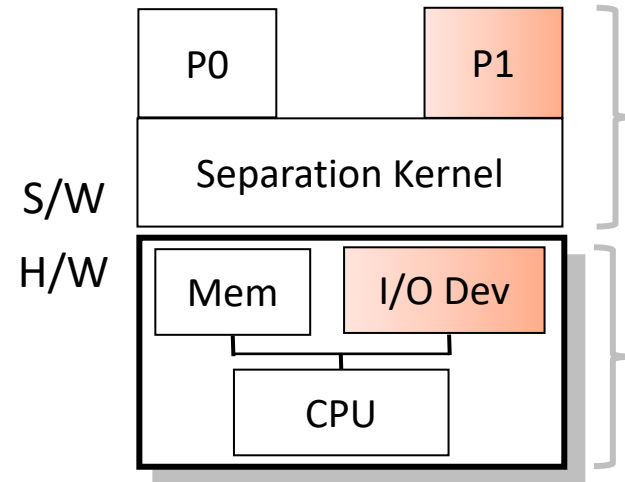
Secure System

High-level View: Track all flows

Secure System

Equivalent State Machine
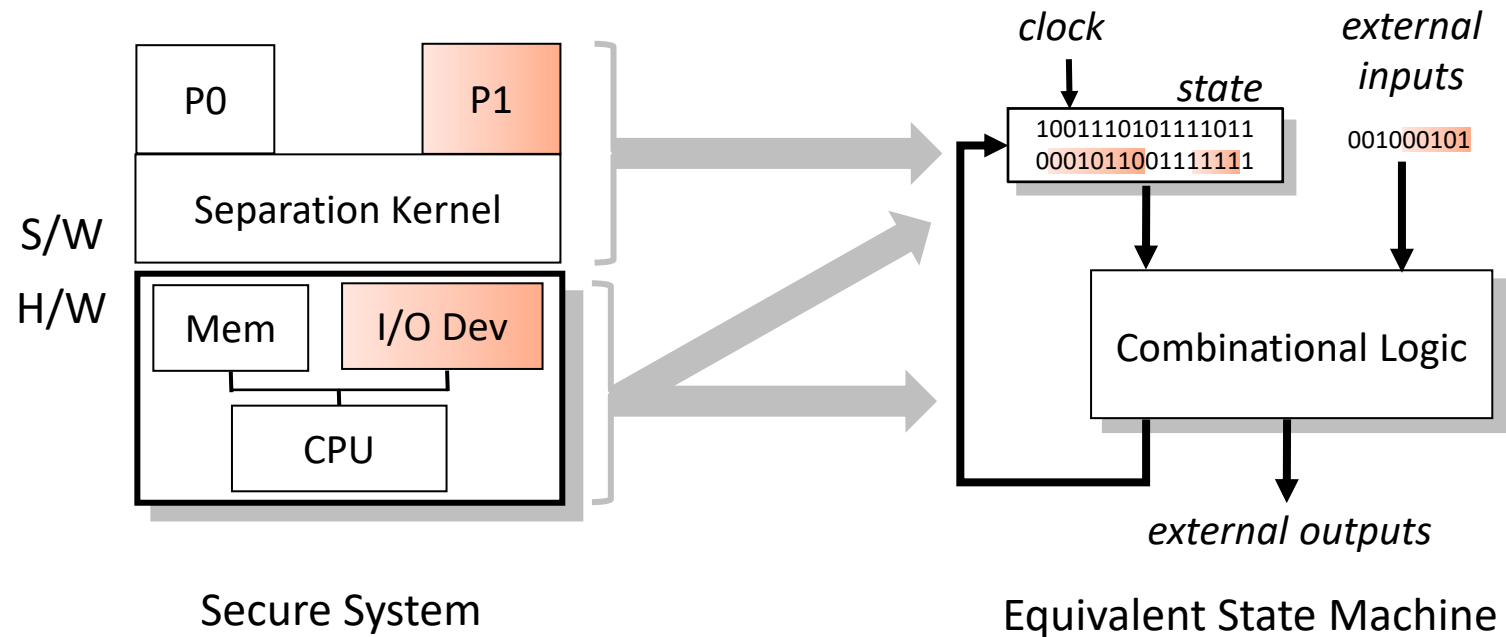
- Flatten design to a (giant) state machine

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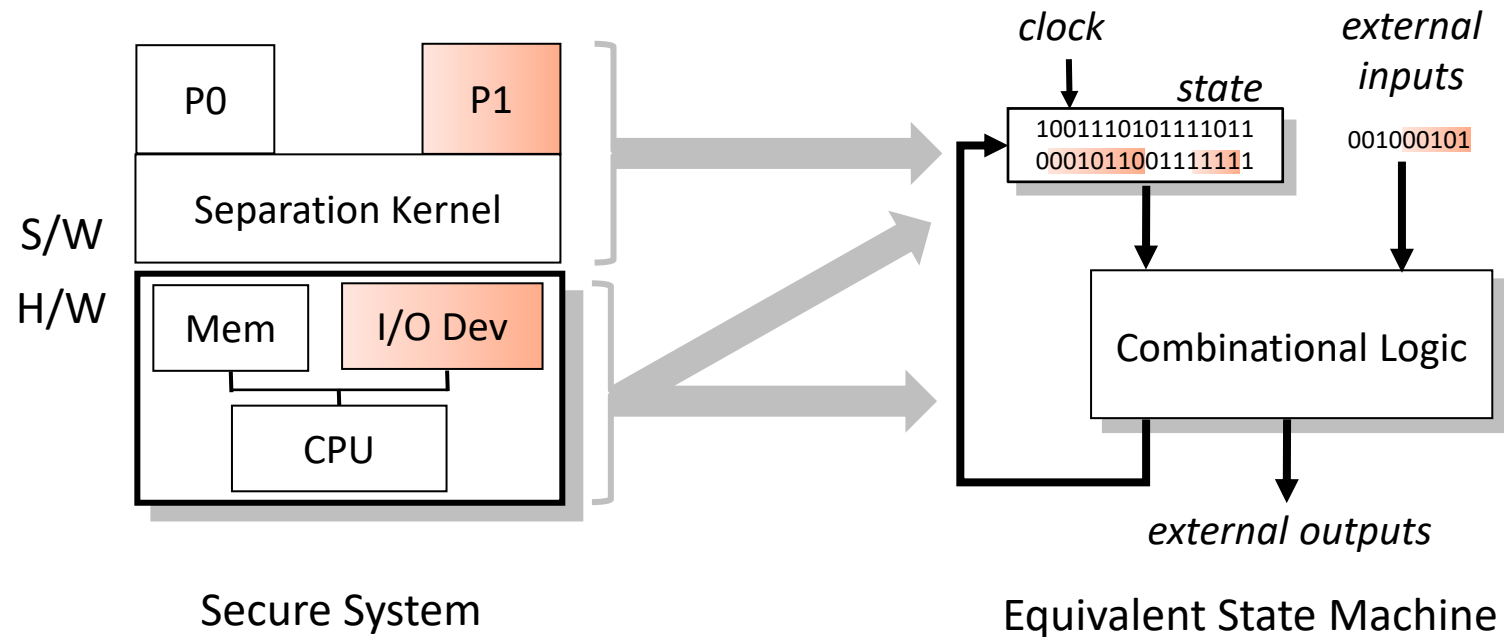
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Equivalent State Machine

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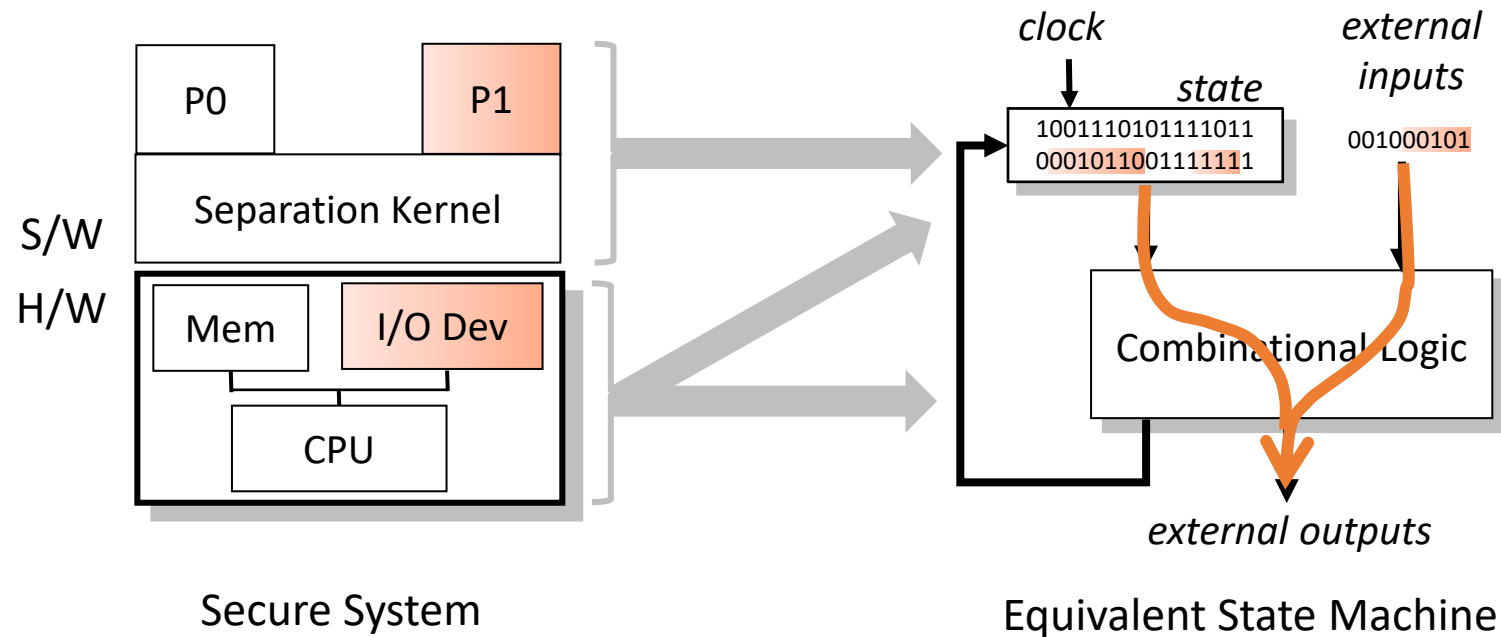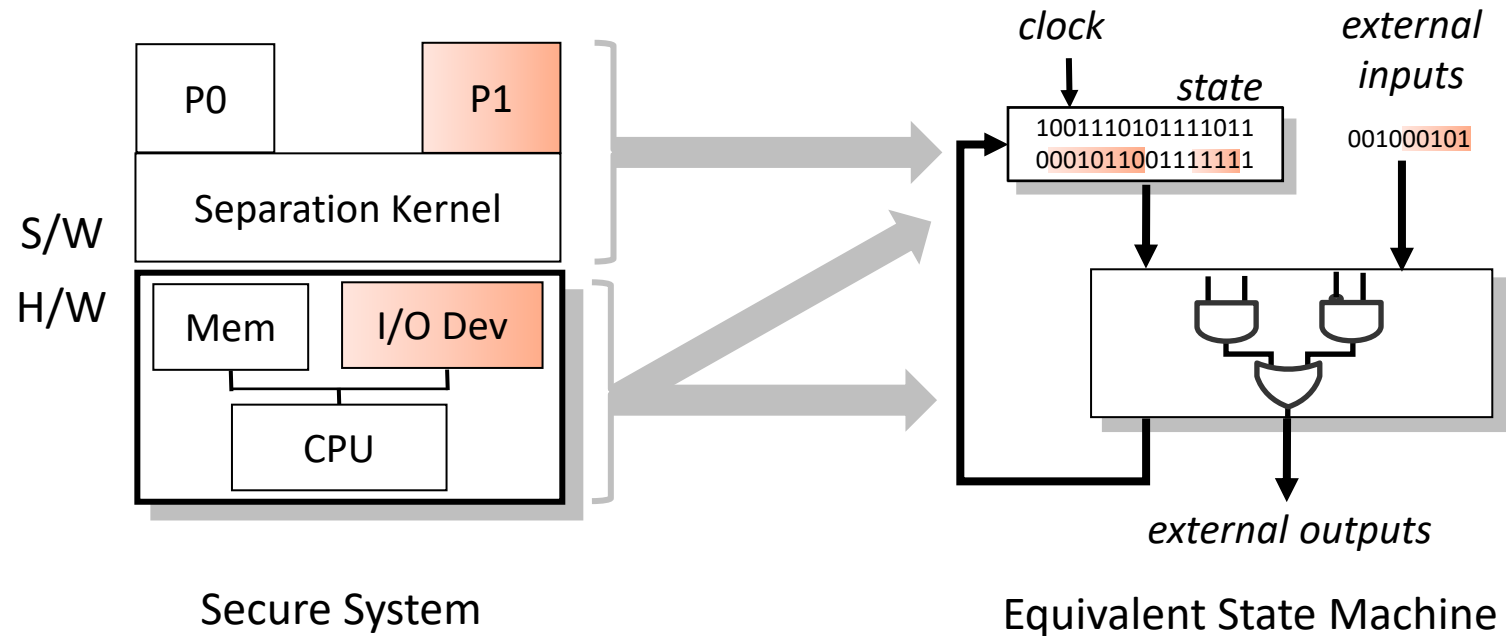
- Insight: All flows explicit at the gate level

High-level View: Track all flows

Secure System

Equivalent State Machine
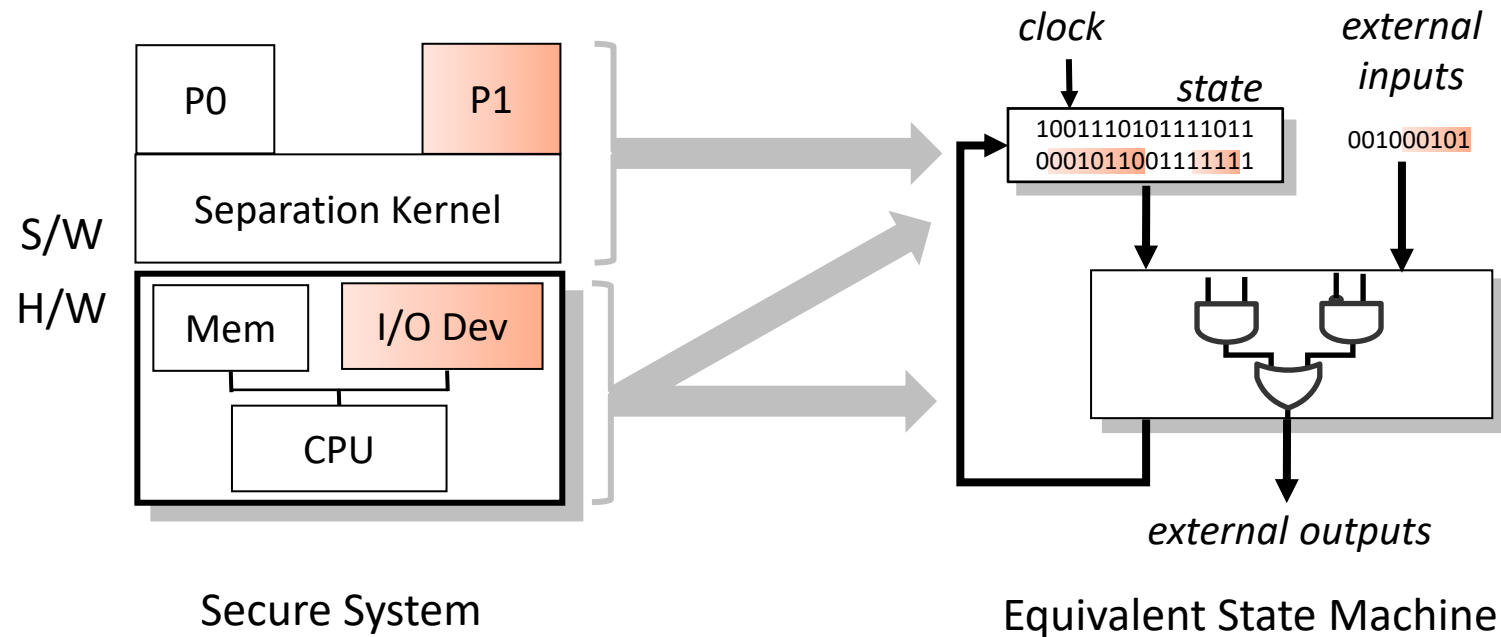
- **Outputs:** Logic function of state and inputs
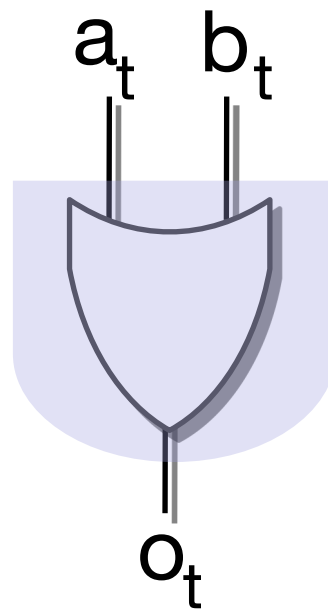- **Output Labels:** Logic func. of state, inputs, and labels

Analysis Technique: GLIFT
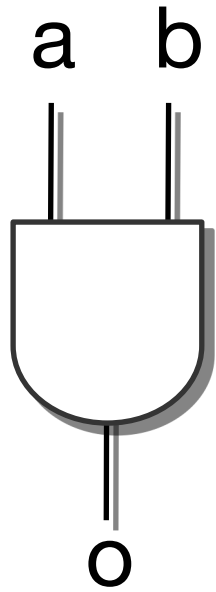
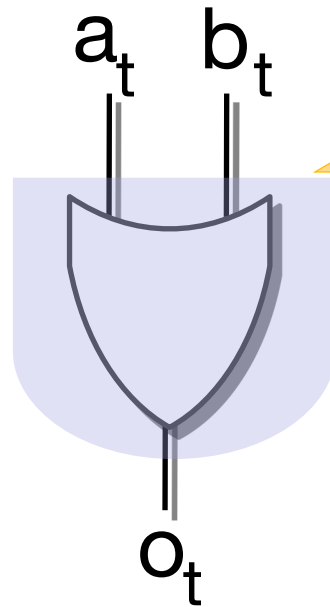a   b

o
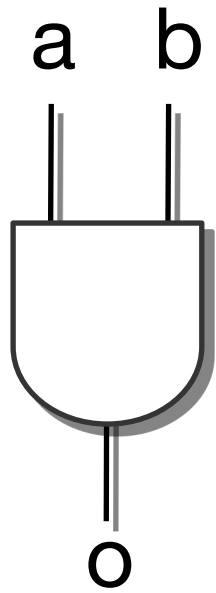
AND

Analysis Technique: GLIFT

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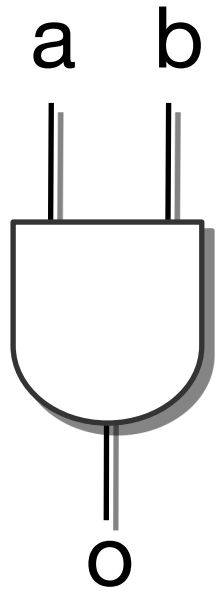
Shadow AND for labels

Analysis Technique: GLIFT

a   b

a_t b_t

o

o_t

Conservative.

If one of a and b is tainted, the output is tainted.
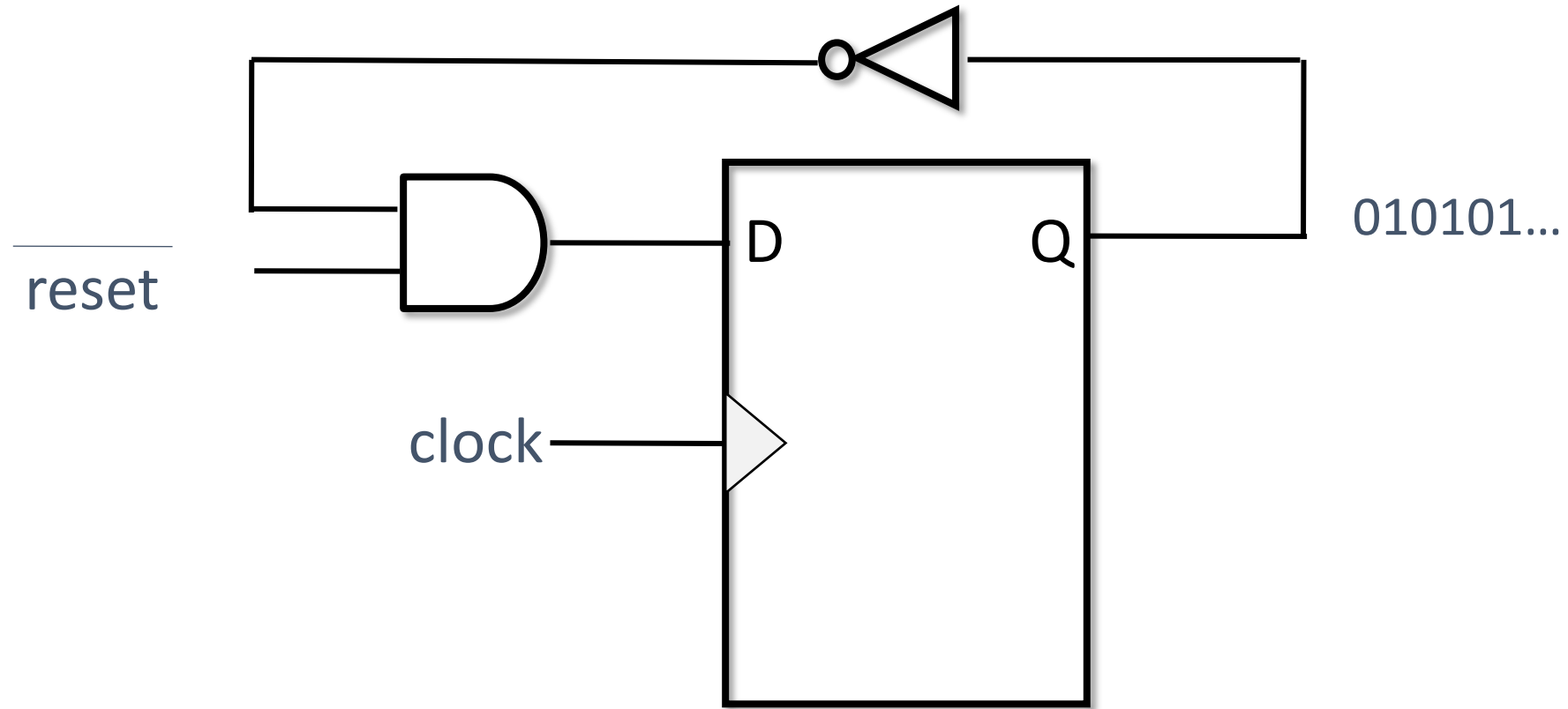
AND

Shadow AND for labels

Motivation: Require Precise Information Flow
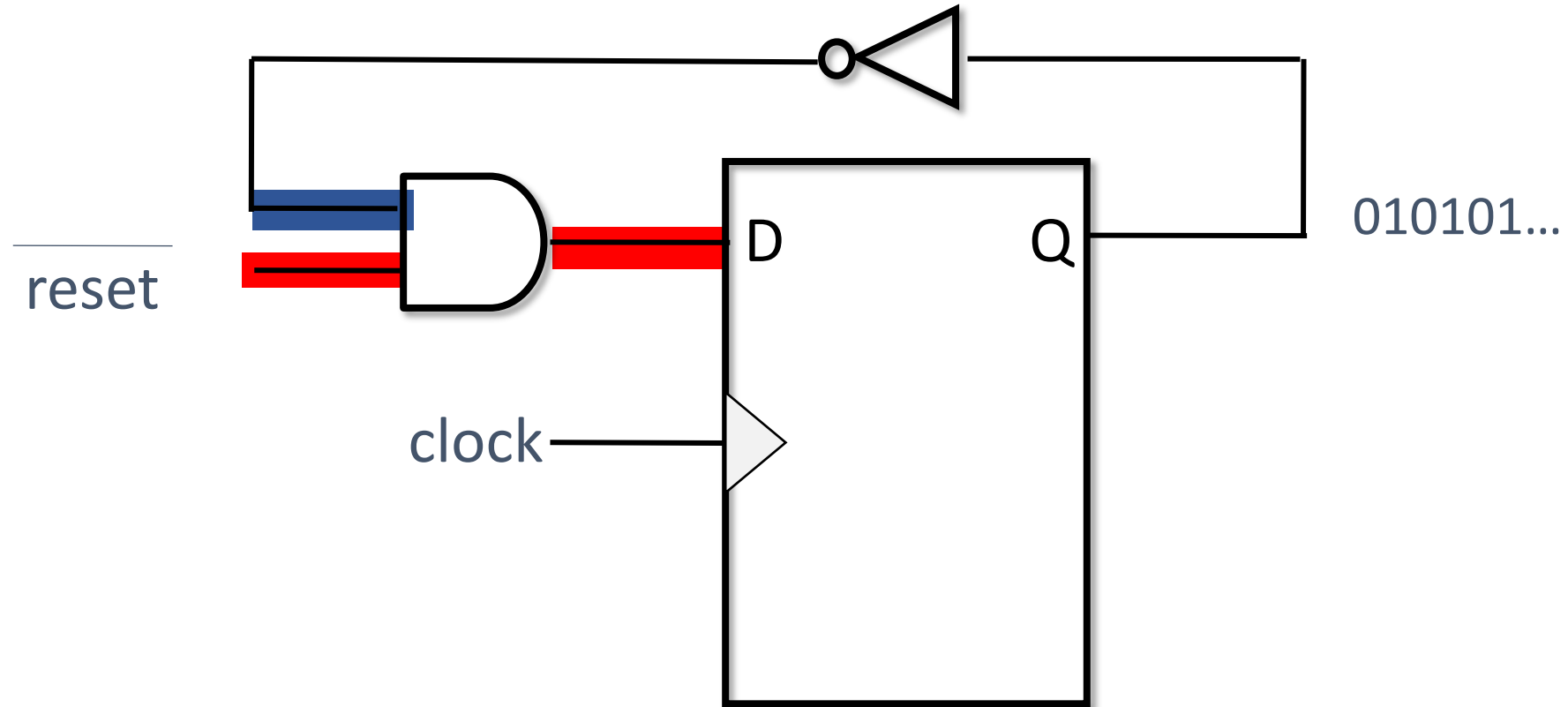

reset
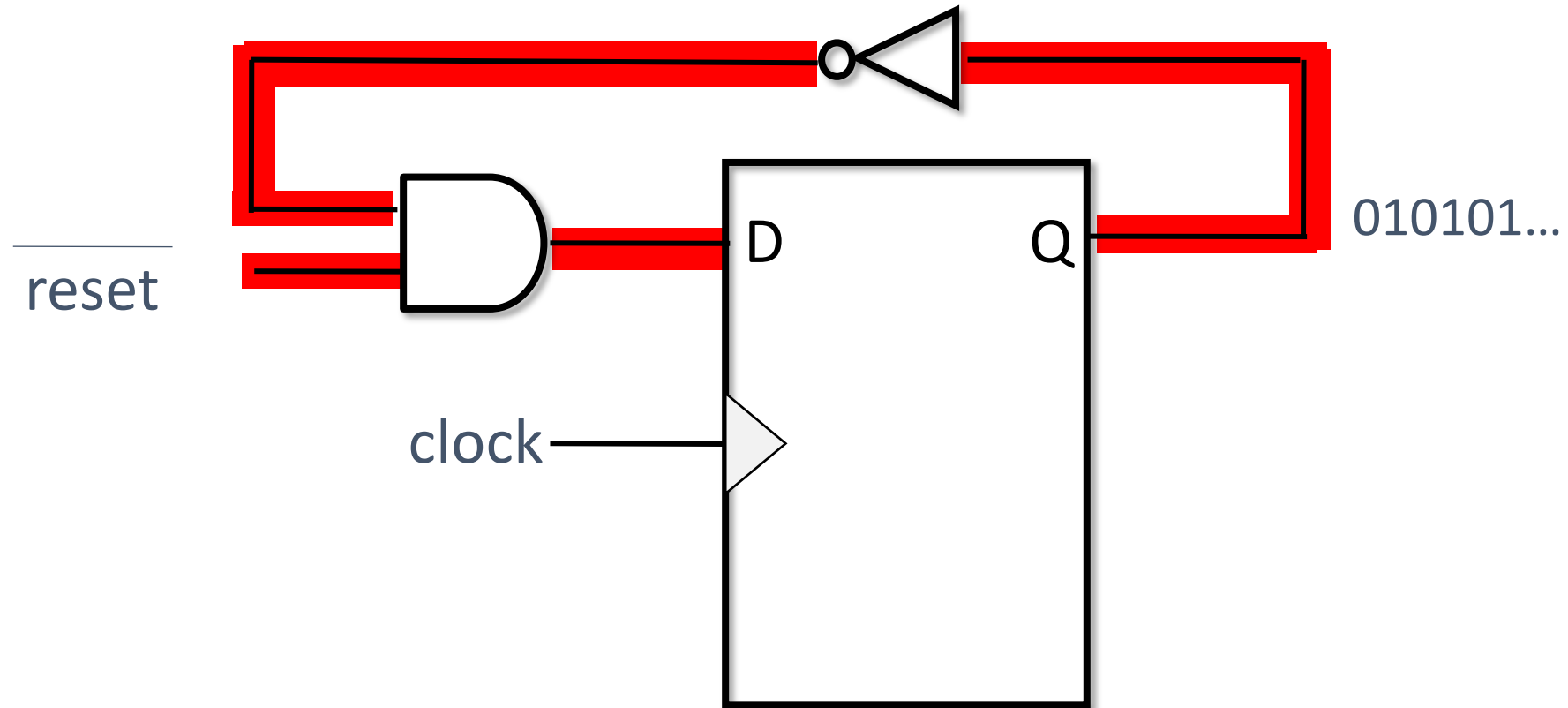
clock

D

Q

010101…

• Conventional OR-ing of labels *monotonic*

Motivation: Require Precise Information Flow

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010101…

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clock

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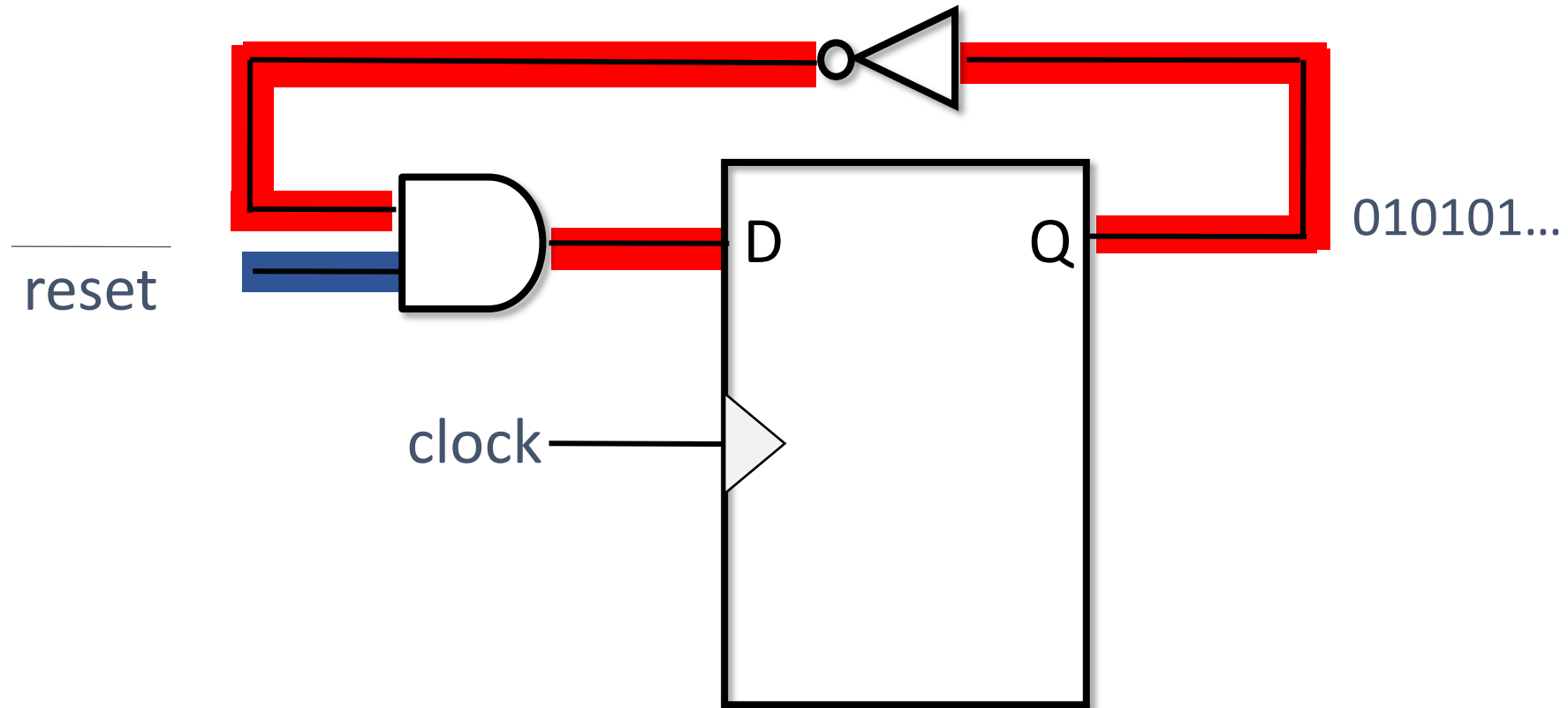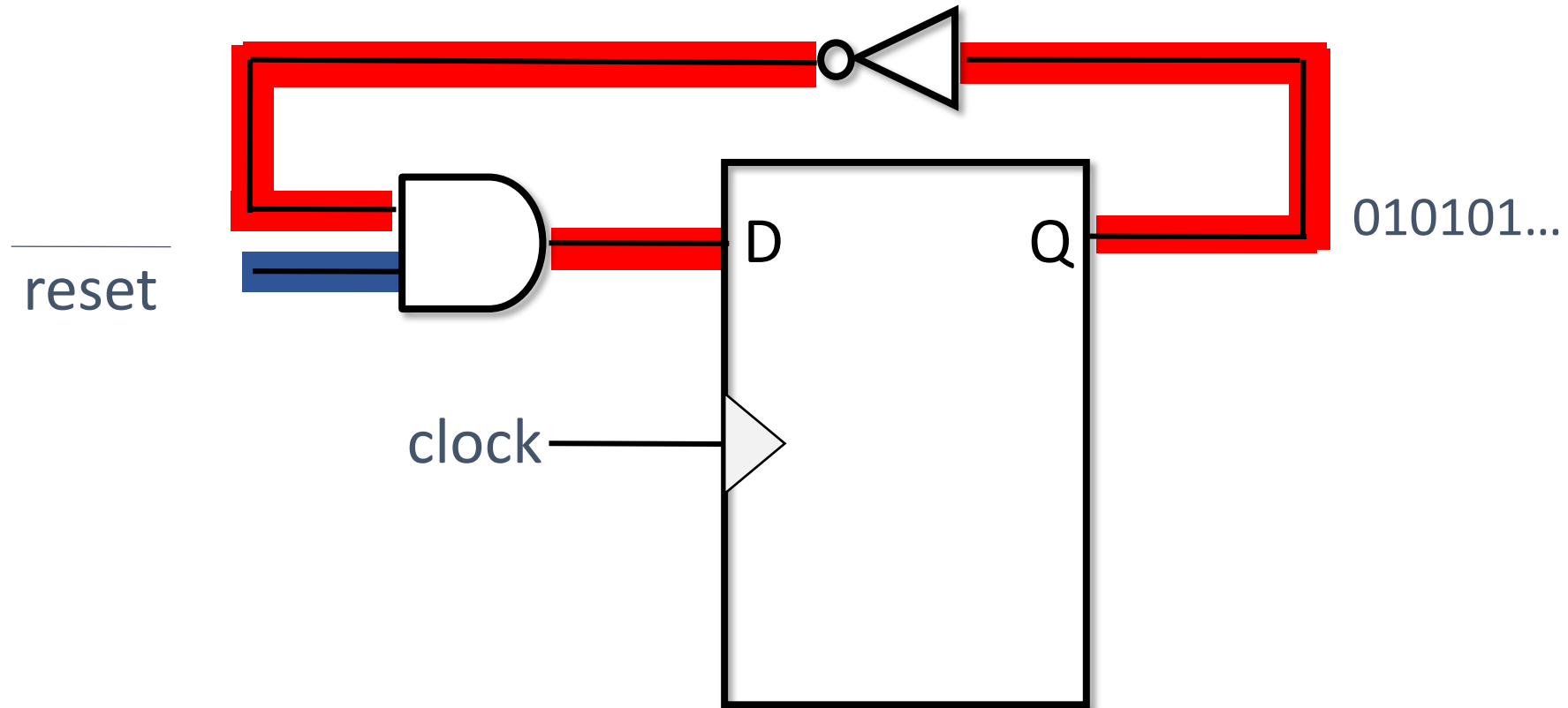reset

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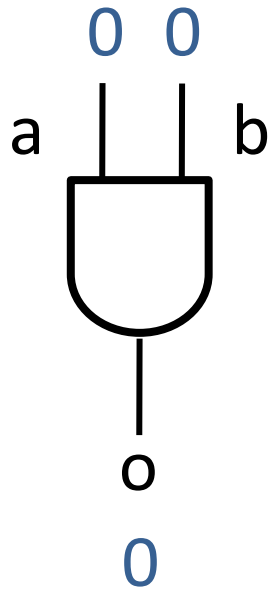
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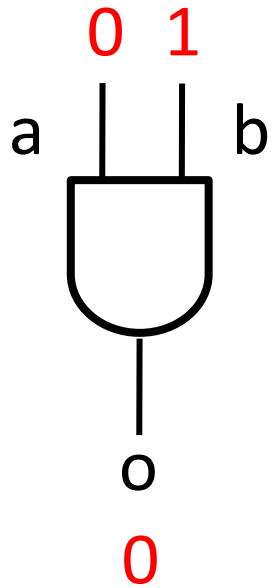
reset

clock

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Precise Information Flow: AND Gate

untainted   tainted

a	b	o
0	0	0

Precise Information Flow: AND Gate

untainted   tainted

a	b	o
0	0	0
0	1	0

0 1

a   b

o

0

Precise Information Flow: AND Gate

0 1

a ___ b

o

0
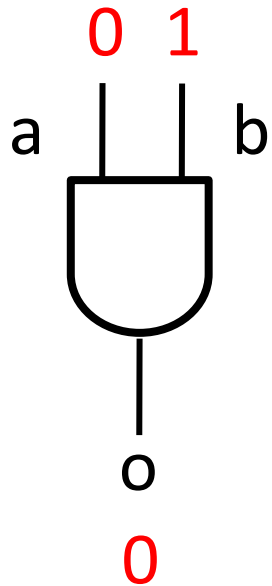
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When a=0, b can not affect the value of the output.
→ no-interference

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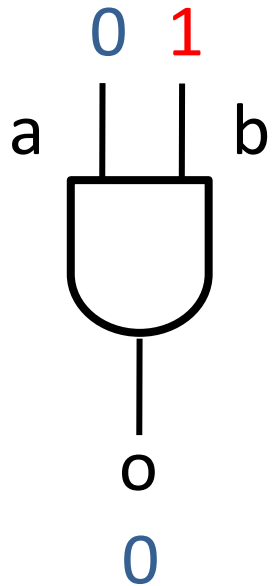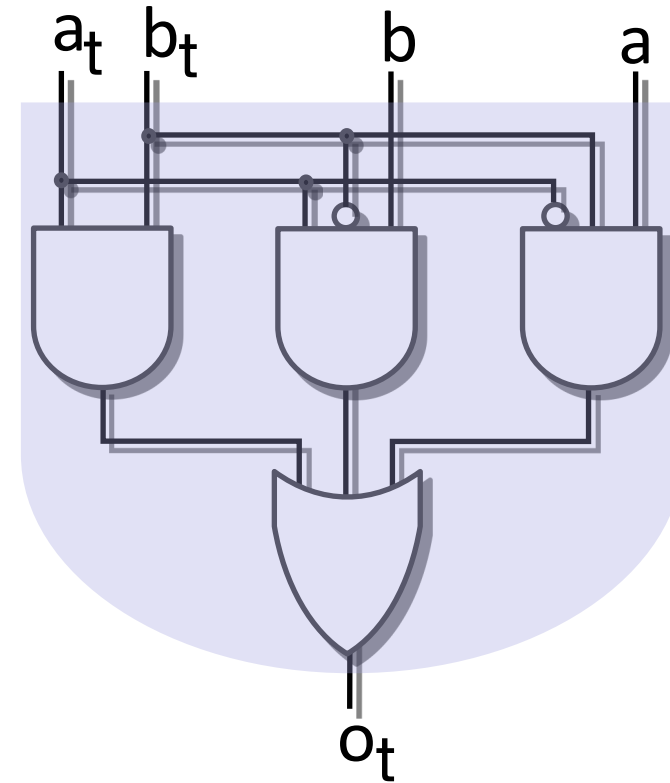
a	b	o
0	0	0
0	1	0
1	0	0
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0	0	0
0	1	0

0   1

a   b

o

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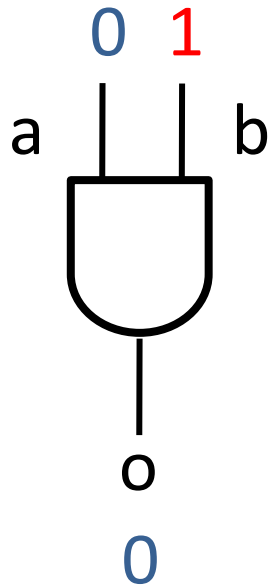
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Use both inputs and input labels

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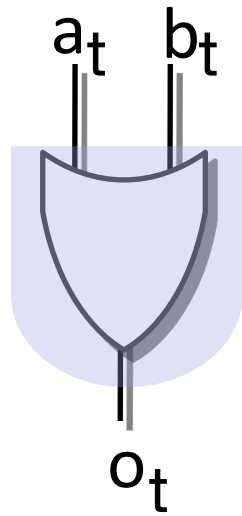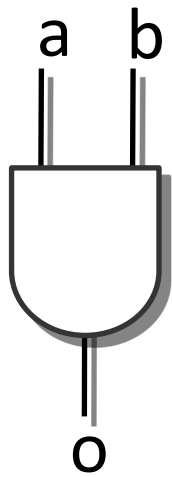
Sound Composition of Shadow Logic
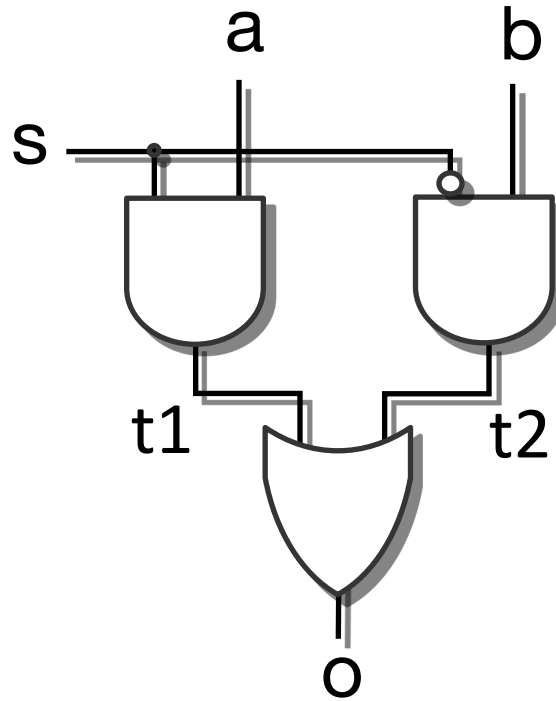
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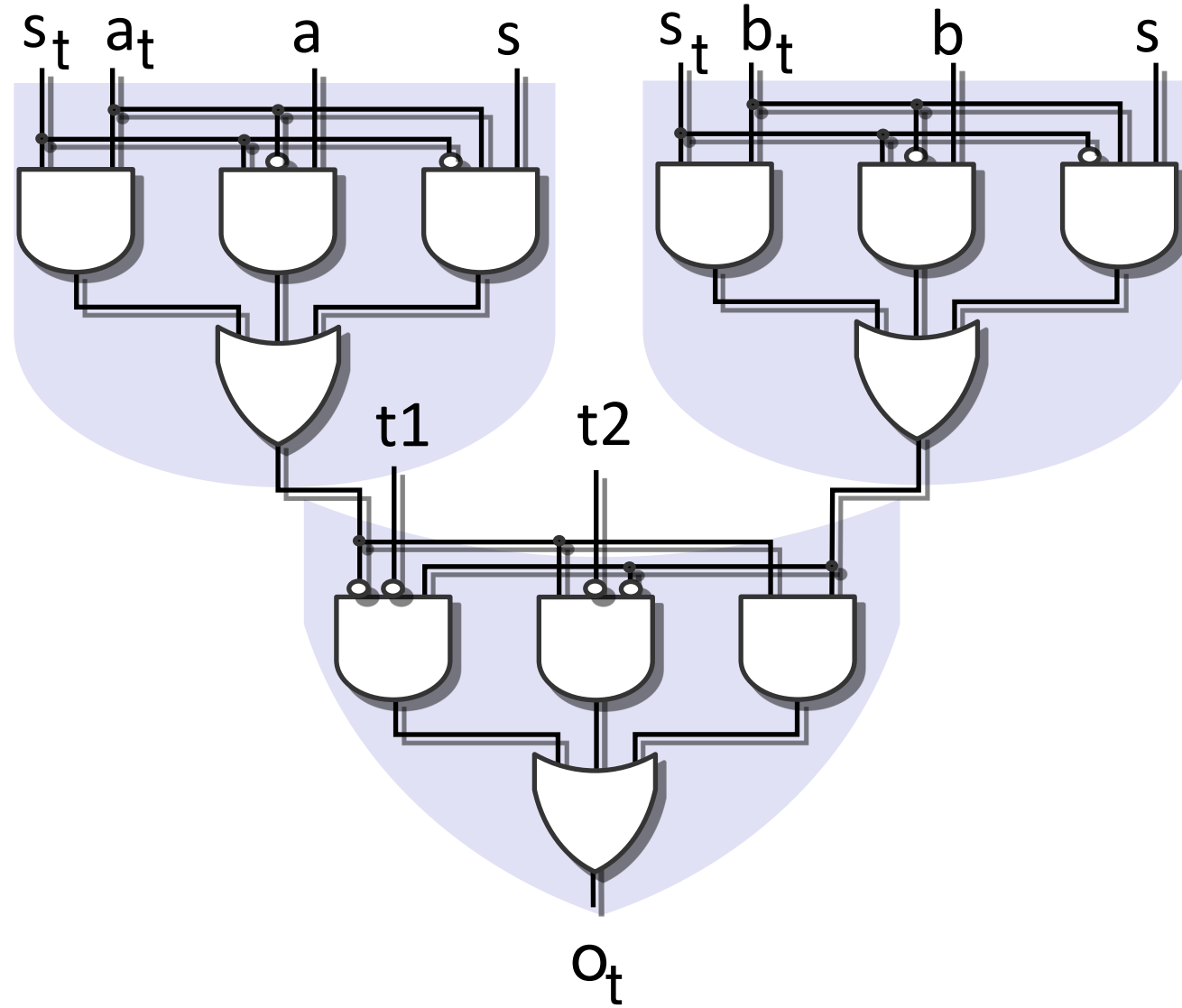
MUX: Gatekeeper of trust
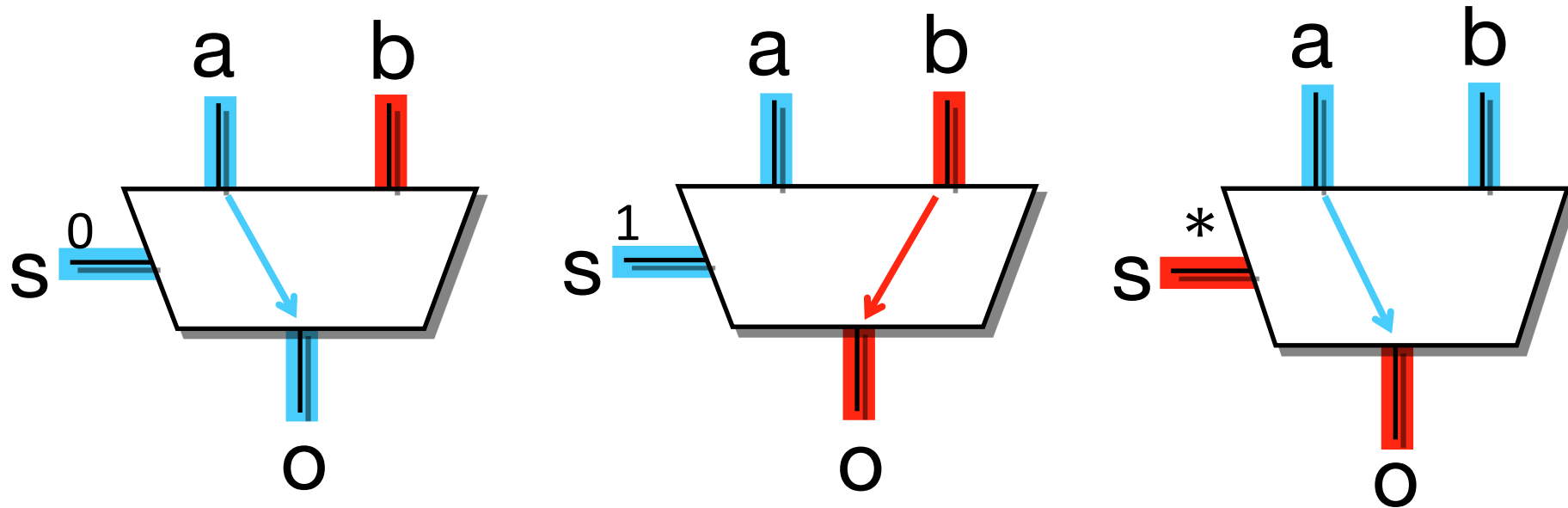
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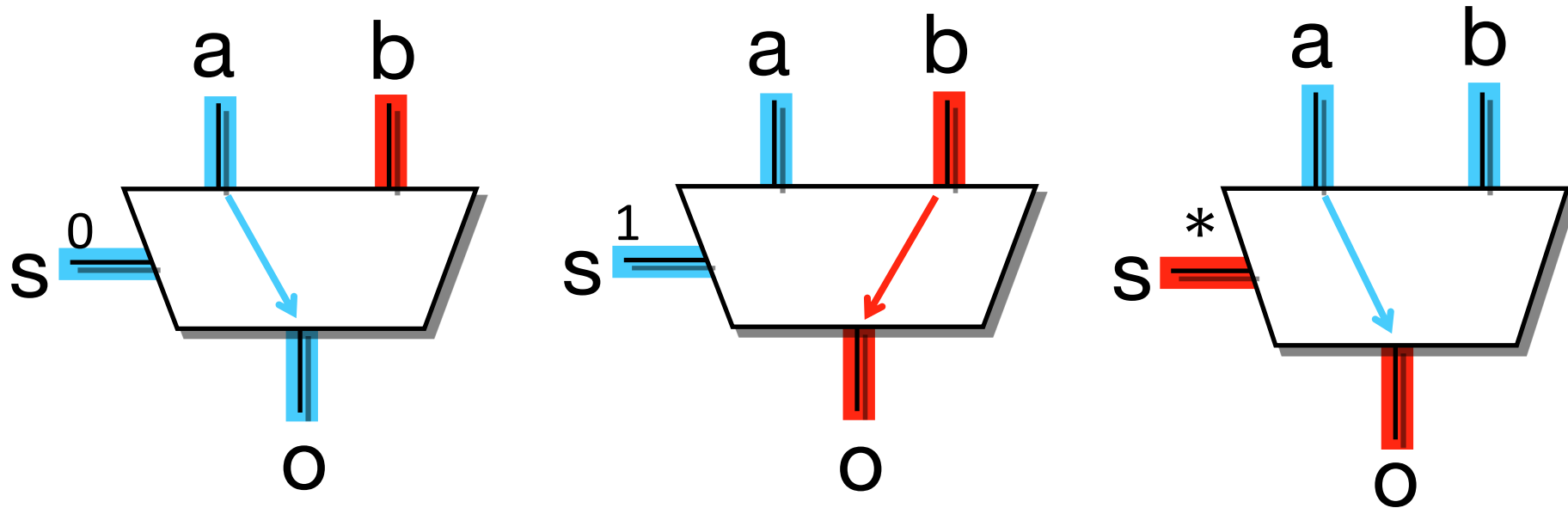
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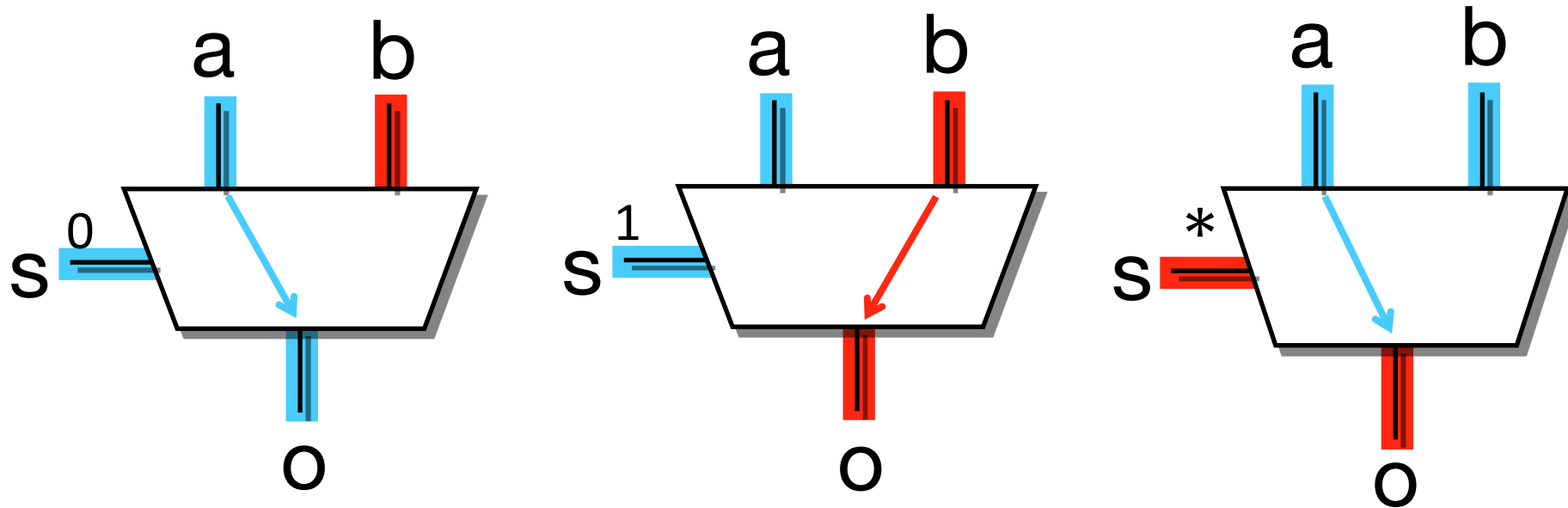
Implicit Information Flows: Taint Explosion

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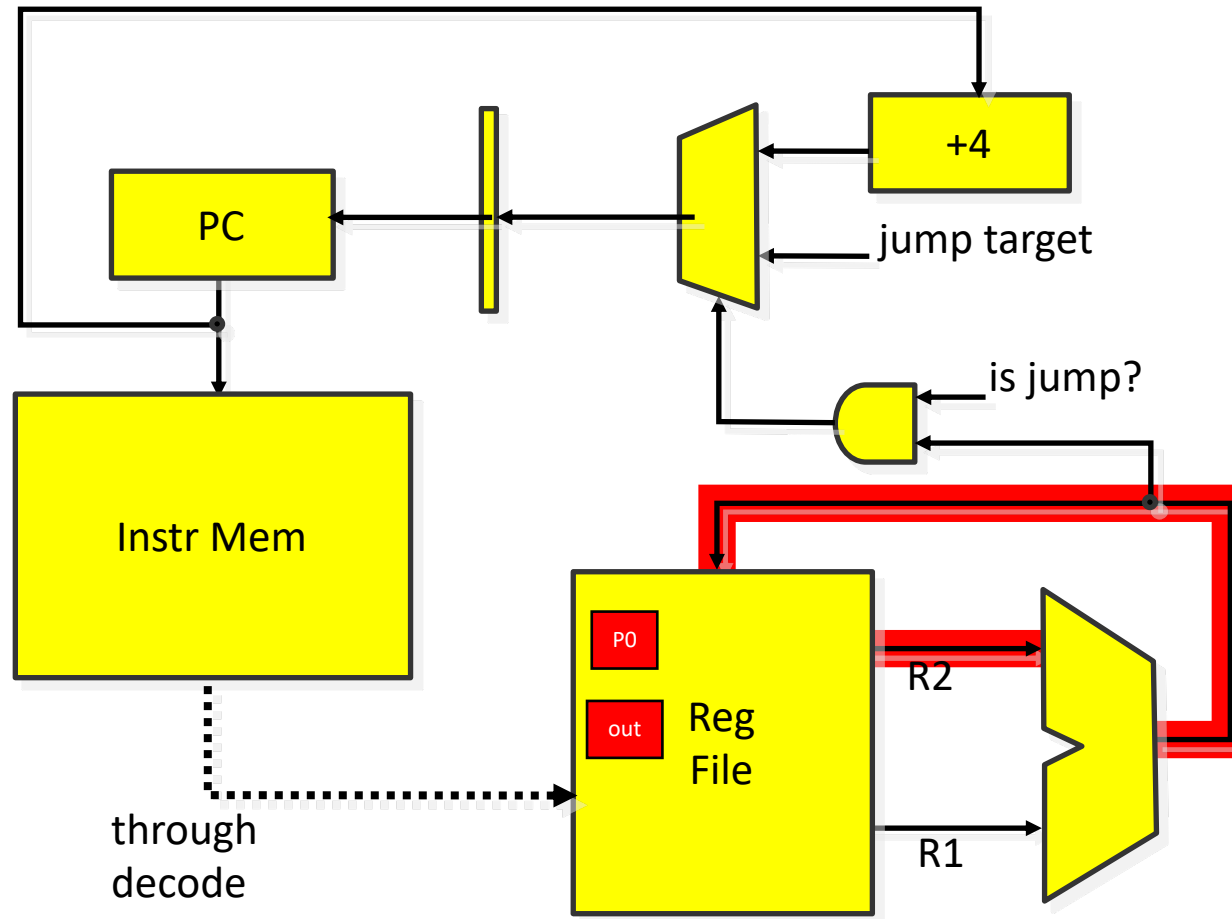
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- Recommend to read their follow-on work:
  - *Execution Leases: A Hardware-Supported Mechanism for Enforcing Strong Non-Interference*; Tiwari et al.; MICRO'09

Evaluation

+ Security

- Area overhead/Power consumption

- Performance overhead

- Programmability

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Appropriate use cases:
- When critical or sensitive operations need to be performed, a *co-processor* augmented with these abilities could be an attractive option.

Discussion Questions

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- How does the GLIFT method handle optimizations such as out-of-order execution, speculation etc? Will the proposed architecture be able to detect covert and side channel attacks such as Meltdown and Spectre?

Example MLS System

Example Satellite Application. [Tzvetan Metodi, Aerospace Corp.]

Interrupt Handlers (Non-sensitive)						
Kernel and Diagnostics	Time Keeping	Crypto	Command Telemetry Interface	I/O Secret	Mission Secret	Mission Unclass.

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Primary Execution Schedule

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Example MLS System

Example Satellite Application. [Tzvetan Metodi, Aerospace Corp.]
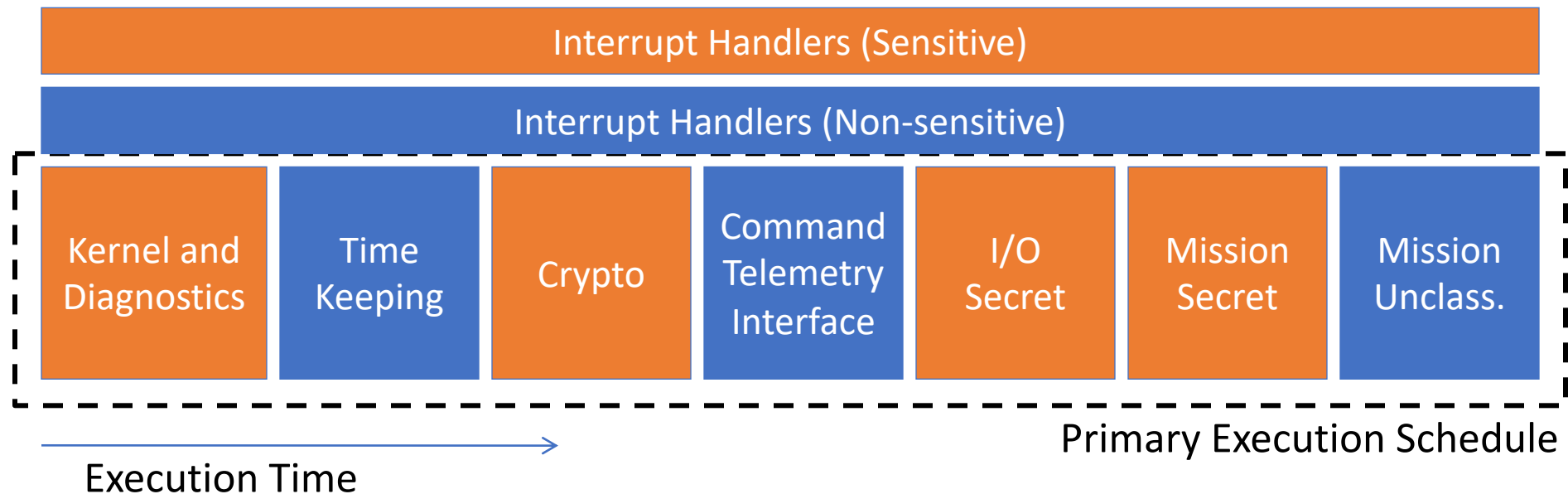
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■ Non-sensitive
■ Sensitive

Example: Satellite System

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Untrusted & Secret

Untrusted & Unclassified

Trusted & Secret

Trusted & Unclassified

Example: Satellite System

Untrusted & Secret

Untrusted & Unclassified

Trusted & Secret

Trusted & Unclassified

Kernel, Interrupt Handlers (Unclassified), Time Keeping Programs

Example: Satellite System

Untrusted & Secret

Untrusted & Unclassified
Diagnostics, Telemetry Interfaces

Trusted & Secret

Trusted & Unclassified

Kernel, Interrupt Handlers (Unclassified), Time Keeping Programs

Example: Satellite System

Untrusted & Secret

Untrusted & Unclassified
Diagnostics, Telemetry Interfaces

Trusted & Secret
Custom code on Secret data

Trusted & Unclassified

Kernel, Interrupt Handlers (Unclassified), Time Keeping Programs

Example: Satellite System

Untrusted & Secret
Libraries (e.g. encryption) that operate on Secret data

Untrusted & Unclassified
Diagnostics, Telemetry Interfaces

Trusted & Secret
Custom code on Secret data

Trusted & Unclassified

Kernel, Interrupt Handlers (Unclassified), Time Keeping Programs

Discussion Questions on Use Cases

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- Are there any programs or algorithms that are rendered impossible (or extremely difficult) to write as a result of the limitations that they've placed on loops?

Discussion Questions on Future Work

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Great idea.
Read "HyperFlow: A Processor Architecture for Nonmalleable, Timing-Safe Information Flow Security"; Ferraiuolo et al. CCS'18

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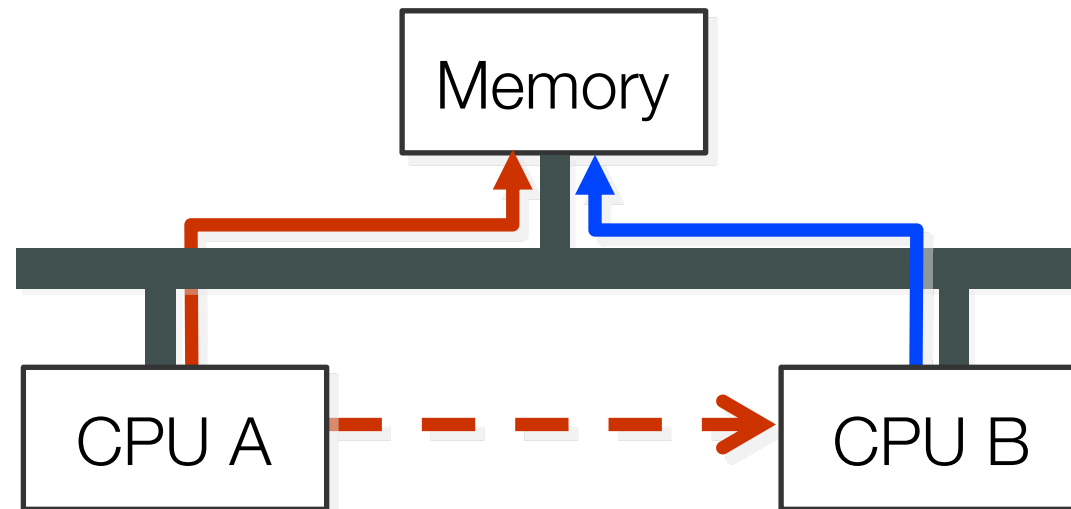
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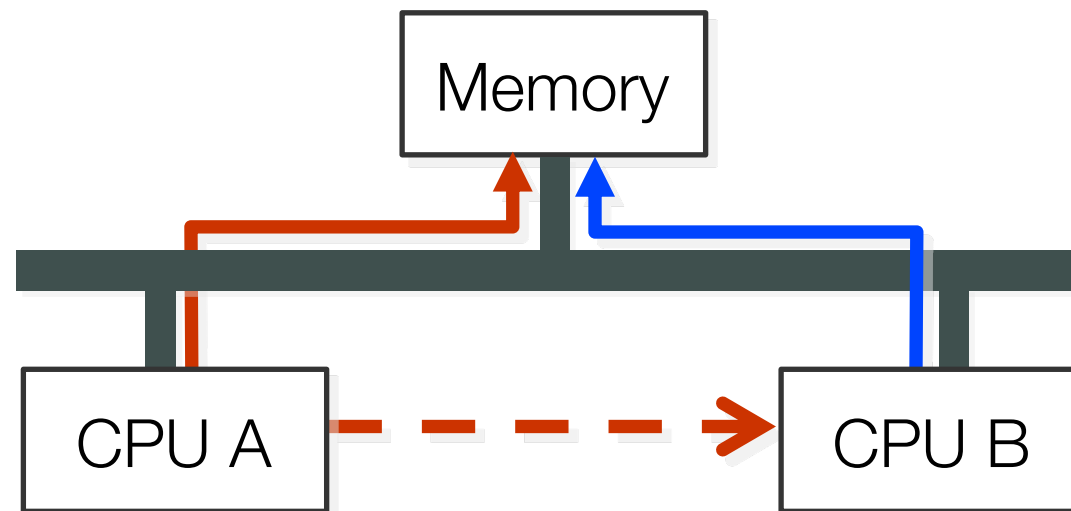- How does the GLIFT detect a side channel/covert channel? What is the "sink" of taint tracking in such cases?

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- How GLIFT different from static taint analysis and traditional dynamic taint analysis?