CLKSCREW: Exposing the Perils of Security-Oblivious Energy Management

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Columbia University

USENIX Security Symposium, 2017, Vancouver, Canada

presented by Sarah Tröndle

Outline

- Problem, Goal and Novelty
- Background
- Key Challenges and Solutions
- Mechanism
- Summary
- Strength and Weaknesses
- Takeaways
- Discussion

Problem, Goal and Novelty

Energy Management

- Commodity devices, such as phones, capable of extremely power intensive computations
- Need to preserve energy when not using maximal performance

→ Energy Management is essential

source picture: https://www.ccp.com.au/b-lithiumbatterychargingadvice/

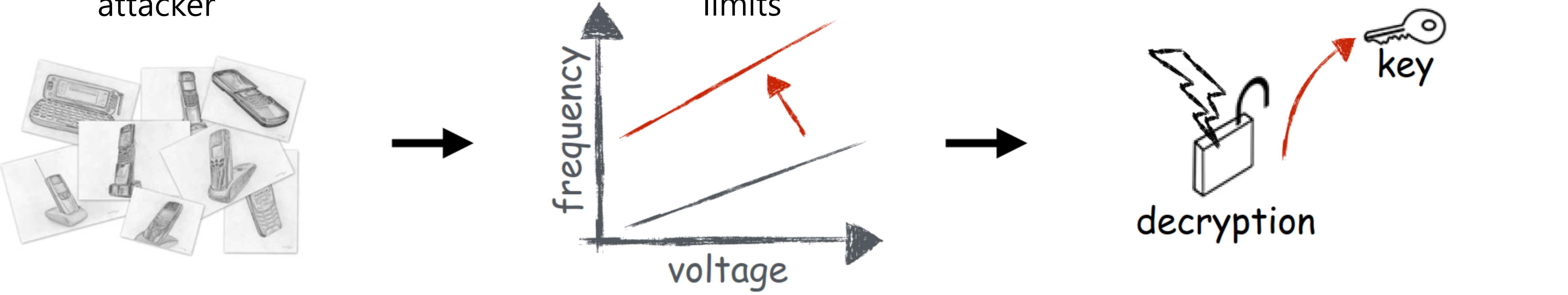
Energy Management and Security

- Today’s energy management:
  - is essential and everywhere
  - usually security is not a big consideration in it’s designs

    → might impose risk on most devices

Goal

- Show importance of security in energy management
- Do so by example attack on ARM Trustzone of Nexus 6 device



Software-based attacker

Stretch operational limits

Induce faults

Novelty

- First security review of energy management technique: Dynamic Voltage and Frequency Scaling (DVFS)
- Fault attack purely from software
- New class of exploitations: induce fault by scaling frequency → CLKscrew

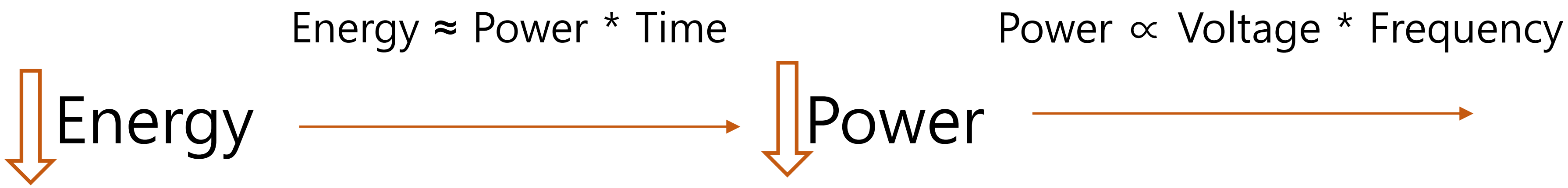
Background

Dynamic Voltage & Frequency Scaling (DVFS)

Energy ≈ Power * Time

⇩ Energy ⟶

Dynamic Voltage & Frequency Scaling (DVFS)



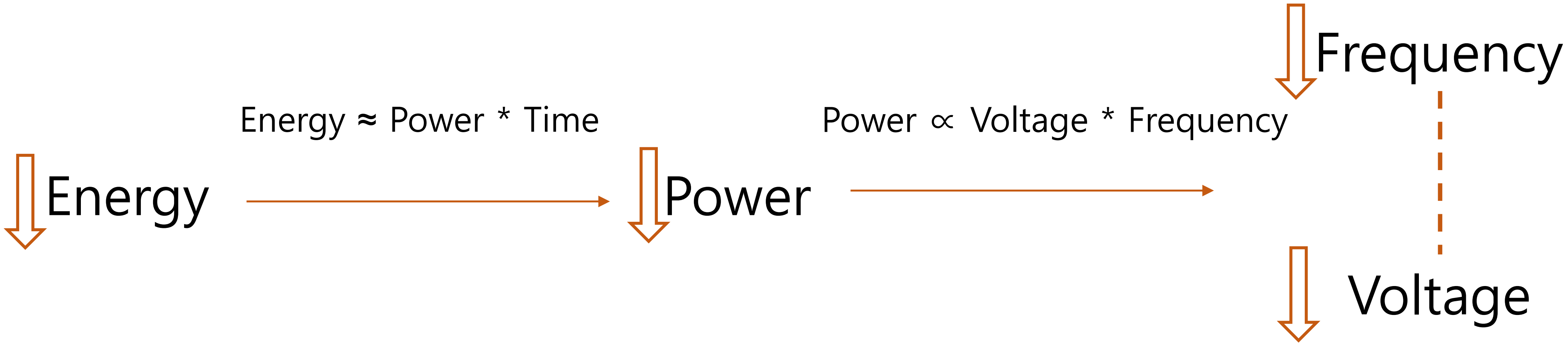
Energy ≈ Power * Time

Power ∝ Voltage * Frequency

Energy

Power

Dynamic Voltage & Frequency Scaling (DVFS)



Energy

Energy ≈ Power * Time

Power

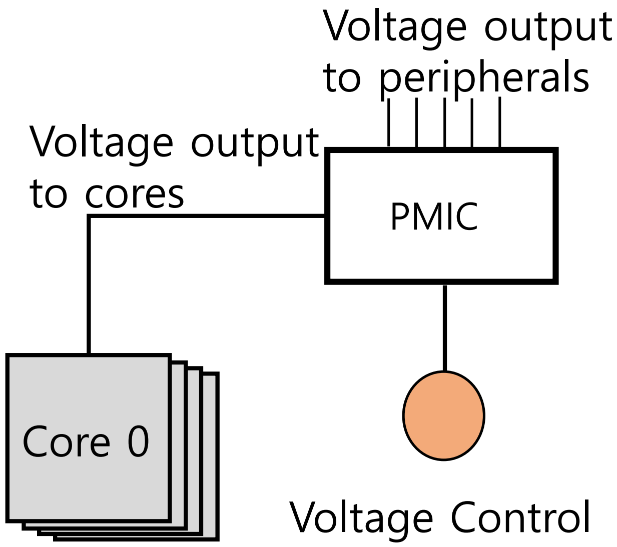
Power ∝ Voltage * Frequency

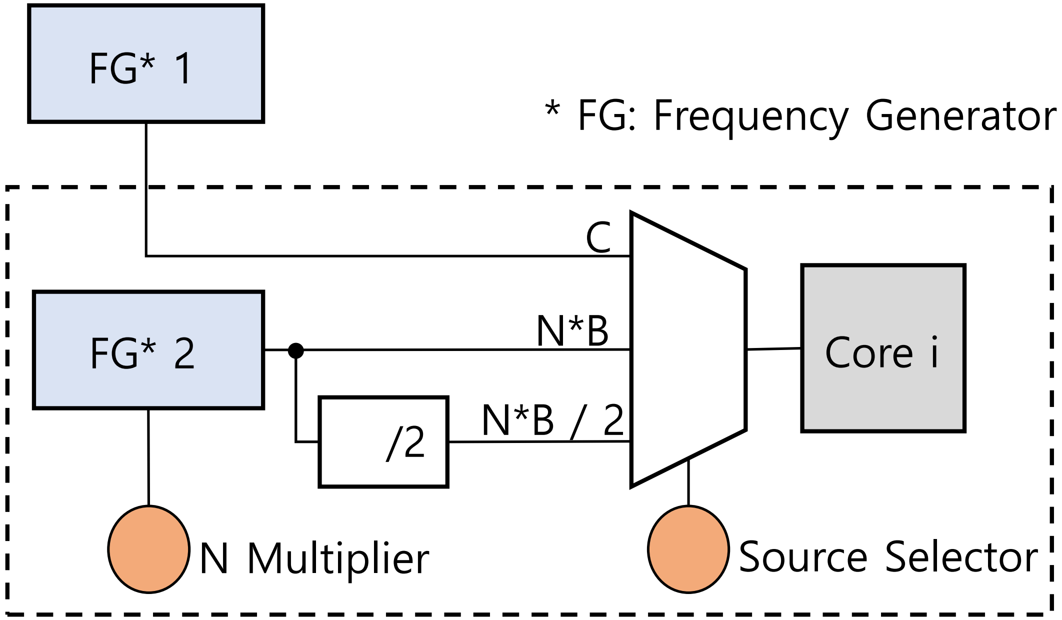
Frequency

Voltage

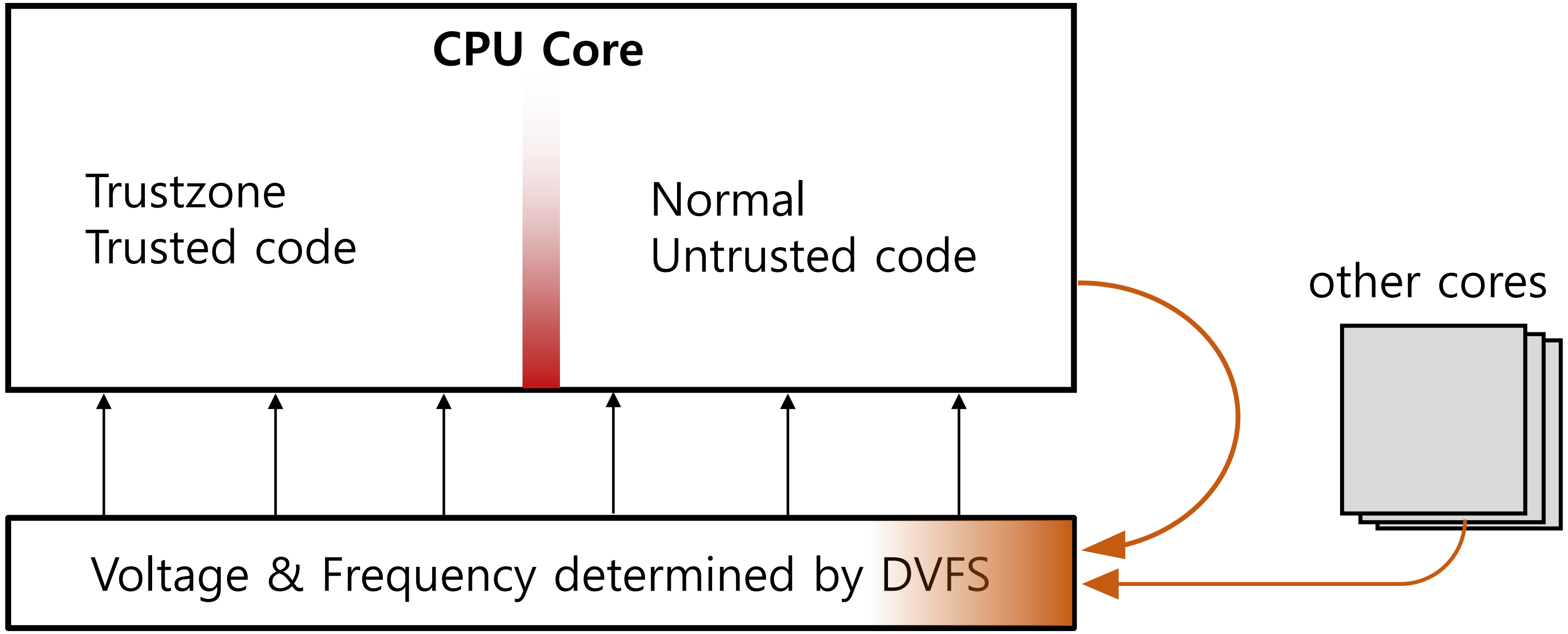
Dynamic Voltage & Frequency Scaling

- DVFS allows software control of voltage and frequency





DVFS and Trustzone



CPU Core

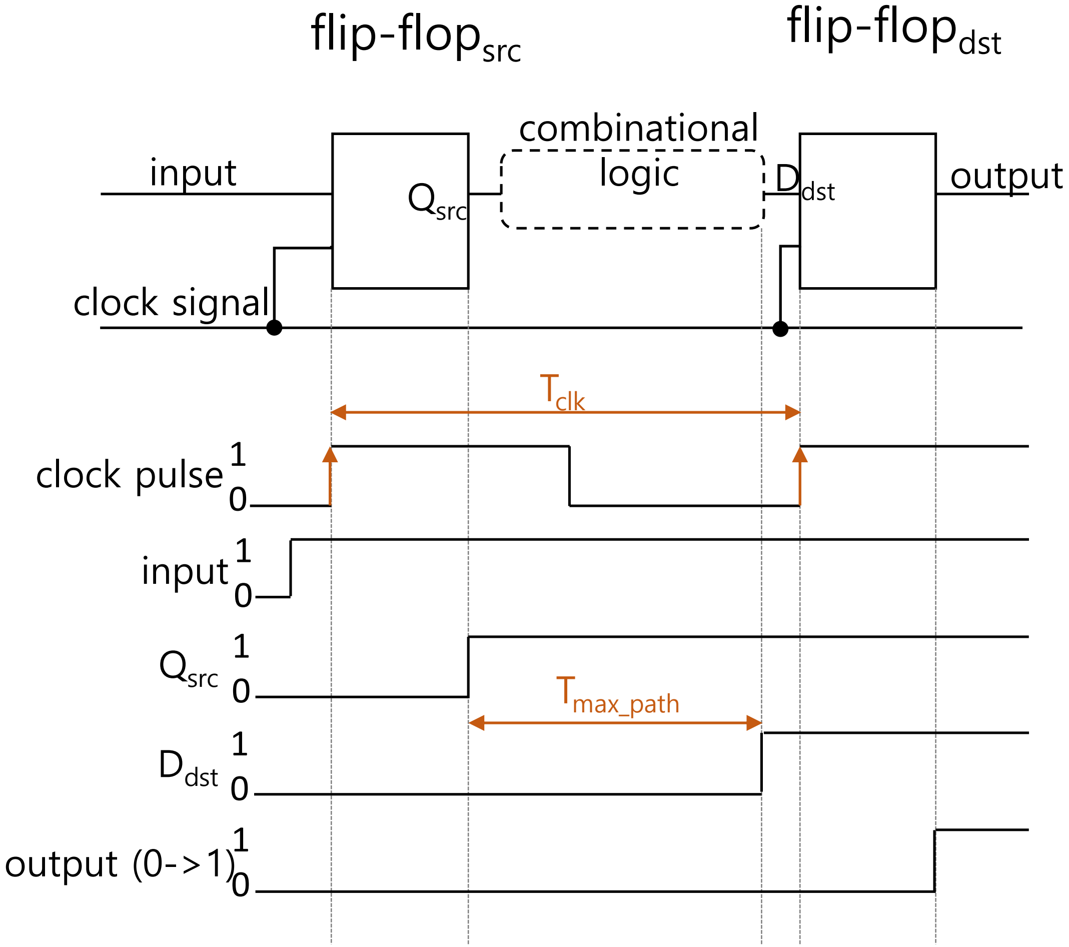
Trustzone
Trusted code

Normal
Untrusted code

other cores

Voltage & Frequency determined by DVFS

Overclocking and Undervolting



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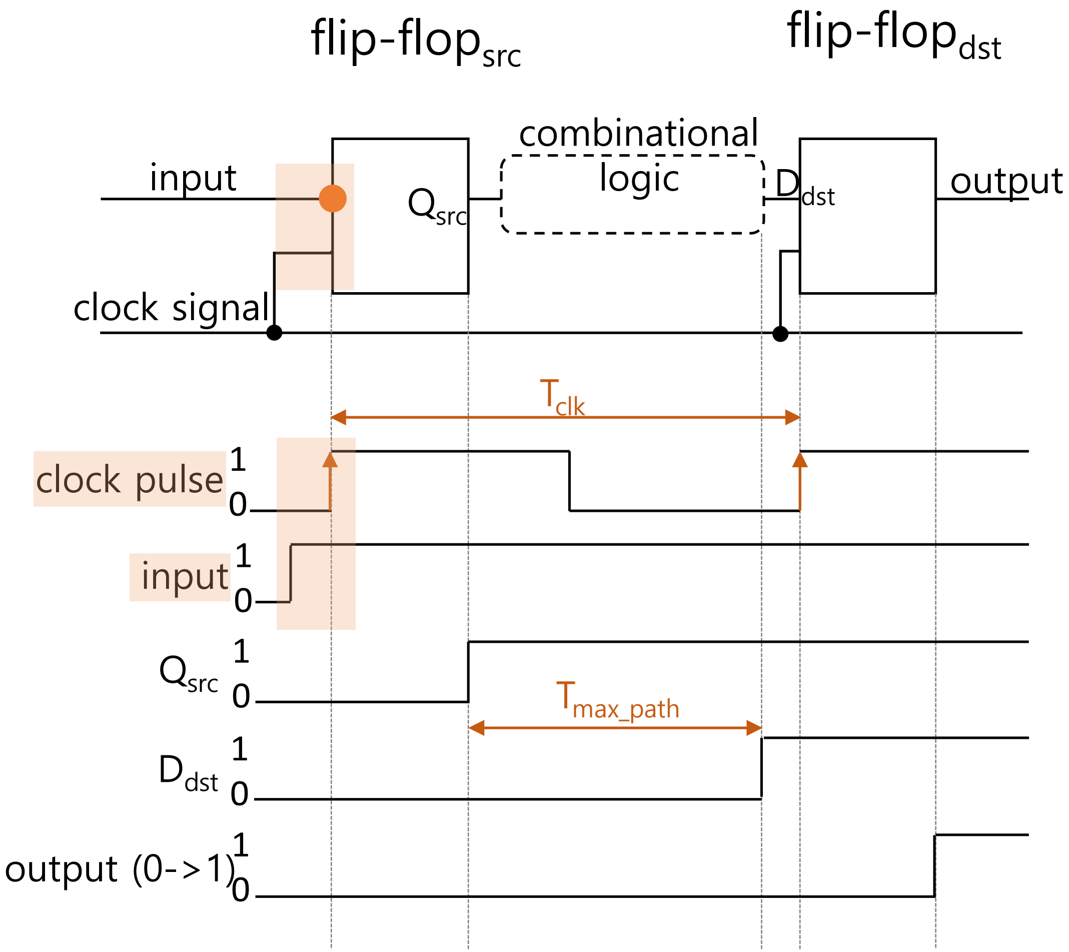

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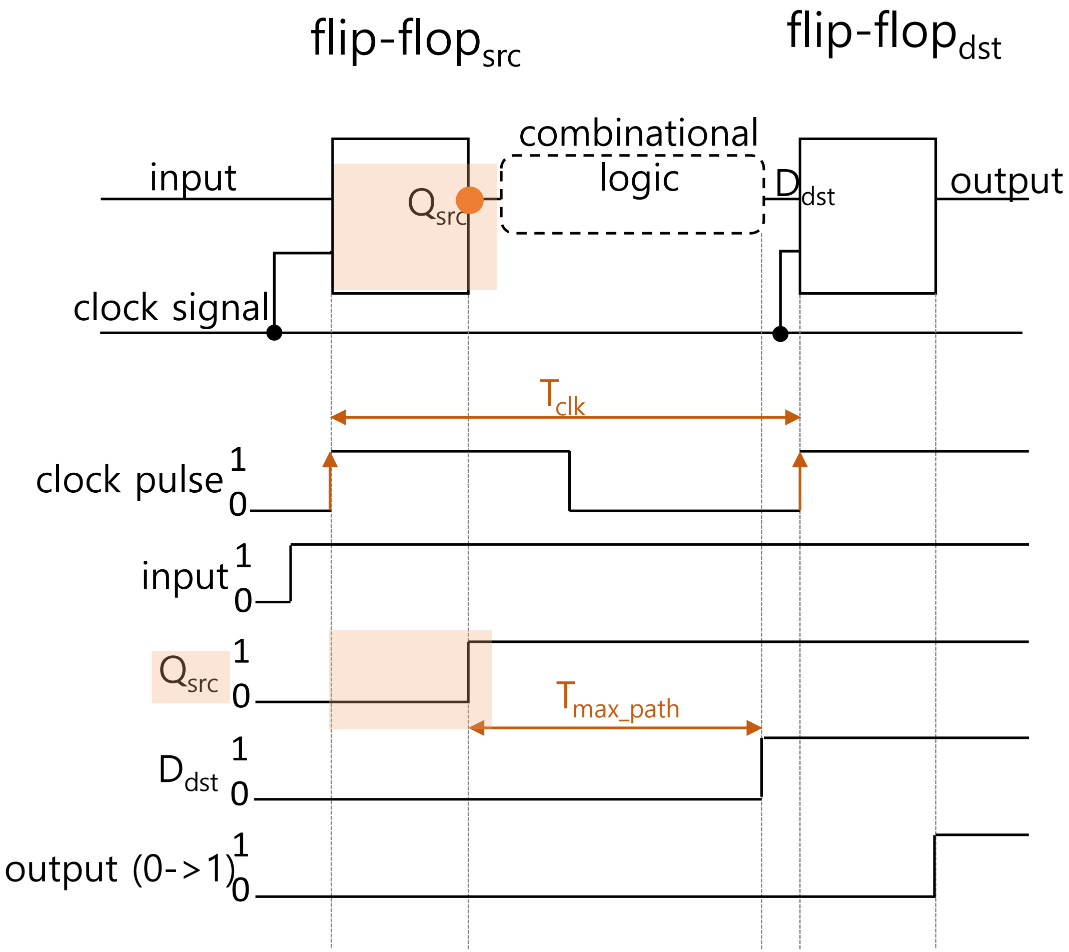

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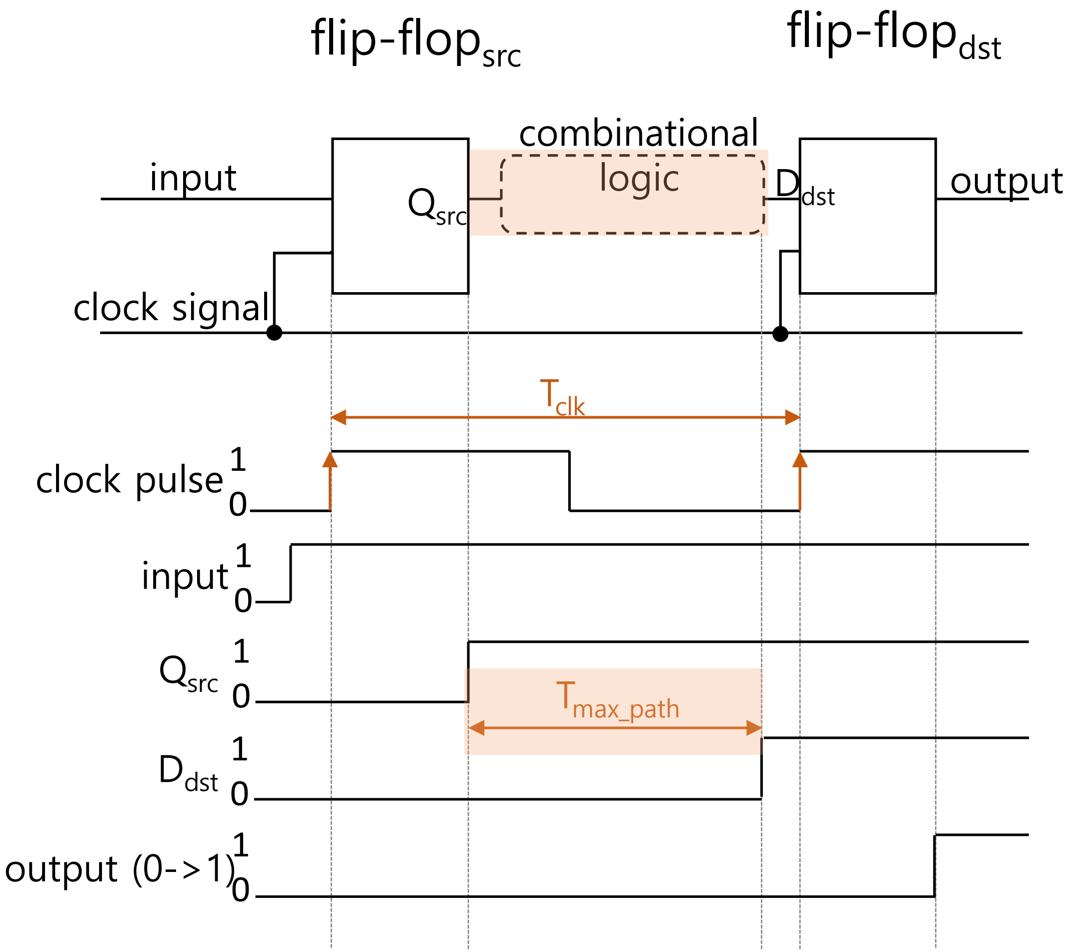

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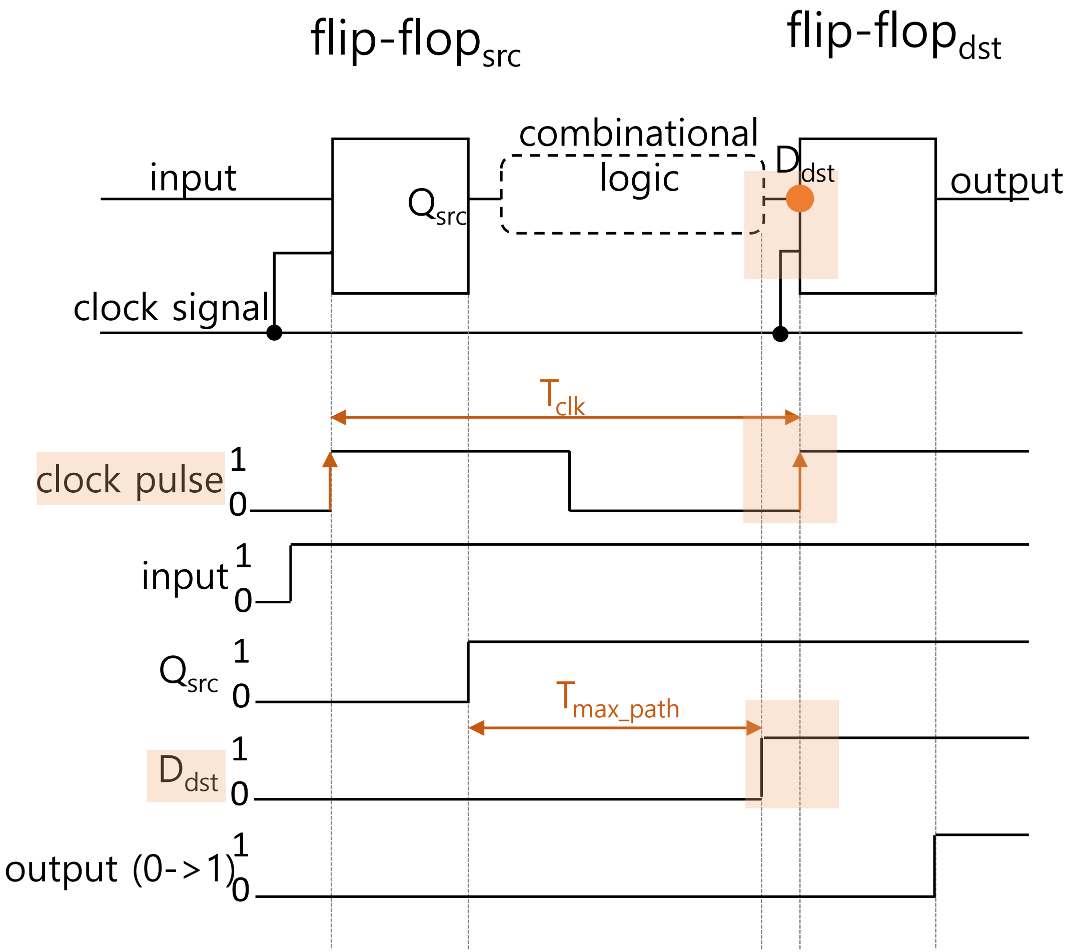

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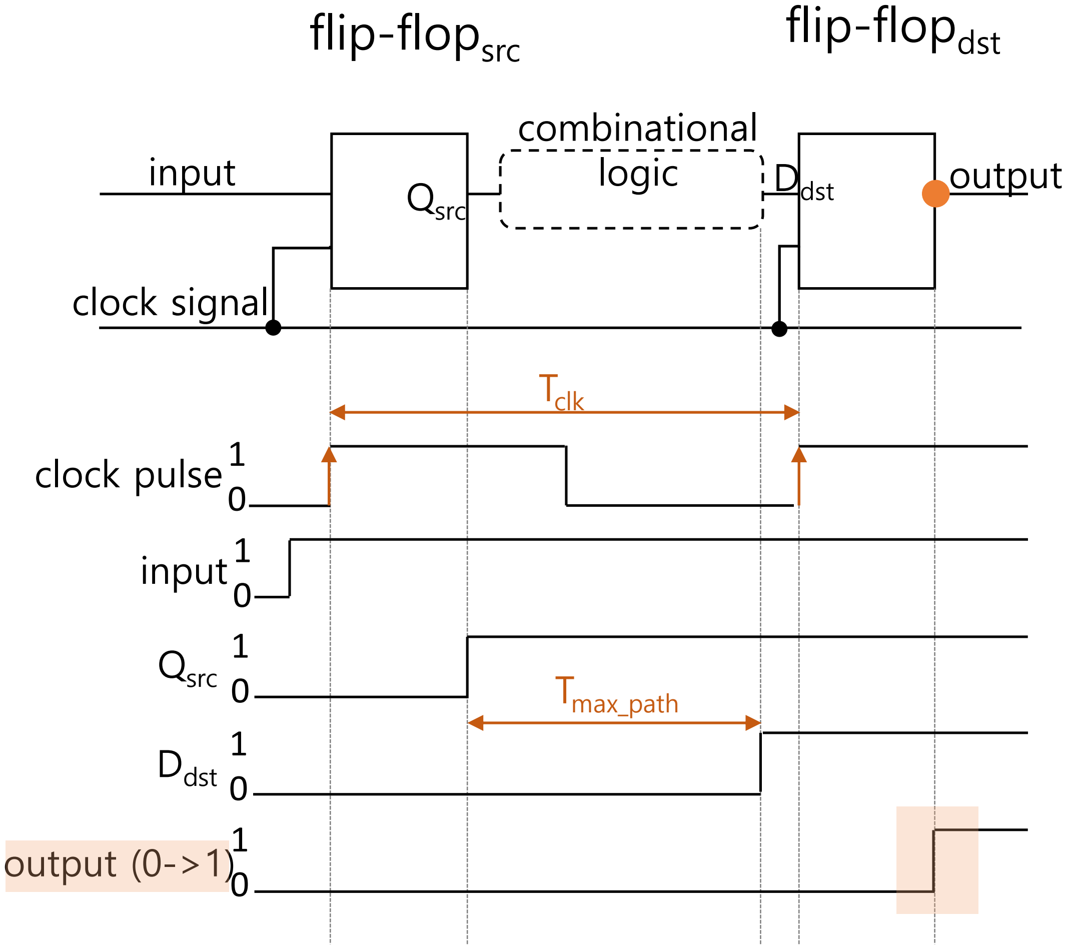

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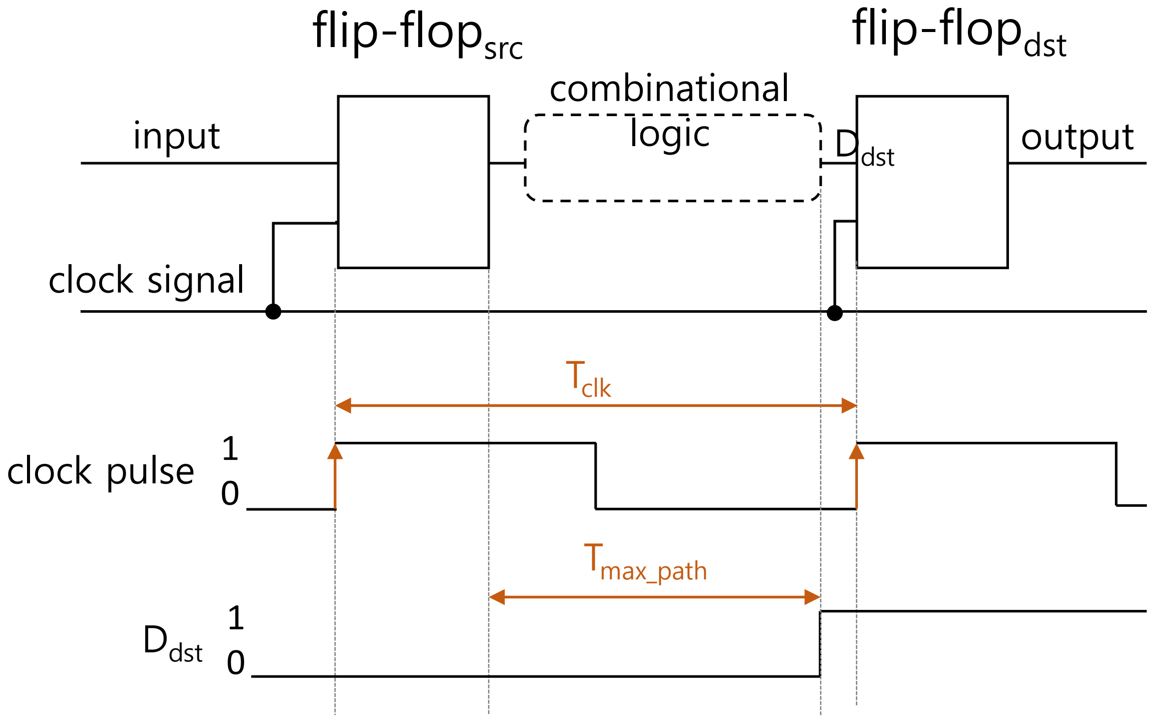
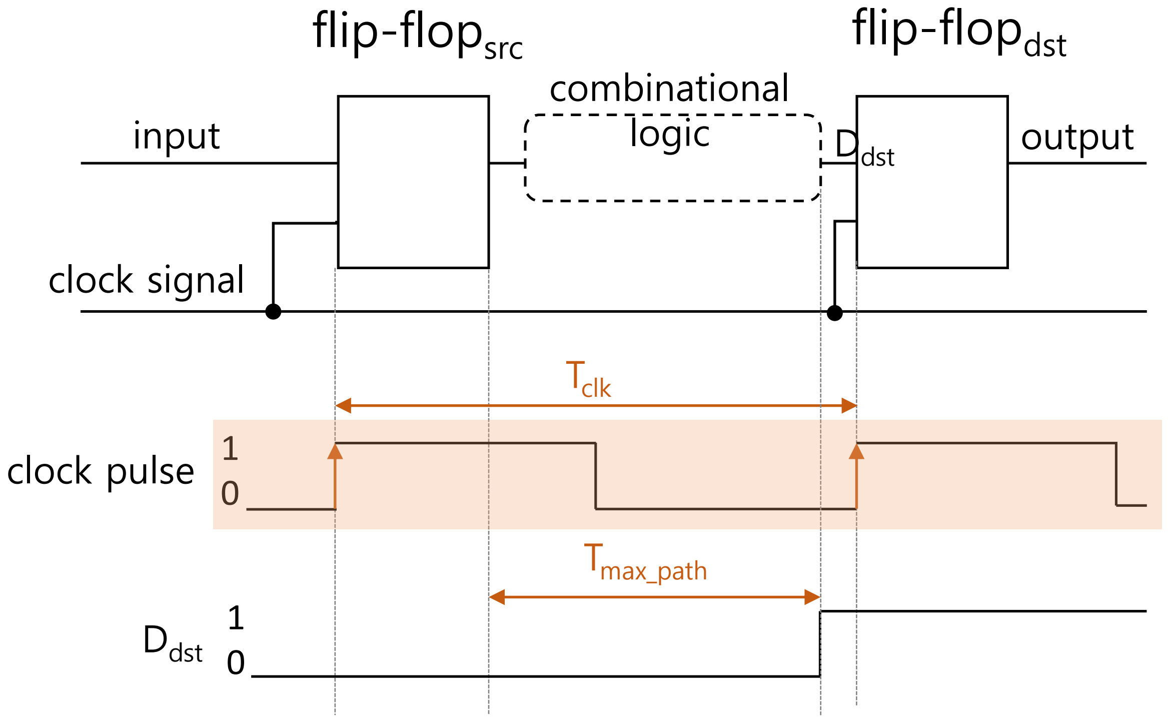


output (0->1)

Overclocking and Undervolting



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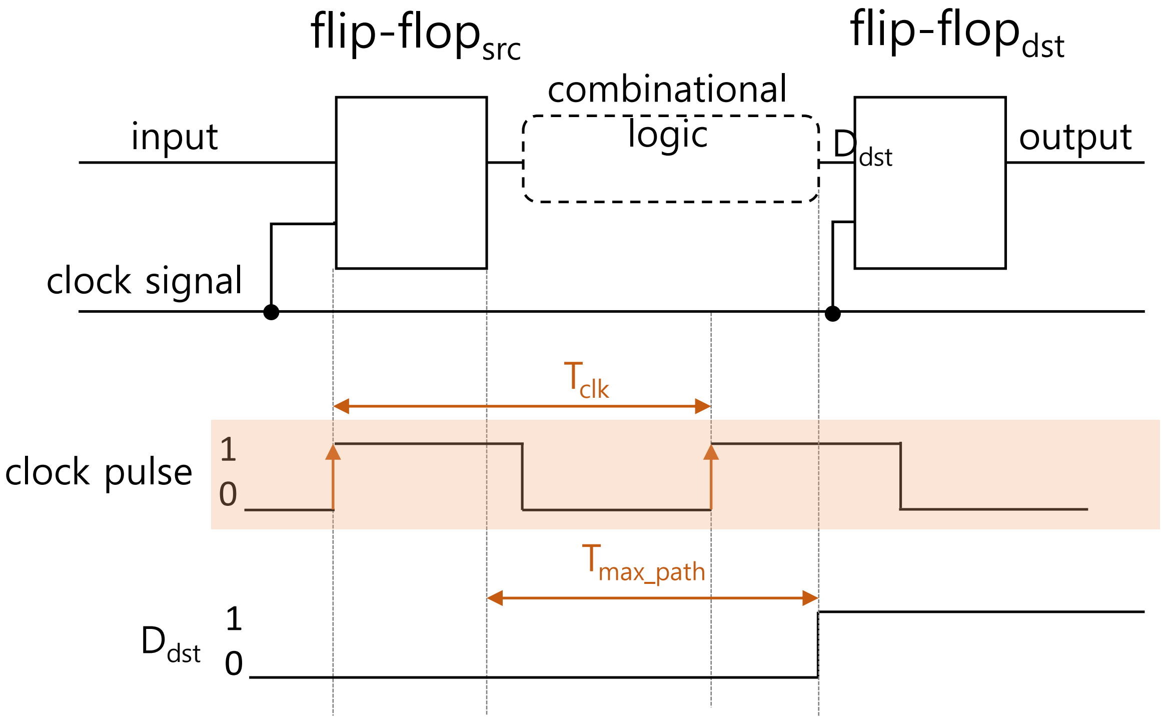

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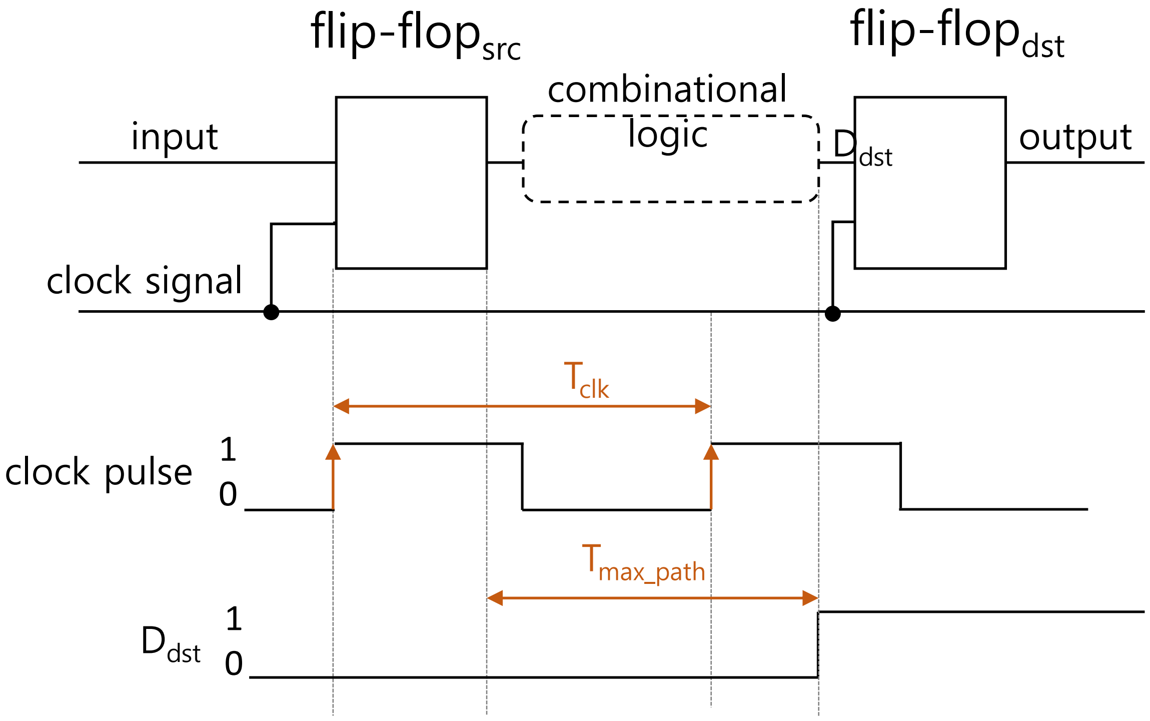

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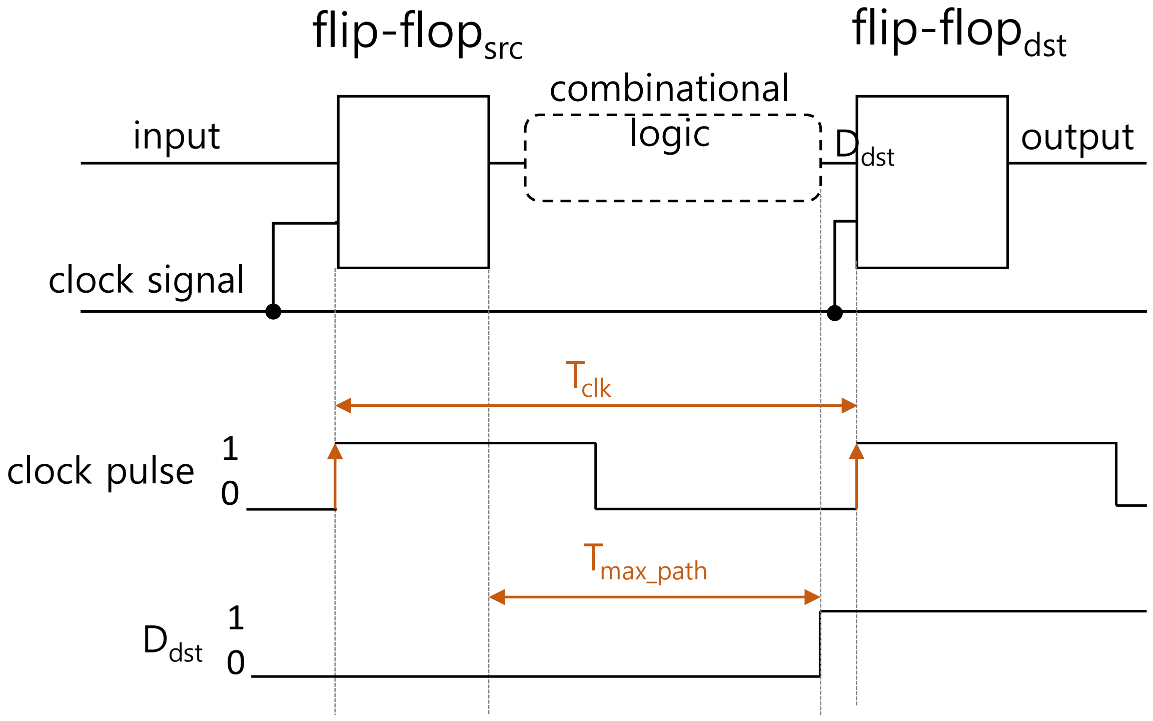

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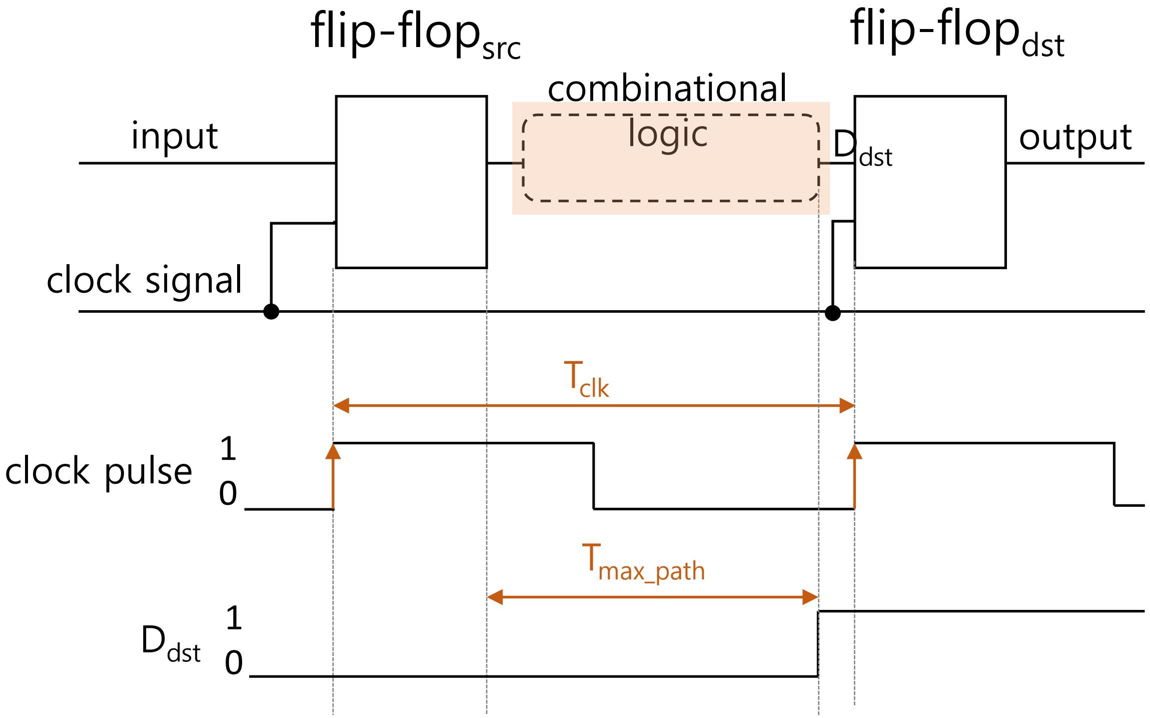

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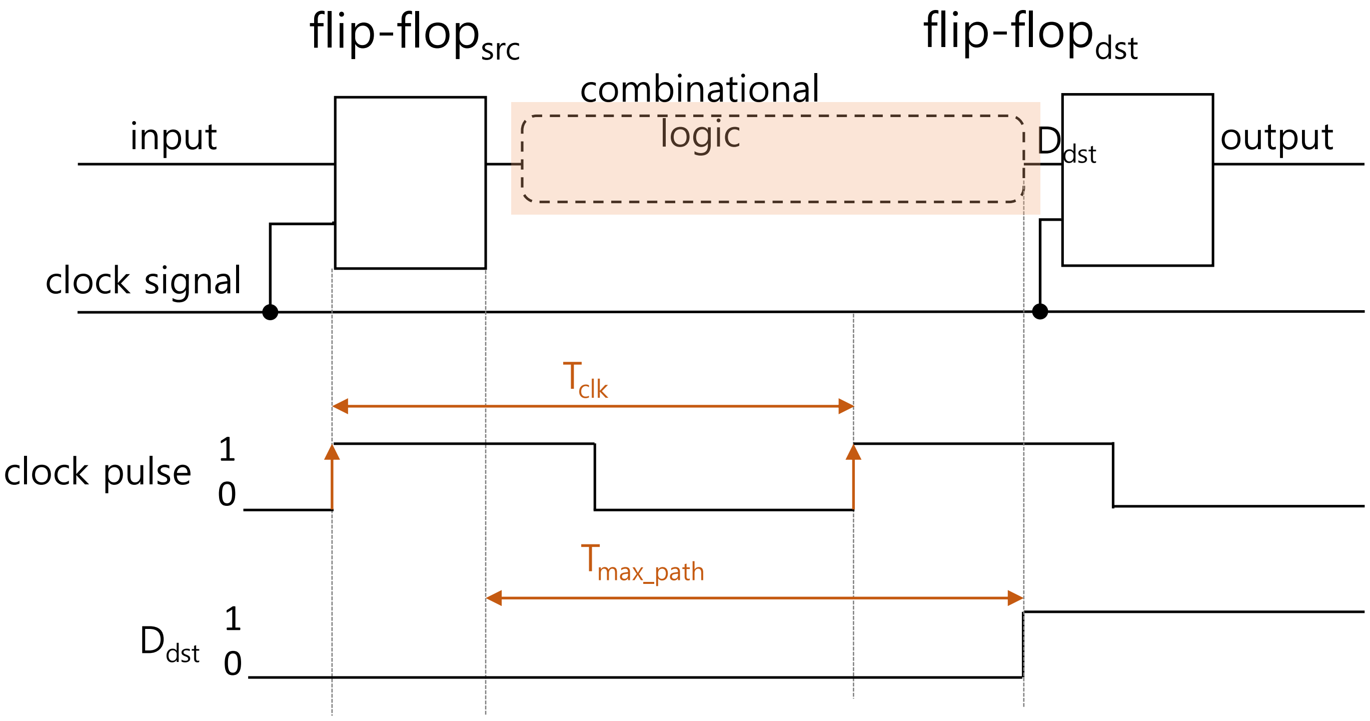

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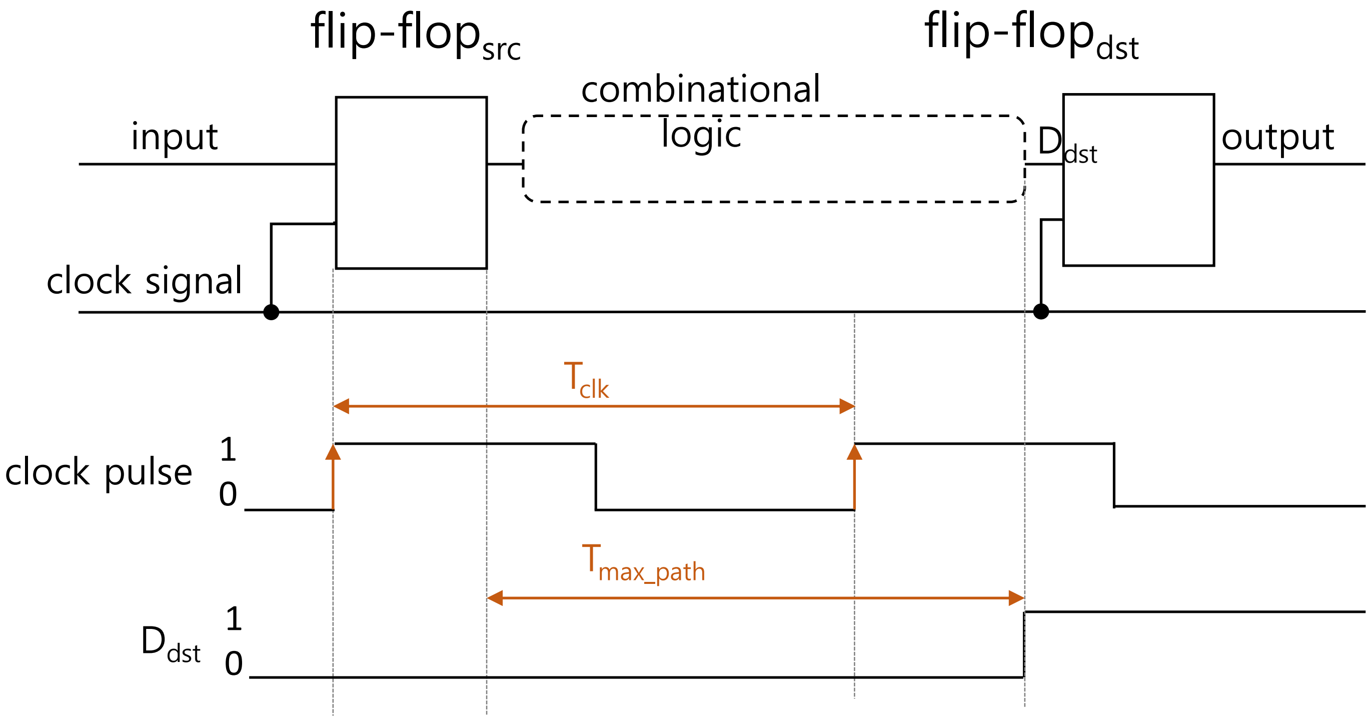


output (0->0)

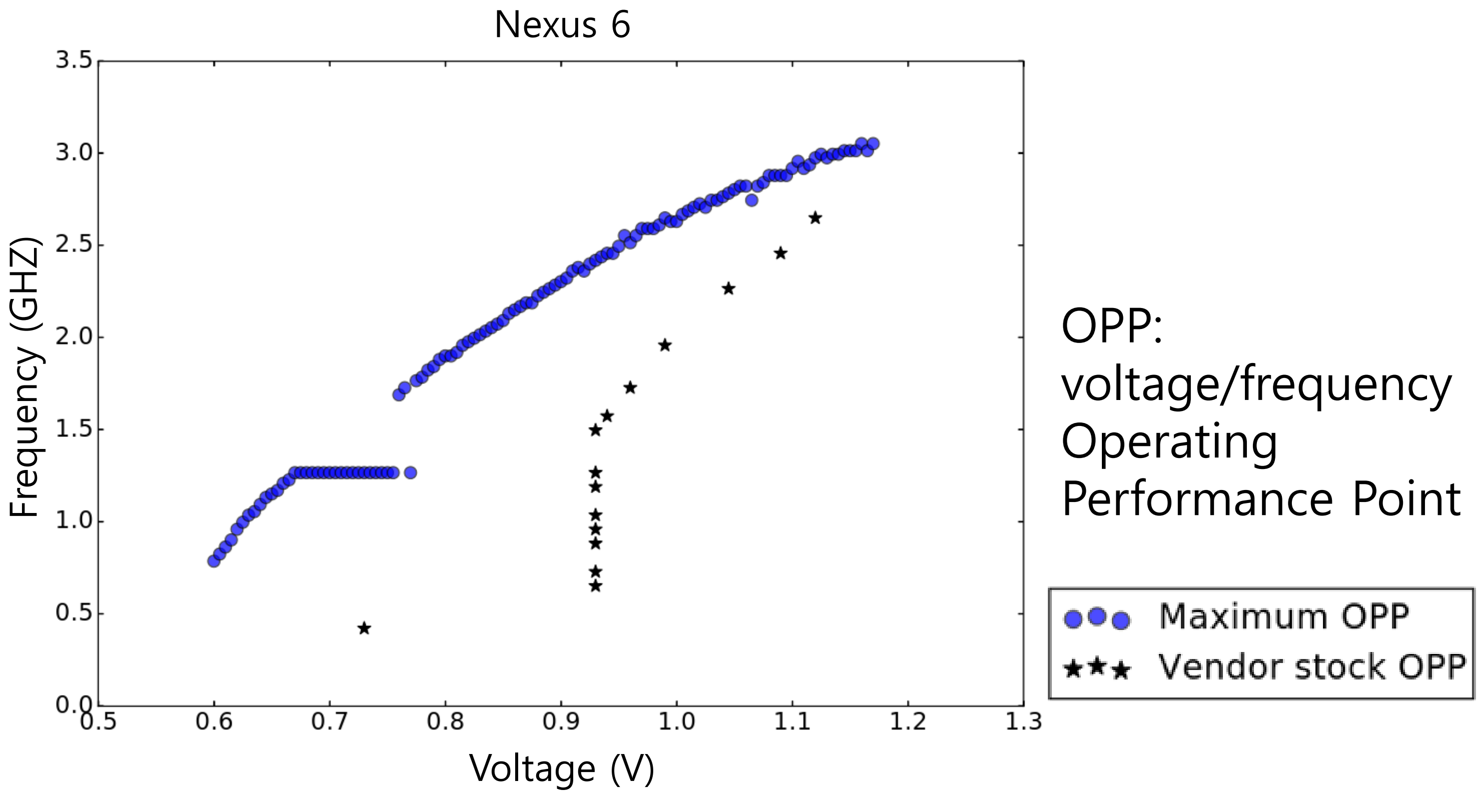
Key Challenges and Solutions

Challenges

- Voltage and Frequency operating limits?
- Self-containment: how to cause fault for victim without an error in the attacker?
- Can attack run without other things interfering?
- How to time attack correctly?

Solutions

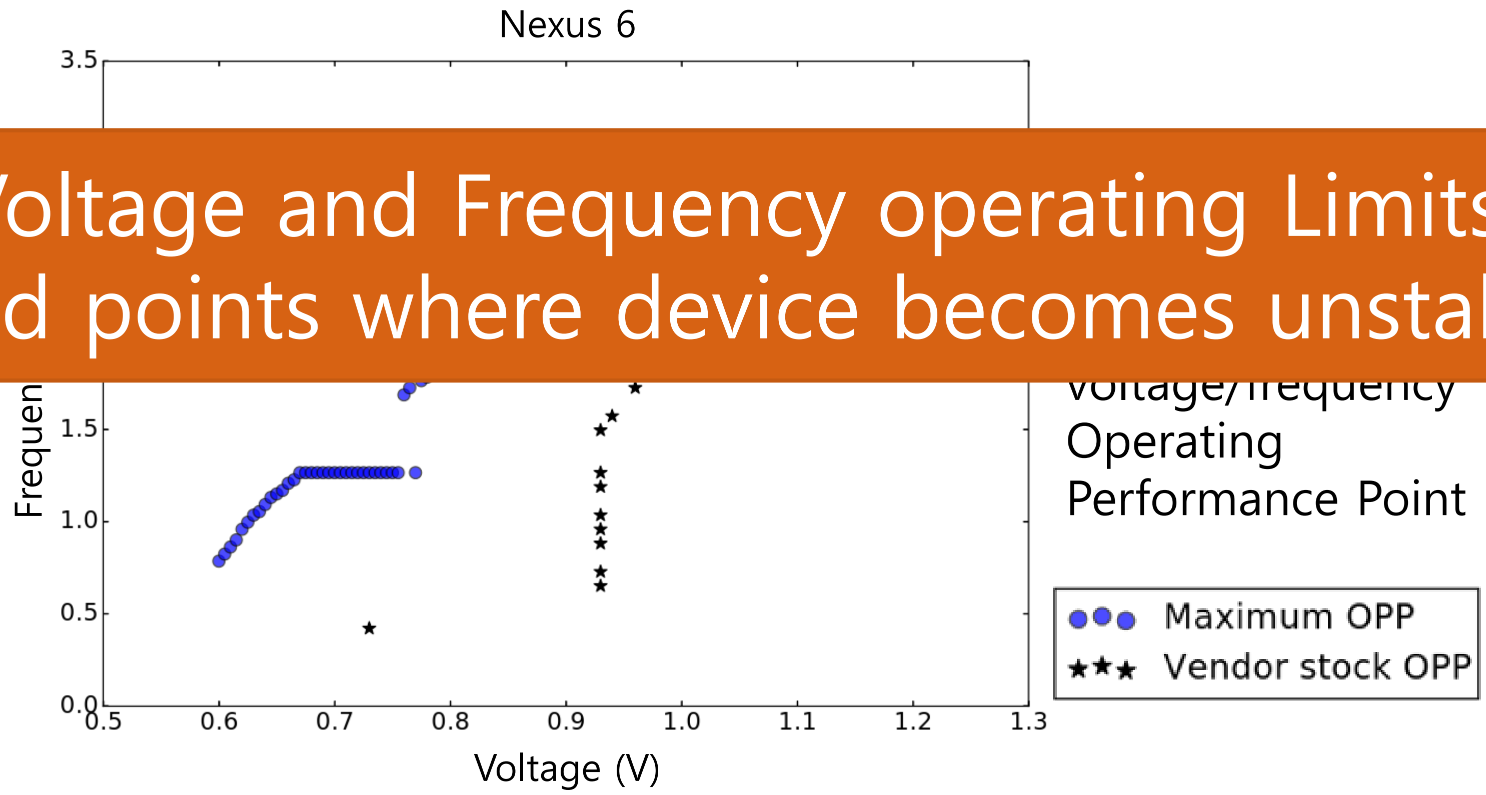
Voltage and Frequency Operating Limits?



OPP:
voltage/frequency
Operating
Performance Point

Solutions

Voltage and Frequency Operating Limits?

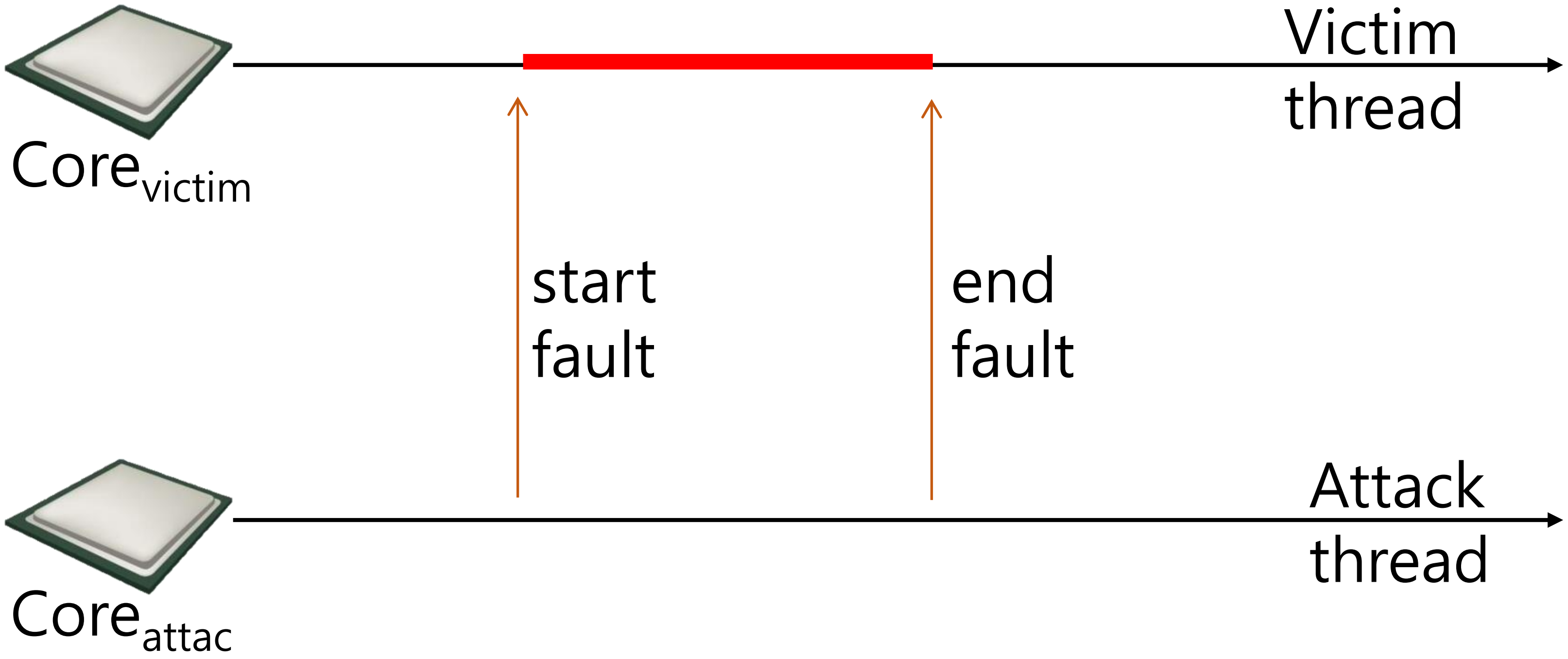


Voltage/frequency Operating Performance Point

No Voltage and Frequency operating Limits. Found points where device becomes unstable.

Solutions

Self-Containment



Victim thread

Core$_{\text{victim}}$

start fault

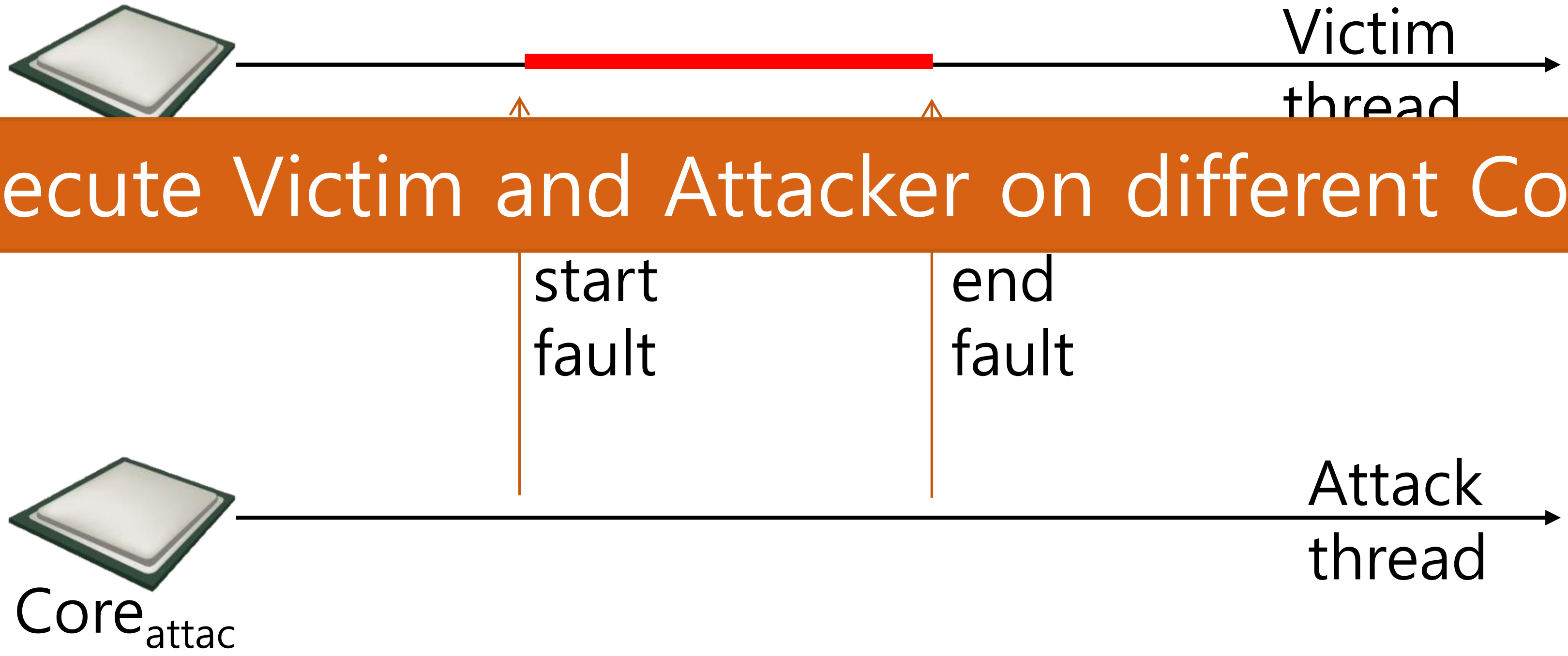
end fault

Attack thread

Core$_{\text{attac}}$

Solutions

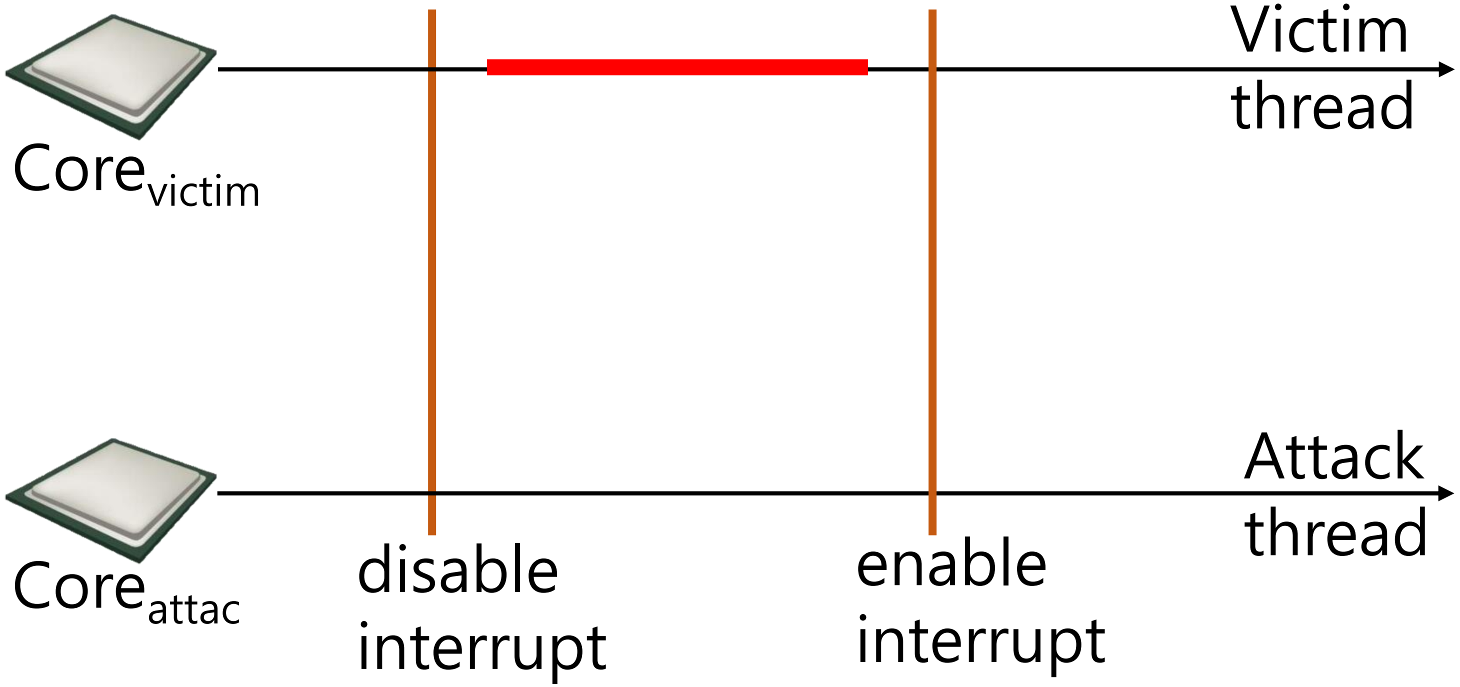
Self-Containment



Execute Victim and Attacker on different Cores

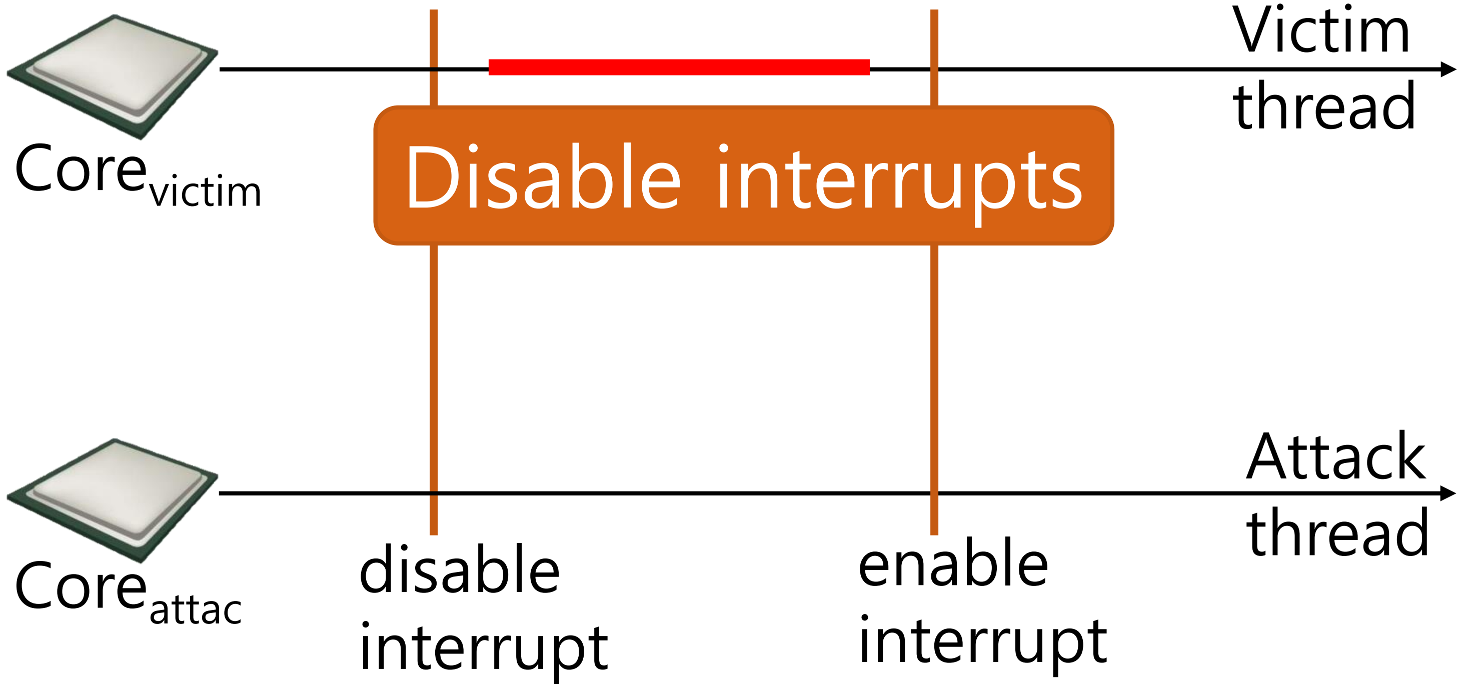
Solutions

Run Attack without Interferences



Solutions

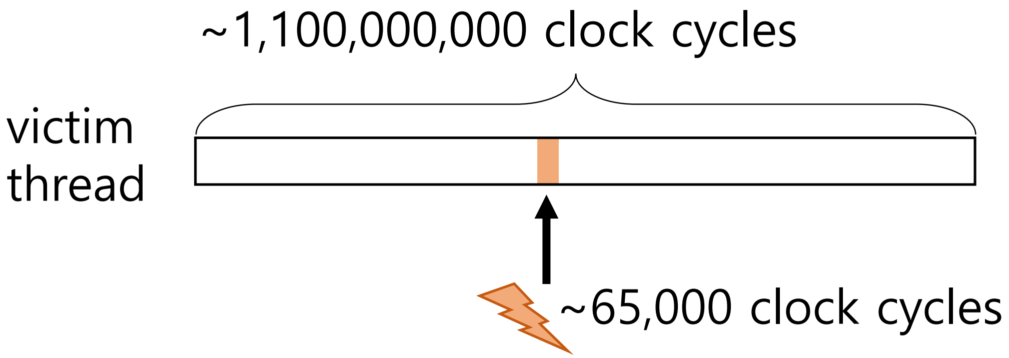
Run Attack without Interferences



Solutions

Timing

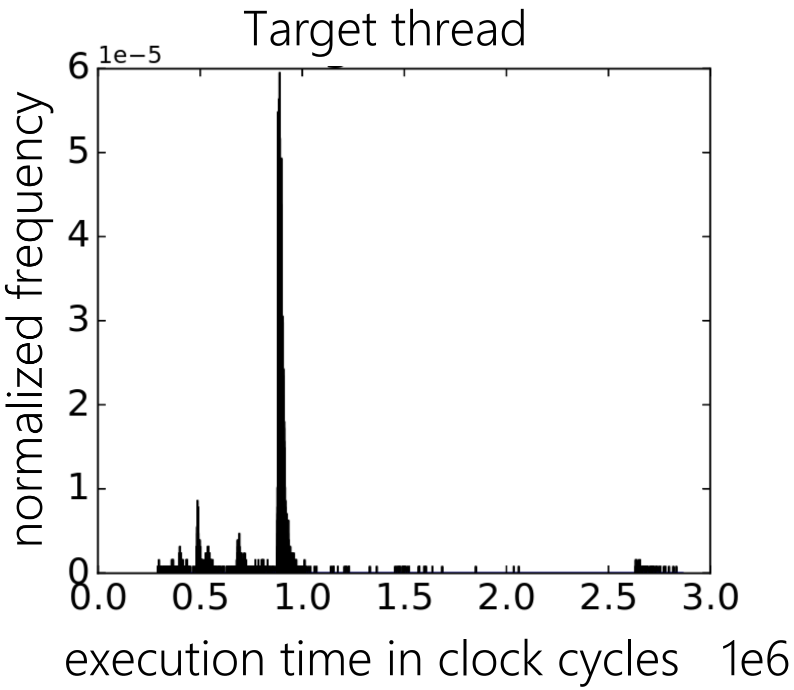
- Need a way to do precise timing



Solutions

Timing

- Use hardware cycle counter to do timing profiling
- Insert no-ops to hit targeted cycle
- Insert anchor times when necessary

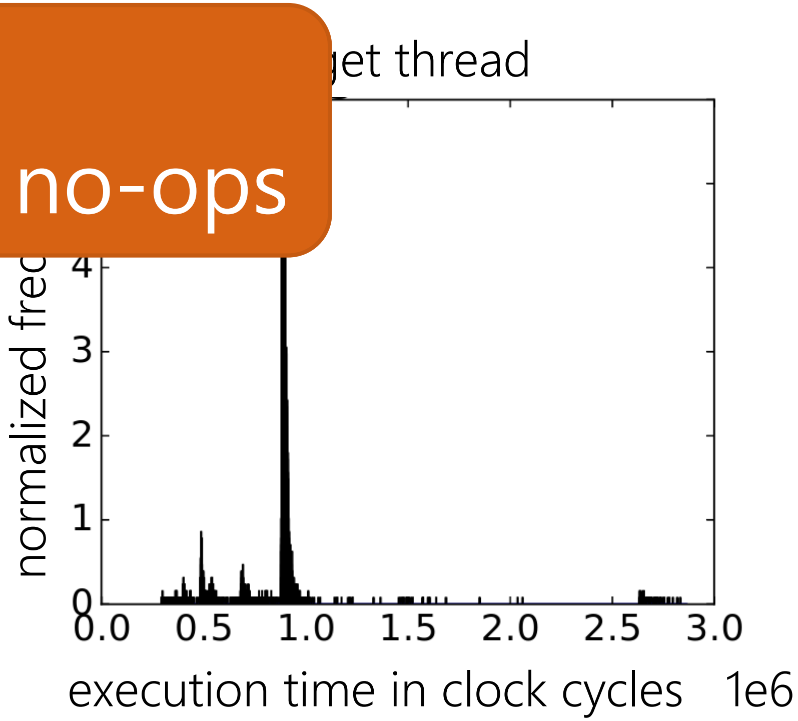


Solutions

Timing

- Use hardware cycle counter to do timing profiling
- Insert no-op
- Insert anchor times when necessary

Do Profiling
Use Anchor Time and no-ops



Challenges

- Voltage and Frequency operating limits?
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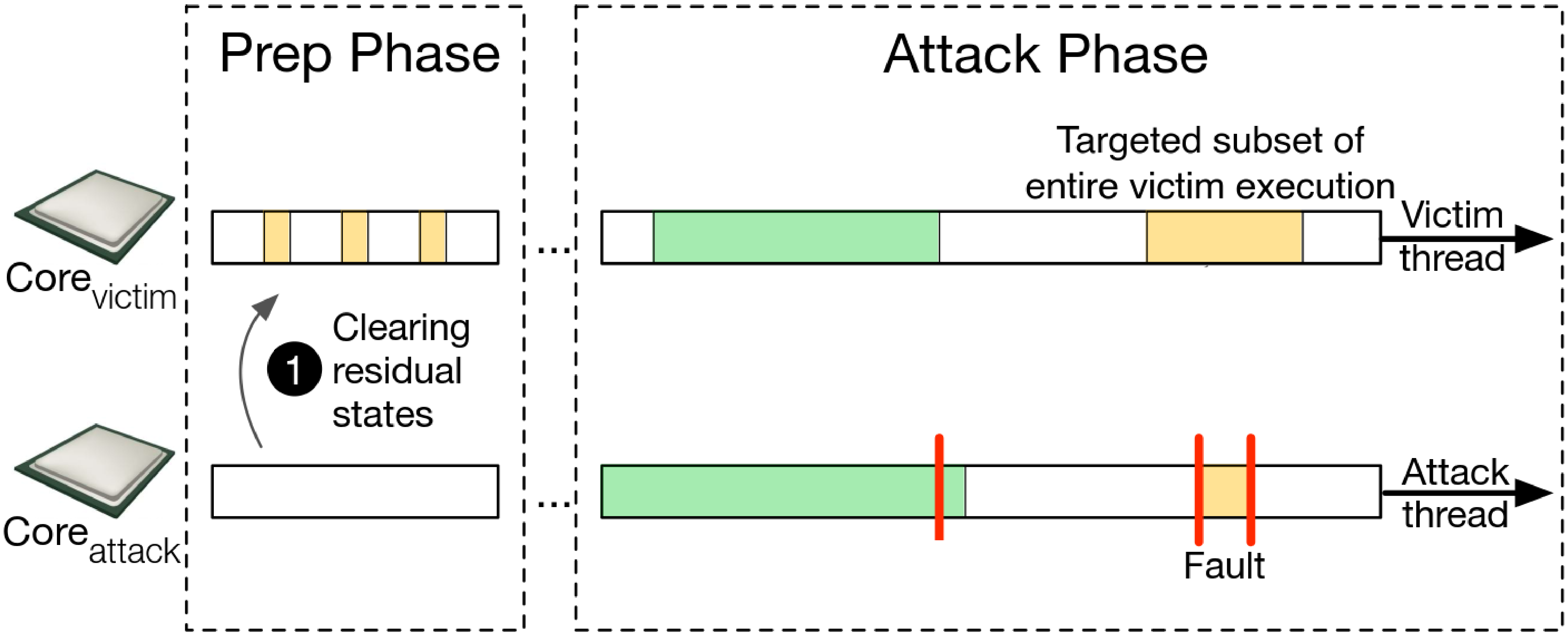
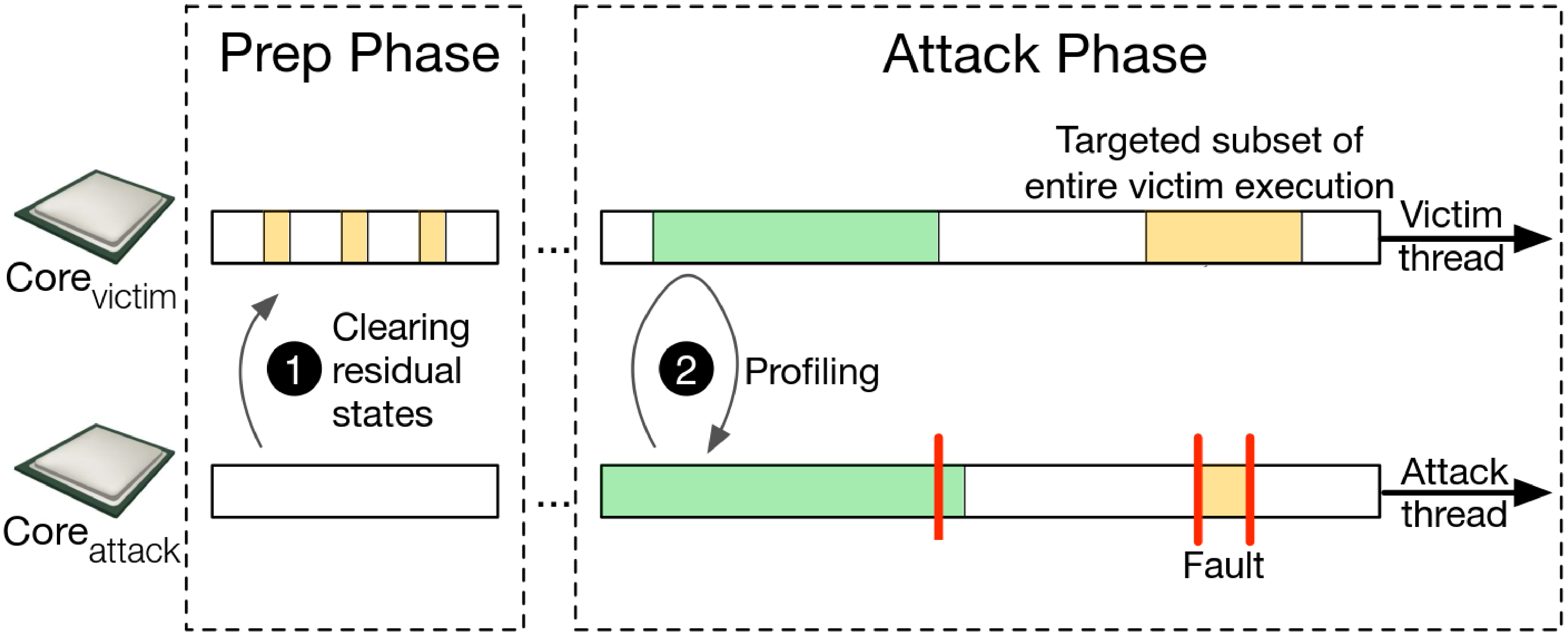
Mechanisms

CLKSCREW fault injection setup



CLKscrew fault injection setup



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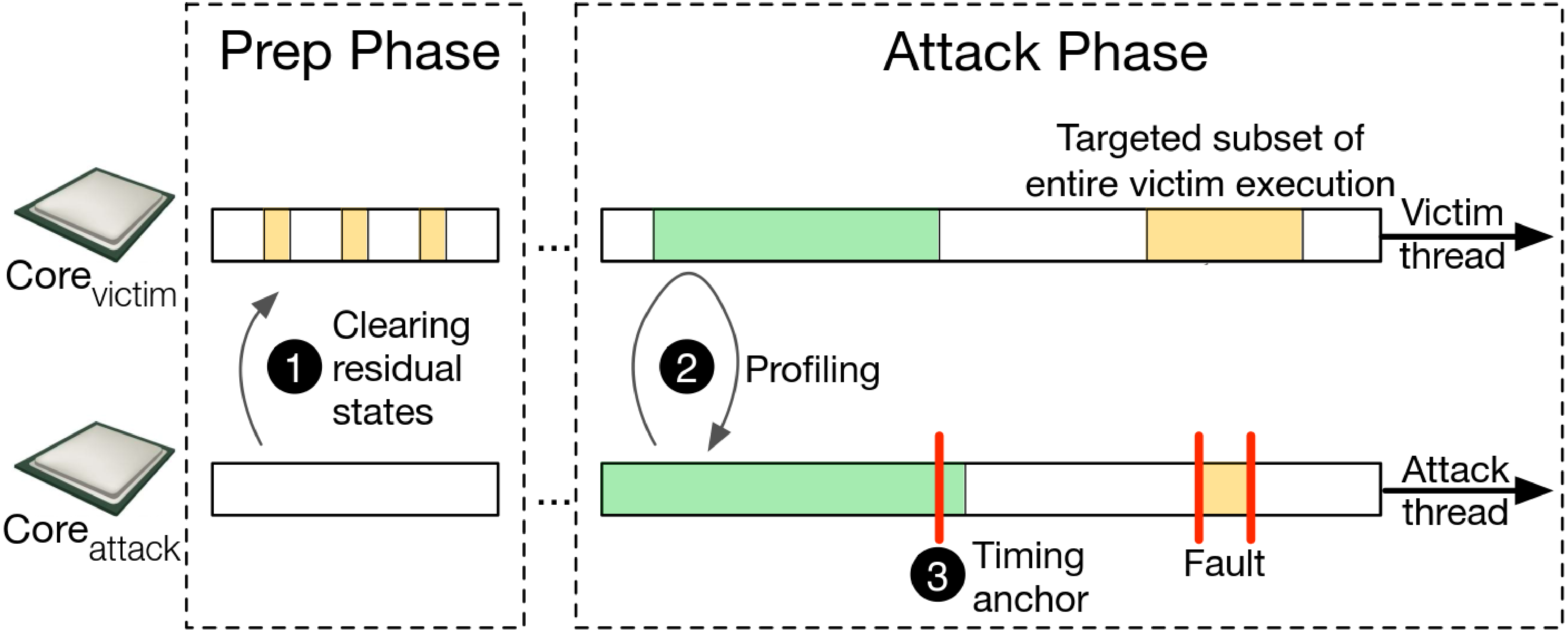

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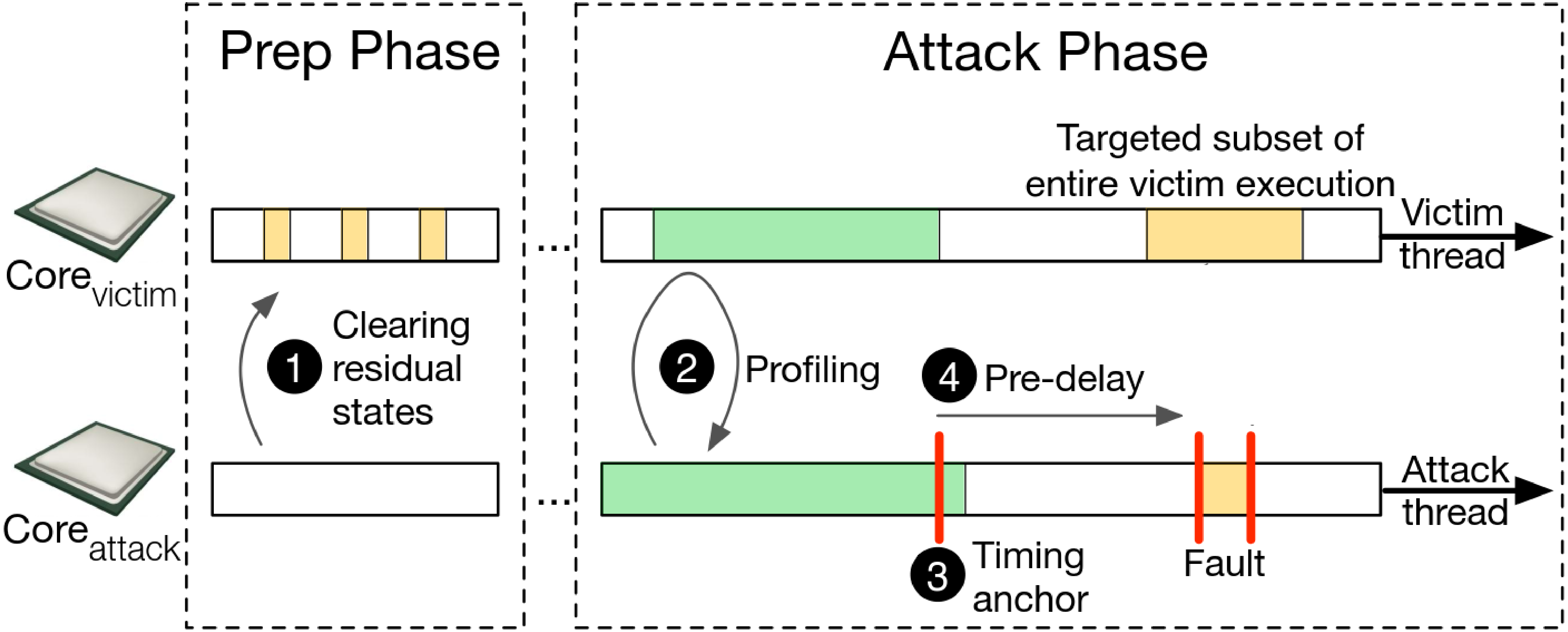

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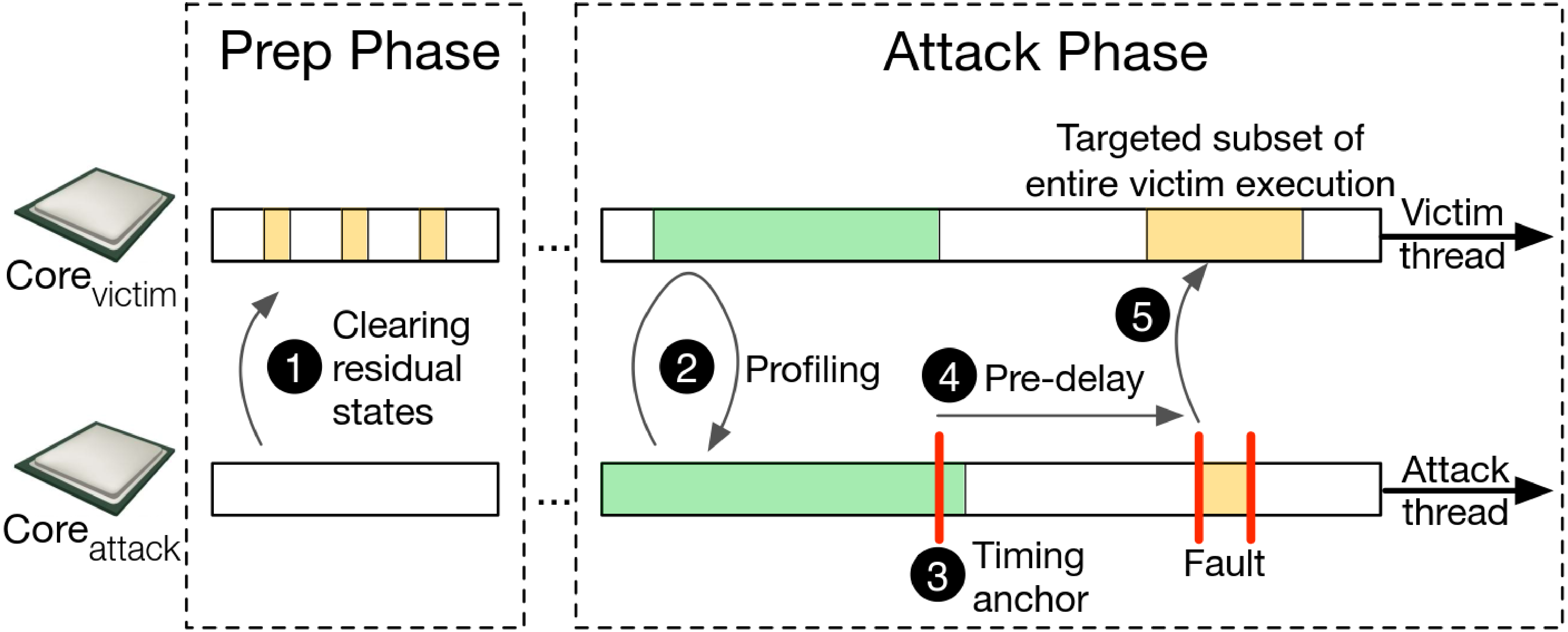

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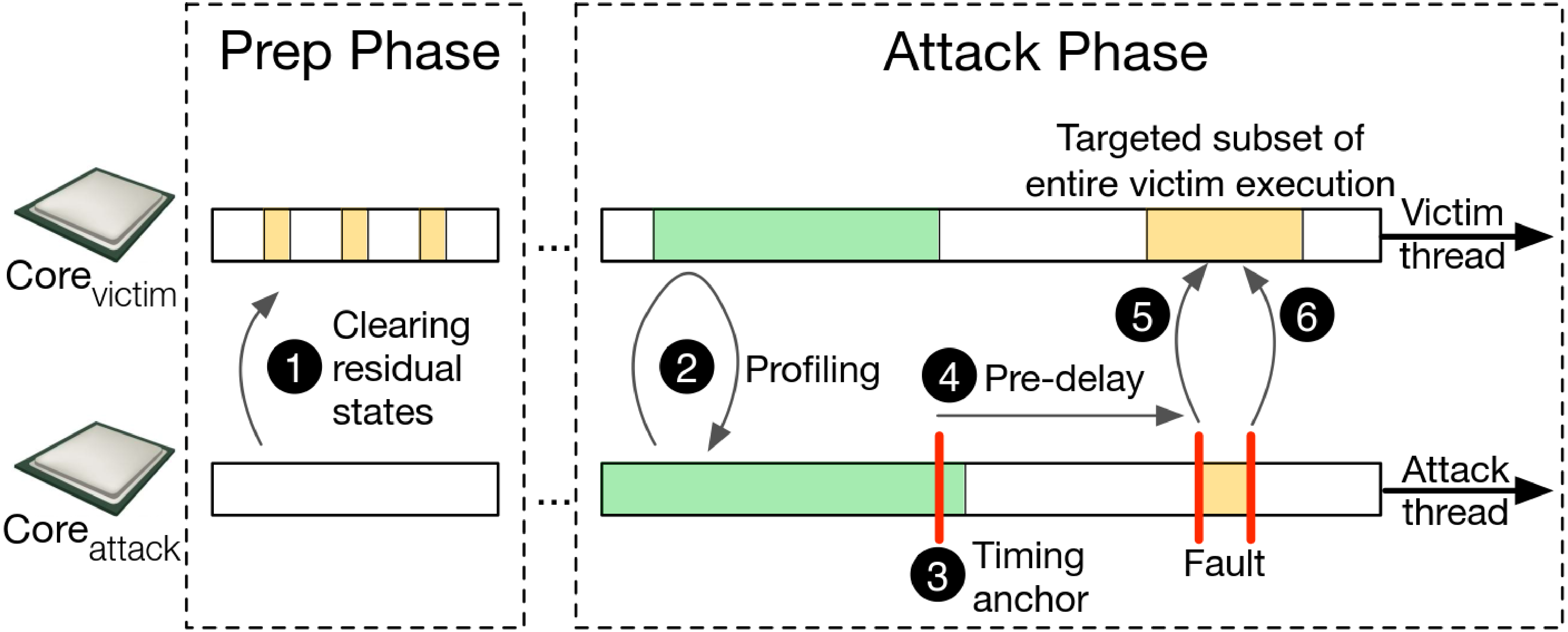
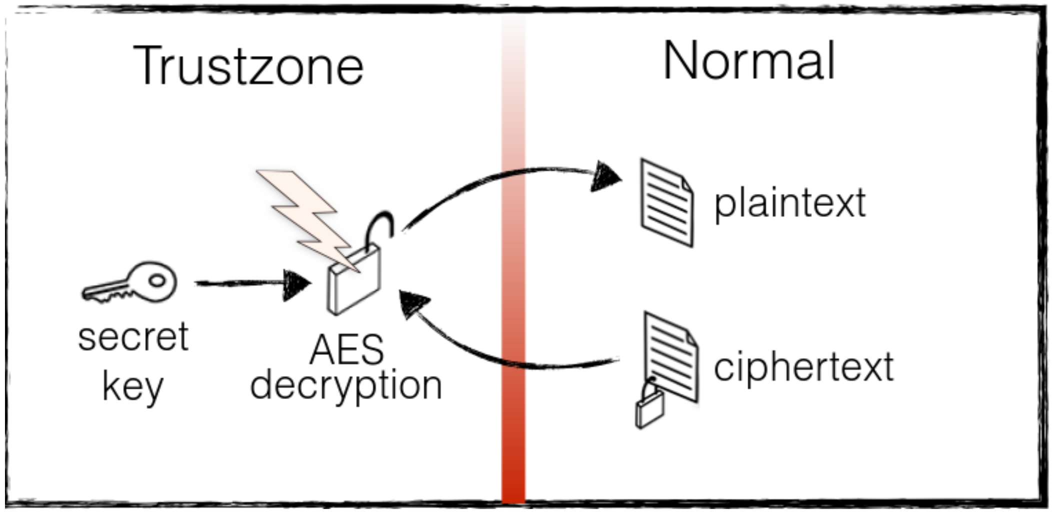
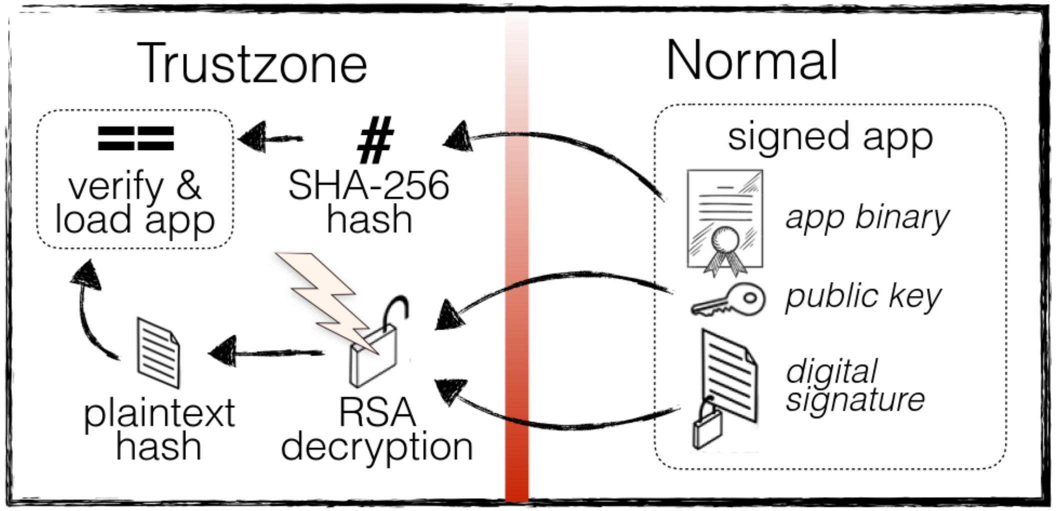


Example Attacks

- TZ Attack #1: Inferring AES Keys



- TZ Attack #2: Loading Self-Signed Apps



source graphics: CLKSCREW presentation USENIX, Adrian Tang, 2017

Example Attacks

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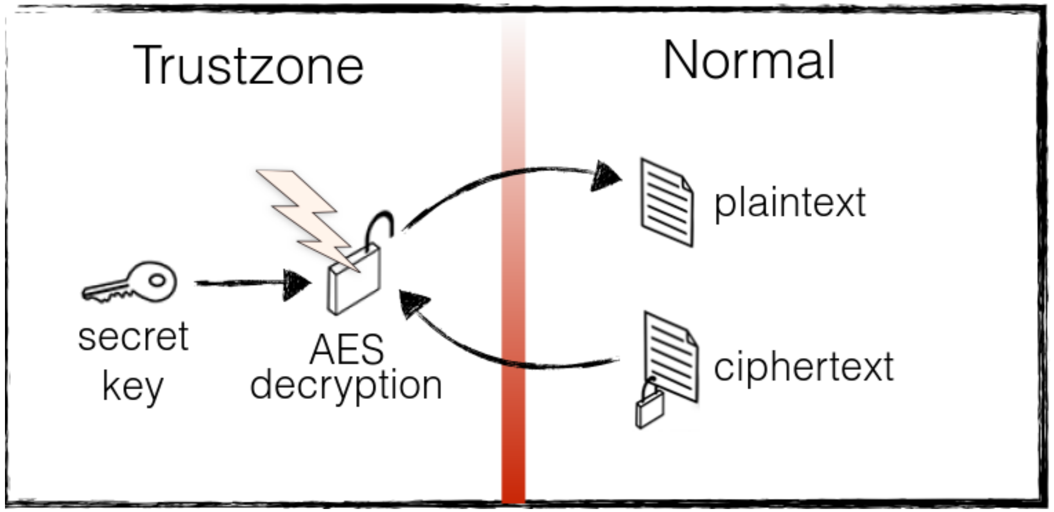

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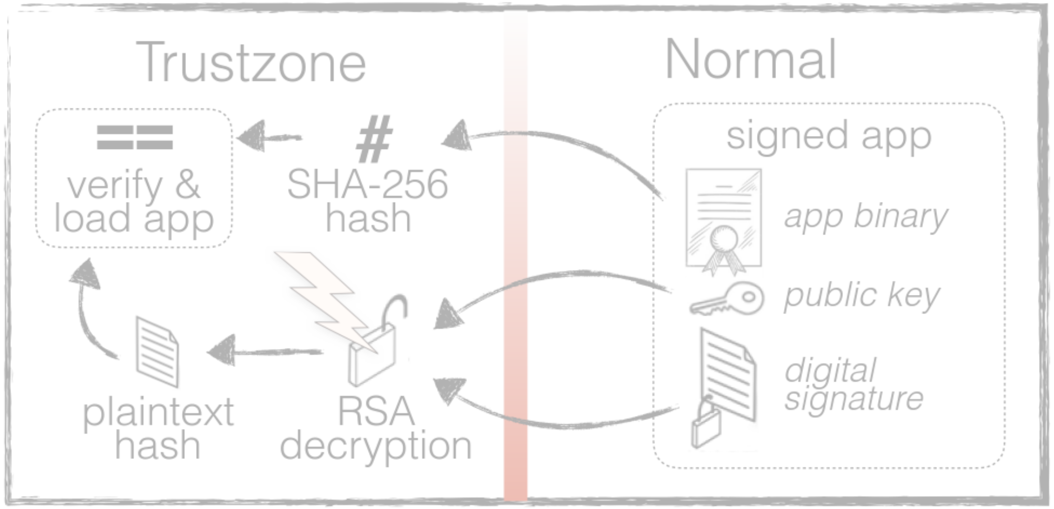
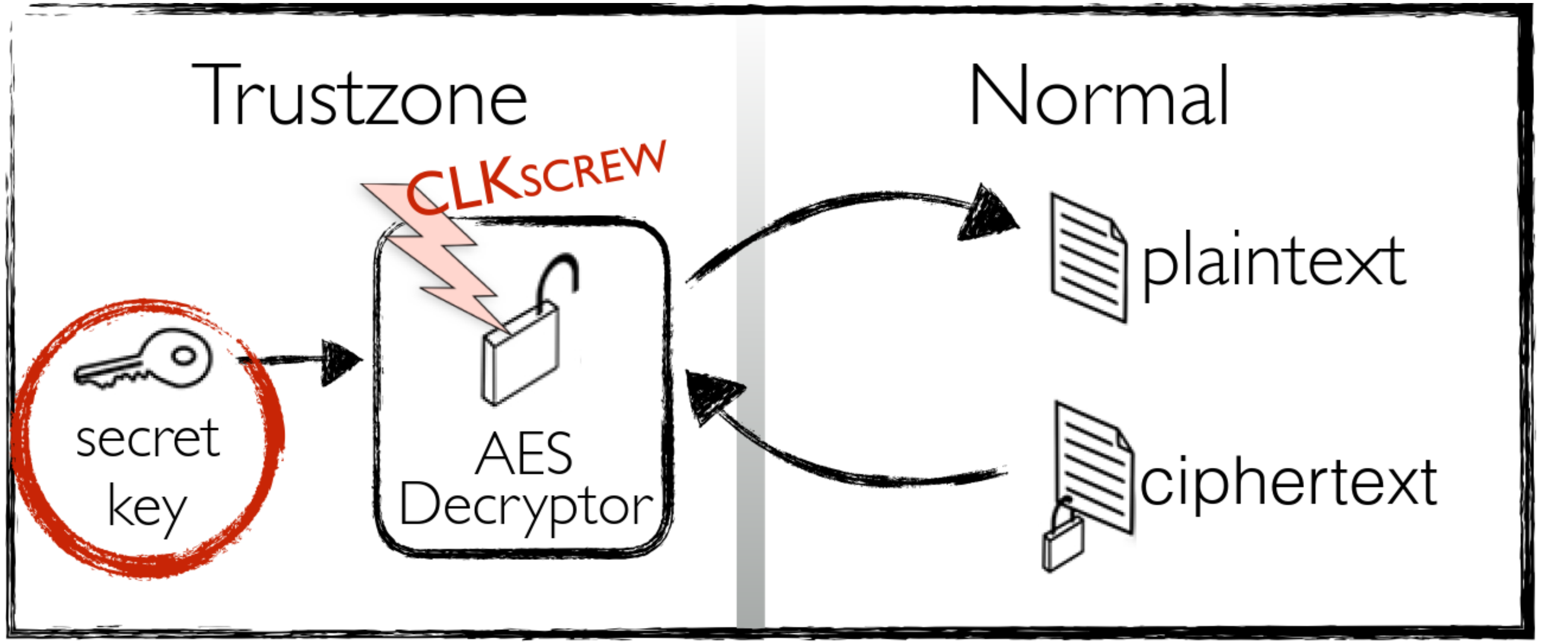


source graphics: CLKSCREW presentation, Adrian Tang, 2017

Key Inference Attack: Threat Model

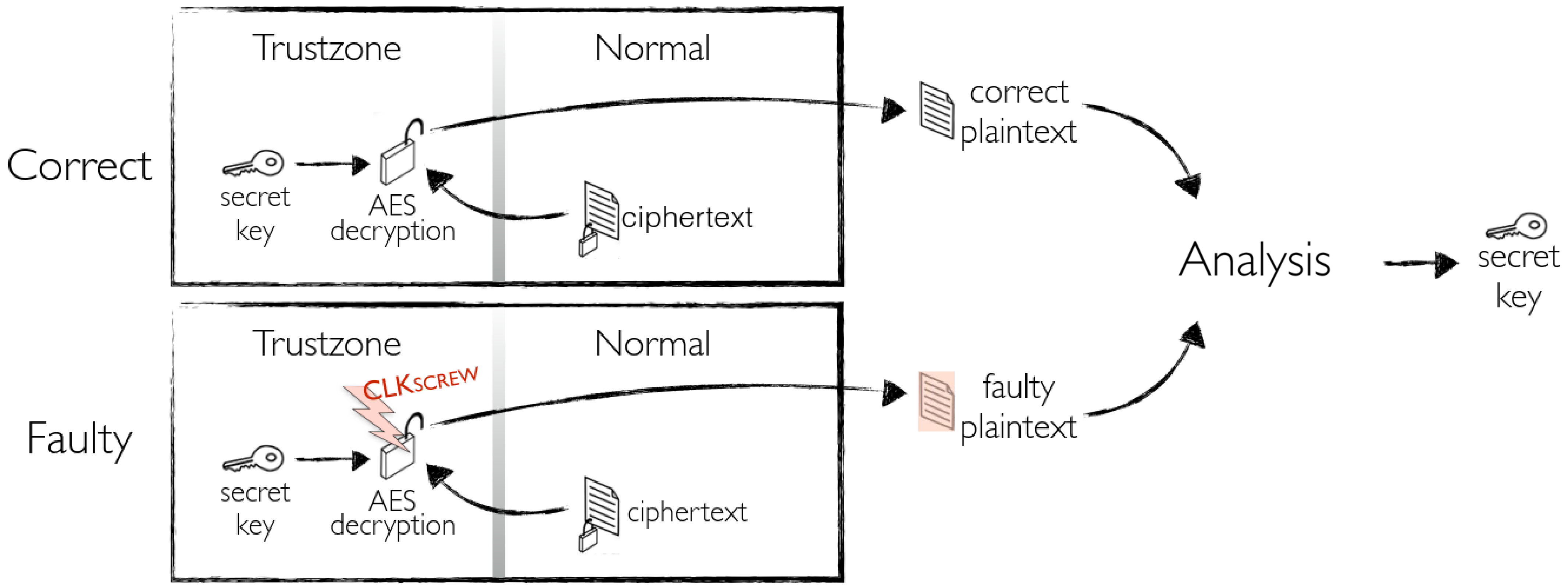
- Victim app: AES decryption app executes in Trustzone
- Attacker's goal: Get secret AES key from outside Trustzone
- Attackers capabilities:
    1. Can repeatedly invoke decryption app
    2. Has software access to hardware regulators

Key Inference Attack: Threat Model



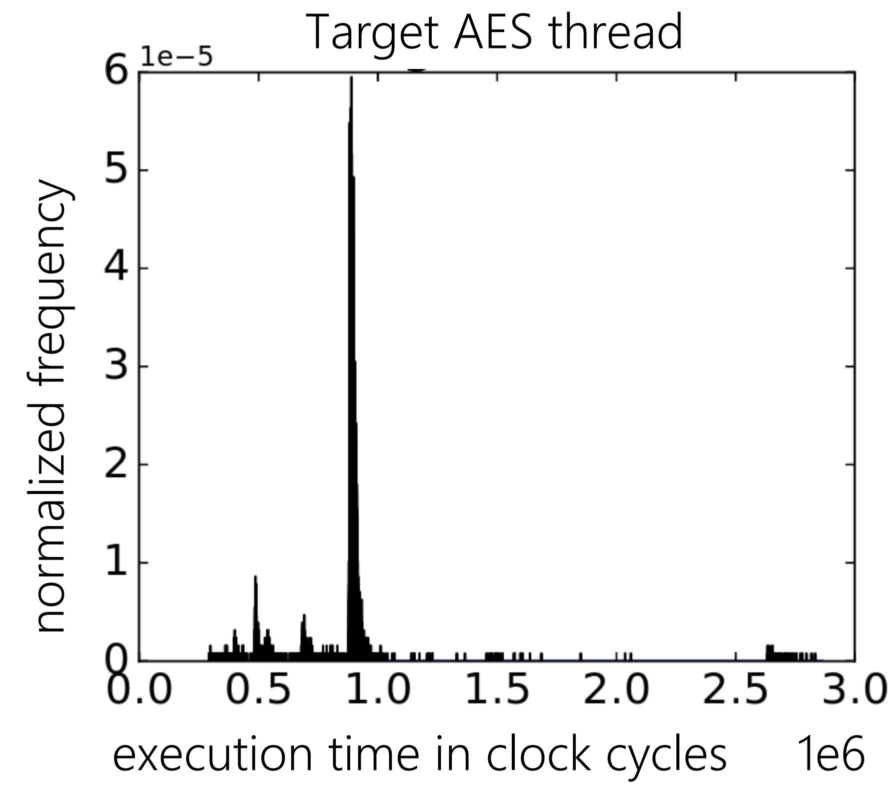
source graphics: CLKSCREW presentation, Adrian Tang, 2017

Key Inference Attack: Overview



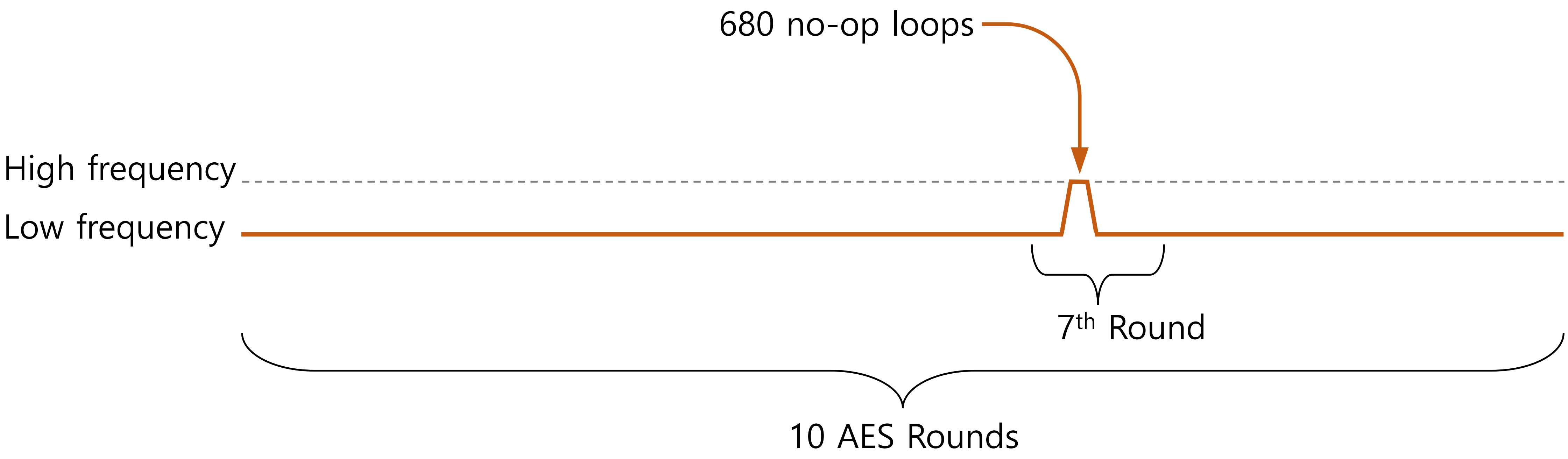
source graphics: CLKSCREW presentation, Adrian Tang, 2017

Key Inference Attack: Timing Profiling



Key Inference Attack: Timing Profiling

- Induce fault of one byte at 7th AES round



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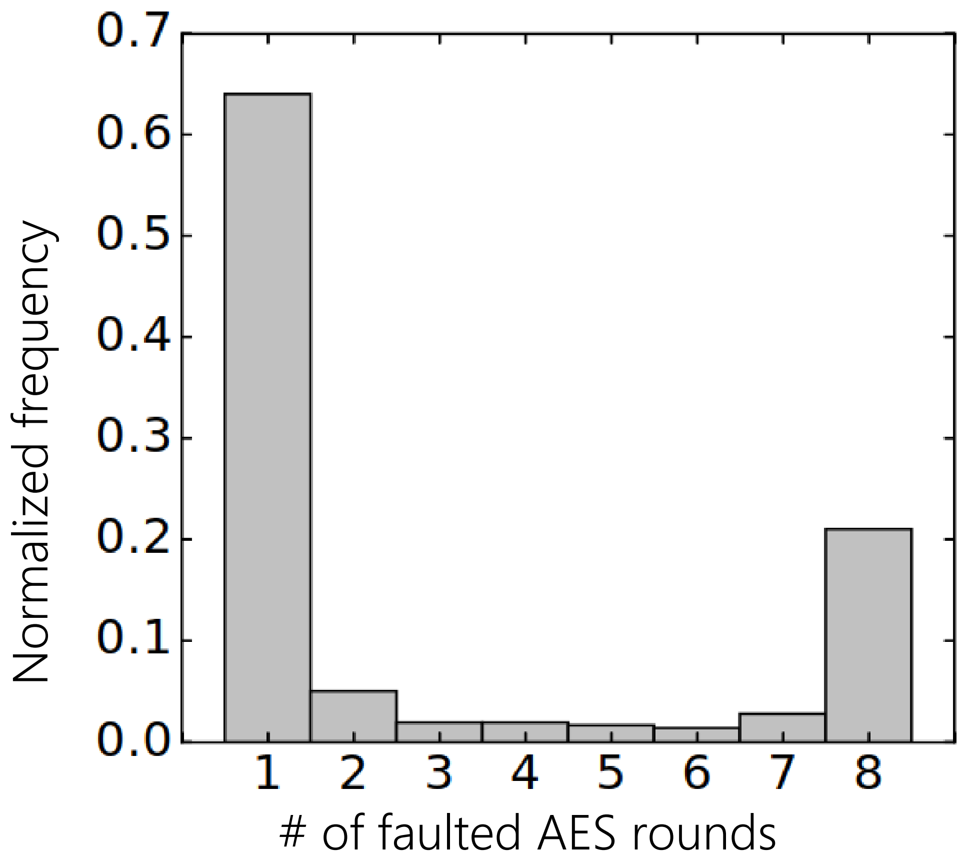
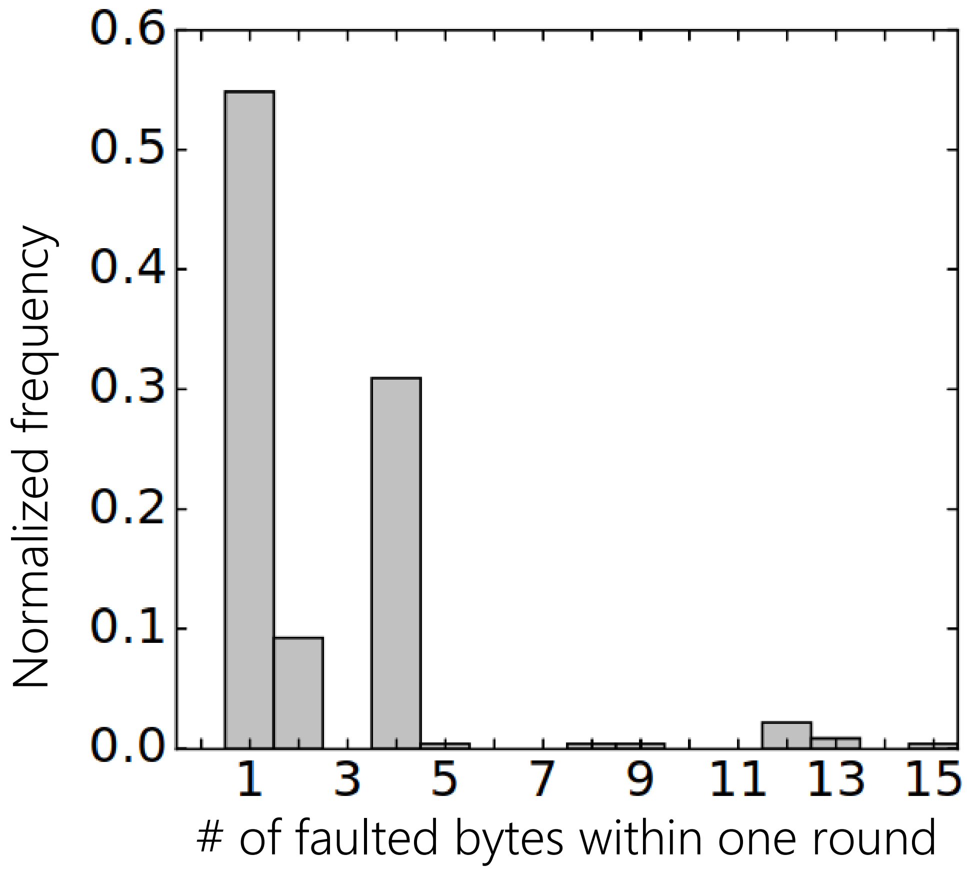
Key Inference Attack: Precision

- Over 60% of generated faults corrupt exactly one AES round



Key Inference Attack: Precision

- Over 60% of generated faults corrupt exactly one AES round
- Of those over 50% corrupt exactly one byte



Summary

Summary

- First security review of DVFS
- DVFS leaves Trustzone vulnerable
- CLKscrew attacks can be timed very precisely
- Can get AES key from outside Trustzone
- Can load untrusted app into Trustzone

Strengths and Weaknesses

Strengths

- First security review of a DVFS
- Managed to do fault attacks purely from software
- Tested two example attacks
  - managed to get the AES key
- only used publicly available knowledge
- Give ideas for possible solutions
- Well written

Weaknesses

- Tested with self written AES decryption app
- Used self written kernel driver to have victim and attacker on different cores.
- Assumed access to hardware regulators
- Tested attacks only on one Nexus 6 device

Takeaways

Takeaways

- New attack surface: Energy management software interface
- Not because of bug but because of fundamental design flaw
- Example attacks on ARM Trustzone
- Energy management designs must take security into consideration

Discussion

Discussion

- Ideas on possible solutions?
    - Hardware?
    - Software?
- What else could be done by exploiting DVFS
    - can you think of specific attacks?

Discussion

Blacklist Core: Machine-Learning Based Dynamic Operating-Performance-Point Blacklisting for Mitigating Power-Management Security Attacks

Sheng Zhang, Adrian Tang, Zhewei Jiang, Simha Sethumadhavan, Mingoo Seok,
Columbia University, 2018

Discussion

- Ideas on possible solutions?
  - Hardware?
  - Software?
- What else could be done by exploiting DVFS?
  - can you think of specific attacks?

Discussion

- How widely spread is this energy management issue?
- How important will this be for the future?
  - will it be considered enough? does it have to?
- General thoughts on the paper?
  - Additional strength, weaknesses, ideas?