Formal Foundations for Intel SGX Data Center Attestation Primitives

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Thanks to: Rasha Faqeh, Do Le Quoc, Franz Gregor

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Arm Research Summit 2020

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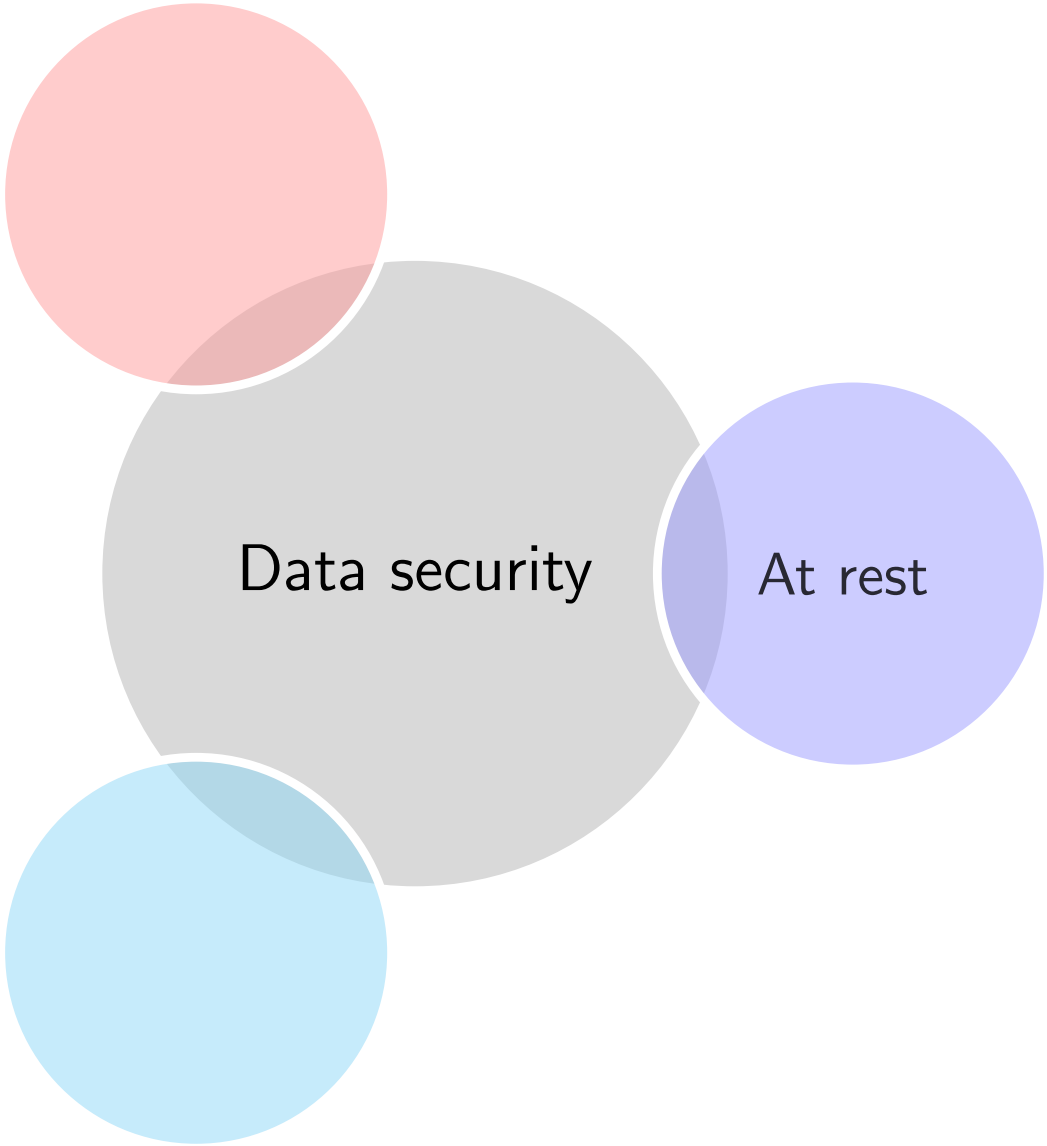
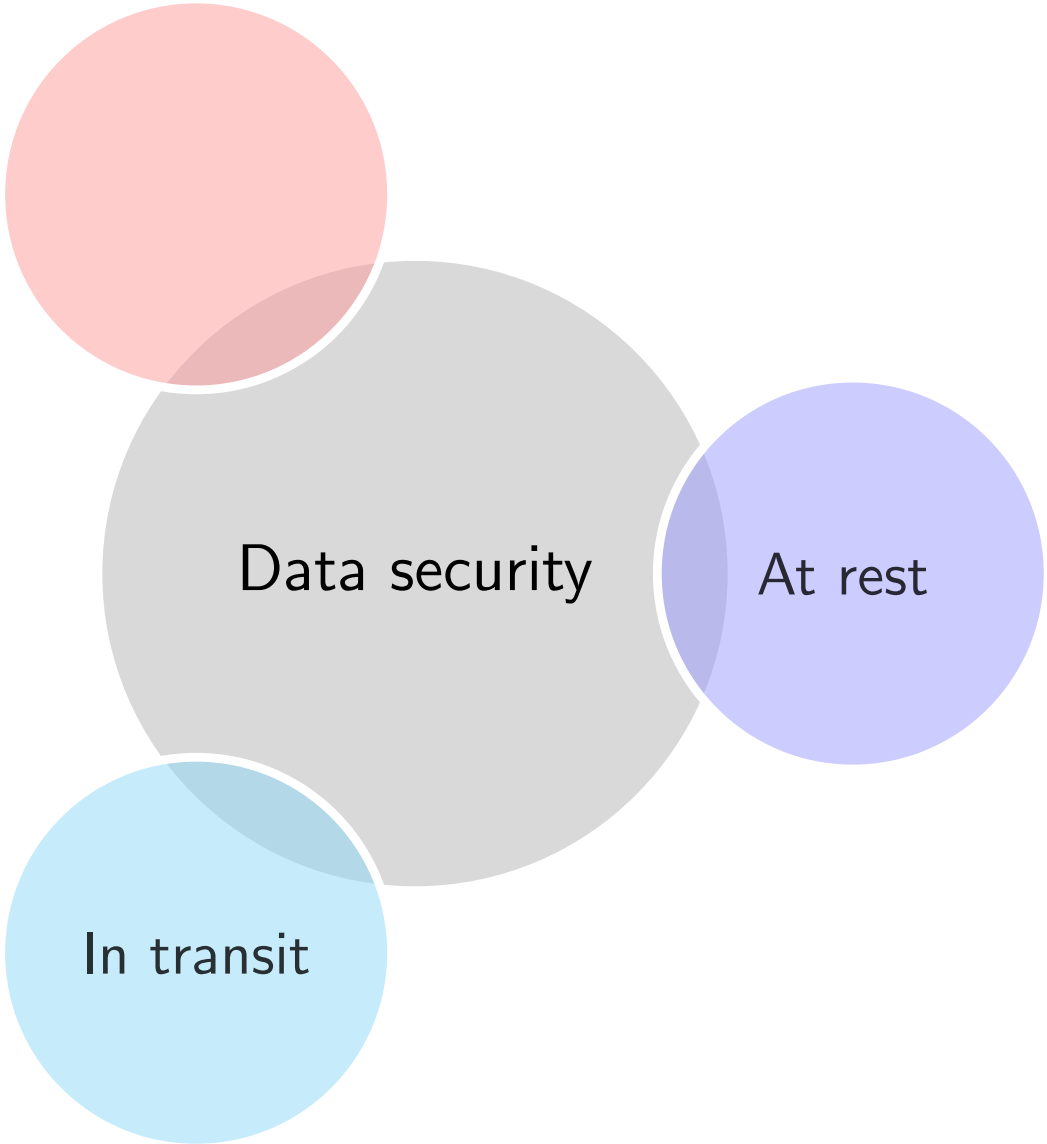
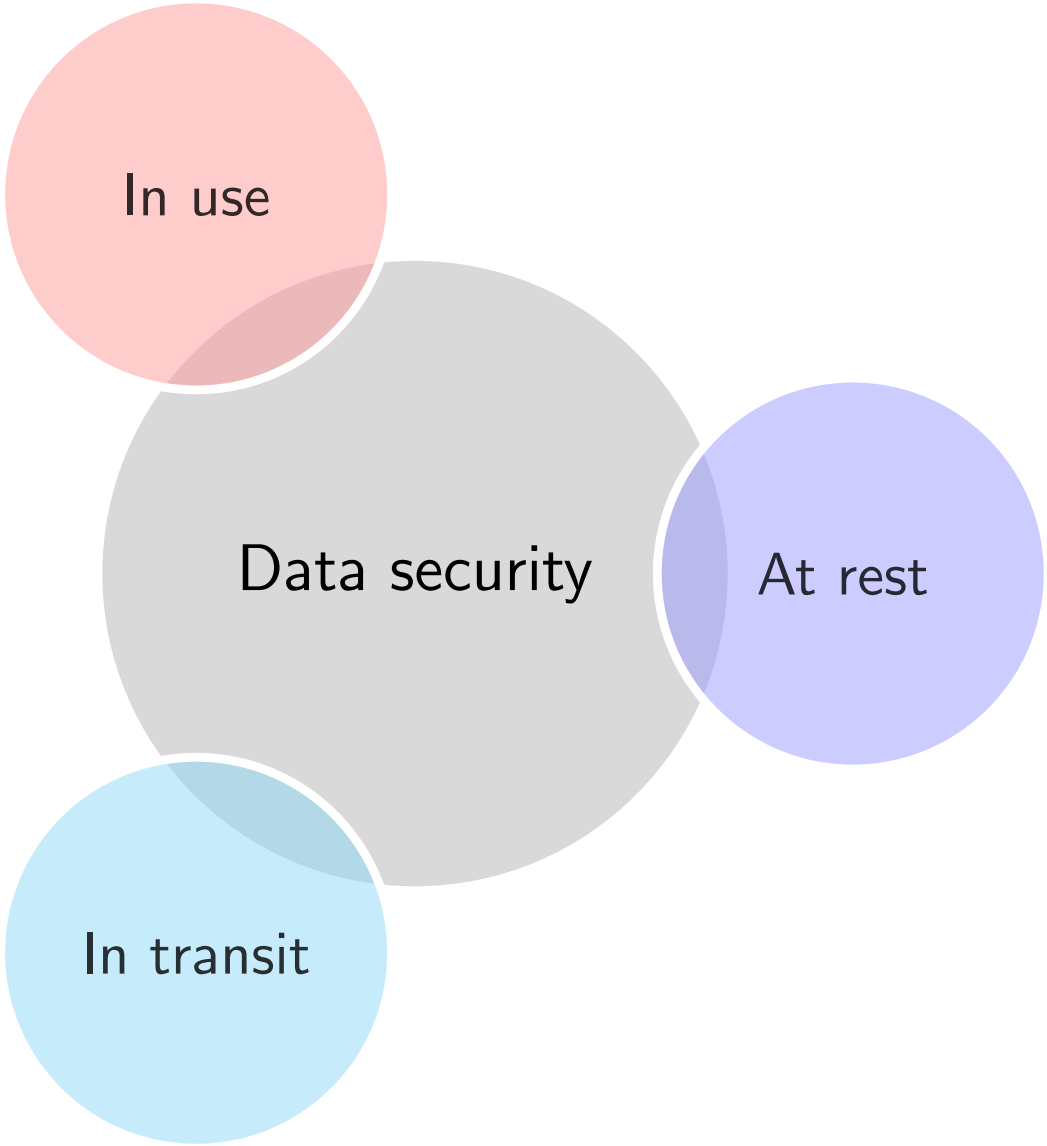
Data Security Paradigms



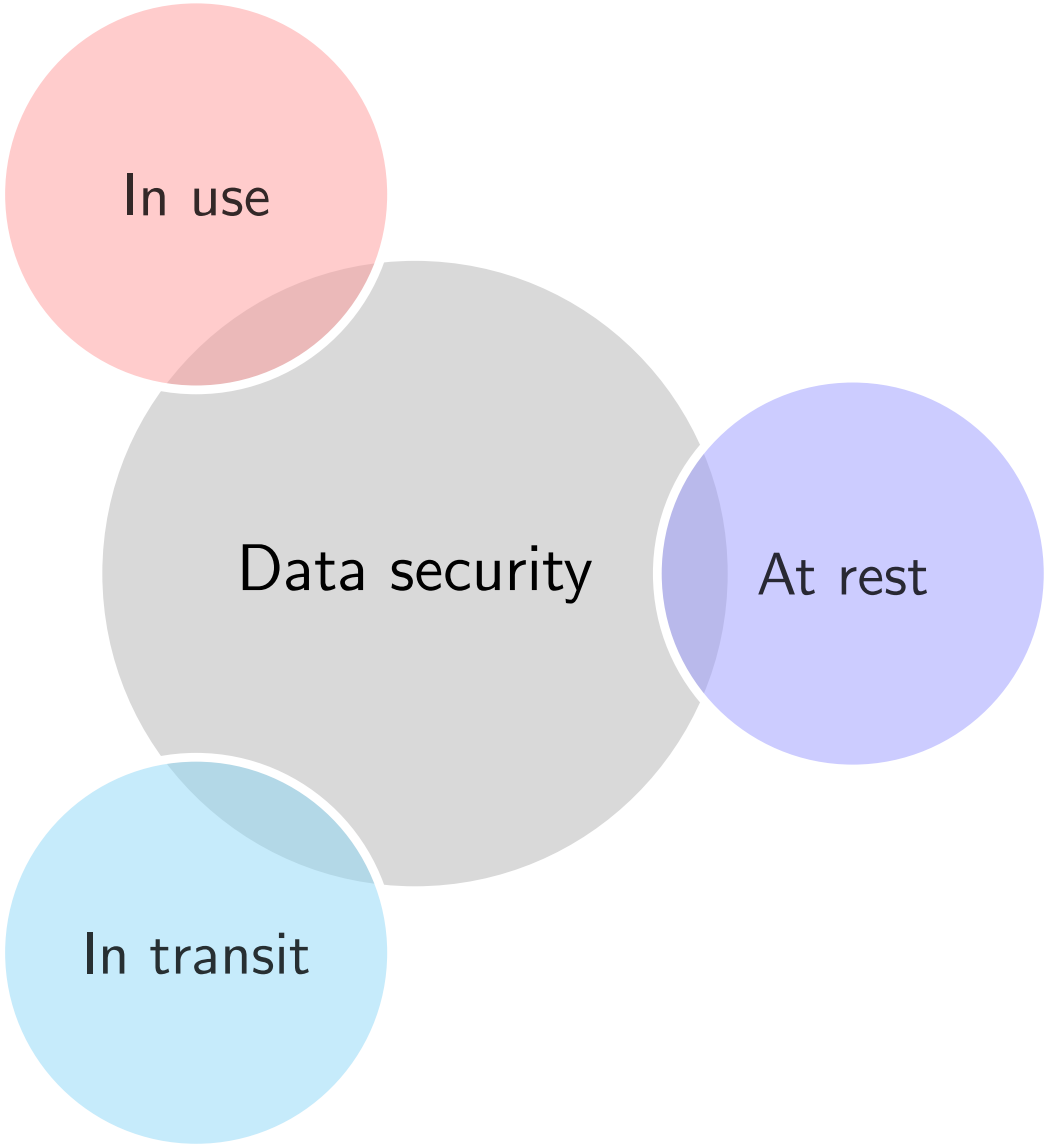
Data Security Paradigms



Data Security Paradigms



Data Security Paradigms



- Formal methods (e.g., for Needham–Schröder protocol)

Introduction

- HW-based Trusted Execution Environments (TEEs)

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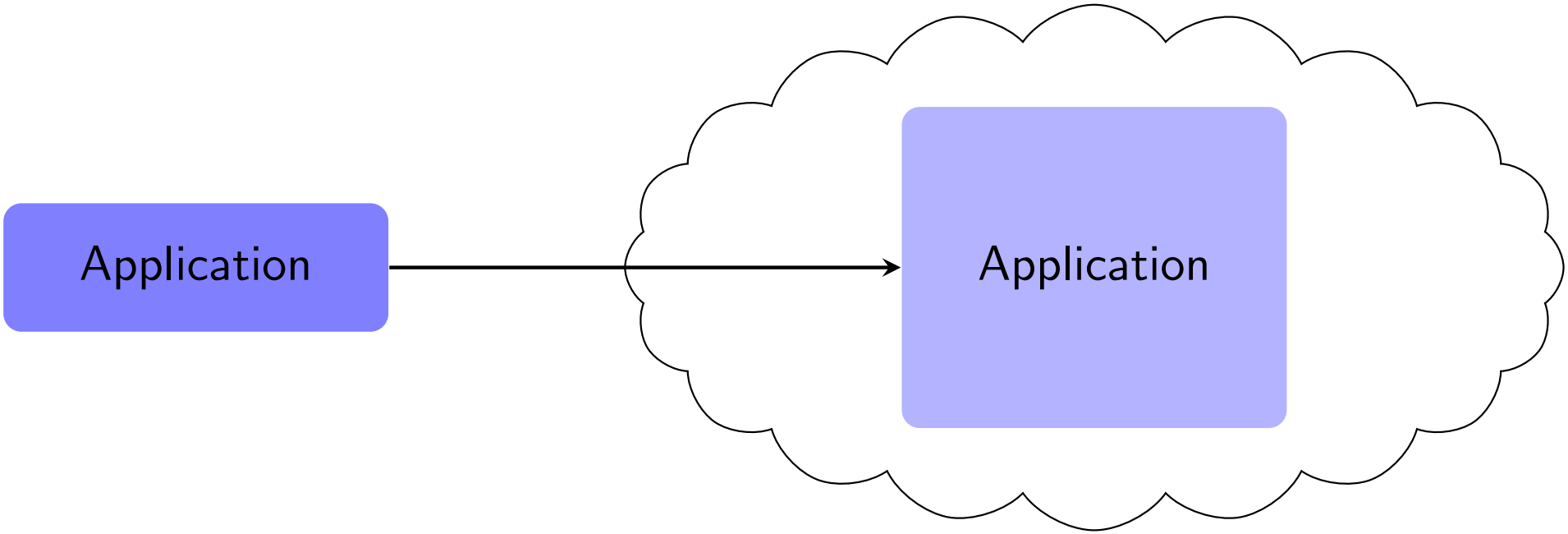
Application

Introduction

- HW-based Trusted Execution Environments (TEEs)



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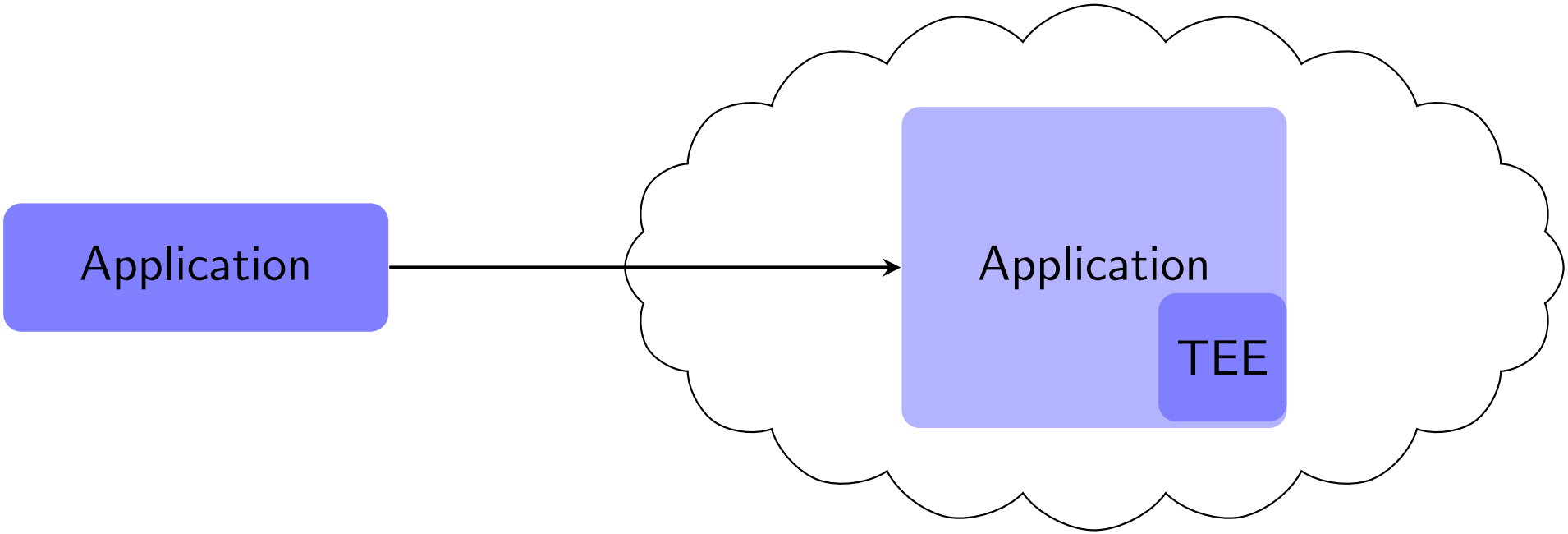

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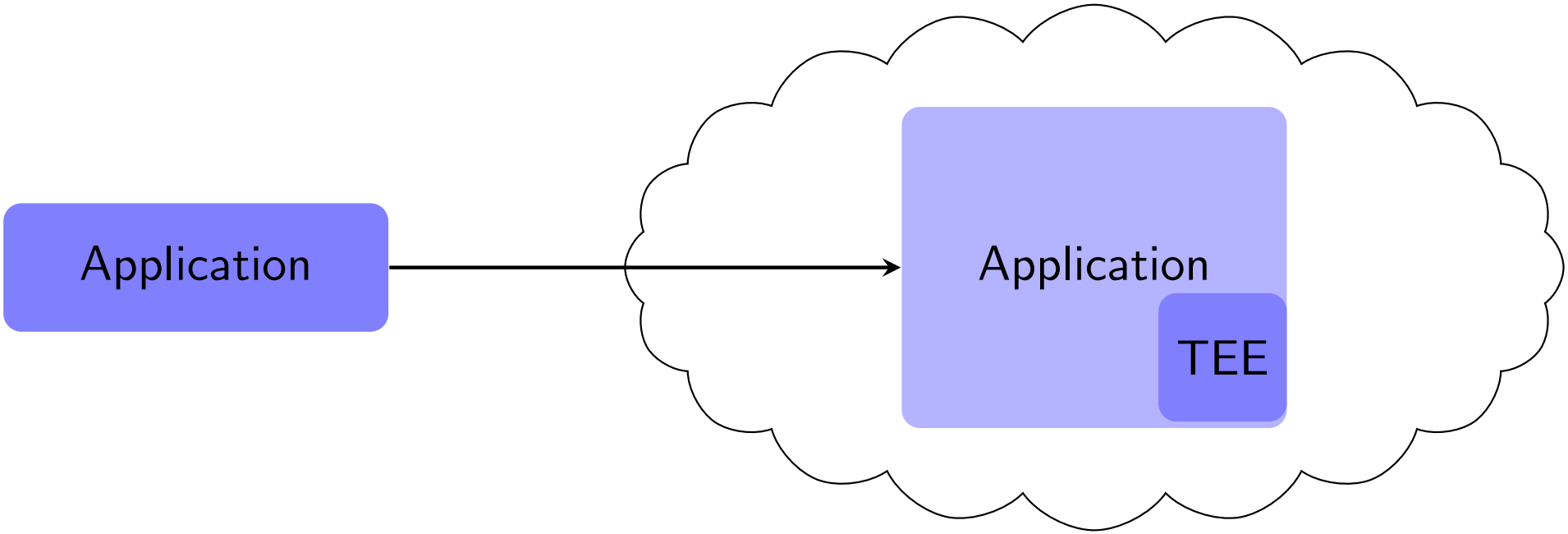

- Intel SGX, AMD SP, ARM TrustZone

Attestation

- Trust to challenger: right app in right platform

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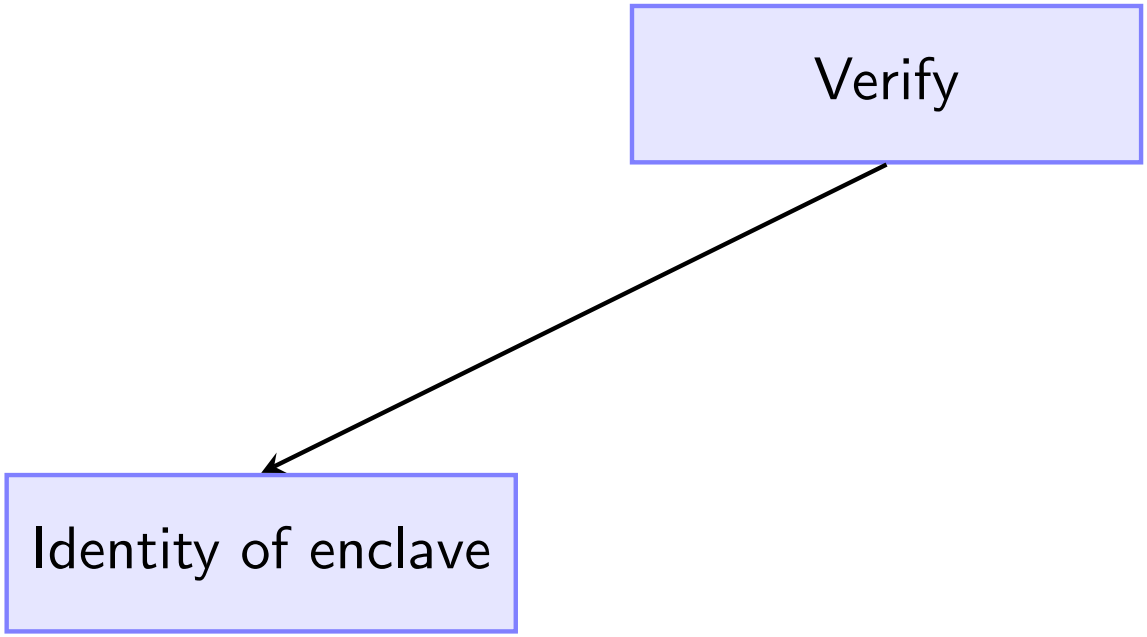

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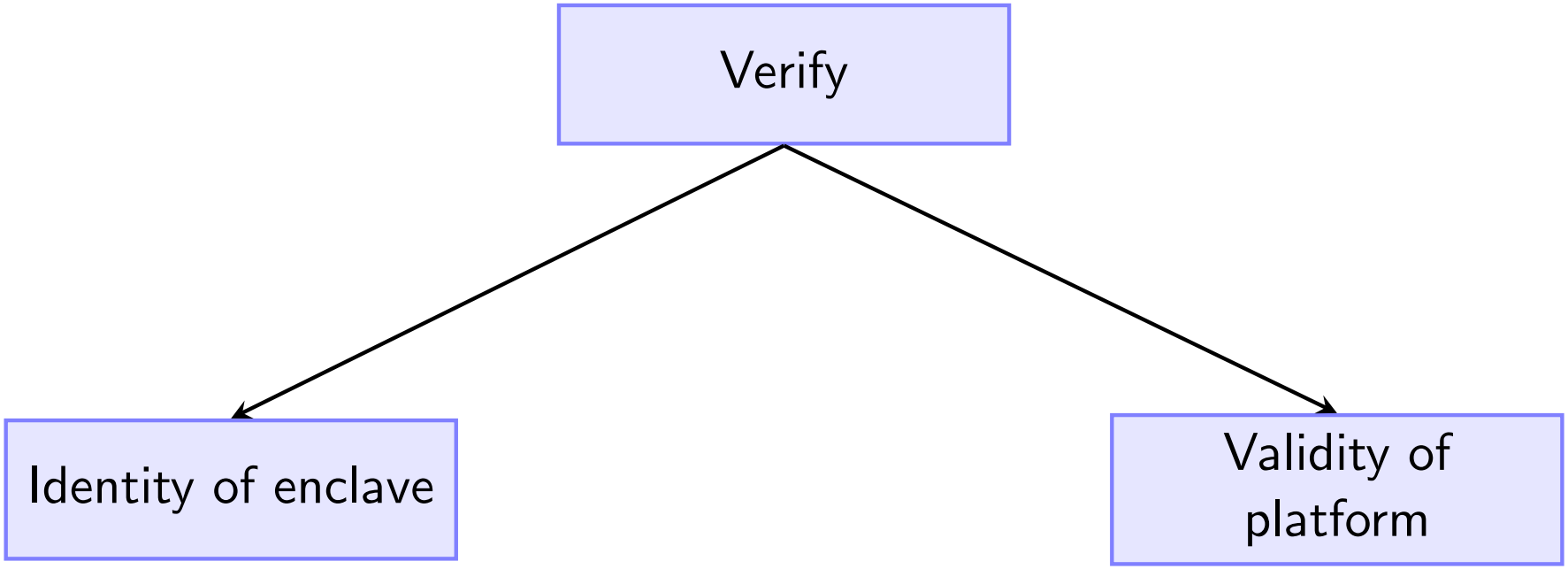

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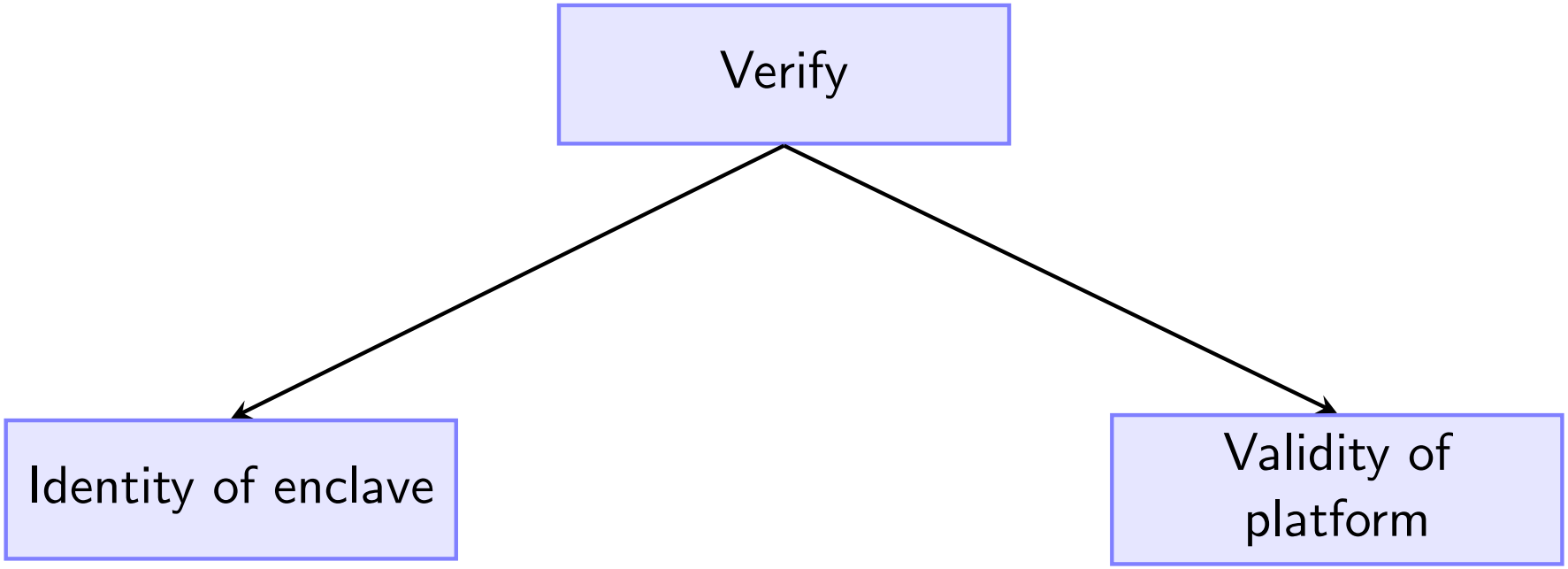
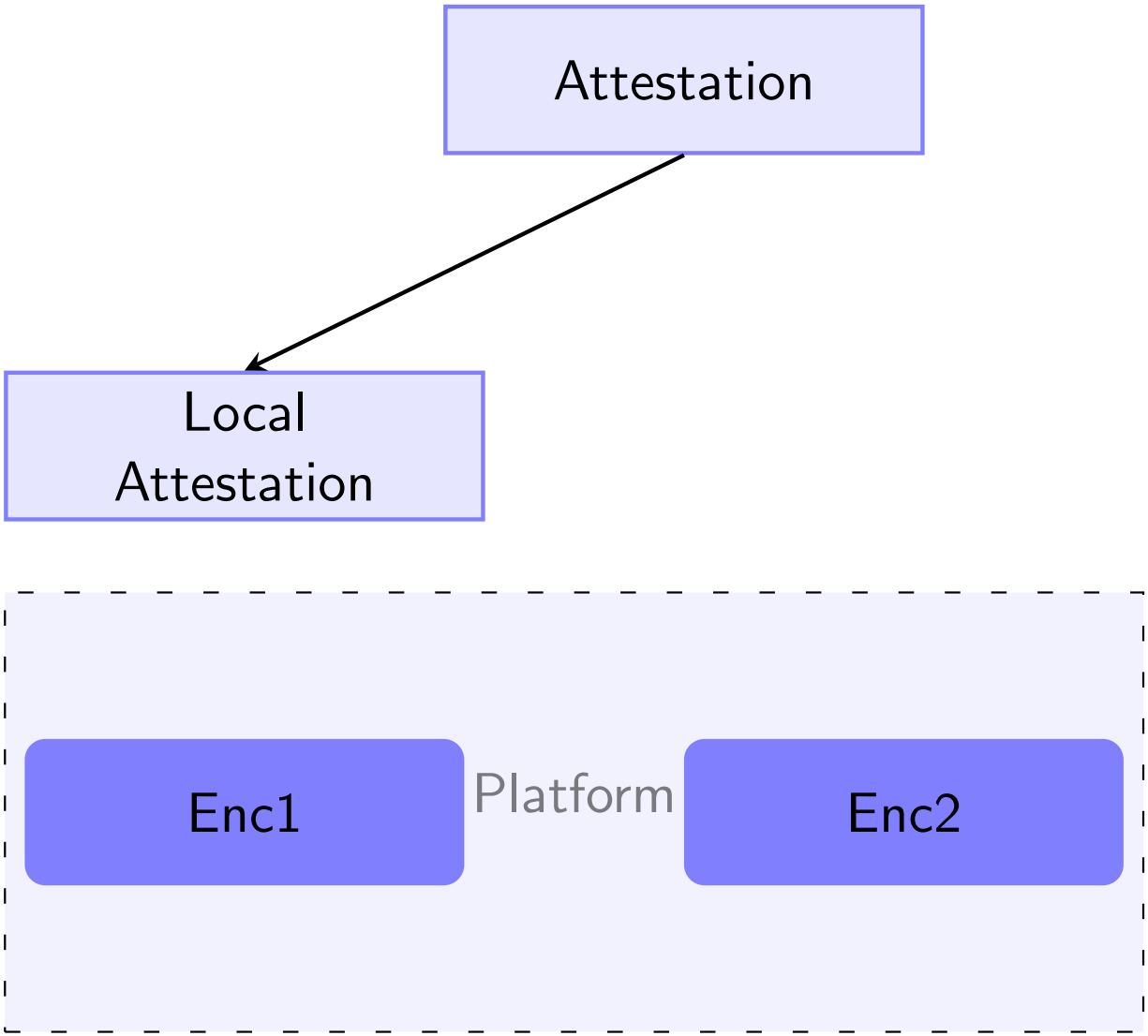


- Importance $\rightarrow$ Provisioning of secrets

Attestation in Intel SGX



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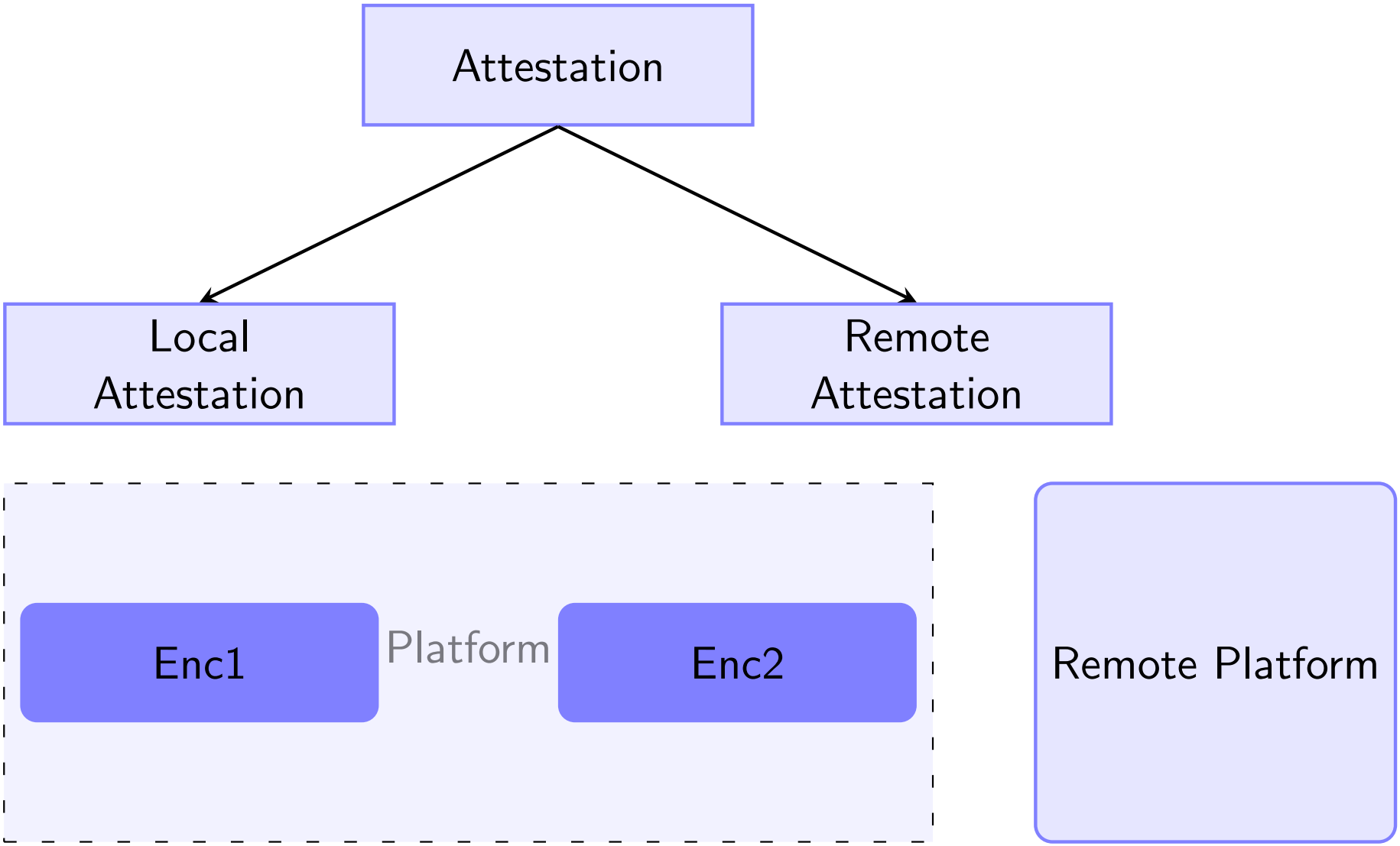

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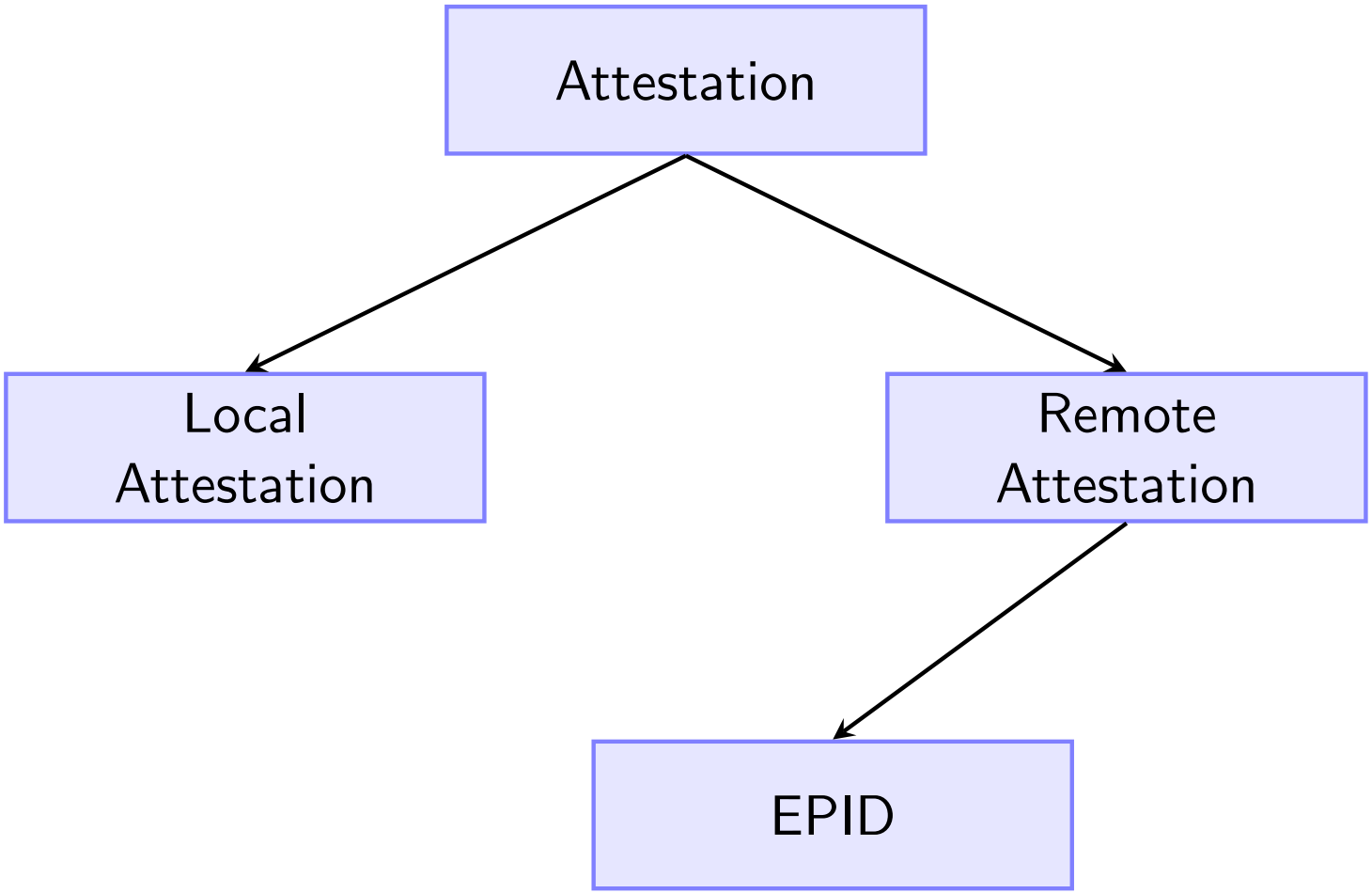

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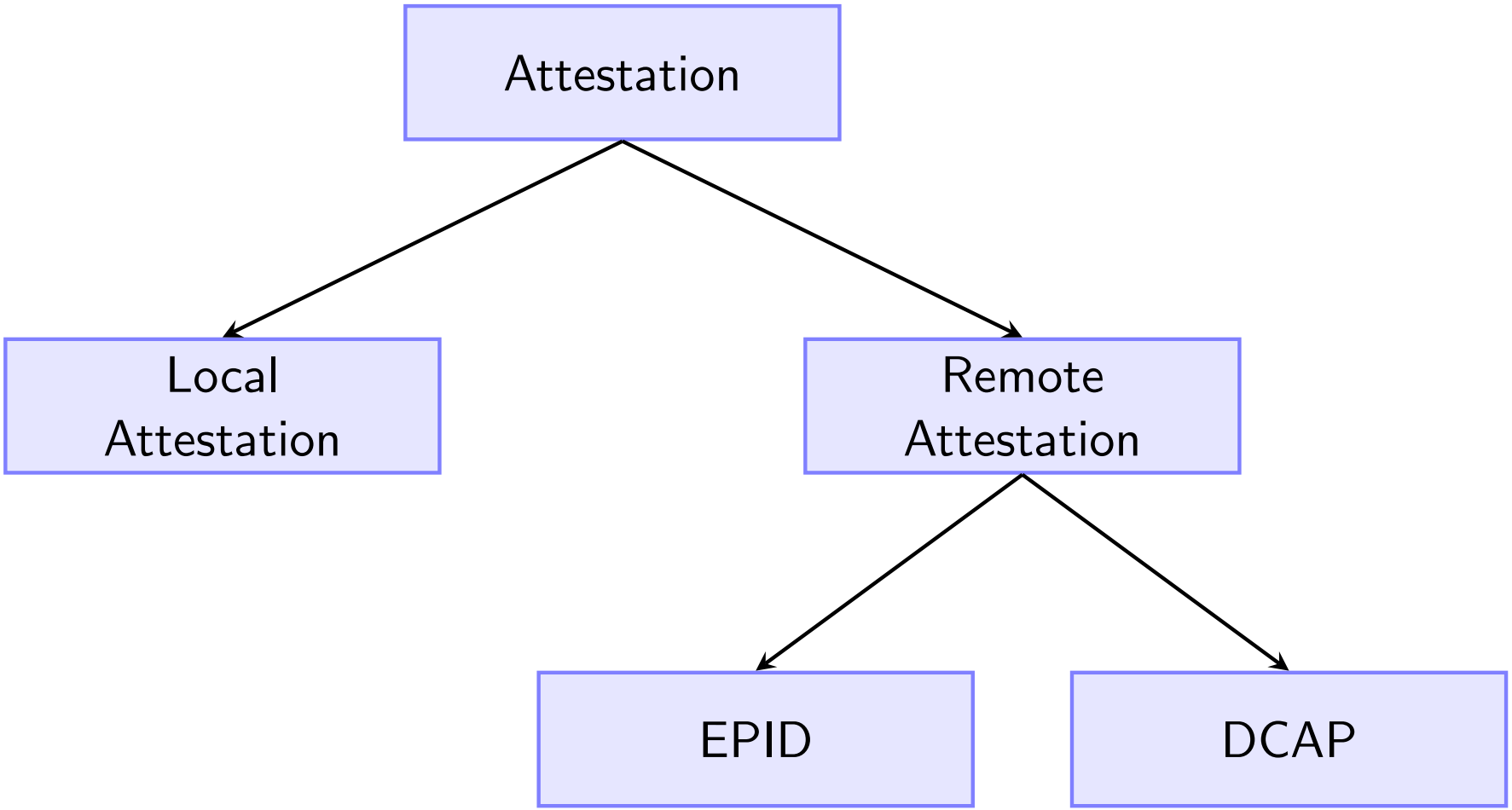
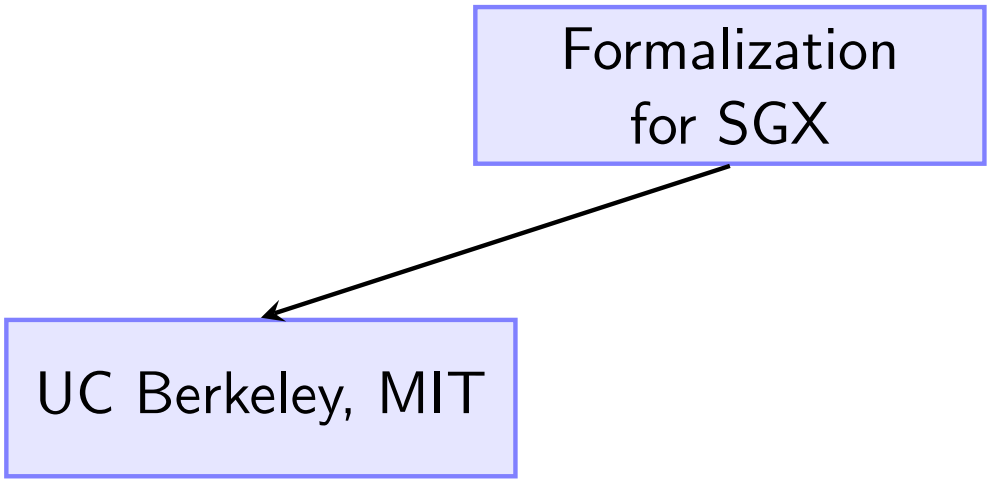


Related Work



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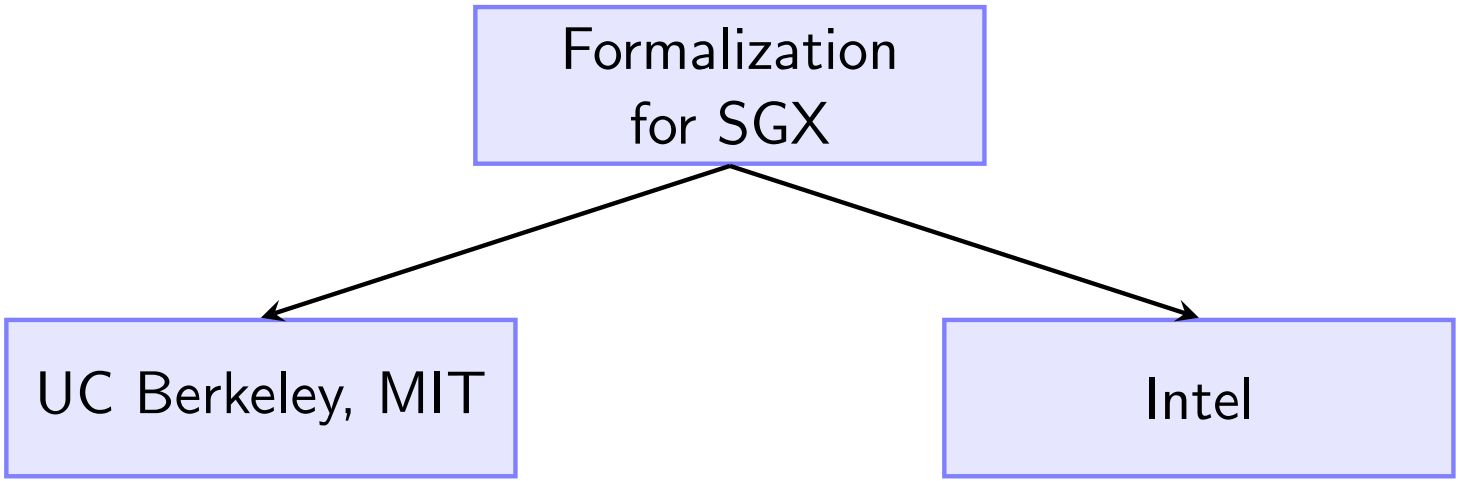

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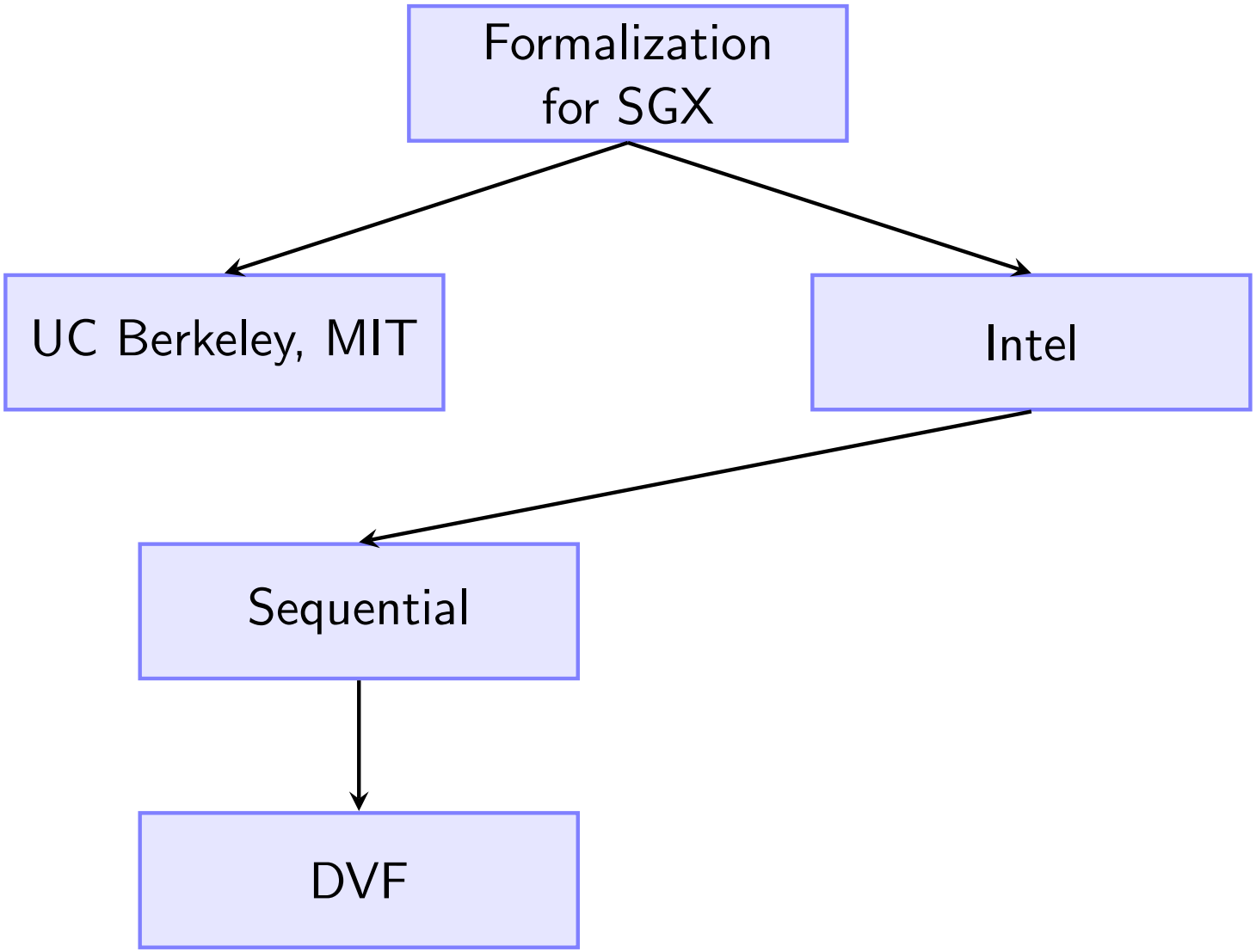

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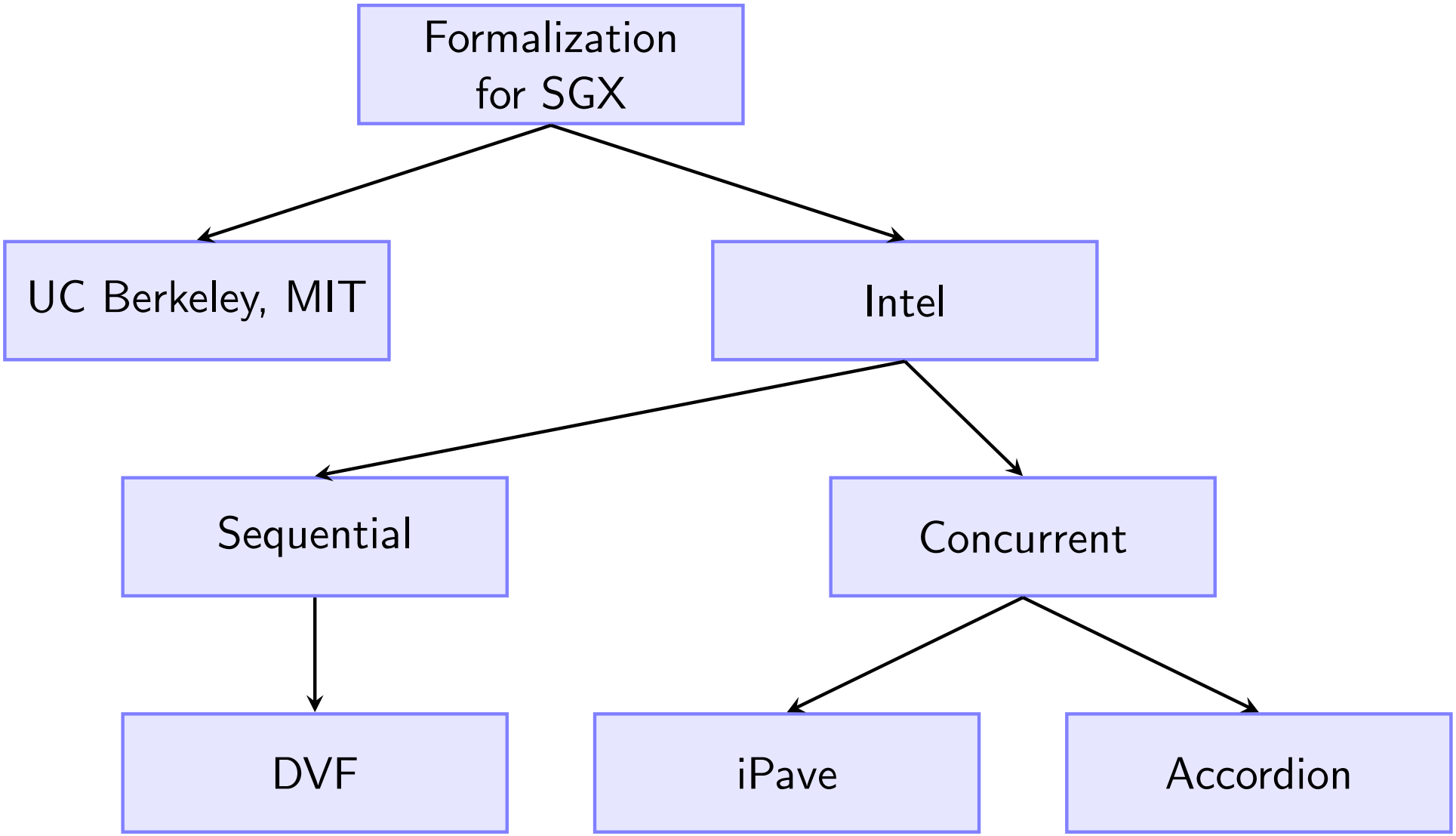

Comparison with Intel's related work

Tool				
DVF[1]				
iPave[2]				
Accordion[3]				
Proposed				

[1] Amit Goel et al. "SMT-Based System Verification with DVF". In: *Satisfiability Modulo Theories*. Vol. 20. EasyChair, 2013, pp. 32–43.

[2] Ranan Fraer et al. "From visual to logical formalisms for SoC validation". In: *2014 Twelfth ACM/IEEE Conference on Formal Methods and Models for Codesign (MEMOCODE)*. ACM/IEEE. 2014, pp. 165–174.

[3] Rebekah Leslie-Hurd, Dror Caspi, and Matthew Fernandez. "Verifying linearizability of Intel® software guard extensions". In: *International Conference on Computer Aided Verification*. Springer. 2015, pp. 144–160.

Comparison with Intel's related work

Tool	Concurrency			
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Comparison with Intel's related work

Tool	Concurrency	Non-determinism		
DVF[1]	No	Yes		
iPave[2]	Yes	No		
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Proposed	Yes	Yes		

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Comparison with Intel's related work

Tool	Concurrency	Non-determinism	Open-source	
DVF[1]	No	Yes	No	
iPave[2]	Yes	No	No	
Accordion[3]	Yes	No	No	
Proposed	Yes	Yes	Yes	

[1] Goel et al., "SMT-Based System Verification with DVF".

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Comparison with Intel's related work

Tool	Concurrency	Non-determinism	Open-source	Implementation details
DVF[1]	No	Yes	No	High
iPave[2]	Yes	No	No	High
Accordion[3]	Yes	No	No	High
Proposed	Yes	Yes	Yes	Low

[1] Goel et al., "SMT-Based System Verification with DVF".

[2] Fraer et al., "From visual to logical formalisms for SoC validation".

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Workflow of the Proposed Approach

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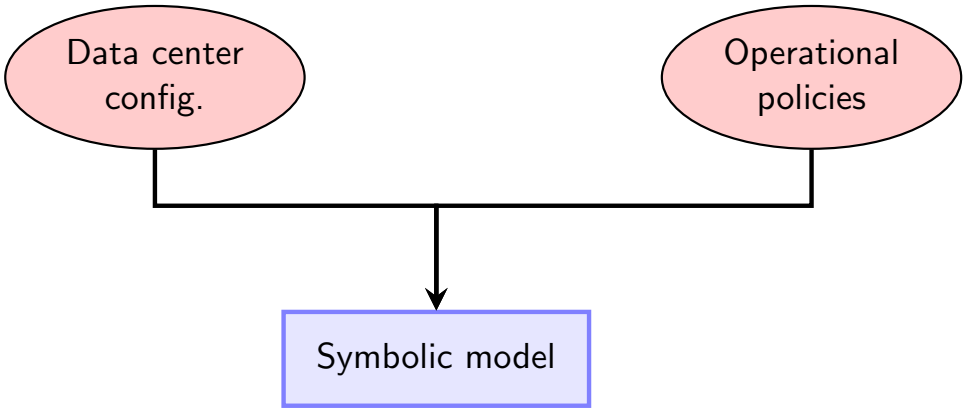

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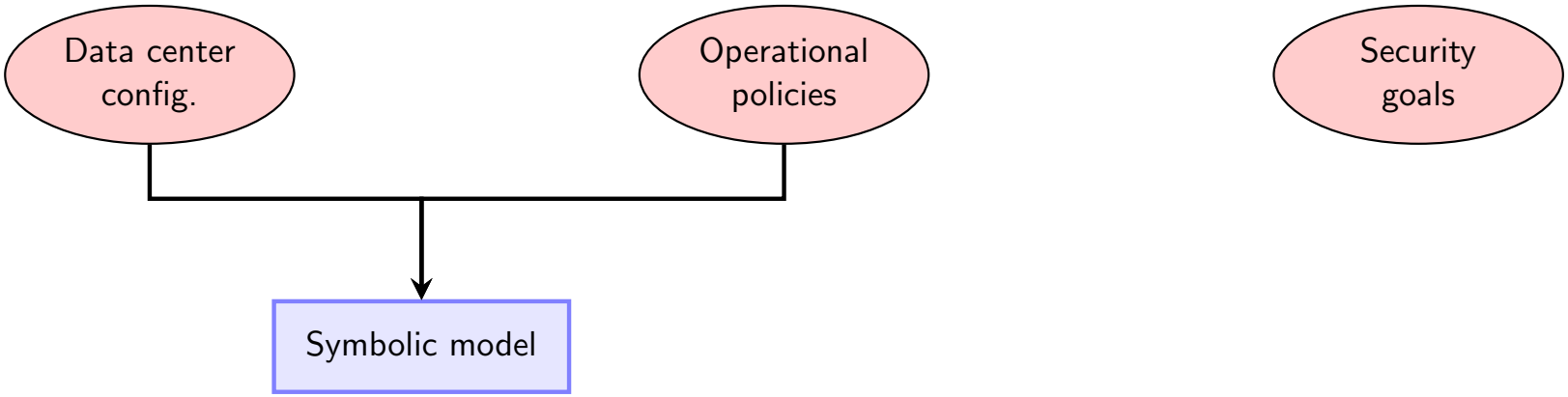

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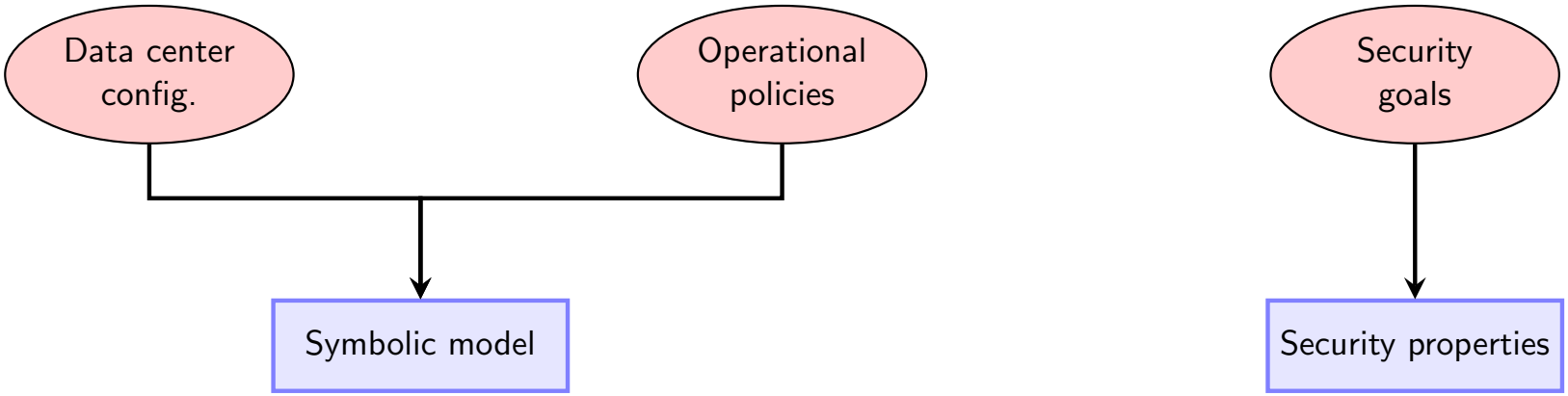

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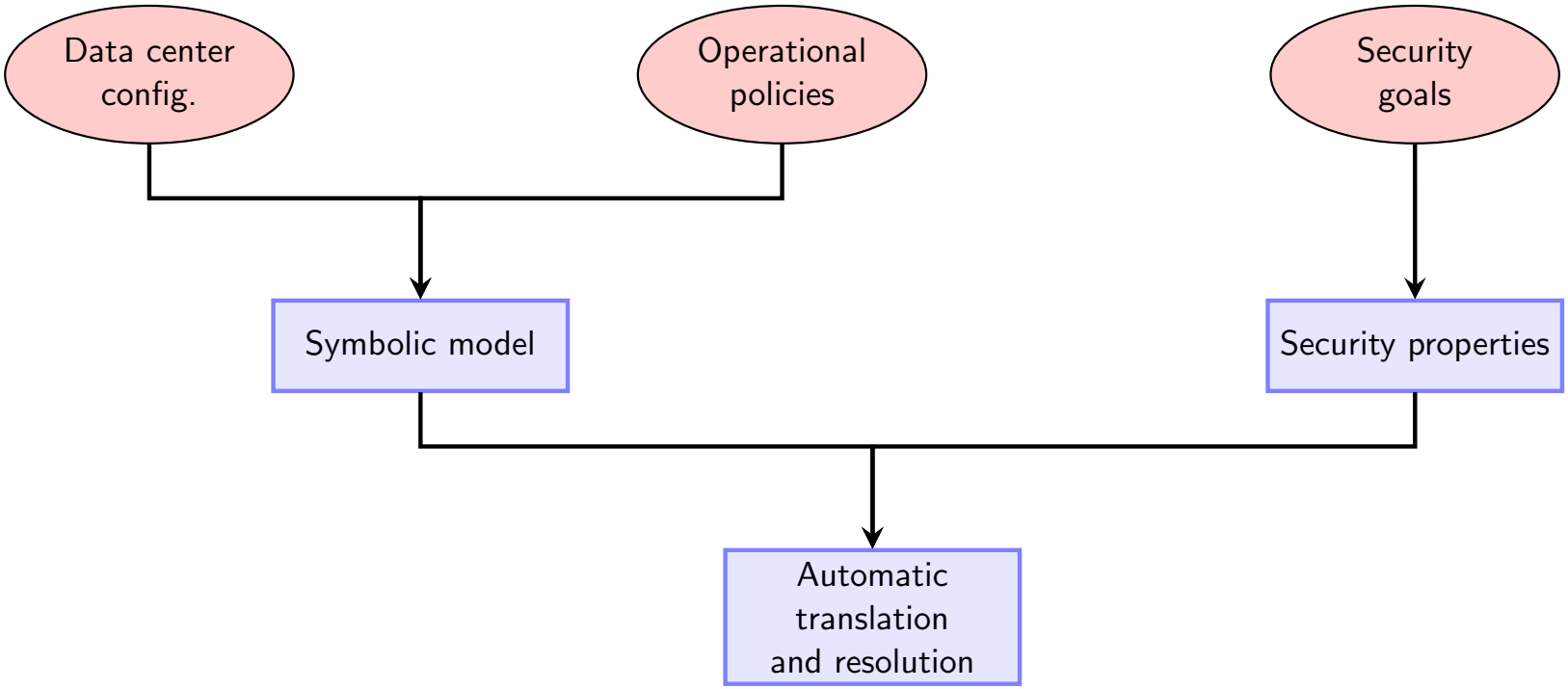

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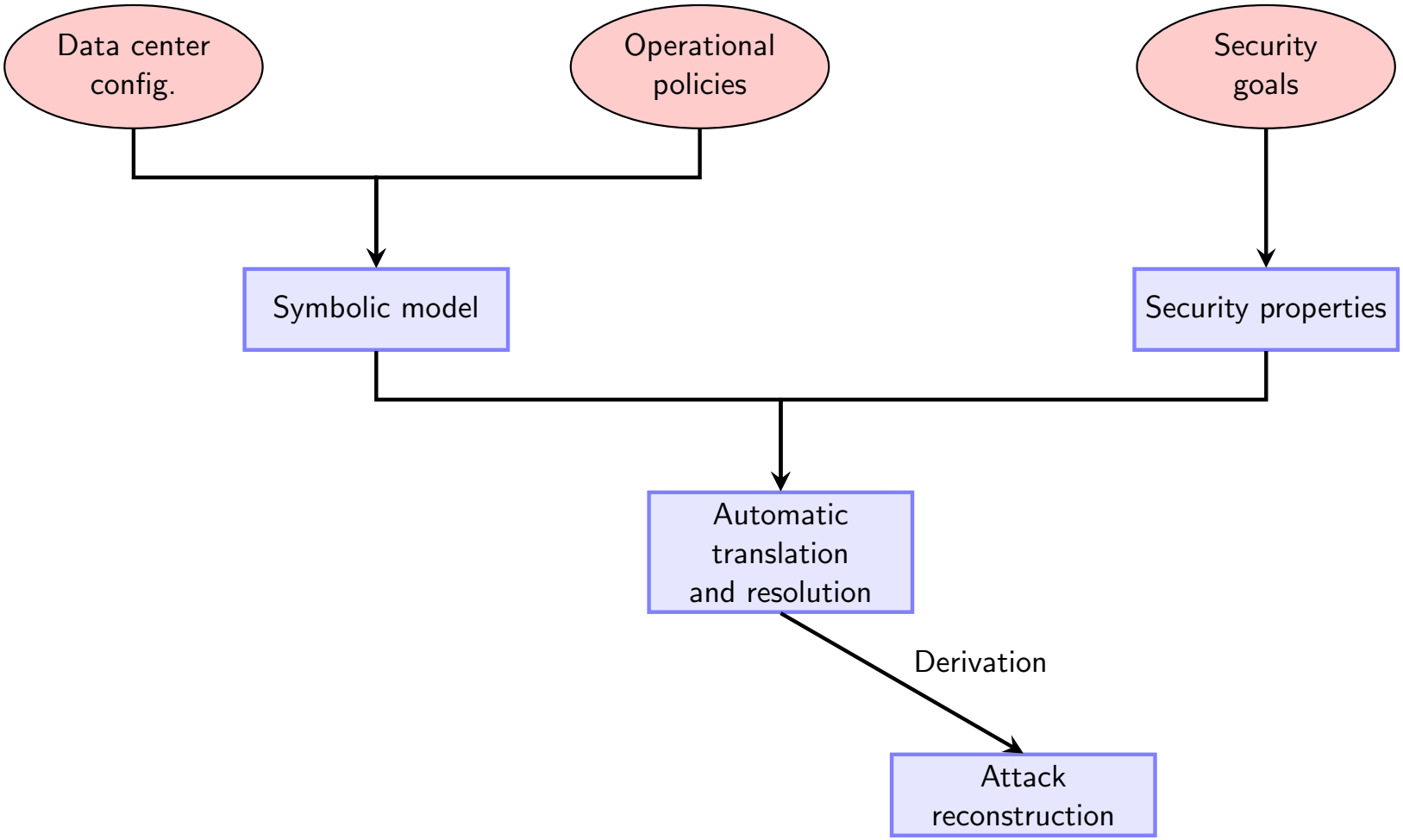

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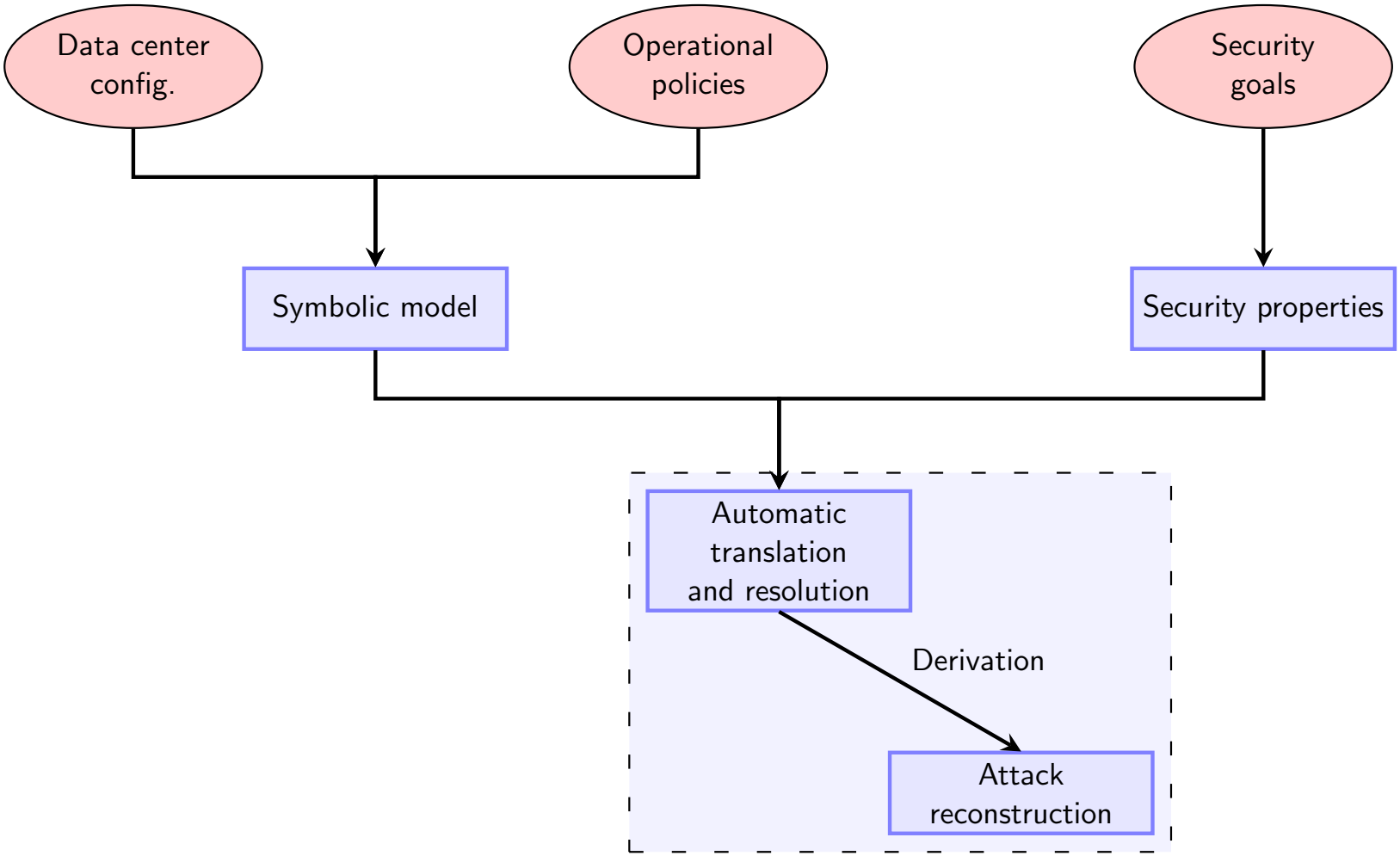

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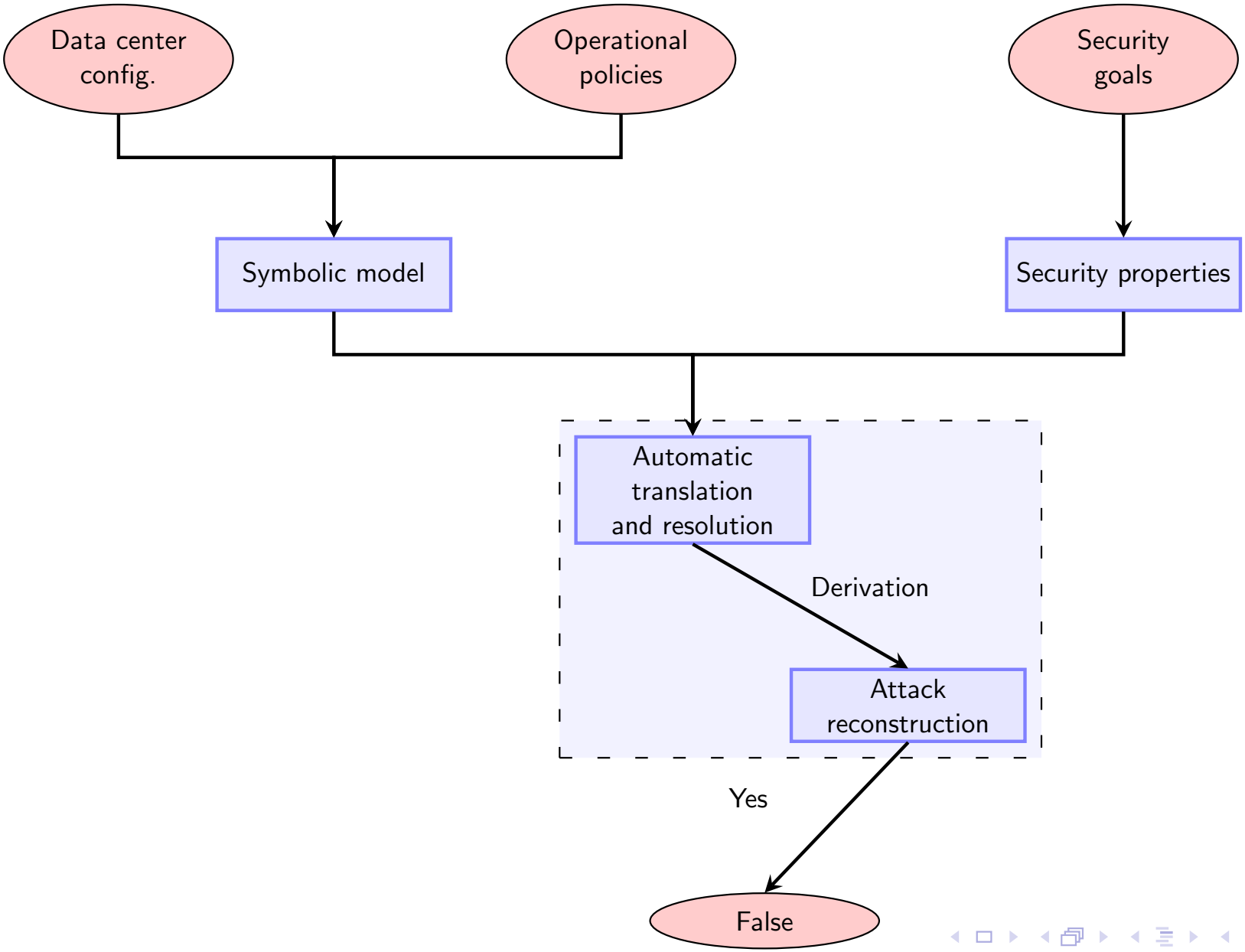

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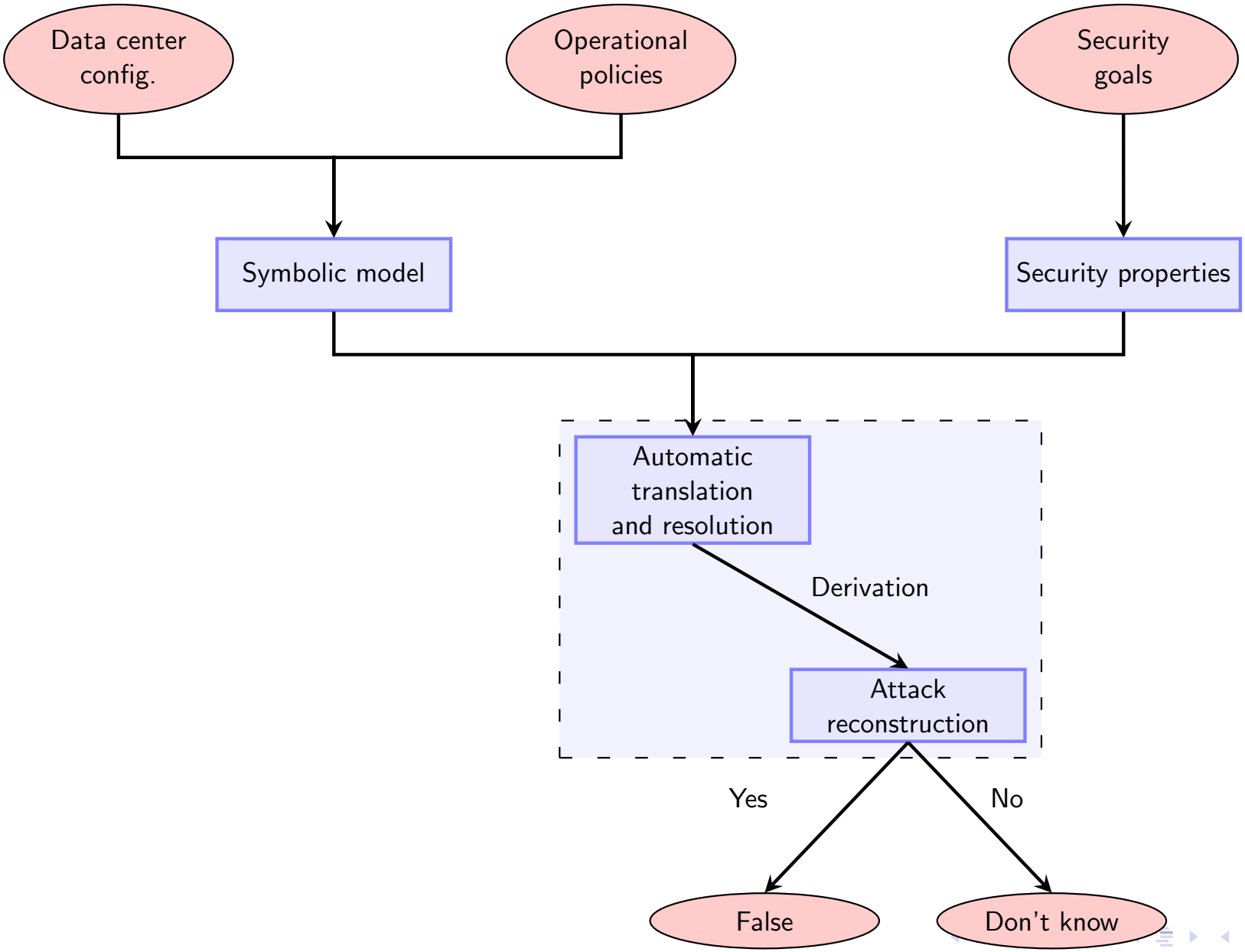

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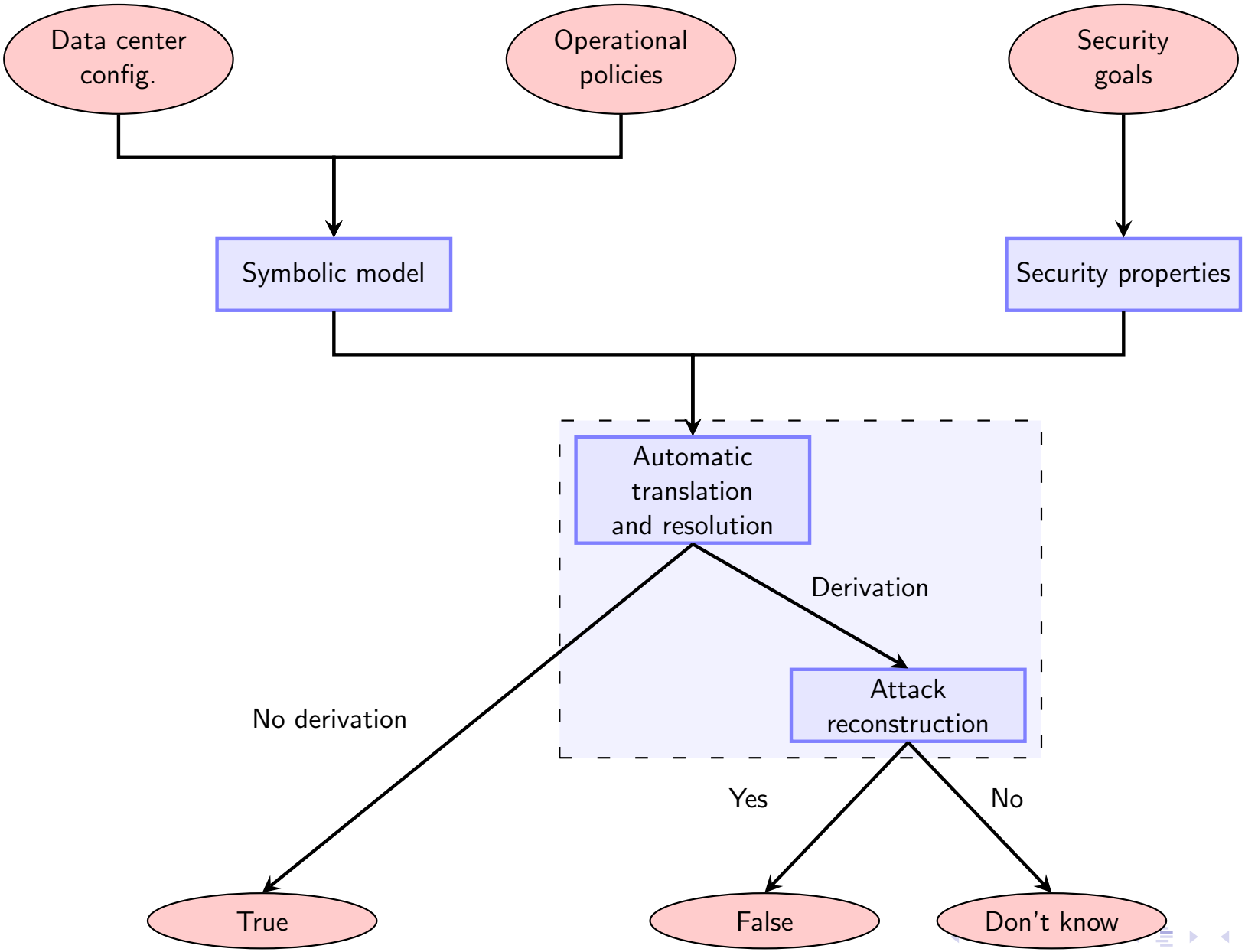

Symbolic Model (DCAP)

App Enclave

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App Enclave

Application

Symbolic Model (DCAP)

App Enclave

Application

QE

Symbolic Model (DCAP)

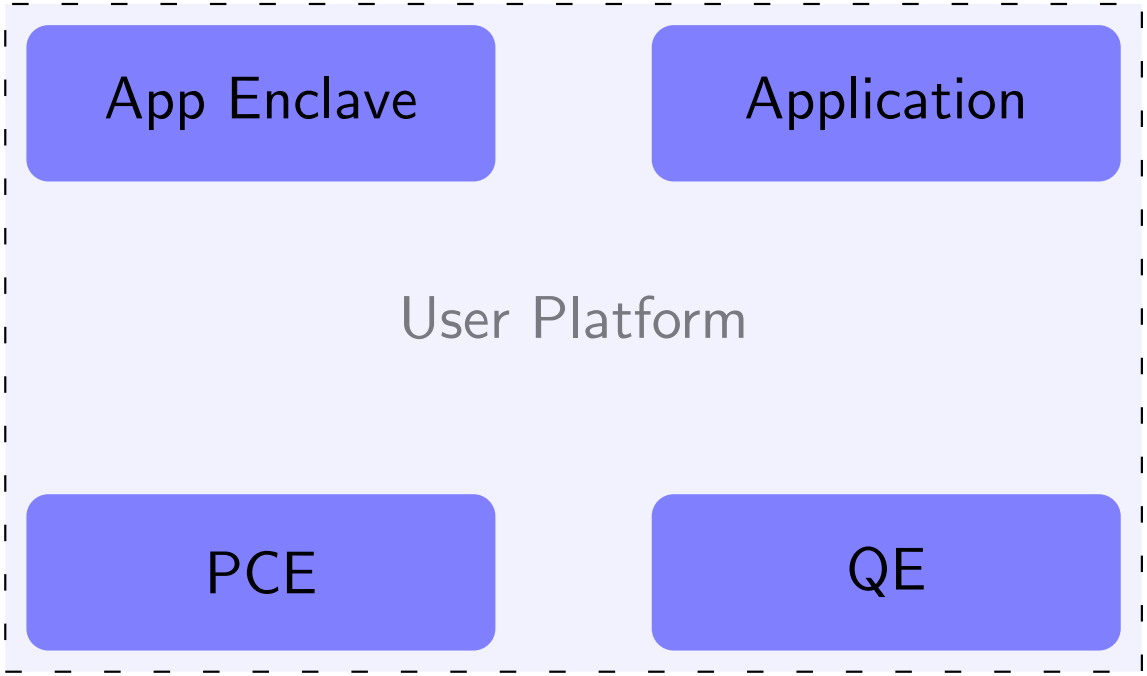
App Enclave

Application

PCE

QE

Symbolic Model (DCAP)



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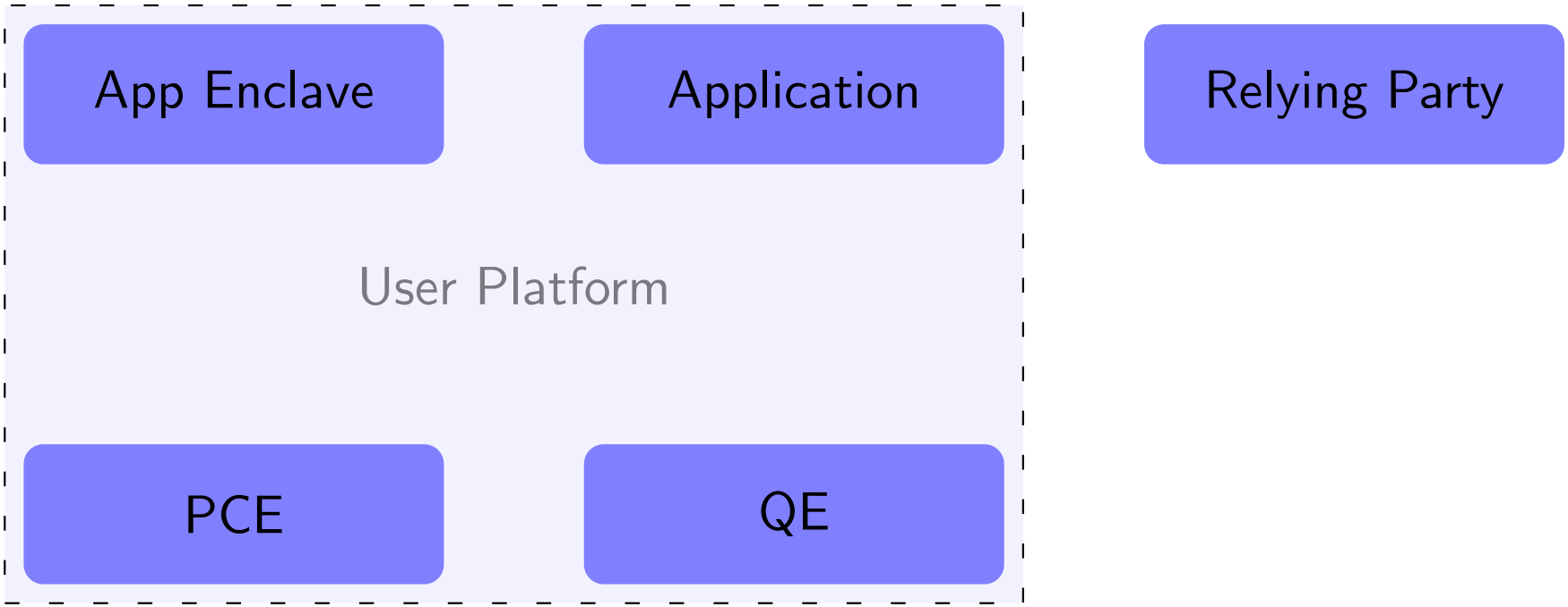

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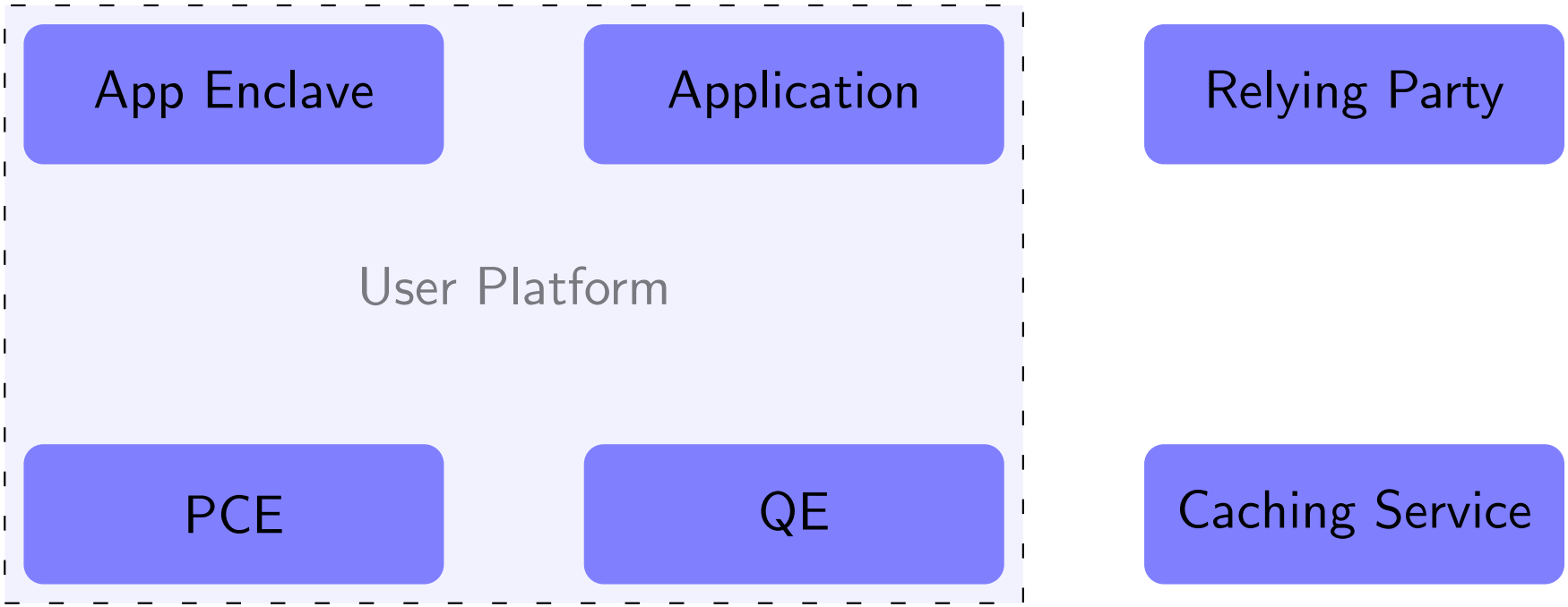

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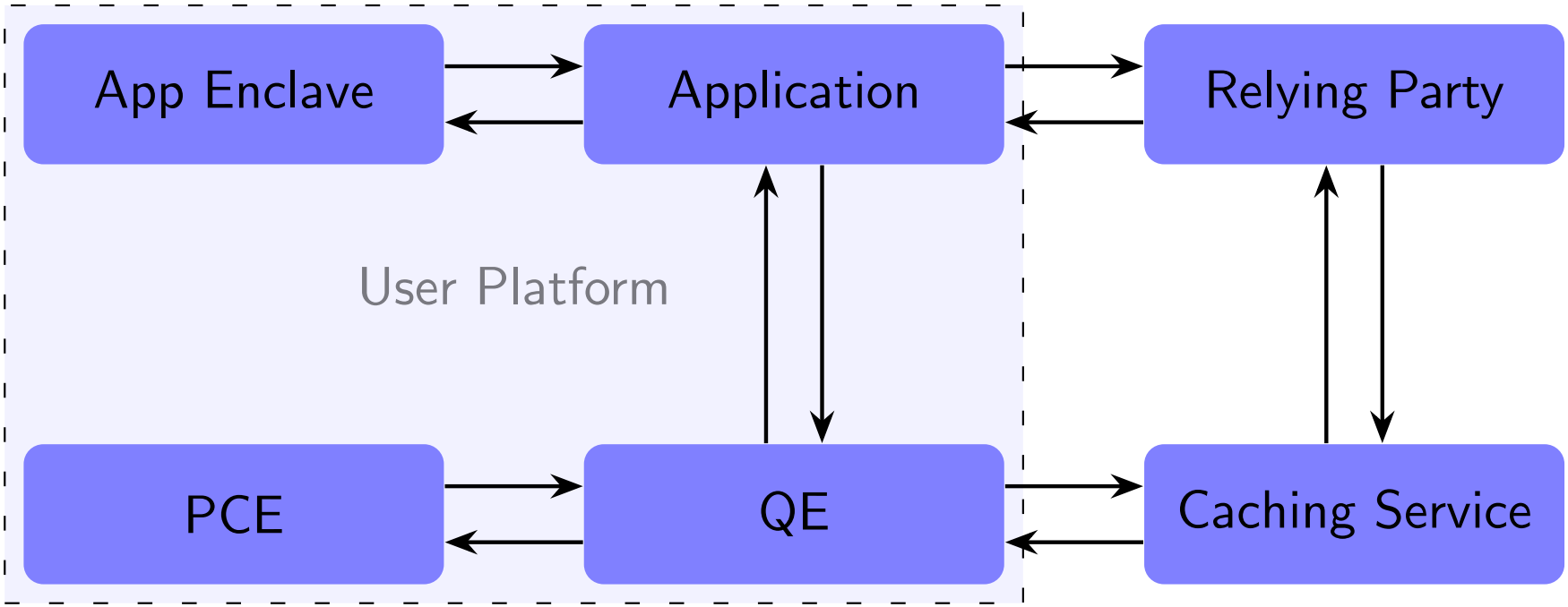

Challenges in Specification

- Costan and Devadas[4] claim about padding for report key derivation

[4] Victor Costan and Srinivas Devadas. "Intel SGX Explained". In: *IACR Cryptology ePrint Archive*. https://www.semanticscholar.org/paper/Intel-SGX-Explained-Costan-Devadas/a42e086f2382d518a0213879050e344539c2bcfa. 2016, pp. 83–85.

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  - EREPORT instruction → Hard-coded

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  - In fact, the reverse![5]

[4] Costan and Devadas, "Intel SGX Explained".

[5] Intel. "Intel® 64 and IA-32 Architectures: Software Developer's Manual". In: https://software.intel.com/sites/default/files/managed/39/c5/325462-sdm-vol-1-2abcd-3abcd.pdf. Oct. 2019.

Challenges in Specification

- Costan and Devadas[4] claim about padding for report key derivation
  - EREPORT instruction → Hard-coded
  - EGETKEY instruction → SECS
  - In fact, the reverse![5]
- Ambiguous statements, such as "The QE Report is a report when the QE Report is certified."[6]

[4] Costan and Devadas, "Intel SGX Explained".

[5] Intel, "Intel® 64 and IA-32 Architectures: Software Developer's Manual".

[6] Intel. *Intel® Software Guard Extensions (Intel® SGX) Data Center Attestation Primitives: ECDSA Quote Library API*. Revision March 2020, updated 08-07-2020, last accessed on 07-08-2020. URL: https://download.01.org/intel-sgx/sgx-dcap/1.7/linux/docs/Intel_SGX_ECDSA_QuoteLibReference_DCAP_API.pdf.

Specification of Security Goals

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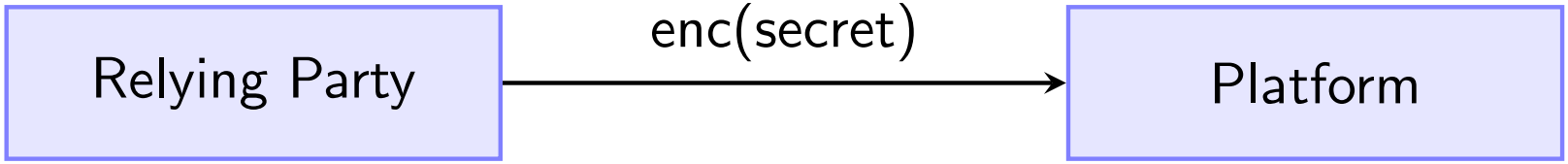

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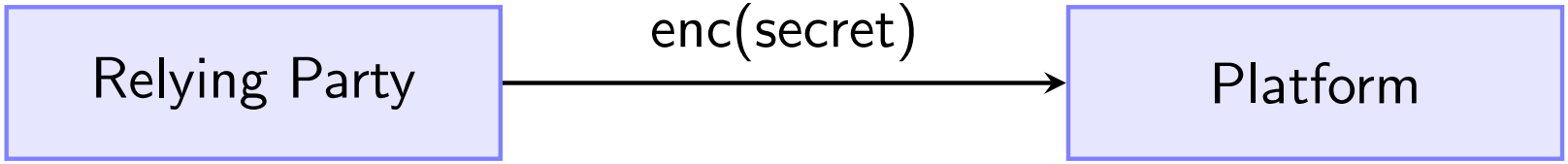

  - Formalized as a reachability property

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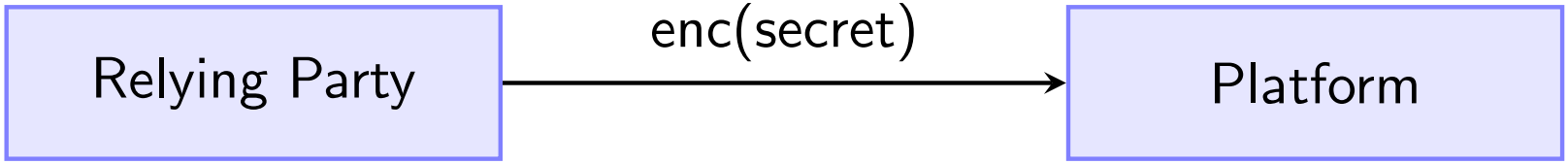

  - Formalized as a reachability property
- Integrity

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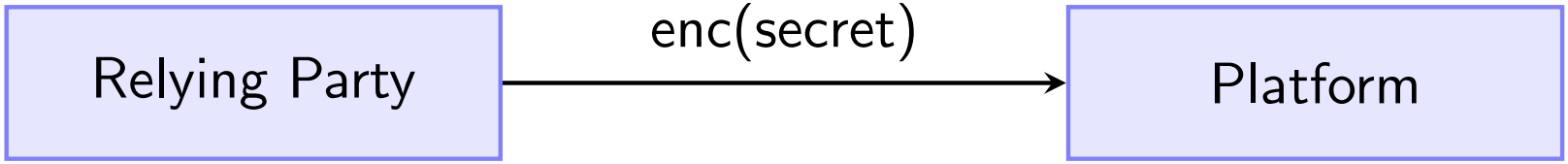

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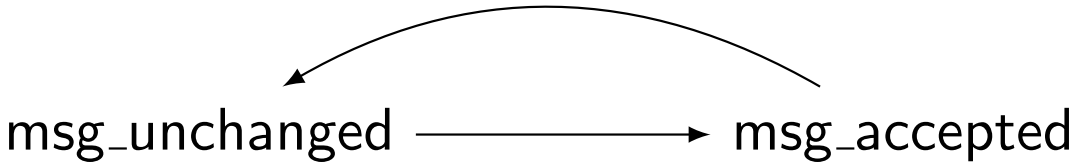

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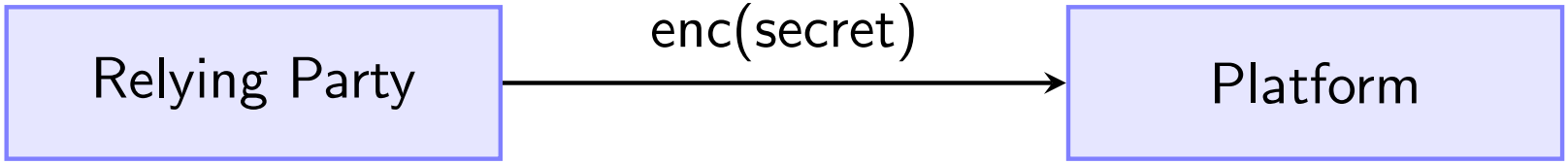

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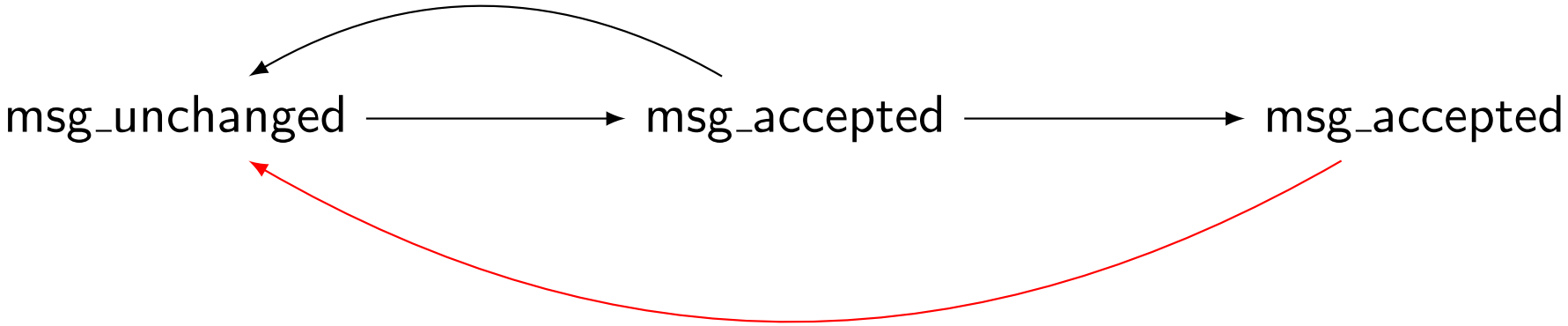

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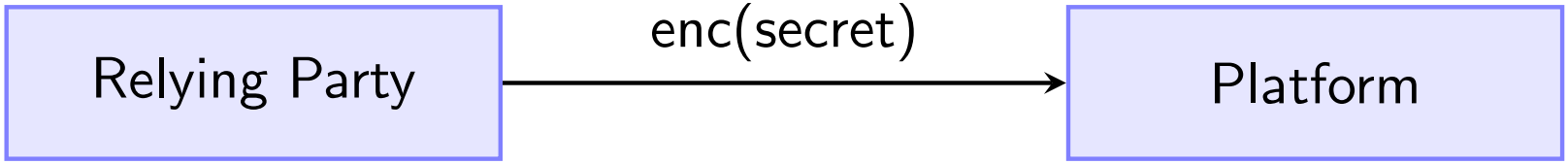

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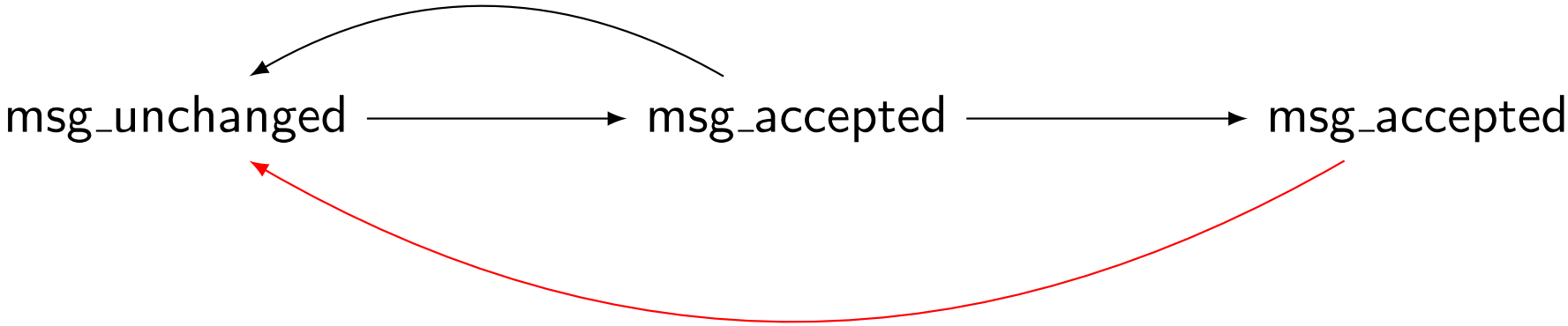
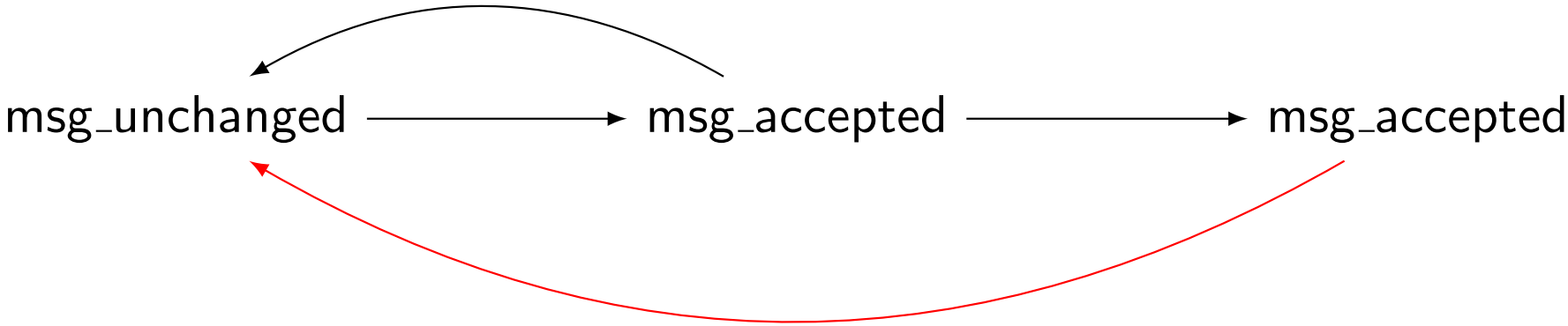
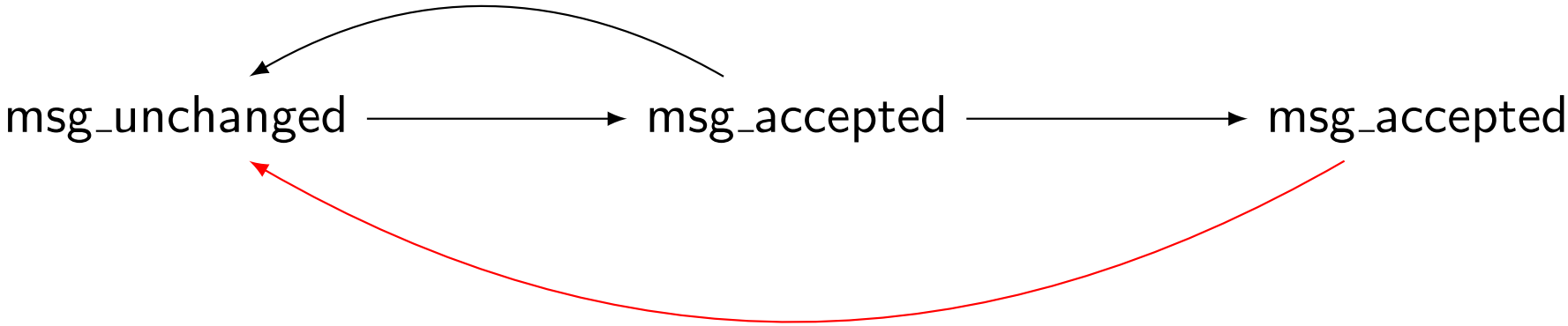


  - Correspondence assertions

Integrity



Integrity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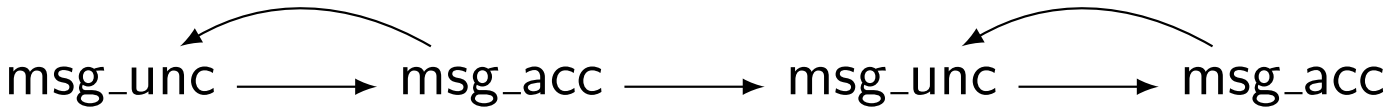
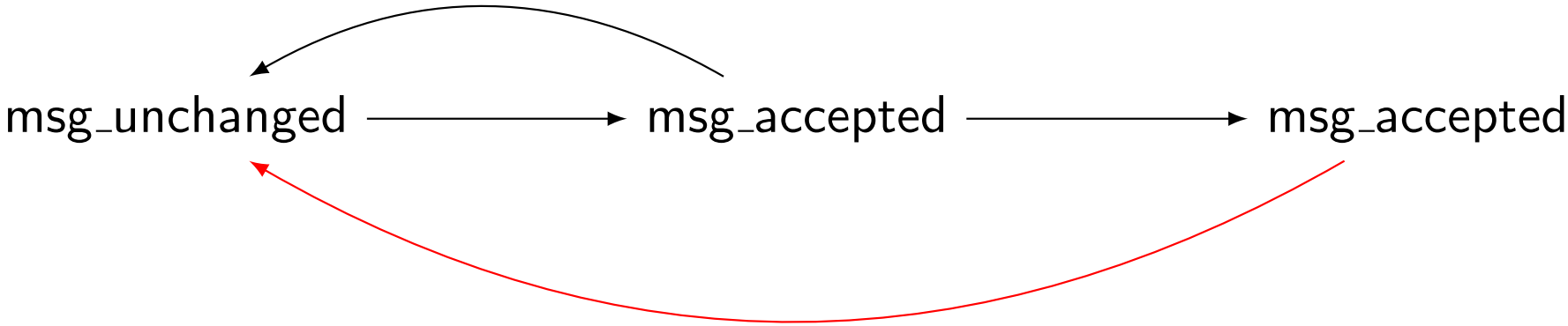
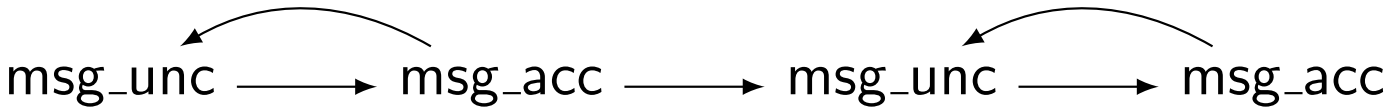
msg_accepted
msg_accepted


msg_unc
msg_acc
msg_unc
msg_acc

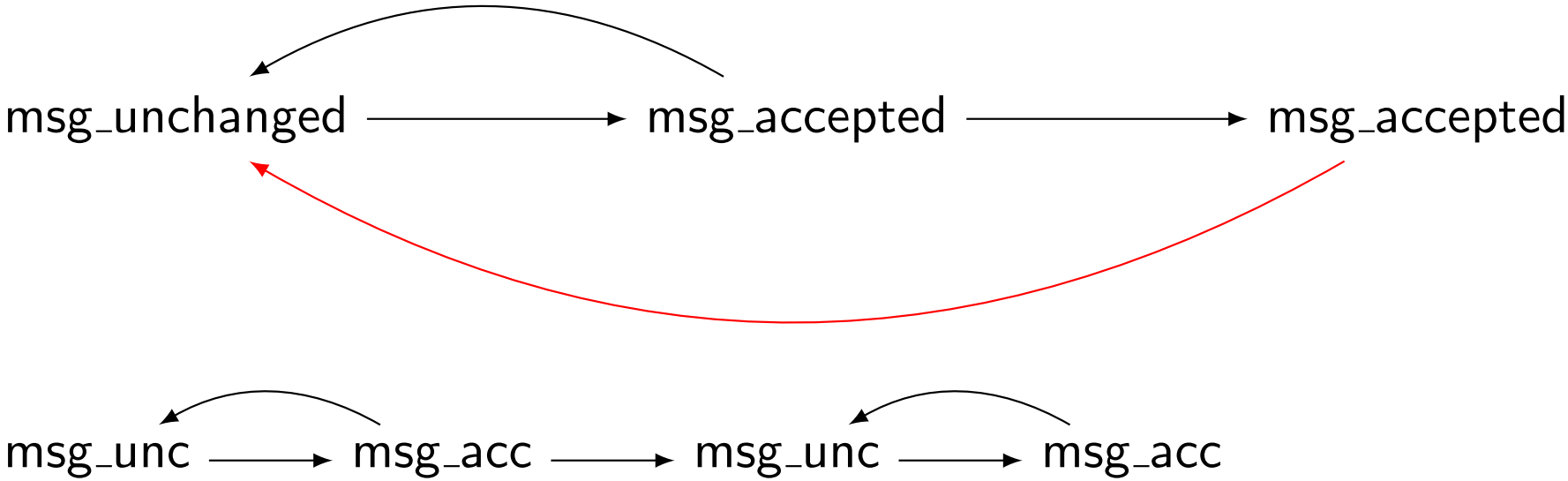
Integrity





- Injective correspondence assertions

Integrity



- Injective correspondence assertions
- Additional check: Reachability of `msg_accepted`

Summary and Future Work

- Specification of Intel SGX DCAP

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- Discovery of various discrepancies

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- Future work:
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  - Other TEEs (e.g., ARM TrustZone)

Key References

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Thank You for Your Attention!

Questions and Comments?

Project updates here

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