Giving State to the Stateless:

Augmenting Trustworthy Computation with Ledgers

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BEWARE!

HERE BE BLOCKCHAINS!

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BEWARE!

HERE BE SGX!

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BEWARE!

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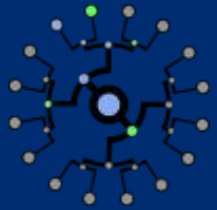
Why care about the bogeymen?

- Ledgers exist *in practice* and they aren't going away
  - Blockchains
  - Google Certificate Transparency Log



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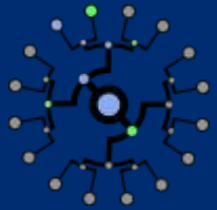

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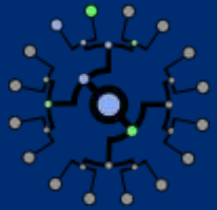


- Trusted Execution Environments exist *in practice* … kinda?
  - Intel SGX and ARM Trustzone
  - Software only obfuscation
  - FPGA style hardware with burned keys

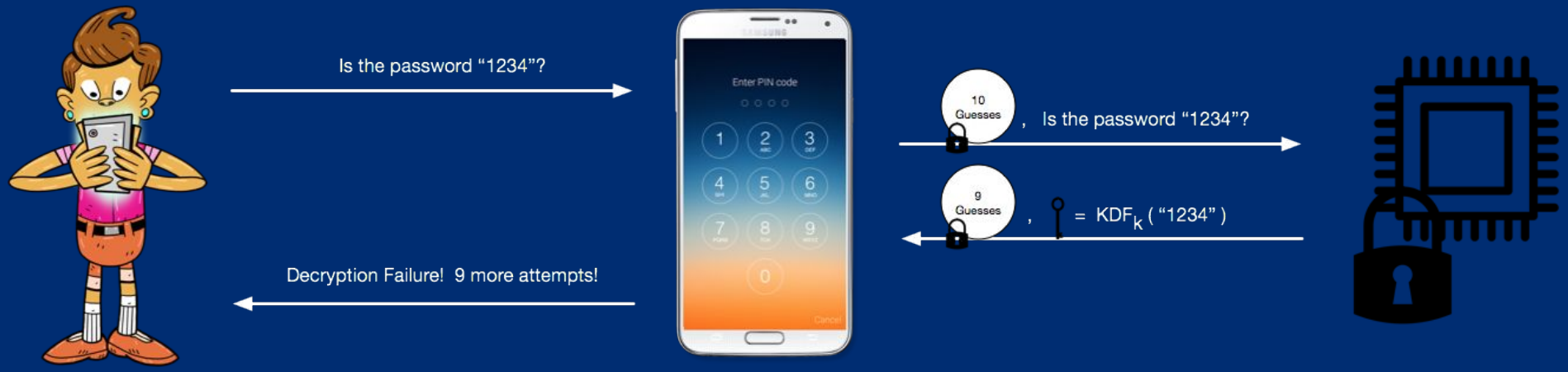
How can TEEs augment ledgers?
vs
How can ledgers augment TEEs?

Rewind Protection

Is the password “1234”?

Nope! You have 9 more attempts!

Rewind Protection



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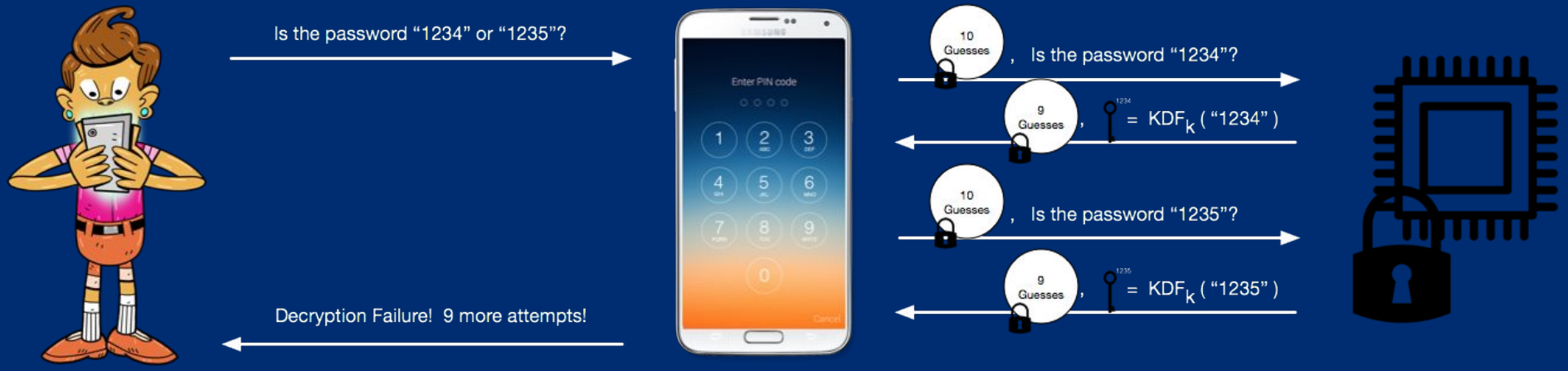

Rewind Protection

- Hardware based TEE's require NVRAM for protection
  - Scale poorly, expensive, and require special considerations for power fluctuations
  - Prior Work: Memoir [PLDMM11]

- Software only obfuscation can't get hardware-back protections
  - Prior Work: Goyal and Goyal [GoyGoy17] get one time programs from Ledgers + Obfuscation

- This problem is *real*

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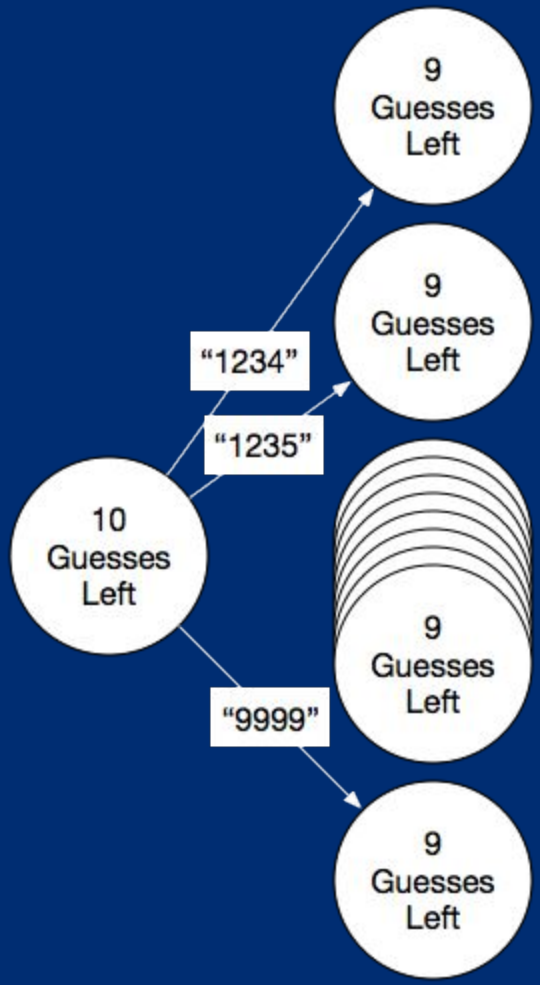
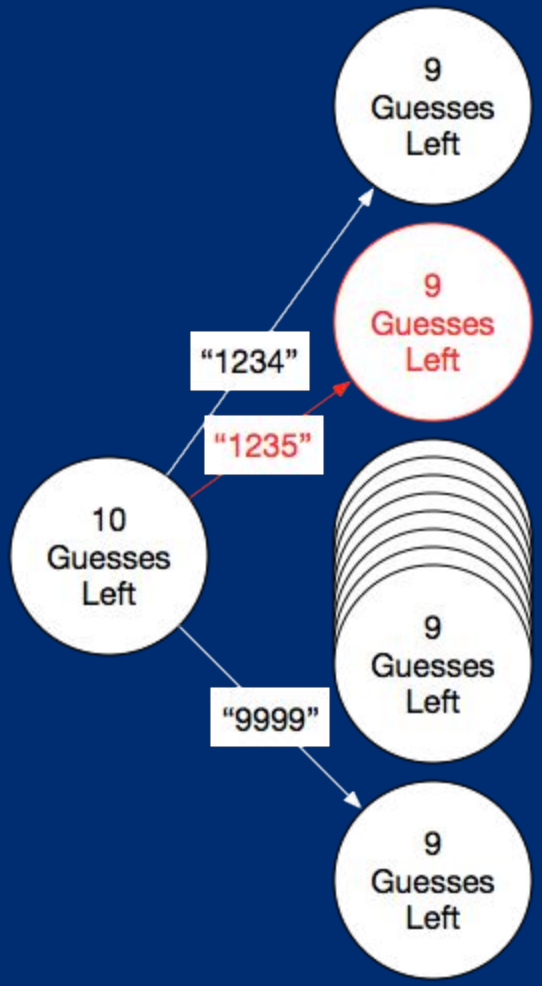
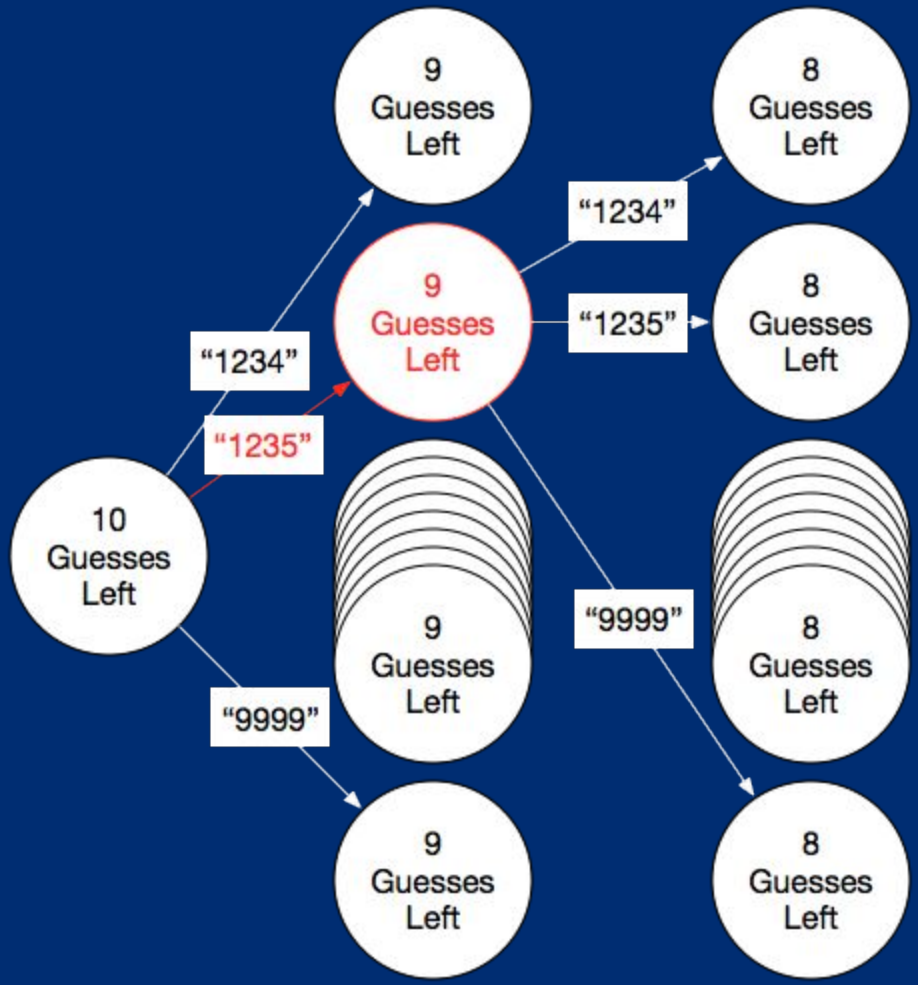
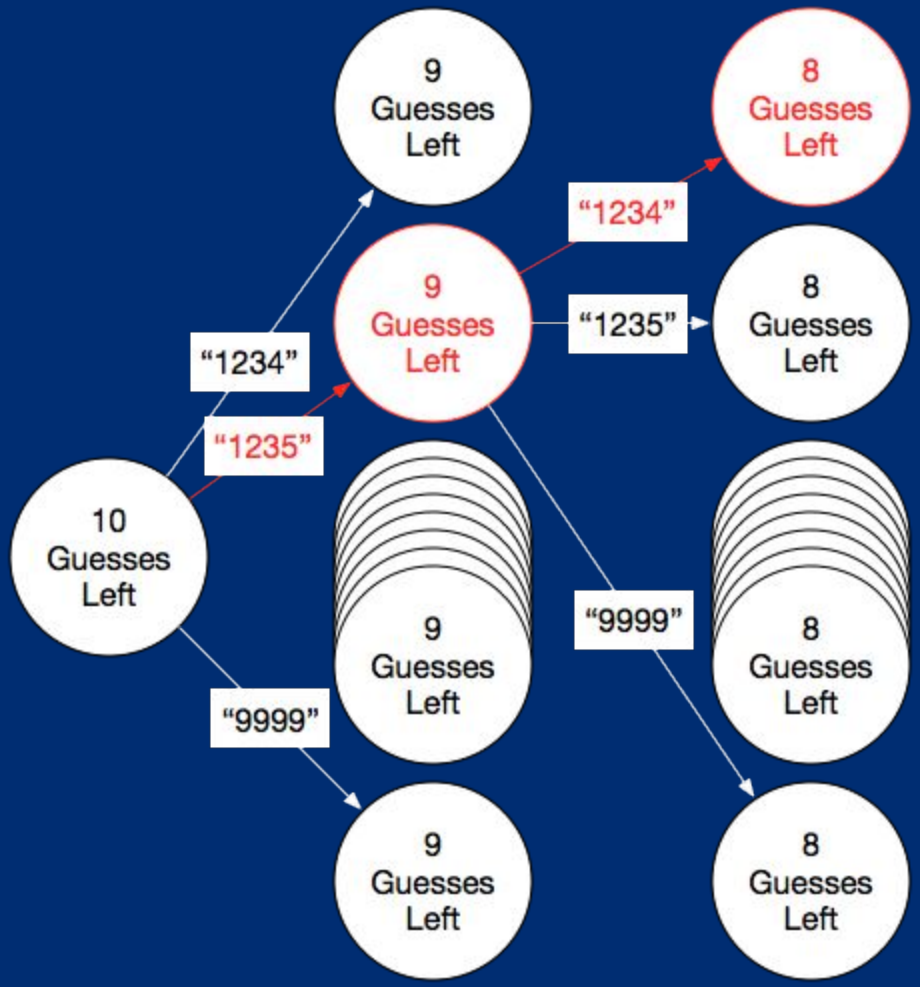
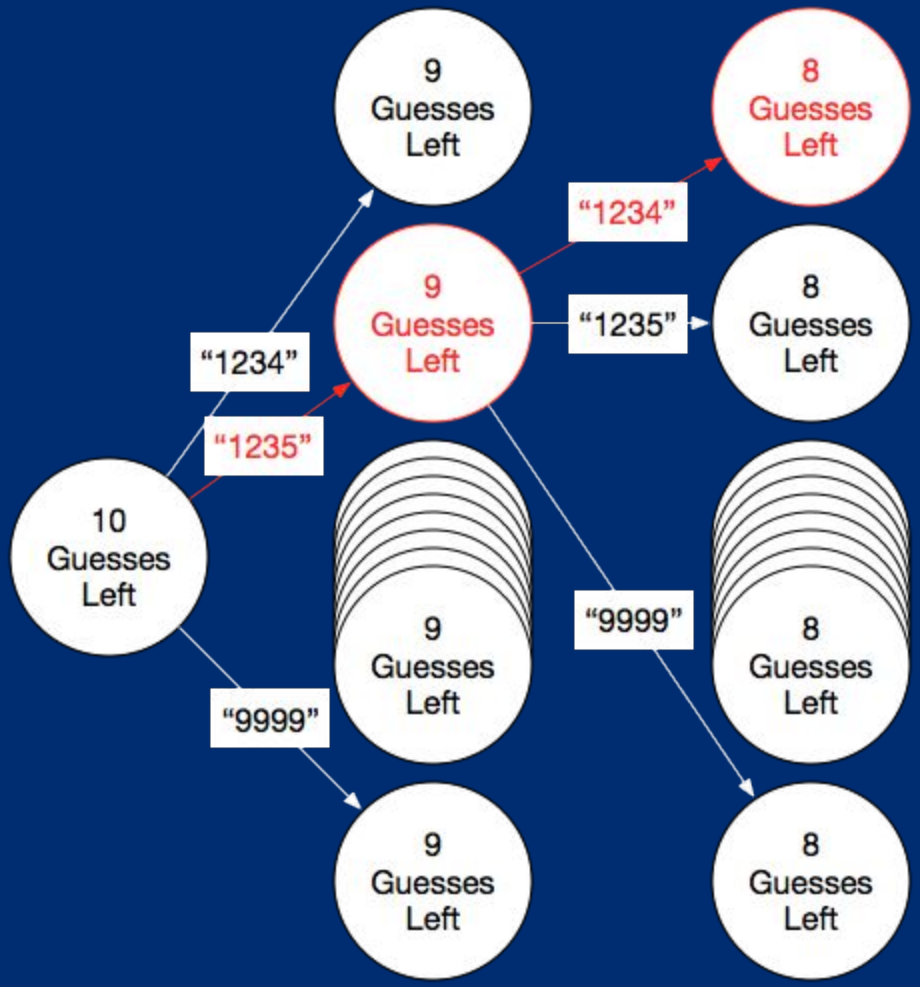
10
Guesses
Left





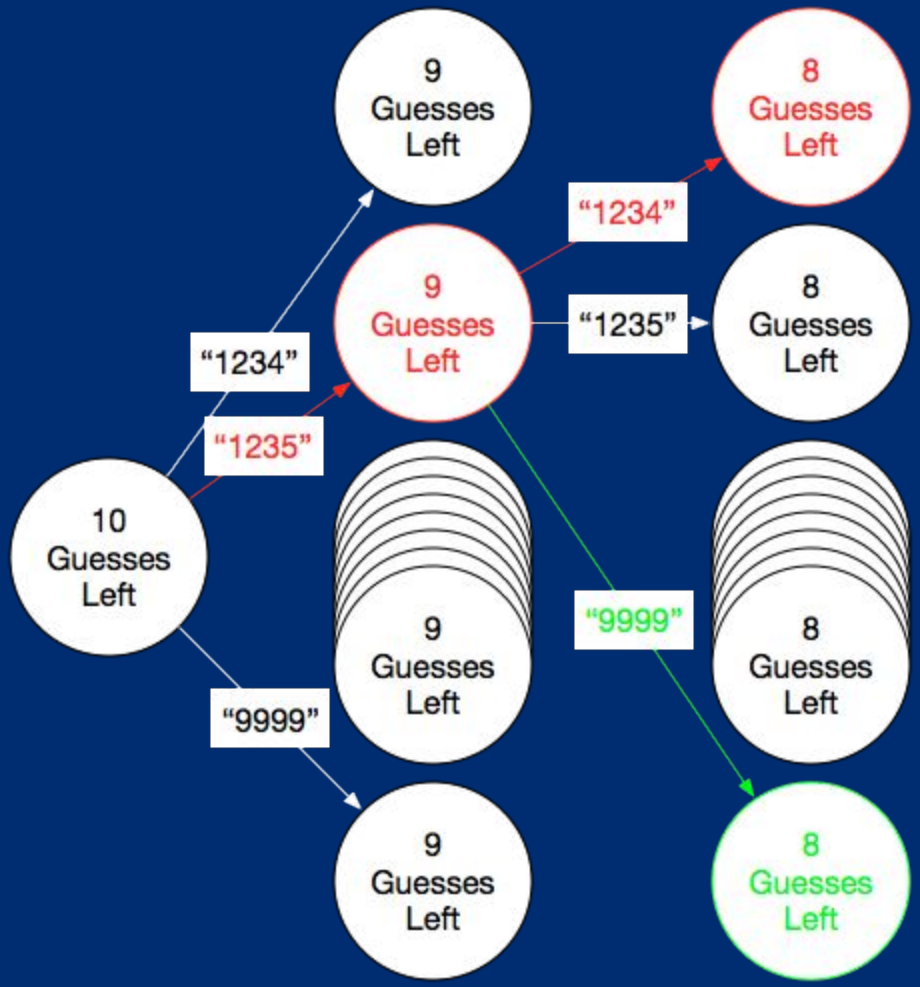






Repeated Execution

- Re-execution of a path doesn't cause a vulnerability
  - Derive the same key repeatedly
  - Starting again generates new master key



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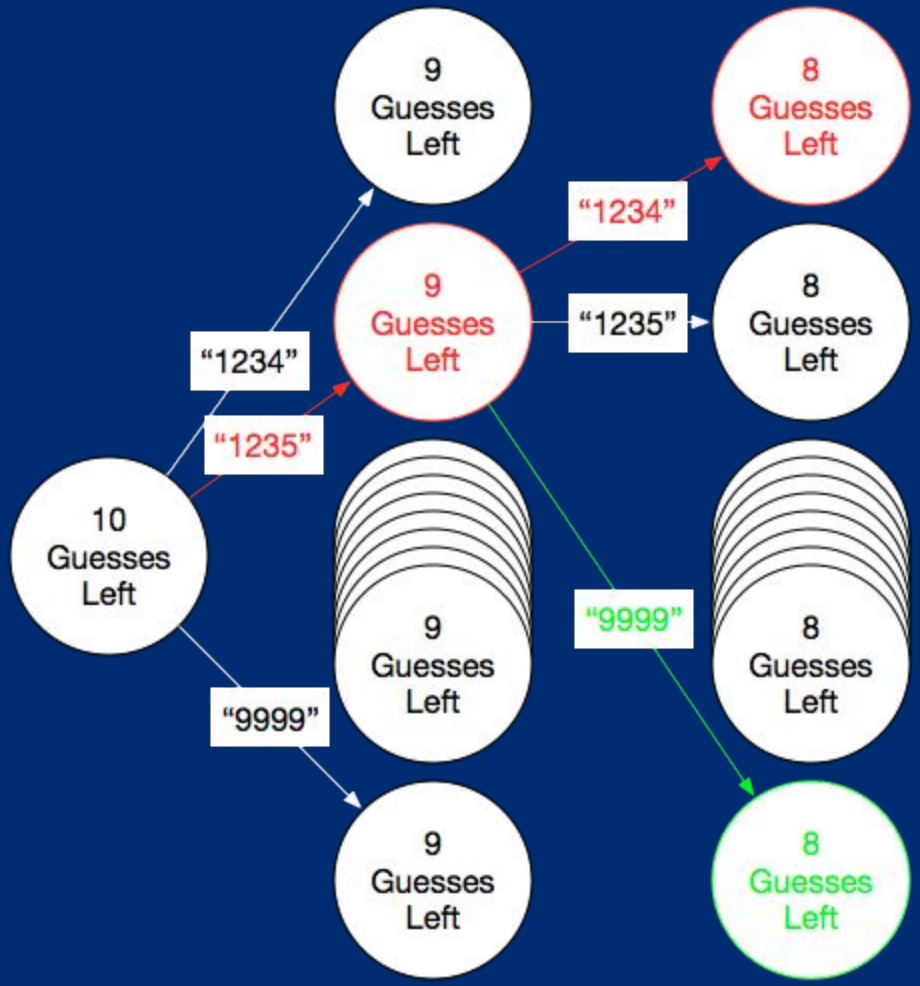
  - Running new inputs on old state
  - Running old steps with new randomness



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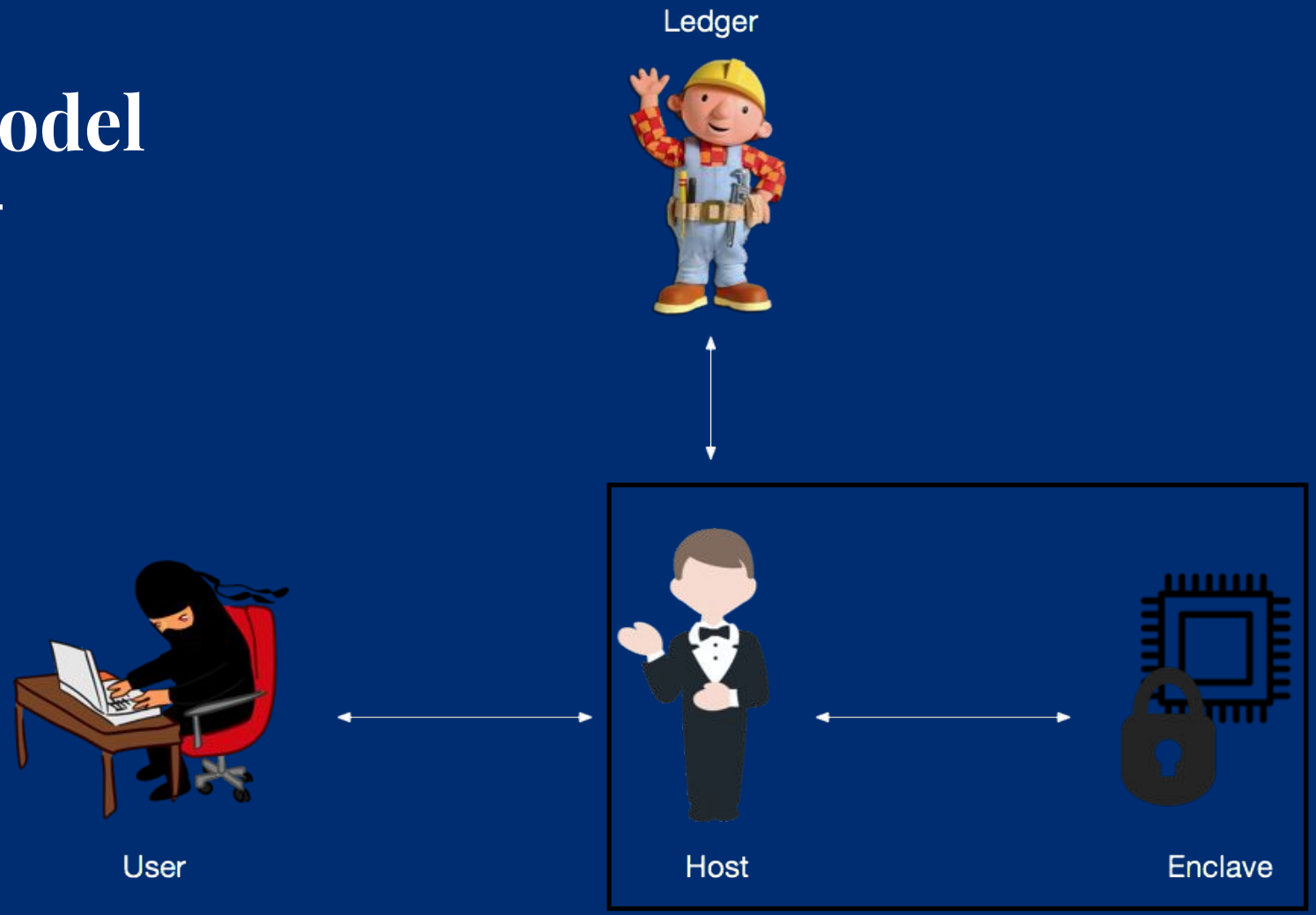
- Strategy: bind program execution to something linear

Model



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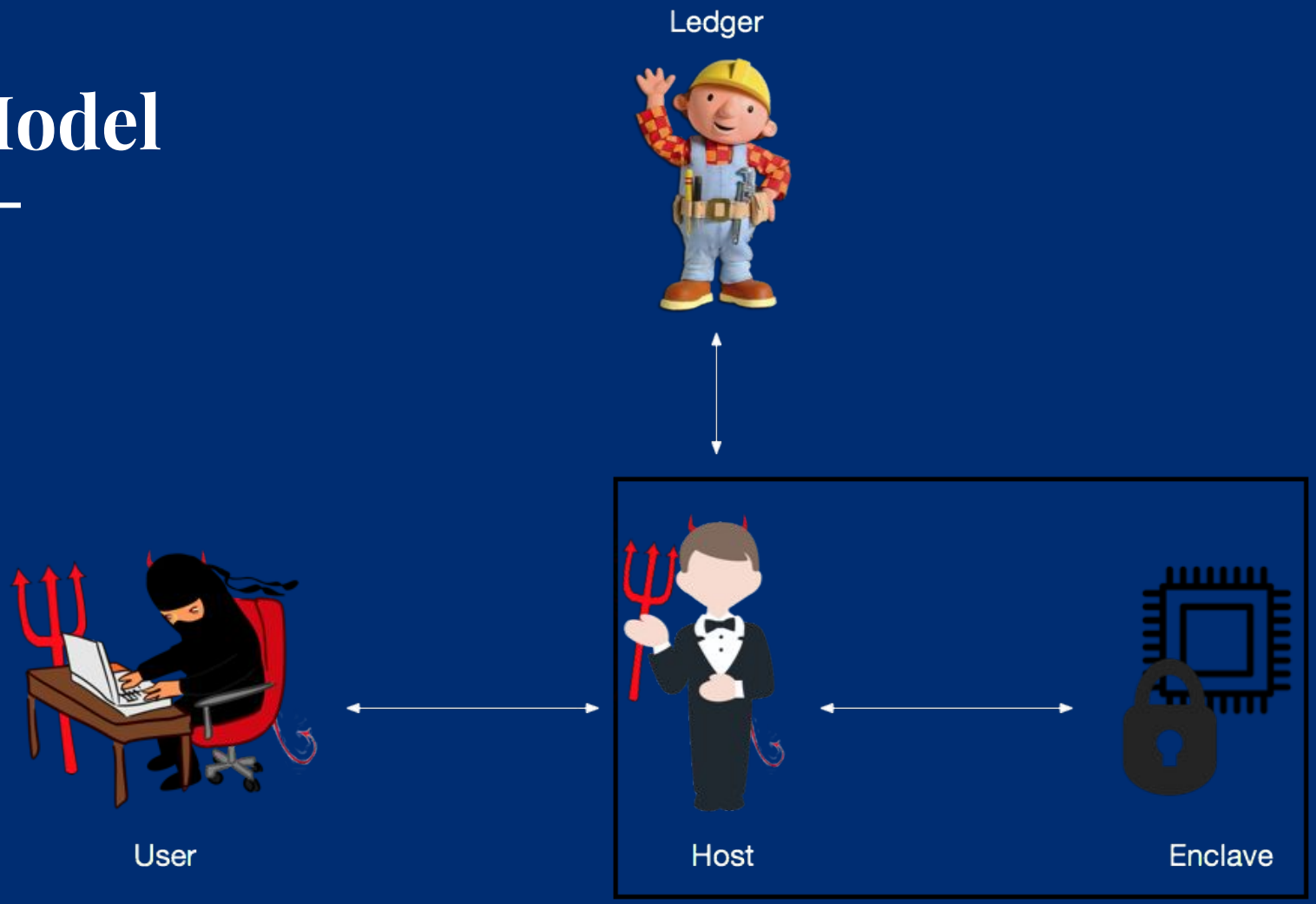

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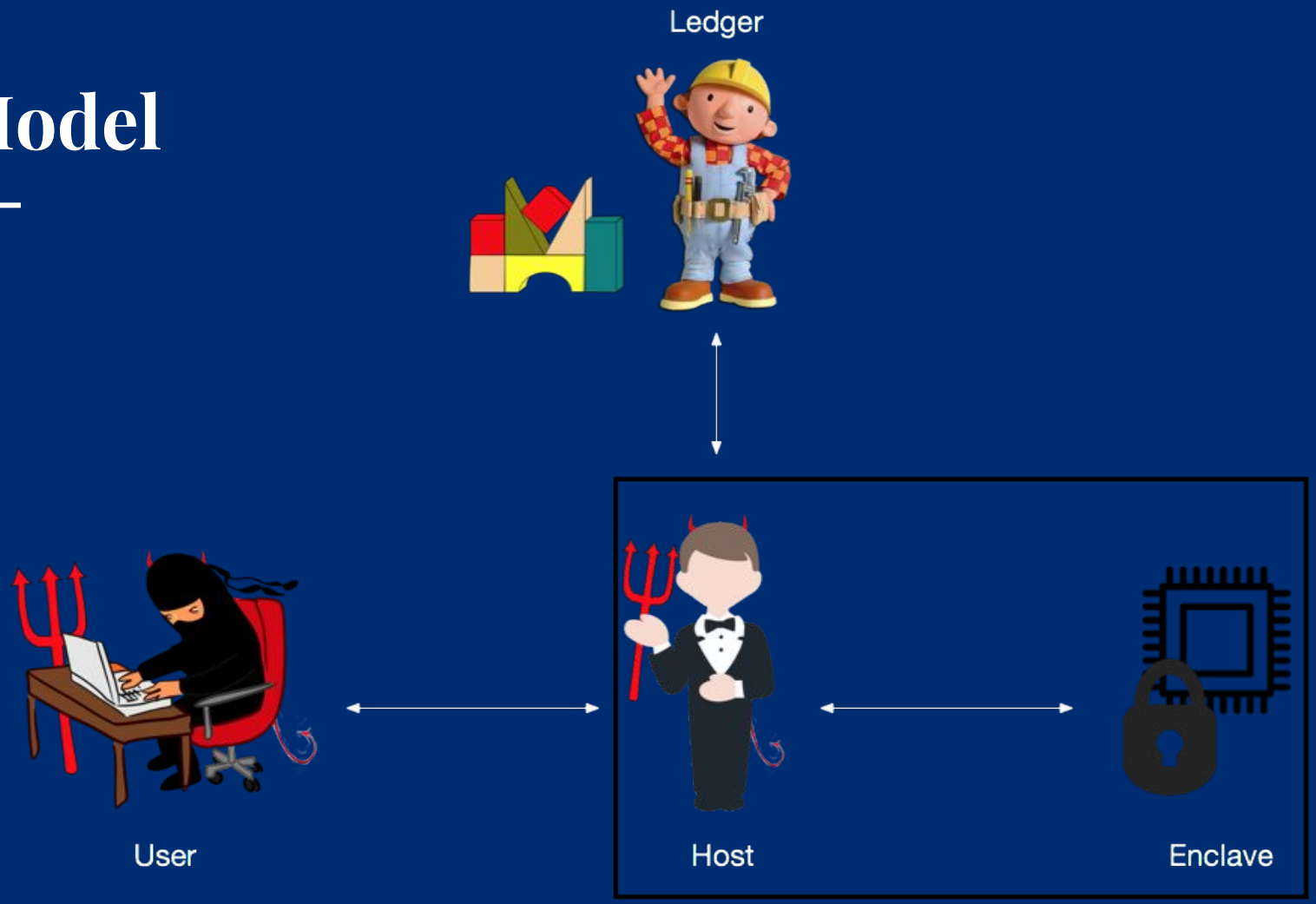

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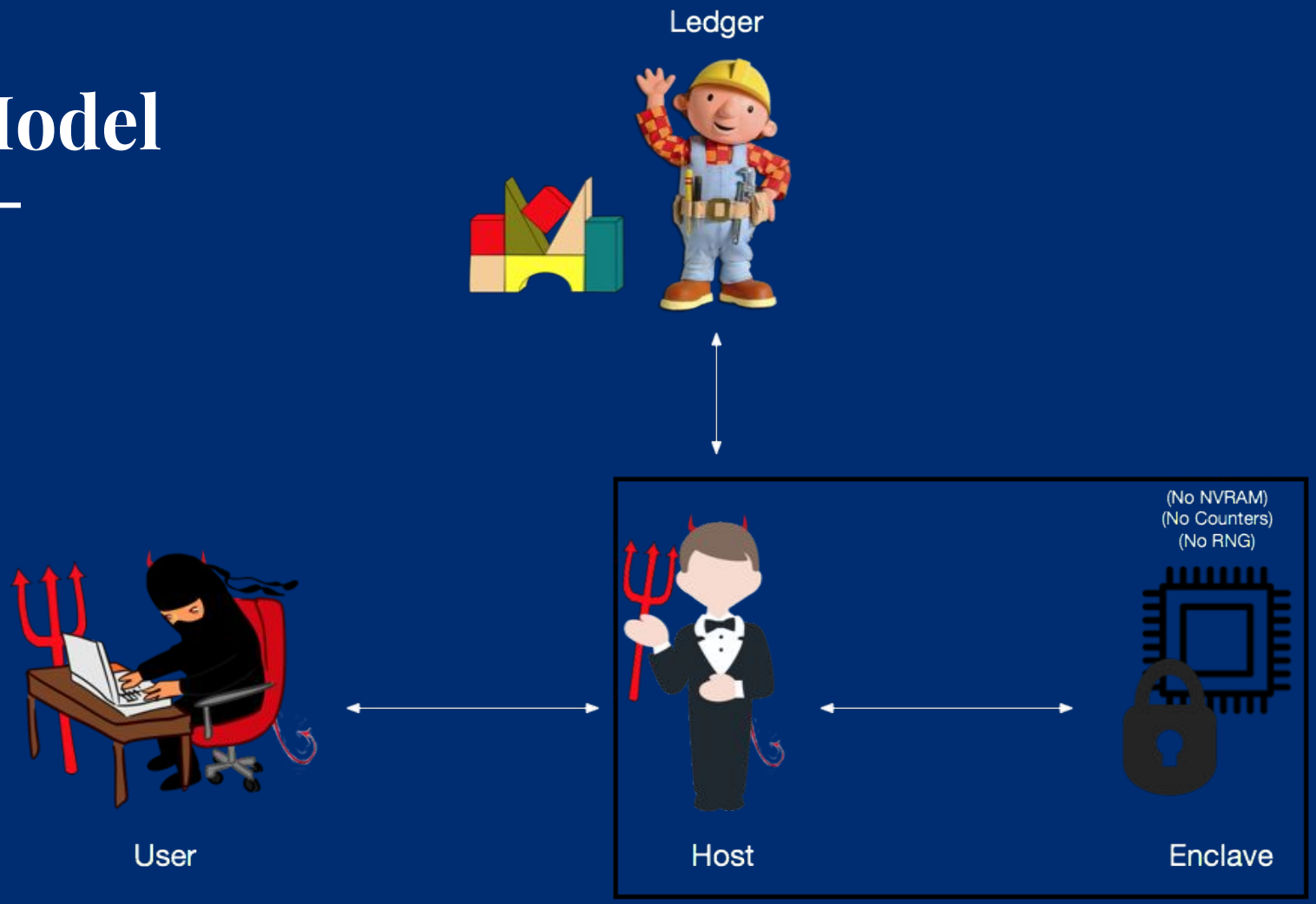

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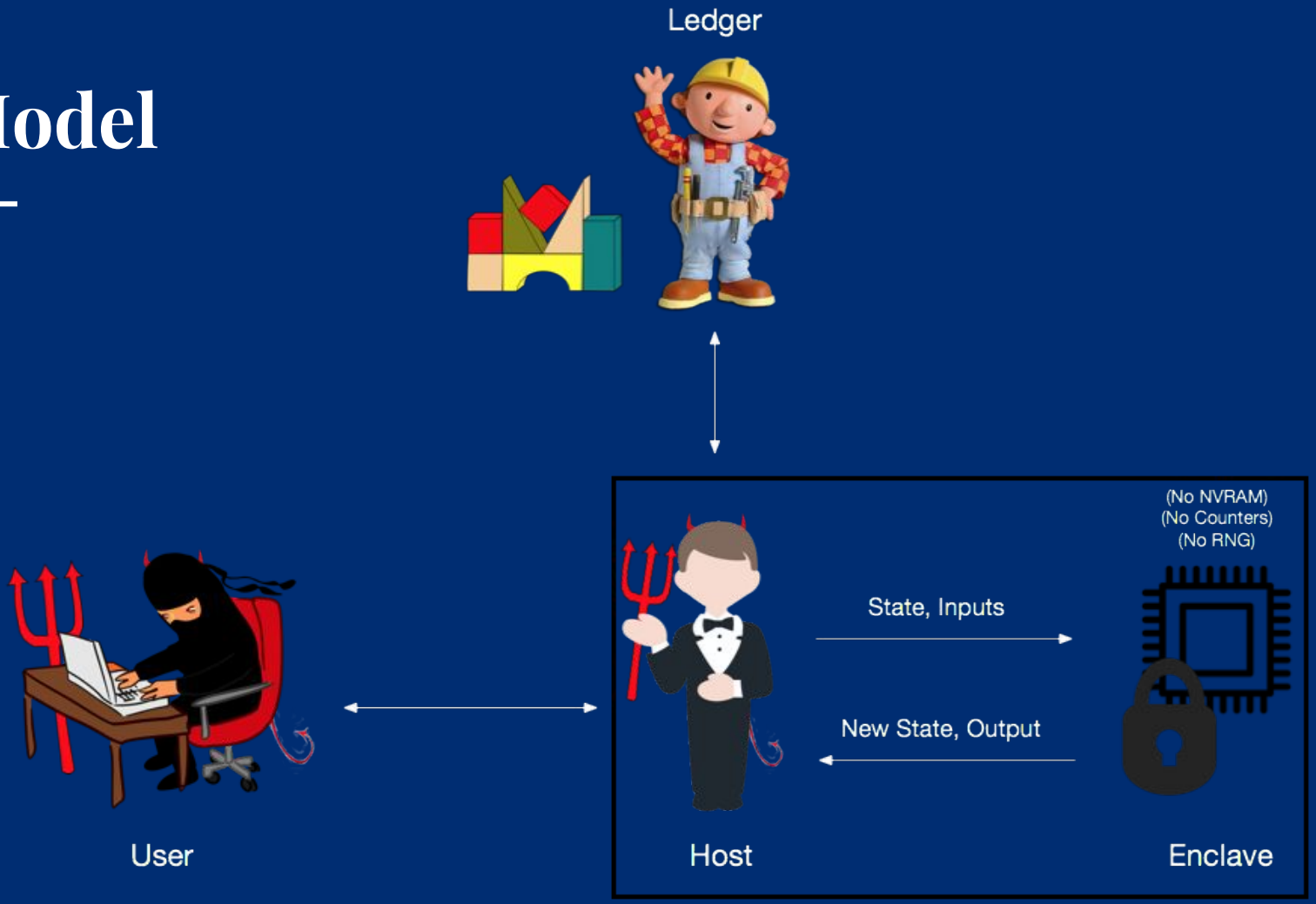
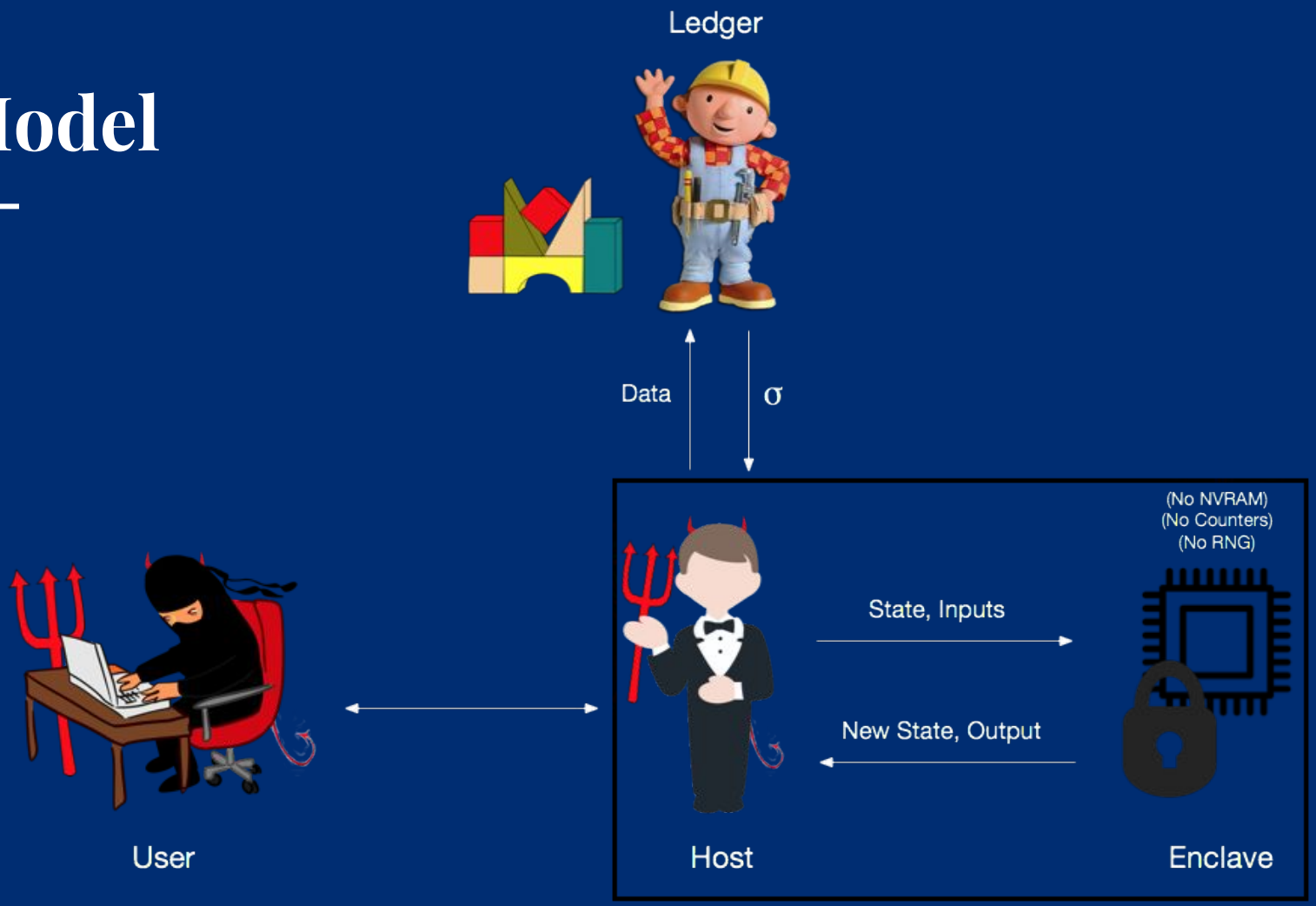

Ledger
(No NVRAM)
(No Counters)
(No RNG)
State, Inputs
New State, Output
User
Host
Enclave

Model


Ledger
Data
σ
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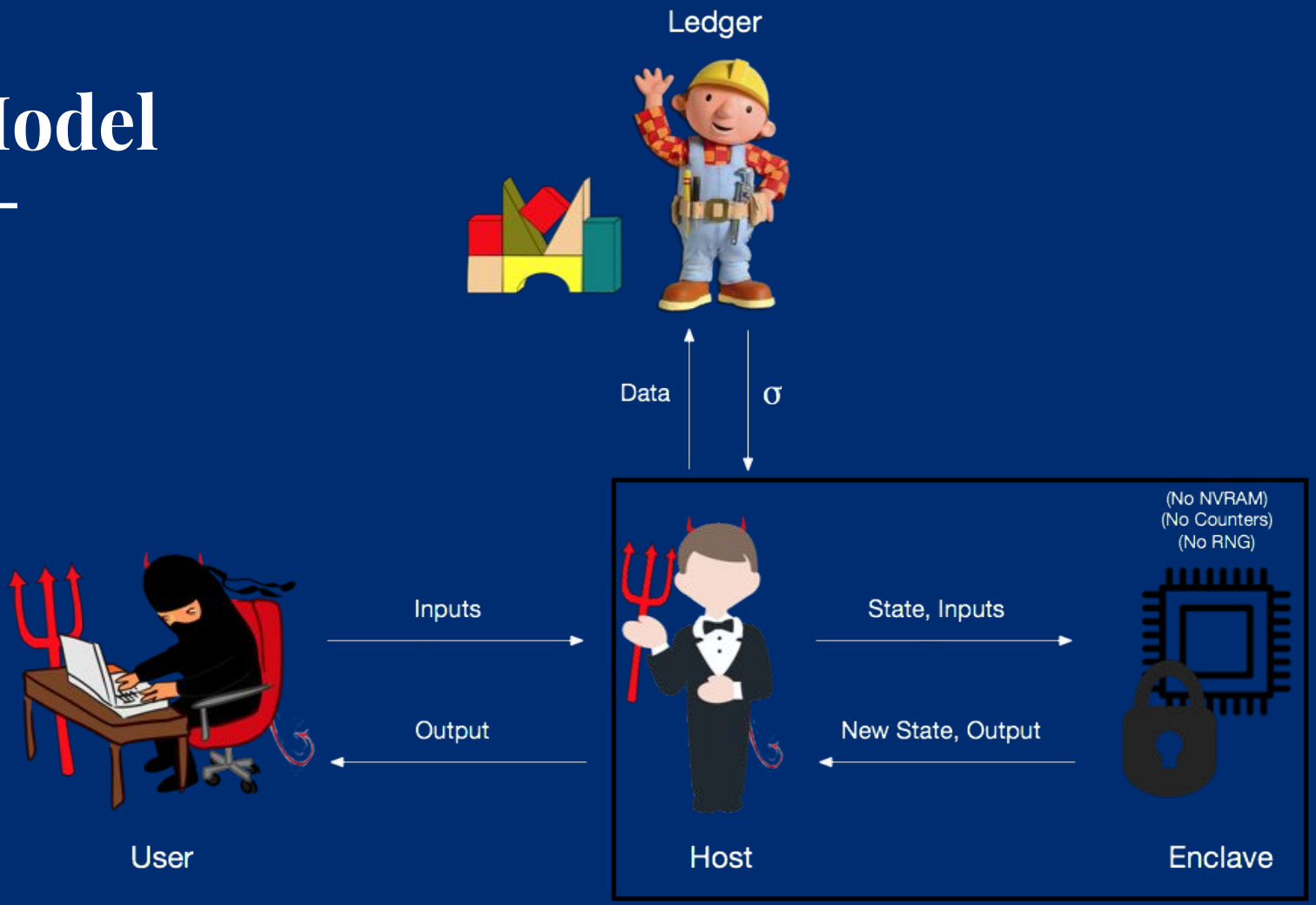
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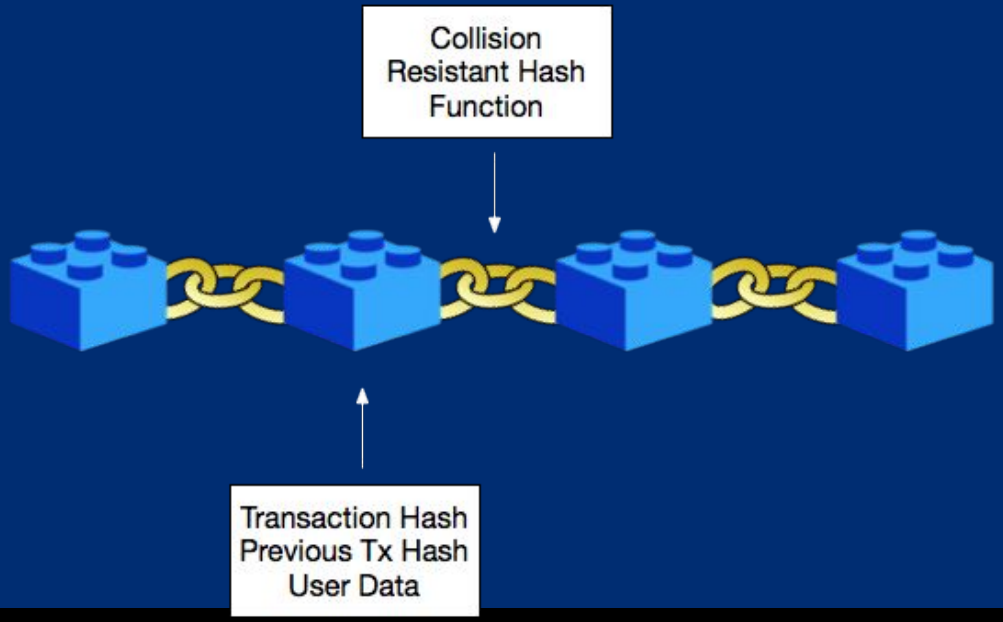
Ledger Requirements

- Creates hash chains of transactions
  - Similar to transaction in bitcoin, ethereum, etc...



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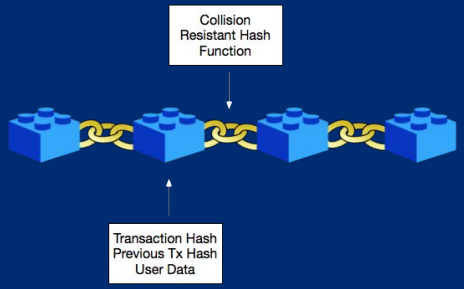

- Publicly verifiable proof of publication and public access
  - Digital signatures for computational security
  - Proof of work for economic security

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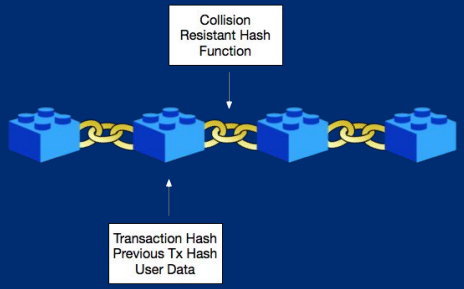

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  - Digital signatures for computational security
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- Simplifying assumption: Single user ledgers

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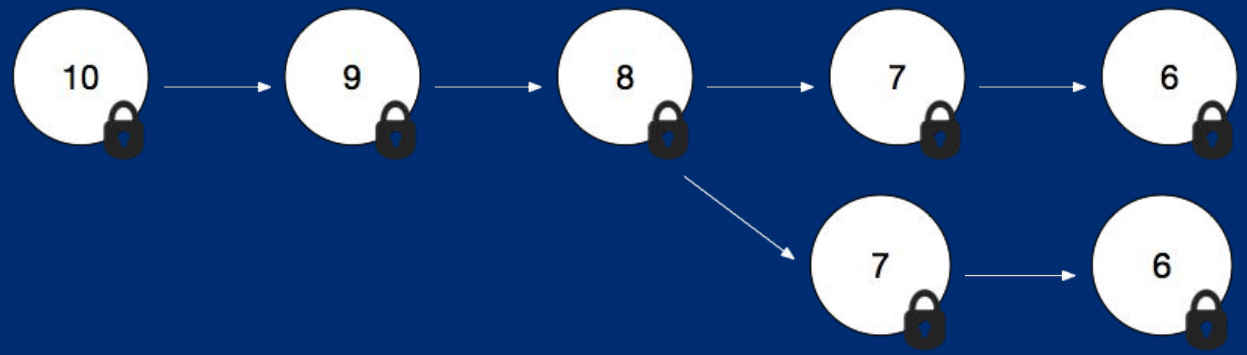

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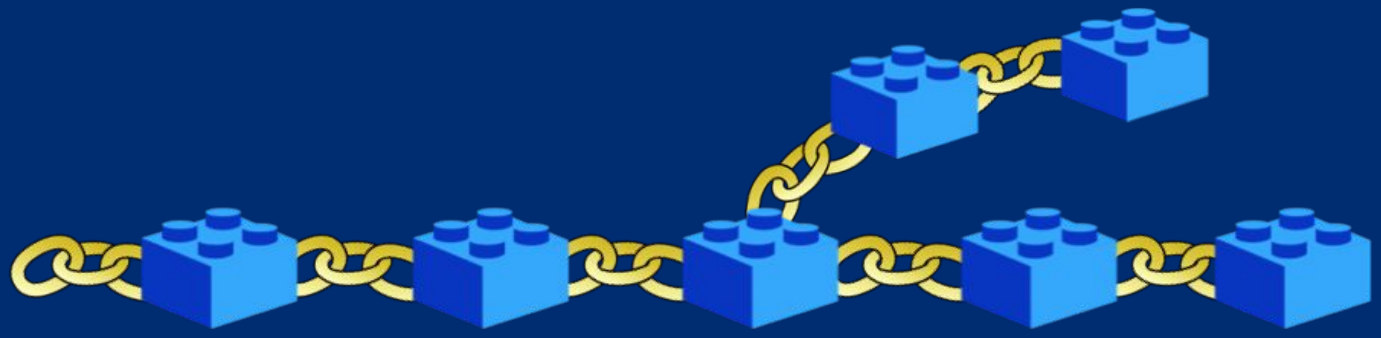

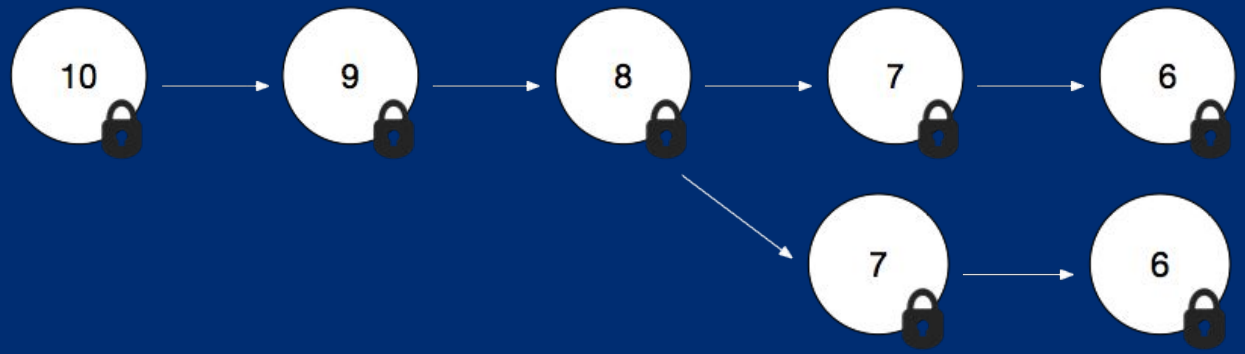

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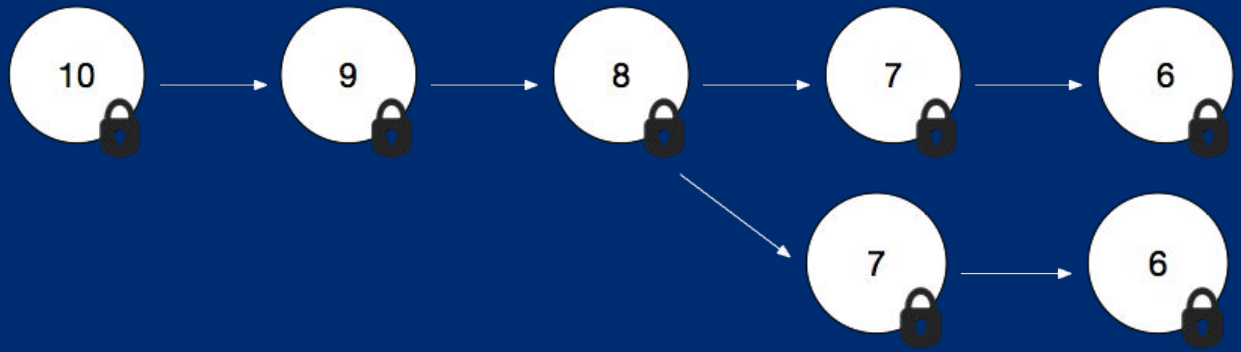

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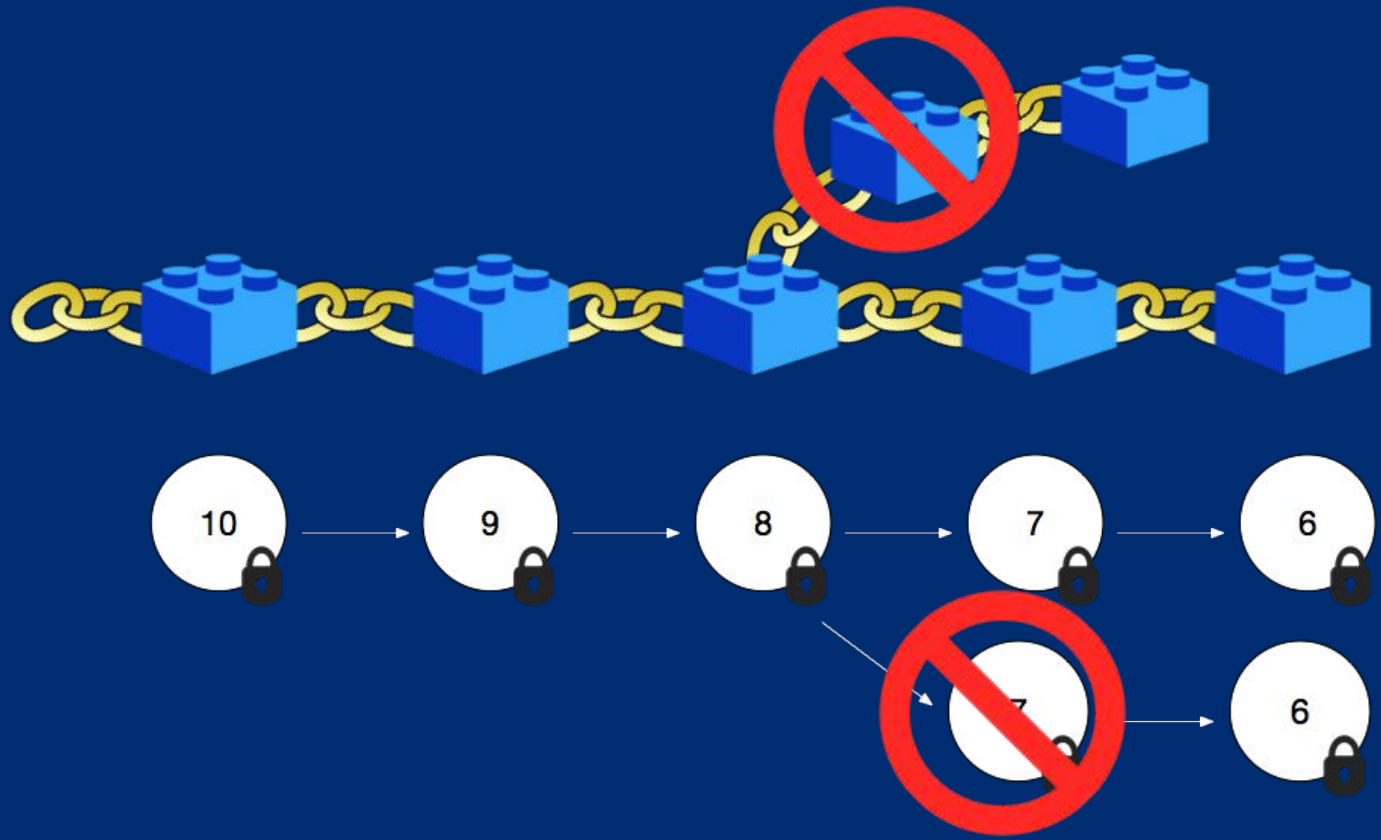

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Ledger

User

Host

Enclave

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Ledger

User

"1234"

Host

Enclave

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Ledger

C = Com(10 , “1234”; r)

User

“1234”

Host

Enclave

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Ledger

C = Com(10 , "1234"; r)

, σ

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C = Com(10 , "1234"; r)

, σ

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10 , "1234", C, r, , σ

Enclave

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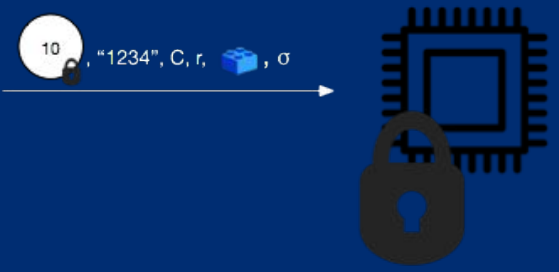
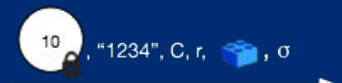

10
, “1234”, C, r,
, σ



Verify(, σ)

Verify(C = Com(10 , “1234”; r))

Derive encryption key for next state

Transaction Hash
Previous Tx Hash
C

Derive decryption key for previous state

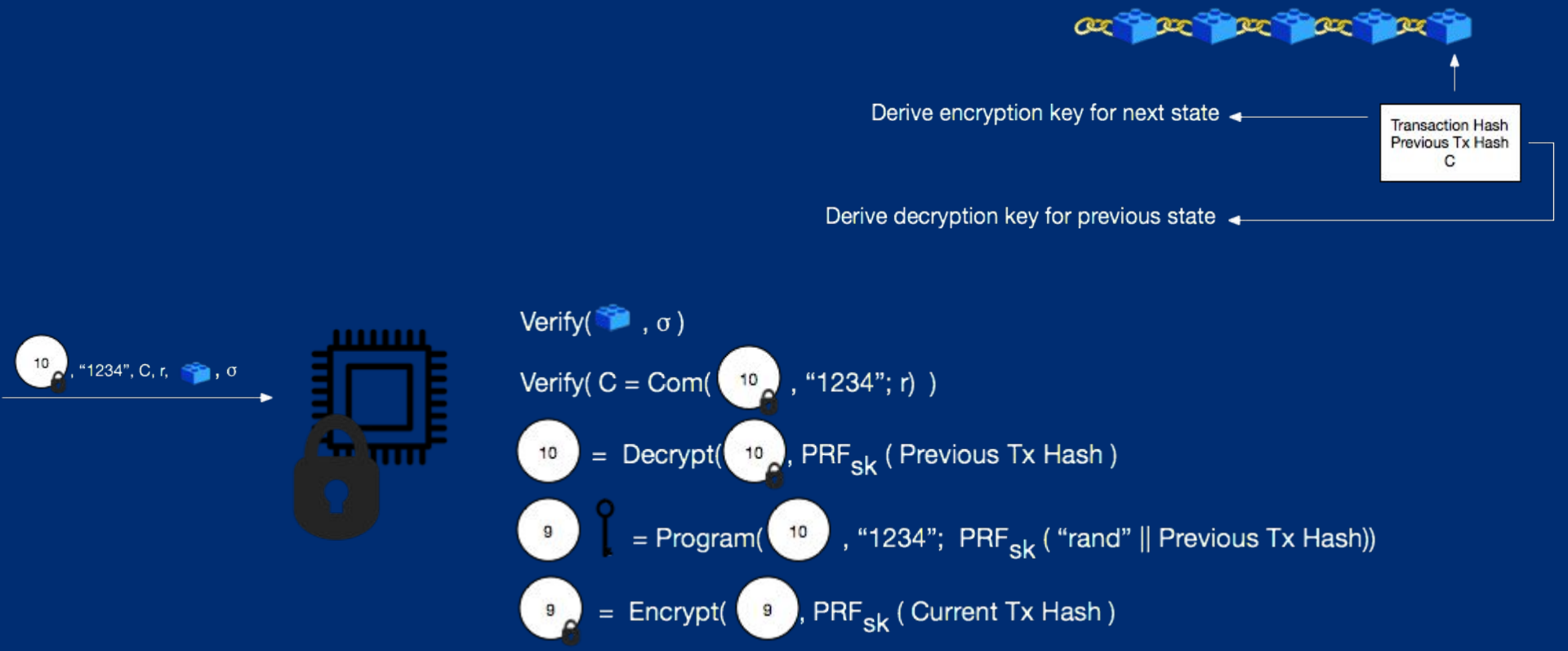
10 , "1234", C, r, , σ

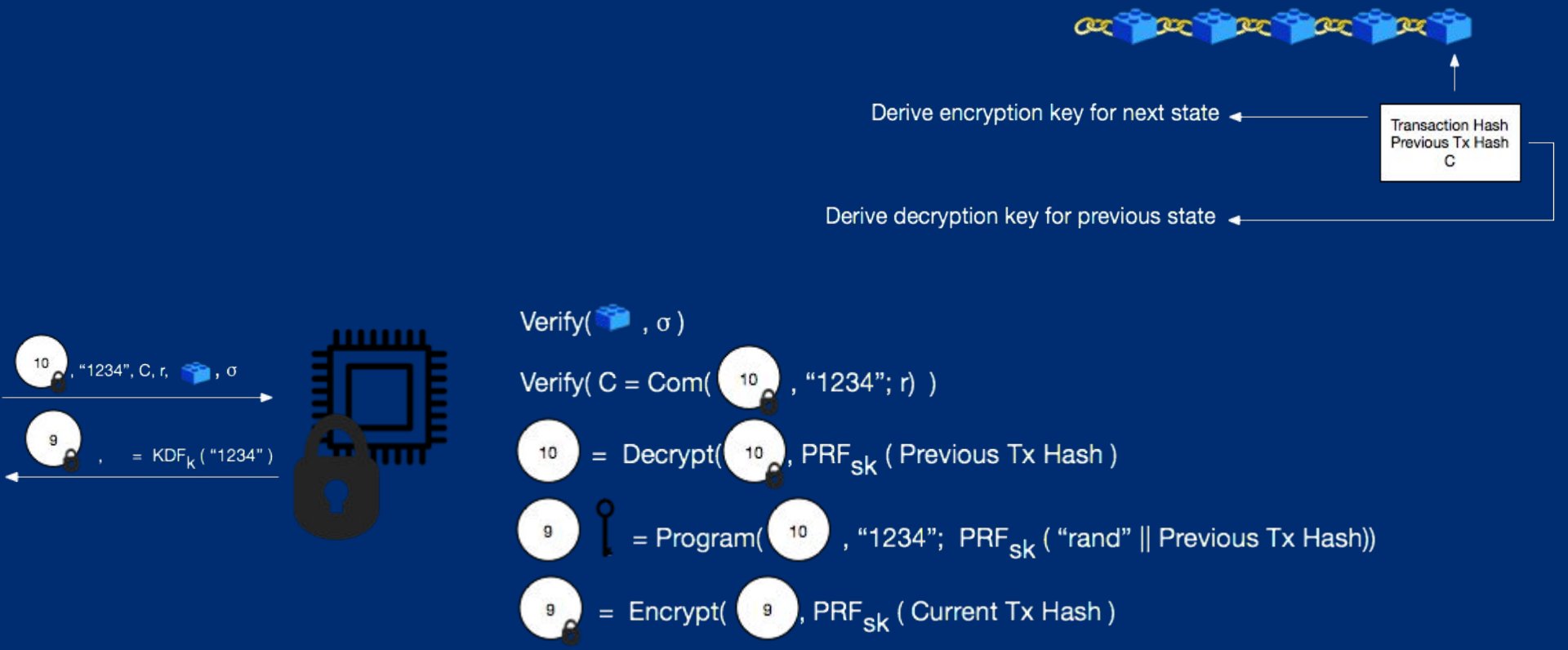
Verify(, σ)

Verify(C = Com(10 , "1234"; r))

10 = Decrypt(10 , PRF_{sk} (Previous Tx Hash)


Derive encryption key for next state
Transaction Hash
Previous Tx Hash
C
Derive decryption key for previous state
10 , "1234", C, r, , σ
Verify(, σ)
Verify(C = Com(10 , "1234"; r))
10 = Decrypt(10 , PRF$_{sk}$ (Previous Tx Hash)
9 = Program(10 , "1234"; PRF$_{sk}$ ("rand" || Previous Tx Hash))




Derive encryption key for next state
Transaction Hash
Previous Tx Hash
C
Derive decryption key for previous state
10 , "1234", C, r, , σ
9 , = KDF_k ("1234")
Verify(, σ)
Verify(C = Com(10 , "1234"; r))
10 = Decrypt(10 , PRF_sk (Previous Tx Hash)
9 = Program(10 , "1234"; PRF_sk ("rand" || Previous Tx Hash))
9 = Encrypt(9 , PRF_sk (Current Tx Hash)

Ledger

C = Com(10 , "1234"; r)

, σ

"1234"

10 , "1234", C, r, , σ

9 , = KDF_k ("1234")

User

Host

Enclave

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Ledger

C = Com(10 , "1234"; r)

, σ

"1234"

Decryption Failure, 9 more

User

10 , "1234", C, r, , σ

9 , = KDF_k ("1234")

Host

Enclave

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Protocol Extensions

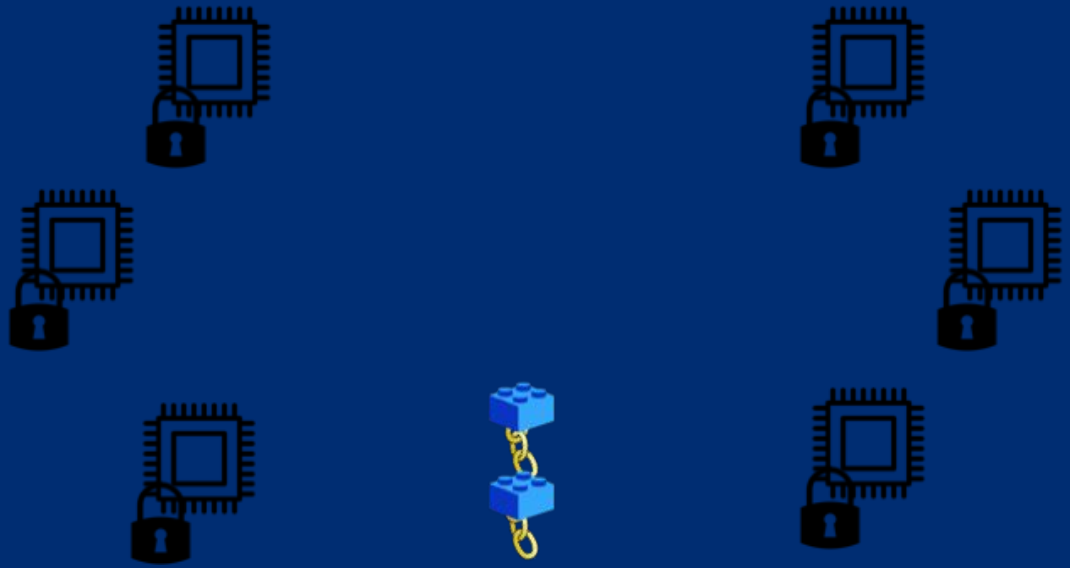
- We have managed to condition execution on ledger postings

- Extension #1: Programs can require public posting
  - *E.g.* Error reporting, guaranteed logging

- Extension #2: One Time Programs
  - Swept under the rug: so far we have secure *multi-execution programs*
  - Derive *unique* valid hash chain from program code

Additional Applications

- Smart contracts computing on private data
  - Concurrent work with Intel's Private Data Objects
  - Later follow-up work in the same area [Eikiden]



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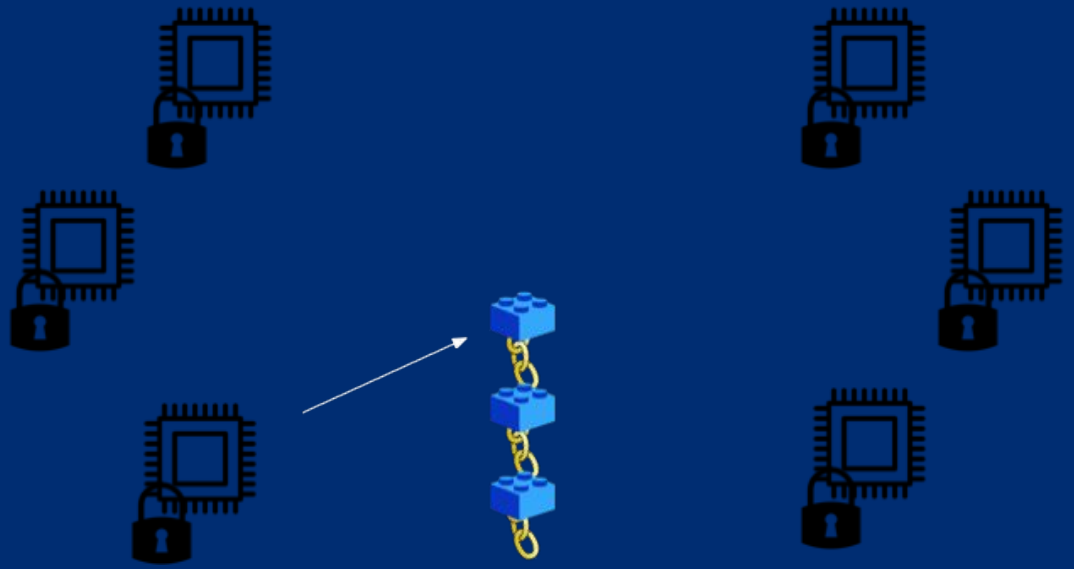

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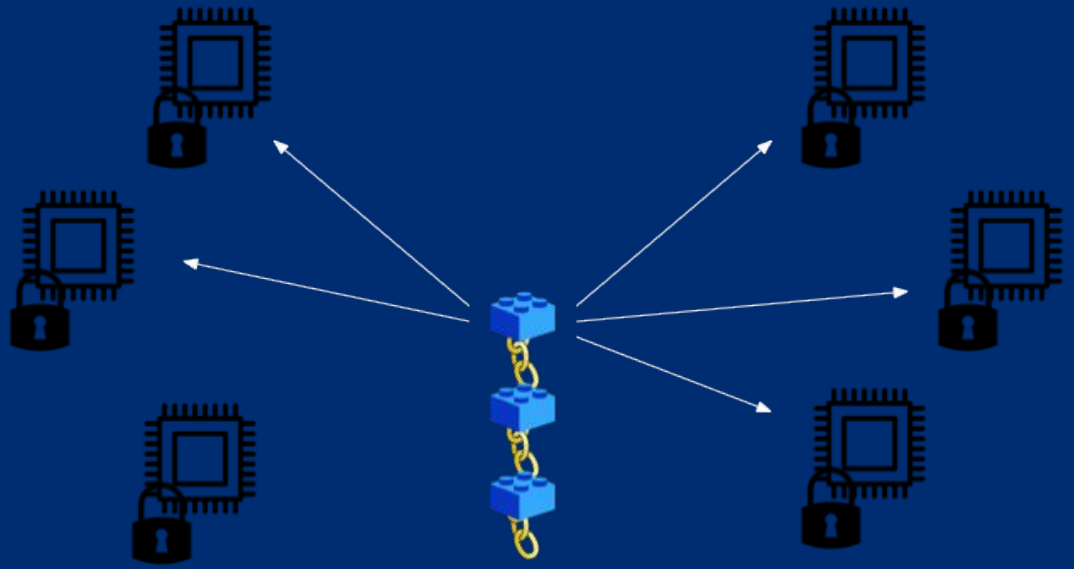

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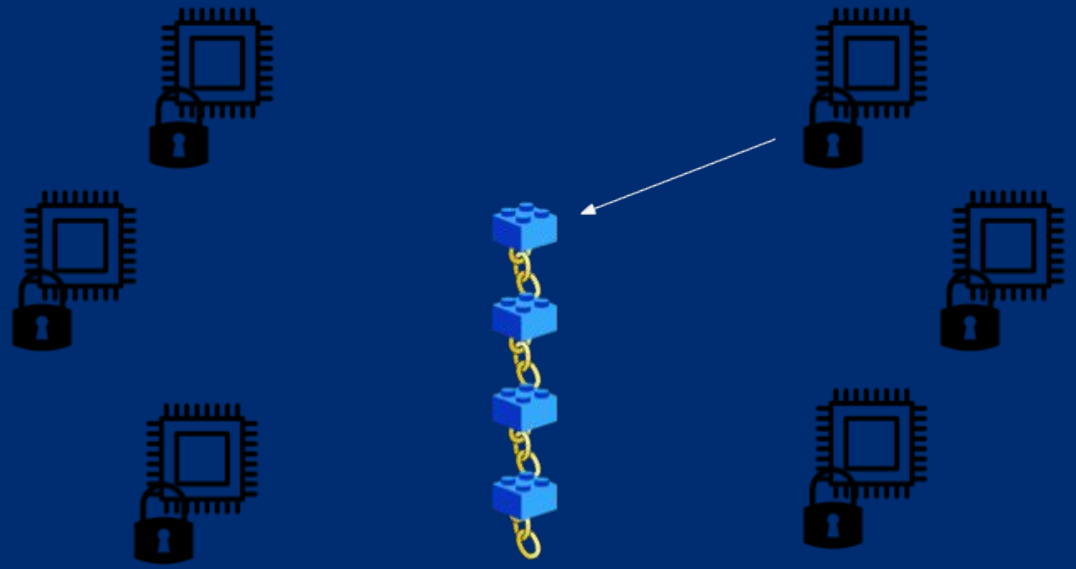

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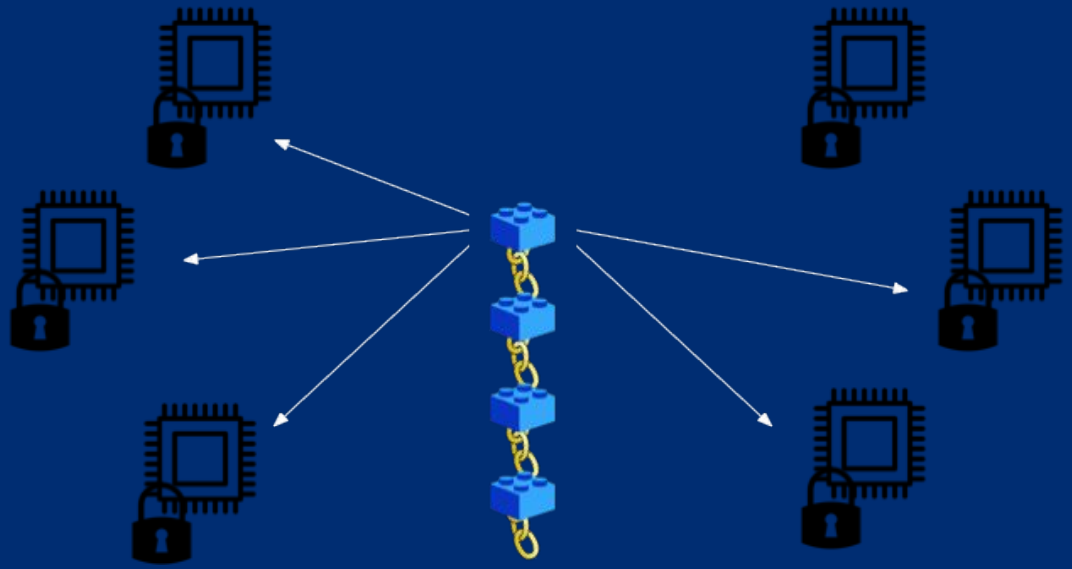

Additional Applications

- Autonomous Ransomware
  - Inevitable outcome of malicious trusted execution environments
  - Eliminates the need for command and control systems

Conclusions

- We create a novel protocol that provides trustworthy state for TEE's by binding state to an append-only ledger
- Ledgers are here to stay — lets do more than just currency-related research
- Keeping state is a difficult problem with wide ranging applications

Thank You!

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Bonus Slides