Making Classical (Threshold) Signatures Post-Quantum for Single Use on a Public Ledger

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EPFL
LASEC

Background

Discrete Log Problem (DLP)

$$x \rightleftarrows g^x \mod p$$

(p is a prime with some structure)

One-way Hash Functions

$$x \rightleftarrows H(x)$$

Commitment Schemes

$\mathsf{com} \leftarrow \mathit{Commit}(x, \mathit{open})$

$\xrightarrow{\mathsf{com}}$

$\xrightarrow{x,\, \mathit{open}}$ $\mathsf{com} \stackrel{?}{=} \mathit{Commit}(x, \mathit{open})$

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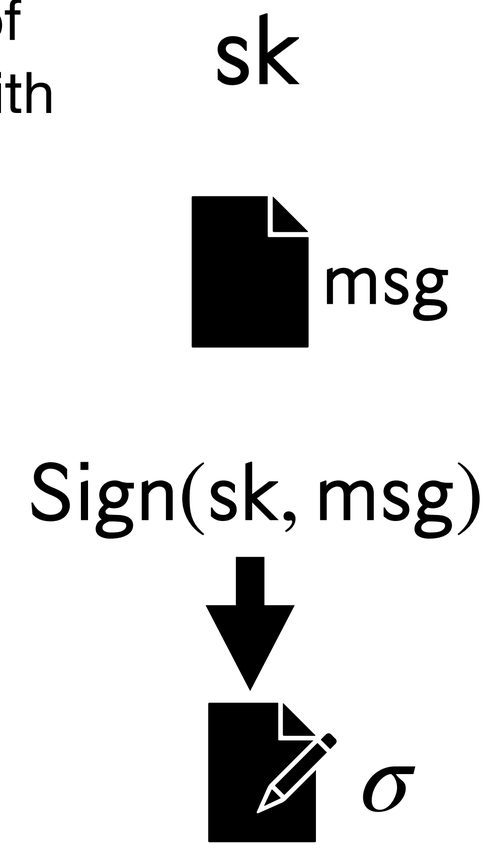
Digital Signatures

A digital signature scheme is a tuple of algorithms $(\mathsf{KeyGen}, \mathsf{Sign}, \mathsf{Verify})$ with key space $\mathscr{D}$ and message space $\mathscr{M}$ such that:

$\mathsf{KeyGen}(1^\lambda) \rightarrow (\mathsf{sk}, \mathsf{pk})$

$\mathsf{Sign}(\mathsf{sk}, \mathsf{msg}) \rightarrow \sigma$

$\mathsf{Verify}(\sigma, \mathsf{pk}, \mathsf{msg}) \rightarrow 0/1$



pk

$\mathsf{Verify}(\sigma, \mathsf{pk}, \mathsf{msg})$

Discrete Log Problem (DLP)

$$x \quad \rightleftarrows \quad g^x$$

KeyGen

x $\rightleftarrows$ g^x

sk pk

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Threshold Keys

x $\rightleftarrows$ g^x

sk pk

Threshold Keys

sk $\quad x = x_1 + x_2 + x_3$

$\mathsf{sk}_1 \quad x_1 \longrightarrow g^{x_1}$

$\mathsf{sk}_2 \quad x_2 \longrightarrow g^{x_2}$

$\mathsf{sk}_3 \quad x_3 \longrightarrow g^{x_3}$

Threshold Keys

sk $\quad x = x_1 + x_2 + x_3$

$\mathsf{sk}_1 \quad x_1 \longrightarrow g^{x_1}$

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g^x

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$\mathsf{sk}_3 \quad x_3 \rightarrow g^{x_3}$

$$g^{x}$$

$$g^{x_1+x_2+x_3} = g^{x_1} \cdot g^{x_2} \cdot g^{x_3}$$

Threshold Keys

sk $\quad x = x_1 + x_2 + x_3$

$\mathsf{sk}_1 \quad x_1 \longrightarrow g^{x_1}$

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$\mathsf{sk}_3 \quad x_3 \longrightarrow g^{x_3}$

g^{x}

$g^{x_1+x_2+x_3} = g^{x_1} \cdot g^{x_2} \cdot g^{x_3}$

pk

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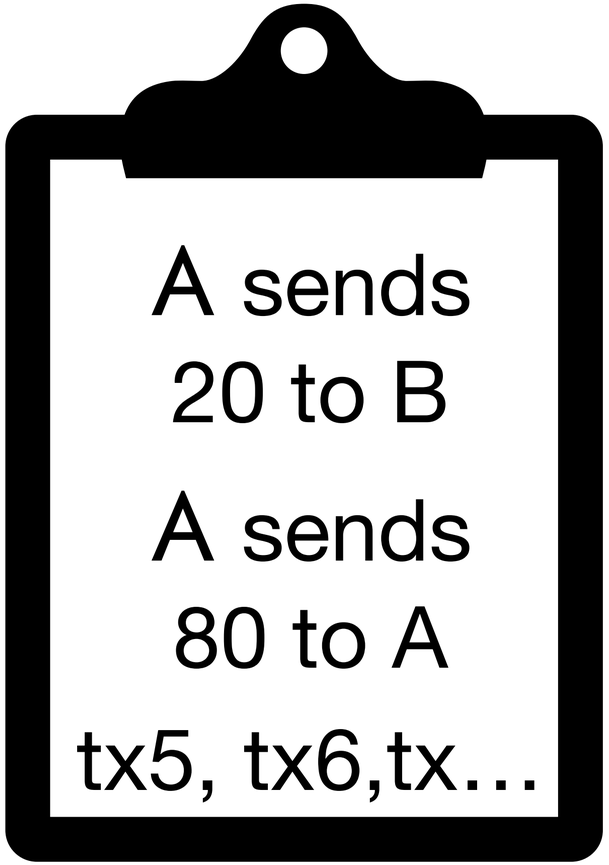
Public Ledger

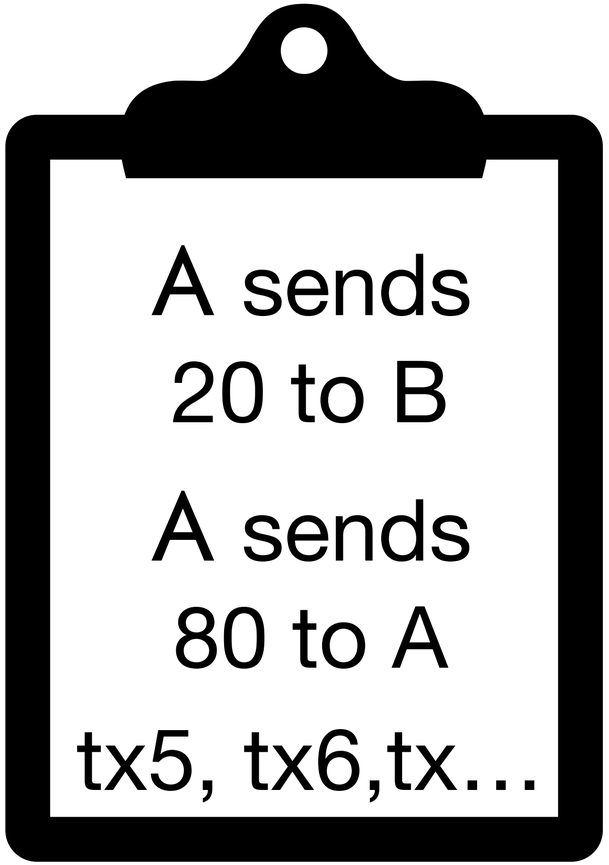
A
100



B

Public Ledger

A
100



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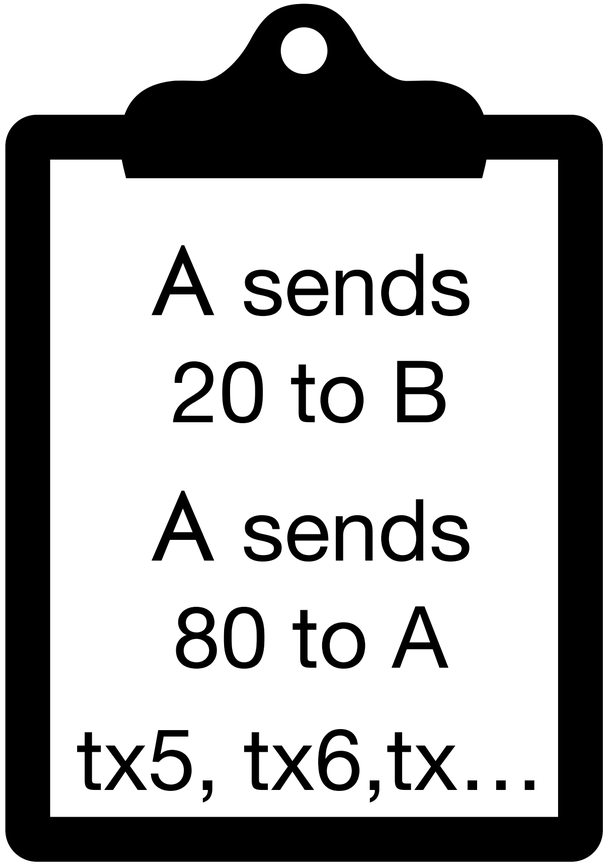

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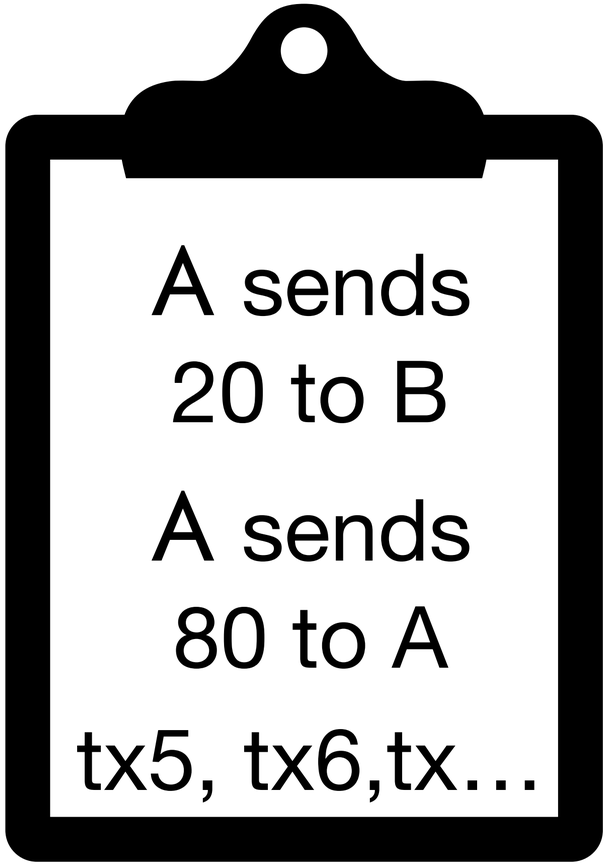

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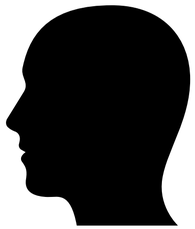
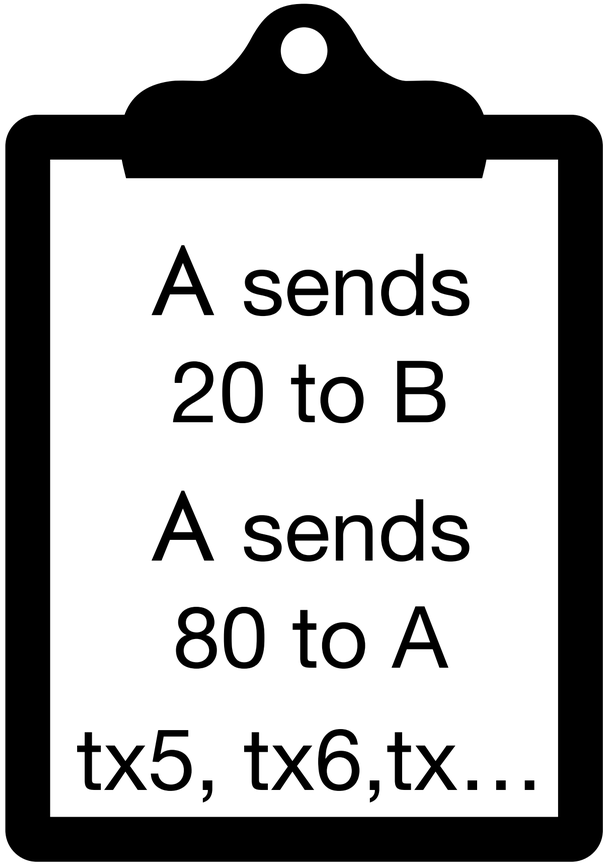


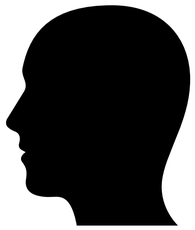
Public Ledger

A, sk_A, pk_A
100

$\sigma \leftarrow \text{Sign}(sk, tx)$



B, pk_B



$\text{Verify}(\sigma, \text{pk}, \text{tx})$

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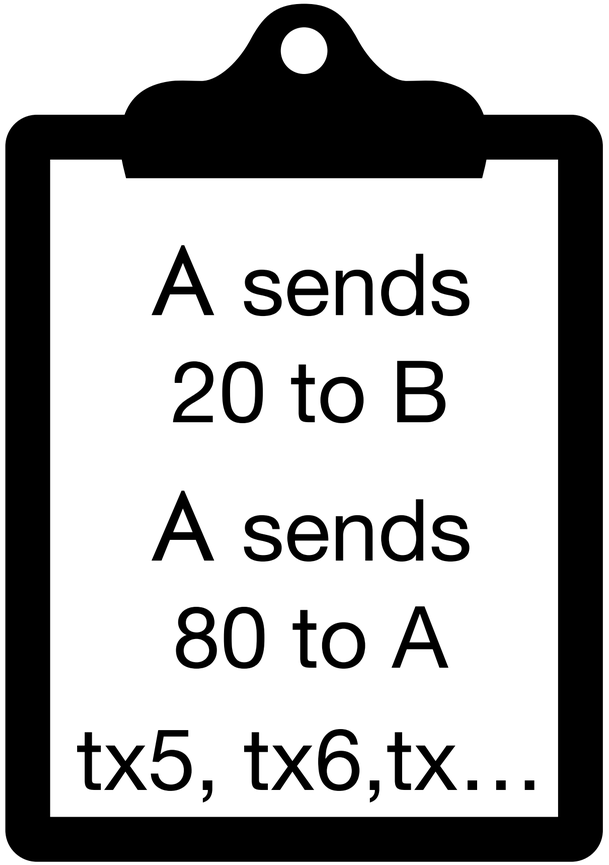

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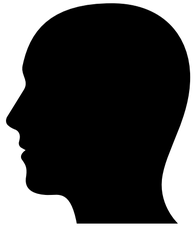

Verify(σ, pk, tx)

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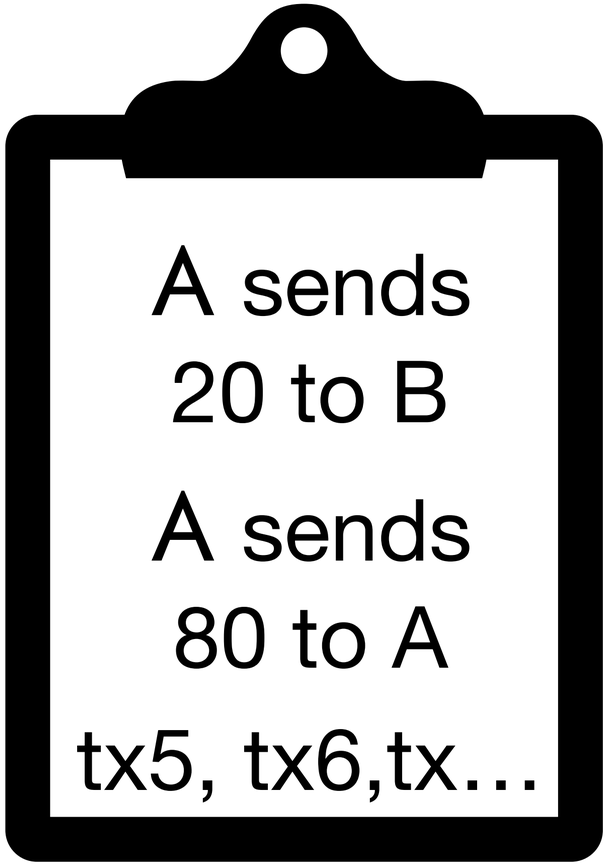

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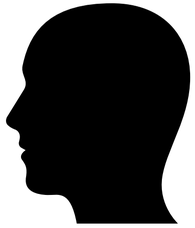

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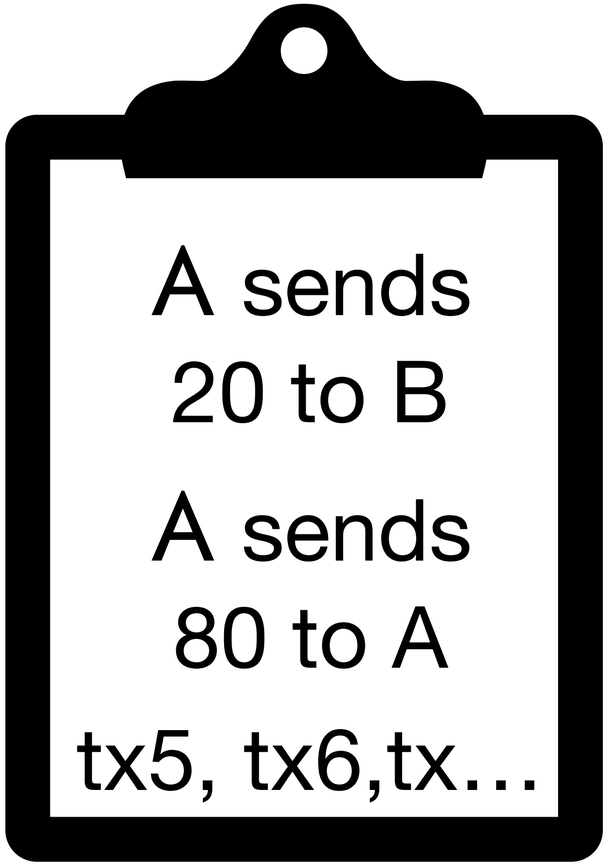

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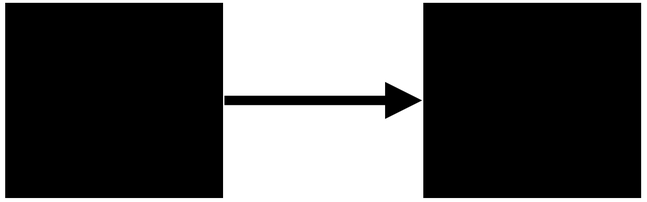

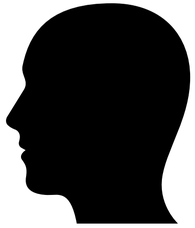

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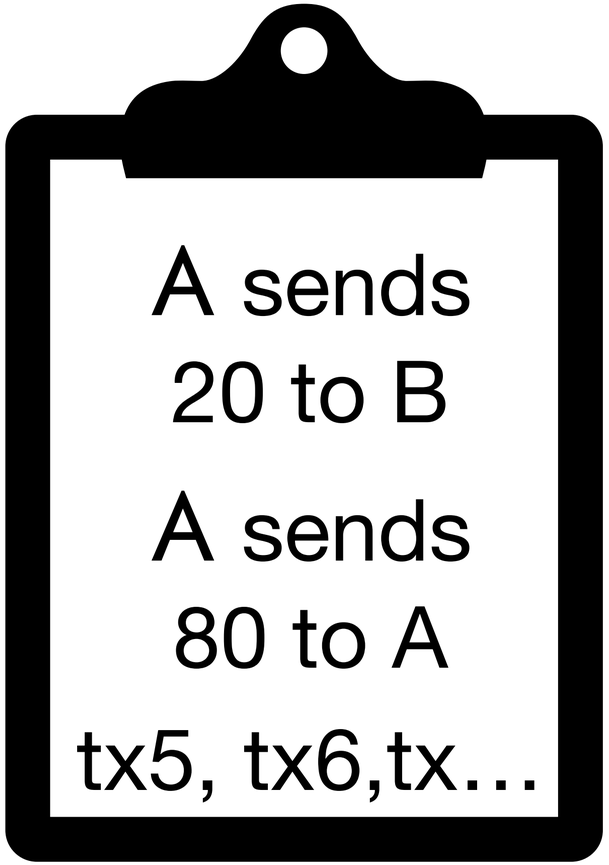

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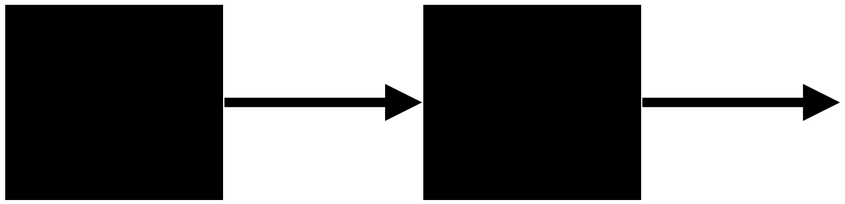

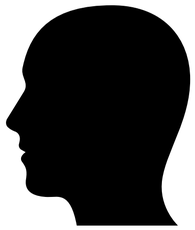

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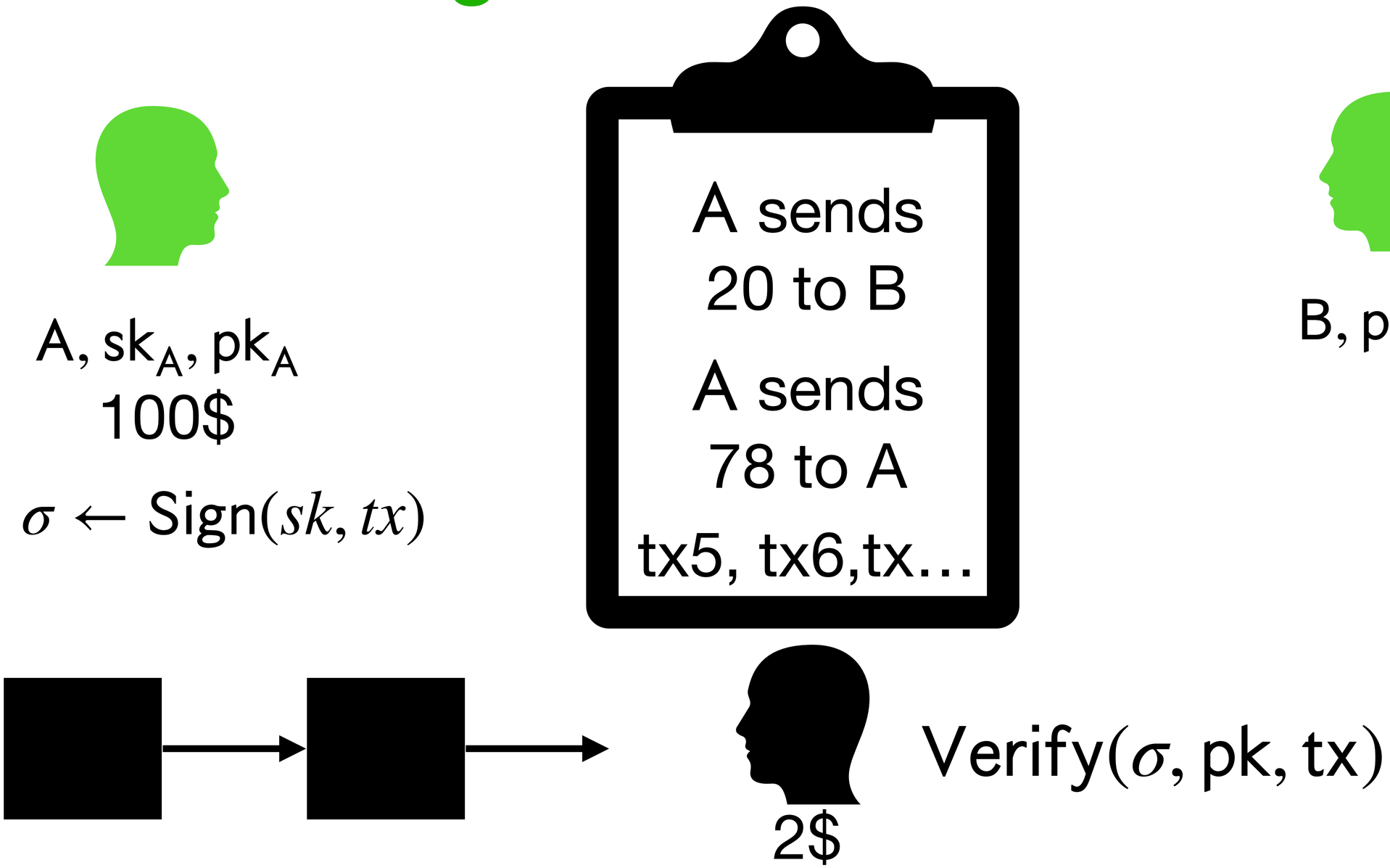
Public Ledger



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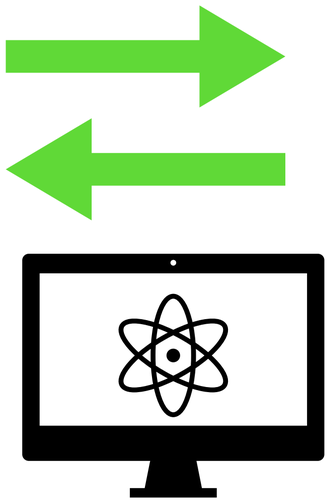
Discrete Log Problem (DLP)

x



g^x

Quantum Computers

Public Ledger

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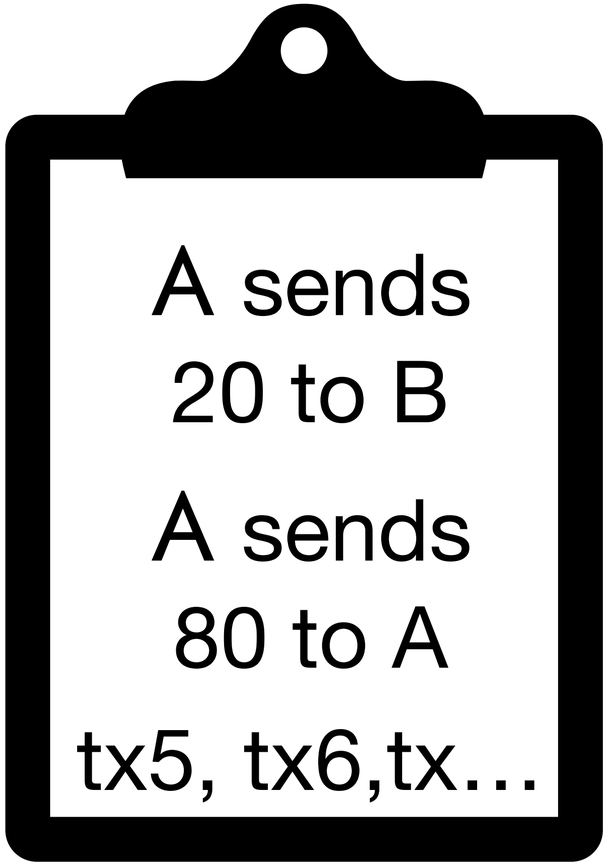
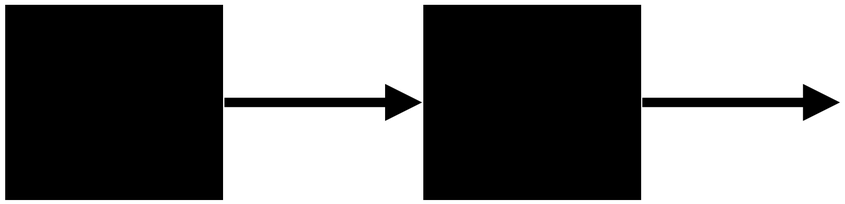


B, pk_B

sk

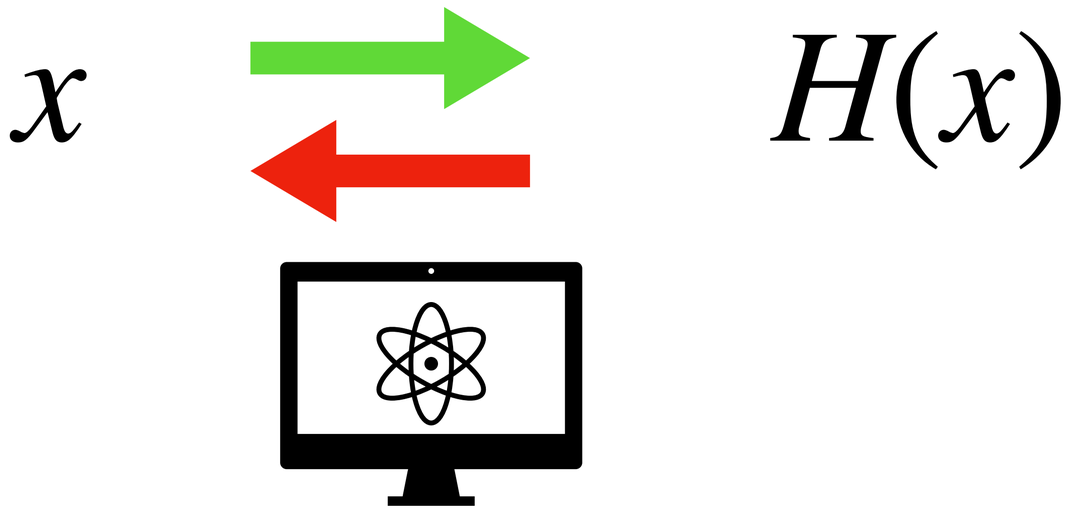


Verify(σ, pk, tx)

One-way Hash Functions

$$x \rightleftarrows H(x)$$

One-way Hash Functions



Quantum Computers

Making Classical (Threshold) Signatures Post-Quantum for Single Use on a Public Ledger

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Motivation

Motivation

Public Key Cryptography

Motivation

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Public Key Cryptography

Motivation

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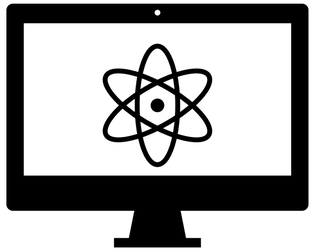

Public Key Cryptography

Quantum Computers

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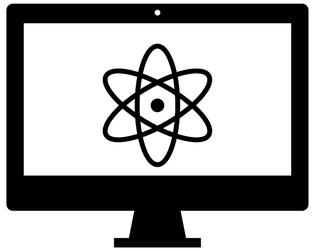

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Public Key Cryptography

Quantum Computers

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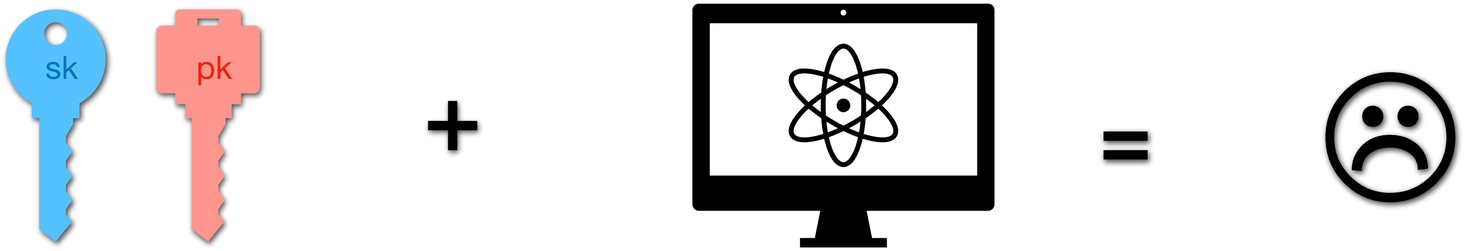
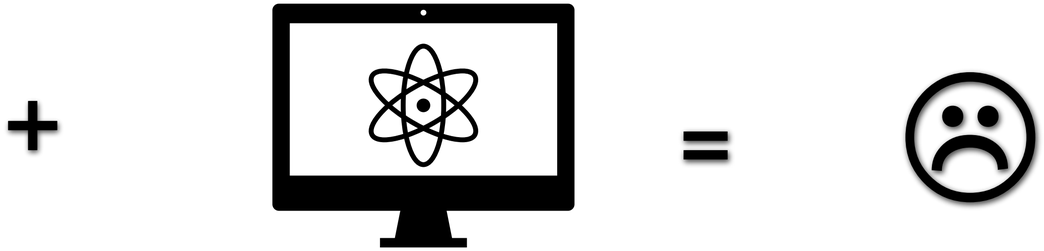


Public Key Cryptography

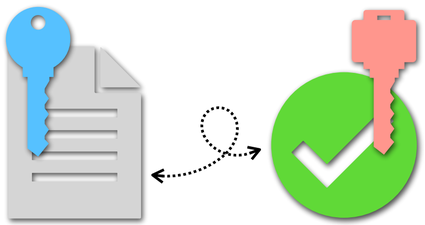
Quantum Computers

Motivation



Quantum Computers

Motivation



Digital Signatures

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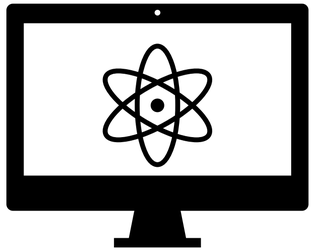

Quantum Computers

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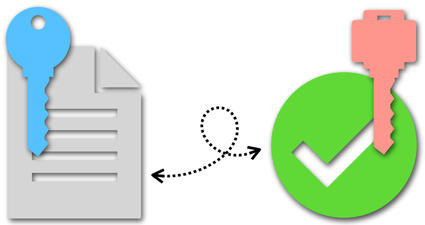

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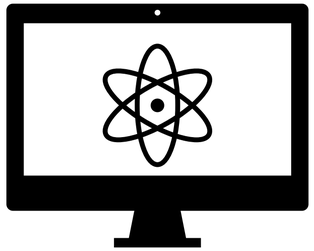

Quantum Computers

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→

- Post-Quantum Signatures (NIST) : secure, not yet widely deployed
- Hiding the public key : one time secure, ready to use with classical algorithms

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P2PKH

P2PKH hides the public key behind a hash → Generalised HashedPK transform

HashedPK-KeyGen(λ)	HashedPK-Sign($\tilde{\mathsf{sk}}$, msg)	HashedPK-Verify($\tilde{\sigma}$, $\mathsf{pk}_{\mathcal{H}}$, msg)
$(\mathsf{pk}, \mathsf{sk}) \leftarrow\$ \mathsf{KeyGen}_{\Sigma}(\lambda)$	$(\mathsf{sk}, \mathsf{pk}) \leftarrow \tilde{\mathsf{sk}}$	$(\sigma, \mathsf{pk}) \leftarrow \tilde{\sigma}$
$\mathsf{pk}_{\mathcal{H}} \leftarrow H(\mathsf{pk})$	$\sigma \leftarrow \mathsf{Sign}_{\Sigma}(\mathsf{sk}, \mathsf{msg})$	**if** $\mathsf{pk}_{\mathcal{H}} = H(\mathsf{pk})$:
$\tilde{\mathsf{sk}} \leftarrow (\mathsf{sk}, \mathsf{pk})$	$\tilde{\sigma} \leftarrow (\sigma, \mathsf{pk})$	**return** $\mathsf{Verify}_{\Sigma}(\sigma, \mathsf{pk}, \mathsf{msg})$
return $(\tilde{\mathsf{sk}}, \mathsf{pk}_{\mathcal{H}})$	**return** $\tilde{\sigma}$	**return** 0

Hiding the public key

$\Sigma = (\mathsf{KeyGen}_\Sigma, \mathsf{Sign}_\Sigma, \mathsf{Verify}_\Sigma)$
with additive public key domain
+ hash function H

$\xrightarrow{\text{Generic Transform}}$

Signature scheme with hidden public key

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Hiding the public key

$\Sigma = (\mathsf{KeyGen}_\Sigma, \mathsf{Sign}_\Sigma, \mathsf{Verify}_\Sigma)$
with additive public key domain
+ hash function H

$\xrightarrow{\text{Generic Transform}}$

Signature scheme with hidden public key

HiddenPK-KeyGen(λ)

1 : $(\mathsf{sk}, \mathsf{pk}) \leftarrow\$ \mathsf{KeyGen}_\Sigma(\lambda)$
2 : $\rho \leftarrow\$ \mathcal{D}$
3 : $\tilde{\mathsf{sk}} \leftarrow (\mathsf{sk}, \rho)$
4 : $\tilde{\mathsf{pk}} \leftarrow (H(\rho), \mathsf{pk} + \rho)$
5 : **return** $(\tilde{\mathsf{sk}}, \tilde{\mathsf{pk}})$

Hiding the public key

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$\rho \leftarrow\$ \mathcal{D}$	$\sigma \leftarrow \mathsf{Sign}_\Sigma(\mathsf{sk}, \mathsf{msg})$
$\tilde{\mathsf{sk}} \leftarrow (\mathsf{sk}, \rho)$	$\tilde{\sigma} \leftarrow (\sigma, \rho)$
$\tilde{\mathsf{pk}} \leftarrow (H(\rho), \mathsf{pk} + \rho)$	**return** $\tilde{\sigma}$
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$\rho \leftarrow\$ \mathcal{D}$	$\sigma \leftarrow \mathsf{Sign}_\Sigma(\mathsf{sk}, \mathsf{msg})$	$(\tilde{\mathsf{pk}}_1, \tilde{\mathsf{pk}}_2) \leftarrow \tilde{\mathsf{pk}}$
$\tilde{\mathsf{sk}} \leftarrow (\mathsf{sk}, \rho)$	$\tilde{\sigma} \leftarrow (\sigma, \rho)$	**if** $H(\rho) = \tilde{\mathsf{pk}}_1$
$\tilde{\mathsf{pk}} \leftarrow (H(\rho), \mathsf{pk} + \rho)$	**return** $\tilde{\sigma}$	$\mathsf{pk} = \tilde{\mathsf{pk}}_2 - \rho$
return $(\tilde{\mathsf{sk}}, \tilde{\mathsf{pk}})$		**return** $\mathsf{Verify}_\Sigma(\sigma, \mathsf{pk}, \mathsf{msg})$
		return 0

Hiding the public key

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Problem
Front Running

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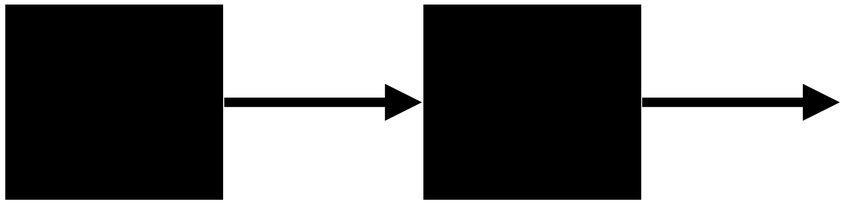
Front Running



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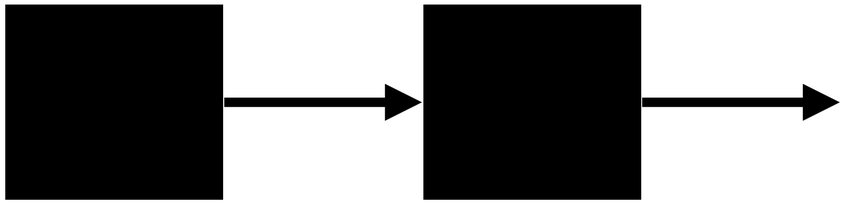

$\tilde{\mathsf{pk}} : (H(\rho), \mathsf{pk} + \rho)$

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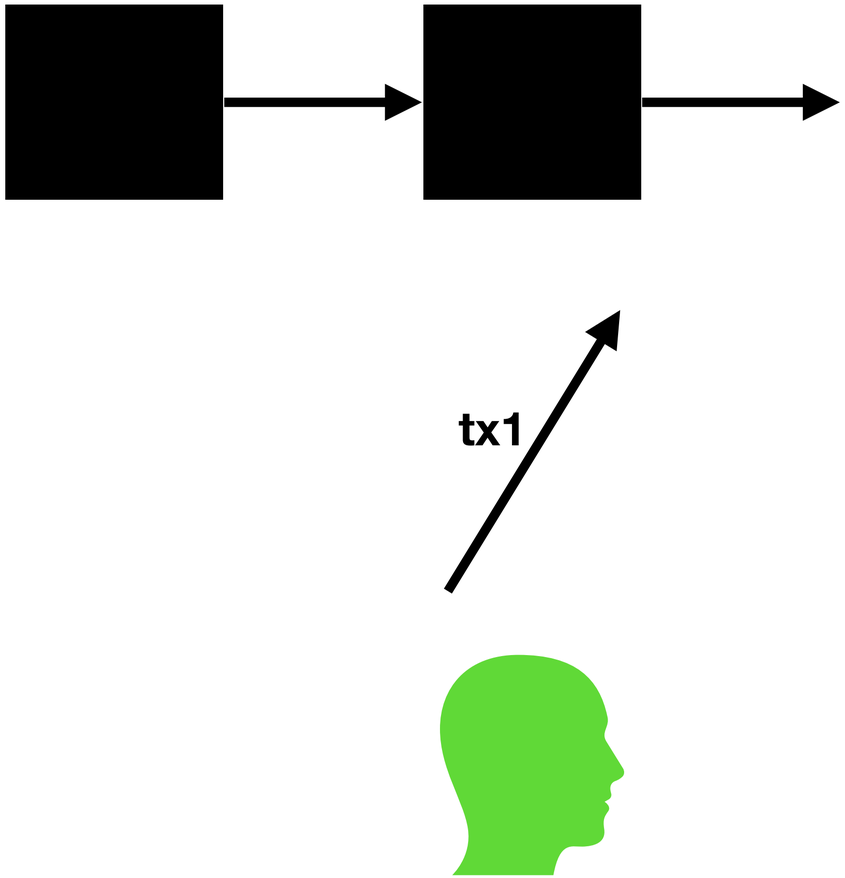

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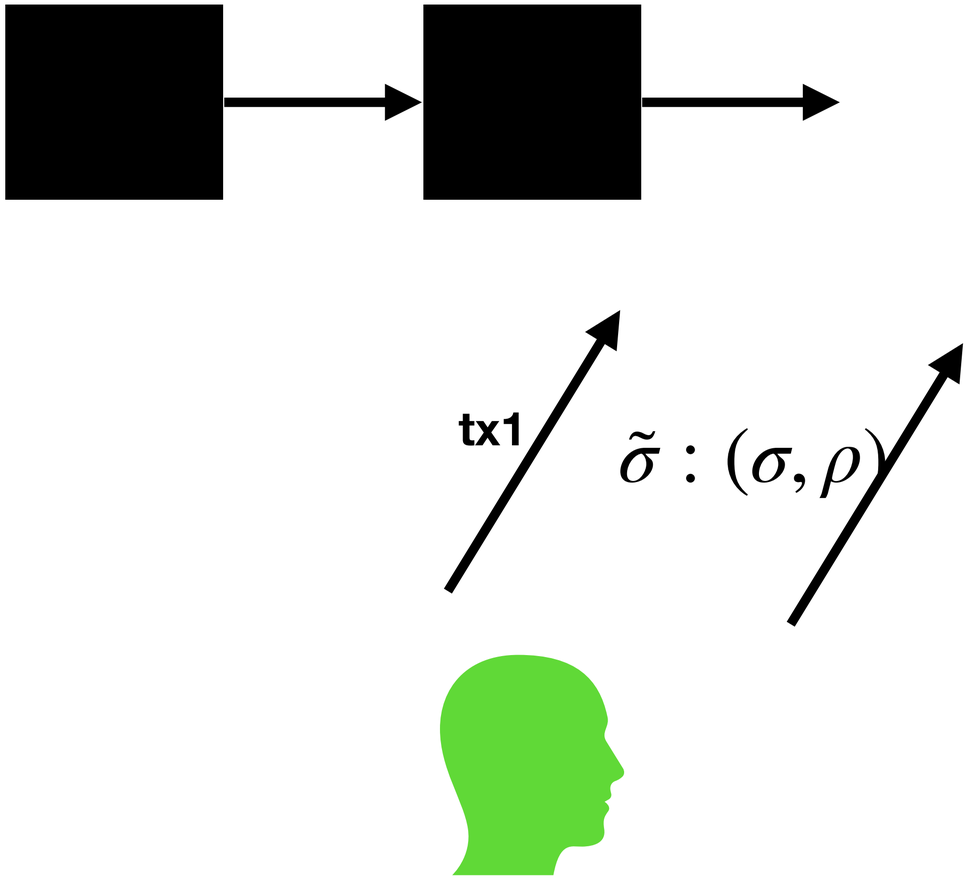
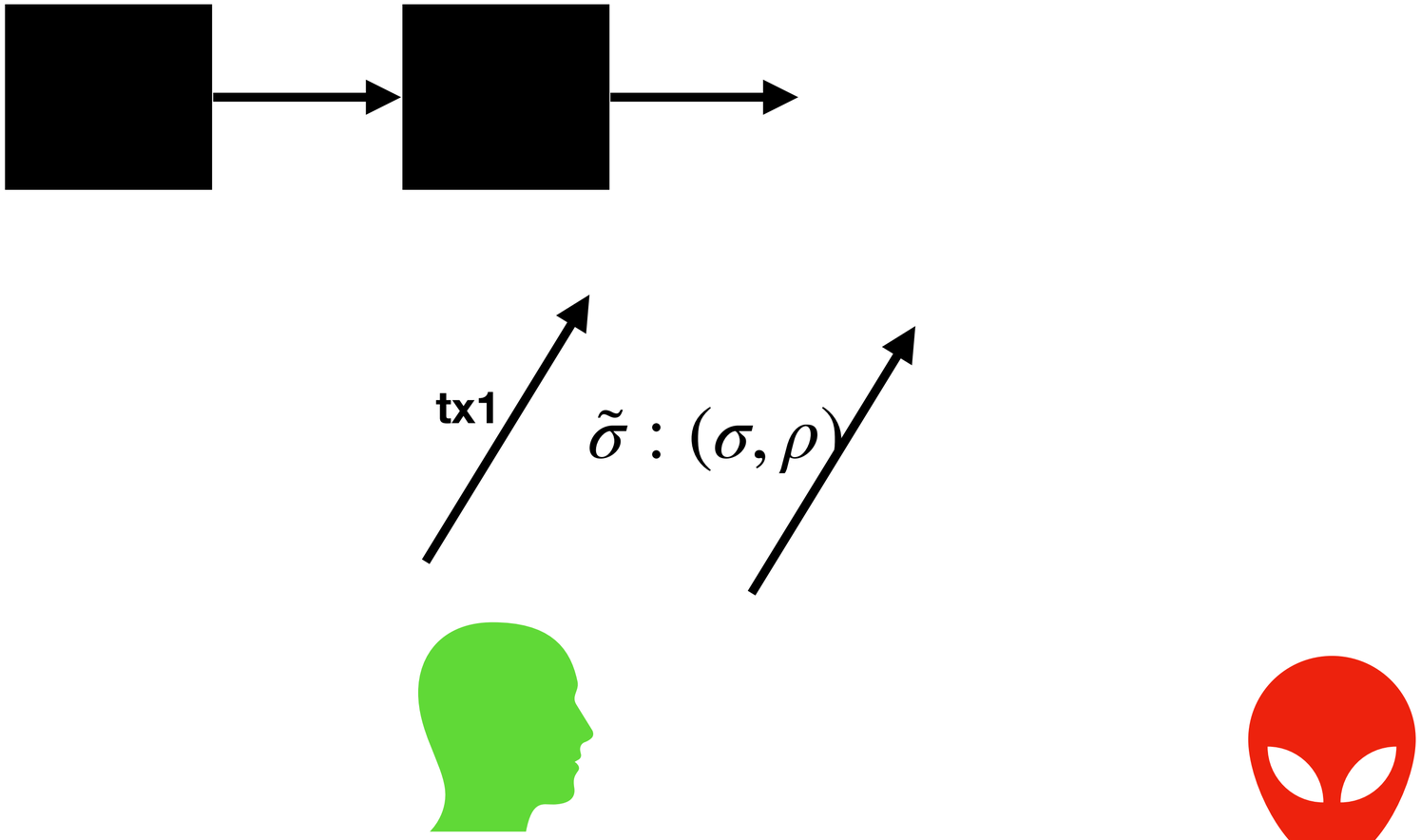


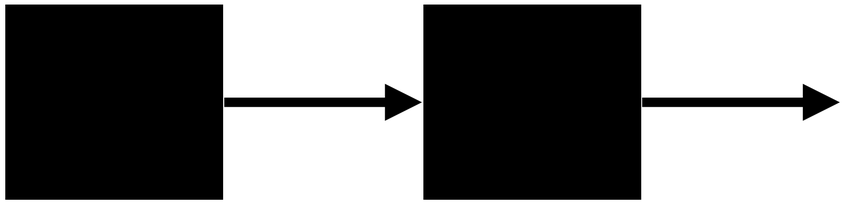
EPFL LASEC

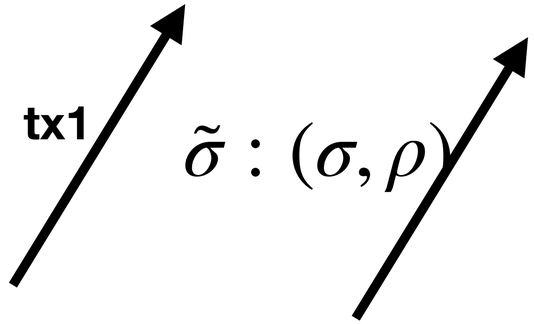
Front Running



EPFL LASEC

Front Running





$\tilde{\sigma} : (\sigma, \rho)$

$\tilde{\mathsf{pk}} : (H(\rho), \mathsf{pk} + \rho)$

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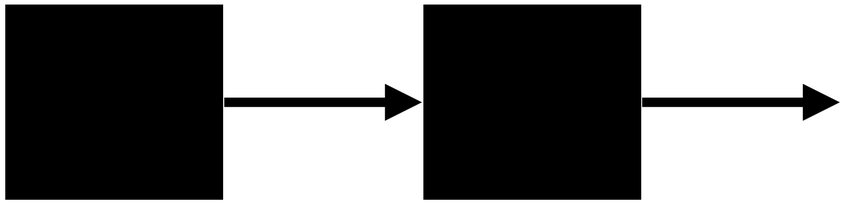
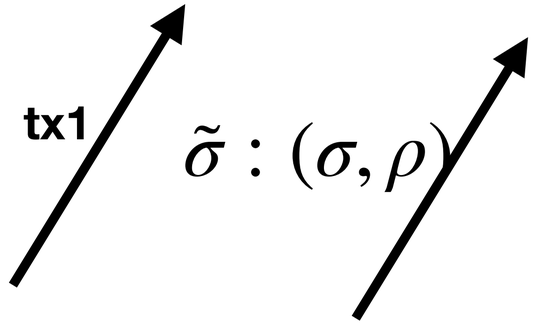
Front Running





$\tilde{\mathsf{pk}} : (H(\rho), \mathsf{pk} + \rho)$

$\tilde{\sigma} : (\sigma, \rho)$

Recover pk

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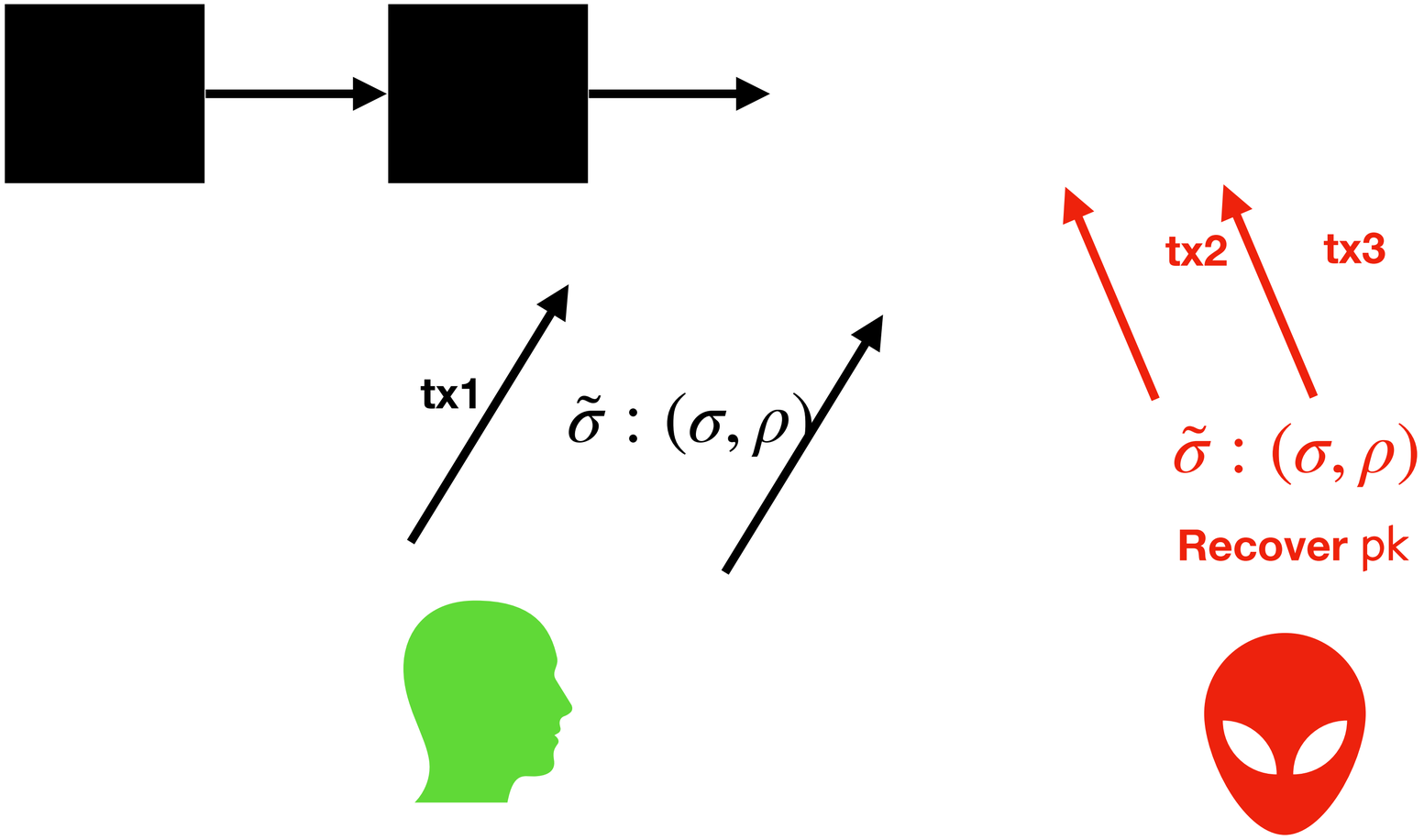
Front Running



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One-Time Signature

with Delayed Ledger

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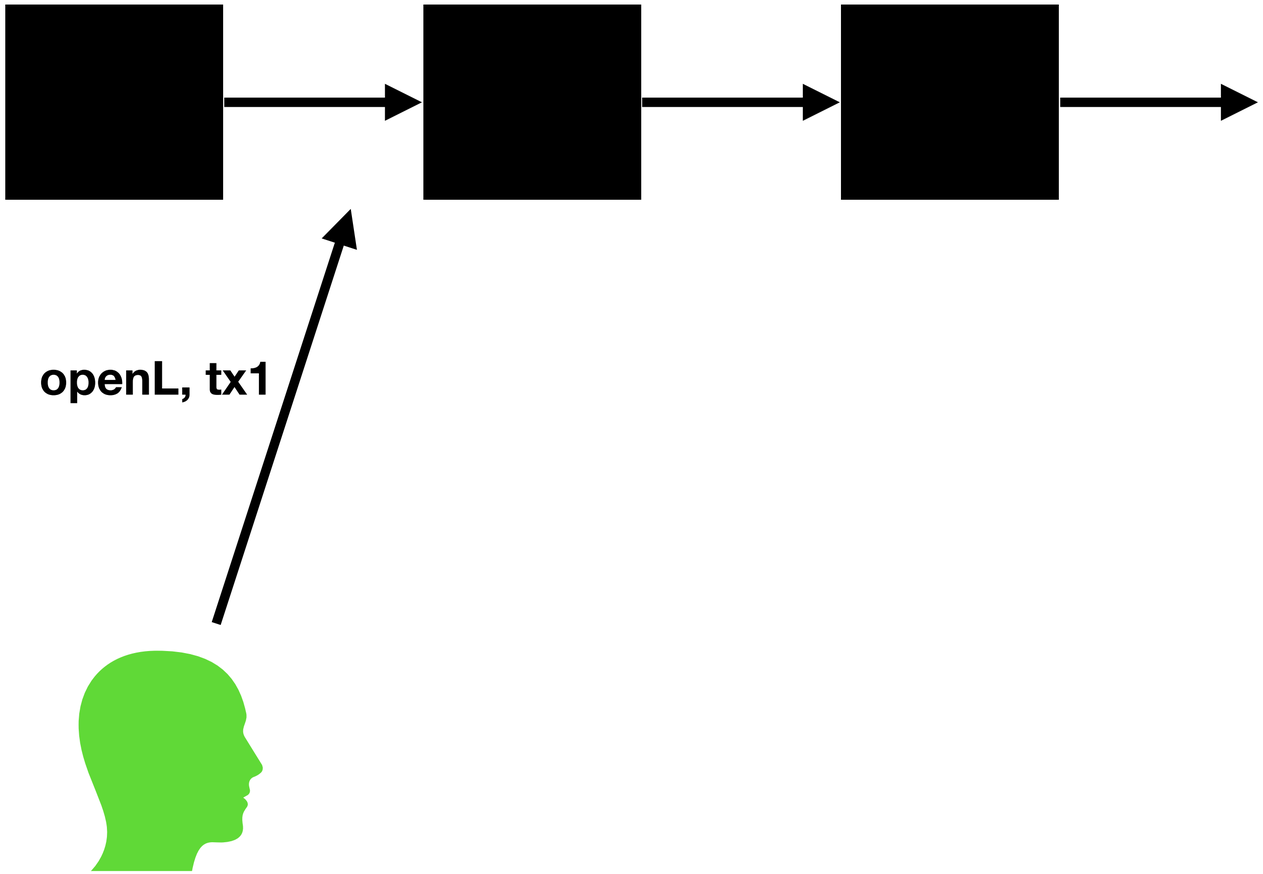

One-Time Signature

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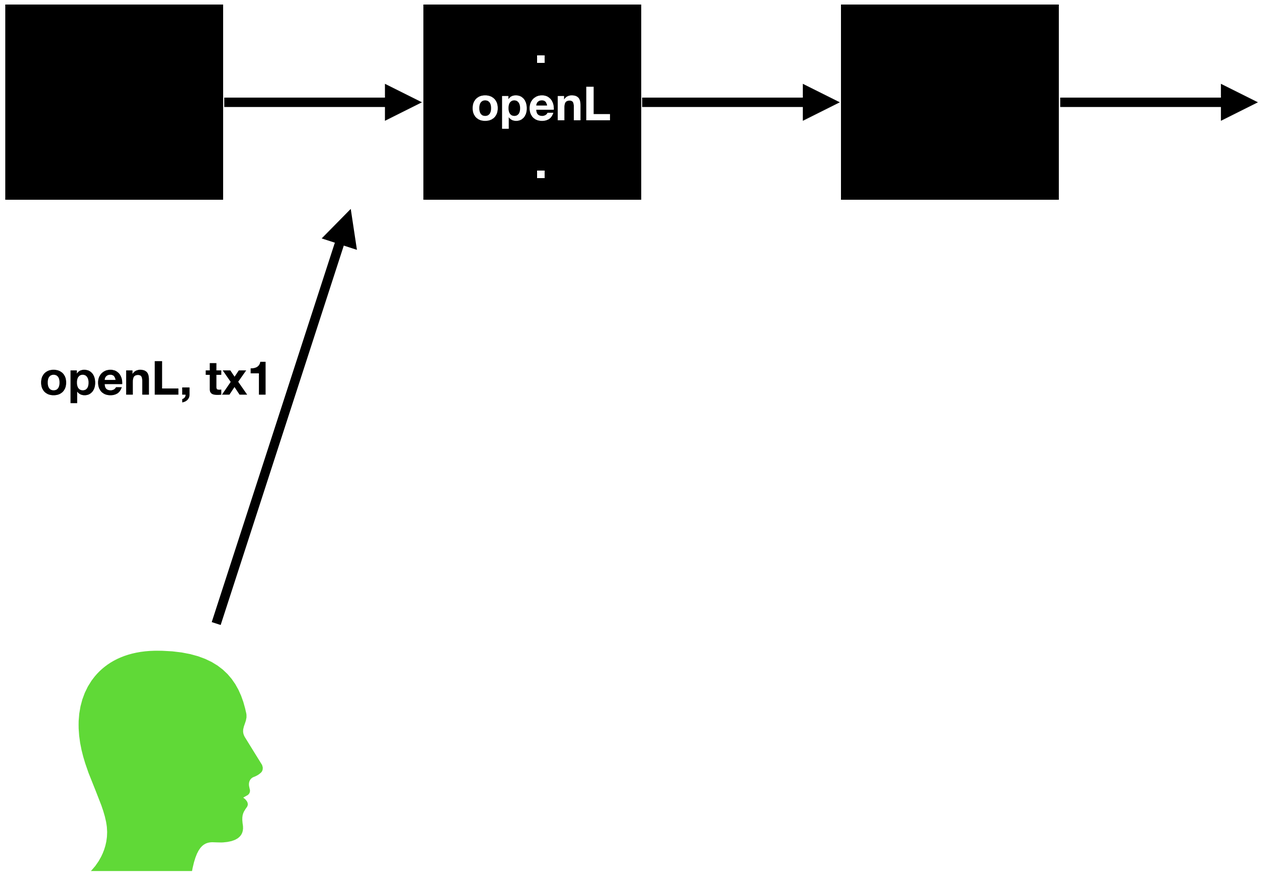

One-Time Signature

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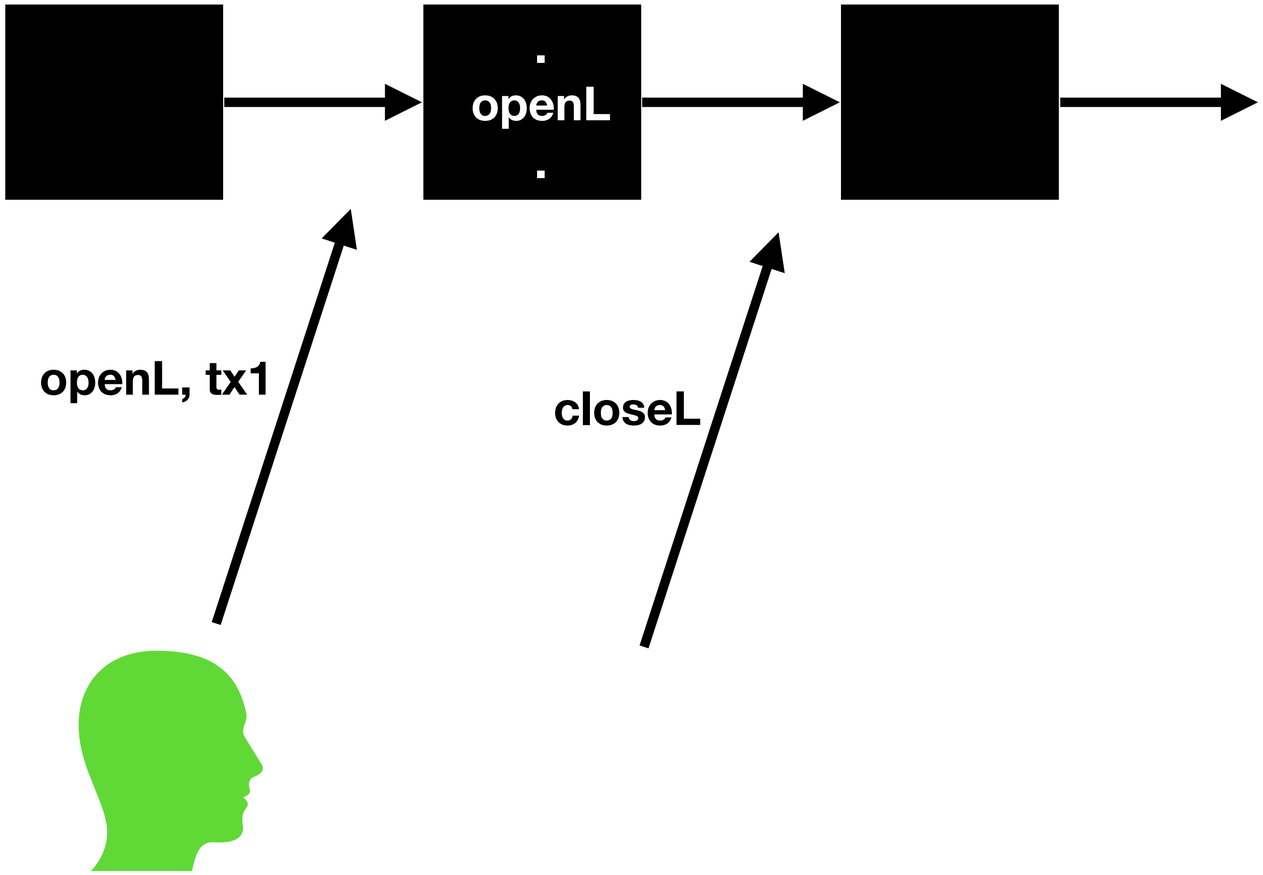
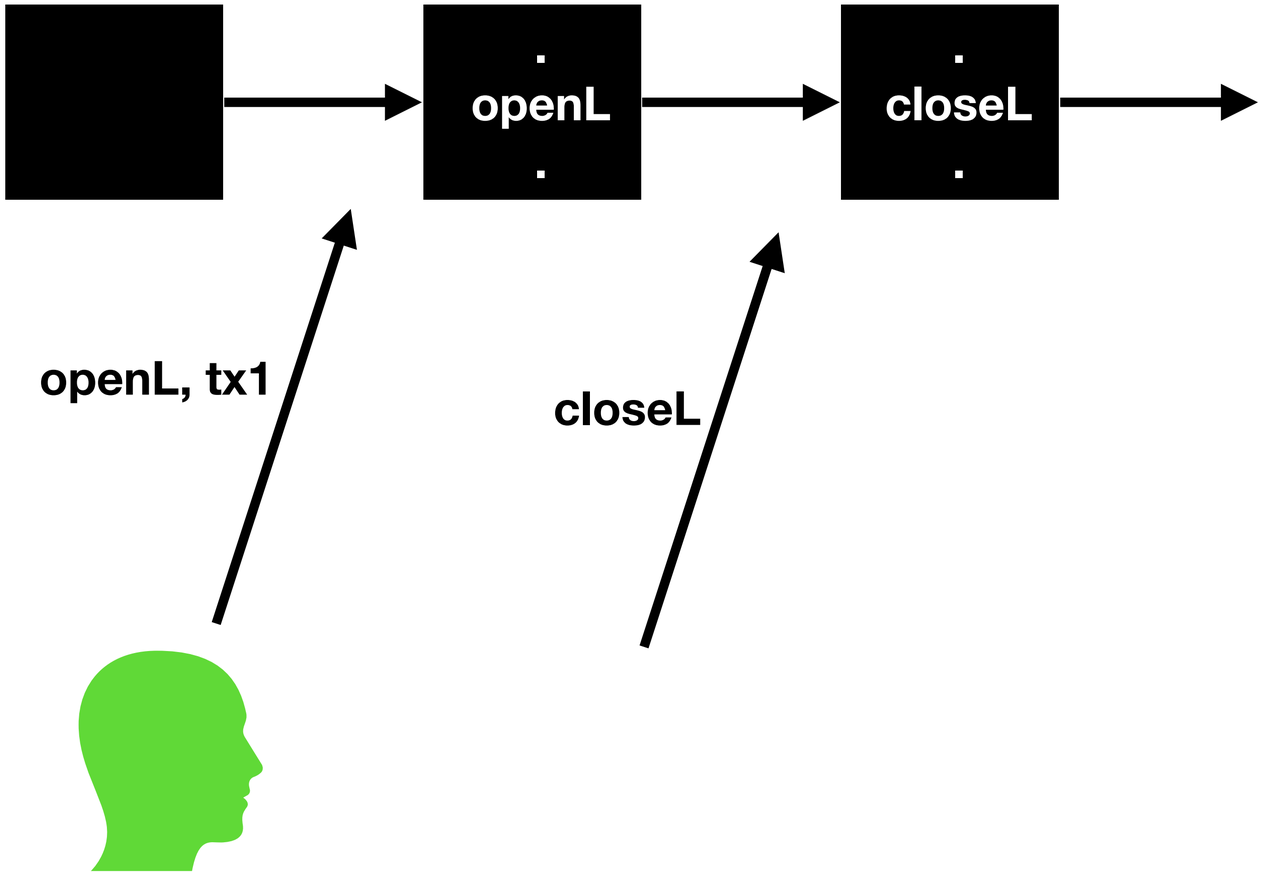


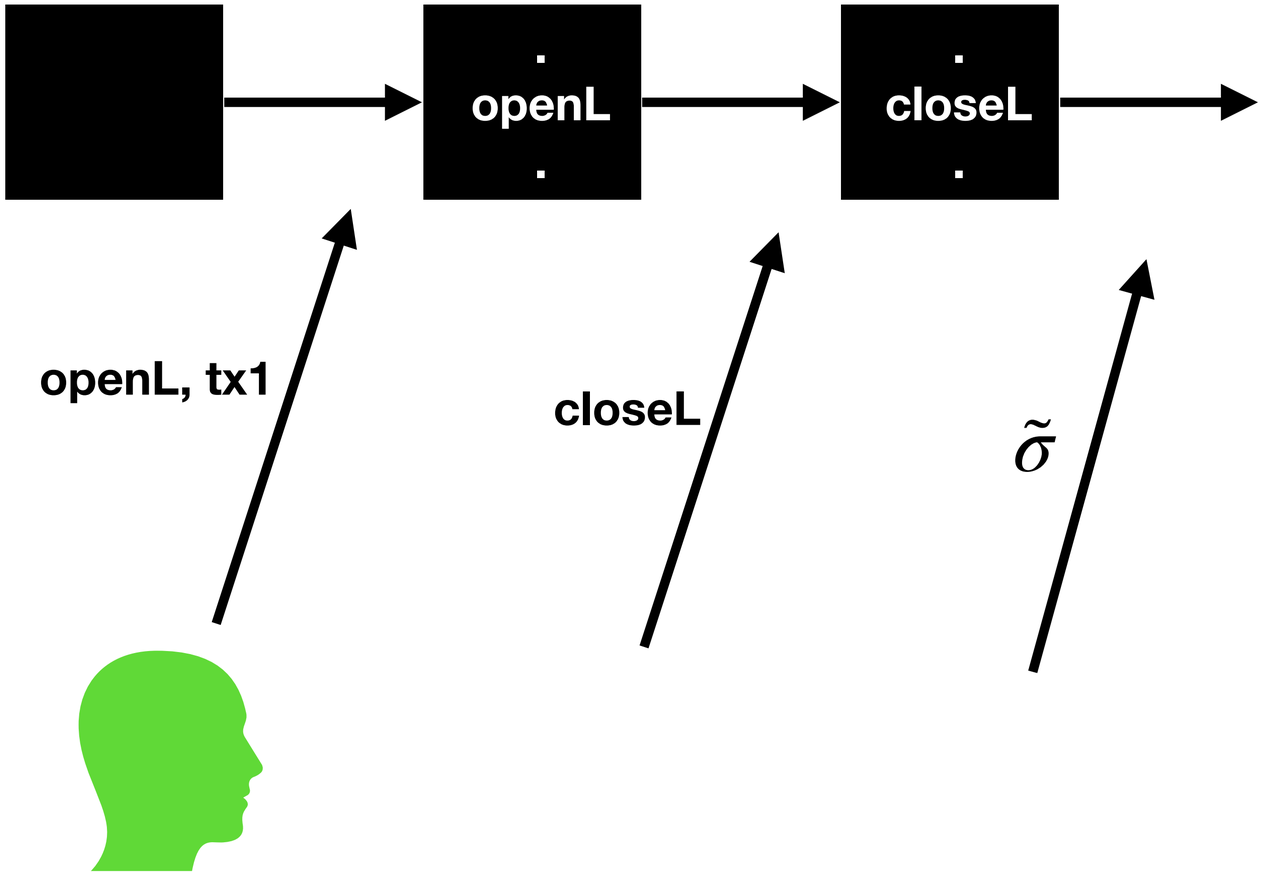
One-Time Signature

with Delayed Ledger



One-Time Signature

with Delayed Ledger



Conclusion & Takeaway

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- Formal study of hiding a public key in a public ledger setting.

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Conclusion & Takeaway

- Formal study of hiding a public key in a public ledger setting.
- HiddenPK is easier to extend to threshold setting compared to P2PKH.
- Practical instantiations require improvement in DDoS protection & miner motivation.

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Thanks!

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