Pixel: Multi-Signatures for Consensus

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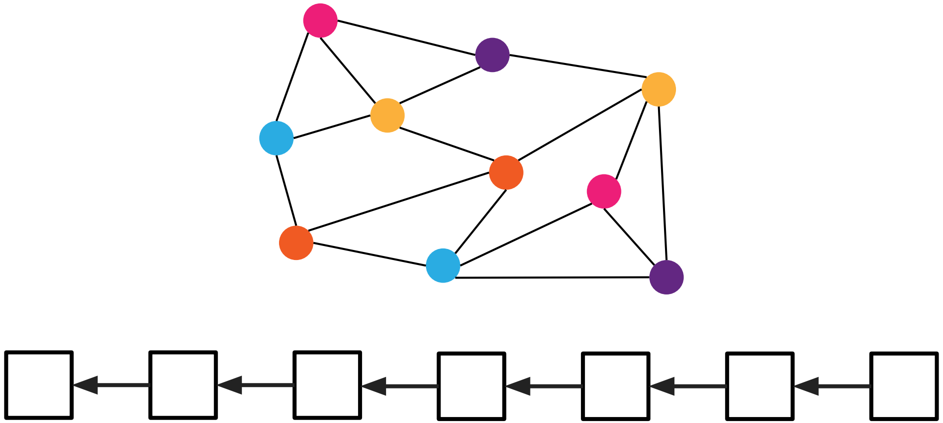
Permissioned/Proof-of-Stake Blockchains



Consensus: nodes agree on sequence of blocks

Proof of stake (PoS): nodes vote on block proposals, weighted by stake
e.g., Algorand, Cardano, Ethereum Casper

Permissioned: nodes vote by access structure
e.g., Ripple, Hyperledger Fabric

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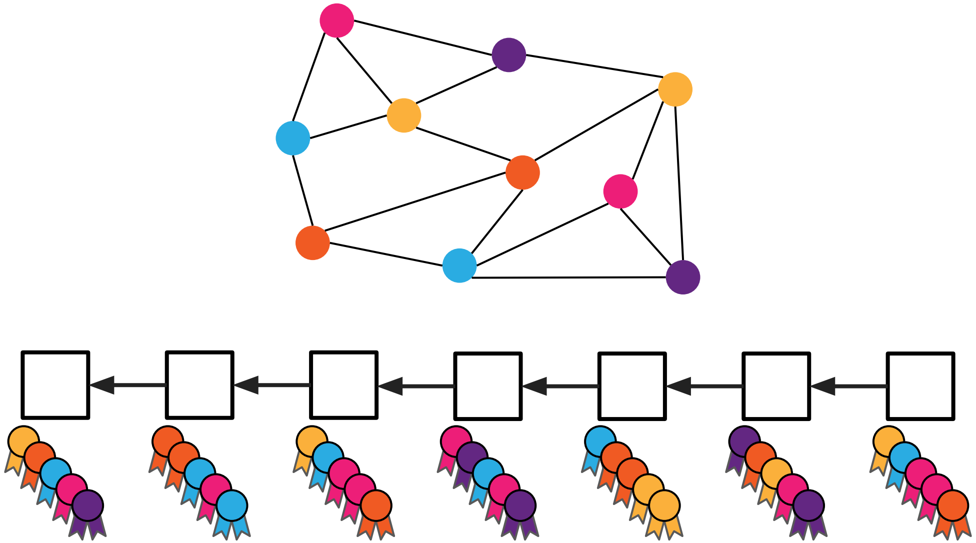
Permissioned/Proof-of-Stake Blockchains



Proof of stake (PoS): nodes **sign** block proposals, weighted by stake

e.g., Algorand, Cardano, Ethereum Casper

Permissioned: nodes **sign** by access structure

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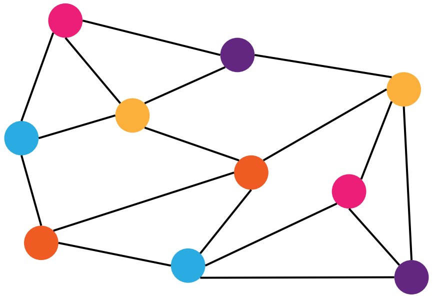
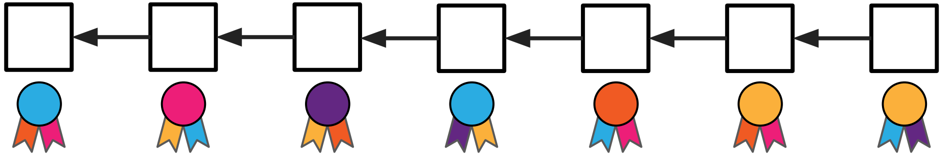
Multi-Signatures in Blockchains





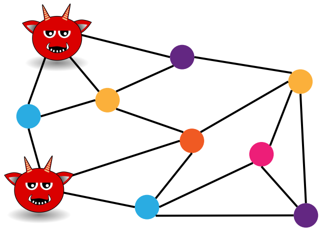
single multi-signature Σ under $pk_1,\ldots,pk_n$ on m

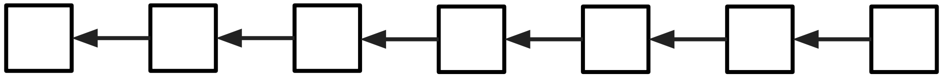
short signature, efficient verification
(preferably ≈ single signature)

[IN83, OO91, MOR01, BLS01, B03, BN06, BDN18, ...]

The Problem of Posterior Corruption [BPS16]

aka long-range attacks [B15], costless simulation [P15]





Chain integrity assumption:
≤ fraction f of nodes/stake corrupt

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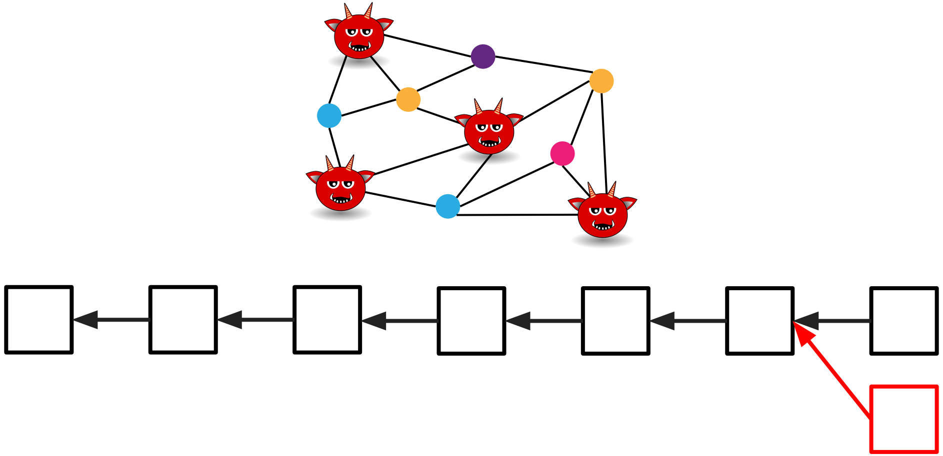

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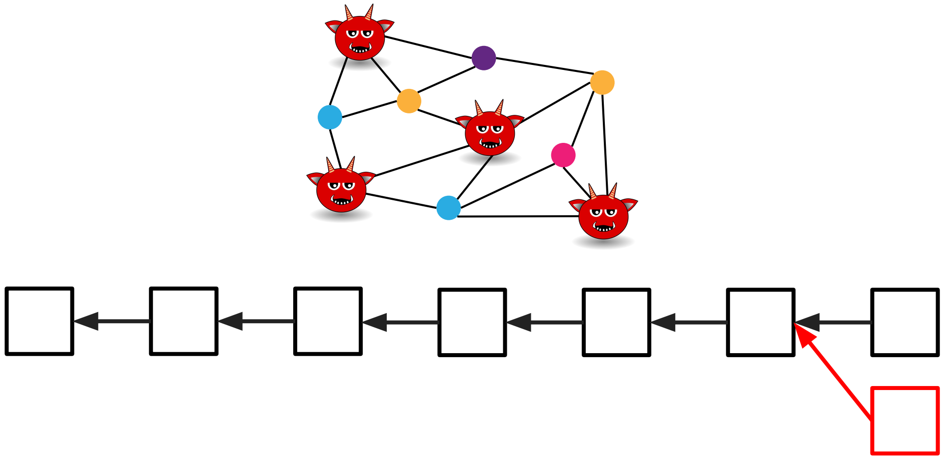

Chain integrity assumption:

≤ fraction f of nodes/stake signing keys corrupt

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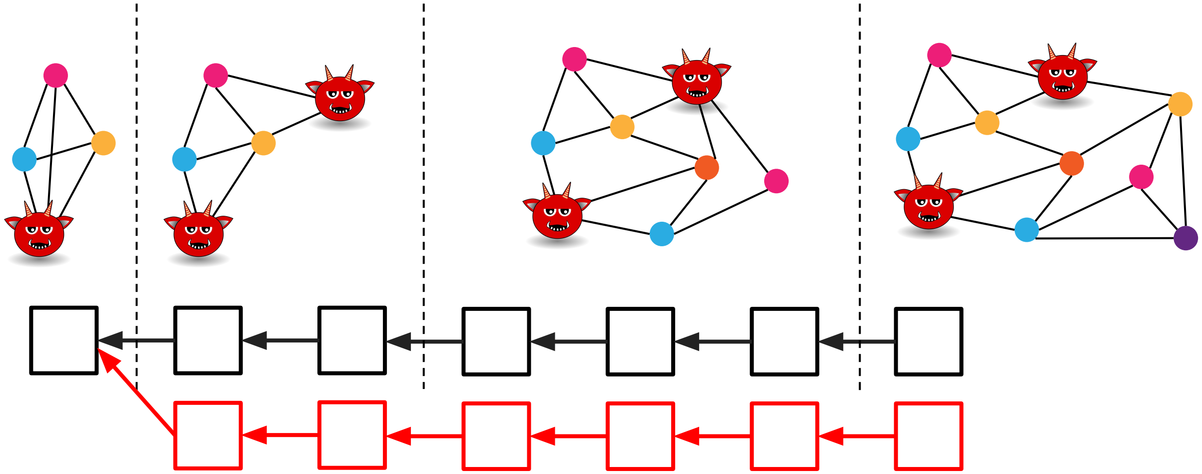

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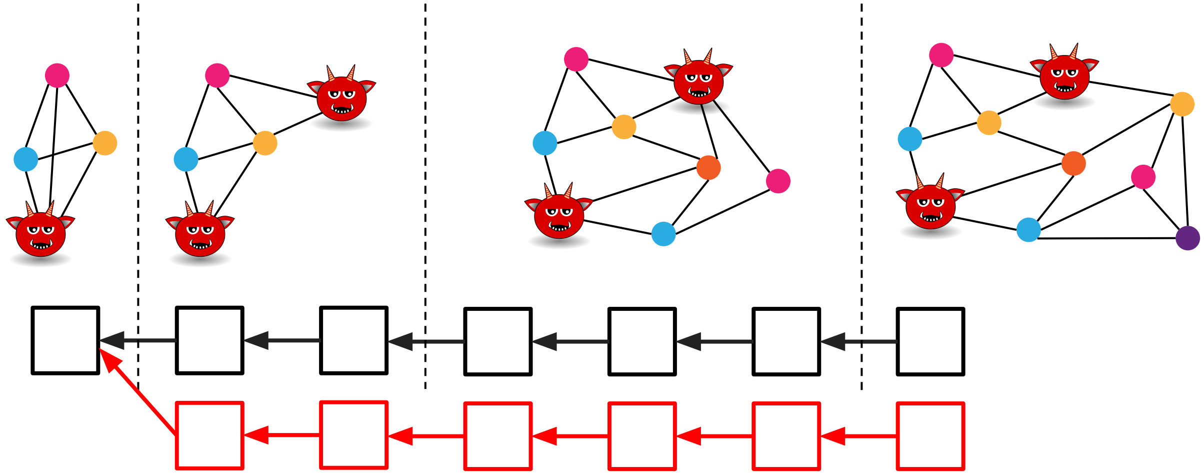

Chain integrity assumption:

≤ fraction f of node/stake keys corrupt **at any point in the past!**

Long after nodes left, sold stake

Aggravated by committee signing (adaptive attacks)

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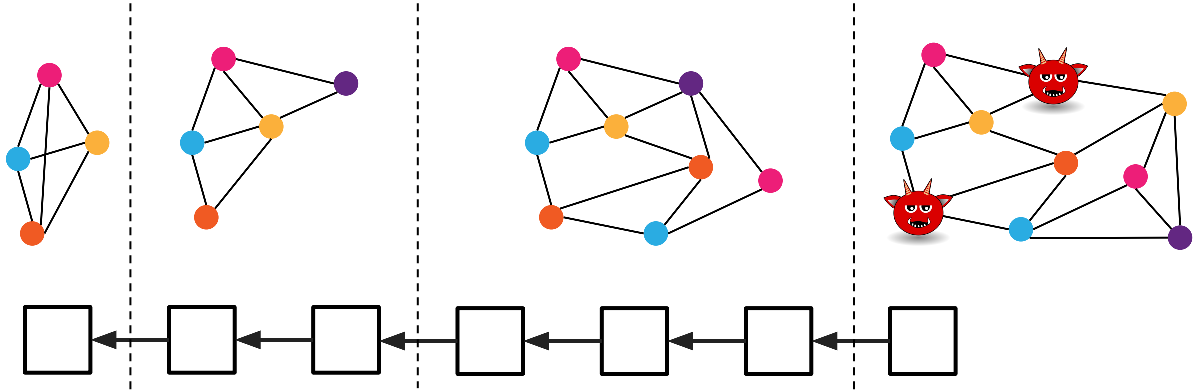
Solution: Forward-Secure Signatures



Solution: forward-secure signatures [A97,BM99,...]

$(pk, sk_0) \leftarrow$ KeyGen , $sk_{t+1} \leftarrow$ Update(sk_t)

$\sigma \leftarrow$ Sign(sk_t,m) , b $\leftarrow$ Verify(pk, t, m)

sk_t can't be used to forge signatures < t

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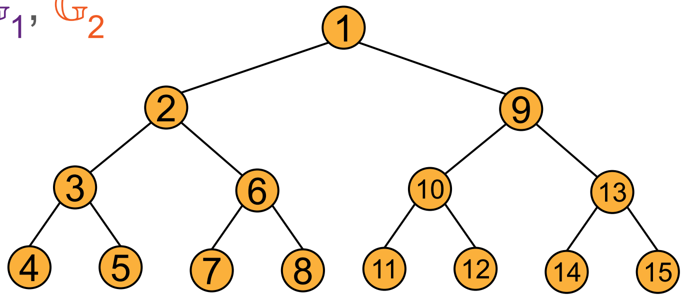
Pixel : Forward-Secure Multi-Signatures

Bilinear map $e : \mathbb{G}_1 \times \mathbb{G}_2 \rightarrow \mathbb{G}_T$, generators g_1, g_2 of $\mathbb{G}_1$, $\mathbb{G}_2$

$pk = g_2^x$ for $x \xleftarrow{R} \mathbb{Z}_q$

sk_t : HIBE-style binary tree [CHK03, BBG05]



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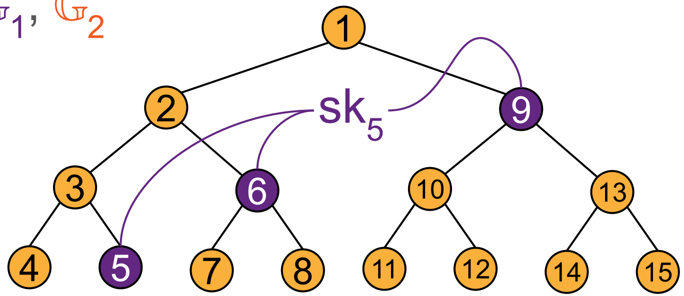

Public parameters $h, h_0, \ldots, h_\ell \in \mathbb{G}_1$

$\mathbf{H}(t,m) = h_0 \cdot \prod h_i^{\,t_i} \cdot h_\ell^{\,H'(m)}$ where $t = t_1 \ldots t_{\ell-1}$

Sign(sk_t, m) : $(\; h^x \cdot \mathbf{H}(t,m)^r \; , \; g_2^{\,r} \;)$

Verify(pk, t, m) : $e(\quad , g_2) = e(h , pk) \cdot e(\quad , \mathbf{H}(t,m))$

Aggregate : $(\prod_{i=1}^{N} h^{x_i} \cdot \mathbf{H}(t,m)^{r_i} \; , \; \prod_{i=1}^{N} g_2^{\,r_i})$, verify wrt $apk = \prod_{i=1}^{N} pk_i$

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Pixel : Features

- Provably secure in random-oracle model assuming secure erasures and hardness of log(T) weak bilinear Diffie-Hellman inversion (wBDHI*)
- Performance on BLS12-381 curve with 1500 signers, 2^{32} time periods
  - **small:** pk 48 B , multi-signature 144 B
  - **fast:** sign 2.8 ms (4 exp), aggregate 7.2 ms (N mult), verify aggregate 6.7 ms (3 pair + 1 exp), key update 1.8 ms (2 exp)
  - trade off key/signature sizes vs computation by switching $\mathbb{G}_1$ and $\mathbb{G}_2$
- No trusted setup (hash to curve)
- Rogue key protection via proofs of possession [RY07]

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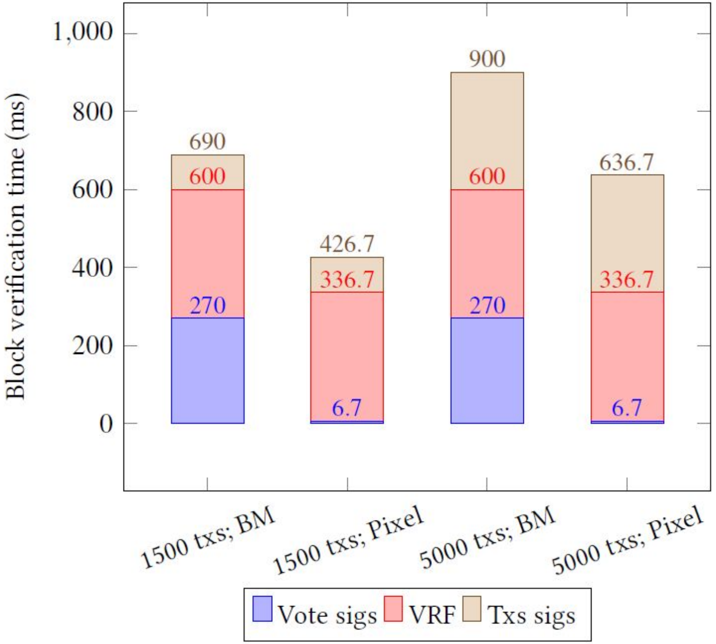
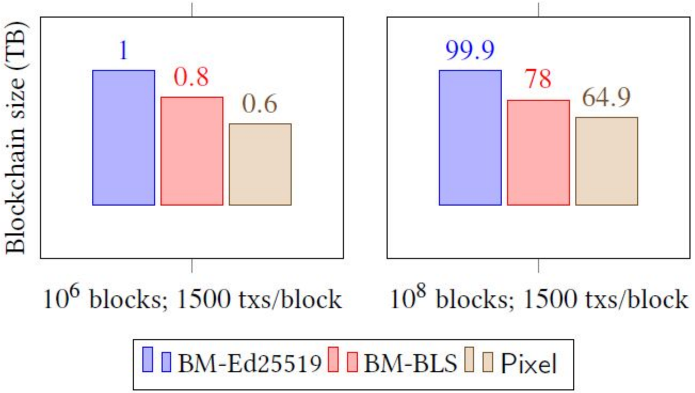
Integration into Algorand blockchain

1500 certifying votes (signatures) per block
≈ 33% savings in blockchain size and block verification time
compared to BM-Ed25519





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Thanks!

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