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How to Build Digital Signatures From Hash Functions

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HOW TO BUILD DIGITAL SIGNATURES FROM HASH FUNCTIONS

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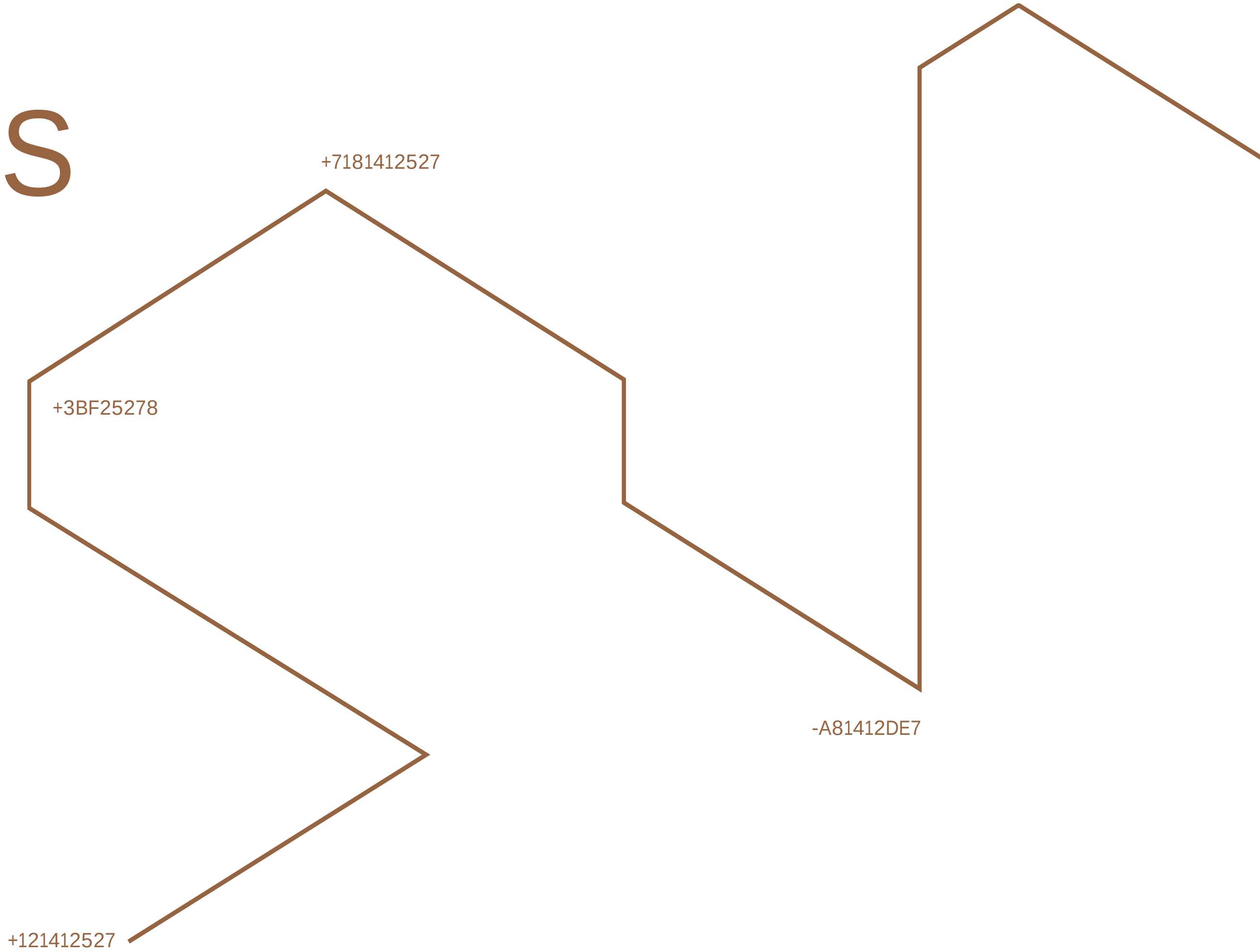
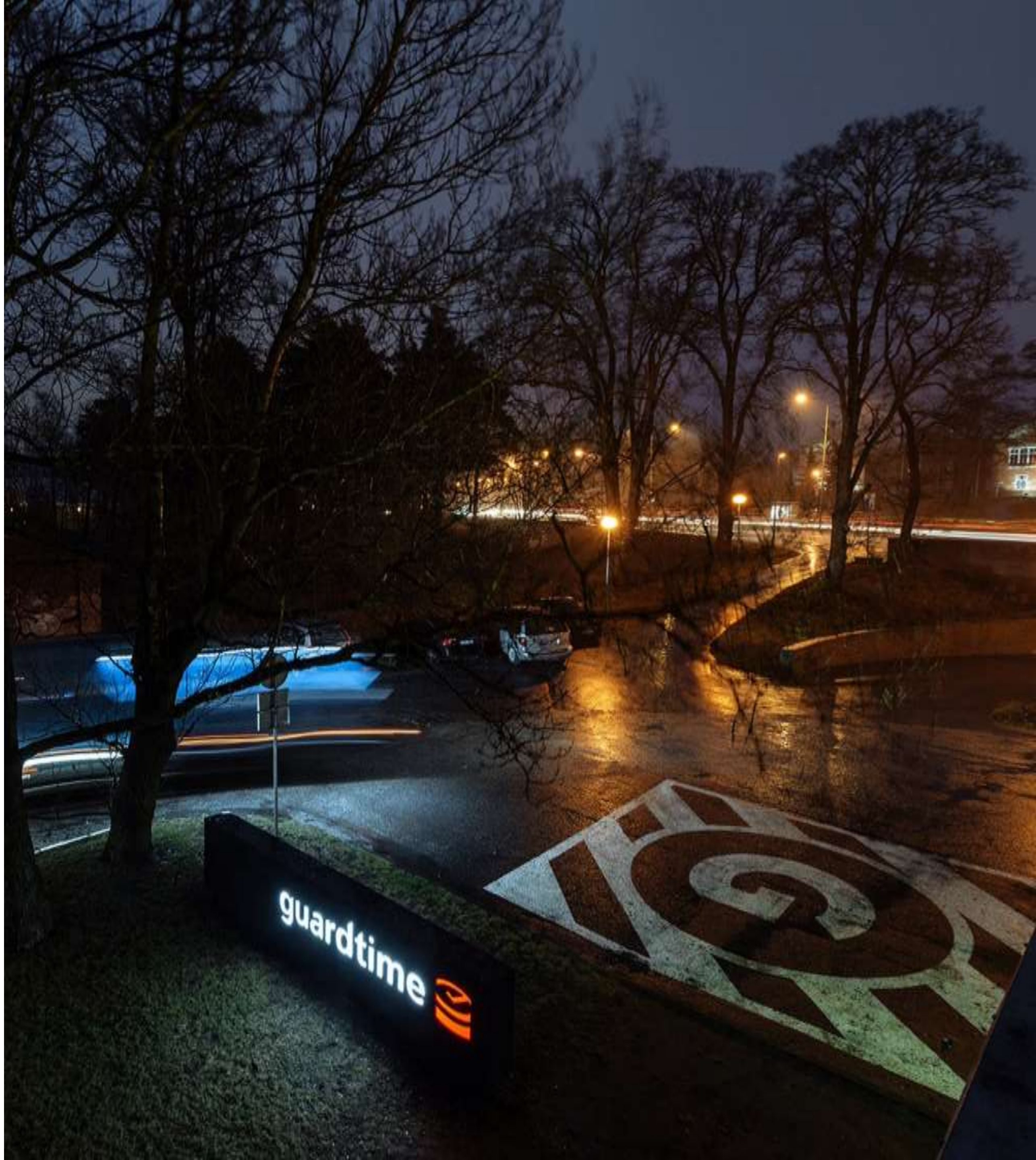
SOFTWARE ARCHITECT, GUARDTIME

ACCU CONFERENCE, 12-MAR-2021



ABOUT GUARDTIME

- Systems engineering company focusing on data security solutions
- Founded in 2007 in Tallinn, Estonia
- Global HQ in Lausanne, Switzerland
- Offices in US, EU and China
- 150 employees
- 80% engineers and researchers
- https://guardtime.com/

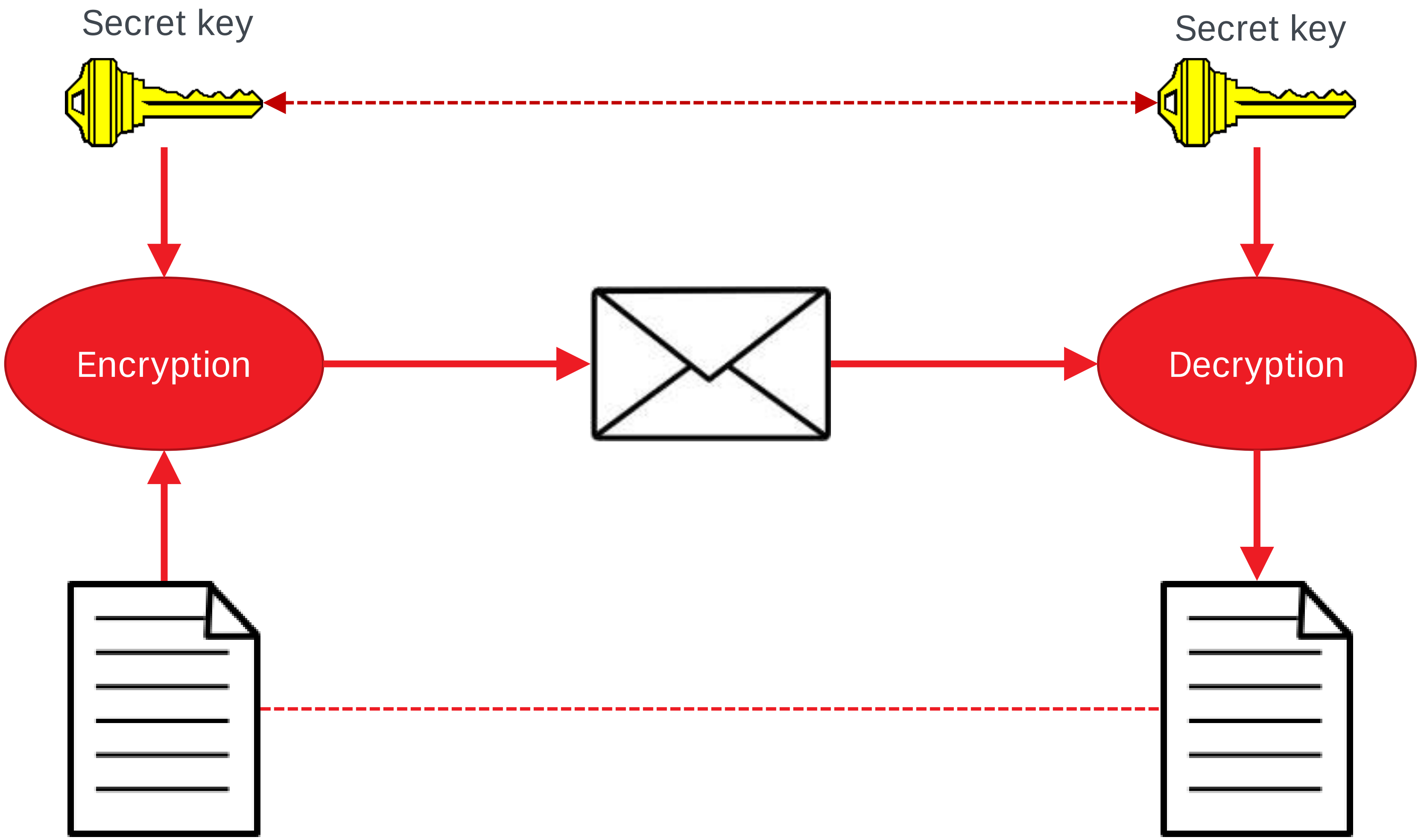


AGENDA

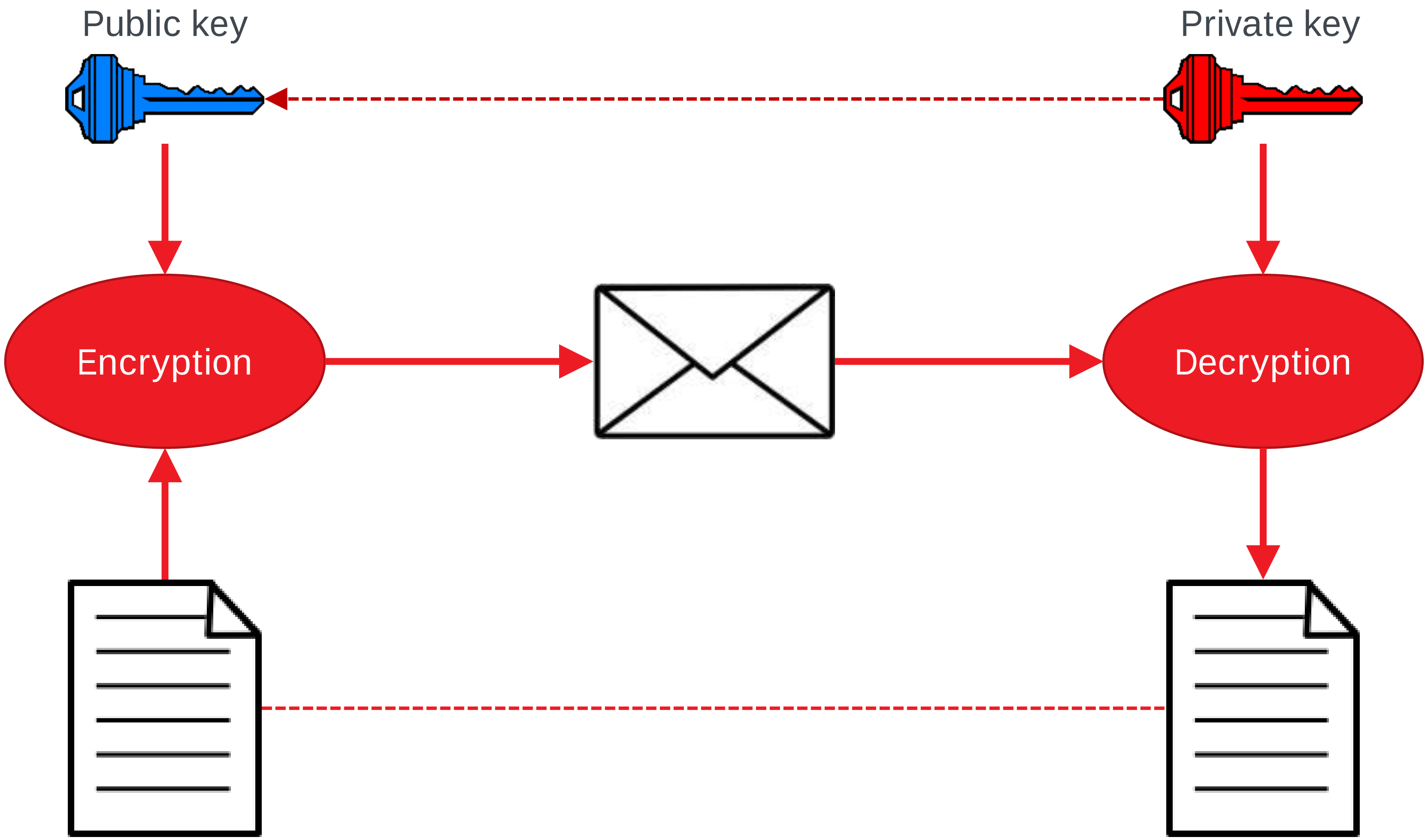
+ Introduction
+ Digital signatures
+ Hash functions
+ Hash signatures
+ Time-stamping
+ BLT signatures

1/
INTRODUCTION

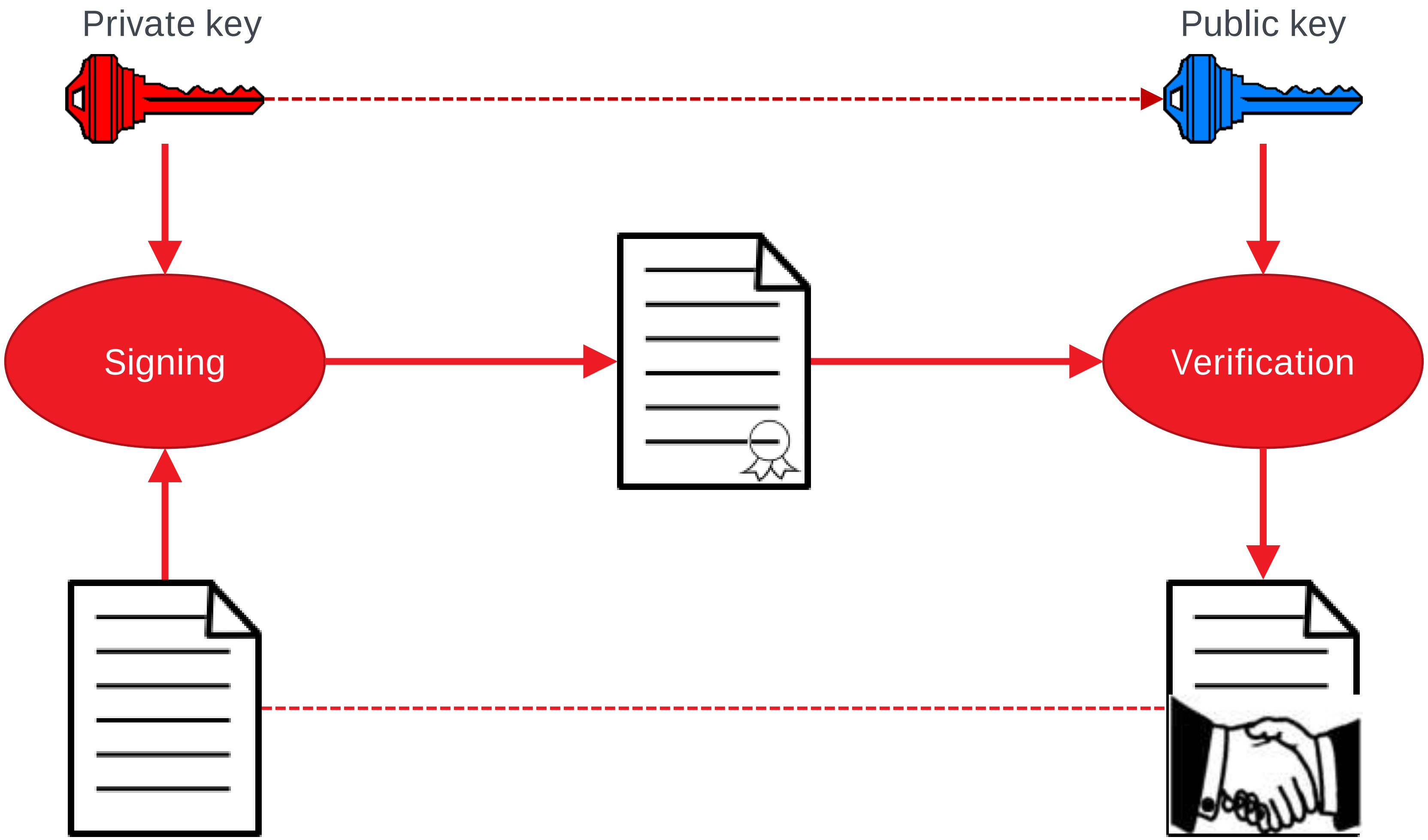
SYMMETRIC ENCRYPTION



ASYMMETRIC ENCRYPTION



DIGITAL SIGNATURES



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DIGITAL SIGNATURES

DIGITAL SIGNATURES: WHAT ARE THEY

Aim to be the electronic equivalent of hand-written signatures

- Intent: signer's endorsement of the content

- Integrity: authenticity of content
- Identity: authenticity of origin
- Time: authenticity of signing time

- Non-repudiation: signer can't deny a signature afterwards

DIGITAL SIGNATURES: USE-CASES

Relying party (recipient of a signed document) can:

- Verify the authenticity of the document for themselves
- Prove the authenticity of the document to third parties

Main use case types:

- Document signing
- Access control

DIGITAL SIGNATURES: MATHEMATICAL MODEL

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+ Each signer has two related keys:
  - Private key for creating signatures
  - Public key for verifying signatures

+ A signature scheme consists of three algorithms:
  - Key generation: creates a pair of related keys
  - Signing: gets a document and a private key and creates a signature
  - Verifying: gets a document, a signature, and a public key; checks whether the signature was created with the private key corresponding to the public key

DIGITAL SIGNATURES: SECURITY MODEL

+ For a signature scheme to be secure, it must be infeasible for an attacker to:
  - Change the document without making the verification fail
  - Derive the private signing key from the public verification key
  - Create a signature without access to the private key

+ Also need to make sure unauthorized parties can't access the private key:
  - Best practice to generate the key pair in a secure hardware module
  - Only the public key is exported, the private key never leaves the module
  - For signing, data is sent to the module and signature exported

DIGITAL SIGNATURES: SIGNER IDENTITY

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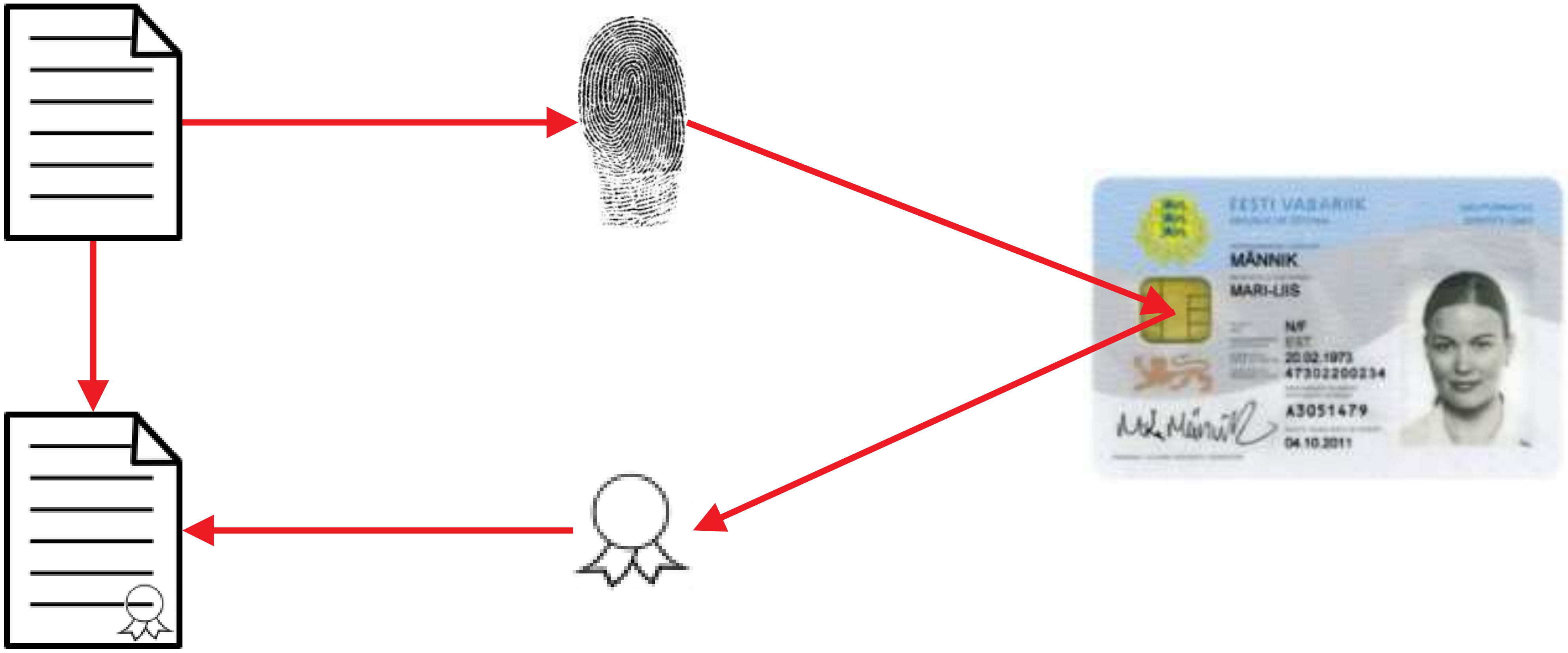
+ A public key is just a piece of data: large random-looking number
+ To authenticate the origin, public keys must be bound to the identities of their holders:
  - The key holder hands the public key directly to the relying party: Mostly used in access control systems
  - Identity of key holder witnessed by someone the relying party knows: Used in the PGP web of trust system, for example
  - Identity of key holder witnessed by a designated authority: Used in the PKI model, where certificates are statements binding public keys to the identities of their holders, signed by dedicated certificate authorities

DIGITAL SIGNATURES: SIGNING TIME

+ Often, digital signature systems must also prove signing time:
- For legal reasons:
  - In most cases a signature is only valid if created in a specific time frame
    - For example, a board member's authority to sign on behalf of the company
- For technical reasons:
  - When an unauthorized party gets the private key, the key must be revoked
  - But this should not be a way for the key holder to disown all previous signatures
  - Need to be able to distinguish between signatures created before and after the key was revoked
- Usually done with the help of time-stamping services

3/ HASH FUNCTIONS

DIGITAL SIGNATURES IN PRACTICE



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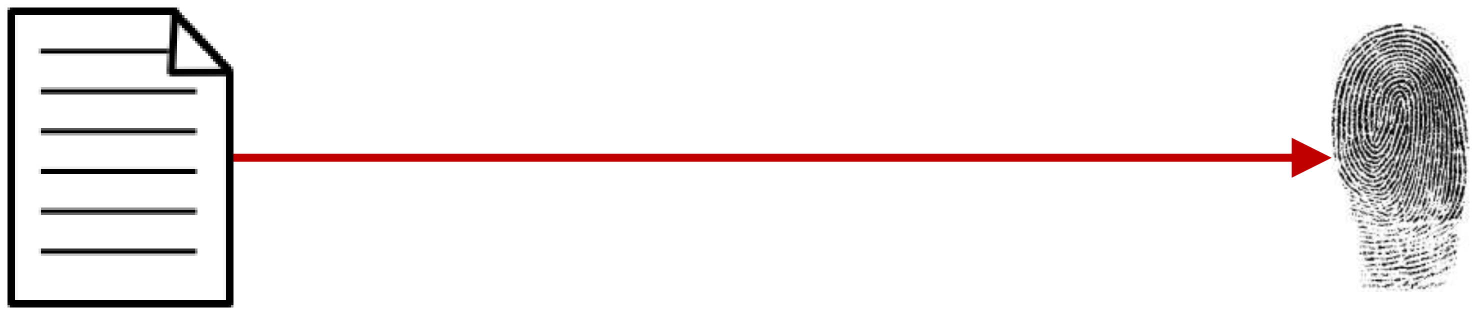
HASH FUNCTIONS



PROPERTIES OF HASH FUNCTIONS

+ Efficiently computable
  - Given x, easy to compute y = f(x)
+ Pre-image resistant
  - Given y, infeasible to find x such that f(x) = y
+ Second pre-image resistant
  - Given x, infeasible to find x’ ≠ x such that f(x’) = f(x)
+ Collision resistant
  - Infeasible to find $x_1 \neq x_2$ such that $f(x_1) = f(x_2)$

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SECOND PRE-IMAGE RESISTANCE

Bob

- Creates the contract X
- Signs it via h(X)
- Gives it to Alice

Alice

- Modifies X to X’,
  with h(X’) = h(X)
- Claims Bob signed X’

Forgery after signing

X = “I owe Alice $10”

X’ = “I owe Alice $1000”

h(X) = h(X’)

COLLISION RESISTANCE

Alice

- Creates X_1 and X_2 with $h(X_1) = h(X_2)$

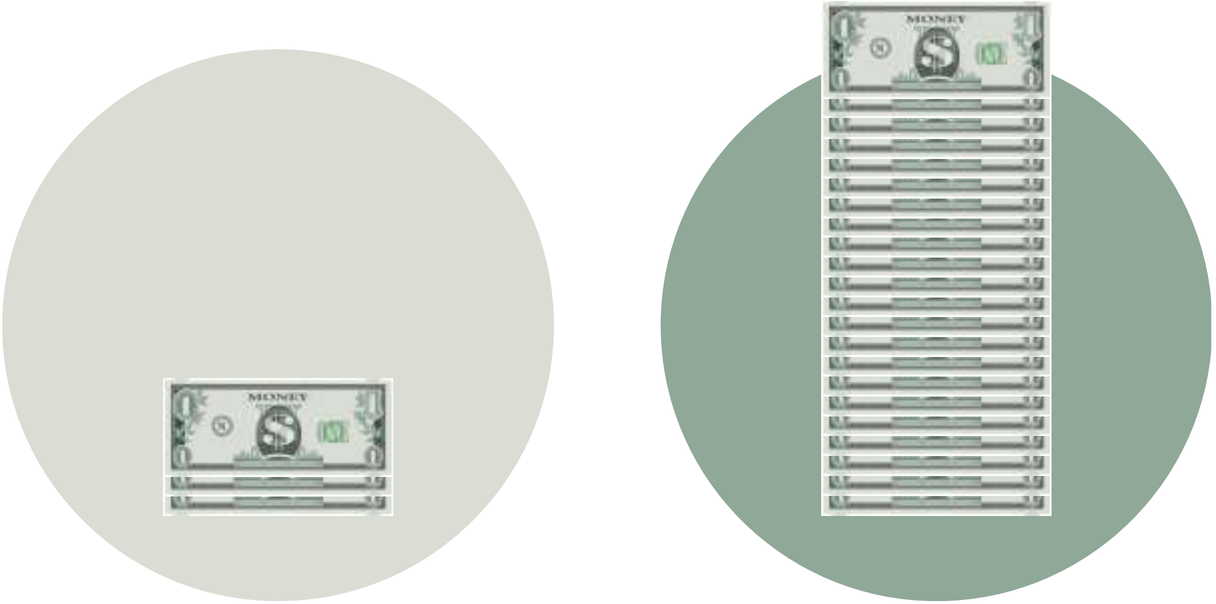
Bob

- Signs X_1 via $h(X_1)$

Alice

- Claims Bob signed X_2

Forgery before signing



X_1 = “Bob owes me $10” X_2 = “Bob owes me $1000”

$h(X_1) = h(X_2)$

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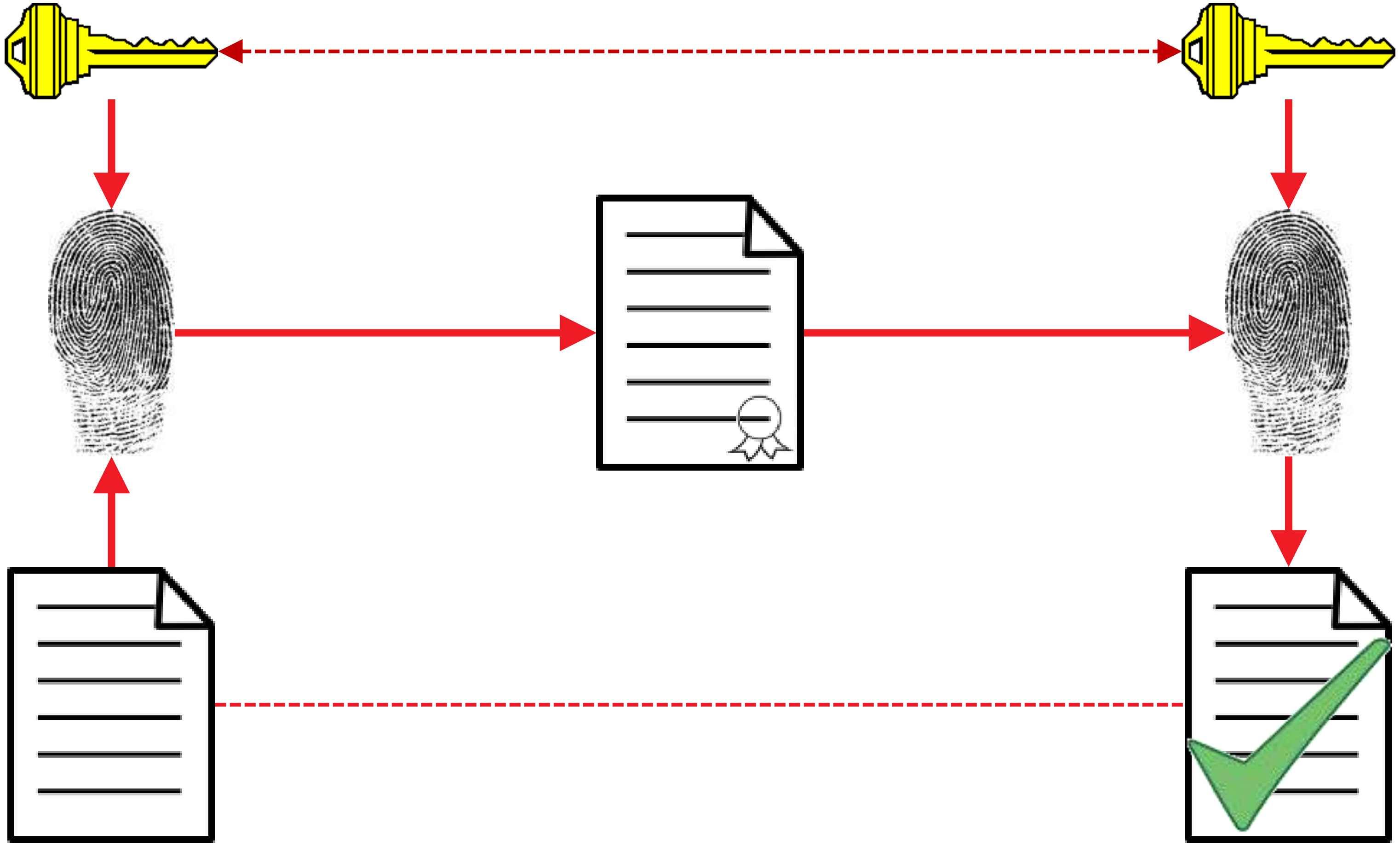
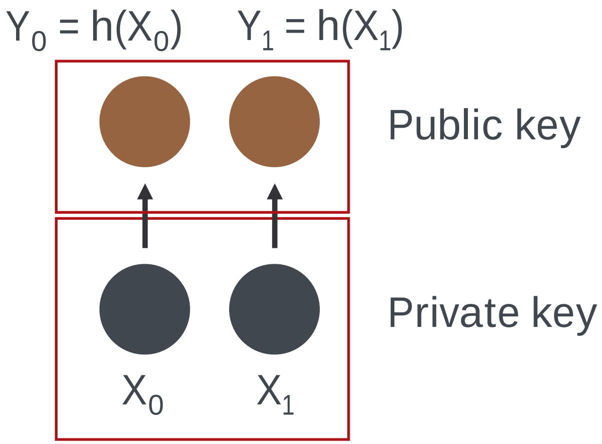
HASH SIGNATURES

MESSAGE AUTHENTICATION CODES



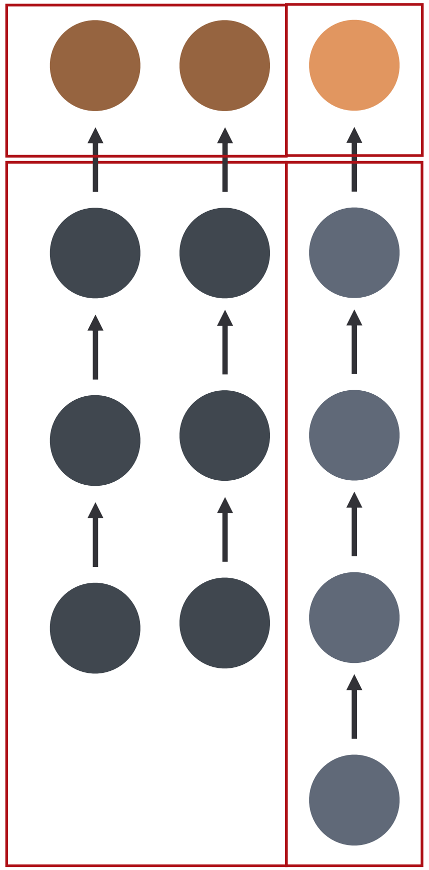
LAMPORT SIGNATURES

+ 1-bit case
  - Private key (X_0, X_1)
  - Public key (Y_0, Y_1)
  - Signature on 0: X_0 (destroy X_1)
  - Signature on 1: X_1 (destroy X_0)
+ Longer inputs
  - Sign each bit separately



WINTERNITZ SIGNATURES

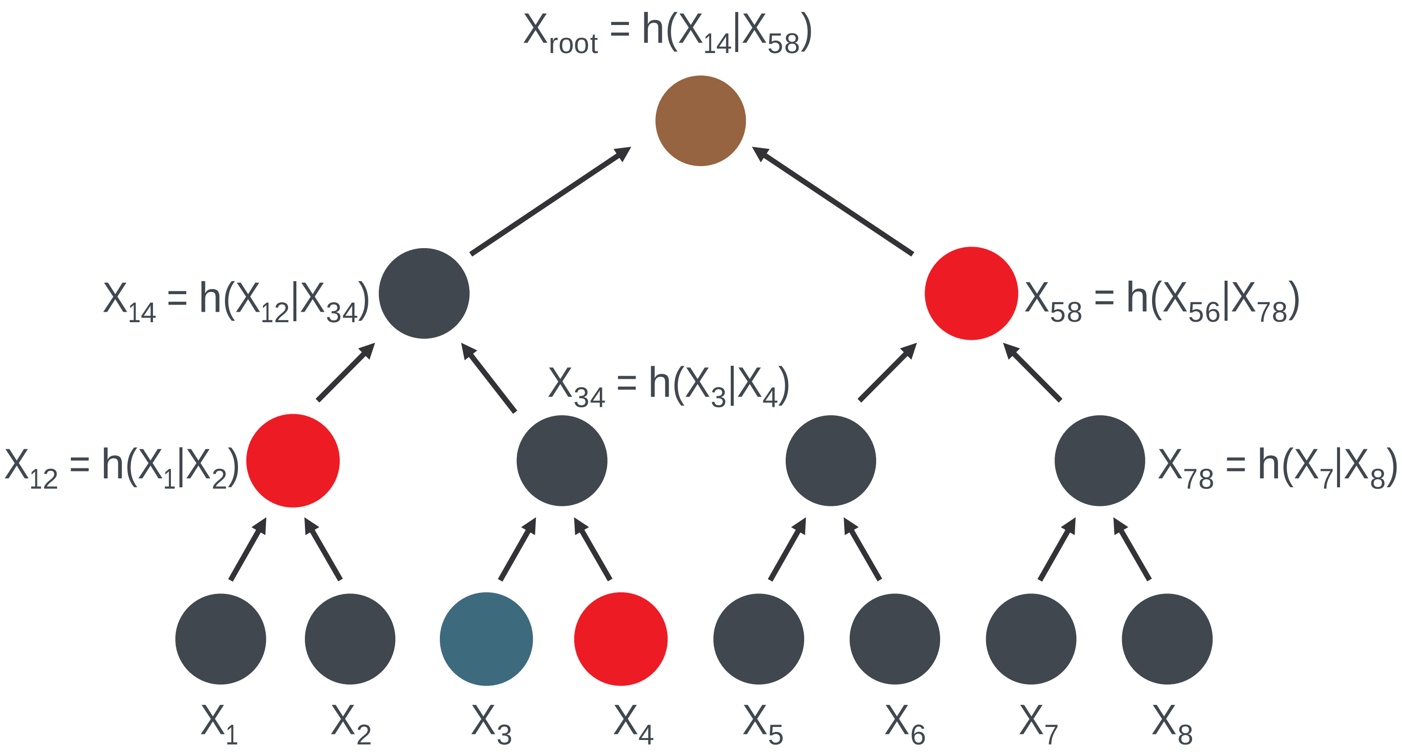
+ W-bit groups
  - 2^W-step hash chains
    $X_i = h(X_{i-1})$
  - Signature on value k: X_k
+ Checksum
  - Sign the total number of steps to public key components



MERKLE TREES

+ A hash tree, or a Merkle tree, aggregates many inputs into a single hash value

+ Afterwards, a compact proof of participation can be extracted for each input



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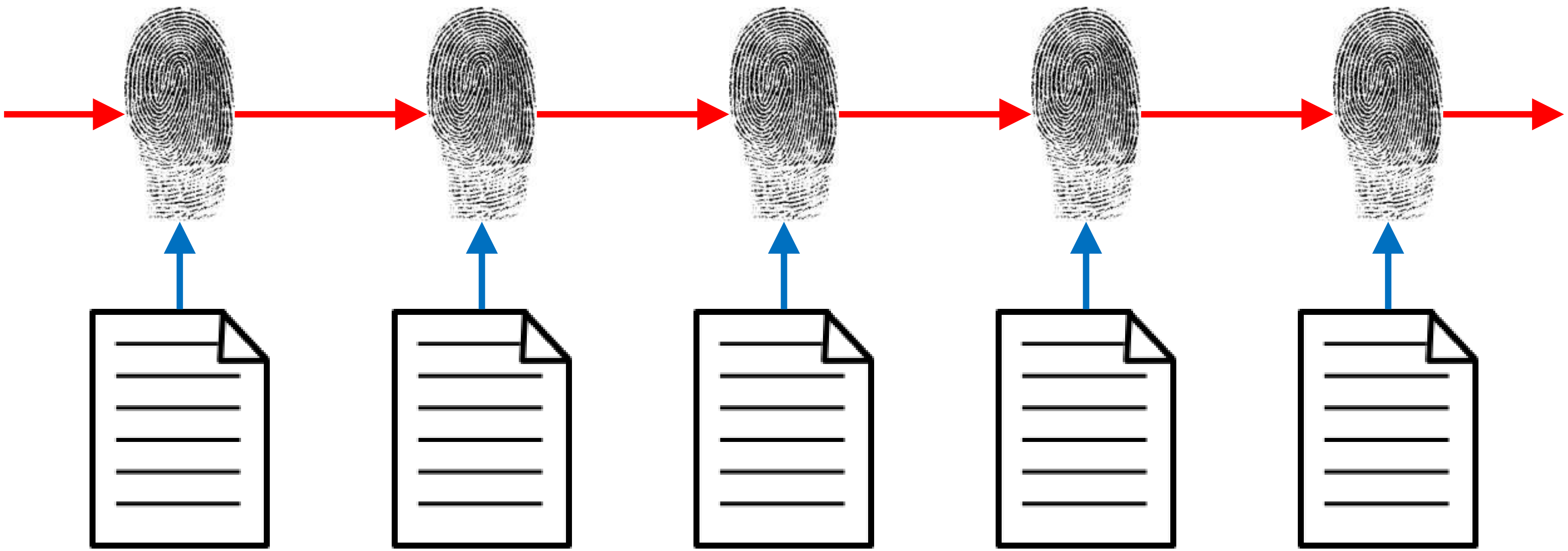
5/ TIME-STAMPING

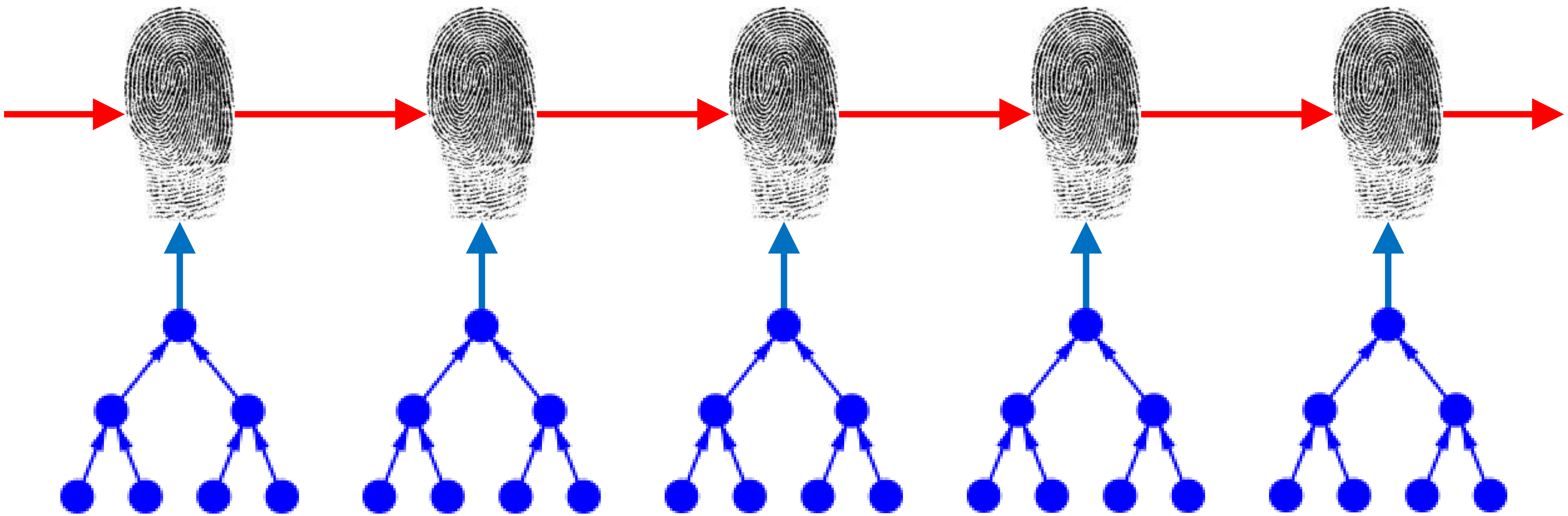
HASH-THEN-PUBLISH TIME-STAMPING

+ To prove the existence of some information: publish it
+ If the information is confidential: publish a hash instead
  - Can later reveal the information and show it matches the hash
+ Galileo, Hooke

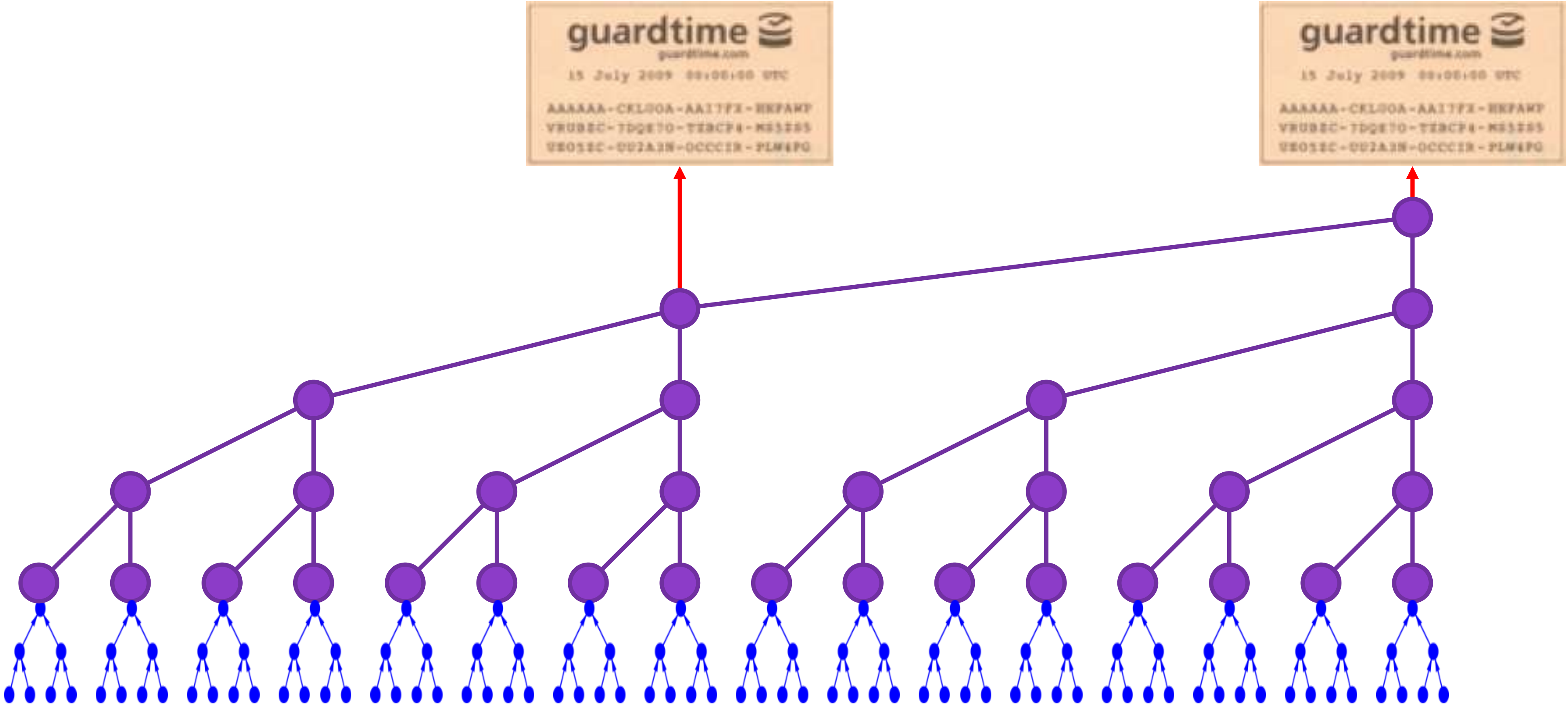
PUBLISHING TO HASH-LINKED LEDGER



HASH-TREE AGGREGATION OF INPUTS



HASH-TREE AGGREGATION OF LEDGER



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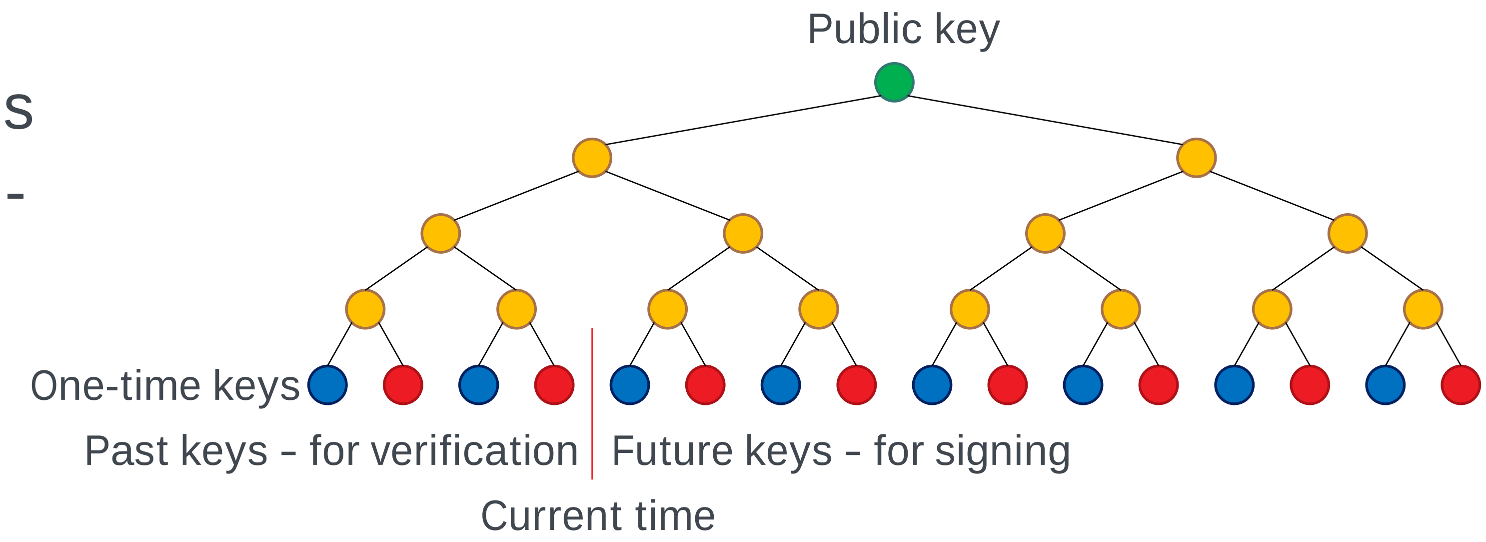
BLT SIGNATURES

BLT-TB: TIME-BOUND KEYS

+ One-time keys for message authentication
+ Message authentication is symmetric and lacks non-repudiation
+ Use time to break the symmetry



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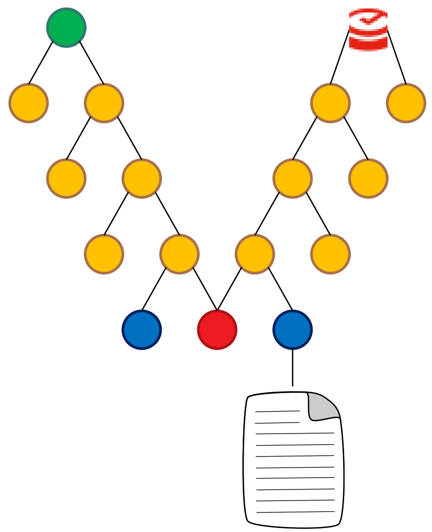
BLT-TB: SIGNING

To sign a document at a given time:

- Authenticate the document with the corresponding one-time key
- Time-stamp the authenticator to prove the signing time
- Include proof of the key-time binding in the signature

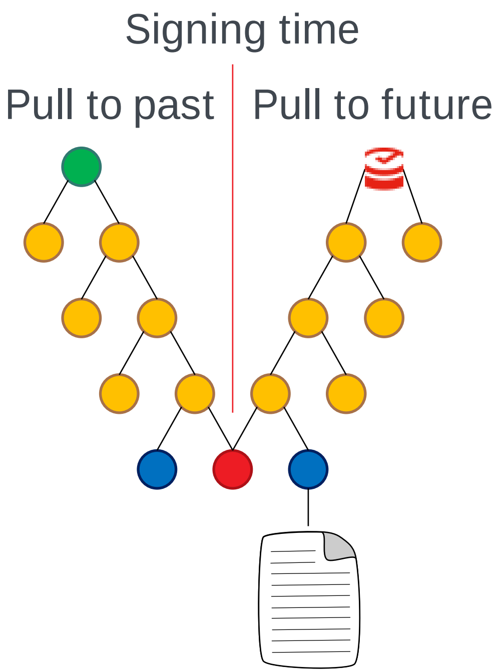


BLT-TB PROPERTIES

- Keys pre-generated for each possible signing time
- Suitable for full-size computers that have
  - Reasonable computing power
  - Reliable clocks
  - Direct network access
- Suitable for applications that need to sign often
  - Ideal for server applications used by many clients

NEW CONCEPT: FORWARD-RESISTANT TAGS

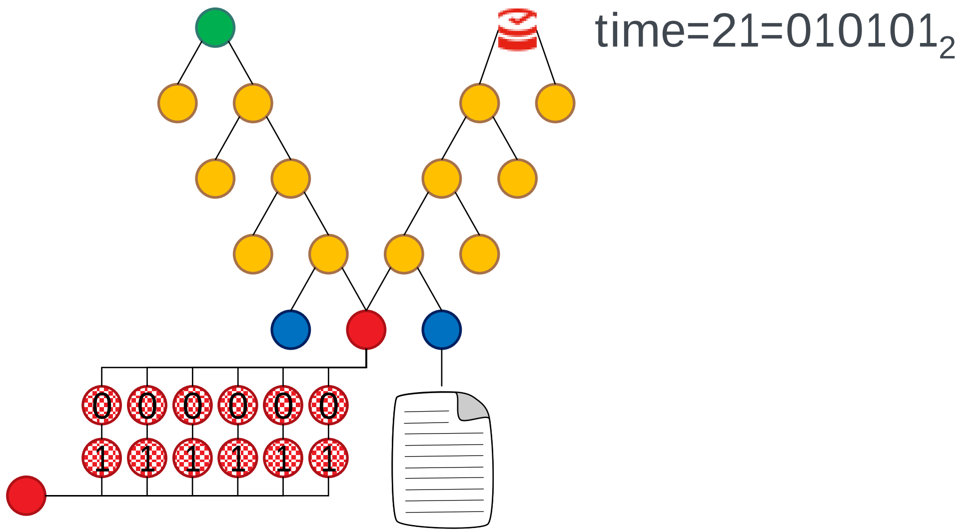
- Pre-binding keys to time slots is wasteful
- Time-stamp already prevents moving the signing event to past
- So, the key binding only needs to prevent moving to future
- So, we can relax the requirement on the key binding



BLT-OT: ONE-TIME KEYS

Inspired by Lamport's signatures

- Generate a multi-component private key
- Bind it to time after time-stamping
- The time value is shorter than a hash value, so less components are needed
- Extra optimization: generate all the key components from a single seed
- Can pre-generate several such keys and use them in sequence



REFERENCES

+ BLT-TB scheme in more detail
  https://eprint.iacr.org/2019/671
+ BLT-OT scheme in more detail
  https://eprint.iacr.org/2019/673

THANK YOU

QUESTIONS?

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