CS1699: Blockchain Technology and Cryptocurrency

4. Digital Signatures And Centralized Ledgers

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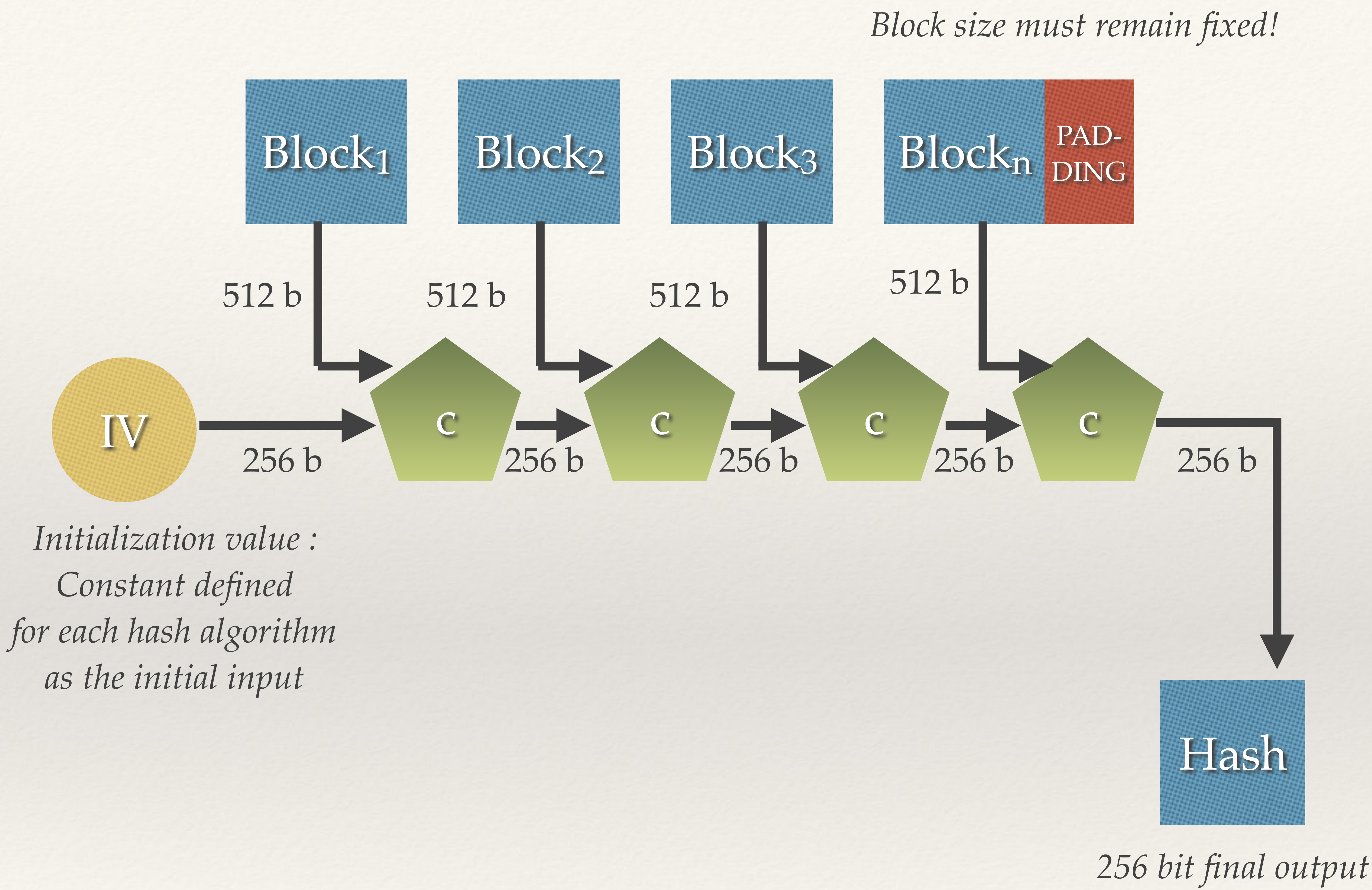
Merkle-Damgård Transforms

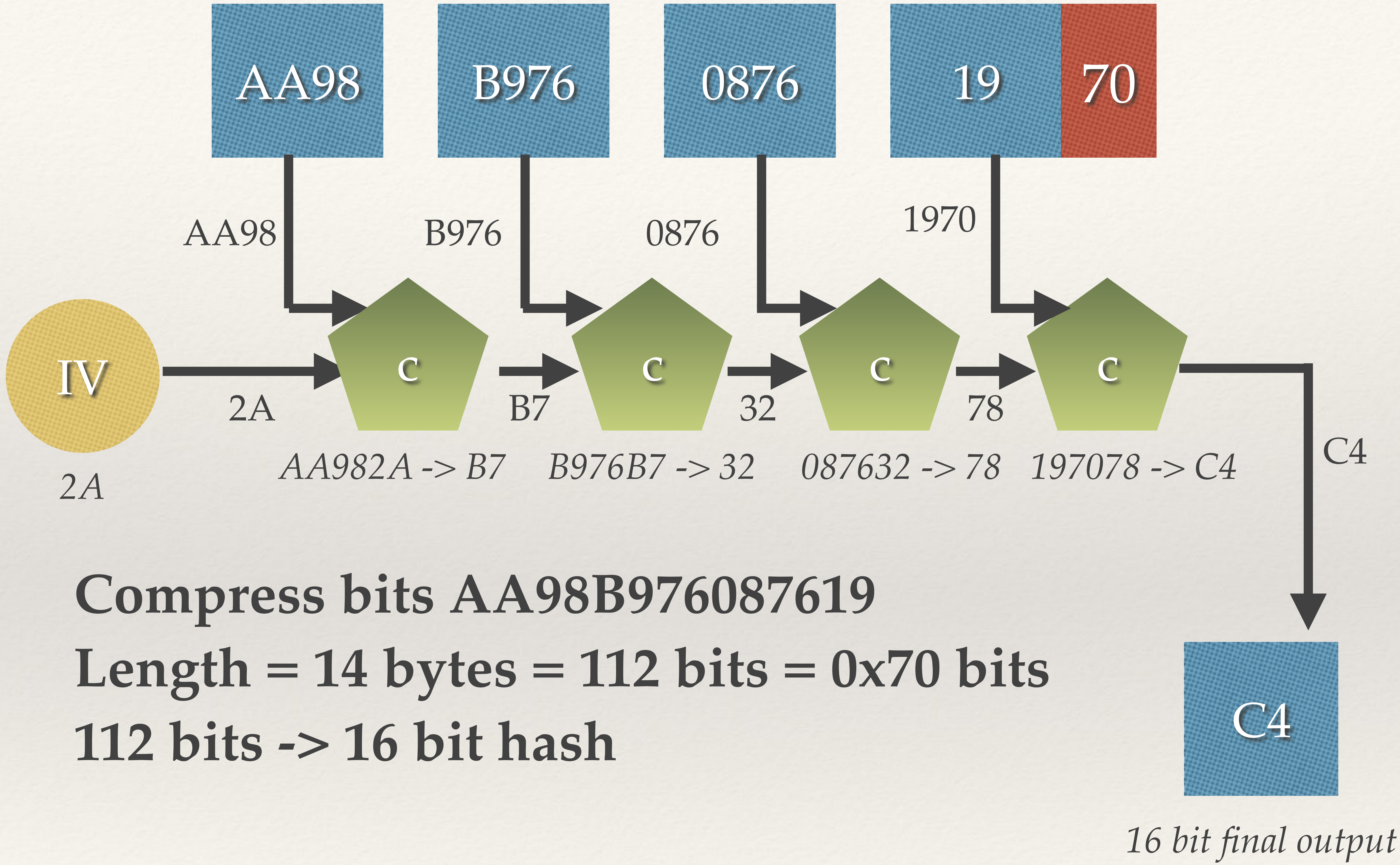
- Recall that hash functions should compress an arbitrary-length string into a fixed-size output
- Also recall our initial attempt at this, BadHash
    - Convert each character into a corresponding value, sum them up modulo size of output
    - Variety of problems with this scheme

Merkle-Damgård Transforms

- Merkle-Damgård transforms solve some of the problems converting arbitrary “input to fixed output” using a very similar process to a blockchain!
- “Chunks” data into blocks (padding if necessary)
- Accepts results of previous blocks along with current block to produce a new output
  - compression algorithm accepts two arguments: current block (size m) and previous result (size n)
  - Outputs result of size n (where $n < m$)
- Can repeat as many times as needed


Block size must remain fixed!
Block1
Block2
Block3
Blockn
PAD-
DING
512 b
512 b
512 b
512 b
IV
c
c
c
c
256 b
256 b
256 b
256 b
256 b
Initialization value :
Constant defined
for each hash algorithm
as the initial input
Hash
256 bit final output

Example w/ m = 32 b, n = 16b



Compress bits AA98B976087619

Length = 14 bytes = 112 bits = 0x70 bits

112 bits -> 16 bit hash

Digital Signatures

- We have already discussed how cryptographic hashes can be used to hide information
- We can also use them to prove our identity using digital signatures

Characteristics of Digital Signatures

- Only I can make a signature, but anyone can verify its validity
- The signature cannot be re-used - it is tied to a specific document (= set of bits)
- Note this is more powerful than a hand-written signature which can easily be forged, cannot easily be validated, and can be re-used!

Digital Signature Scheme = Three Algorithms

```
(sk, pk) = generateKeys(keysize)
```

Given a key size keysize, return a "keypair" - a public key used for verification and a secret key for signing

```
sig = sign(sk, message)
```

Given a secret key sk and a message, return a signature for that message

```
isValid = verify(pk, message, sig)
```

Given a public key pk, a message, and a signature, return a Boolean value indicating whether or not the message was properly signed

Unforgeability Game

Unforgeability Game

(sk, pk) (pk)

m_0

sig = sign(sk, m_0)

m_1

sig = sign(sk, m_1)

m', sig (where m' not in $\{m_0, m_1..m_n\}$)

verify(pk, m', sig)

TRUE = Attacker wins

FALSE = Attacker loses

Key = Identity

- Now that I can always prove that I am me, I have a digital identity
- If I want a new identity, I can always make a new keypair - I will be just another face in the crowd
  - But be careful! Could use other ways to link your real identity to a generated keypair
- If someone wants to impersonate me, it should be computationally infeasible

GoofyCoin

- The first rule of GoofyCoin is that only one entity, Goofy, can create a new coin, and all new coins belong to Goofy
- The second rule of GoofyCoin is whoever owns a coin can transfer the coin to somebody else
- Both of these rules can be implemented using cryptographic operations

Generating Money With GoofyCoin

- Goofy generates a unique coin ID *u*
- Goofy computes a digital signature *s* with his secret key
- $u \| s$ (*u* concatenated with *s*) is a coin
- Anyone can run *verify(pk, u, s)* to determine if a coin is valid (i.e., has been signed by Goofy)

Transferring Coins with GoofyCoin

- Goofy creates a new transaction "Give *this* to *Alice*" where *this* is a hash pointer to a coin and *Alice* is Alice's public key
- Then Goofy signs that transaction with his private key
- We can now verify that Goofy generated the coin and that it was transferred to Alice

Transferring Coins with GoofyCoin

- Since Alice's public key is specified in the transaction, if Alice tries to send the coin to someone else, she will need the corresponding secret key
- Anyone can verify that the secret key she used to sign off sending the coin to someone else matches the public key used to give the coin to her!

The GoofyCoin Ecosystem

- Goofy can generate an infinite amount of new coins (as long as he can think up new unique strings)
- Whoever owns a coin can transfer it by saying "Give this to the person with public key X"
- Anybody can verify by following the "chain of ownership" back to Goofy (the originator of all coins)

Goofy
(knows pk_{Goofy}, sk_{Goofy})

“I am creating coin A763BA.
sig = sign(sk_{Goofy}, msg)
Signature is 98"

Alice
(knows pk_{Goofy})

“Coin A763BA, signed 98..
isValid = verify(pk_{Goofy}, msg, sig)
I can verify Goofy made this coin"

Goofy
(knows pk_{Goofy}, sk_{Goofy}, pk_{Alice})

"I am giving coin A763BA to pk_{Alice}.
sig = sign(sk_{Goofy}, msg)
Signature is 3A"
Note msg includes pk_{Alice}.

Alice
(knows pk_{Goofy})

"Coin A763BA to pk_{Alice}, signed 3A..
isValid = verify(pk_{Goofy}, msg, sig)
I can verify Goofy gave me this coin"

Alice
(knows sk_{Alice}, pk_{Bob})

"I am giving coin A763BA to pk_{Bob}.
sig = sign(sk_{Alice}, msg)
Signature is 7B"
Note msg includes pk_{Bob}.

Bob
(knows pk_{Alice}, pk_{Goofy})

"Coin A763BA to pk_{Alice}, signed 3A..
Coin A763BA to pk_{Bob}, signed 7B..
isValid = verify(pk_{Goofy}, msg, sig)
isValid = verify(pk_{Alice}, msg, sig)
I can verify Goofy gave this to Alice and Alice is giving it to me"

Problem!

- What if Alice gave that coin to Bob and neither Bob nor Alice have told anyone?
- Alice can also give the coin to Carol and Bob would be none the wiser!
- Double-spending attack

Alice
(knows sk_{Alice}, pk_{Carol})

Note: I already gave coin A763BA to pk_{Bob}!
I am giving coin A763BA to pk_{Carol}.
sig = sign(sk_{Alice}, msg)
Signature is DF"
Note msg includes pk_{Carol}.

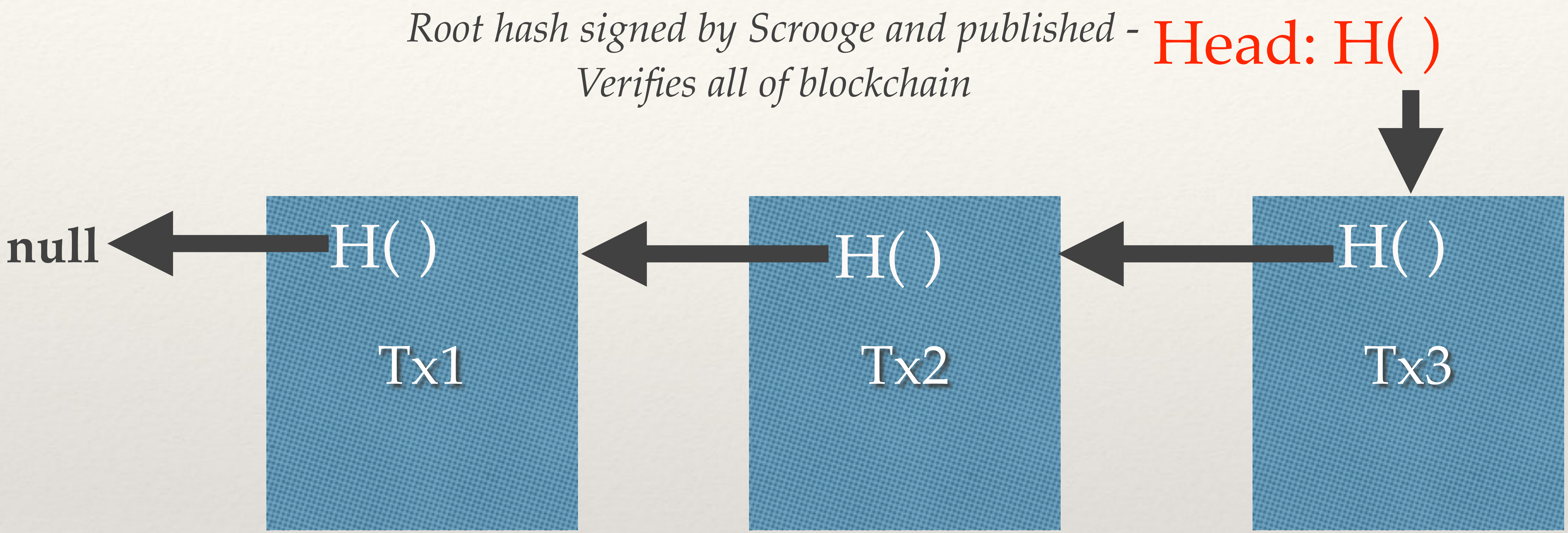
Carol
(knows pk_{Alice}, pk_{Goofy})

"Coin A763BA to pk_{Alice}, signed 3A..
Coin A763BA to pk_{Carol}, signed DF..
isValid = verify(pk_{Goofy}, msg, sig)
isValid = verify(pk_{Carol}, msg, sig)
I can verify Goofy gave this to Alice and Alice is giving it to me"

ScroogeCoin

- Transactions occur just as in GoofyCoin BUT..
- Scrooge also creates an append-only ledger (blockchain) where people can verify that a coin transfer is "official"
- Scrooge determines that a transaction is valid (i.e. signed correctly and no double-spend) and signs the block
- Transactions that are not recorded on Scrooge's blockchain (and signed with Scrooge's digital signature) are not official

ScroogeCoin Blockchain



Note: for simplicity, only showing one transaction per block. As an optimization, multiple transactions can be in a block.

Alice
(knows sk_{Alice}, pk_{Carol})

```
Note: I already gave coin A763BA to p
I am giving coin A763BA to pkCarol.
```

`sig = sign(skAlice, msg)`

```
Signature is DF"
Note msg includes pkCarol.
```

Carol
(knows pk_{Alice}, pk_{Goofy})

```
"Coin A763BA to pkAlice, signed 3A..
 Coin A763BA to pkCarol, signed DF..
```

`isValid = verify(pkGoofy, msg, sig)`

`isValid = verify(pkCarol, msg, sig)`

```
BUT I check Scrooge's blockchain and
see Alice already gave this coin to Bob!"
```

ScroogeCoin works… If We Trust Scrooge!

- Scrooge can’t steal coins (as he does not know secret keys of individual account holders)
- But he can:
  - Blacklist users or coins
  - Create new coins for himself
  - Stop updating the blockchain (holding the entire system hostage)

Centralization

- So far, technical challenges have been minimal - earlier cryptocurrencies got to approximately this far, but all relied on some centralized intermediary
- Central technical challenge and breakthrough of Bitcoin: how do we come to a consensus of valid transactions without a coordinating entity? We need to figure out a way:
  - For users to agree on a single, published, authoritative blockchain
  - For users to agree on what transactions are valid and which occurred
  - IDs to be assigned in a decentralized way
  - Minting of coins to be done in a decentralized way