Aalto University

Payment systems

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Outline

1. EMV card payment
2. (More card security features)
3. (Anonymous digital cash)
4. Bitcoin

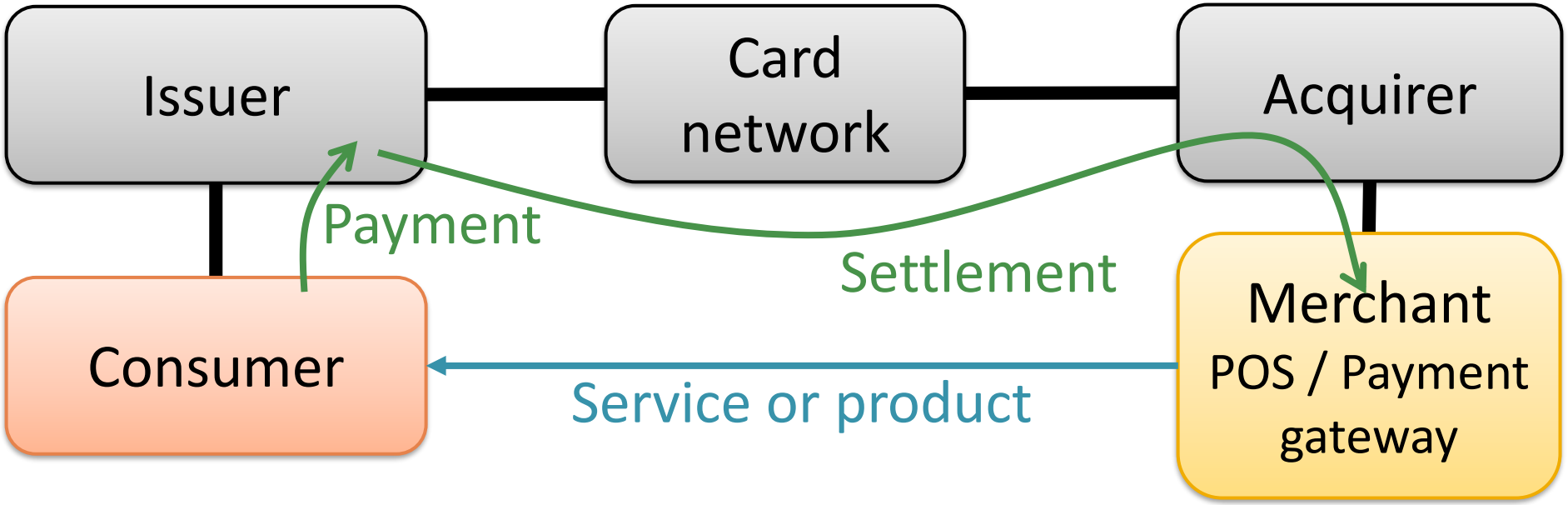
EMV CARD PAYMENT

EMV bank cards

- Smart card chip (ICC)
  - Tamperproof ICC stores the private signature key and a certificate
  - Also, a shared key with card issuer
- EMV standard specifies protocols between card, terminal, issuer
  - Message contents between card and issuer left somewhat open (no need for interoperability)
  - Many options, implementations vary between countries

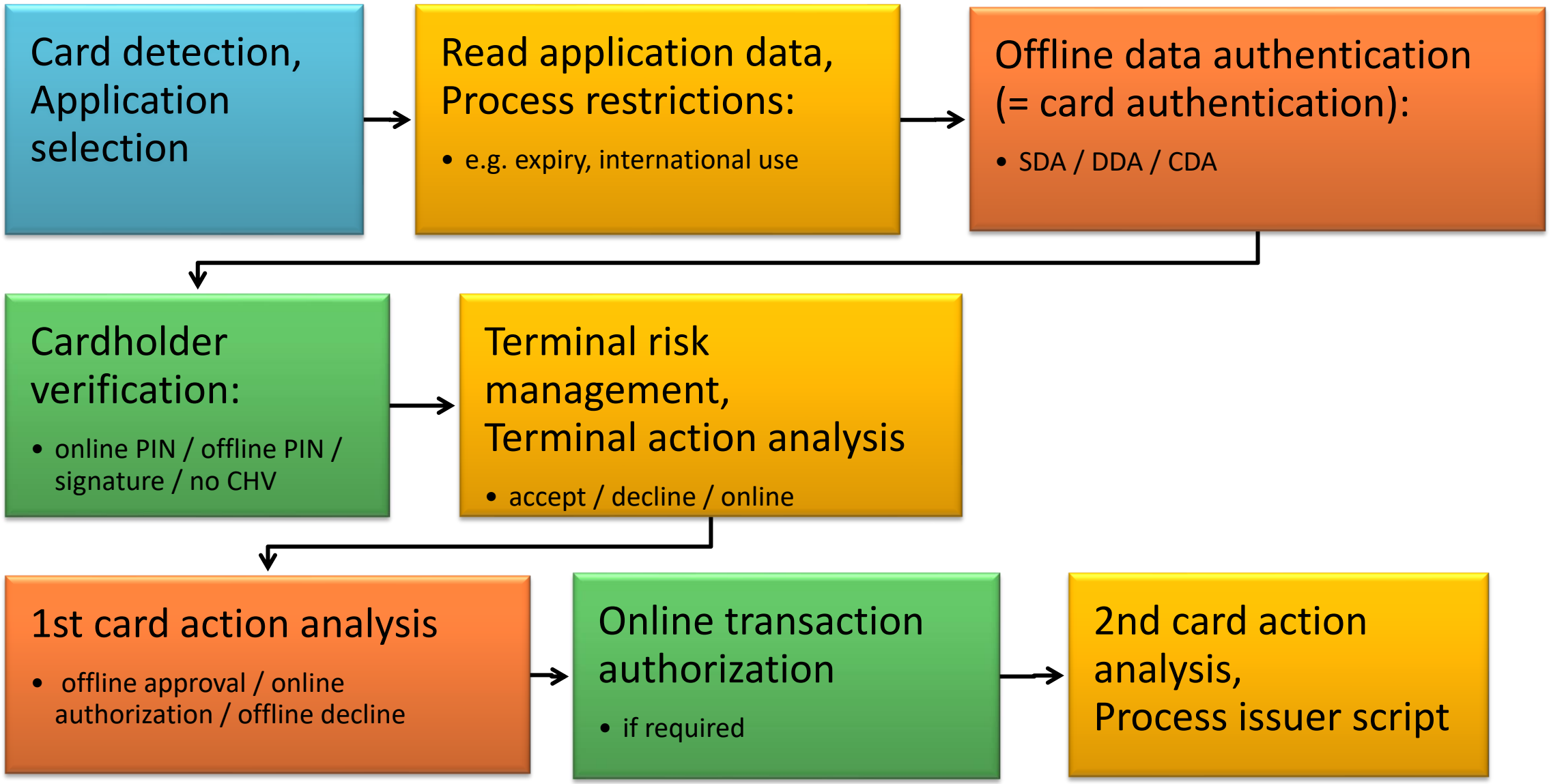
Photos: Mastercard, Visa

Terminology



- Four-corner model i.e. four-party scheme
- Card networks: Mastercard, Visa etc.
- Issuing bank, acquiring bank

Card payment process



Card authentication

- Called offline data authentication
  - Takes place offline, before deciding whether to contact the issuer online or not
- Three levels of card authentication:
  1. Static data authentication (SDA):
     - Certificate verification only, no signature

     No longer used in Finland; certificate can be copied
  2. Dynamic data authentication (DDA):
     - Card signs a random challenge from terminal with RSA; terminal verifies certificate and signature

     Currently the main method
  3. Combined data authentication (CDA):
     - Card signs transaction details (in a later step)

     Limited advantage over DDA (why?)

Cardholder verification

- Cardholder verification methods (CVM)
  - Online PIN: PIN sent to card issuer for verification
  - Offline plaintext PIN: plaintext PIN verified by card
  - Offline enciphered PIN: PIN sent to the card encrypted with the card's RSA key (2nd key and cert)
  - Handwritten signature
  - No CVM
- Terminal reads the list of methods supported by the card and chooses one
- Online PIN used mainly for debit cards, offline for credit cards

Photo: Wikimedia

Payment authorization – offline

- Offline approval for low-risk transactions:
  - Card produces Transaction Certificate (TC) in 1st card action analysis phase
  - The online transaction authorization is skipped
- TC contains transaction details and a MAC with the card-issuer shared key
- Card can also decline the transaction offline, or require online approval

- In CDA, card also returns Signed Dynamic Application Data (SDAD)

Payment authorization – online

- Online authorization:
  - Card produces Authorization Request Cryptogram (ARQC) in 1st card action analysis phase
  - Terminal sends ARQC to issuer to approve or decline
  - ARQC is authenticated with the card–issuer shared key
  - Issuer returns Authorization Response Cryptogram (ARPC), and terminal passes it to the card
  - Card produces Transaction Certificate (TC) or declines the transaction

Risk management

- Banks and credit-card issuers focus on risk management
- Two separate decisions about online vs. offline processing: PIN verification and transaction authorization
- The main decision is online vs. offline authorization
  - Dynamic risk assessment by both card and terminal
  - Offline risk parameters on the card limit offline transactions
  - Terminal may have its own limits
  - ATM cash withdrawal is always authorized online
  - Some cards (e.g. Visa Electron) only allow online authorization
- After transaction processing:
  - Offline limit is reset after successful online authorization
  - Issuer may also update limits or block the card

Contactless (NFC) payment

- Fast DDA (fDDA)
  - optimized signed message for contactless transactions
- No PIN verification
- Risk parameters for offline use
  - After a certain number of contactless transactions or total amount of money spent, require an online contact transaction with PIN entry
  - Soft and hard limits: after soft limit, online transaction is preferred but not required
  - Hard limits prevent some uses, e.g. busses

Picture: visa.ca

MORE CARD SECURITY FEATURES

Bank cards

These slides use Visa terminology and acronyms

- Credit or debit card features
  - Card number (issuer identification number IIN + primary account number PAN)
  - Card holder name, expiration date, CVV2
  - Magnetic stripe, chip in integrated circuit card (ICC), contactless (NFC) interface
  - Card holder signature, hologram
- PIN

[Picture: www.korttiturvallisuus.fi, Nets Oy]

- Terminal types
  - Point of sale (POS)
  - Automated teller machine (ATM) = cash machine

CVV2

- How credit card numbers are mostly stolen:
  - Merchant's customer database hacked and credit card data leaks, e.g. SQL injection attacks (huge problem!)
  - Mag stripe skimmers in payment terminals get the same data
- CVV2 (card verification value 2) to reduce online fraud
  - 3-4 digits printed on card but not on mag stripe or chip
  - Used in card-not-present transactions: web and phone
  - Merchant verifies CVV2 online from the issuer
  - Merchant is not allowed to store CVV2
  - Code changes when card renewed
  - Still vulnerable to phishing, corrupt merchants, and anyone with physical access to the card

Picture: Wikimedia

3-D Secure

- Web- and XML-based protocol for authorizing payments
  - Merchant opens an iframe at the card issue
  - Card holder authorizes payment by authenticating to the card issuer
- Implementations:
  - Verified by Visa
  - MasterCard SecureCode
- Meets the requirements of EU Payment Services Directive (PSD2): strong customer authentication for most payments

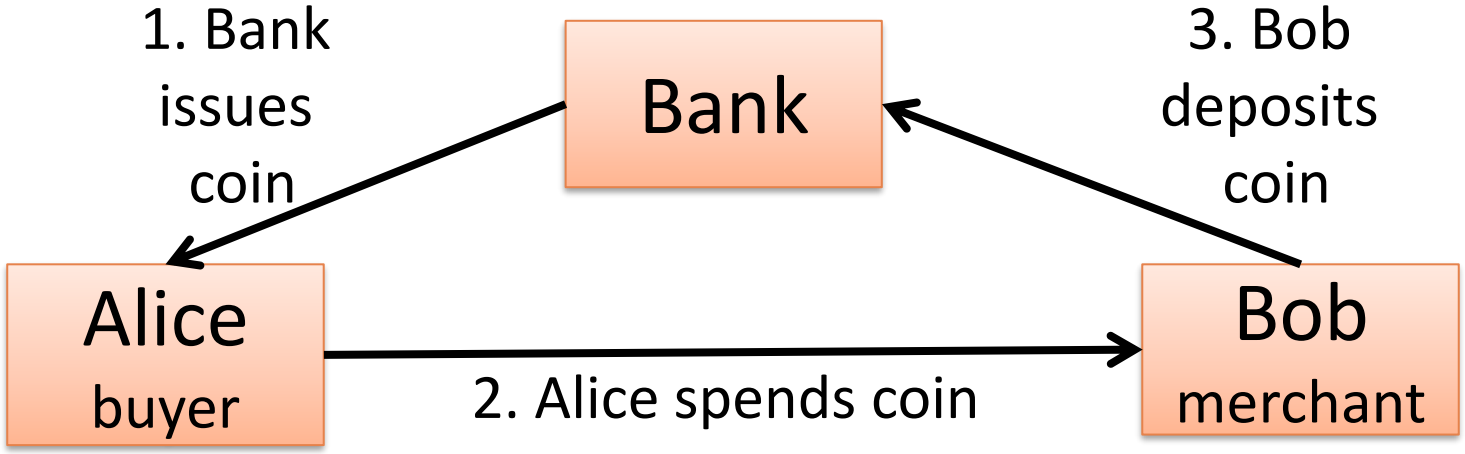
3-D Secure – security analysis

- Advantages:
  - Stolen or copied card cannot be used for online fraud
  - iframe and the same-origin policy prevent the merchant from spoofing user input to approve the transaction
- Weaknesses:
  - iframe does not allow user to check the bank URL or certificate
    → MitM attack by merchant: spoof the card issuer iframe and use input to approve a different transaction
  - Consumers cannot travel with just the credit card; have to carry bank credential with them
- Is regulation better than risk management by financial institutions?
- Anything else?

ANONYMOUS PAYMENTS

This is what university courses taught about digital cash before Bitcoin. The idea was Proposed by David Chaum in 1982. His DigiCash product was never launched

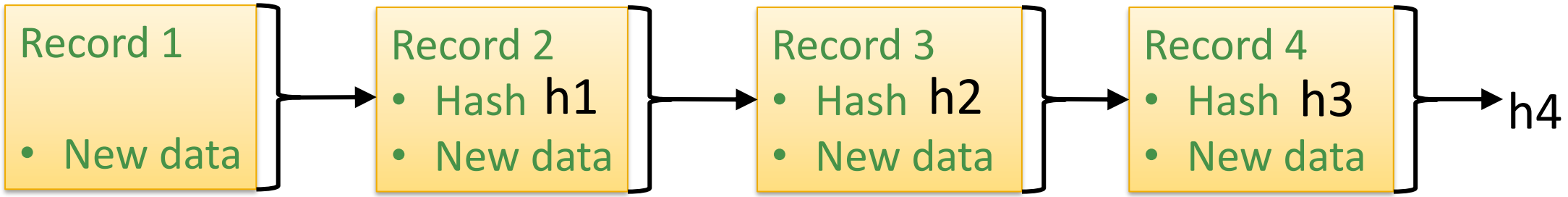
Anonymous digital cash



- Anonymous payment: issuing and spending events should be unlinkable by bank and merchant – even if the two collude
- Non-transferable: coin must be deposited to bank after payment
- Uses blind signatures: bank signs coins without seeing them
- Double-spending: if buyer spends a coin twice, identity revealed

BITCOIN

Background info: hash chain

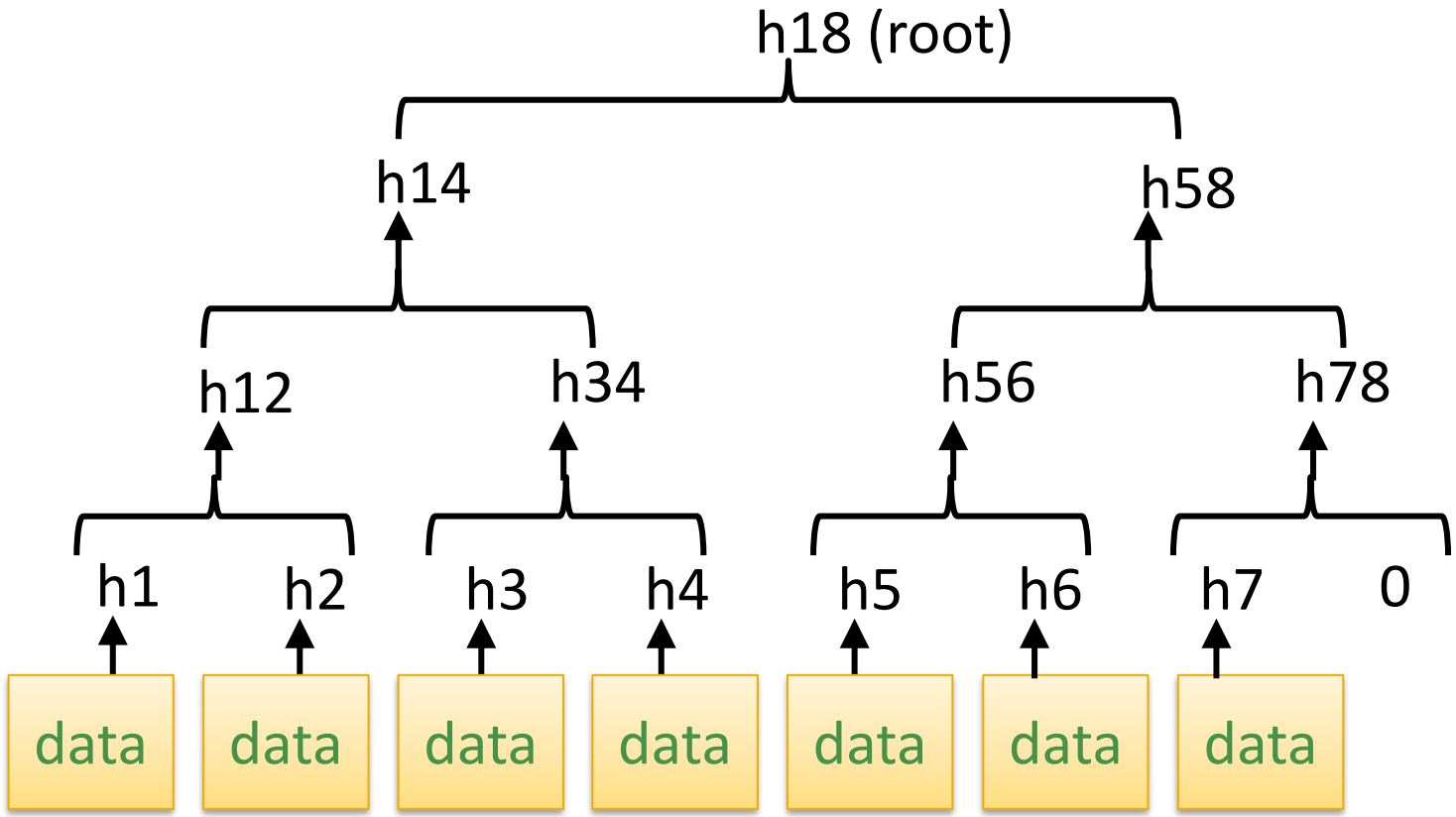


h1=h(data1,0)
h2=h(data2,h1)
h3=h(data3,h2)
…

- Cumulative hash of data: backward-linked list, with a hash value as the unambiguous reference to the previous records
- Verifying that some data is in the chain costs O(N)
- Appending a data item costs O(1), but updating the hash costs O(N) if earlier data changes

Background info: Merkle hash tree

- Binary or n-ary tree of hash values
- Verifying presence of data costs O(log N) in computation and communication
- Adding or updating data costs O(log N)

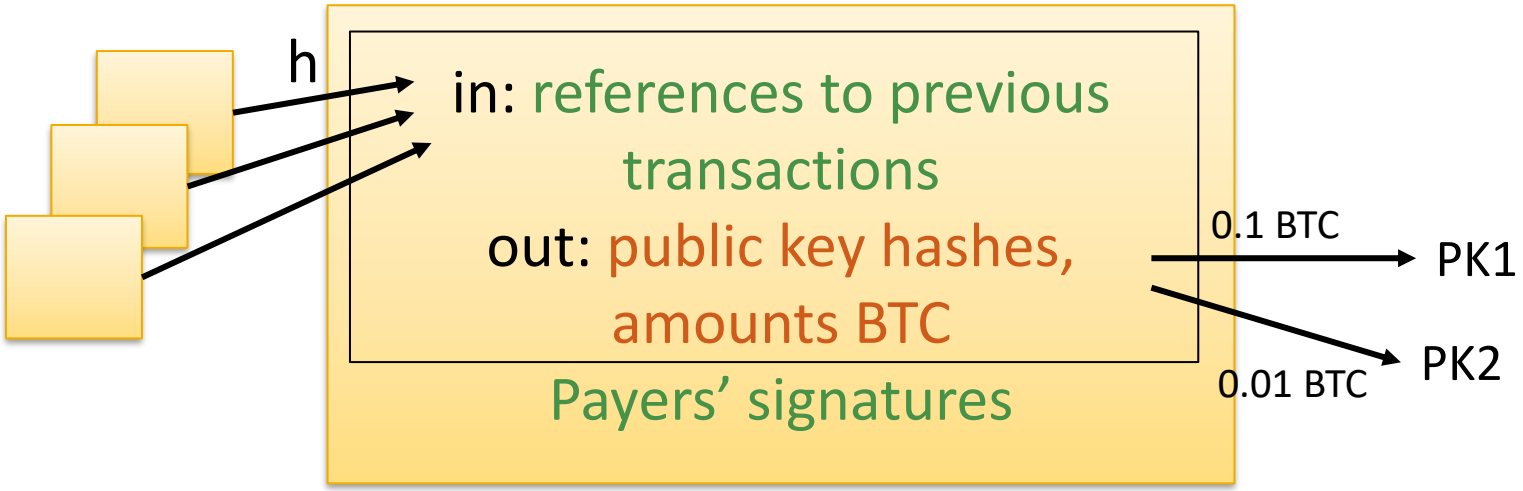


Bitcoin

- Created in 2008 by pseudonym Satoshi Nakamoto
- Transferable digital money
  - Based on cryptographic signatures and hash functions
- Public signature keys used as identities
- P2P system, no central bank or trusted issuer
- Competitive mechanism for the initial issue
  - Money distributed in proportion to waisted CPU power

Bitcoin transaction

- Direct transactions between public key pairs:
  - Transaction record contains (A) inputs, (B) outputs
  - Inputs: references to ealier transactions where payer received the money
  - Outputs: payee public key hashes and amounts
  - Total inputs from previous transactions must be ≥ total outputs



Bitcoin transaction

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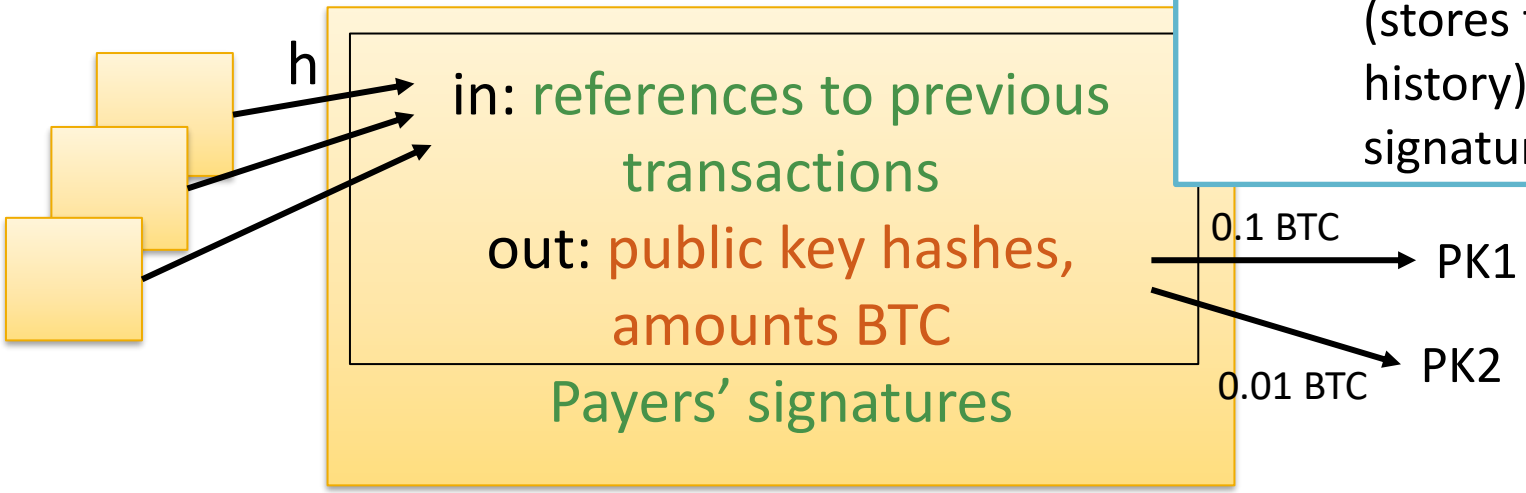
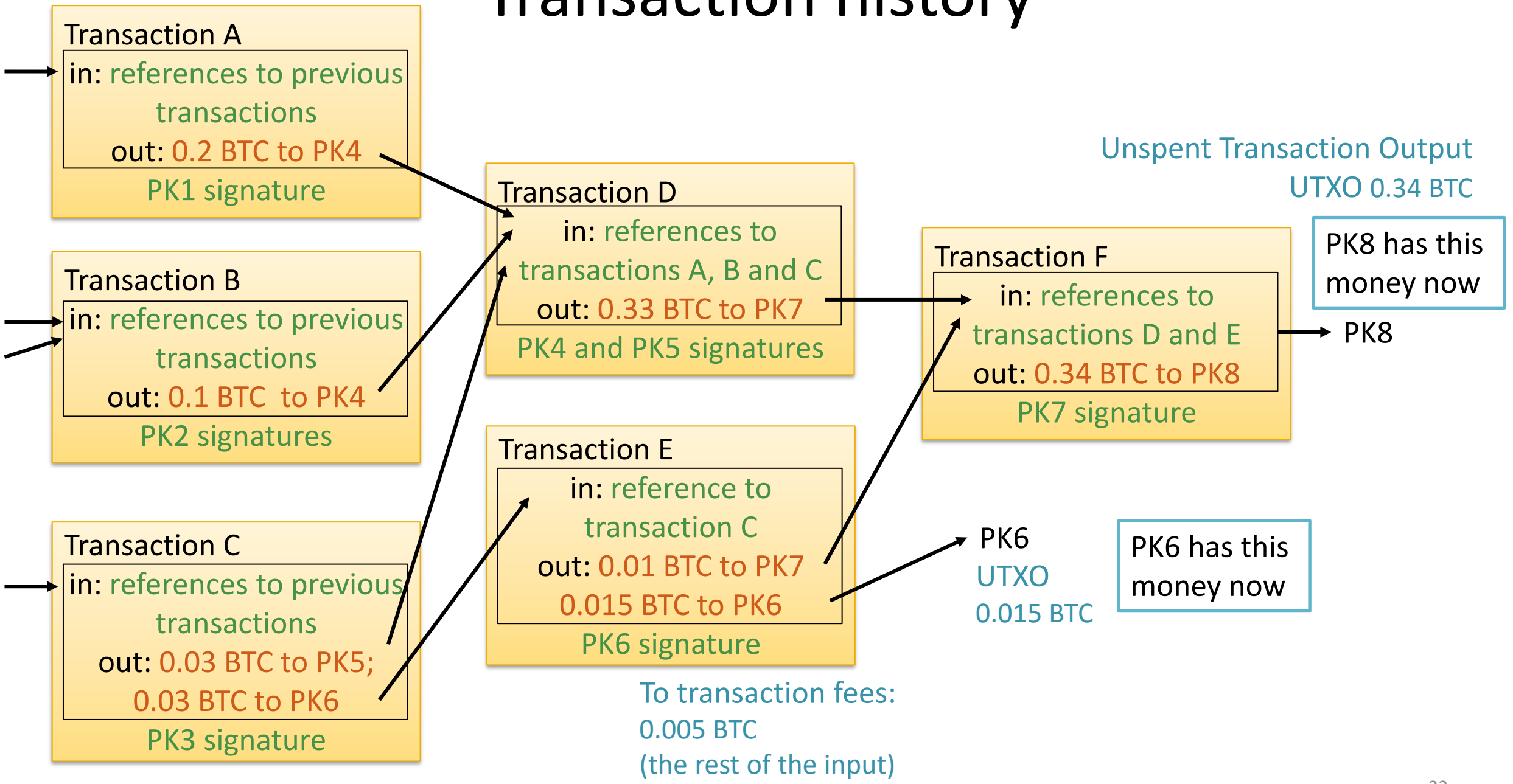
  - Inputs: references to ealier transactions where p
  - Outputs: payee public key hashes and amounts
  - Total inputs from previous transactions must be ≥

Questions:

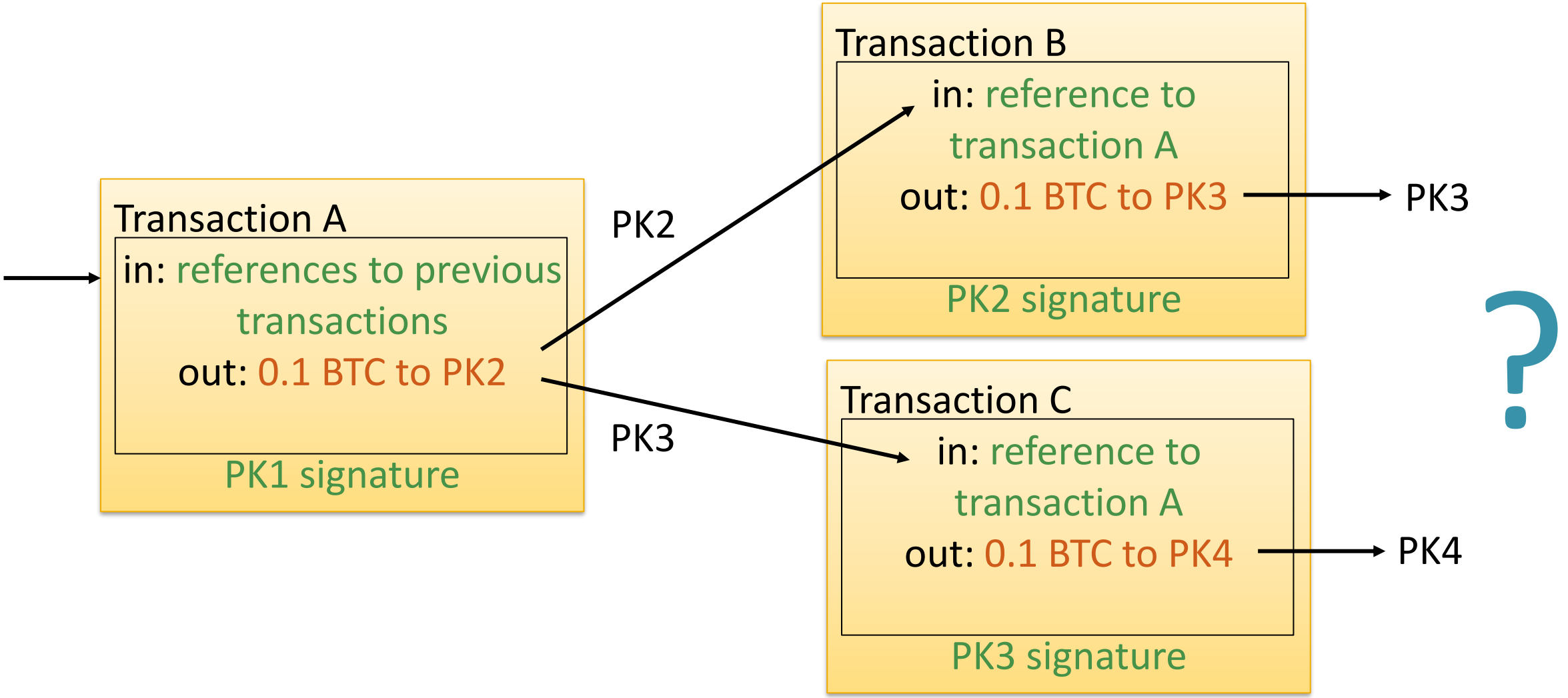
- How to bundle received small outputs, or to get change for a large input?
- What happens if outputs < inputs?
- Who keeps the books (stores the transaction history) and checks the signatures?



Transaction history



Double spending



How to prevent double spending?

Public ledger

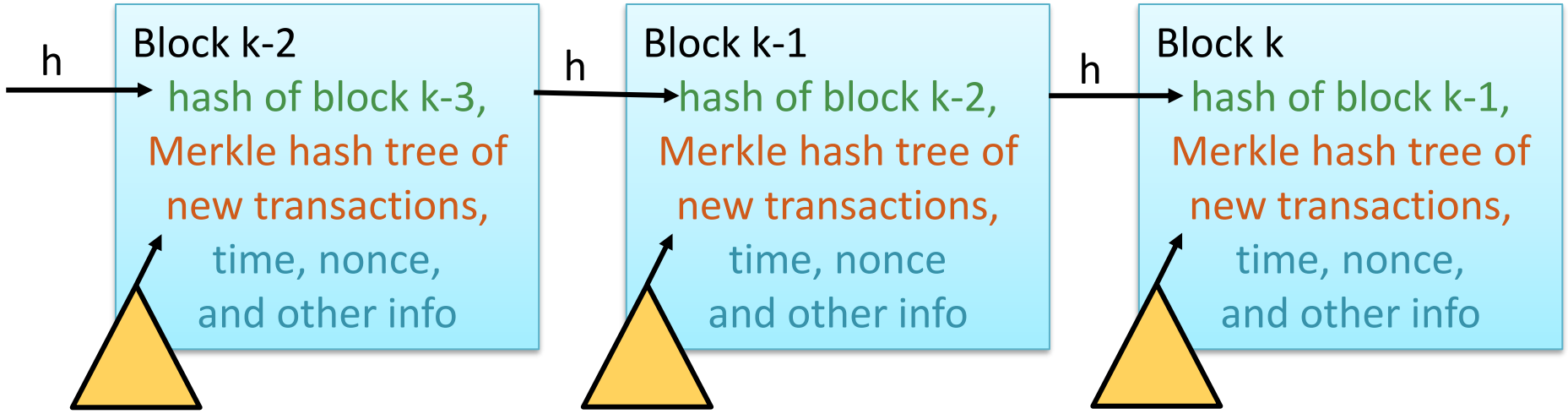
Public ledger: public log of all past transactions

- Verifiable: includes transaction signatures
  - Anyone download and verify the full history or parts of it
- Global consistency: everyone agrees on what is in the log
- Immutable history: nobody can change the log later
- Double spending prevention: the first one of conflicting transactions accepted, others rejected

- Q: Who can be trusted to maintain the ledger?
  In Bitcoin, a global P2P network

Block chain

- Public ledger in Bitcoin is implemented as a block chain
  - Hash chain: block contains hash of the previous block and Merkle hash tree of new transactions
- New block is added every ~10 minutes (ledger size grows)
- The latest block is a cumulative hash of all transactions ever



Mining

- Global P2P network propagates all transaction data and maintains the block chain
- Anyone can add blocks to the block chain
  - Must perform proof-of-work i.e. solve a cryptographic puzzle: Brute-force search a nonce (any number) such that the SHA-256 hash of the block is smaller than a target value

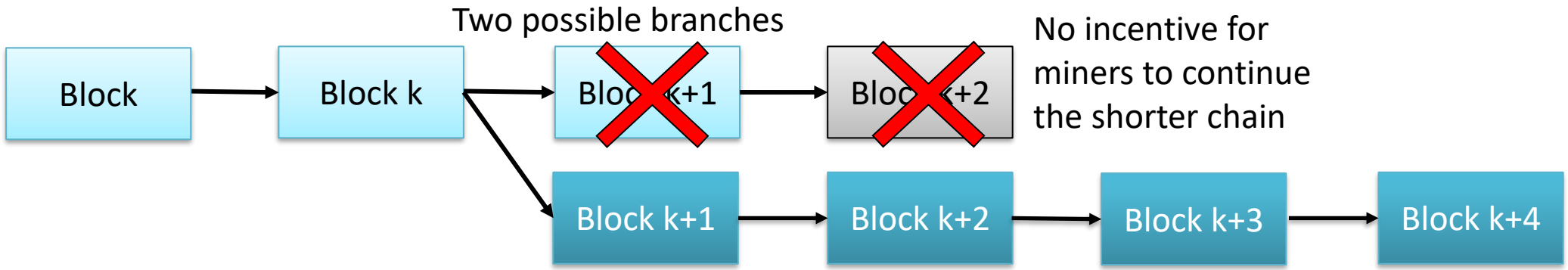
    $$h(\text{block header, nonce}) \leq \text{target 256-bit value}$$

  - The first to find a solution gets a reward, and everyone moves to search for the next block
  - The difficulty of the puzzle is adjusted to keep the average block generation time at 10 minutes

How new coins are issued

- Reward for generating a new block is the transaction fees of included transactions plus some new BTC
  – This is how the new coins are issued!
- Maximum 21M BTC to be issued over time
  – Initially 50 BTC per block
  – Currently 12.5 BTC per bock
  – Halved every 210k blocks i.e. every ~4 years

Security of the block chain



- Global consistency = how to avoid chain branching?
- Rule: if the chain branches, the longest branch wins
  - If there are two conflicting blocks, the next block determines the winner
  - Payee should wait for 6 new blocks (~1 hour) before considering the transaction final
- If someone controls more than 50% of the global hash rate, they can modify the history and double spend

Security issues with Bitcoin

- Block size limit caps global transaction rate to ~7 per second; small transaction may never succeed (e.g. buying coffee)
- 10..60 minutes wait for transaction confirmation
- A few large Chinese mining pools dominate the P2P network
- Malware attacks against wallets, bank robbery by hackers
- No way to reverse a transaction without the payee's cooperation
  - Stolen BTC are gone for good
- Governments may want to take control
- Competing digital currencies are easy to create and could have stronger business and political support

Why would anyone use Bitcoin?

Extra material

Even the most dysfunctional money is better than not having a means for economic exchange

SUMMARY

List of key concepts

- EMV, issuer, card holder, ICC, offline card authentication, SDA, DDA, CDA, cardholder verification, online vs. offline PIN, offline approval or authorization, online authorization, contactless payment, NFC, risk management, soft and hard limits, CVV2, card skimmer, mag stripe
- Anonymous payment, unlinkability, transferable money, double spending
- Hash chain, Merkle tree,
- Bitcoin, transaction, inputs, outputs, transaction fee, transaction history, public log, global consistency, block chain, block, P2P network, mining, proof of work, cryptographic puzzle, puzzle difficulty, chain branching, longest chain, transaction confirmation, hash rate

Reading material

- Ross Anderson: Security Engineering, 2nd ed., chapter 10
- Interesting reading online:
  - University of Cambridge Security Group: http://www.cl.cam.ac.uk/research/security/banking/
  - EMV in nutshell, https://www.cs.ru.nl/E.Poll/papers/EMVtechreport.pdf
  - BitCoin wiki: https://en.bitcoin.it/wiki/Main_Page

Exercises

- What are the main threats in
  a) online card transactions?
  b) POS transactions?
  c) ATM cash withdrawals?

  What differences are there in the way credit cards and bank debit cards address these threats?
- Could you (technically) use bank cards or credit cards
  a) as door keys?
  b) as bus tickets?
  c) for strong identification of persons on the Internet?

  (This question may require quite a bit of research.)
- How could a malicious merchant perform a man-in-the-middle attack against EMV chip-and-PIN transactions?
- When a fraudulent bank transaction occurs, who will suffer the losses? Find out about the regulation and contractual rules on such liability.
- Bank security is largely based on anomaly detection and risk mitigation. In what ways could a bank reduce the risk of fraud in mag-stipe or chip-and-PIN payments?
- Even though DigiCash coins are unlinkable, what ways are there for the merchant or bank (or them together) to find out what Alice buys?
- How anonymous are Bitcoin payments?
- Find a Bitcoin block explorer web site with the full transaction record and browse around. Find the latest blocks and transactions, and the first block ever. See how the mining difficulty has changed over time.