ETHEREUM

Blockchain technologies, lecture 2

Course overview

- Ethereum -- transaction-based state machine
- Merkle-Patricia Trie
- Block structure, Transactions
- Ethereum accounts
    - Smart contracts
- EVM and code execution

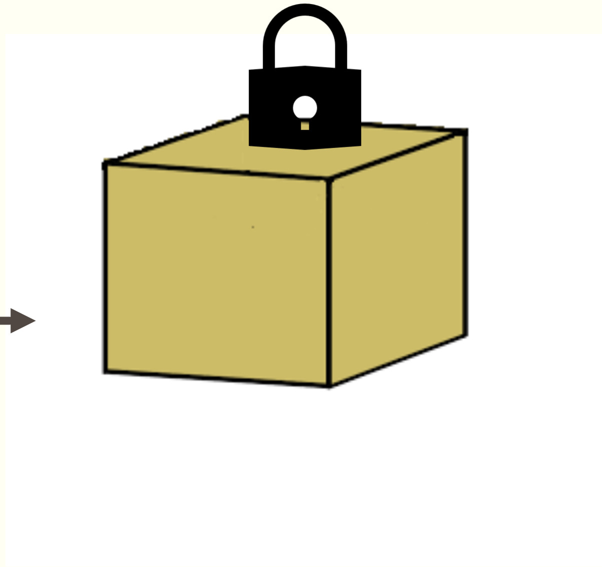
MERKLE PROOFS

MERKLE-PATRICIA TRIE

- MERKLE TREE or hash trees are named after Ralph Merkle, 1979.
- Every leaf node is labelled with the cryptographic hash of a data block.
- Every non-leaf node is labelled with the cryptographic hash of the labels of its child nodes.
- Allows efficient and secure verification of large data
- Example of commitment scheme.

AssignmentCommitments schemes and zero knowledge proofs in Ethereum

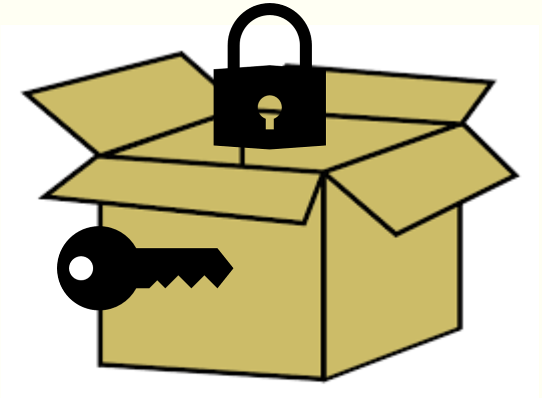
COMMIT (binding property)



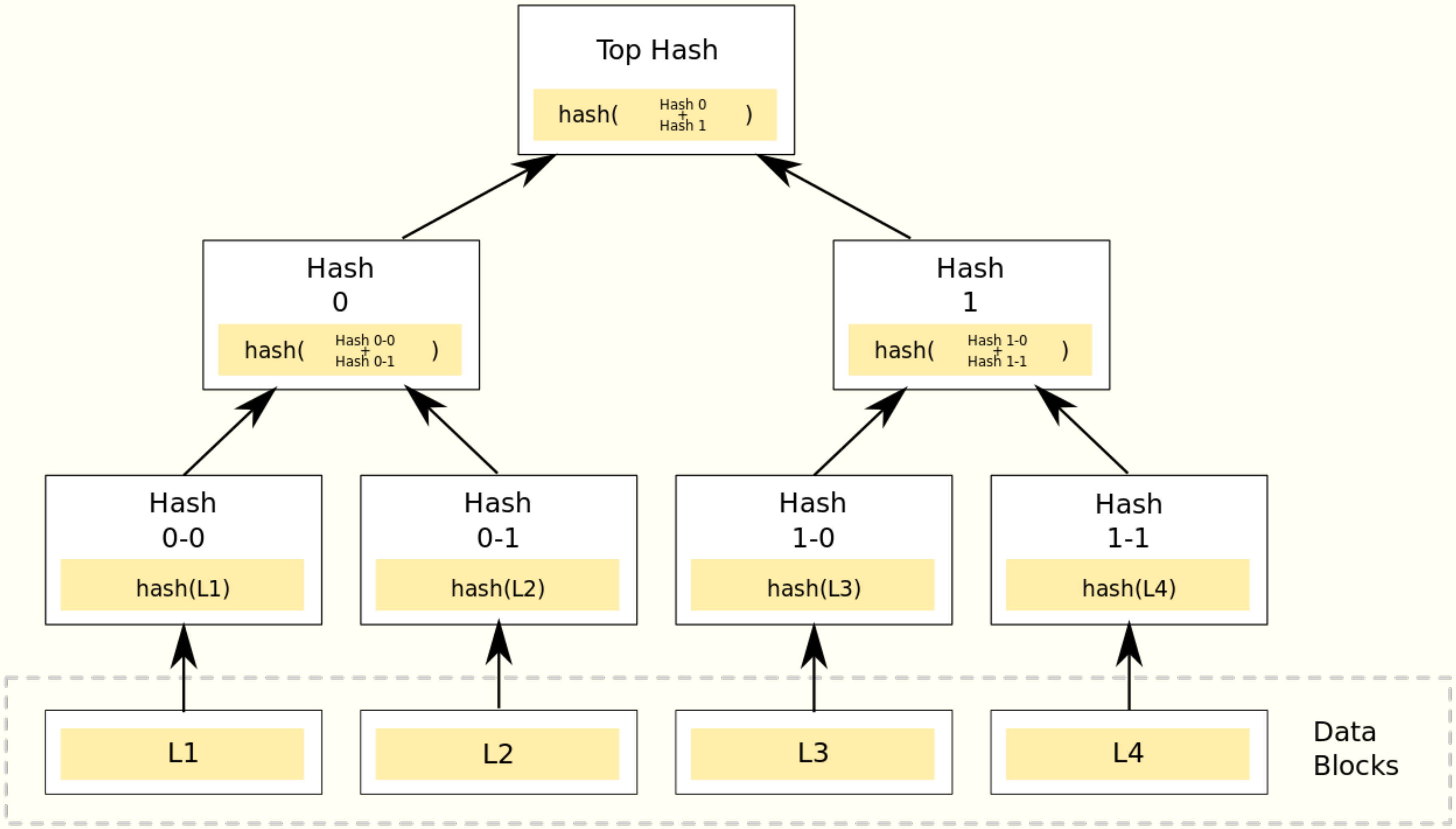
ALICE

BOB

REVEAL (hiding property)



MERKLE-PATRICIA TREEs – hash trees

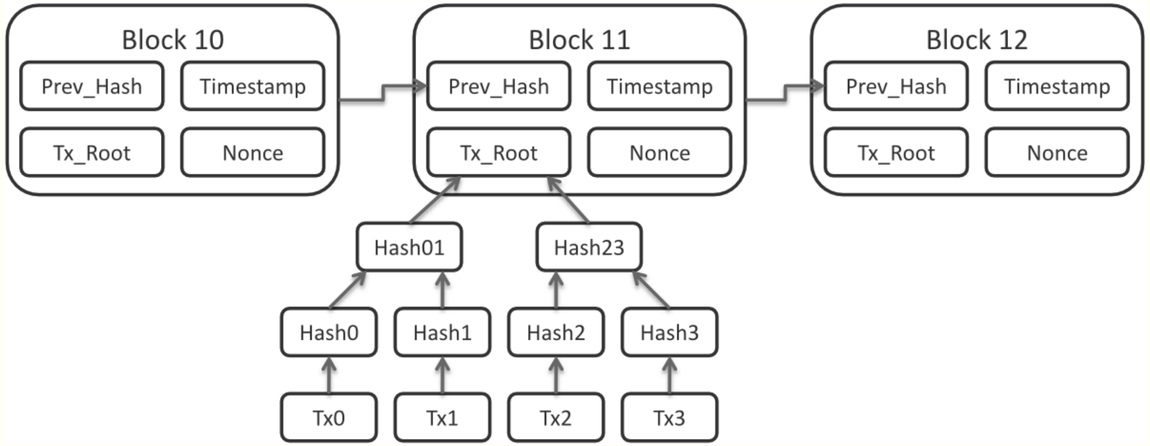


MERKLE PROOFS BITCOIN -- LightClients

Light clients download only block headers.

80-bytes chunks of data for each block that contain:

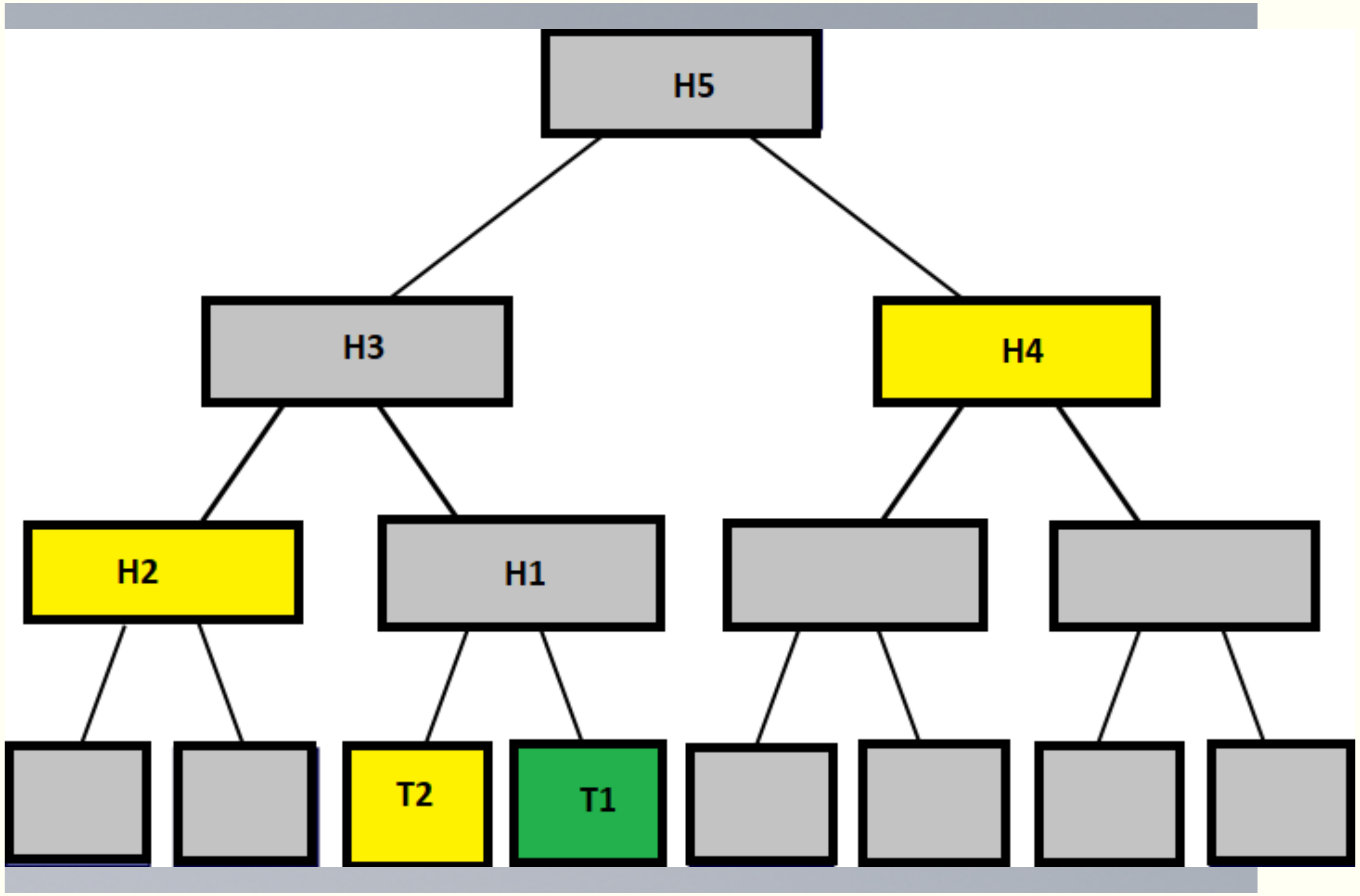
- Previous block hash
- Timestamp
- Mining difficulty
- PoW None
- Root hash for Merkle tree of transactions



MERKLE PROOFS BITCOIN -- LightClients

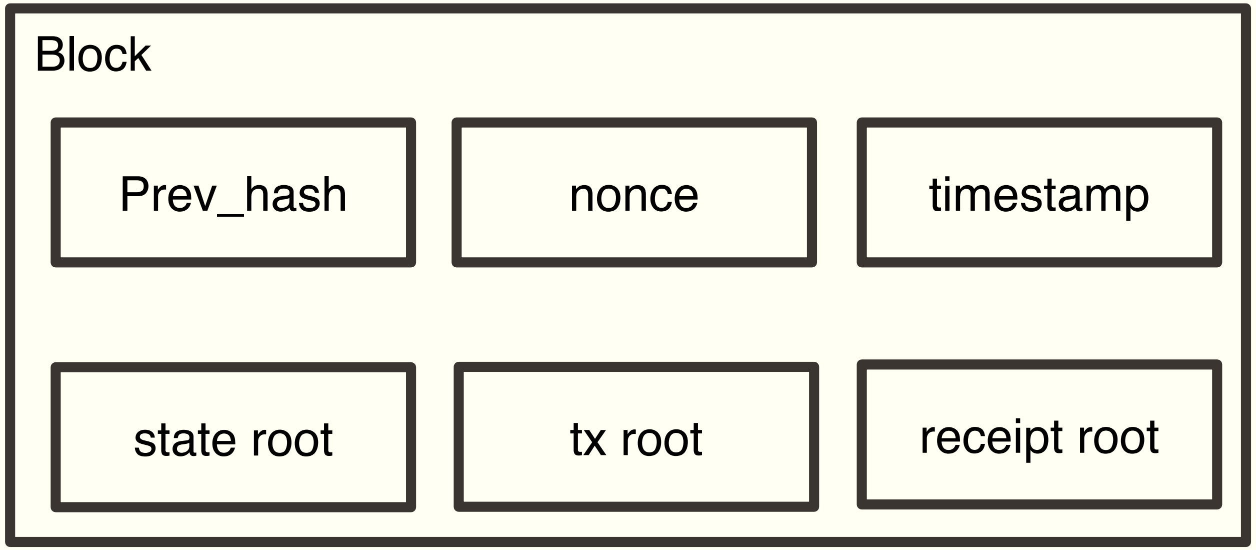
Light clients can be used to determine the status of a transaction:

- Ask for a Merkle proof showing that a transaction is in one of the Merkle trees.
- A Merkle proof consists of a chunk, the root hash of the Merkle tree, and the “branch” consisting of all of the hashes on the path from the chunk to the root.
- Bitcoin proof not enough to know current state (balance, asset current holder etc.). One must authenticate all transactions.



MERKLE PROOFS ETHEREUM -- LightClients

- Is the transaction included in a block (tx root)?
- Does account X exists?
- What is the current balance of the account X?
- All events of type X?
- What will be the outcome of a certain transaction, effect on balances?



- Transaction tree immutable
- State-tree updates: new accounts, update balance, update storage for smart contracts etc.

ETHEREUM STATE MACHINE

Ethereum state machine

- Ethereum – transaction-based state machine
- Turning complete (pseudo-complete due to gas limits)

- State transition function: Y(S,T) = S’
  - State is a modified Merkle Patricia Tree storing hashes of all accounts.

- EVM code execution – stack machine
  - OP CODES: ADD, SUB etc. ADDRESS, BALANCE, BLOCKHASH
  - Each operation has a gas cost

EVM - STORAGE

- Any contract data must be assigned to a location (storage or memory)
- Each account has a data area called storage.
- A contract can only read or write to its own storage.
- Key-value store. Maps 256-bit words to 256-bit words.
- Values stored in storage are stored permanentaly on the blockchain.
- Modify storage is costly and should be avoided.

EVM – MEMORY AND STACK

- Memory -- Values only stored for the lifetime of a contract function's execution.
- Cheaper, not permanently stored.
- Writes can be either 8 bits or 256 bits wide.

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- Stack maximum size of 1024 elements and contains words of 256 bits
- Swap between top 16 elements and top, copy from top 16 elements, operation with topmost two elements.
- Each operation has a gas cost

MERKLE-PATRICIA TRIE

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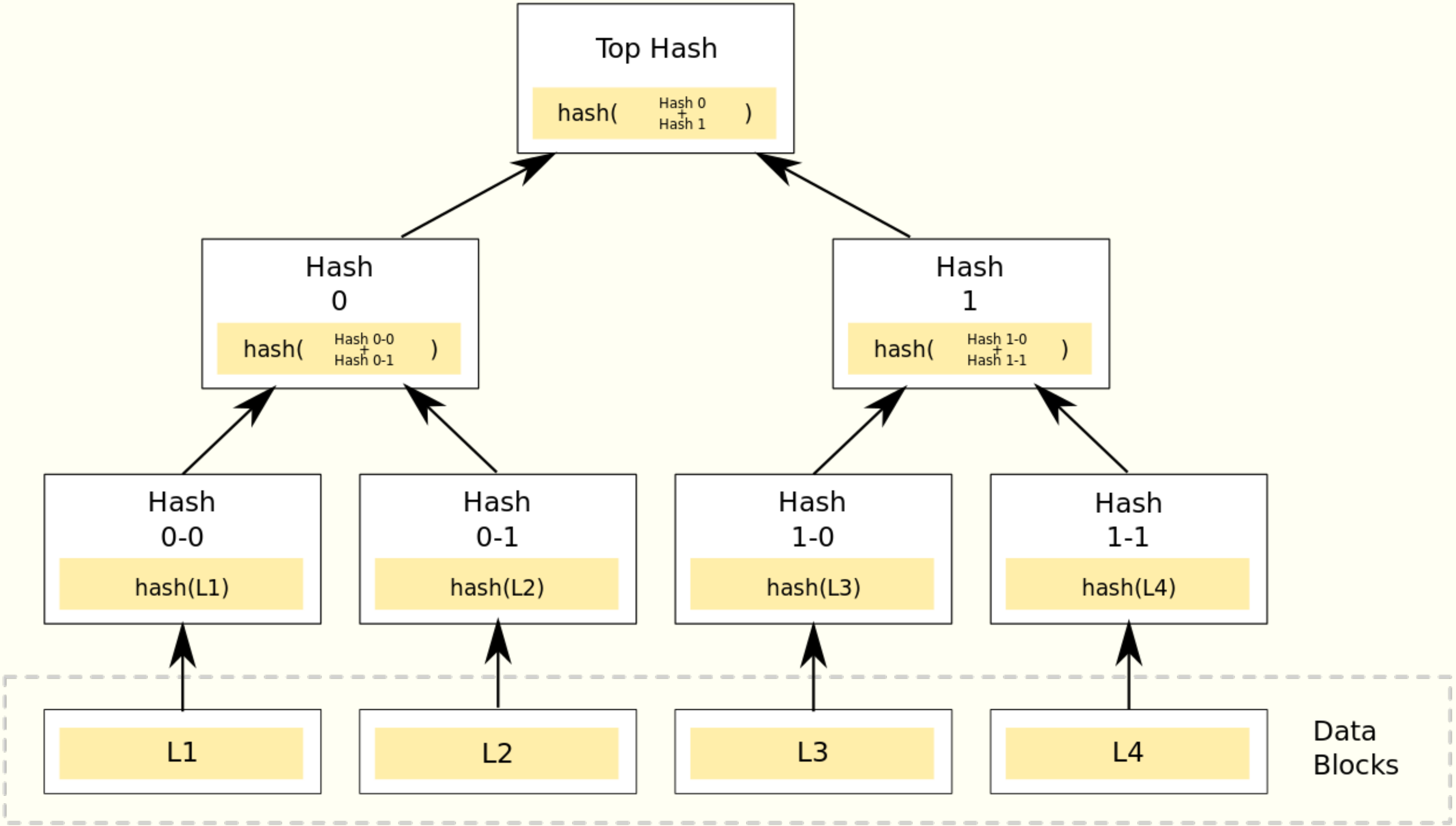
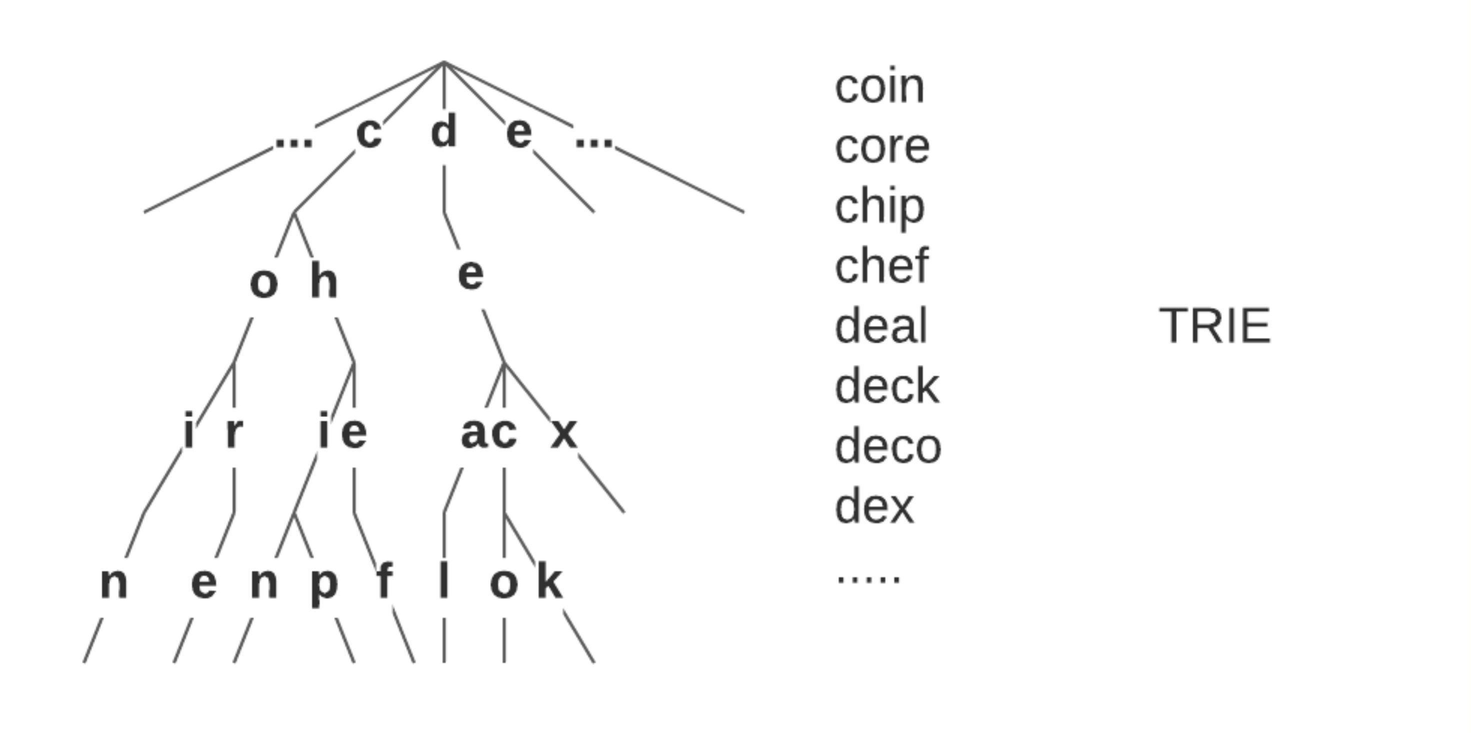
MERKLE-PATRICIA TRIE – hash trees



MERKLE-PATRICIA TRIE

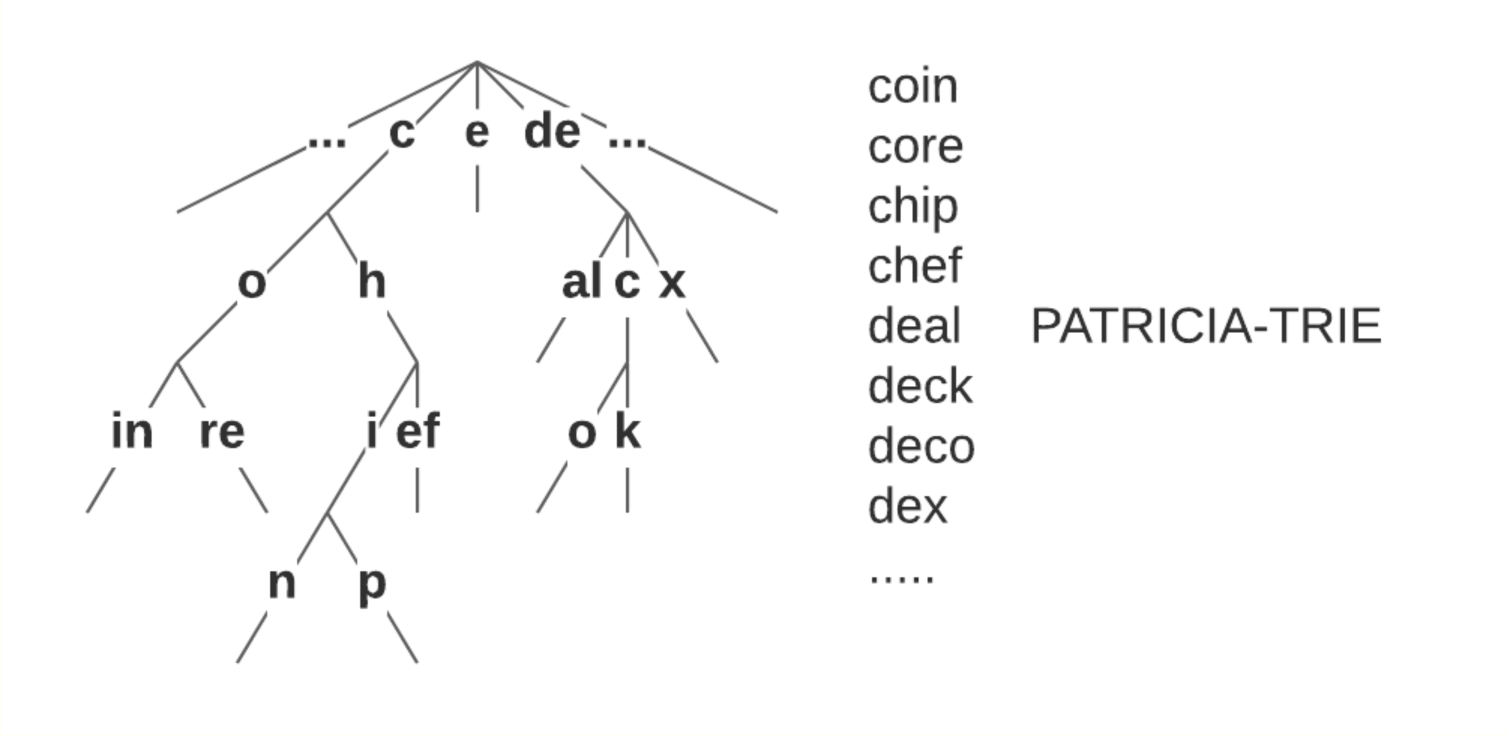
- PATRICIA derived from the Latin word patrician, meaning "noble".

Practical Algorithm to Retrieve Information Coded in Alphanumeric, D.R.Morrison (1968)



MERKLE-PATRICIA TRIE

- PATRICIA optimized trie - each node that is the only child is merged with its parent.



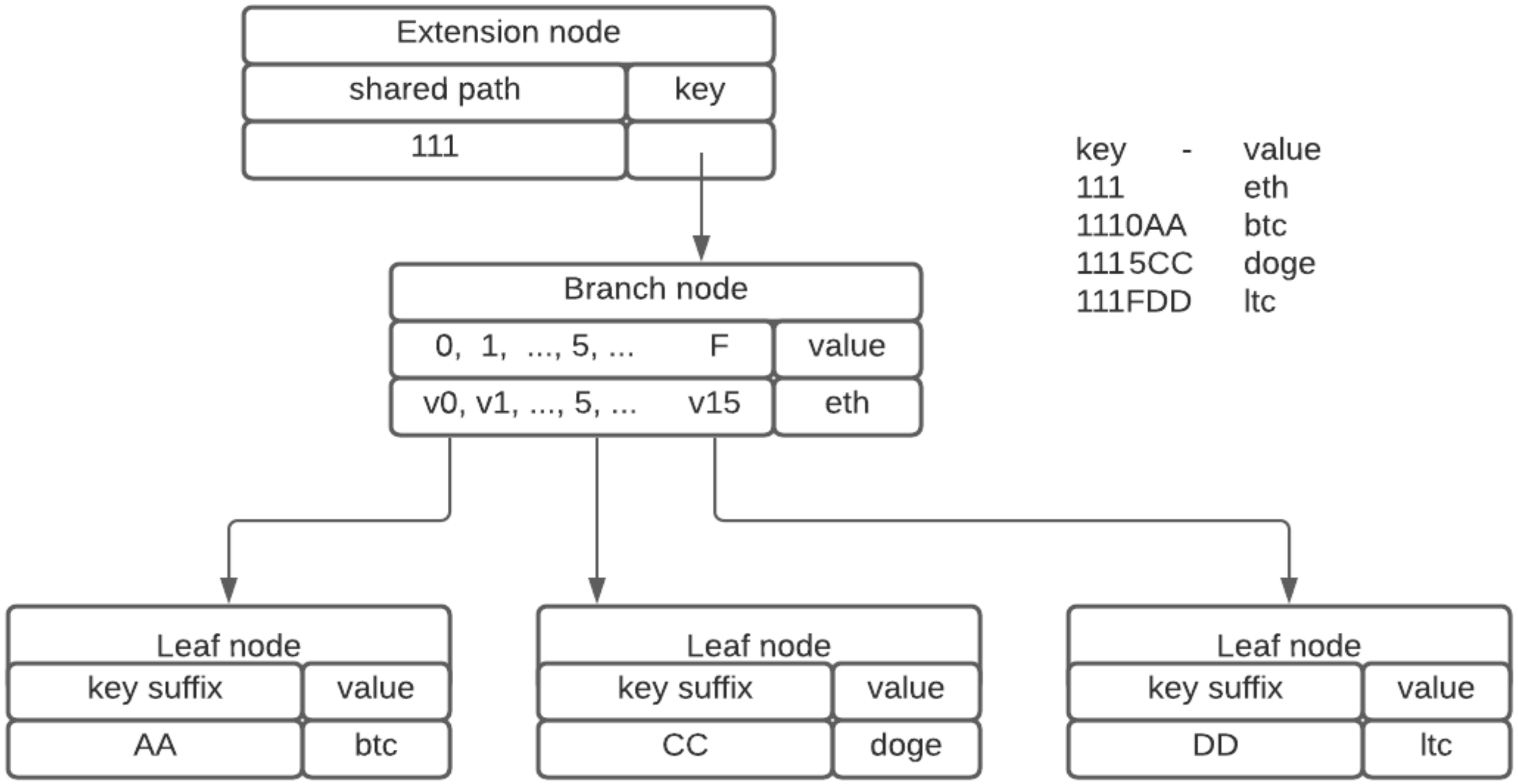
MERKLE-PATRICIA TREEs

- Hashing in the sense of MERKLE tree, a child node is referred by its cryptographic hash.
- Groups common prefixes in the sense of PATRICIA tries, branches only when branching is necessary.
- Allows 16 branches.
- Three types of nodes:

Branch node	[$i_0, i_1, \ldots, i_{15}$, value]	The i–position contains a link to a child node. The 17th item is used in the case of terminal nodes
Extension	[path, value]	Compression, stores common path for multiple keys, value links to a child node.
Leaf	[path, value]	Compression, terminal node.

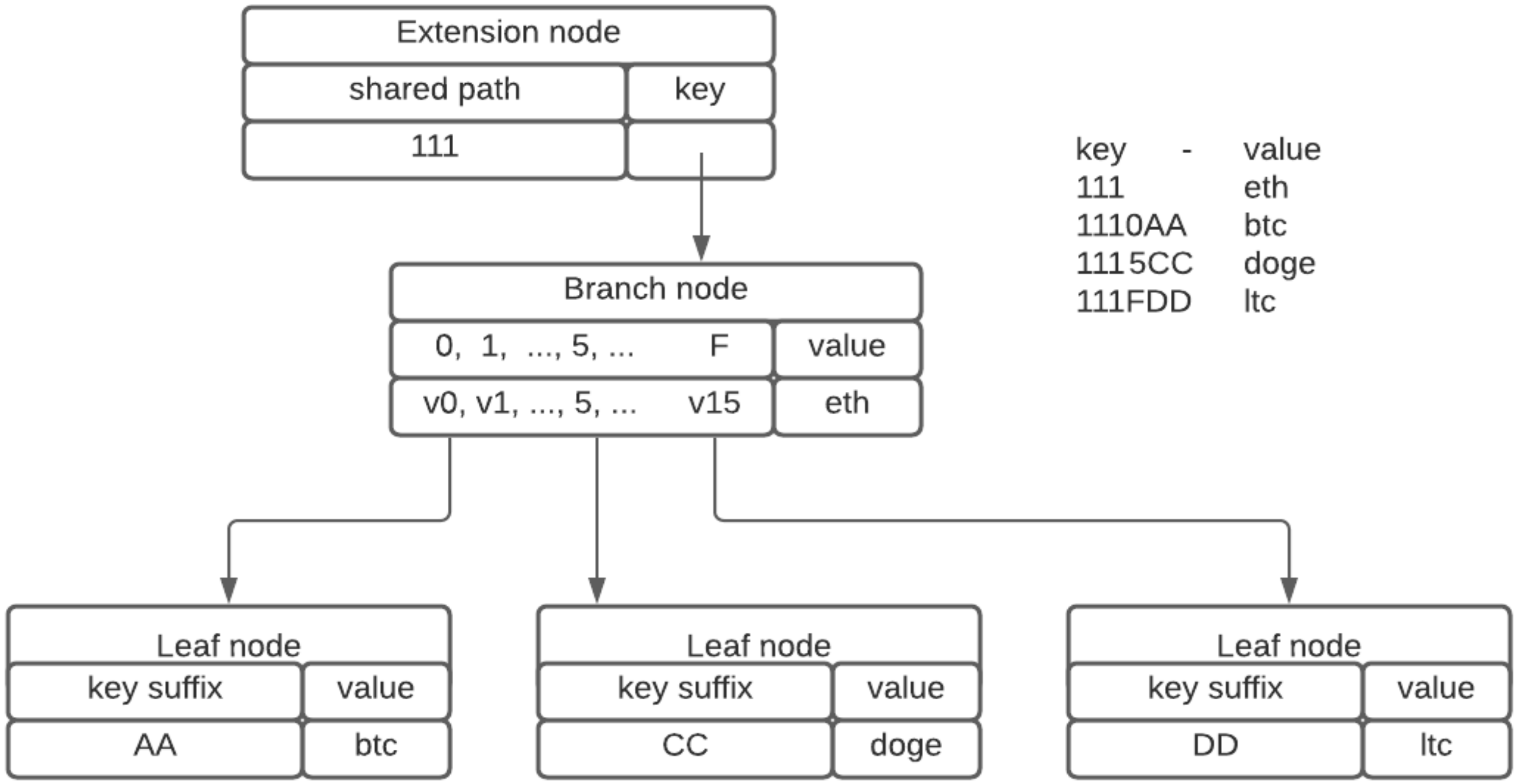
MERKLE-PATRICIA TREEs

- MARKLE PATRICIA TREE - Groups common prefixes in the sense of PATRICIA tries.
- use key-vale storages, RocksDB (Parity) LevelDB (Geth)



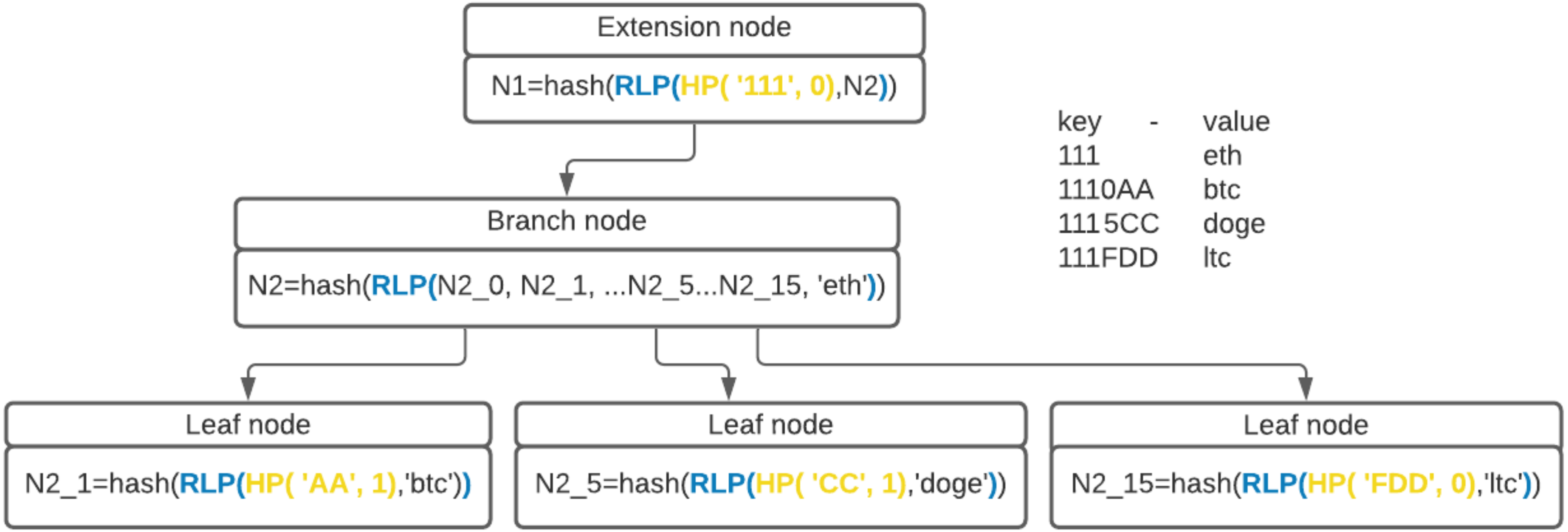
MERKLE-PATRICIA TREEs

- MARKLE PATRICIA TRIE - Groups common prefixes in the sense of PATRICIA tries.
- Assignment: key-vale storages, RocksDB (Parity) LevelDB (Geth) for blockchain



MERKLE-PATRICIA TREEs

- MARKLE PATRICIA TREE - a child node is referred by its cryptographic hash.
- RLP function, serializes a set of input arrays into one array.
- HP encodes node structures into compressed byte arrays.
- hash = keccak implementation of SHA3



key -	value
111	eth
1110AA	btc
1115CC	doge
111FDD	ltc

MERKLE-PATRICIA TREEs Hex Prefix encoding

- $f(t) = \begin{cases} 2, & t = 1 \\ 0, & t = 0 \end{cases}$ HP encodes a path stream so that two (4-bit) nibbles compose one (8-bit) byte.

- $$\mathrm{HP}(x,t) = \begin{cases} \big(16f(t),\ 16x[0]+x[1],\ 16x[2]+x[3],\ \ldots\big), & \|x\|\ is\ even \\ \big(16\big(f(t)+1\big)+x[0],\ 16x[1]+x[2],\ 16x[3]+x[4],\ \ldots\big) & \|x\|\ is\ odd \end{cases}$$

t		x	prefix	X[0] or 0	Grup 1	Grup 2
t=0 extension	even	0xa, 0xb, 0xc, 0xd	0000	0000	1010 1011	1100 1101
	odd	0x09, 0xa, 0xb, 0xc, 0xd	0001	1001	1010 1011	1100 1101
t=1, leaf	even	0xa, 0xb, 0xc, 0xd	0010	0000	1010 1011	1100 1101
	odd	0x09, 0xa, 0xb, 0xc, 0xd	0011	1001	1010 1011	1100 1101

MERKLE-PATRICIA TREEs Recursive Length Prefix

- RLP function, serializes (flattens) a set of input arrays into one byte array.
- Flattened byte array is persisted into a key-value storage.
- Length Prefix Every sub-sequence is prefix by a byte encoding its length and a bit-mask to determine the sub-subsequence type: array or string.
- Recursive Every flattened sequence is prefixed by total length of all its sub-sequences.

		RLP(x)	RLP()	
XYZ	3	128 + ‖x‖ , X, Y, Z	10000011 X Y Z	4
AB	2	128 + ‖x‖ , A, B	10000010 A B	3
[XYZ, AB]	2	192 + ‖RLP(), RLP()‖, RLP(), RLP()	11000111 10000011 X Y Z 10000010 A B	8

ETHEREUM BLOCK STRUCTURE

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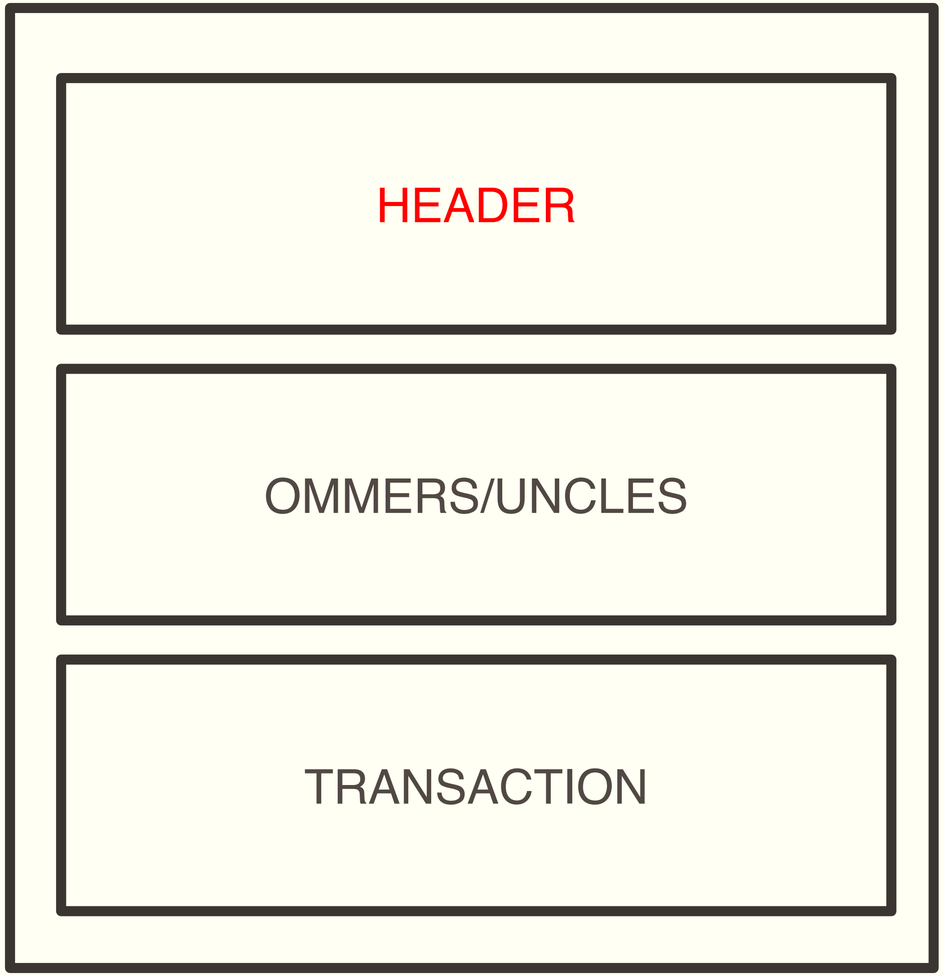
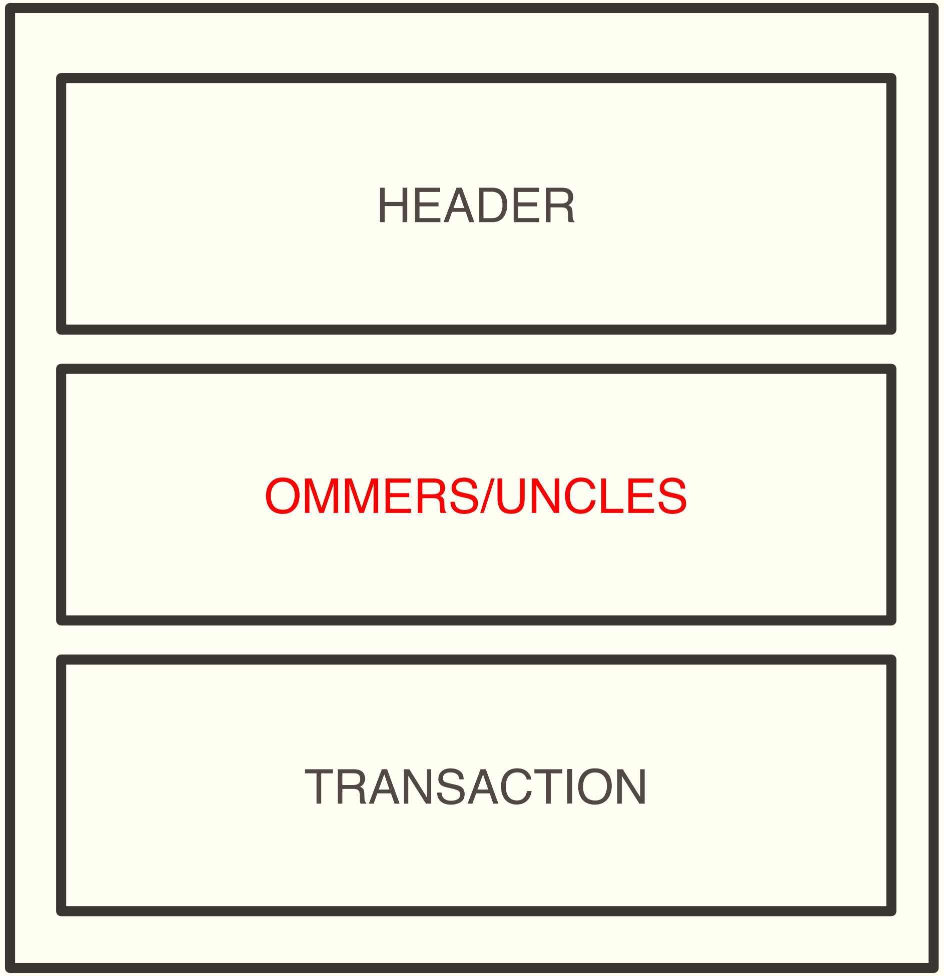


- Transactions, usually representing funds transfers, are grouped in blocks.
- Blocks are linked via cryptographic hashes.
- Block header stores the hash of the previous block in the chain.
- Miners wrap transactions into blocks and compete to append a new block into the chain via PoW protocol.

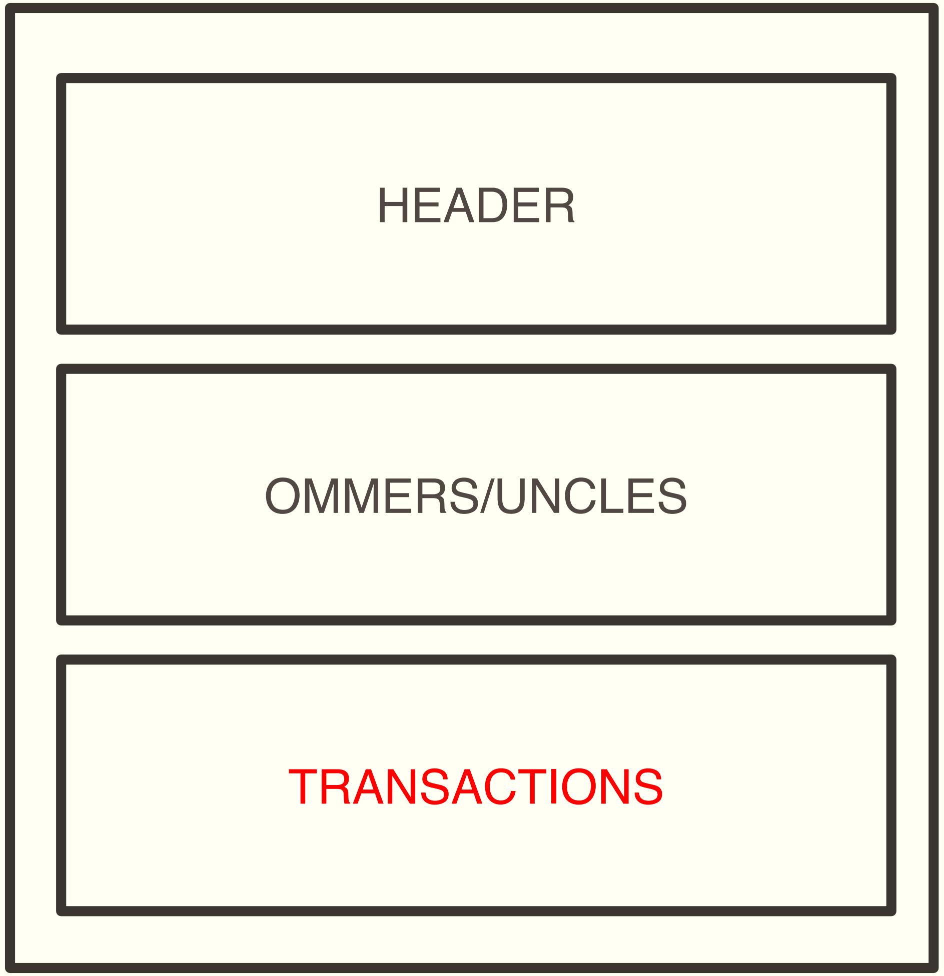
ETHEREUM BLOCK STRUCTURE



- If more blocks are produced at the same time, blocks that are not included in the mainline become ommers, with a smaller reward for miners.
- A new block is added in the mainchain approximately every 15s. Only a number of 6 consecutive ommers is rewarded, after one minute a half the miner will be notice about the consensus and be incentivized to join the mainline.
- Modified GHOST protocol (see next lecture).

Longest chain rule/heaviest chain rule

ETHEREUM BLOCK STRUCTURE



- Transactions are stored in MERKLE PATRICIA TRIE structures.
- In Ethereum state of the accounts (world state) is also stored, reflecting balances as a result of transactions execution.
- World state is also stored in a MERKLE PATRICIA TRIE.

ETHEREUM BLOCK STRUCTURE -BLOCK HEADER

PoW consensus

▪ parentHash	Keccak 256 bit hash of the parent block
▪ nonce	64 bit value found by miner
▪ mixHash	hash confirming mining
▪ difficulty	scalar value measuring mining effort
▪ ommersHash	Keccak 256 bit hash of list of ommers
▪ Beneficiary	address of miner receiving reward
▪ stateRoot	Keccak 256 bit hash of a root of the World State Trie
▪ receiptsRoot	Keccak 256 bit hash of a root of the Transaction Receipt Trie
▪ transactionsRoot	Keccak 256 bit hash of a root of the Transaction Trie
▪ logsBloom	Bloom filter relating logs hashes with the logs
▪ number	ordinal number of this block. every new block gets a number increased by one.
▪ gasLimit	accumulated gas limit required to process all transactions
▪ gasUsed	accumulated real consumed gas to process all transactions
▪ extraData	32 bytes additional data
▪ timestamp	scalar value equal to the reasonable output of Unix’s time() at this block’s inception

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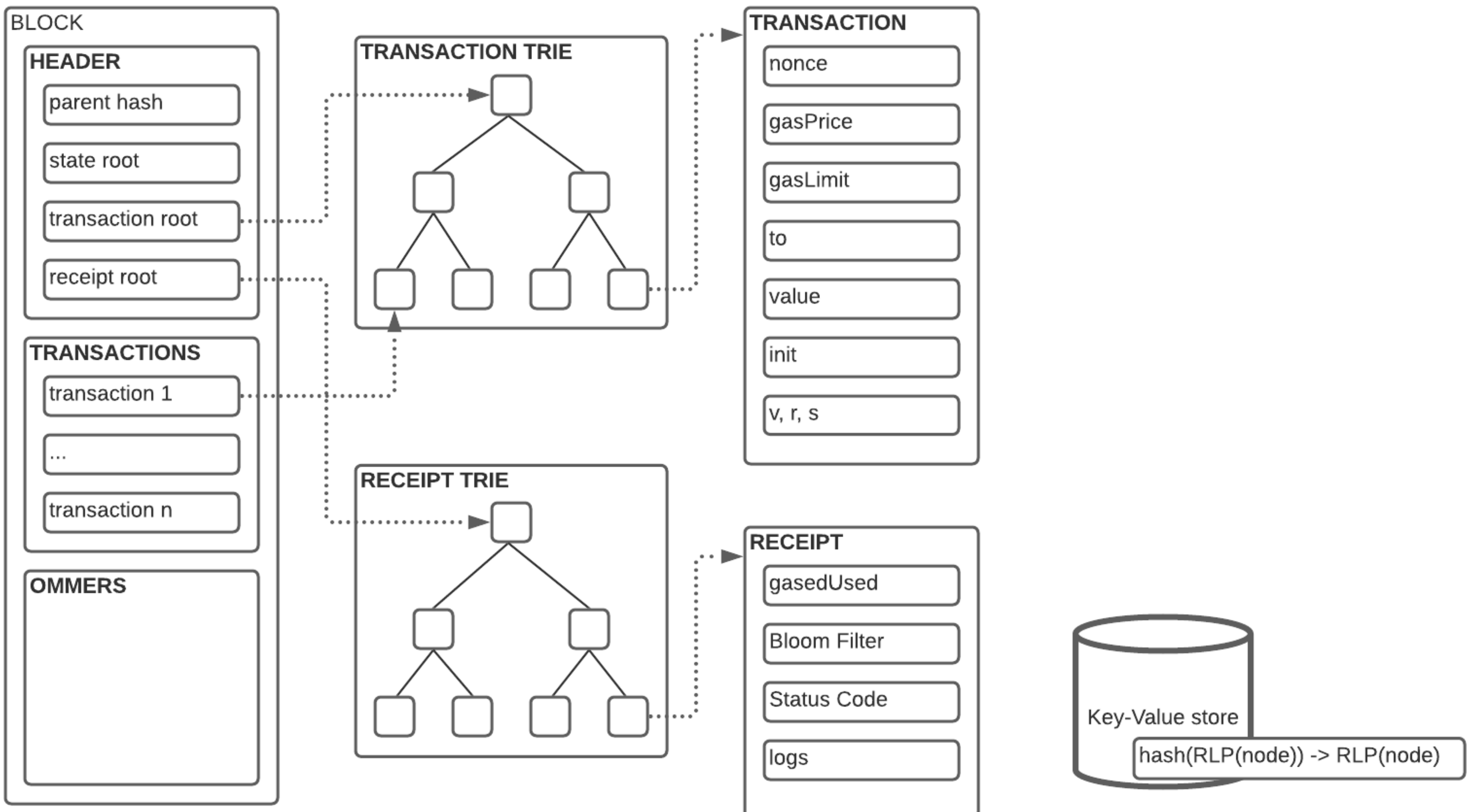
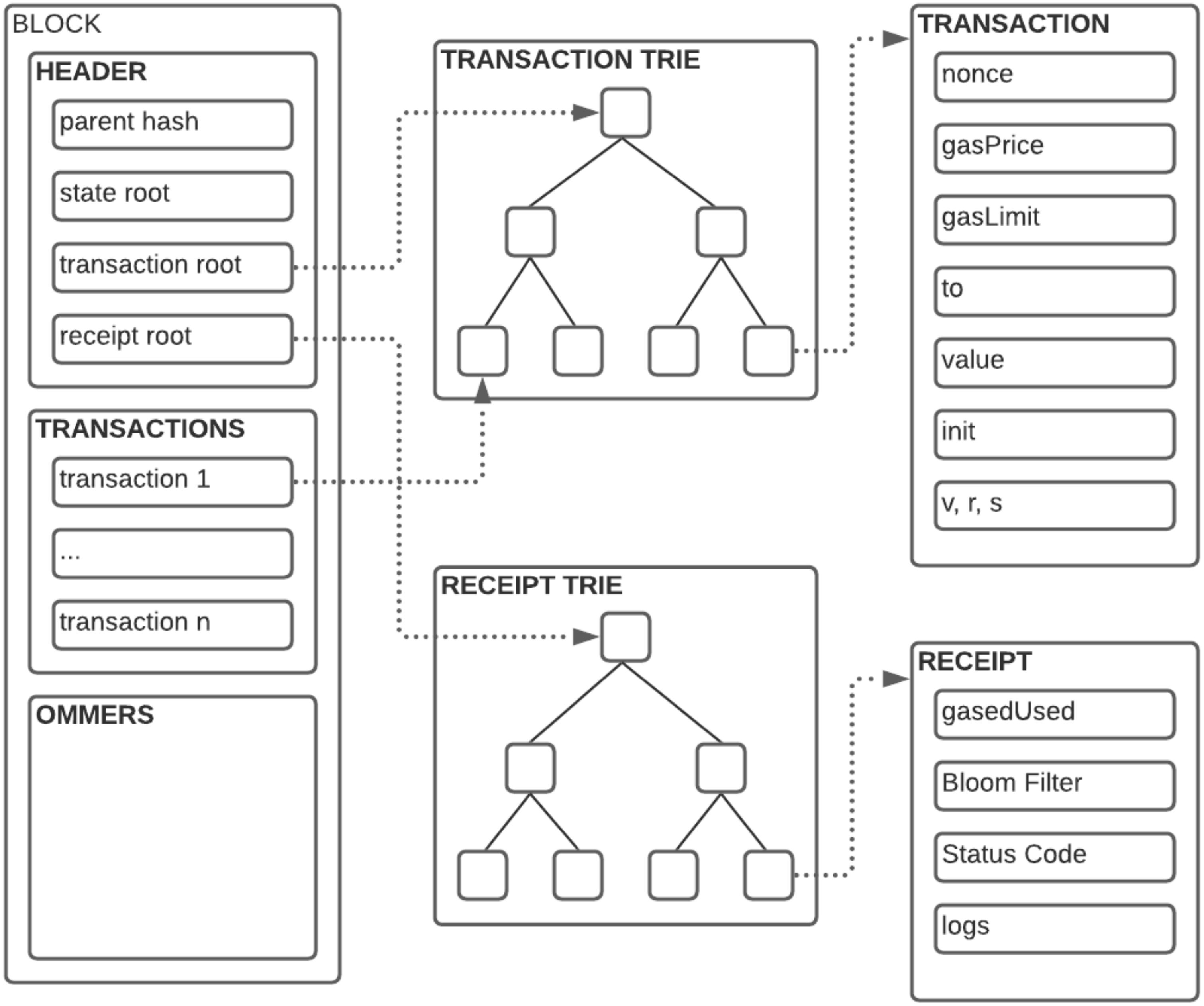

BLOCK
HEADER
parent hash
state root
transaction root
receipt root
TRANSACTIONS
transaction 1
...
transaction n
OMMERS
TRANSACTION TRIE
RECEIPT TRIE
TRANSACTION
nonce
gasPrice
gasLimit
to
value
init
v, r, s
RECEIPT
gasedUsed
Bloom Filter
Status Code
logs
Key-Value store
hash(RLP(node)) -> RLP(node)



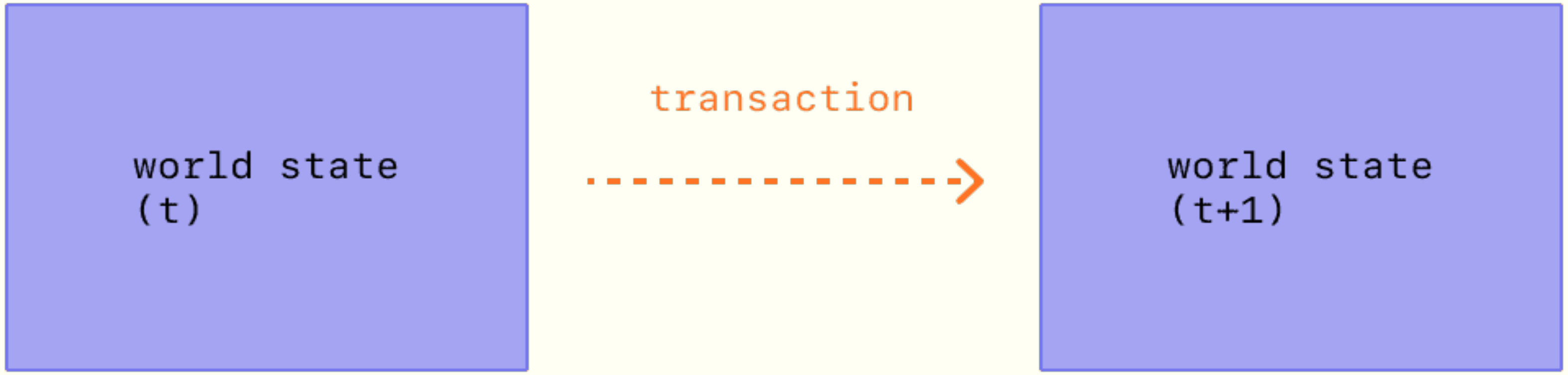
Receipts – effect of transactions

check log hash
bloom filter – false positives

ETHEREUM TRANSACTIONS AND GAS

ETHEREUM TRANSACTION

- A transaction is initiated by an externally-owned account
- The result of the transaction is changing word state.
- Lifecycle:
  - Generate transaction hash
  - Broadcast to the network, include transaction in transaction pool
  - Miner include transaction in a block
  - Transaction receive confirmations



ETHEREUM TRANSACTION

- Two types of transactions: contract creation (resulting in a new contract account containing compiled smart contract bytecode) and message calls

- Nonce scalar value equal to the number of transactions sent by the sender
- gasPrice scalar value equal to the number of Wei(10^{-18}) to be paid per unit of gas.
- gasLimit scalar value equal to the maximum amount of gas that should be used in executing the transaction
- to 160-bit address of the message call's recipient or null
- value number of Wei to be transferred.
- init unlimited size byte array, EVM code.
- data unlimited size byte array, input data.
- signature confirms that sender has authorize transaction

EVM - GAS

- Measures the amount of computational effort required to execute operations.
  - “Fuel” for Ethereum network – not currency!
- Each operation costs a specific amount of gas.
- For each transaction sender specify a “gas limit”, maximum amount he is willing to pay for the transaction to be processed.
- Gas limit is implicitly purchased from the sender’s account balance.
- The transaction is considered invalid if the account balance cannot support paying gas limit.
- Gas can be partially return to the sender.
- If transaction runs out of gas, then it’s reverted back to its original state.
- “Block gas limit” determines that amount of gas that can be spent per block.

ETHEREUM TRANSACTION

- Transaction validity

- Transaction is well formed RLP, no additional bytes.
- Transaction signature is valid.
- Transaction none is valid, equivalent to the sender’s current nonce.
- Gas limit is smaller than gas used by the transaction.
- The sender account balance contains at least the cost required to pay transaction.

- Gas limit * gas cost
- Gas limit * Base fee + tip

EVM - GAS EIP 1559

- Before EIP 1559 Gas cost set by first price auction system
- Everyone submit bid, miners select transactions with the highest fee.
- Often users pay more than 5x than necessary.

- Before EIP 1559 block size had fixed-size
- After EIP 1559 block size is variable and will increase or decrease depending on the network demand up until the block limit (30 million gas)

- After EIP 1559 block has a base fee determined by the blocks before. If block size is greater than block limit increase fee, if is less then the block size, decrease fee.

EVM – GAS EIP 1559

- Ethereum Improvement Proposals (EIP) describe standards for the Ethereum platform
  - Core improvements requiring consensus fork, miner startegy changes.
  - Networking
  - ERC – contract standards (ERC-20, ERC-721) Ethereum Request for comment.
- (London Upgrade) August 5th, 2021
  - Better transaction fee estimation, predictable transaction fees
  - Quicker transaction inclusion
  - counteract the release of ETH by burning a percentage of transaction fee.
- Replace first auction system with base fee.
- **maxPriorityFeePerGas** amount of gas paid as tip

Bibliography

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