MimbleWimble

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Incredibly powerful protocol

- Built-in anonymity
  - Transactions are confidential
  - No addresses, public identities, or etc.
  - Obfuscated transaction graph
    - Several challenges however yet to be solved to guarantee this
- Great scalability
  - No high CPU/memory demand, mobile/embedded-friendly
  - Modest transaction size
  - Transaction cut-through
- Despite its versatility, it’s formulated entirely in terms of “elementary” ECC
  - No complex constructs like bilinear pairing, zk-SNARK, or etc.
  - No trusted setup needed
  - Relies solely on the hardness of the discrete logarithm problem

What's different in MW

- No addresses
  - Each UTXO has a secret key, and it belongs to whoever knows it
- Transaction
  - No scripts in the blockchain
  - To build a valid transaction entities must collaborate.
    - i.e. it's an interactive process
    - This is where complex schemes may be negotiated (a.k.a. scriptless scripts)
  - Once built, the transaction is obscured, and basically only proves that:
    - No illegal inflation, i.e. money created from nothing
    - Authorization verification. In order to build a valid transaction the secret keys of all the input UTXOs must have been used.
      - This is the meaning of ownership – ability to spend it.

UTXO encoding

- Two generator points: G,H (for starters).
  - Must be “nothing-up-my-sleeve“ – i.e. their relation must not be known. A brief generating scheme must be specified (such as hashing strings).
- $C = \alpha \cdot G + v \cdot H$
  - α- blinding factor, a uniform (pseudo)random.
  - v - Value
- Pedersen Commitment (linear combination of those generators).
  - Hiding: the value of v is blinded
  - Binding: impossible to substitute other values for α, v.
  - Homomorphic: $C(\alpha_1, v_1) + C(\alpha_2, v_2) = C(\alpha_1 + \alpha_2, v_1 + v_2)$

Naïve transaction

Alice owns an UTXO containing v_A, wants to send Bob v_B, and receive a change v_A-v_B. This is their transaction:

- $C(\alpha_A, v_A) \rightarrow C(\alpha_A - \alpha_{A`}, v_B) + C(\alpha_{A`}, v_A - v_B)$

The verifier checks:

- $\sum(Input\ UTXOs) = \sum(Output\ UTXOs)$

Is it a good scheme? Of course no.

- Illegal inflation verification – FAILED.
  - no verification that $v_A \geq v_B$, output UTXO may contain "negative" (overflown) value.
- Authorization verification – FAILED.
  - Anyone can spend UTXO without the knowledge of its opening (the blinding factor and the value):
  - $C(?, ?) \rightarrow C(\alpha, v) + C(? - \alpha, ? - v)$

  (The second transaction output is a "fake" UTXO, its opening is unknown.)

Rangeproof

- A zero-knowledge non-interactive proof that proves that the value of the UTXO is within a limited range.
- Practically for a 256-bit ECC the value of the UTXO is restricted to 64 bits, which is both a fairly large number to encode the value, and far enough from the overflow risk when large number of UTXOs are summed.
- In addition to restricting the value of the UTXO, it can also be seen as a cryptographic signature, which is impossible to create (with non-negligible probability) unless the opening of the UTXO is known.
  - Prevents “tampering” with existing UTXO (adding/removing value or blinding factor).
  - Prevents creation of “fake” UTXOs with unknown opening.
- MW relies on Bulletproofs
  - Pretty sophisticated, yet implemented in terms of “elementary” ECC.
  - Dramatically smaller than other similar schemes (but not on par with zk-SNARK of course).
    - 64-bit rangeproof in terms of 256-bit ECC is encoded with 674 bytes.
  - Supports multi-signature (would require 3 iteration cycles).
  - Modest CPU load
  - Seems to be feasible to implement on embedded devices (HW wallets)
  - Verification is faster than signing
  - Multiple verification (like verifying a block) is speeded-up.

Another attempt

- $C(\alpha_A, v_A) \rightarrow C(\alpha_A - \alpha_{A`}, v_B) + C(\alpha_{A`}, v_A - v_B)$
- Rangeproofs are attached to all the outputs

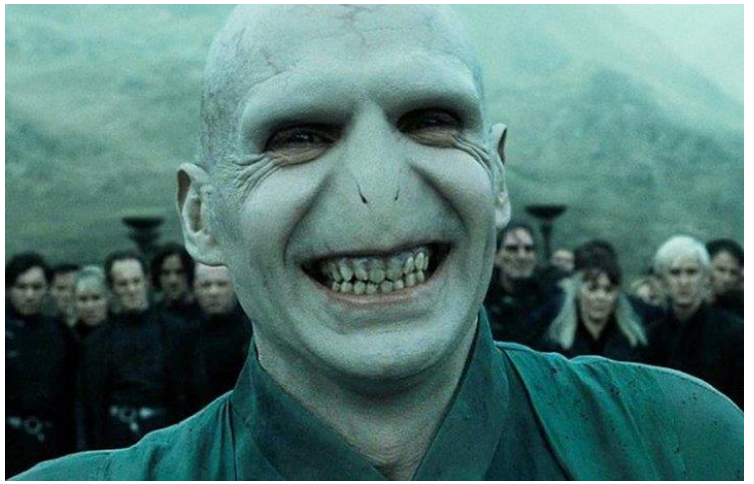
The verifier checks:

- $\sum(Input\ UTXOs) = \sum(Output\ UTXOs)$
- Rangeproofs for all the outputs are valid

Still not good enough:

- Authorization verification – FAILED.
  - Such a transaction is reversible
  - Alice knows the opening of Bob's UTXO, hence she can spend it any moment without Bob's permission.
    - No ownership transfer
  - This is inherent property of transactions which sum to zero, regardless to how many outputs there are.
    - Means, if Bob creates several outputs to receive v_2, Alice still knows their overall value and the total blinding factor, and can spend them all at-once.

Transactions with excess



- $C(\alpha_A, v_A) \rightarrow C(\alpha_B, v_B) + C(\alpha_{A`}, v_A - v_B) + \Delta\alpha \cdot G$
- Bob picks a random α_B, and it's unknown to Alice
- $\Delta\alpha = (\alpha_A - \alpha_{A`}) + (0 - \alpha_B)$

The $\Delta\alpha \cdot G$ is the transaction excess. It must be signed (Schnorr's signature), which proves that:

- It only contains the blinding factor, no Value is hidden
- The creator(s) of the excess must know the transaction excess ($\Delta\alpha$).

How the transaction is negotiated

- In a simple scenario Alice reveals $\alpha_A - \alpha_{A`}$ to Bob, and he completes the transaction
- In an advanced scenario – no one reveals blinding factors. Instead Alice and Bob co-sing the transacton excess (Schnorr's multi-signature)

The verifier checks:

- $\sum(Input\ UTXOs) = \sum(Output\ UTXOs) + \sum(Excesses)$
- Rangeproofs for all the outputs are valid
- Excess(es) are properly signed

Is this is a robust system? Are there unnoticed pitfalls?

- Illegal inflation verification.
  - Based on the homomorphic property of Pedersen Commitments
  - Rangeproofs prevent overflow attacks
  - Excesses are signed to prove (in particular) no money is hidden in the excess.
- Authorization verification.
  - All the transaction elements (UTXOs and excesses) are signed, to prevent tampering and creation of unknown objects.
  - Outputs are known – means inputs must be known as well.
  - Irreversibility of a transaction is due to the fact that excess may only be created in a transaction, and never spent.

Transaction kernel

- Since the excess is signed – we can add auxiliary data to it, which can apply additional validation rules and parameters.
- This concept is extended to a Transaction kernel object, which contains:
  - Public excess $\Delta\alpha \cdot G$
  - Optional fields (timelock parameters, hashlock preimage, etc.)
  - Transaction fee (optional as well)
  - Schnorr's signature.
    - Signs all the kernel contents (to prevent tampering)
    - The public is assumed to be $\Delta\alpha \cdot G$.
    - The private key is naturally $\Delta\alpha$.
- This is another reason why it's preferred to co-sign the kernel: all the agreed kernel parameters are collectively co-signed.
- Unlike UTXOs kernels can only be created, and never spent, so they are a "dead weight".
  - This has an impact on the system scalability.
  - With some effort it seems possible to eliminate kernels sometimes (more about this later)
  - But since they're guaranteed to stay - they may be used in various ways:
    - Prove the fact of the transaction
    - Implicitly reveal secret data to the transaction parties upon successful payment (private keys, hash preimages)
    - Flag transactions for 3rd party (more about this later)

Scriptless scripts (at a glance)

- Example: Alice pays Bob for revealing a secret key sk for a public key Pk.
  1. Alice and Bob agree on the price, pick UTXOs, reveal their parts of the excess, and create a kernel to be signed.
  2. Bob creates his part of the multi-signature. However he adds sk to the preimage (part of the Schnorr's signature).
  3. Alice verifies that, after adding her signature part, the signature sums not to zero, but to Pk.
  4. Alice adds her signature part, saves the current preimage, and sends the result to Bob.
  5. Bob fixes the preimage, and broadcasts the transaction to the network.
  6. Once visible in the blockchain – Alice subtracts the saved preimage from the correct one. The result is the sk.
  - In reality it's more complex
    - Both Alice and Bob must have locked their assets.
    - Alice must have created a time-locked UTXO, which she can't spend without Bob's permission
- Example: Alice buys something from Bob's internet store, she wants an invoice/warranty signed by Bob's known public key.
  1. Alice and Bob create a transaction kernel to be signed.
  2. Bob creates all the digital docs, which include the Kernel Excess, and sign them, and sends to Alice.
  3. After receiving and verifying the docs, Alice signs the kernel to complete the transaction
  - The signed documents are considered valid iff the kernel is indeed in the blockchain, means the payment actually took place.

Block

- Merged transactions is also a valid transaction
- Block is essentially one big transaction with many inputs and outputs.
- All the transaction elements (inputs, outputs, kernels) are sorted to obscure the original transaction graph

Is the transaction graph truly obscured? Well, No.

- Transactions are mixed, but not “dissolved”
- All the elements are blinded and signed – means it’s impossible to combine them non-interactively
- Trying different combinations it’s still feasible to puzzle out the original transactions.

Transaction Offset

- $C(\alpha_A, v_A) \rightarrow C(\alpha_B, v_B) + C(\alpha_{A`}, v_A - v_B) + \text{Kernel}(\Delta\alpha` \cdot G) + \beta$
  - Whereas $\alpha_A = \alpha_{A`} + \alpha_B + \Delta\alpha` + \beta$
  - Means – the transaction excess $\Delta\alpha$ is split into 2 parts
    - $\Delta\alpha`$ - goes into kernel (as before)
    - β - just revealed unencoded (scalar).

The verifier checks:

- $\sum(Input\ UTXOs) = \sum(Output\ UTXOs) + \sum(Excesses) + \beta \cdot G$

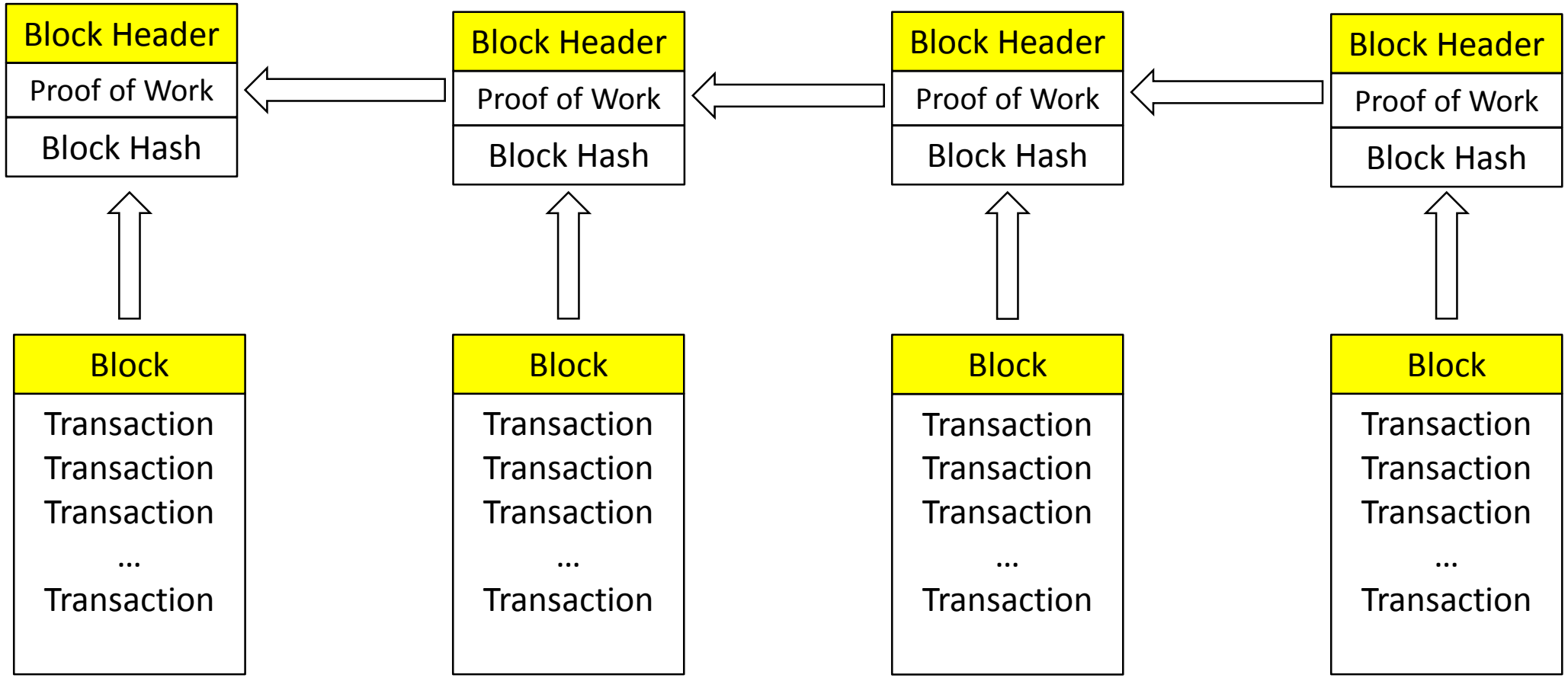
There is finally a transaction element, which can be merged (simply summed)!

- Doesn't break the robustness of the system, since offset – is a preimage. It can't conceal money or compensate for unknown blinding factors.
- Once the transactions are combined, their offsets are merged, and this is irreversible.
  - It's not possible anymore to split a combined transaction into independent components.
- Block contains multiple inputs, outputs, and kernels (sorted in an unambiguous way), and a single offset
- Transaction graph is now truly obscured (almost…)

Transaction cut-through

- Block is a big transaction
- Multiple blocks can be merged as well, to create one big transaction
- Output UTXOs that are created and then spent can be removed completely
  - Means – combined blocks tend to be smaller
- The whole blockchain can be combined into a single huge block, with only outputs that are unspent yet.
  - Dramatic scalability improvement
  - Some information is lost (obviously). But it's still possible to verify that the combined block describes a valid system transformation according to the rules.
- <u>But how the authenticity of the combined blocks can be verified?</u>

Standard Blockchain organization



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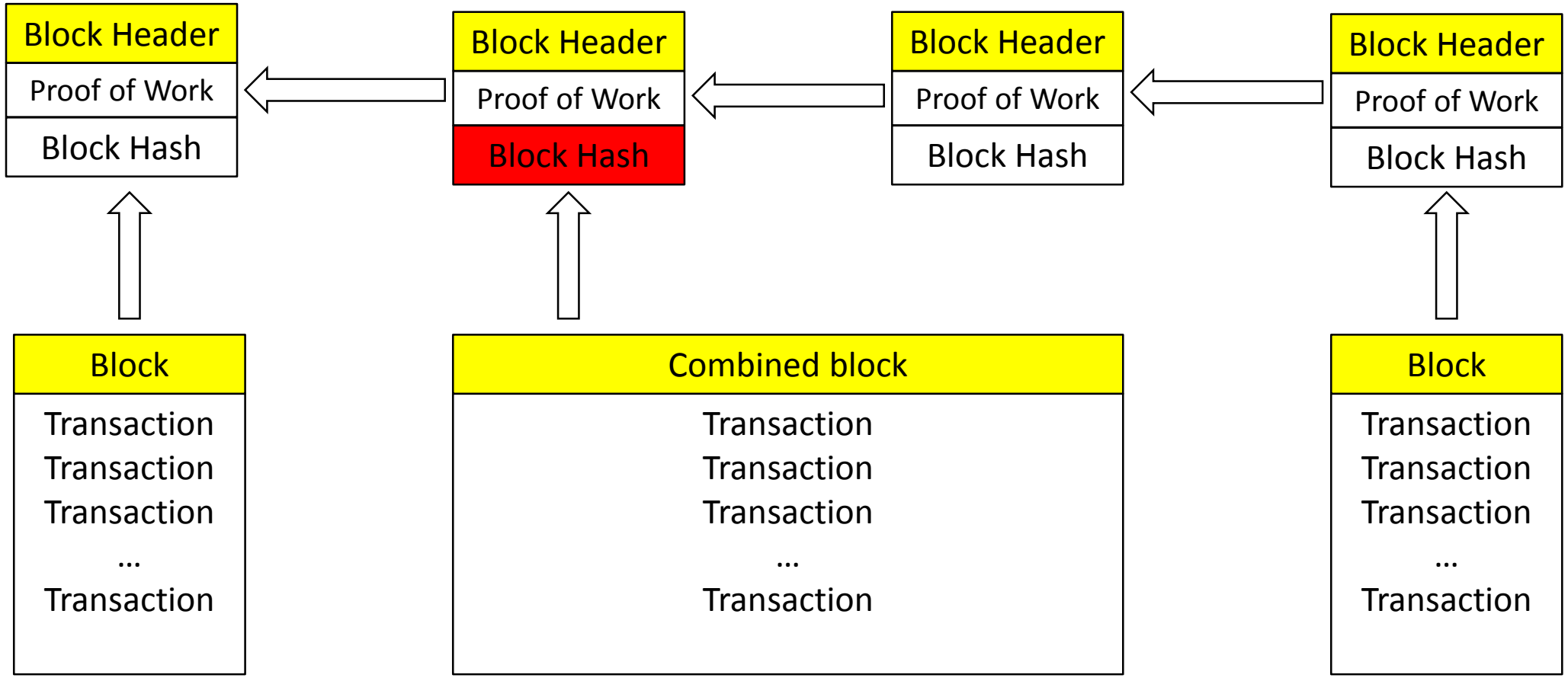
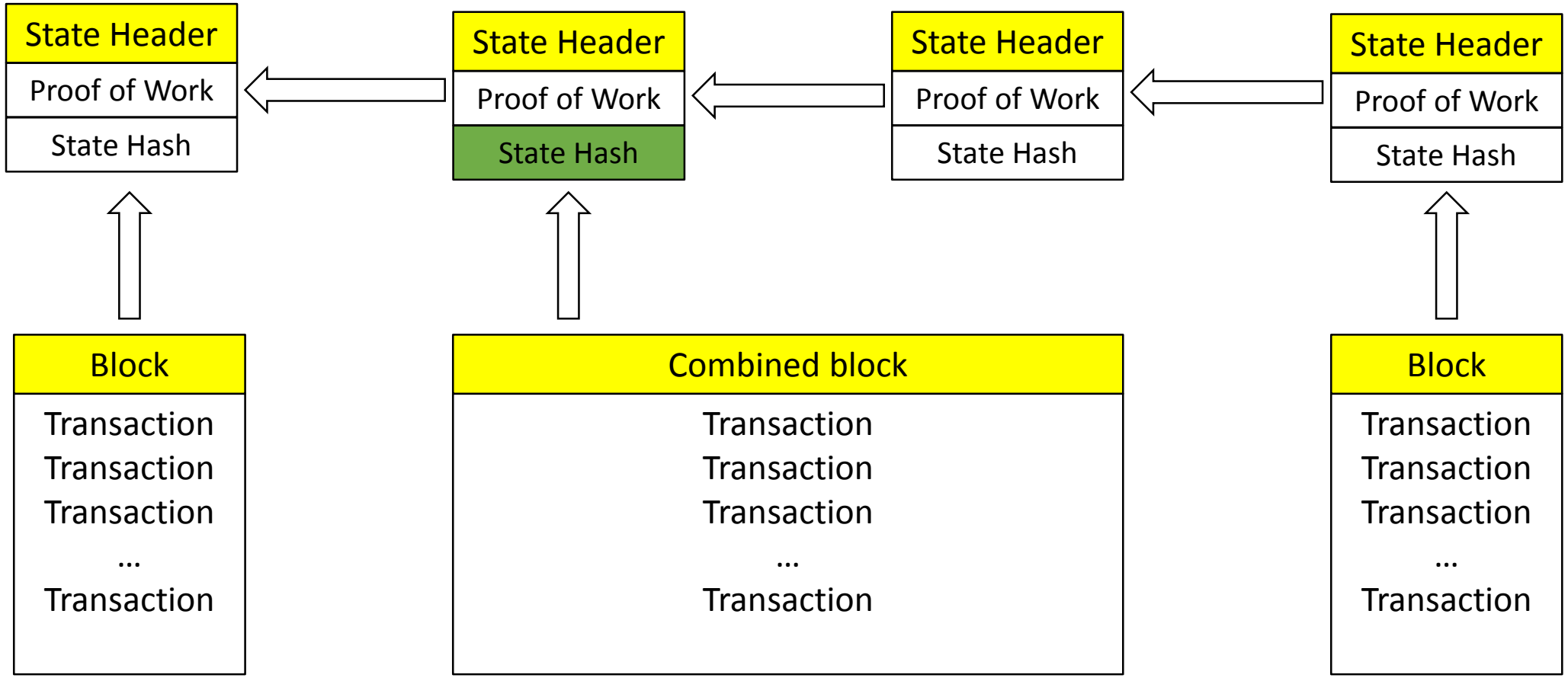


BEAM Blockchain



System State

- All the elements present in the system, with the relevant parameters
  - UTXOs
  - Kernels
  - Inherited States
- Implemented as a combination of several MMR-like constructs
  - Invariant to the history
  - Fast Hash evaluation after state transition (i.e. not from scratch)
  - Supports Merkle proofs for all the contained elements
  - No need to “save” proofs

Transaction broadcast

- Obscured Transaction graph is of critical importance
- Naïve broadcast scheme immediate reveals the transaction graph!
  - A single malicious node immediately gets all the original transactions
- Known solutions
  - CoinSchuffle, ValueSchuffle
    - Seems promising, but maybe cumbersome in practice
    - Requires large group of unrelated users to collaborate
    - DoS attack is easy
    - Attacker may create many malicious users “for free”
  - Dandelion(++)
    - Was designed to conceal the identity, regardless to the transaction graph
- A simple solution, which *may* be practically good enough
  - Modified Dandelion, with partial transaction merge during the stem phase.
  - No hassles for the users (actually transparent, may complement CoinSchuffle and etc.).
  - No guarantee of expected behavior, but non-conforming Nodes can be identified
  - Disadvantage: easy to abuse the transaction fee.

Transaction Negotiation

- Secure channel with authentication is a must
- P2P – ok, but
  - Requires users to be online simultaneously
  - Cumbersome in some networks (NAT & friends)
  - Identities can be traced by traffic analyzers
- Secure BBS system
  - Separate from the blockchain, but may use the same network addresses
  - Solves network configuration hassles
  - Asynchronous communication
  - Messaging via “addresses”
    - May be (and usually are) temporary for one-time usage
    - Have nothing to do with the blockchain
  - E2E encryption, To/From addresses are not leaked
  - For obfuscation: many unrelated negotiators exchange messages over the same channel
    - Every user receives all the channel messages, but is able decrypt only the intended ones

BEAM extensions

Non-interactive payments

- Alice expects to receive payments (no matter from who).
  - Prepares an UTXO and a *compensatory* kernel in advance.
  - Advertises the UTXO, kernel, and the expected value.
- Bob wishes to pay
  - Prepares a transaction where the specific value is “lost”.
  - Adds Alice’s UTXO + kernel to collect the value.
  - Broadcasts the transaction with 2 kernels.
- The problem:
  - Transaction looks ok, but it’s actually consists of 2 parts: donor and acceptor.
  - Blinding factor of each part is zero, the Value is not.
  - Malicious Node can realize this!
    - Maybe aware of Alice expectation
    - Value transfer can be brute-forced!
  - Malicious Node can replace Alice’s acceptor part with its own
- Solution
  - Protocol extension: ***Kernel Fusion***
  - Bob’s kernel must contain an explicit reference to Alice’s

BEAM extensions

Kernel elimination

- Kernels may also be consumed, yet the irreversibility is guaranteed!
  - Assuming kernels may be both inputs and outputs of a transaction
  - Verifier checks that for every input kernel there's a corresponding output kernel, which:
    1. Was (co)signed by the same group of users.
    2. Obviously newer
- Protocol extension: *Kernel Excess Multiplier*
  - Effective kernel excess is multiplied by the explicitly defined multiplier
  - Corresponding output kernel must have
    1. Exactly the same unmultiplied excess
    2. Multiplier which is (strictly) bigger
- Can significantly improve the scalability in the long-run
- Drawback: reveals some info about the transactions
  - Reveals the fact that the same group of users perform a transaction
- Currently – not encouraged

BEAM extensions

Auditable Wallet

- Applicable for business, obliged to operate w.r.t. regulations
- The goal: provide them with the tools to be:
  - As transparent as possible to appropriate authorities
  - Preserve the anonymity to others
  - Disclose only the required information, without compromising other parties
  - Allow the auditor to fully reconstruct the transaction graph of this wallet
- Design
  - Auditable wallet gives a public key to the auditor(s)
  - Every transaction gets an extra kernel, which:
    - Can be identified in the blockchain by the auditor (only), using the provided public key.
    - Contains a commitment to all the relevant details (including spent and received UTXOs)
  - After getting all the details (off-chain), the auditor verifies:
    - Authenticity w.r.t. initially reported commitment
    - Values of all the wallet's UTXOs
      - Using non-confidential signature, which reveals the Value, but not the blinding factor
    - Transaction graph validation (i.e. every spent UTXO must have been reported earlier)
- Transaction and reporting are atomic! No way there's a report without transaction taking place.

Thoughts

- Trade multiple types of coins on the same blockchain!
  - Easy to implement:
    - Add another H-generator(s)
    - Extend the rangeproof to cover multiple H-generators in a single commitment
      - Bulletproof is very efficient for this case
  - Everything is confidential out-of-the-box!
  - Can (theoretically) be used to trade other currencies or assets
  - What's unclear (yet):
    - How the emission of other coin types should be regulated?
      - Apply different emission rules (constant, halving, etc.)
      - Allow each user to inject arbitrary amount of its type of coin?

Thank you

- For more information please visit our project sites:
  - https://github.com/beam-mw/beam/wiki
  - https://www.beam-mw.com/