# Hardening Lightning

## Harder, Better, Faster Stronger

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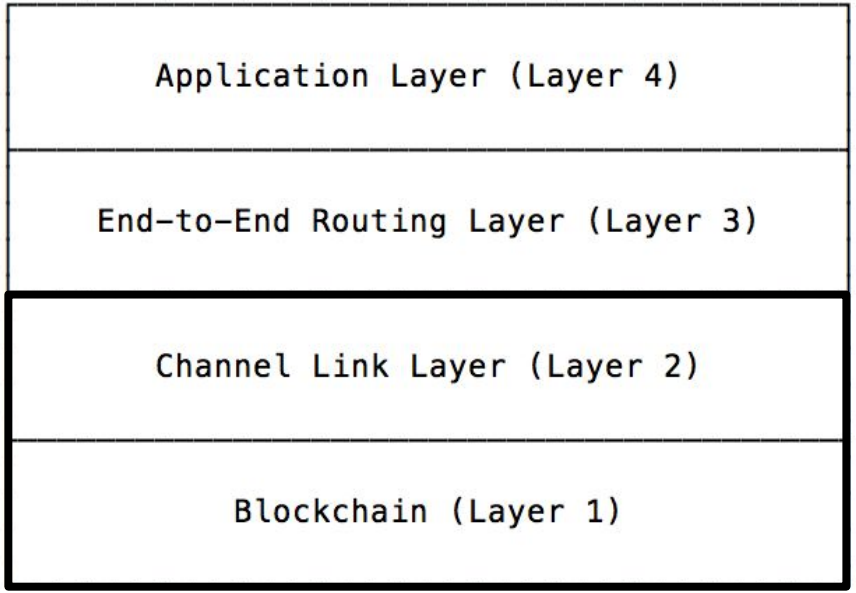
# Lightning's Security Model

- Lightning uses the underlying chain as **dispute mediation** system
  - Contract **creation+enforcement** happen **on-chain**
  - Contract **execution** happens **off-chain**
  - Secure chain acts as the **trust anchor**
- "The easy way □, or the hard way □"
  - **Optimistically** we only require on-chain **enforcement** in the case of a **dispute**.
- In this case of a **dispute**, we assume can write to chain **"eventually"** * (`T`)
  - `T = csv_value`
  - **Configurable**, determines chain watching frequency
- We assume participants don't **collude** with **pool-operators/miners**
  - **Strong non-censorship** assumption

**The Layers of Lightning**



# Hardening Contract Breach Defense (Strategy)

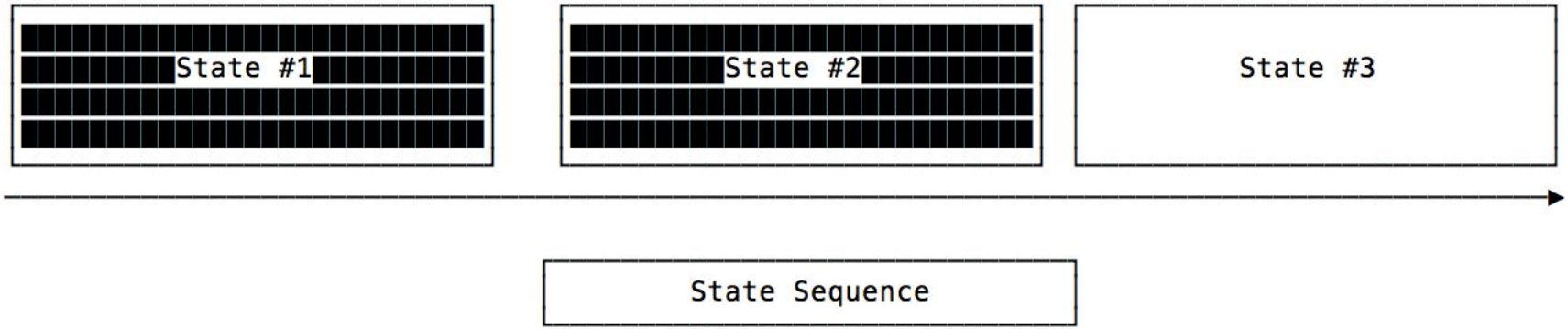
- Active breach defense:
  - Watching chain in order to **refute invalid state attestation**
  - **Provide evidence** to chain showing **violation** of signed **contract**
  - “Blockchain as **judge**” model
- In face of **large backlog** (or low fee rate):
  - Possibility unable to confirm **justice tx** in time
  - **Failure** to provide **evidence**, allow **cheater to succeed** 😱
- Cheater **locked** into **fixed fee** due to commitment structure
- **Cheater** only has **access** to their **active balance**
- Defender has access to **entire balance** in channel
- **Scorched Earth** approach:
  - Strategy: **iteratively siphon** cheater’s **funds** to **fees**!
  - End game: **all cheater’s funds go to miners**, **defender** made **whole**
    - Cheater needs to pay **fees > balance** to “succeed”
  - Assumes widespread replacement by fee rate!

# Reducing Client Side History Storage

- Lightning **contract execution** is **local**:
  - Clients need to **store current state**
  - **Prior states** for possible on-chain **breach remedy enforcement**
  - “**Shadow chain**” only **manifested** on mainchain in event of **breakdown**
- Channels **state transitions:**
  - **Update** to current **commitment** (add/remove HTLCs, new contracts, etc)
  - Each state transition produces a new state
  - Need to **keep track** of *portion* of **prior state** in order to be able to enforce
- **Goal:** reduce per-channel state scales entire system
  - Allows for “lighter” light clients
  - High throughput backbone nodes may see considerable savings
- **Minimally**, one needs to **store the current state**
  - **Required** to be able to go on-chain for enforcement/delivery

# Reducing Client Side History Storage - Overview of Commitment Invalidation

- Commitment Invalidation
  - Each state transition, **invalidates** the prior state
  - **Critical** for safety of **bi-di** channels
  - Incentives promote forward progression
    - If you violate the contract, you get **slashed!**
    - **Worst-case enforcement**: party attempts to claim **prior** state
  - Naive method: keep **all** prior states!
    - In **high-velocity** scenario, quickly becomes **untenable**
    - Would then require **frequent resets** to abandon prior state
      **unnecessary** on-chain **control** traffic!



# Reducing Client Side History Storage - History of Succinct Commitment Invalidation

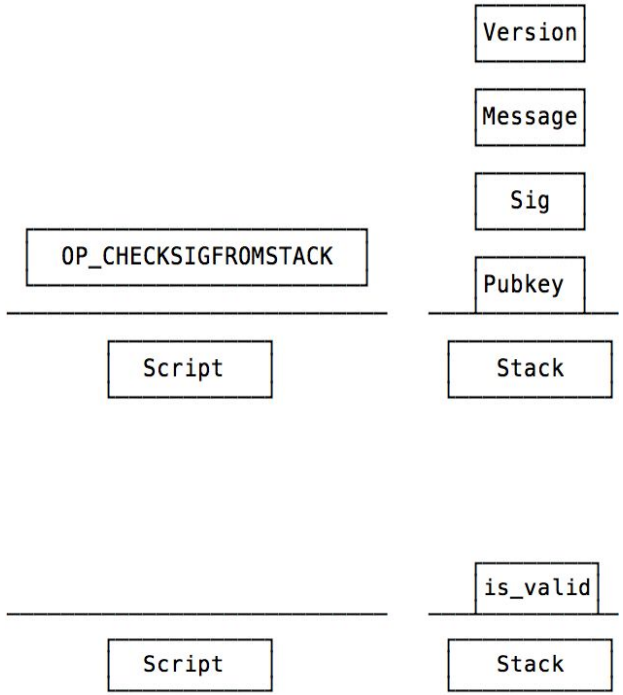
- History of prior commitment invalidation mechanisms
  - **Decrementing** sequence locks (utilizes **BIP 68**)
    - **How**: use relative time-locks s.t latest state can go in **before** prior states
    - **Drawback:** limits number of possible **updates**
  - Commitment **invalidation tree** (used in **Duplex Payment Channels** (cdecker))
    - **How:** structure commitments in **tree** s.t **parent must be broadcast before leaf**
      - Roots have **decrementing** time lock w/“kick-off” allows for indefinite lifetime
    - **Drawback:** at **cost** of **increased on-chain footprint**
  - Commitment **Revocations** (hash or key based, current channel design)
    - **How:** must reveal secret of **prior state** when accepting new state
    - **Drawback:** MUST **critically store** O(log N) of remote party, more complex key derivation
      - Asymmetric state
- Goal: new commitment design with **symmetric state**, constant storage for prior states

# Reducing Client Side History Storage - Commitment Invalidation Lightning 1.1

- Lightning 1.0 uses **key-based** commitment invalidation:
  - Each party has multiple **static EC points** (we call em “basepoints”)
  - Static points **tweaked** with fresh randomness for each state
  - Randomness derived from a **verifiable PRF**
    - Currently used multidimensional hashchain: **shachain(k, i)**
- Revocation Key Derivation (your state, my `revBase`):
  - `R_i = revBase*sha256(revBase || commitPoint_i)+ commitPoint*sha256(commitPoint_i || revBase)`
  - `commitPoint_i = shachain(k, i) * G`
  - Relies on fact that: `P = A + B = (a+b)*G`
- Key Revocation:
  - Reveal `commitSecret = shachain(k, i)`
- Key Validation:
  - `revPriv_i = revokeBasePriv * sha256(revBase || commitPoint) + (commitSecret * sha256(commitPoint || revBase)`
- Cons `(M=num states, M = num_historical_htlcs)`
  - Client Storage: `C + o(log k)`
  - Outsourcer Storage: `O(M) + O(N) + log( k)`
  - Complex key derivation

# Reducing Client Side History Storage - OP_CHECKSIGFROMSTACK

- Current signature validation operations in bitcoin assume an **implicit** message:
  - `message = sighash( transaction=vm.tx, sighash = sig.sighash_flags, )`
- Unable to verify signatures on **arbitrary messages!**
- Enter `OP_CHECKSIGFROMSTACK (CSFS)`
  - Args: `<message_hash> <sig> <pubkey>`
  - Returns: `1 if valid triple else, false`
- Use cases:
  - "*Blessed*" structured messages
  - Output **delegation**
  - Oracles



# Reducing Client Side History Storage - Signed Sequence Commitments

- Signed Sequence Commitments
  - **Generic** commitment state invalidation scheme
  - **Openings** of **signed** commitments **replaces revocation keys**
- State transition:
  - Reveal prior **commitment opening**:
    - `open(c) = (n, r)`
    - `n = state number as int`
    - `r = randomness`
  - Embed `c` within commitment output script
  - Sign next commitment:
    - `c = commit(r, n++)`
    - `s = sig(A+B, c)`
- Enforcement:
  - Present: **(sig, c, n, r),** s.t **verify(sig, key, c) && open(c) == (n', r) && n' > n**
  - **"I know of an opening to a signed commitment (by broadcaster) of a newer seqno"**
  - Each state creates new **signed sequence**, only need to **store latest** one!
- Pros
  - Now **O(1)** storage for client **and** outsourcer
  - Simpler client side implementation
  - Uses **same** BOLT #2 state machine

# Scaling Outsourcing - Review of State Outsourcing

- LN assumes **decentralized** mining, **on-chain liveness**
  - On-chain censorship major issue
  - CSV value **T** acts as **time-based security parameter**
    - **Configurable on a channel to channel basis**
- If **unable** to be **eternally vigilant**, can outsource to **WatchTower**
  - Under current design:
    - For commitments:
      - Send initial base points (needed to construct **witness script template**)
      - For **each** state send a **new signature** for **justice transaction**
      - Send *description* of **justice tx** assumed both sides use BIP 69
    - For HTLCs
      - Encrypt opaque blob with **txid[:16]**
  - Various **compensation**/**authentication** mechanisms possible
    - **ZKP's** for authentication
    - Pay-per-state, only provide bonus upon action, subscription, etc

# Scaling Outsourcing - Lighter Outsourcers

- Outsourcers + Signed Sequence Commitments
  - Only need **single** `(c, n, s, r)` tuple **per-client**
  - Able to **skip** outsourcing states!
    - elekrem/shachain approach have **strict ordering requirement**
- New Scheme:
  - **Authenticate** in **sybil-resistant** manner
    - Ring sig, send channel proof, post time-locked bond, etc
  - Authentication serves as `user_id`
  - For state `N > N'`:
    - `O_blob = {revType || (c, n, s, r) || revInfo}`
    - Send o_blob to outsourcer, it replaces prior state
- As is, constant state if letting outsourcer take all funds:
  - If client **wants cheater's funds**, still need **sig** to **enforce structure**
  - `revInfo` describes what **justice tx** looks like
    - Fees
    - Total compensation for outsourcer
    - Pubkey scripts

# Scaling Outsourcing - Outsourcer Incentivization

- Ideally, outsourcers are **compensated:**
  - They **provide a service**, require running node (light client / full-node)f
  - Two routes: **pay-per-state** or **retribution bonus**
- Retribution Bonus:
  - Outsourcer **negotiates** up front **% of cheater's funds**
  - **Details** (structure of justice tx) **contained** in `revInfo`
  - Sig/covenant **fails** if **structure violated**
  - Ideally, breaches are unlikely, so may not be enough
- Pay-Per-State:
  - **Pay** outsourcer for **each state** sent (able to batch, etc)
  - Use **outsourcer** specific **e-cash tokens** (credits: Anton Kumaigorodski)
    - **Pay** outsourcer to for **batch of tokens** (over LN ideally)
    - **Unblinded** receiver tokens, unlink for initial payment
  - Send token along with `o_blob` for each state
- Why not both?

# Scaling Outsourcing - Outsourcer Static Backups

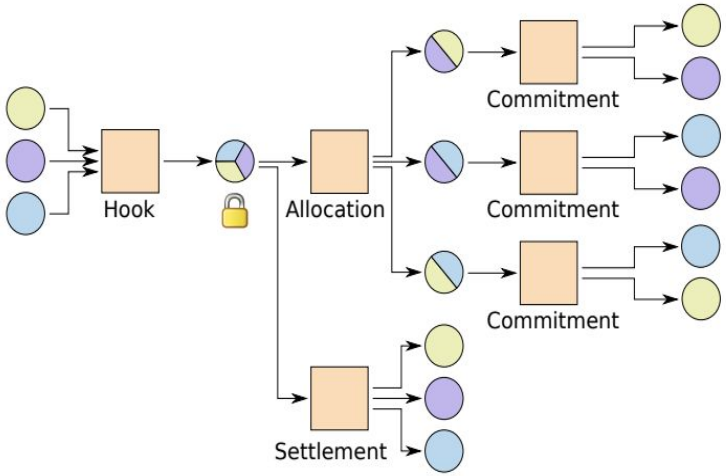
- Lightning wallets have **additional storage requirements** compared to regular on-chain wallets
  - **Static** state:
    - Set of **open channels**, derived keys, etc
  - **Dynamic** state:
    - Optionally delegated to third party outsourcing
- **Overload outsourcer** by also sending **encrypted static** state **backup**
  - **Re-use** prior **authentication** in case of data loss
  - Able to **restore** all **prior channels** + history
  - Upon reconnect **ascertain** if on **prior state**
    - BOLT #2 addition, detect during chan state synchronization
- Who **watches** the **watchers**?
  - Use **proof-of-retrievability protocol** over static+dynamic states
  - **Outsource random challenges**, provider **notifies** client of **outsourcer infidelity**

# On-Chain Succinctness - 2-Stage HTLCs

- In current commitment design (BOLT#3) **CSV+CLTV decoupled** in HTLC's:
  - **Prior issue** where if **CSV is large**, **CLTV in total hop must be >>**
  - Solved by making **HTLC claiming** a **2-stage state machine**
    - **Off-chain** multi-sig **covenants**
    - **Attest** (broadcast) -> **Delay** (csv) -> **Claim** (sweep)
  - Cons:
    - Requires **distinct** transaction for **each HTLC**
    - Must store **signature** for **each HTLC**
    - New state updates require **signing+verifying** N sigs (for each HTLC)
- Solution:
  - Use **actual covenants** in HTLC outputs!
  - **Eliminates** sig+verify w/ commitment creation
  - **Eliminates** sig **storage** of current state
  - Add **independant script** for HTLC revocation clause (reuse commitment invalidation technique!)
- Stop gap: `sighash_single + sighash_acp`
  - Allows 2-stage HTLC transitions to be coalesced into single transaction

# On-Chain Succinctness - Multi-Party Channels

- Recent work on **multi-party channels**:
  - *Scalable Funding of Bitcoin Micropayment Channel Networks*
- Multi-party channels via **hierarchy** of **multisig** and **regular bi-di channels**:
  - **Hook**:
    - **Master** multisig channel **creation**
  - **Allocation**
    - **Fan-out** multisig funds distribution
  - **Commitment**:
    - Regular multisig 2v2 channels
- Keybased revocations blow up state:
  - Paper's solution: use invalidation tree for root allocation replacement
  - **Cons**: **large** number of **on-chain transactions** on **worst case**
- **Reuse** Signed **Sequence Commitments**!
  - **Symmetric** state, maintain **constant** revocation state



# On-Chain Succinctness - Fee Control

- Dangling commitment issue:
  - You need to **force close** due to channel peer **inactivity**
  - Currently, no way to adjust commitment fee
  - All your outputs are **time-locked** can't use **CPFP!**
  - Solution:
    - **CPFP** reserve **hook**:
      - Channel creation specifies reserve value
      - Make portion explicit using distinct outputs w/ no delay
      - Allows either party to **anchor** a commitment
- Participants must **guess fees** ahead of time:
  - Initiator uses `update_fee` message to regulate
  - Massive swings may leave **fees insufficient**
  - Solution:
    - Don't add apriori fee to commitment transaction
    - Instead, use liberal sighash flags to allow for fee paying inputs

# Thank You!

Any questions?