Lightning Network

Joseph Poon joseph@lightning.network
Thaddeus Dryja rx@awsomnet.org

SF Bitcoin Devs
Feb 23, 2015

http://lightning.network/

Problems

- Transactions aren’t instant
- Micropayments don’t actually work
  - High transaction fees
- “Bitcoin Doesn’t Scale”

“Bitcoin Doesn’t Scale”

- 1 MB blocks:
  - 7 transactions per second @ 250 bytes/tx
  - ~220 million transactions per **year**
  - Not enough for a city, let alone the world
- 1 Billion transactions per day:
  - 1.6 GB blocks (1655 MB)
  - 87 Terabytes/year (87029089 MB)
  - Maybe enough for one large metro area?
  - Centralization (mining!)

“Bitcoin Doesn’t Scale”

- 7 billion people doing 2 blockchain transactions per day
  - 24 GB blocks
  - 3.5 TB/day
  - 1.27 PB/year
- Bigger blocks = Centralization
  - Very few full nodes
  - Very few miners
  - De facto inability to validate blockchain

Scalability Solutions

- The SQL Database Model
  - Very scalable, very fast
  - Off chain transactions implemented today with ChangeTip, Coinbase, others
- Sidechains
  - Many blockchains with inter-chain transfers
- Payment Channels
  - Many payments between two pre-determined parties

Scalability Solutions

- The SQL Database Model
  - Also implemented by MTGox Redeemable Codes
- Sidechains
  - Not primarily a scalability solution
  - Sending funds between chains is two transactions
- Payment Channels
  - Only helps when people pay each other many times (recurring billing, time-based microtransactions)

Anyone to Anyone Payments

- In bitcoin, any output can pay to any other
- In the SQL database model:
  - I need to have an entry in your SQL db
- On Sidechains:
  - I need to be on your sidechain
- In a Payment Channel:
  - I need to have a channel open with you

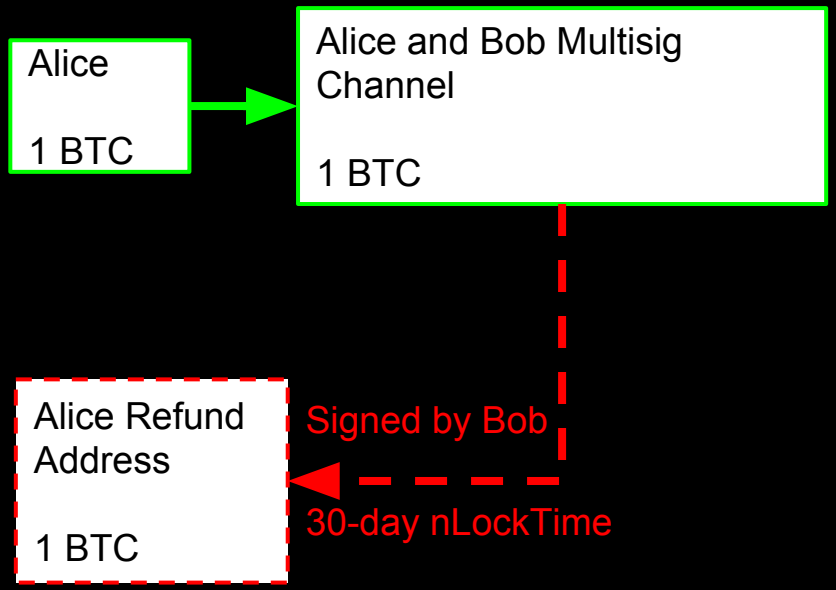
Bitcoin Lightning Network

- Payment channels between many parties in a multi-hop hub and spoke model (similar to internet routing)
- Minimally trusted intermediaries (they can’t take your coins)
- With a malleability fix via a soft-fork, Bitcoin can scale to billions of transactions per day

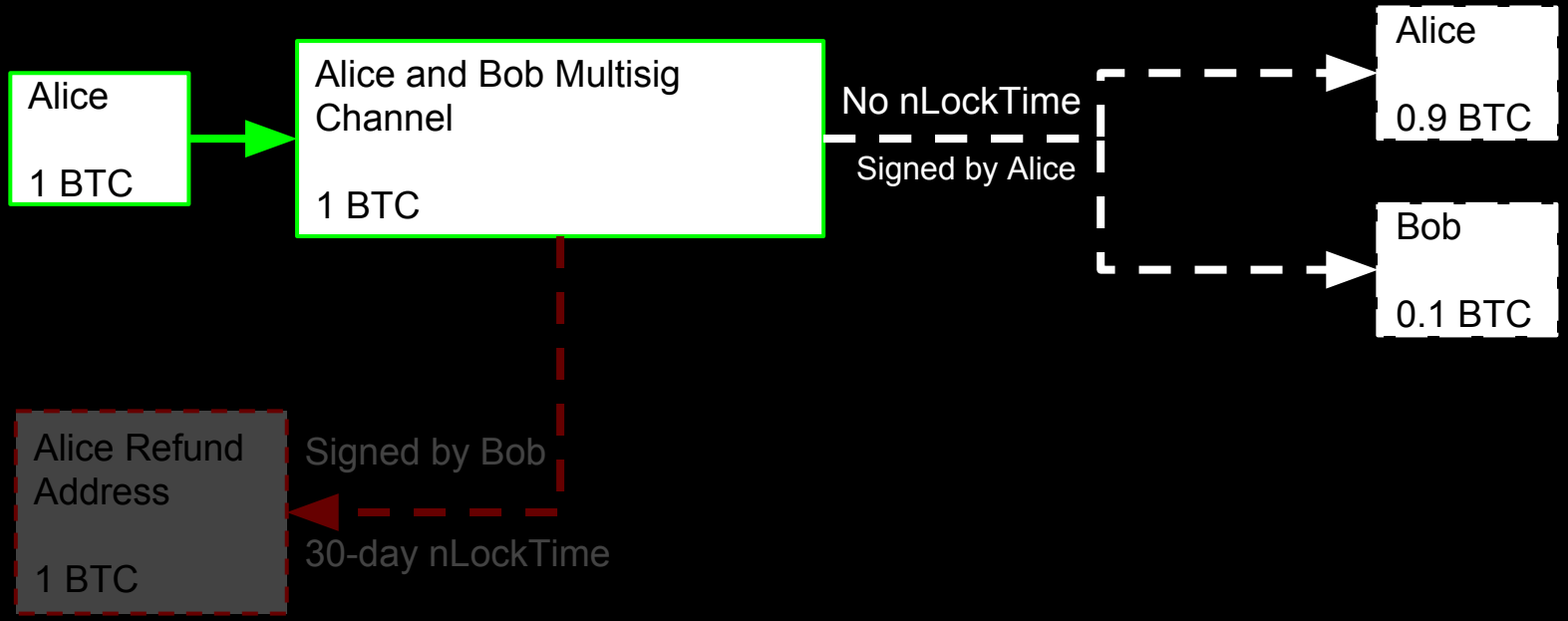
What are Payment Channels

- Introduced a while ago (not a new idea)
- Uses multi-sig
- Allows two people to send transactions to each other without hitting the Bitcoin blockchain

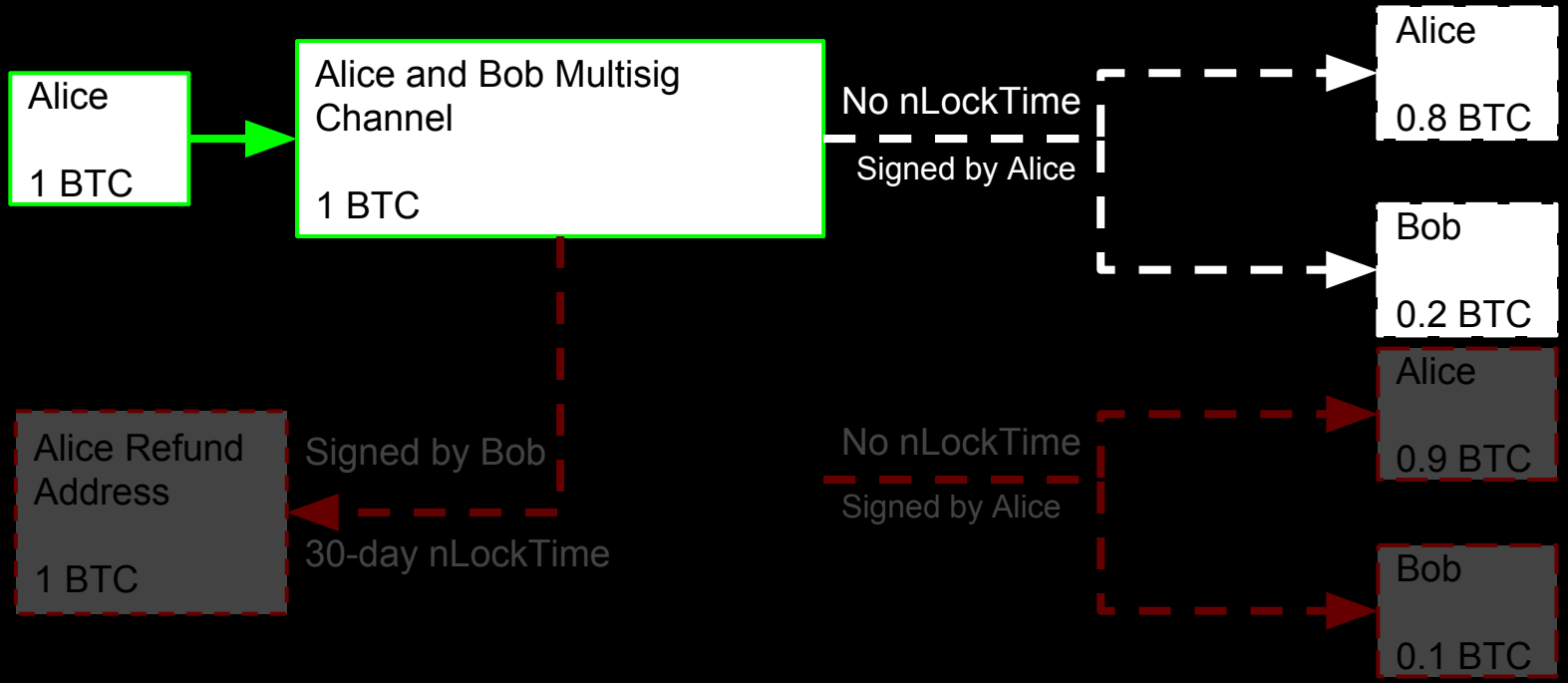
Unidirectional Channel



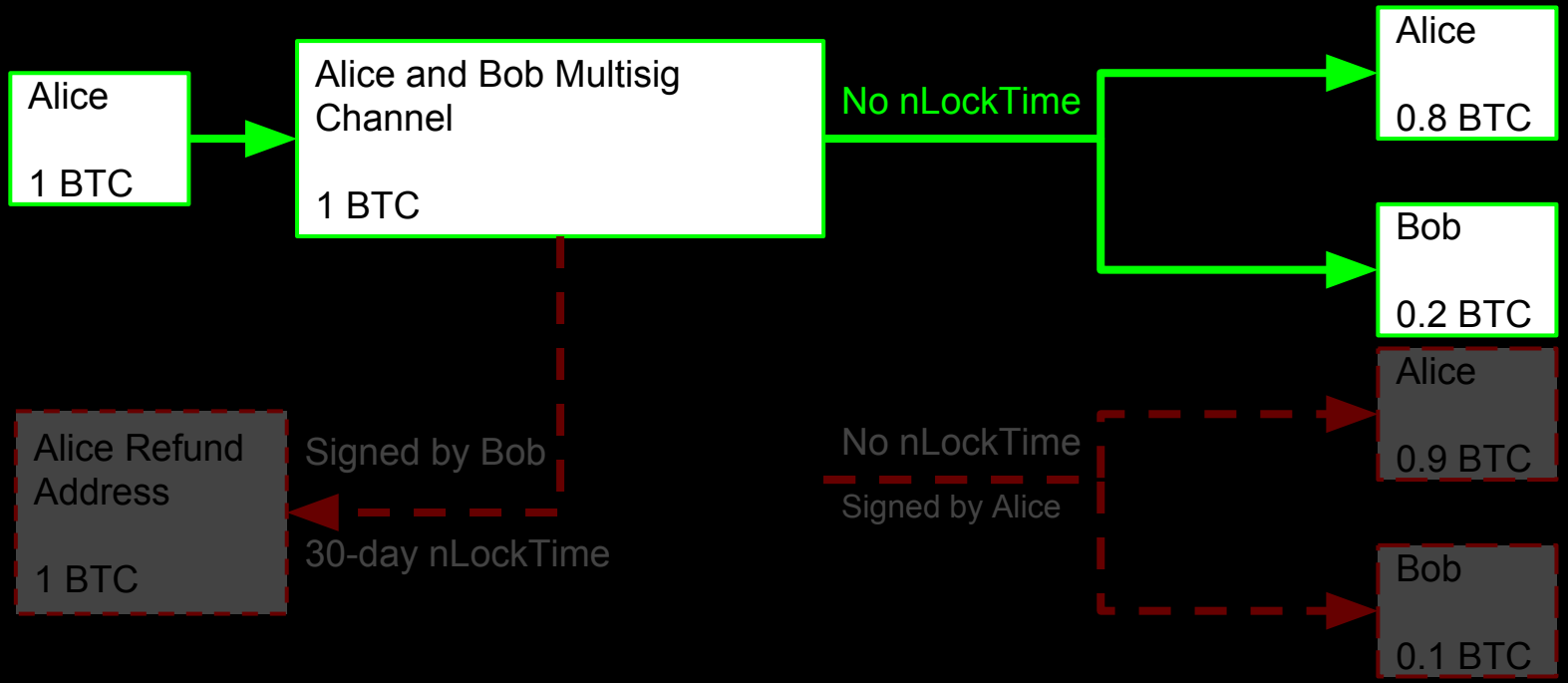
Unidirectional Channel



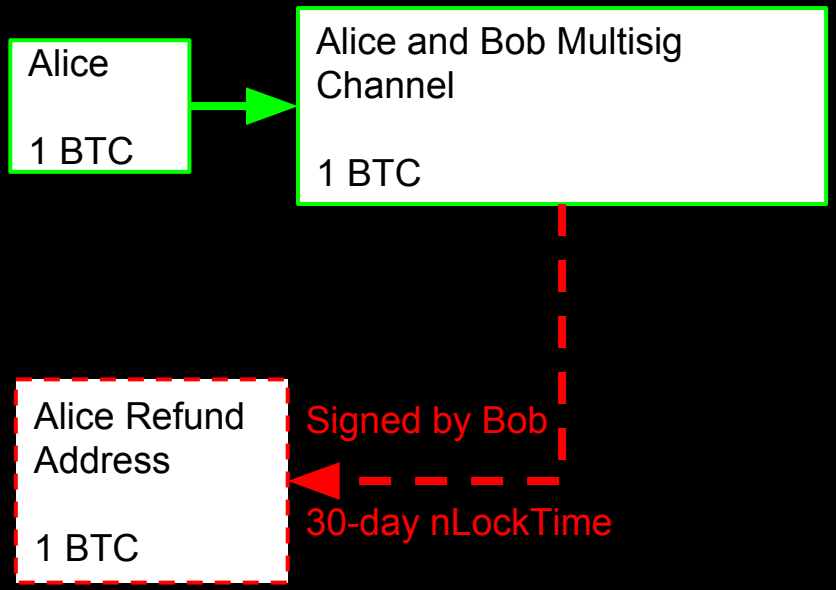
Unidirectional Channel



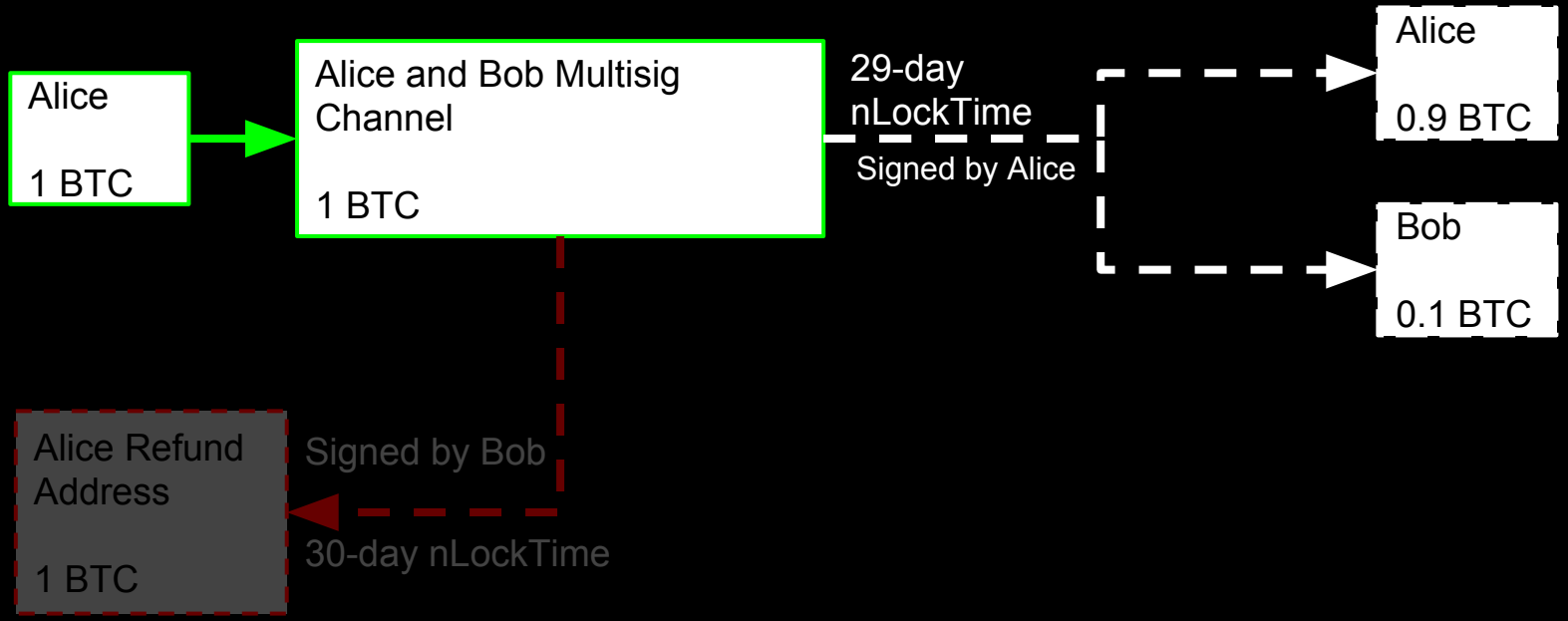
Unidirectional Channel



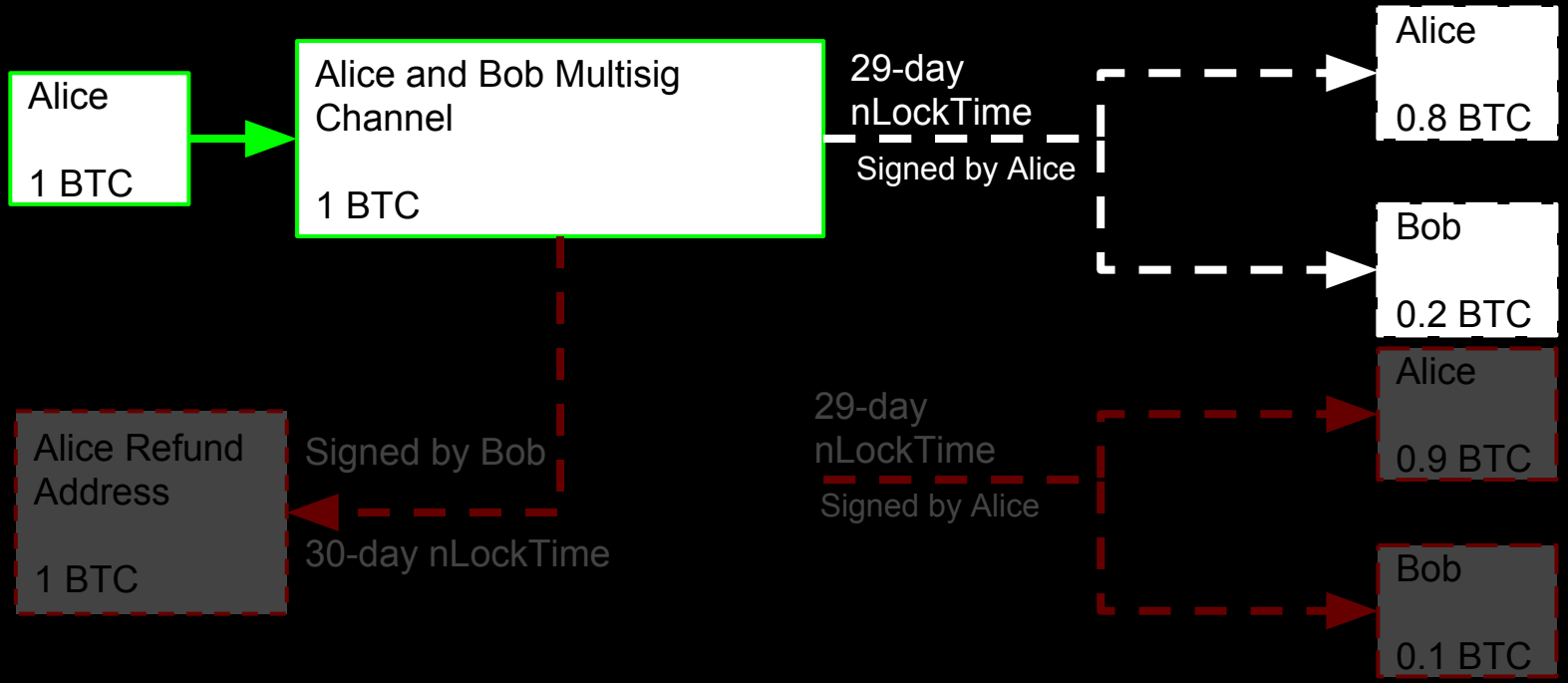
Bidirectional Channel



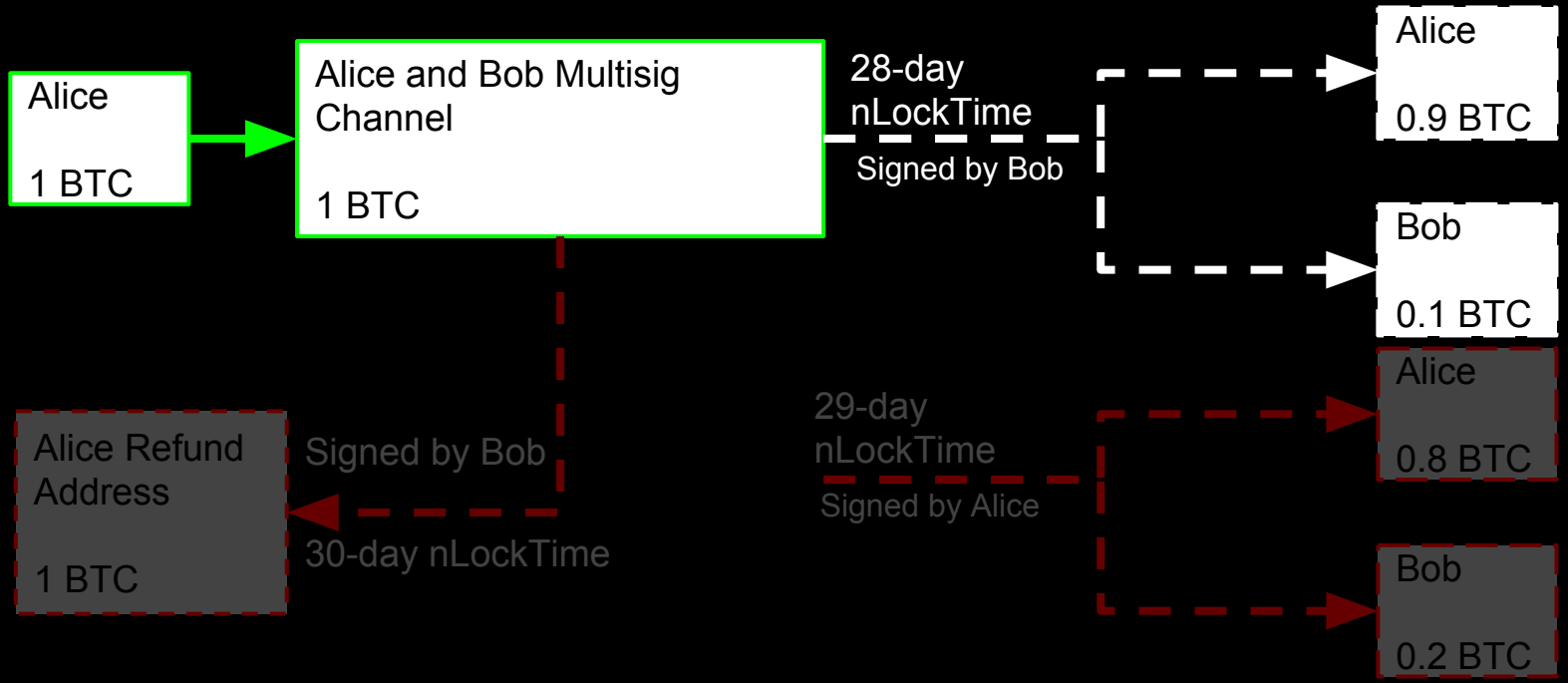
Bidirectional Channel - Payment



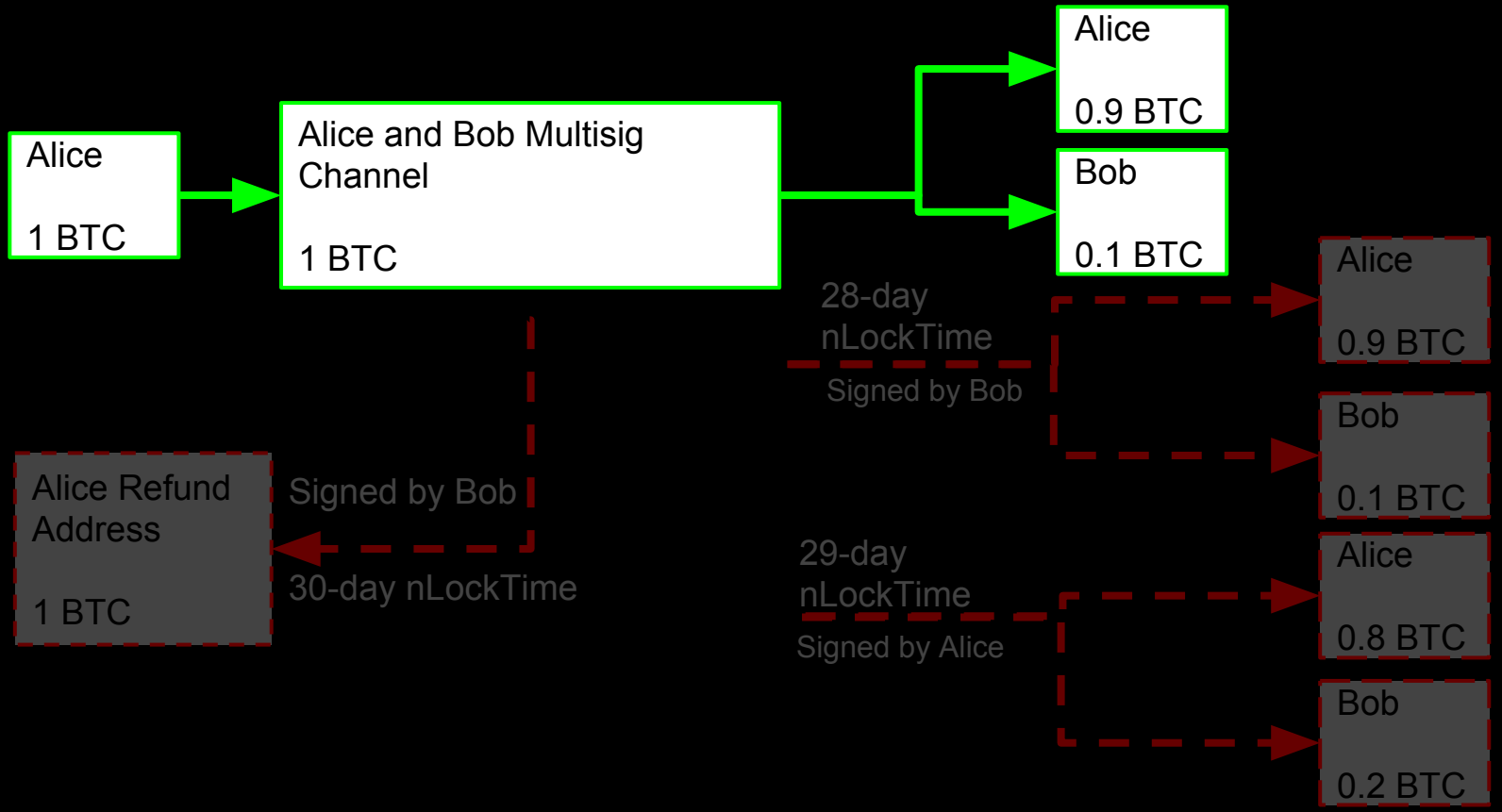
Bidirectional Channel - Payment



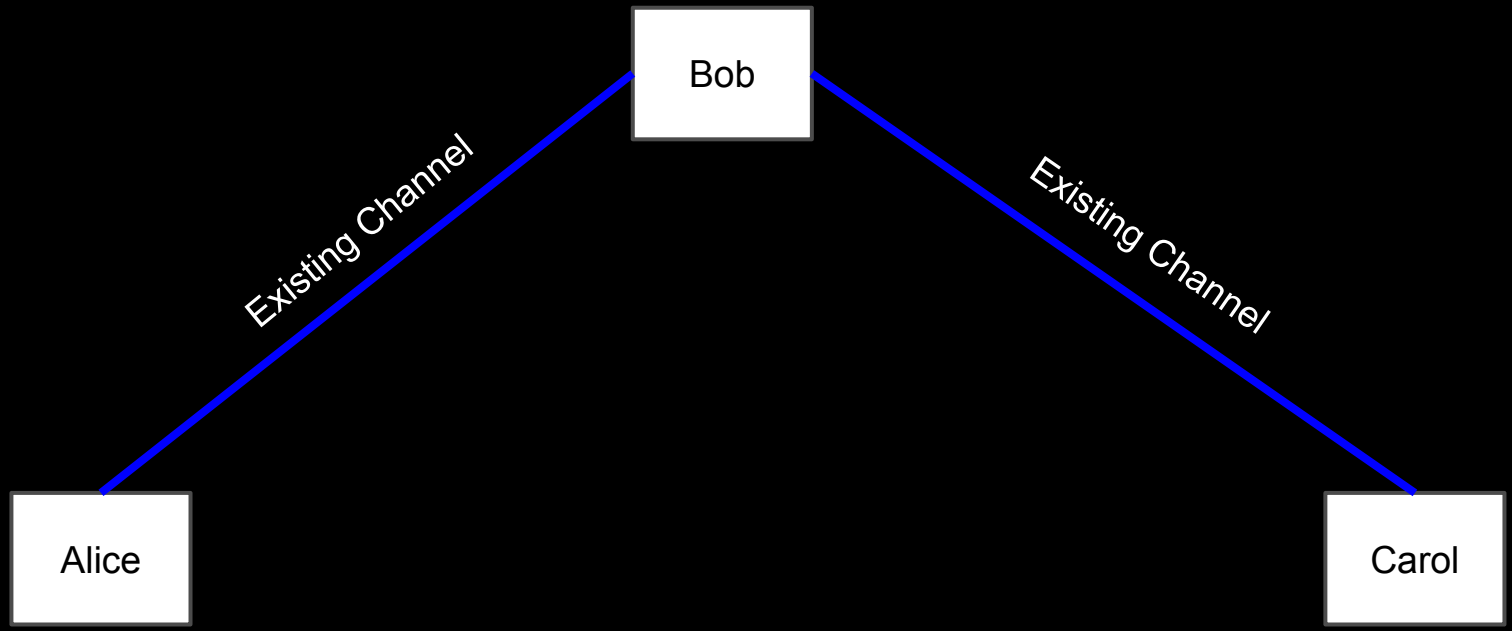
Reversing Direction



Closing Bidirectional Channel

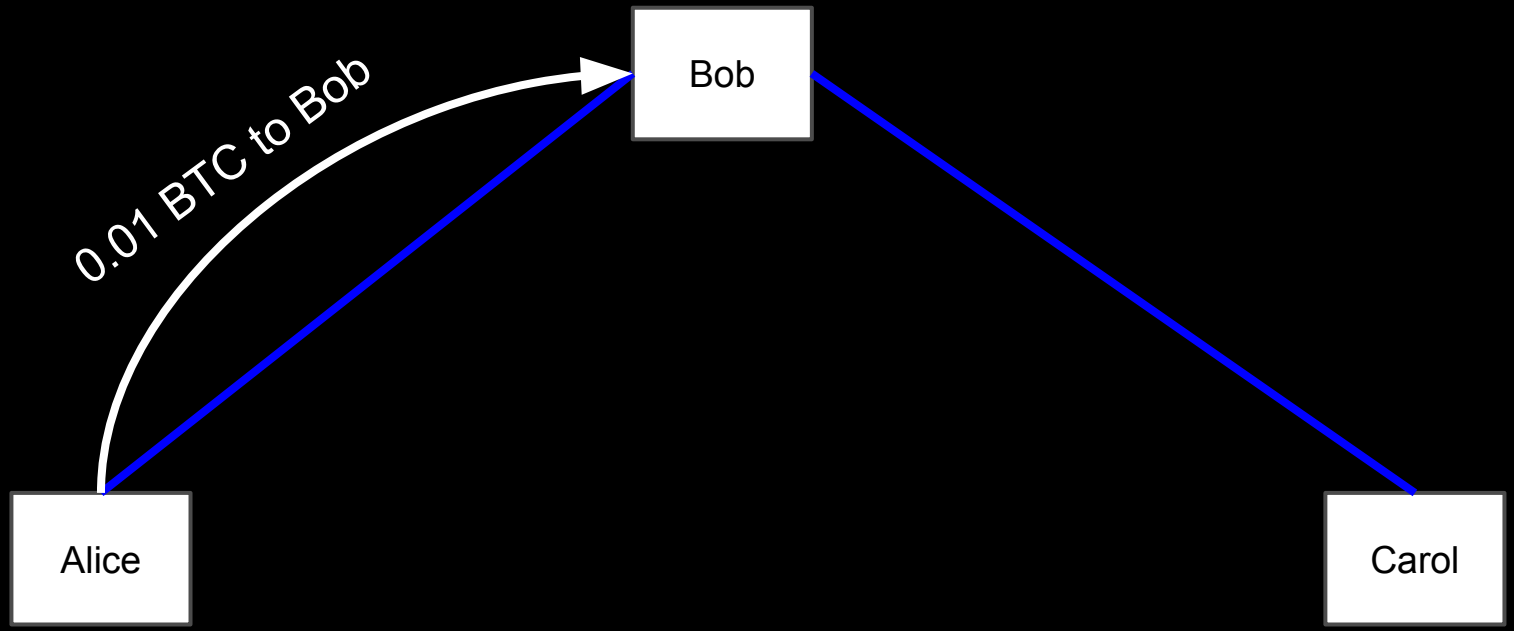


3 Party Payments

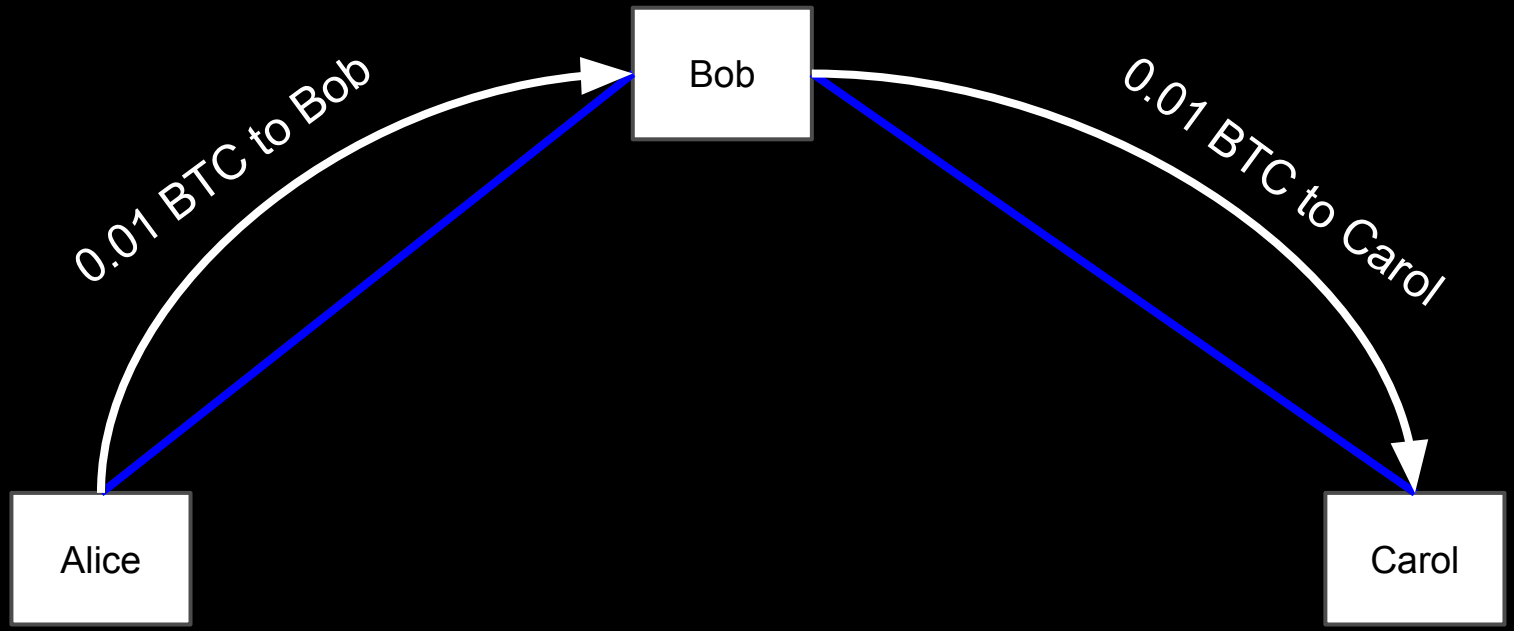


Alice wants to pay Carol, they both have a channel open with Bob

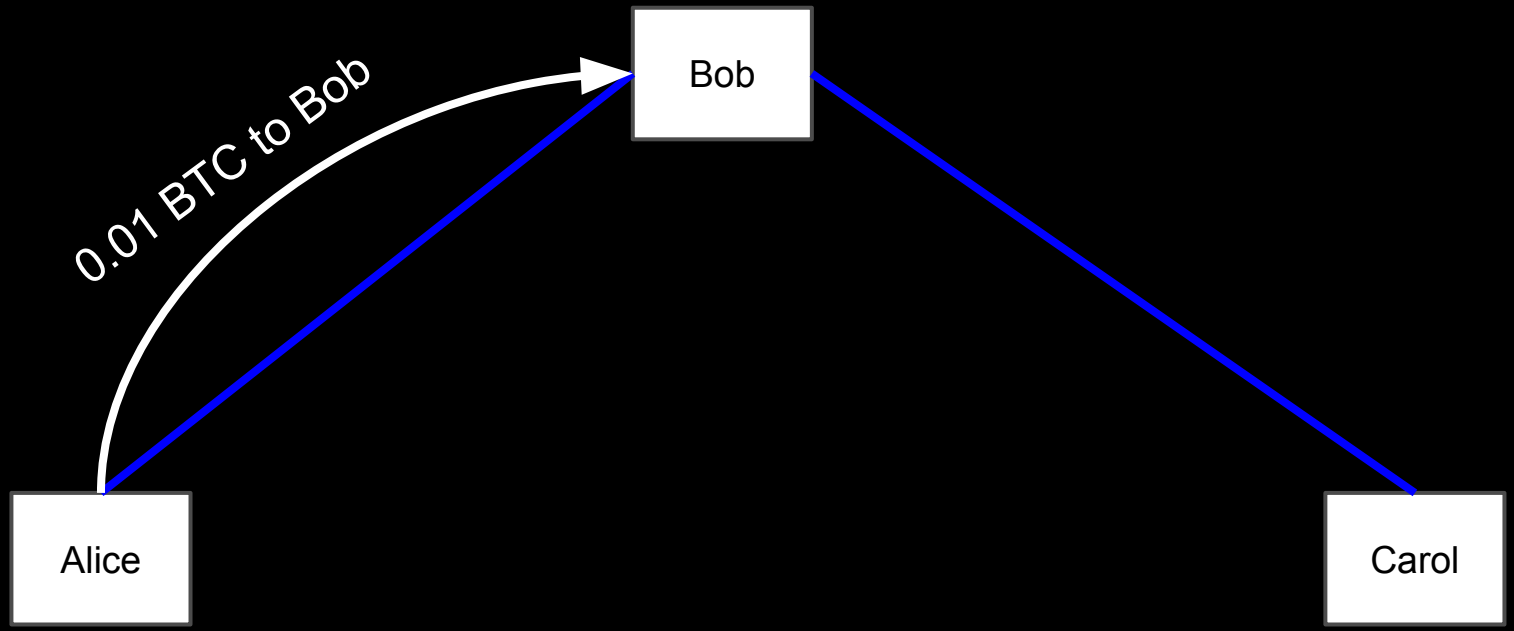
3 Party Payments



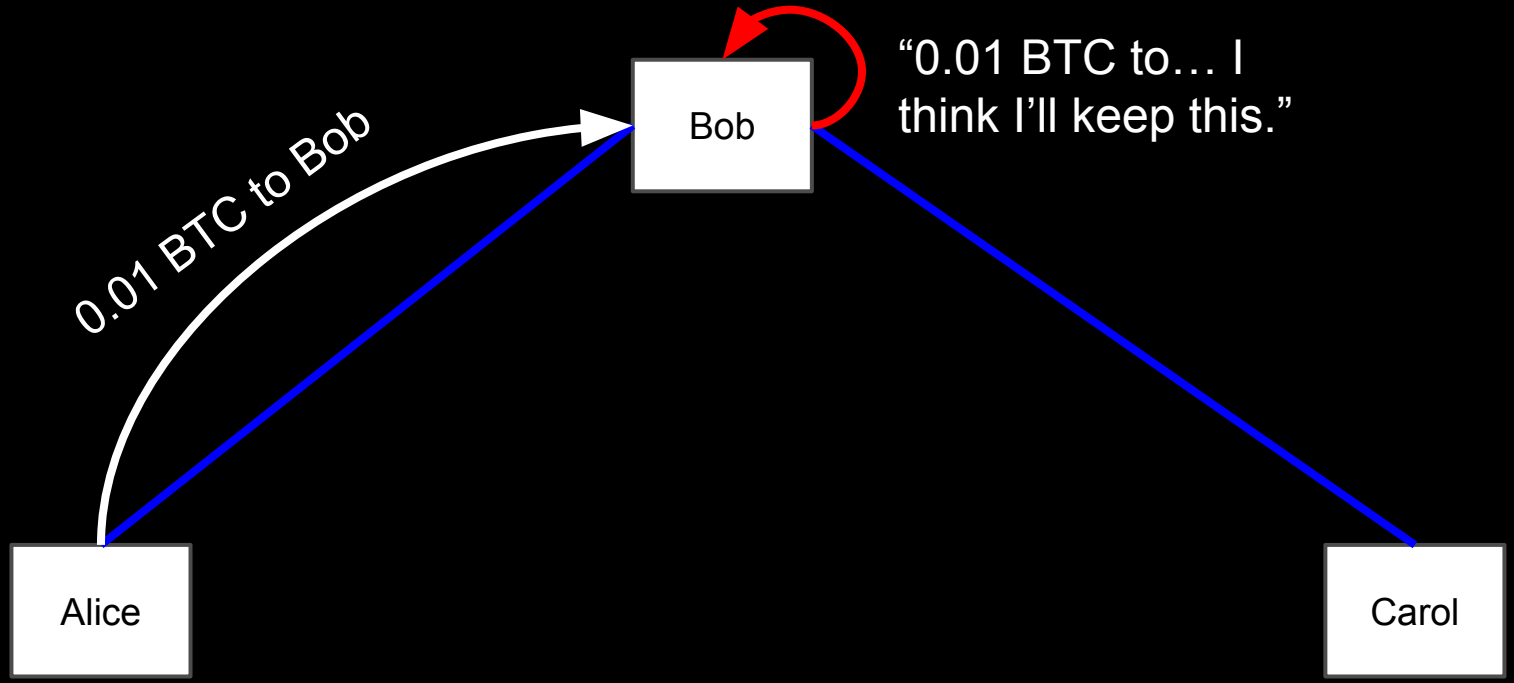
3 Party Payments



3 Party Payments - Trust Issues



3 Party Payments - Trust Issues



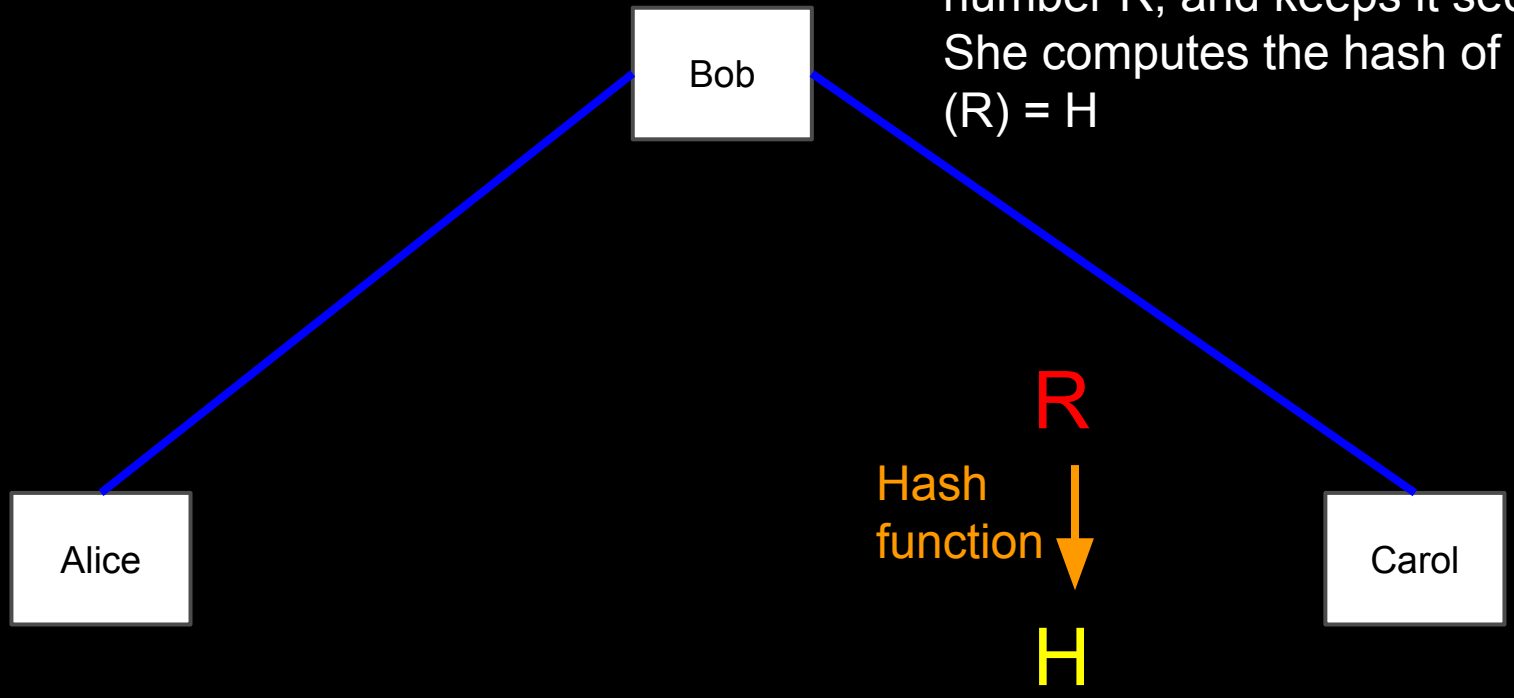
Problem: Bob can simply keep the 0.01 BTC
Problem: Carol can claim she never got the coins!

Hash-Locked Contracts

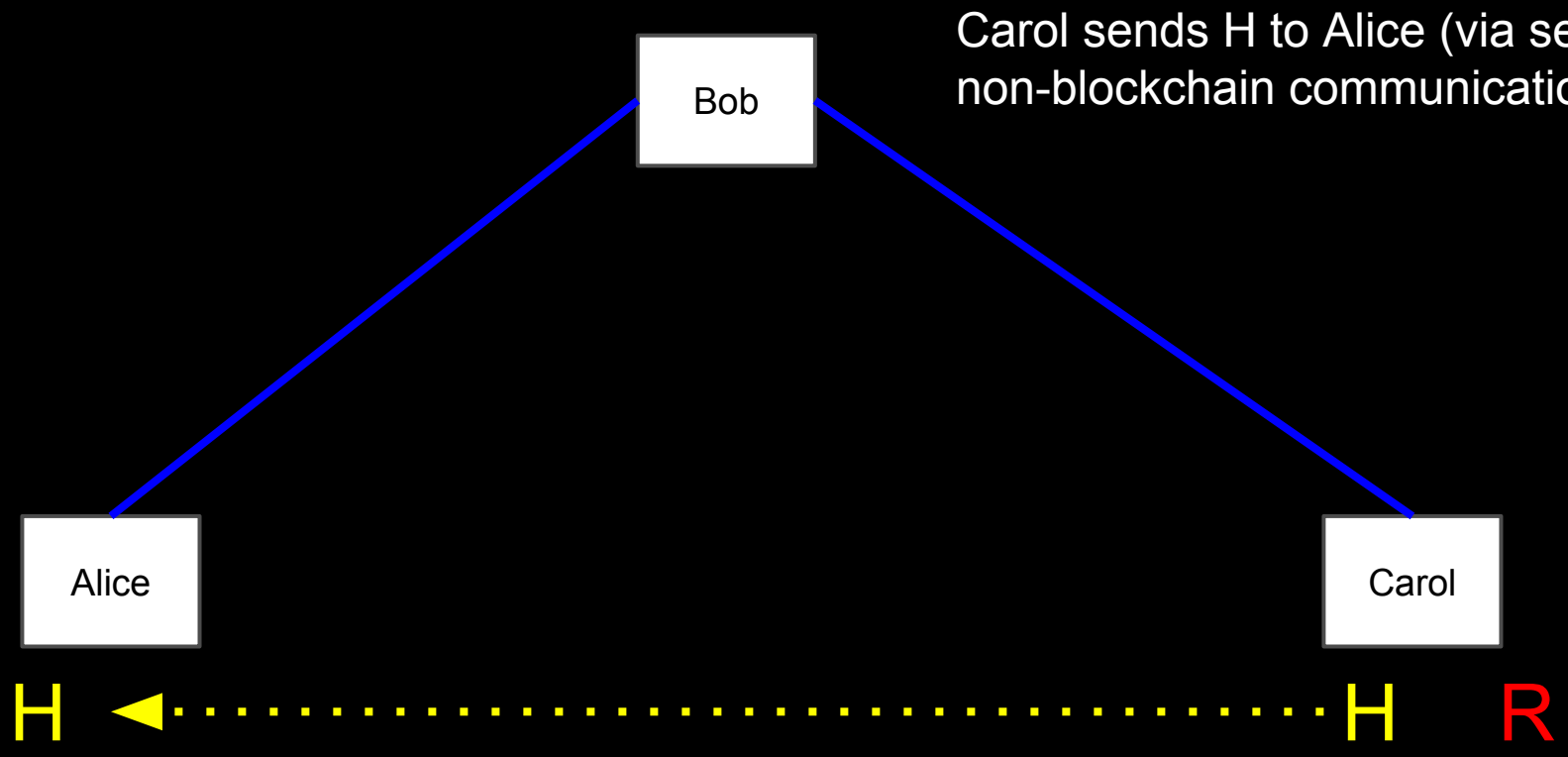
- Using one-way hash functions, Alice can prove she sent funds to Carol off-chain
- Pay to Contract
  - Knowledge of secret R hashed into hash H proves receipt
  - Receiver signs a contract stating if R is disclosed funds have been received

Hash-Locked Contracts

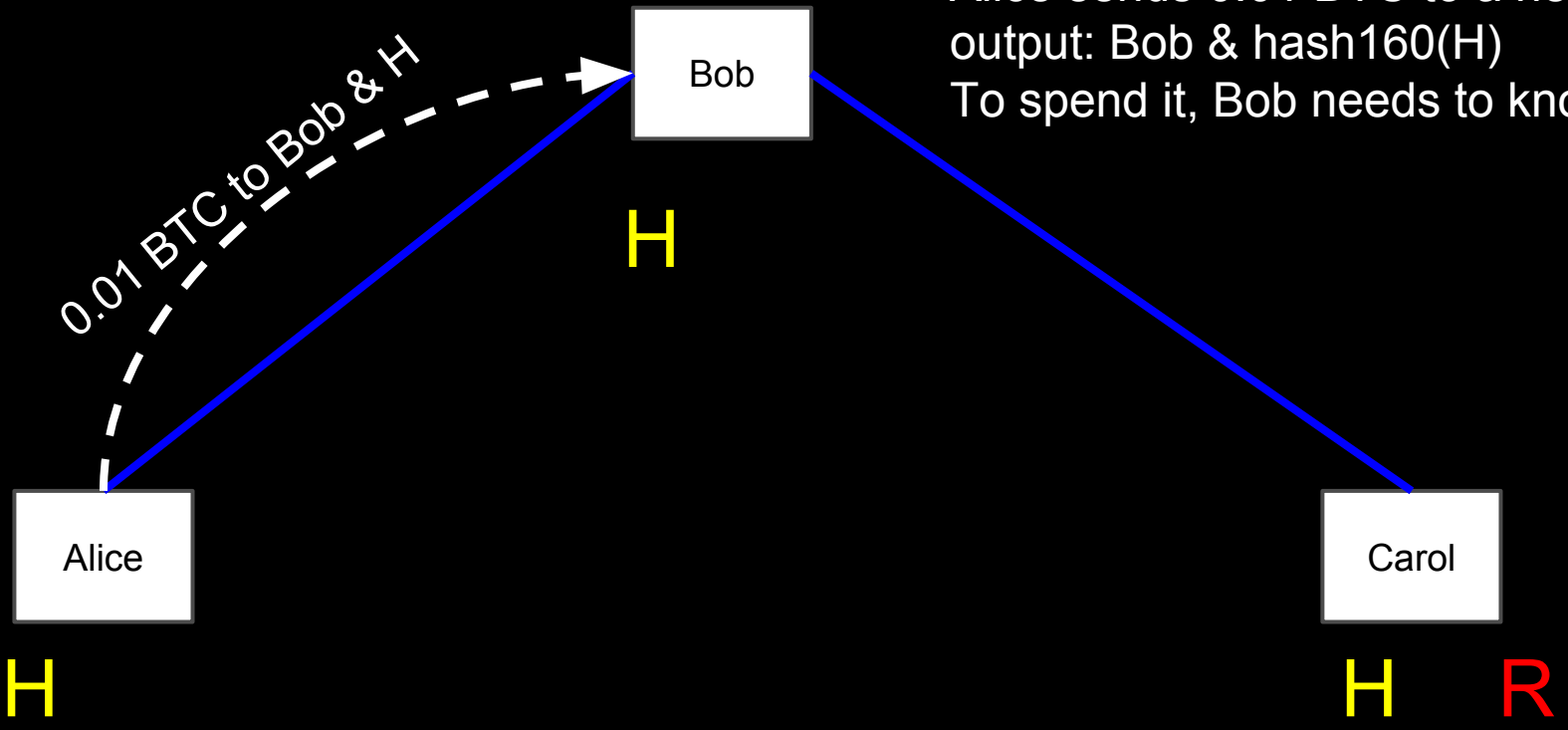
Carol makes a random number R, and keeps it secret. She computes the hash of R, hash (R) = H



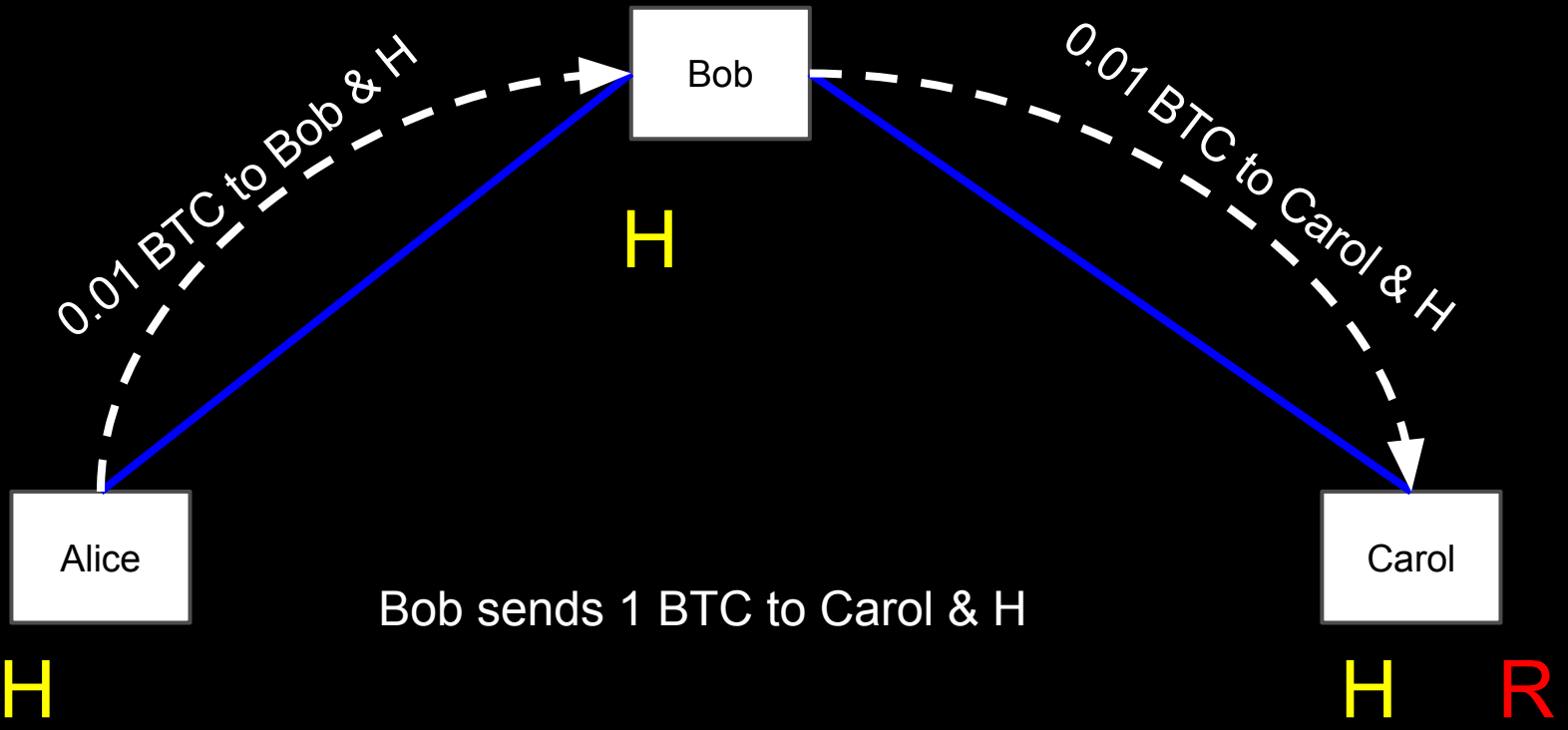
Hash-Locked Contracts



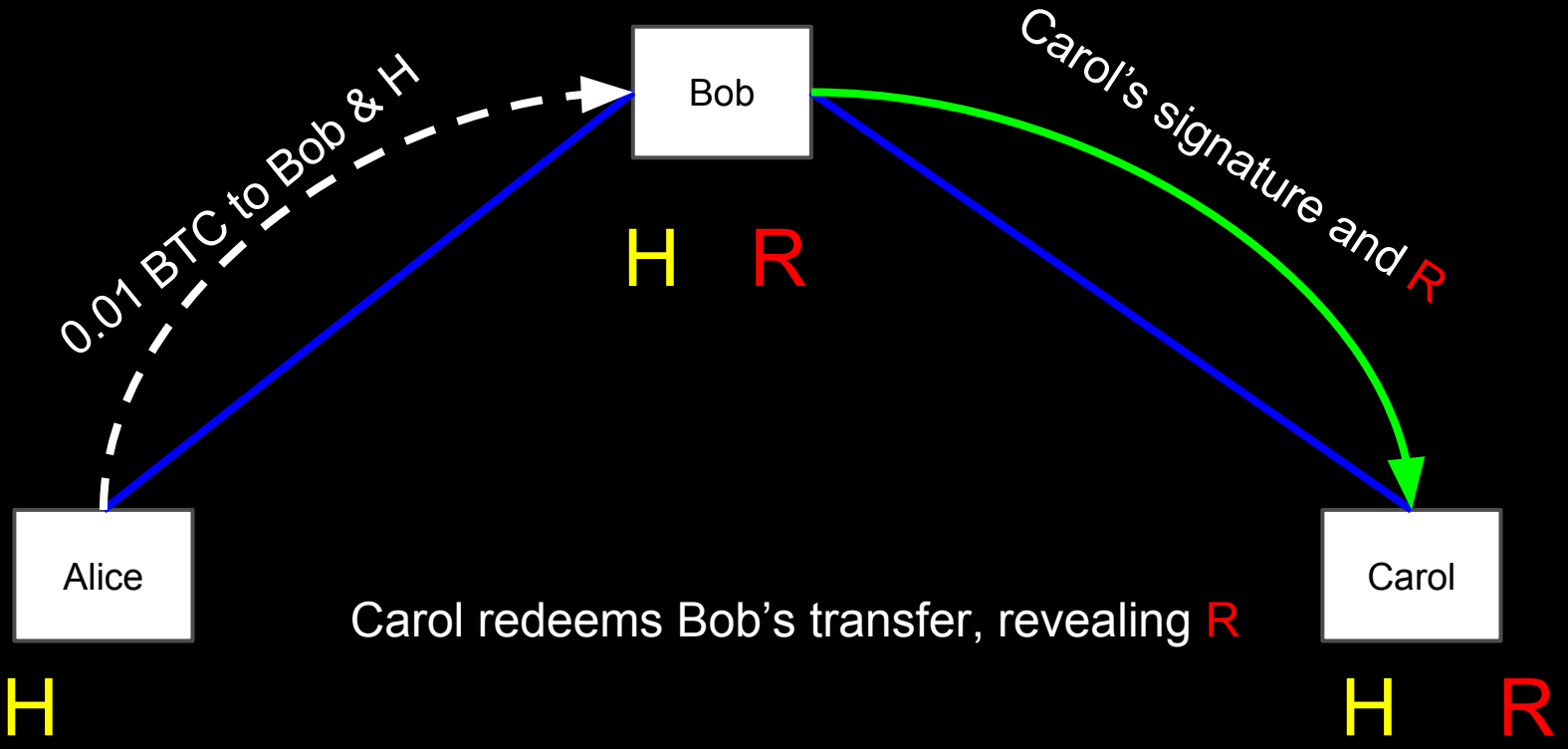
Hash-Locked Contracts



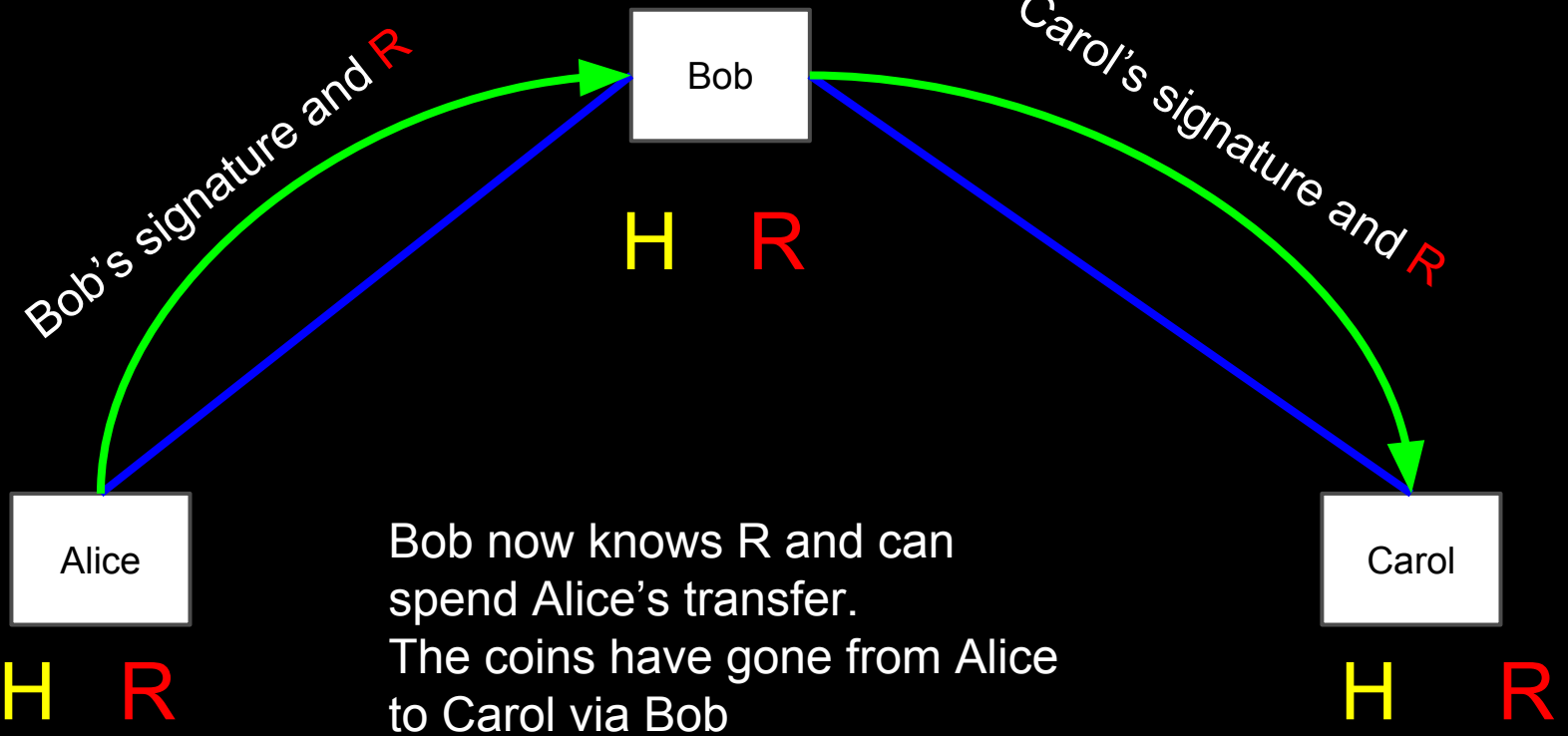
Hash-Locked Contracts



Hash-Locked Contracts



Hash-Locked Contracts



Problem!

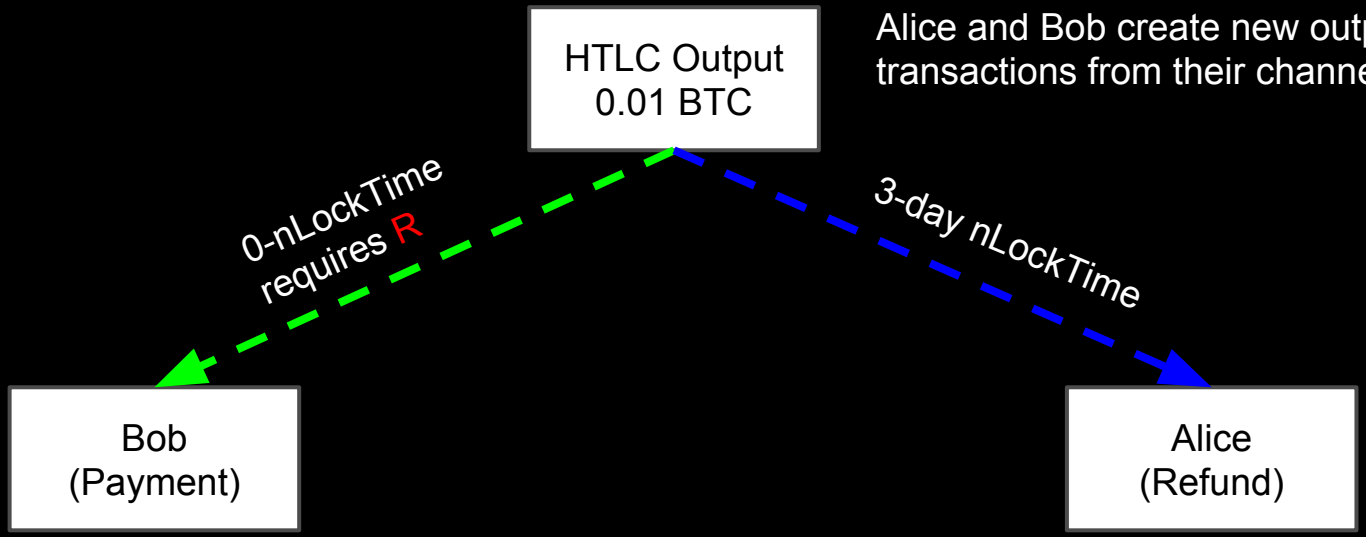
- If Carol refuses to disclose R, she will hold up the channel between Alice and Bob
  - If her channel expires after Alice and Bob's she can steal funds by redeeming the hashlock!
- Bob has to be rich for this to really work

3rd party low-trust multisig and/or extremely small values sent can mostly work today

Hashed Time-Lock Contract

1. If Bob can produce to Alice input R from hash H within 3 days, Alice will pay Bob 0.01 BTC
2. The above clause is void after 3 days
3. Either party may agree to settle terms using other methods if both agree
4. Violation of terms incurs a maximum penalty of funds in this contract

Hashed Time-Lock Contract

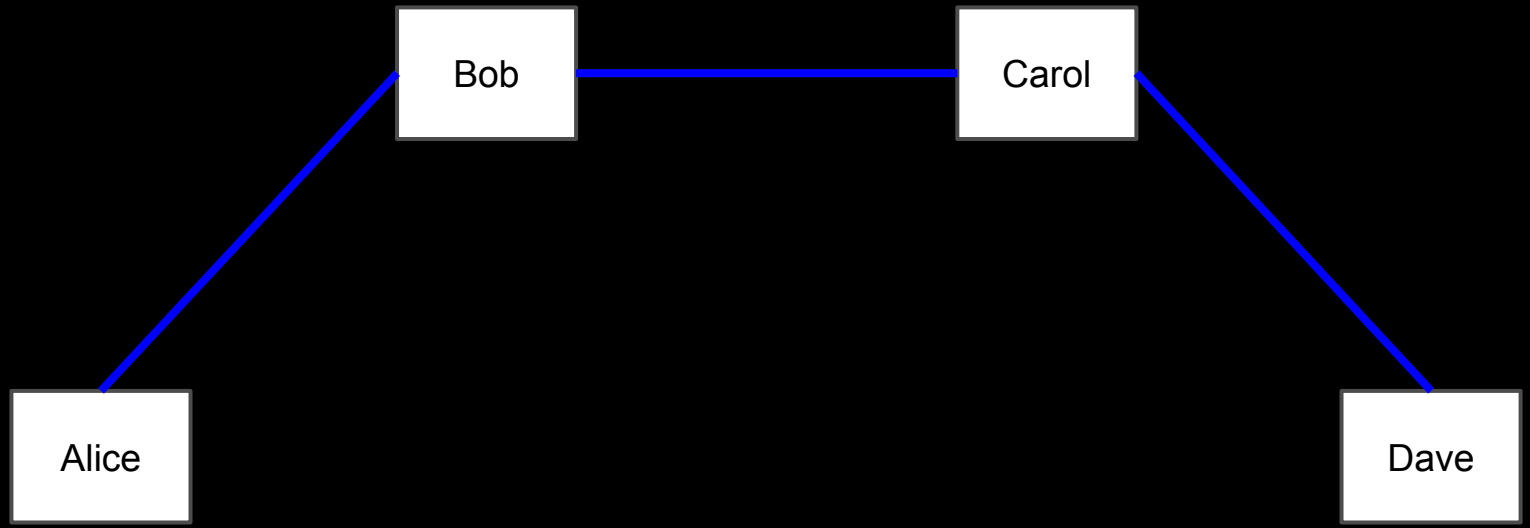


Alice and Bob create new outputs and transactions from their channel (off-chain)

OP_DEPTH 3 OP_EQUAL OP_IF OP_HASH160 <R> OP_EQUALVERIFY OP_0 2
<AlicePubkey1> <BobPubkey1> 2 OP_CHECKMULTISIG OP_ELSE OP_0 2
<AlicePubkey2> <BobPubkey2> 2 OP_CHECKMULTISIG OP_END

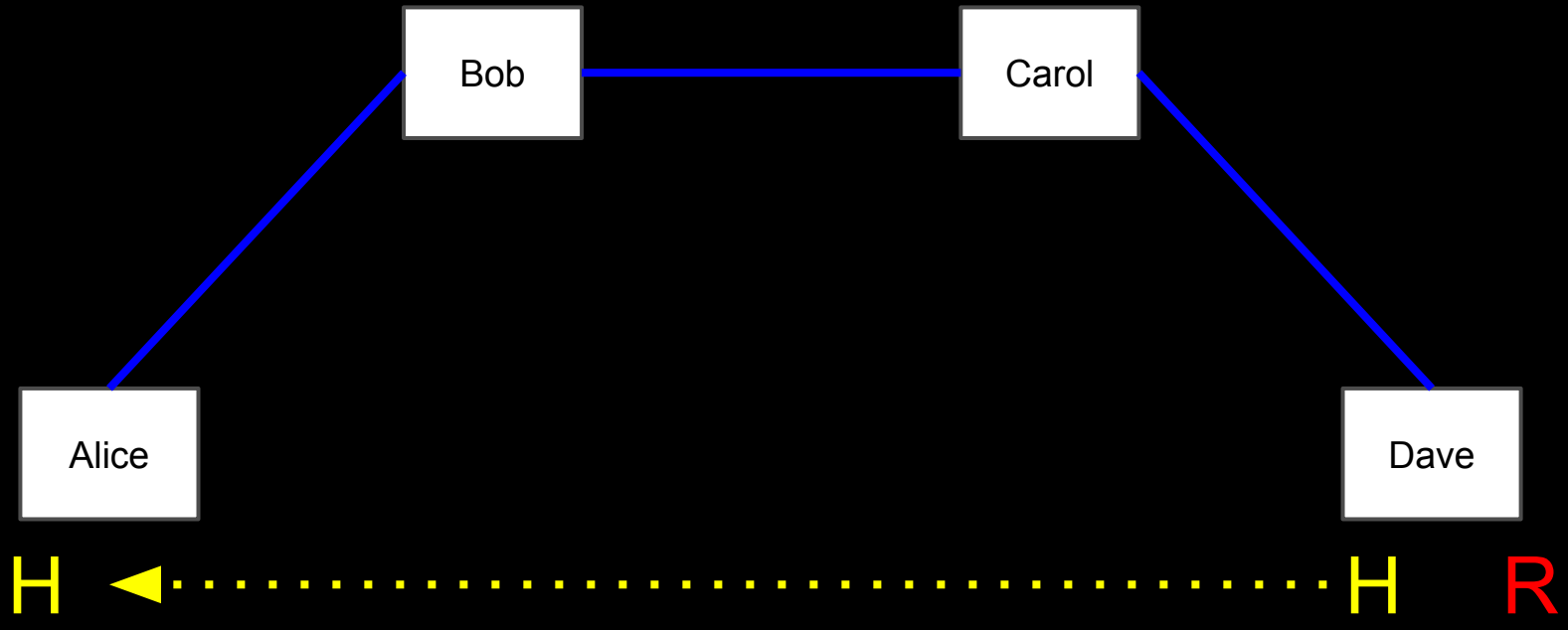
Bitcoin Lightning Network

Alice wants to send funds to Dave via Bob and Carol

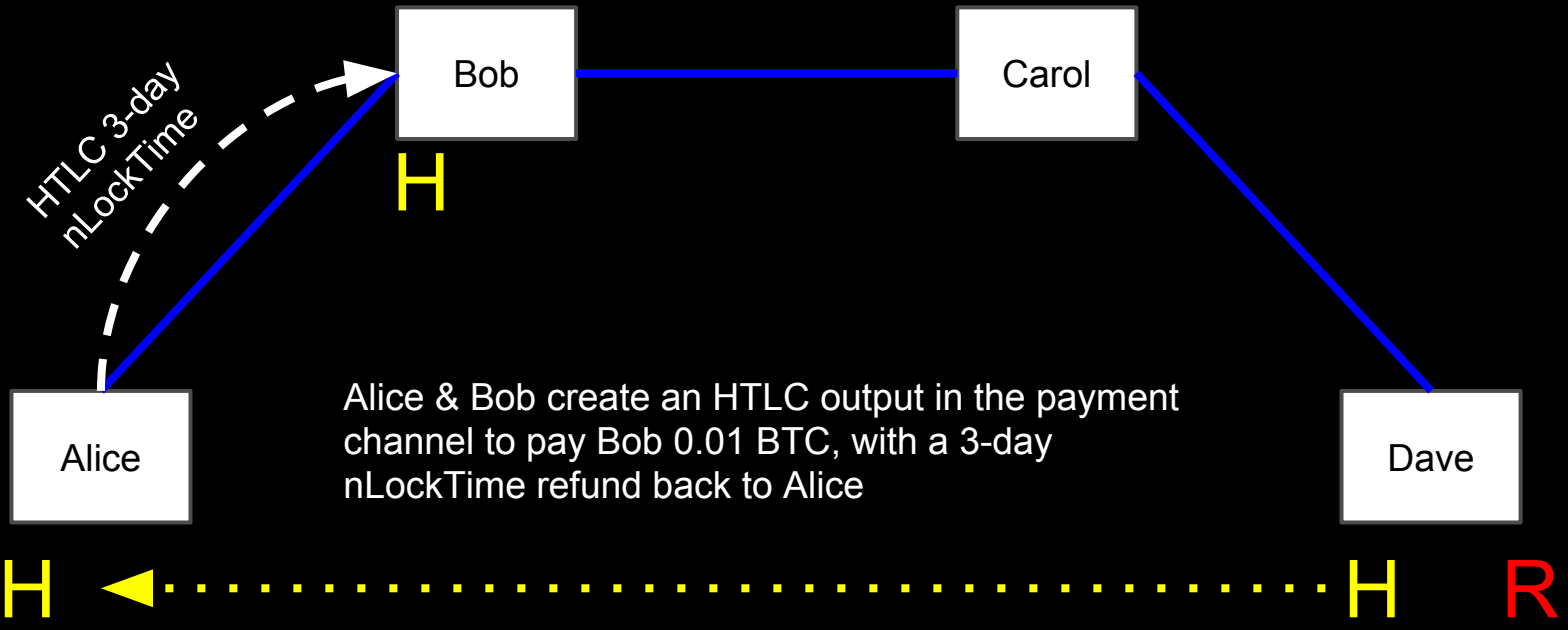


Bitcoin Lightning Network

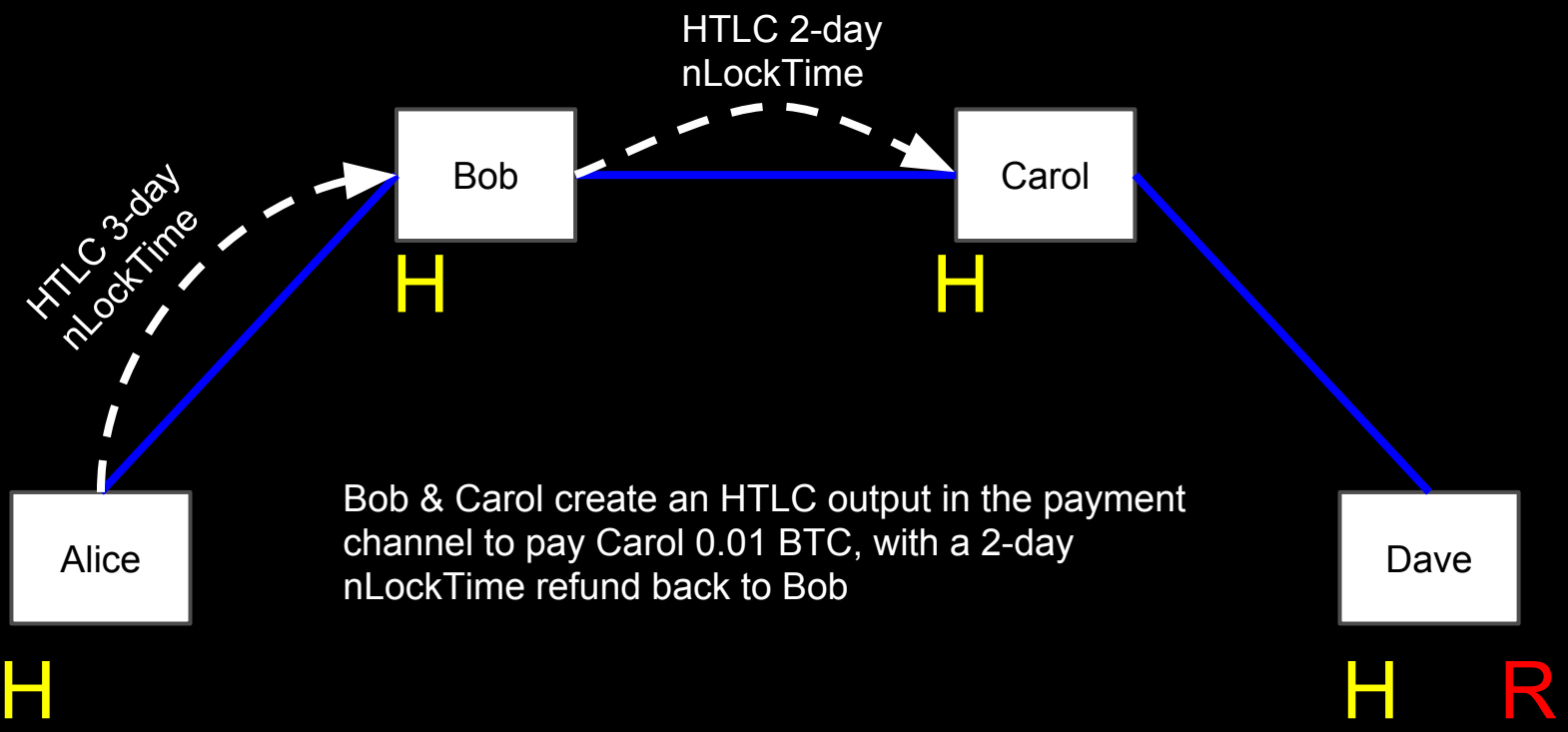
Dave sends Alice hash H produced from random data R



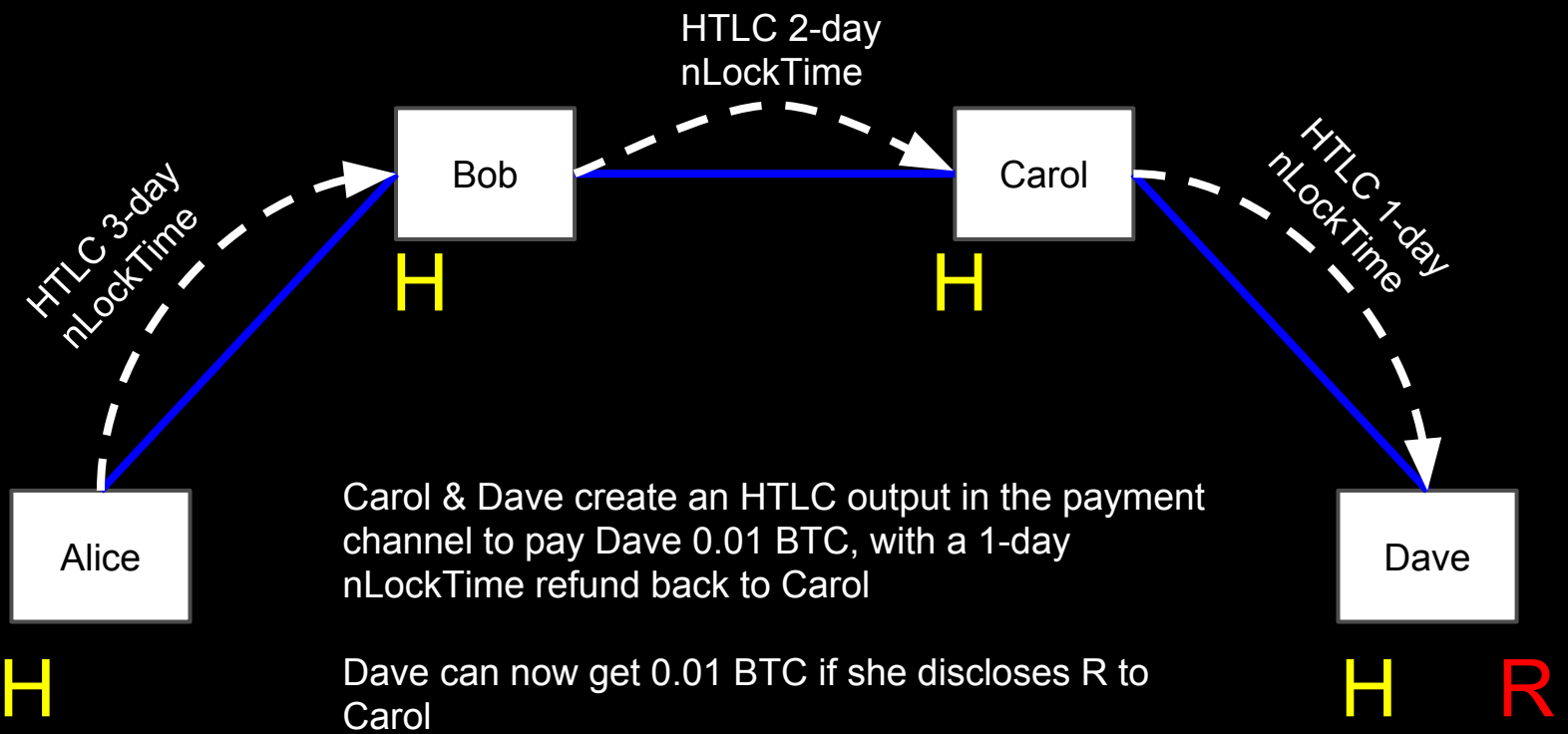
Bitcoin Lightning Network



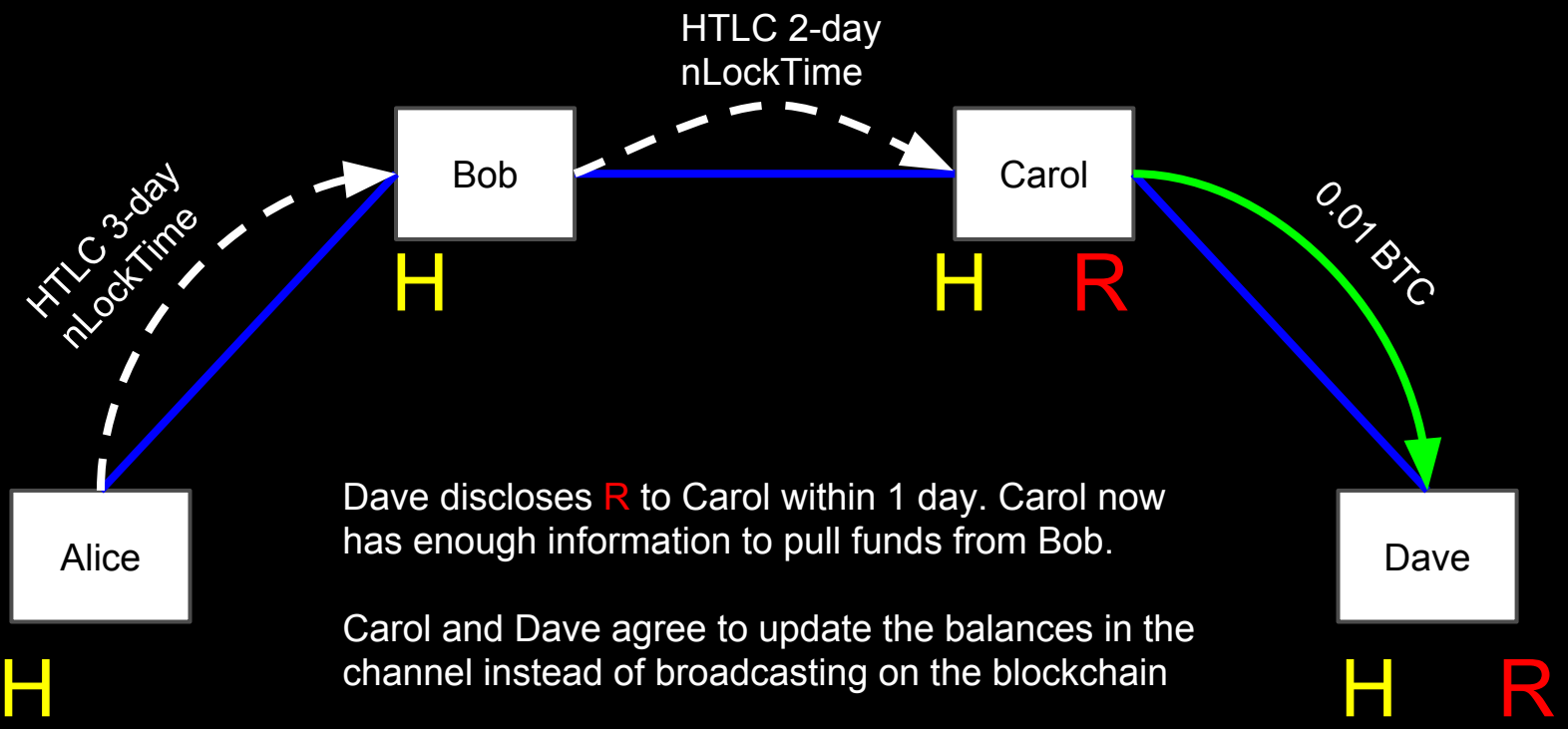
Bitcoin Lightning Network



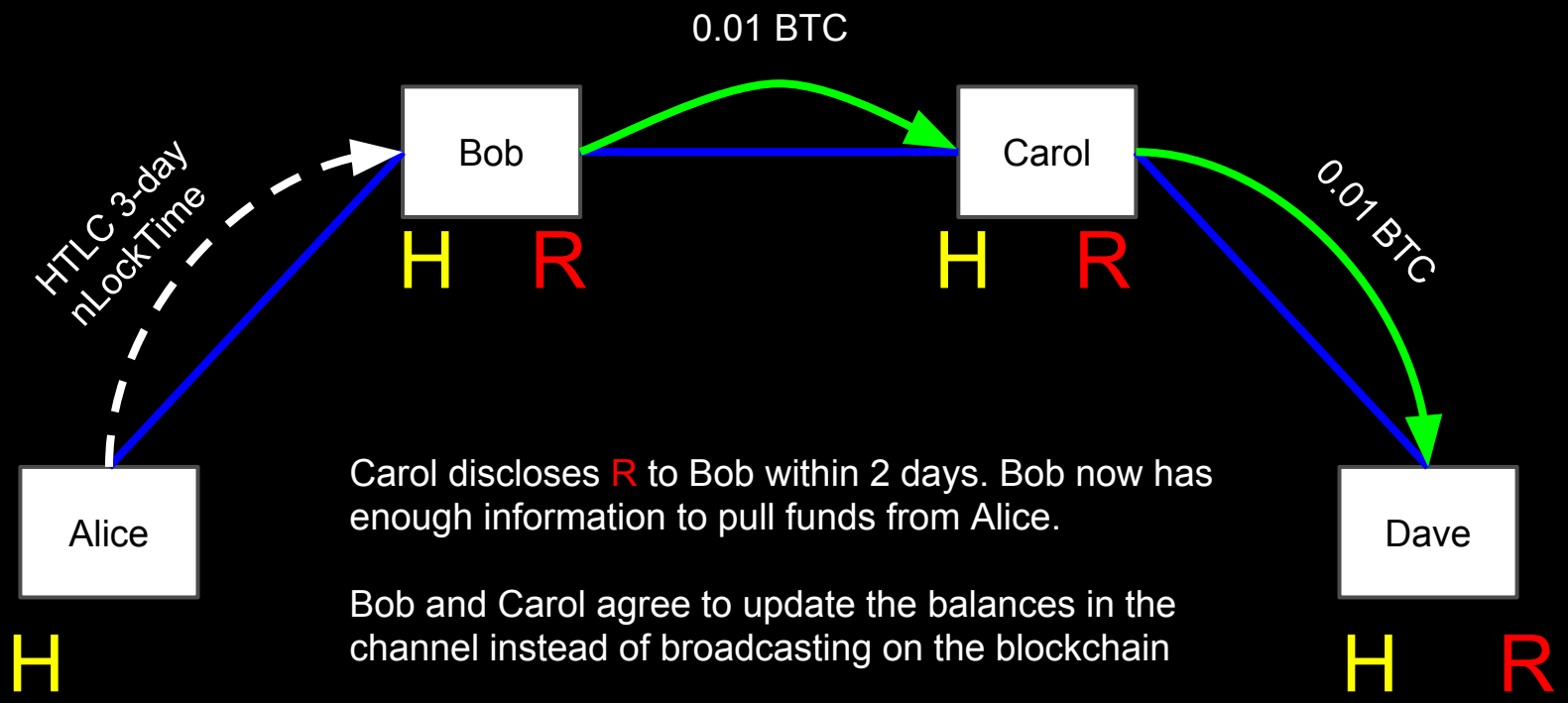
Bitcoin Lightning Network



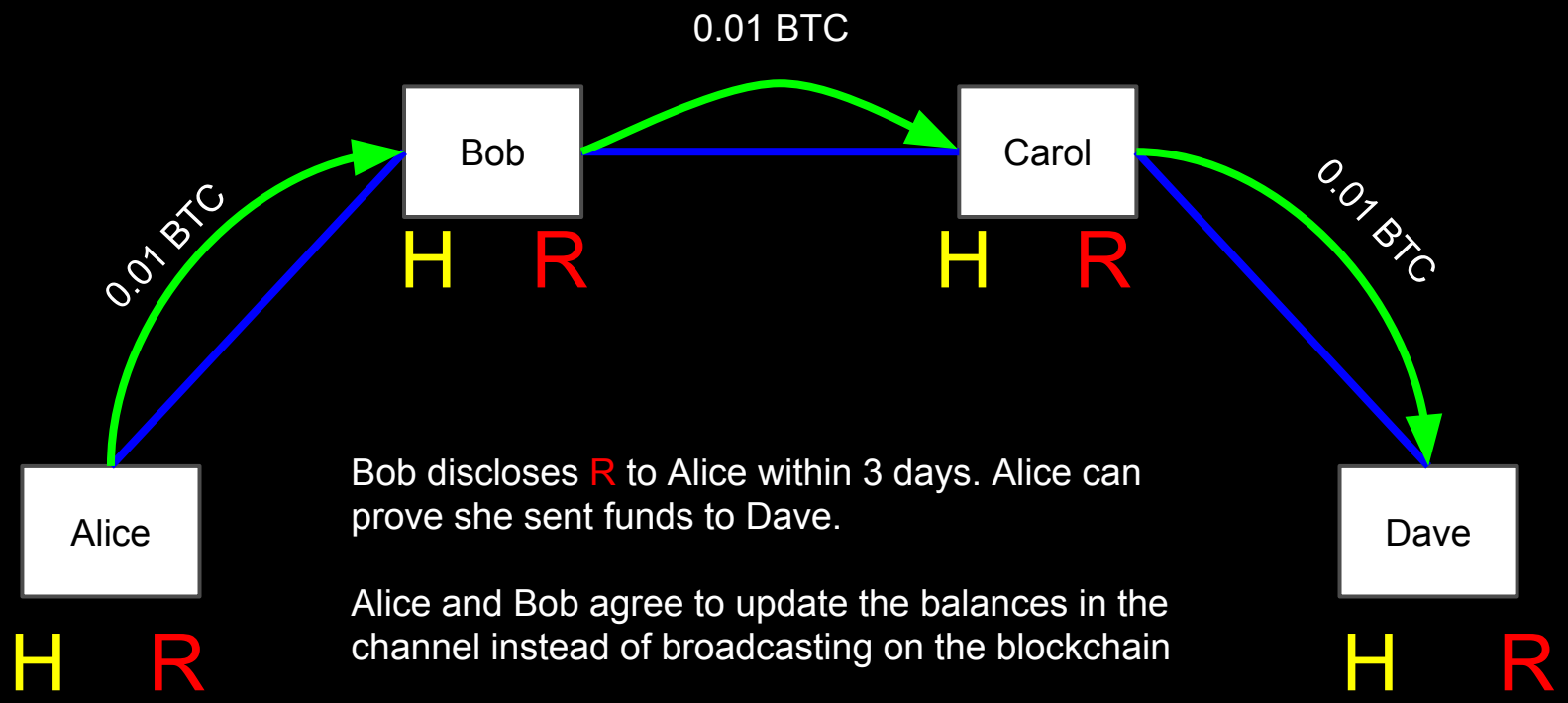
Bitcoin Lightning Network



Bitcoin Lightning Network



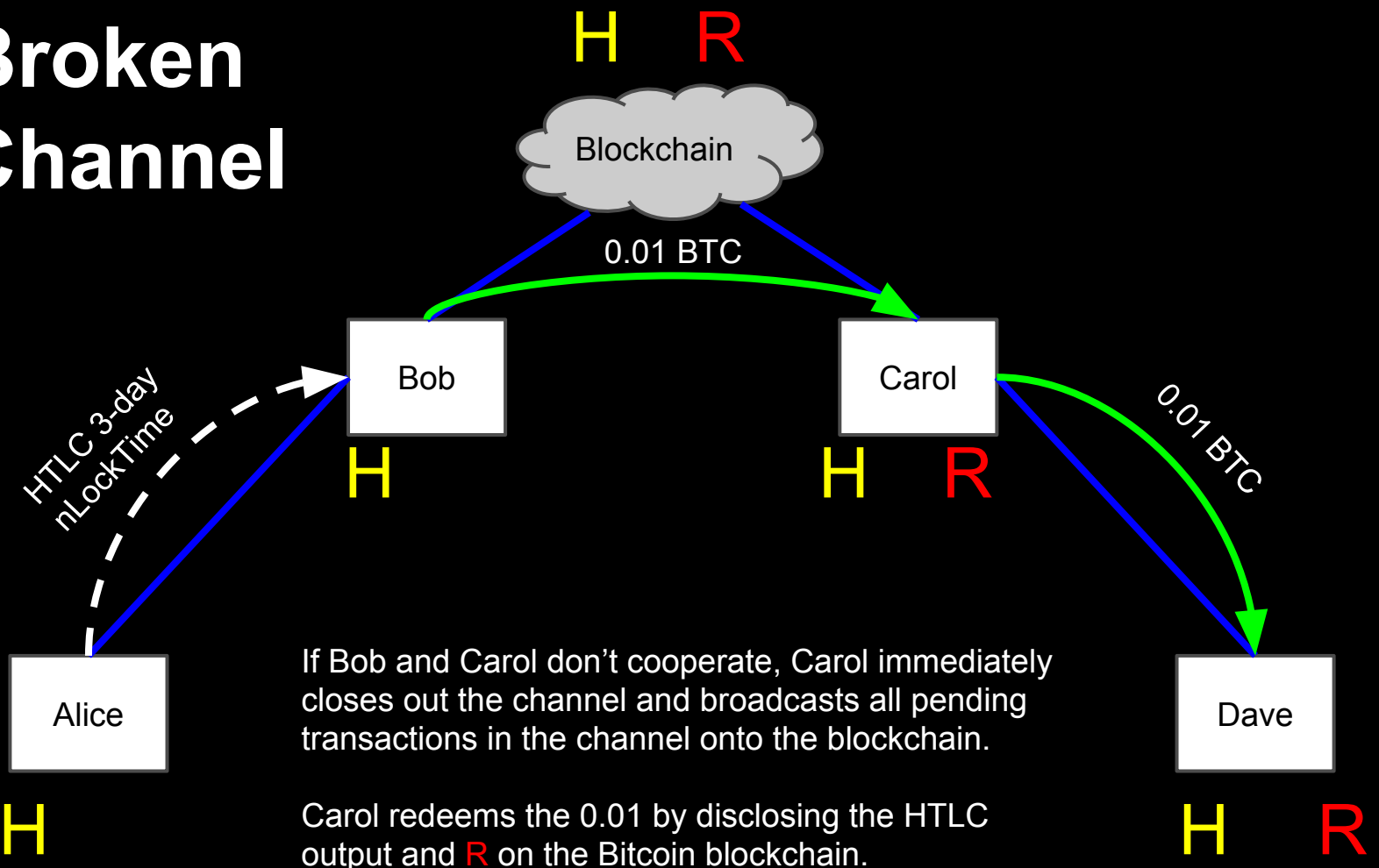
Bitcoin Lightning Network



Bob discloses R to Alice within 3 days. Alice can prove she sent funds to Dave.

Alice and Bob agree to update the balances in the channel instead of broadcasting on the blockchain

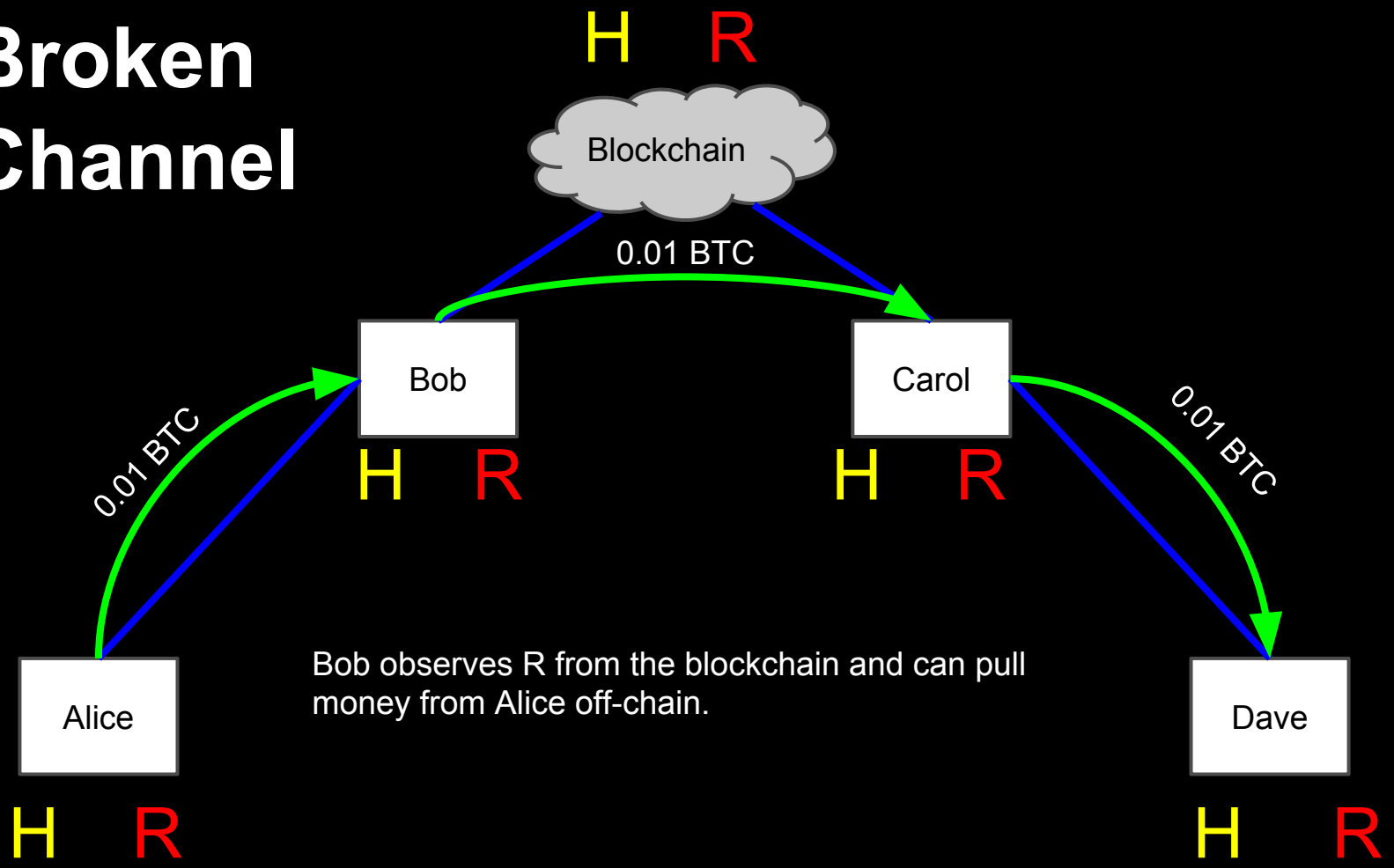
Broken Channel



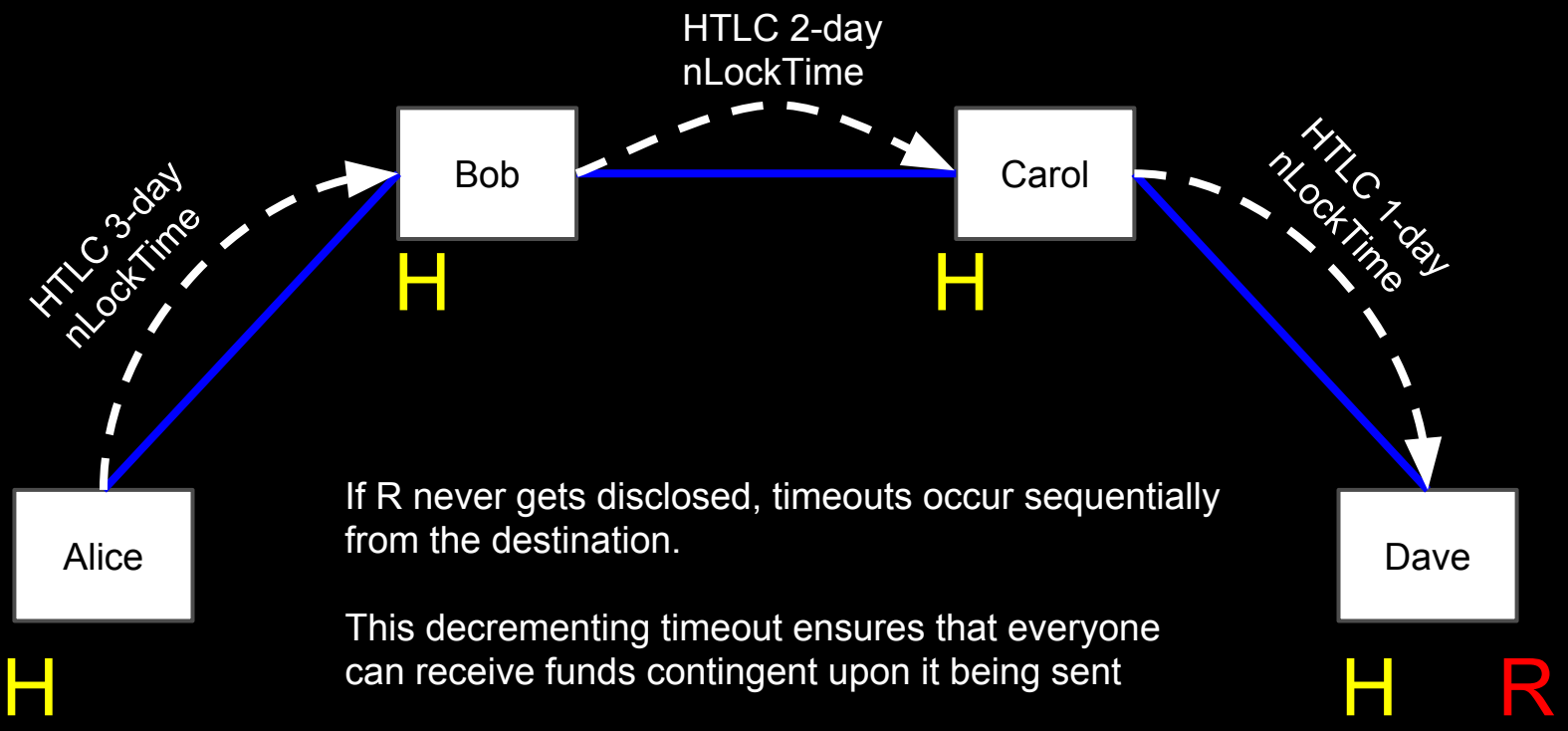
If Bob and Carol don't cooperate, Carol immediately closes out the channel and broadcasts all pending transactions in the channel onto the blockchain.

Carol redeems the 0.01 by disclosing the HTLC output and R on the Bitcoin blockchain.

Broken Channel



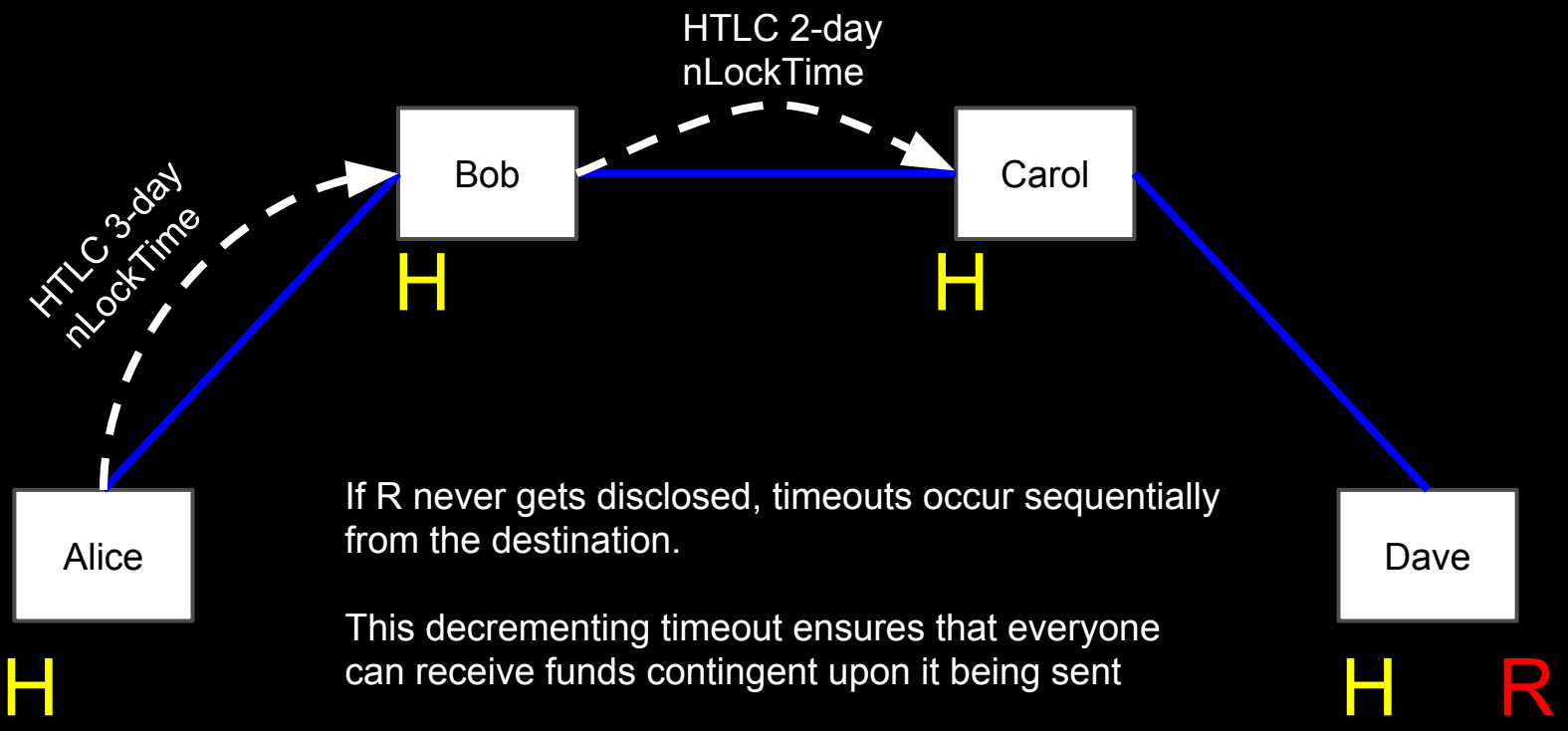
Timeout



If R never gets disclosed, timeouts occur sequentially from the destination.

This decrementing timeout ensures that everyone can receive funds contingent upon it being sent

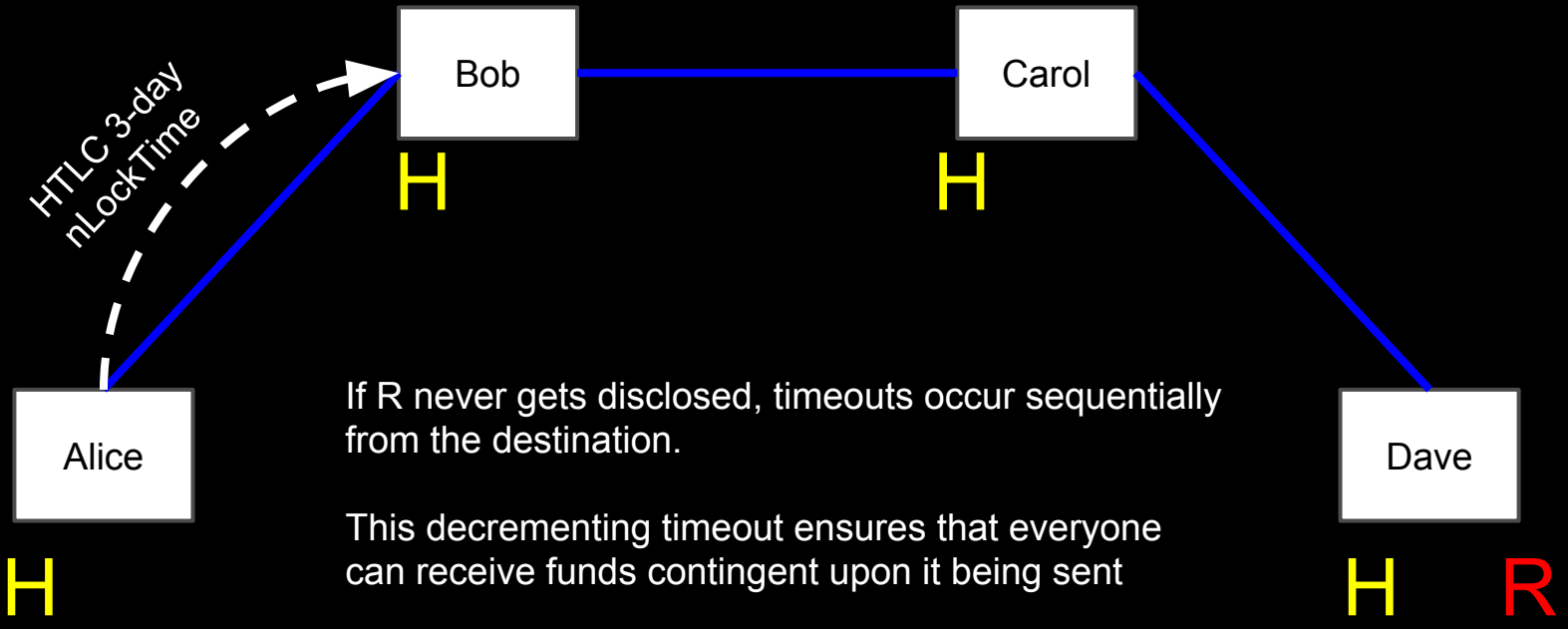
Timeout



If R never gets disclosed, timeouts occur sequentially from the destination.

This decrementing timeout ensures that everyone can receive funds contingent upon it being sent

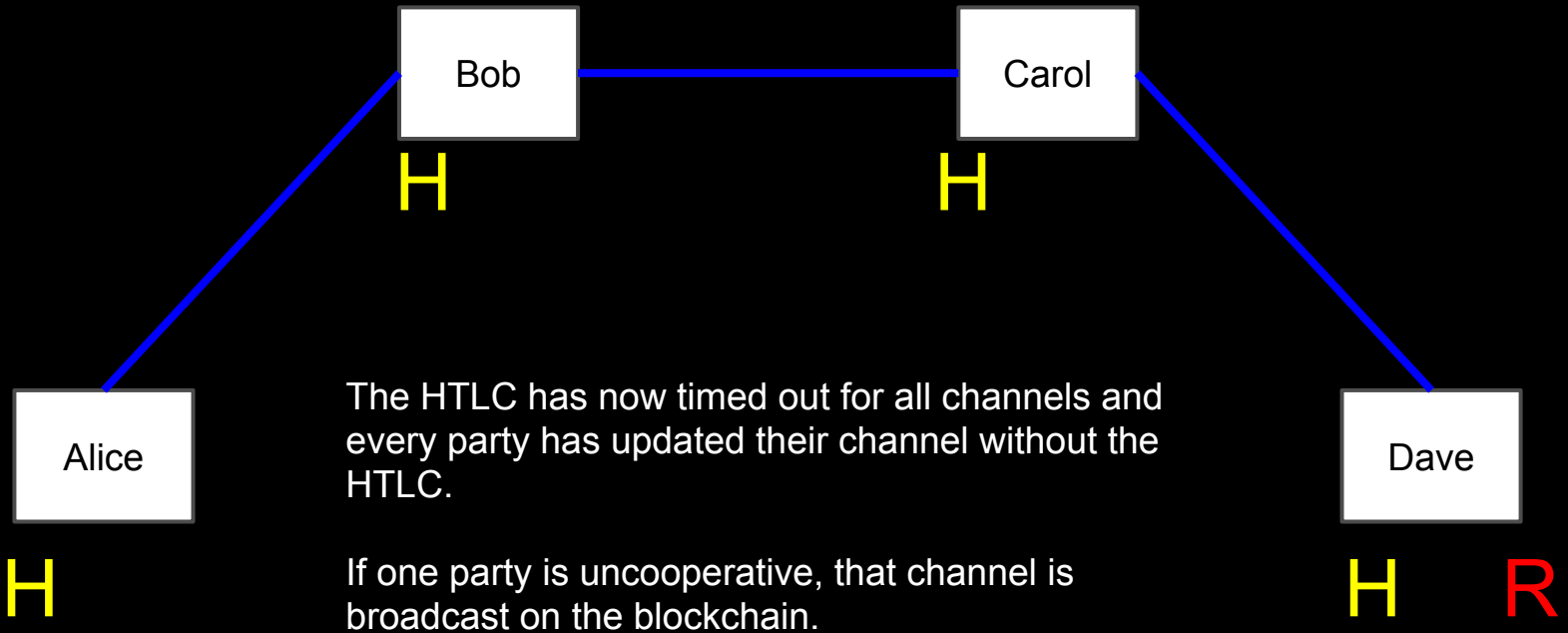
Timeout



If R never gets disclosed, timeouts occur sequentially from the destination.

This decrementing timeout ensures that everyone can receive funds contingent upon it being sent

Timeout



The HTLC has now timed out for all channels and every party has updated their channel without the HTLC.

If one party is uncooperative, that channel is broadcast on the blockchain.