Bitcoin & Blockchains
Landscape & Future Directions

Jeremy Clark

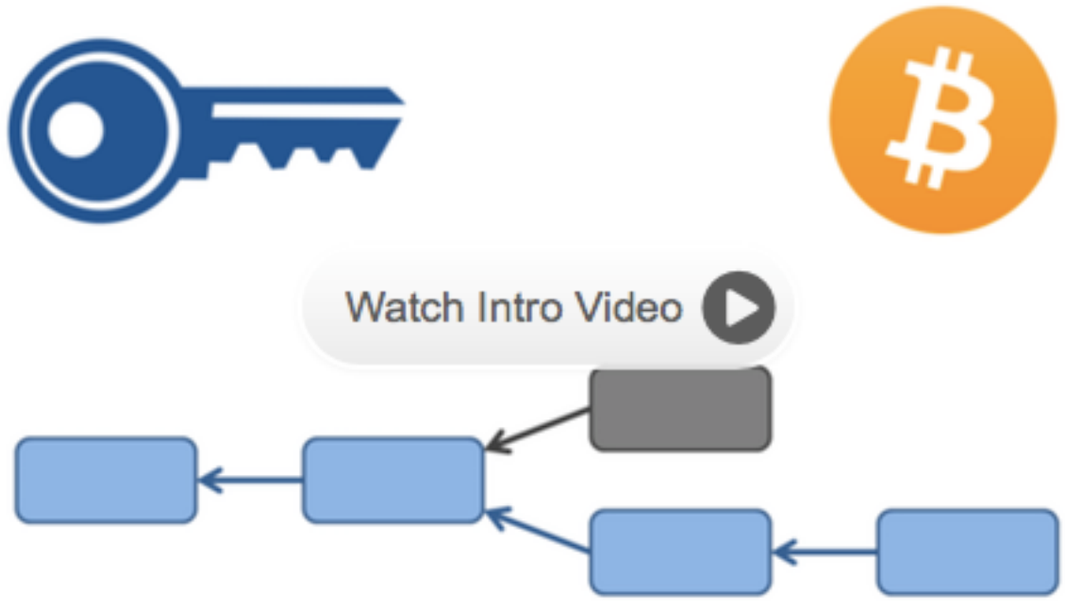
Jeremy Clark

- Assistant Professor at the Concordia Institute for Information Systems Engineering (CIISE) in Montreal
- PhD from the University of Waterloo (2009)
- Team of six graduate students
- Numerous academic papers on Bitcoin, including one of the earliest
- Contributed to courses (Princeton, MIT) & textbook on Bitcoin
- Organized/chaired academic workshop on Bitcoin
- Testified to Canadian Senate on Bitcoin

PRINCETON UNIVERSITY

Bitcoin and Cryptocurrency Technologies

There's a lot of excitement about Bitcoin, but also a lot of confusion about what Bitcoin is and how it works. We're offering this course focusing on the computer science behind Bitcoin to help cut through the hype and get to the core of what makes Bitcoin unique.



About the Course

To really understand what is special about Bitcoin, we need to understand how it works at a technical level. We'll address the important questions about Bitcoin, such as:

How does Bitcoin work? What makes Bitcoin different? How secure are your Bitcoins? How anonymous are Bitcoin users? What determines the price of Bitcoins? Can cryptocurrencies be regulated? What might the future hold?

After this course, you'll know everything you need to be able to separate fact from fiction when reading claims about Bitcoin and other cryptocurrencies. You'll have the conceptual foundations you need to engineer secure software that interacts with the Bitcoin network. And you'll be able to integrate ideas from Bitcoin in your own

Sessions

September 4, 2015 - April 22, 2016

Go to Course

Course at a Glance

- 7 weeks of study
- 3-6 hours/week
- English

Bitcoin and Cryptocurrency Technologies

Arvind Narayanan, Joseph Bonneau, Edward Felten,
Andrew Miller, Steven Goldfeder

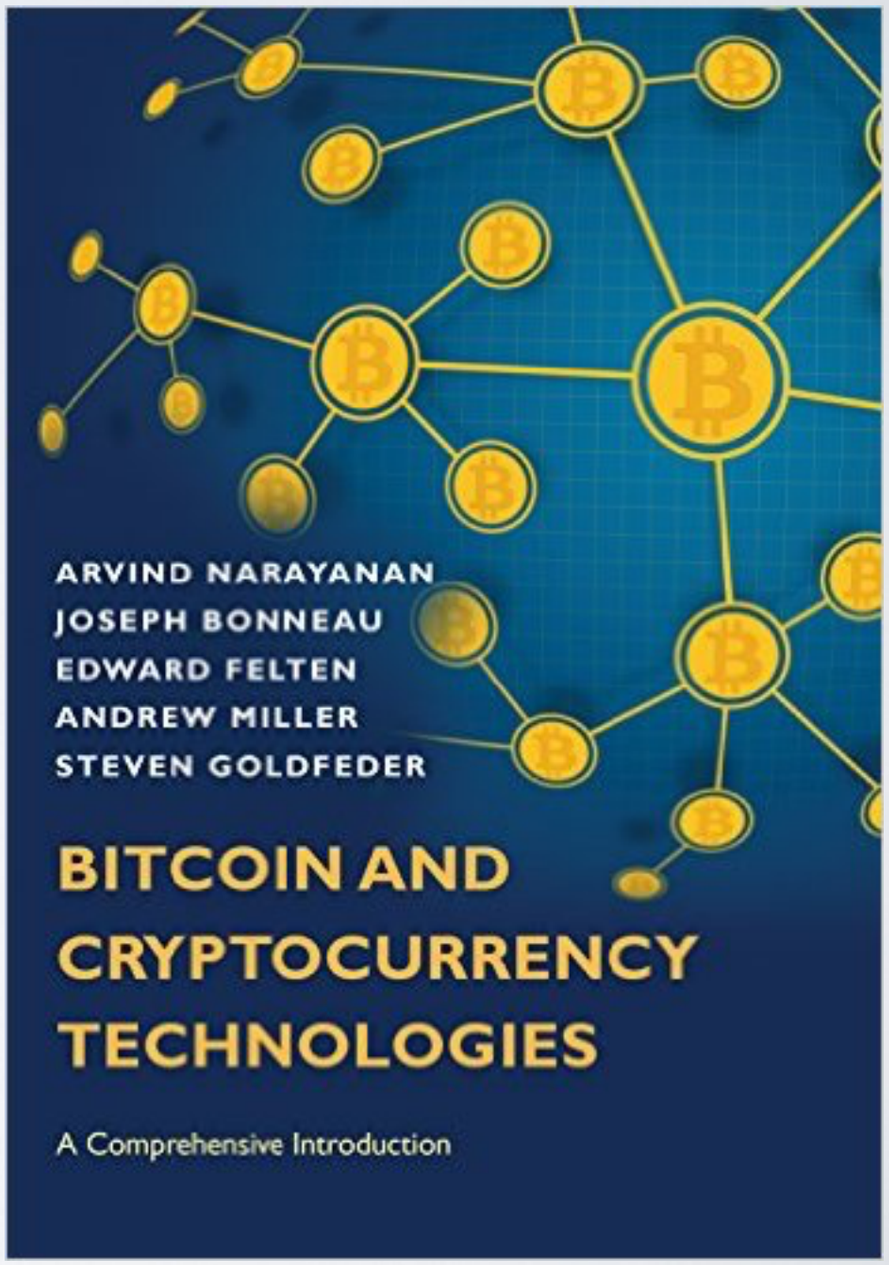
with a preface by Jeremy Clark

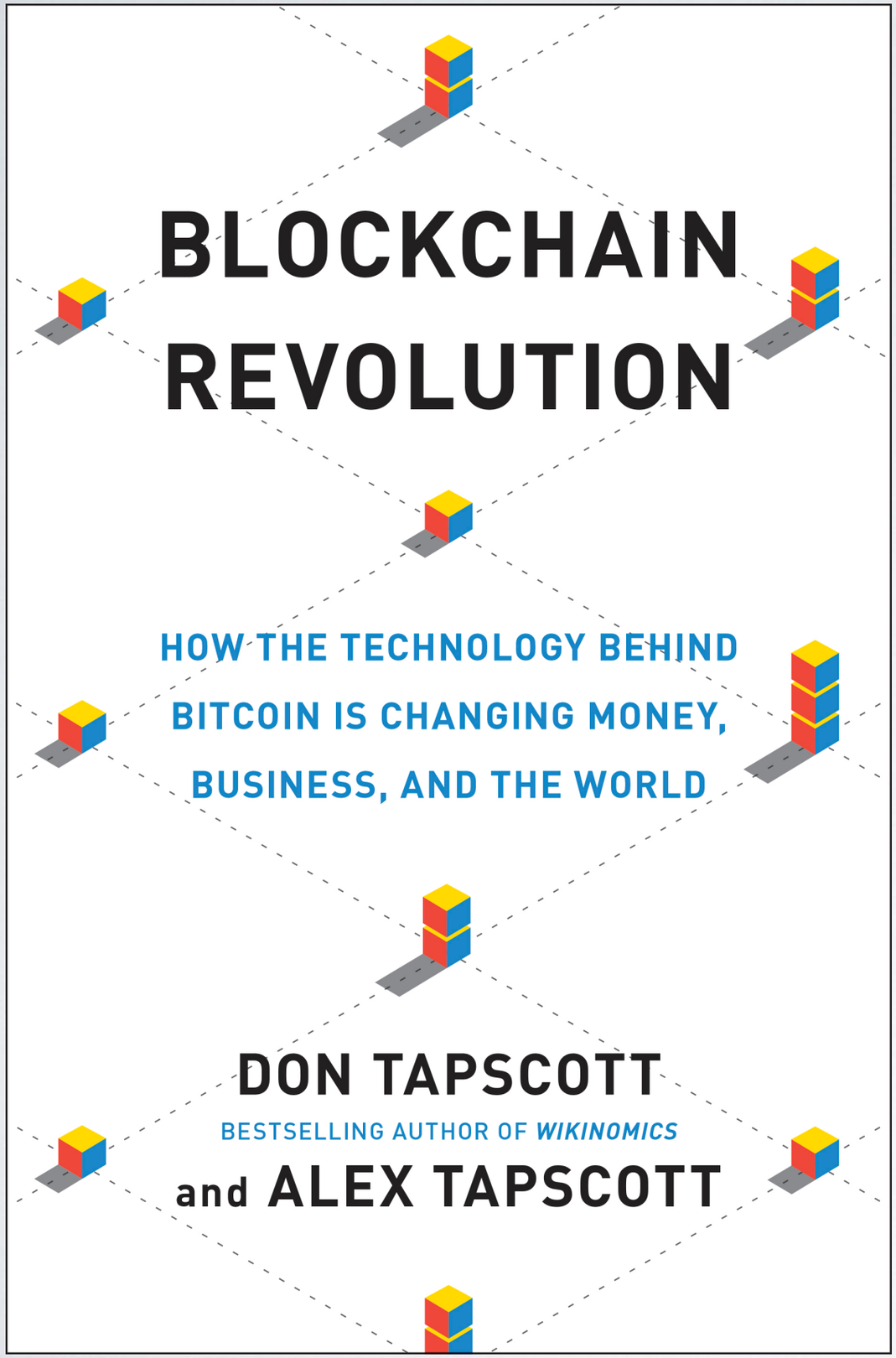
Draft — Feb 9, 2016

Feedback welcome! Email bitcoinbook@lists.cs.princeton.edu

For the latest draft and supplementary materials including programming assignments, see our Coursera course.

The official version of this book will be published by Princeton University Press in 2016. If you'd like to be notified when it's available, please sign up here.





The New York Times
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Bitcoin Technology Piques Interest on Wall St.

By NATHANIEL POPPER AUG. 28, 2015

Fredrik Voss is overseeing work at Nasdaq to use the technology behind Bitcoin to make trading faster and cheaper. Sasha Maslov for The New York Times

Most people still think of Bitcoin as the virtual currency used by drug dealers and shadowy hackers looking to evade the authorities.

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NEC

norbloc

NOKIA

云象
YUNPHANT

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Global IT Innovator

橙色魔方
Orange Magic Cube

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wutongtree.com

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Investrata Foundation

WELLS FARGO

SANY

SBERBANK

S.W.I.F.T.

NXT FOUNDATION

TMX

fondazione INUIT
Università di Roma Tor Vergata

UMP

太一
TAI

保全网
BaoQuan.com

GINGKOO
金丘股份 (837901)

NEXGO

STATE STREET

Skry

点融网
Dianrong.com

SORAMITSU
ソラミツ

symbiont

THOMSON REUTERS

ACC
Agora
AIMP
Allopass
b-money
BankNet
Bitbit
Bitgold
Bitpass

Many Schemes

PayPal

Bitcoin

Bitcoin is designed to be a currency (BTC)

Bitcoin is not a digital form of an existing currency

Thus not like Paypal, EFTs, interact-by-email

Bitcoin is decentralized: no central bank

Expedia

Travel Purchase Order **$83.15 USD**
0.31322605 BTC

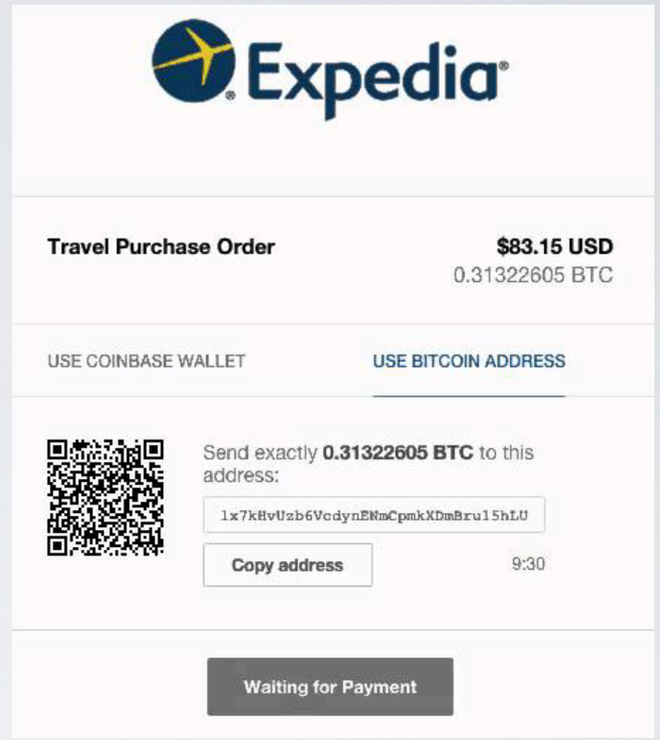
USE COINBASE WALLET | USE BITCOIN ADDRESS

Send exactly **0.31322605 BTC** to this address:

1x7kHvUzb6VcdynENmCpmkXDmBru15hLU

Copy address 9:30

Waiting for Payment



Recent Trades (XBT/CAD)

1 - 15 of 250 trades

Time	Order	Price	Volume
17:16:14 +00:00	sell	C$580.193	0.33660000
17:00:50 +00:00	sell	C$578.291	2.00000000
16:36:44 +00:00	sell	C$578.641	0.18081567
16:36:40 +00:00	sell	C$578.641	0.80000000
16:36:39 +00:00	sell	C$578.641	2.25528436
16:03:06 +00:00	buy	C$582.002	0.03436414
15:55:20 +00:00	buy	C$581.649	0.48183239
15:55:19 +00:00	sell	C$581.649	0.47803974
15:53:01 +00:00	buy	C$584.186	0.07600000
15:23:26 +00:00	sell	C$582.624	0.42260000
15:09:46 +00:00	buy	C$581.855	0.07770000
13:28:01 +00:00	sell	C$578.001	0.73508491
13:28:01 +00:00	sell	C$578.120	3.26491509
13:23:37 +00:00	buy	C$581.077	16.28760000
13:23:36 +00:00	buy	C$579.315	10.71240000

Blockchain in a slide

Bitcoin was proposed in 2008

Under the covers, an open P2P network agrees on the set of valid transactions and records them

The blockchain is the data structure, and its update rules ensure trustless consensus

Recently, interest in blockchain as a general primitive to implementing decentralized ledgers

Keep in Mind

Beyond secure payments, other challenges

How do you get a decentralized entity to agree when money is at stake?

Who do you give the initial supply of currency to?

How it works

Alice

Bob

Digital Monetary Unit

Bank

Alice

Bob

Issued by Bank

Bank

Spent without Bank

Bank

Alice

Bob

Ledger-based System

Bob	Alice	10 BTC
Carol	Alice	5 BTC
Carol	Bob	18 BTC

Ledger

Alice

15 BTC

Bob

18 BTC

Bob	Alice	10 BTC
Carol	Alice	5 BTC
Carol	Bob	18 BTC

Ledger

Bob	Alice	10 BTC
Carol	Alice	5 BTC
Carol	Bob	18 BTC

Ledger

Bob	Alice	10 BTC
Carol	Alice	5 BTC
Carol	Bob	18 BTC
Alice	Bob	5 BTC

Ledger

Bob	Alice	10 BTC
Carol	Alice	5 BTC
Carol	Bob	18 BTC
Alice	Bob	5 BTC

Ledger

Alice
10 BTC

Bob
23 BTC

Access Control

Bob	Alice	10 BTC
Carol	Alice	5 BTC
Carol	Bob	18 BTC
Alice	Bob	5 BTC

Ledger

{Alice, K_A}
10 BTC

{Bob, K_B}
23 BTC

Bob	Alice	10 BTC
Carol	Alice	5 BTC
Carol	Bob	18 BTC
Alice	Bob	5 BTC

Ledger

Bob	Alice	10 BTC
Carol	Alice	5 BTC
Carol	Bob	18 BTC
Alice	Bob	5 BTC

Ledger

{Alice, K_A}
10 BTC

{Bob, K_B}
23 BTC

PKI

Bob	Alice	10 BTC
Carol	Alice	5 BTC
Carol	Bob	18 BTC
Alice	Bob	5 BTC

Ledger

K_A
10 BTC

K_B
23 BTC

Pseudonymity

K_B	K_A	10 BTC
K_C	K_A	5 BTC
K_C	K_B	18 BTC
K_A	K_B	5 BTC

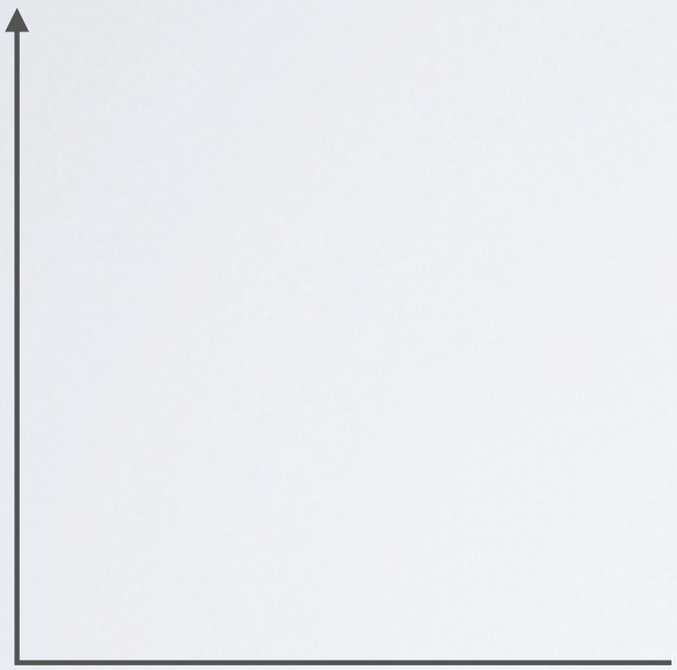
Ledger

Transaction:	T-9833
Inputs:	{T-5292, K_{A1}, 3.5} {T-3928, K_{A2}, 2.5}
Outputs:	{K_{B1}, 5.0} {K_{A3}, 0.99}
Signature:	{Sig_{A1}} {Sig_{A2}}

K_B	K_A	10 BTC
K_C	K_A	5 BTC
K_C	K_B	18 BTC
K_A	K_B	5 BTC

Ledger

Transaction:	T-9833
Inputs:	{T-5292, K_{A1}, 3.5} {T-3928, K_{A2}, 2.5}
Outputs:	{K=Script(In), 5.0} {K=Script(In), 0.99}
Signature:	{Sig_{A1}} {Sig_{A2}}



K_B	K_A	10 BTC
K_C	K_A	5 BTC
K_C	K_B	18 BTC
K_A	K_B	5 BTC

Ledger

K_A
10 BTC

K_B
23 BTC

Decentralize?

T-2351
T-4528
T-9636
T-9833

Ledger

K_A → T-9833

10 BTC

K_B

23 BTC

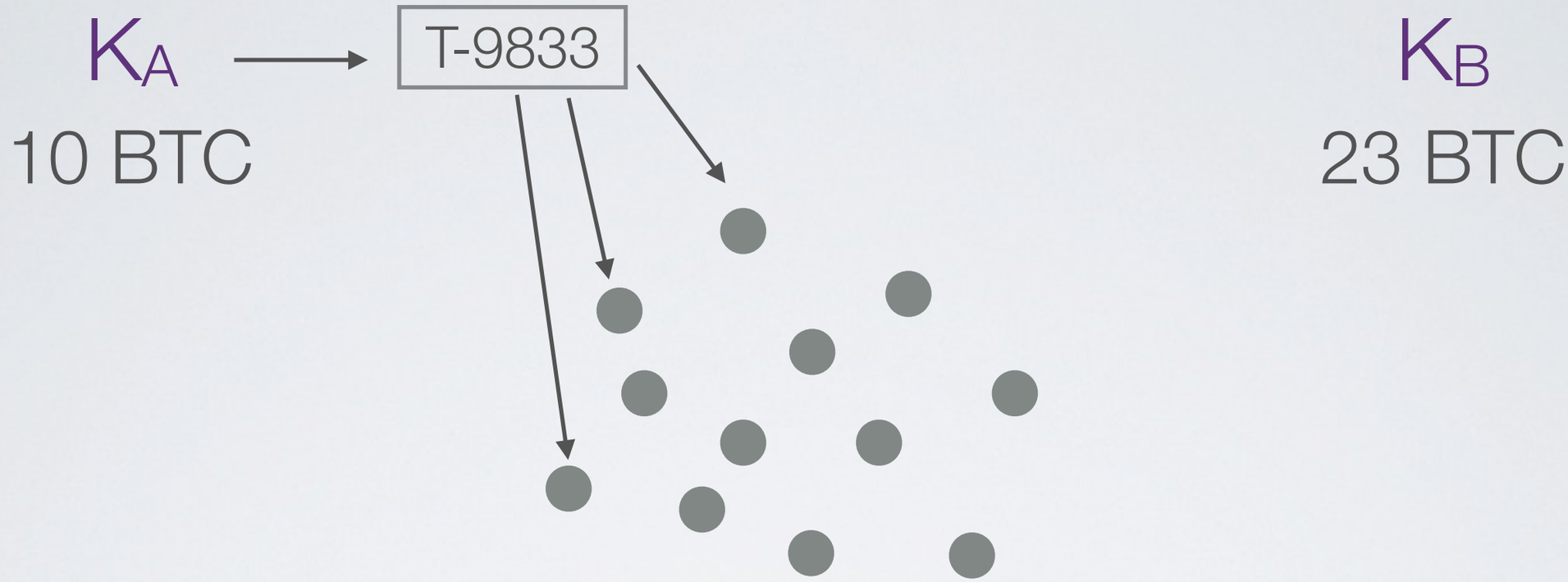
T-2351

T-4528

T-9636

T-9833

Ledger



T-2351

T-4528

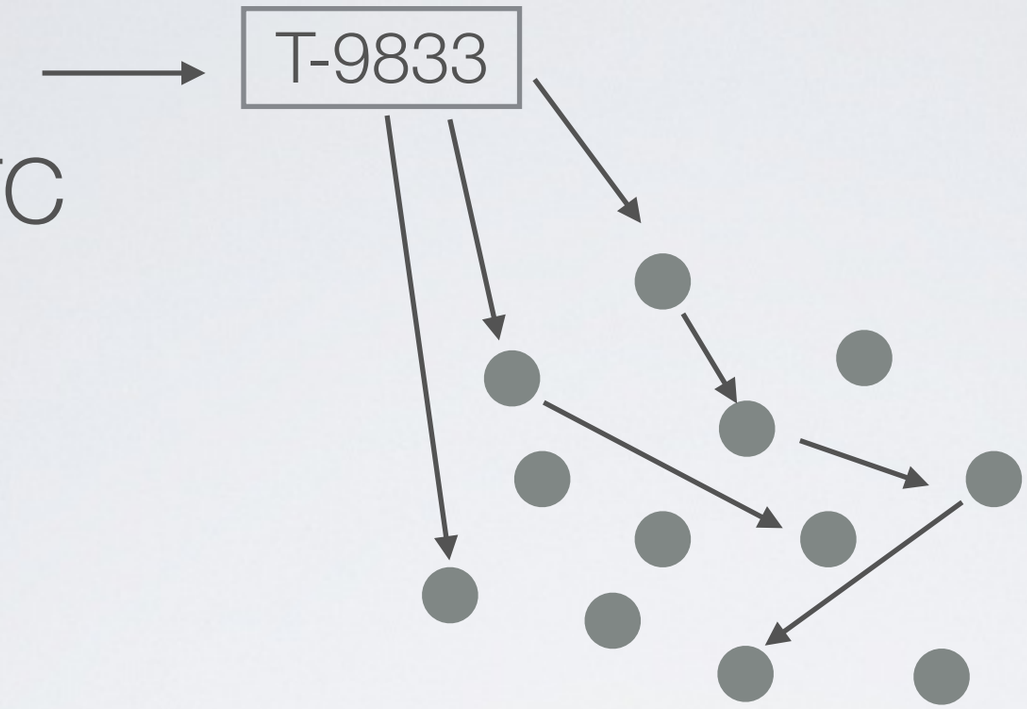
T-9636

T-9833

Ledger

K_A

10 BTC



K_B

23 BTC

T-2351

T-4528

T-9636

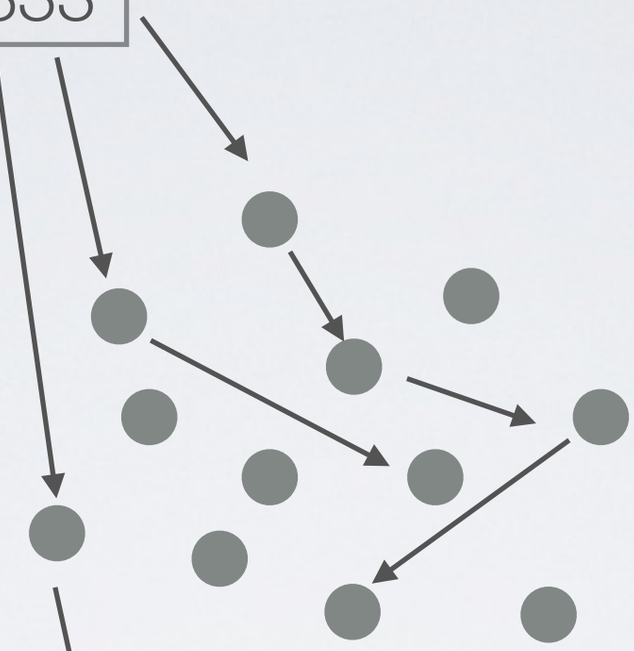
T-9833

Ledger

K_A

10 BTC

T-9833



K_B

23 BTC

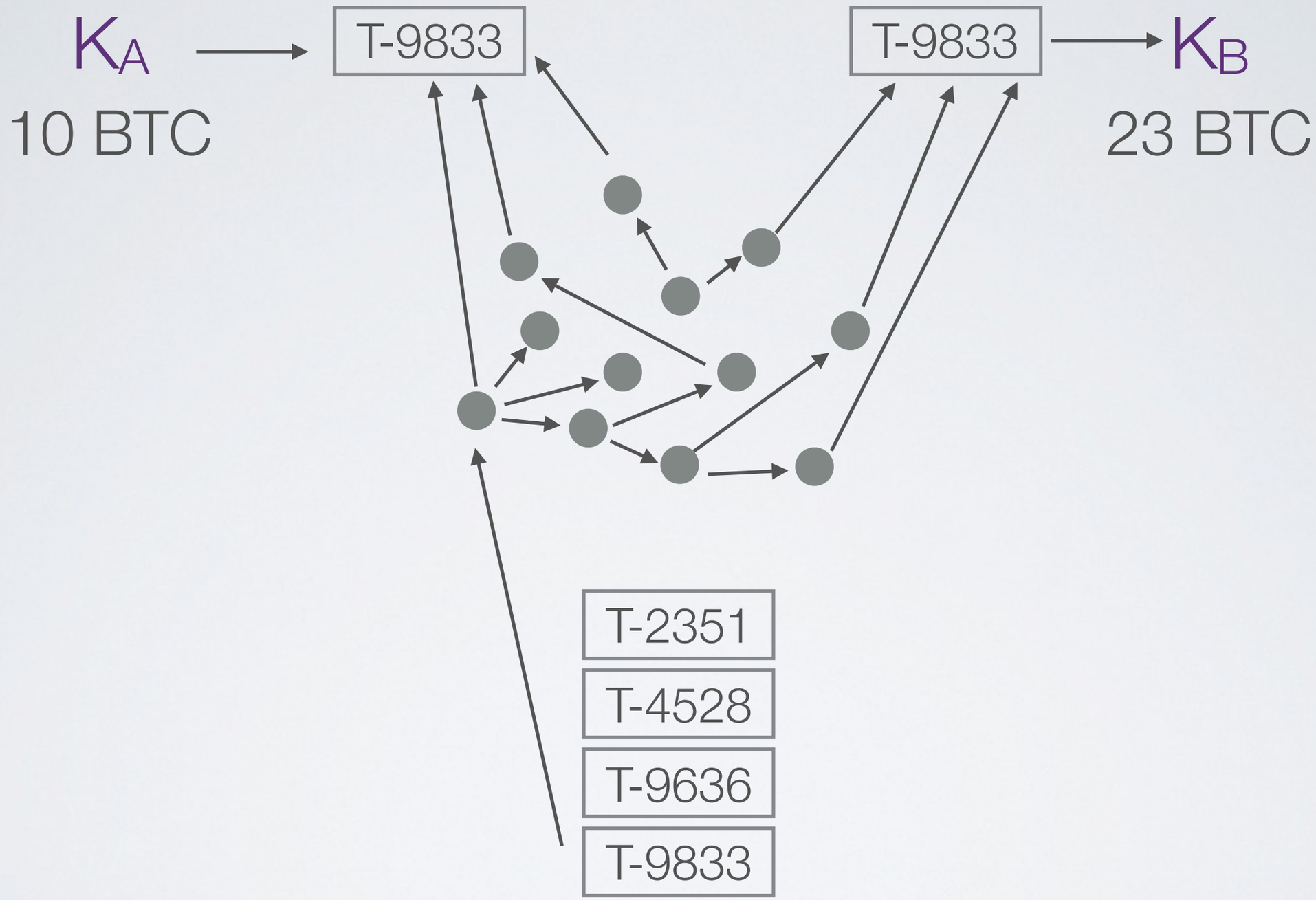
T-2351

T-4528

T-9636

T-9833

Ledger


K_A
10 BTC
T-9833
T-9833
K_B
23 BTC
T-2351
T-4528
T-9636
T-9833
Ledger

Agreement & Append-Only

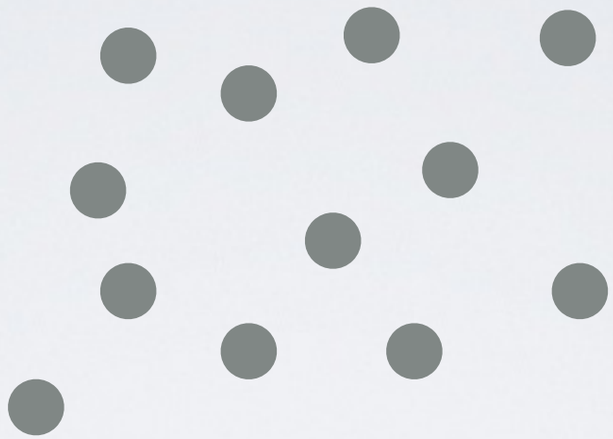
T-2351

T-4528

T-9636

T-9833

Ledger



Block 11

T-2351

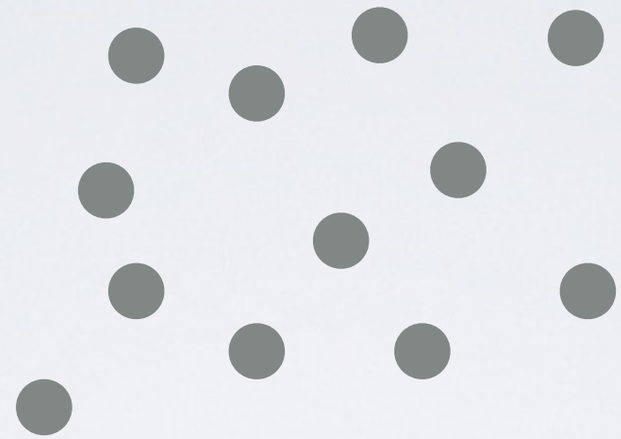
T-4528

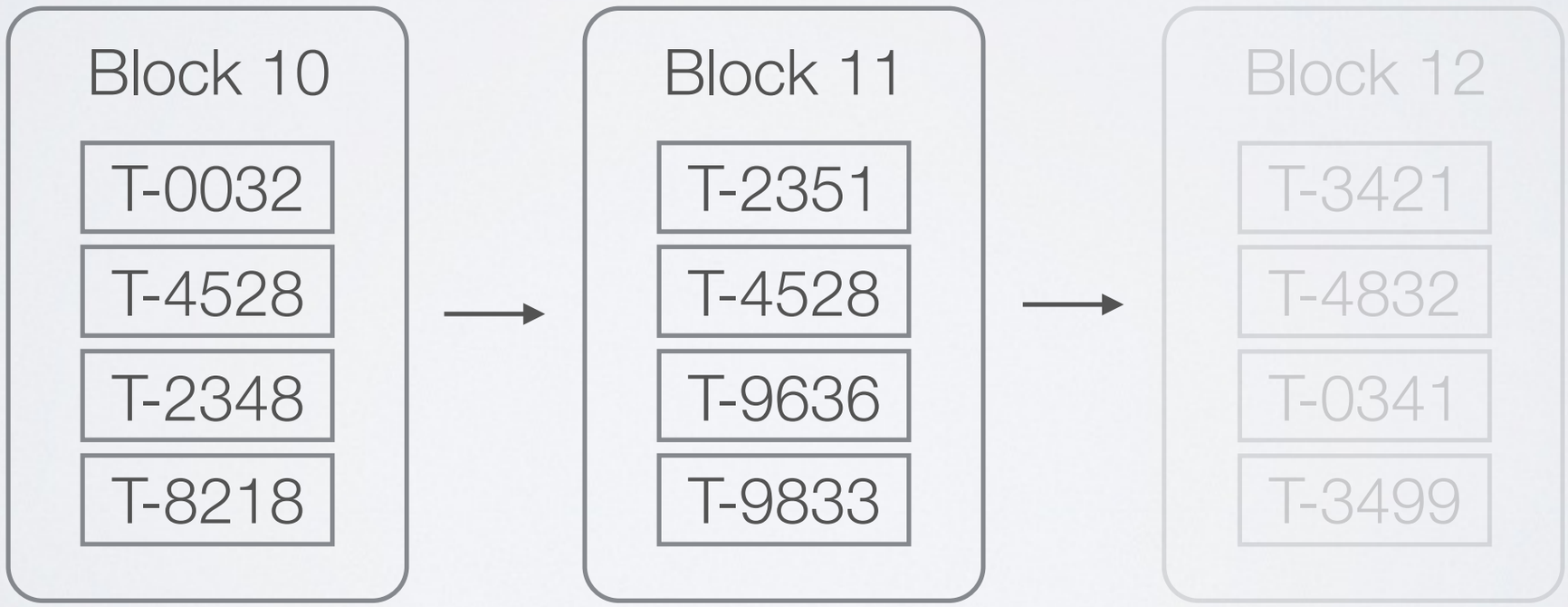
T-9636

T-9833

Ledger

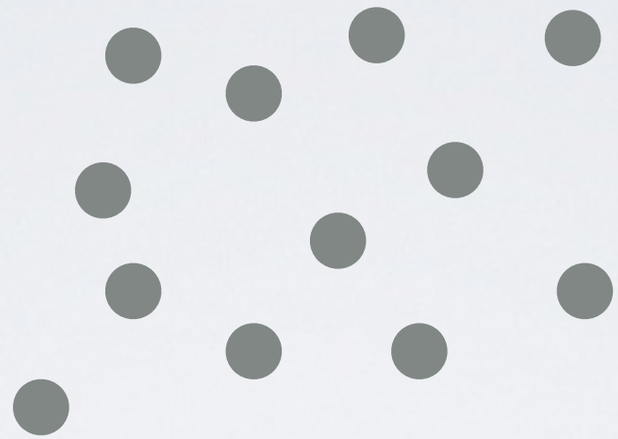
Hash Chain

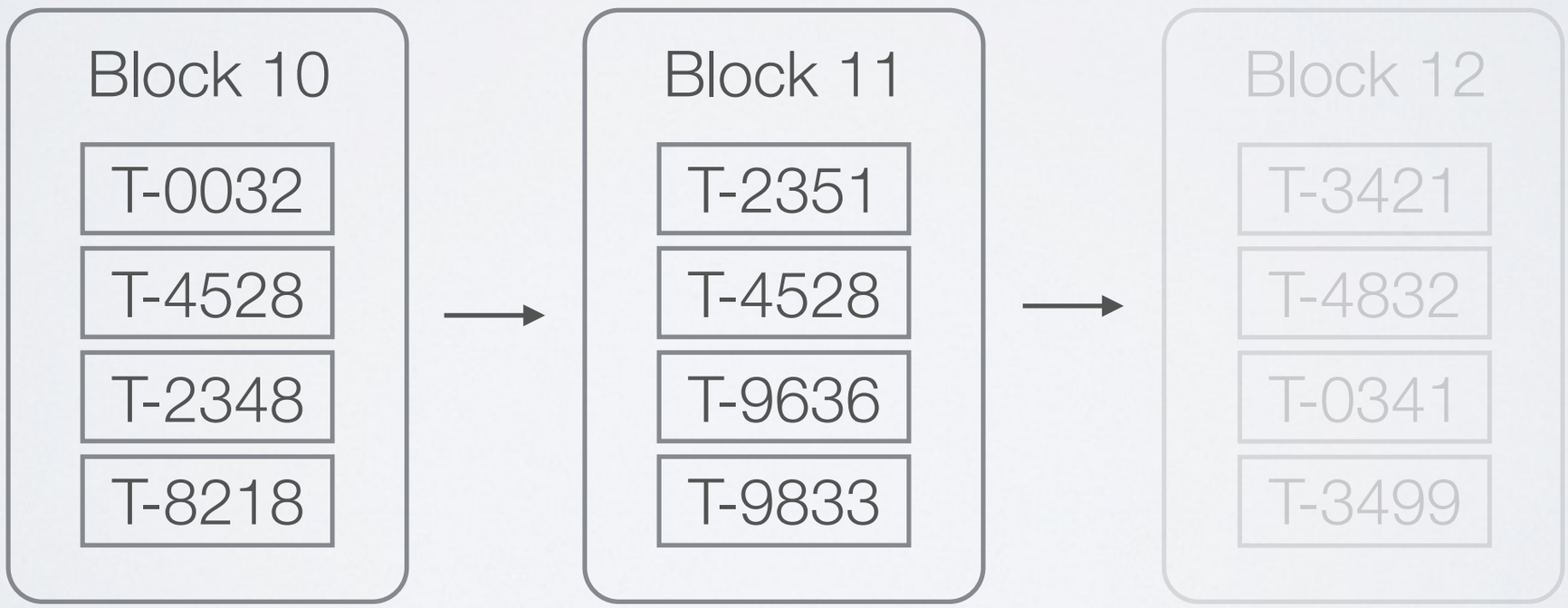


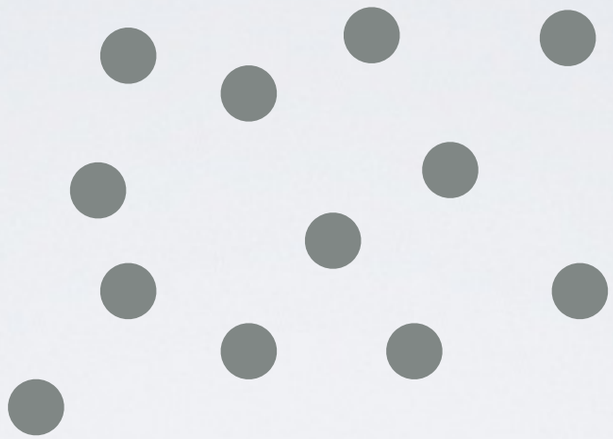


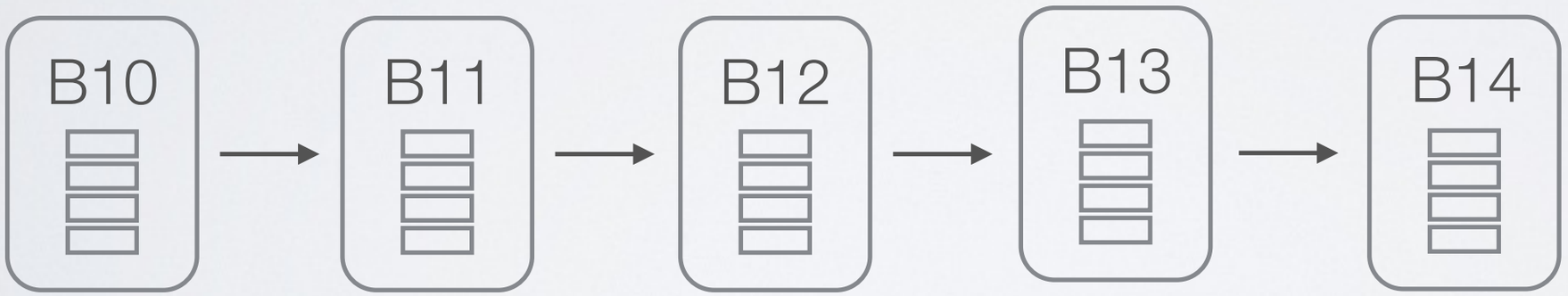
Ledger

Rate-Limit Block Creation





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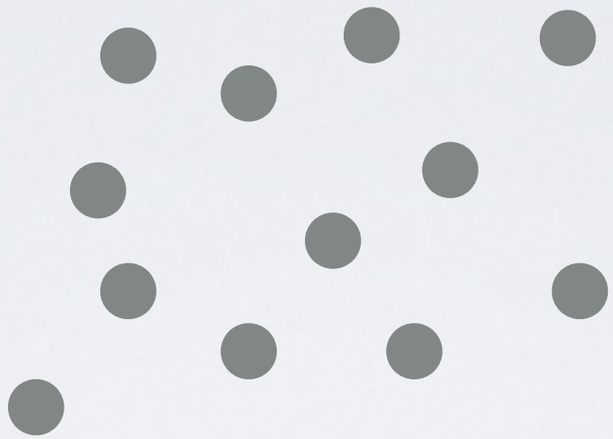

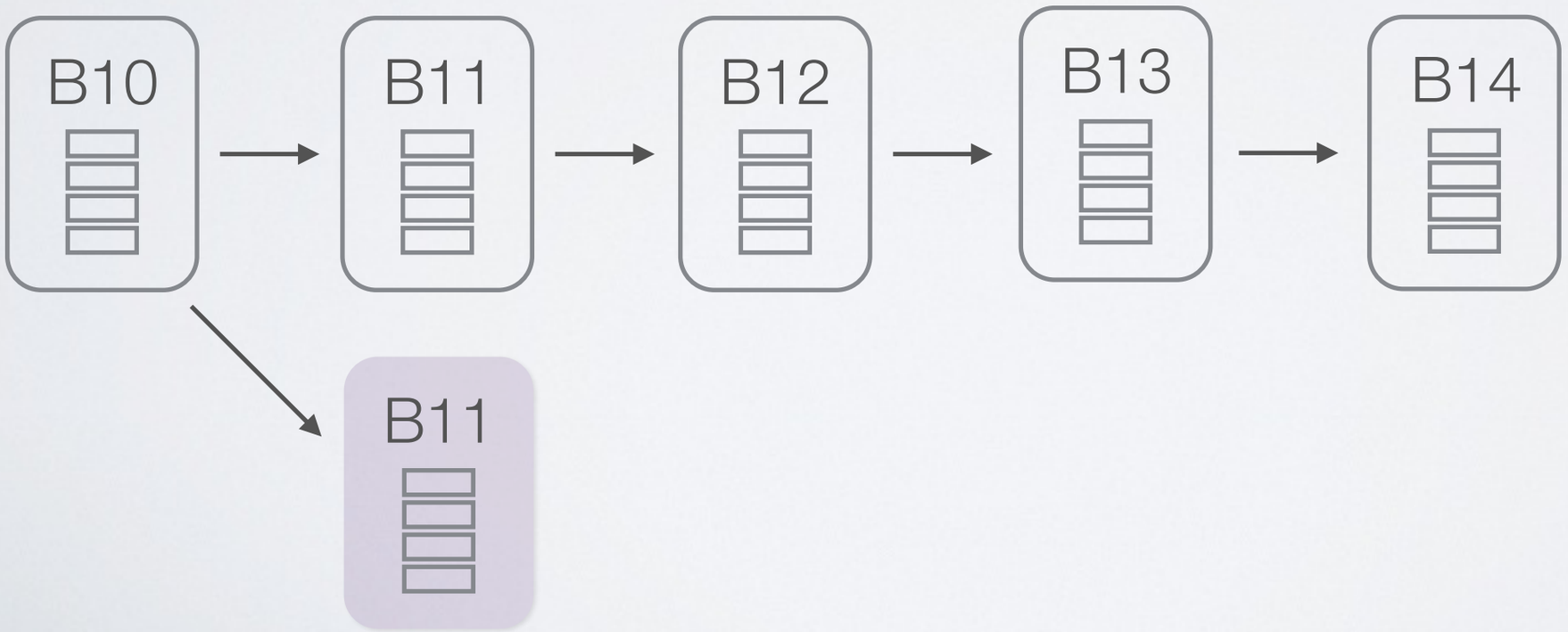
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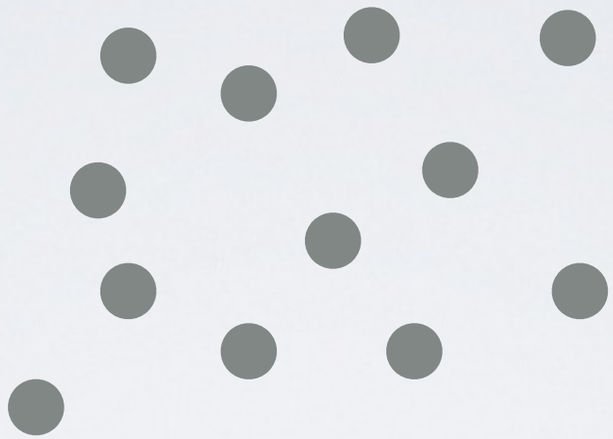

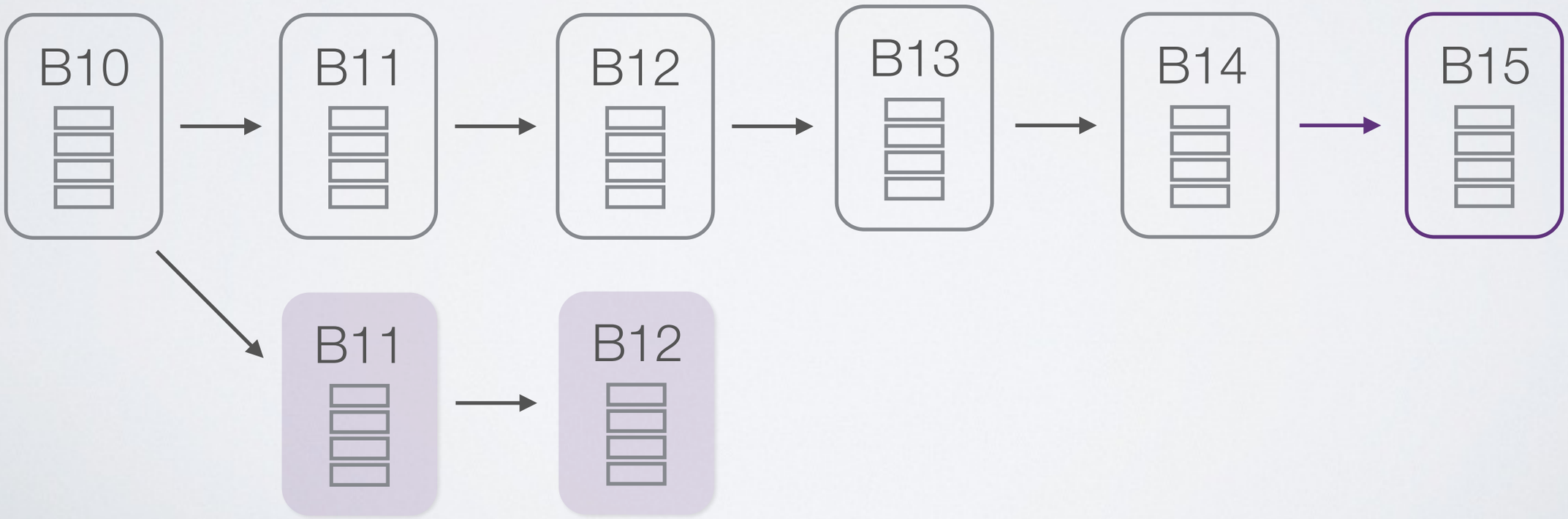
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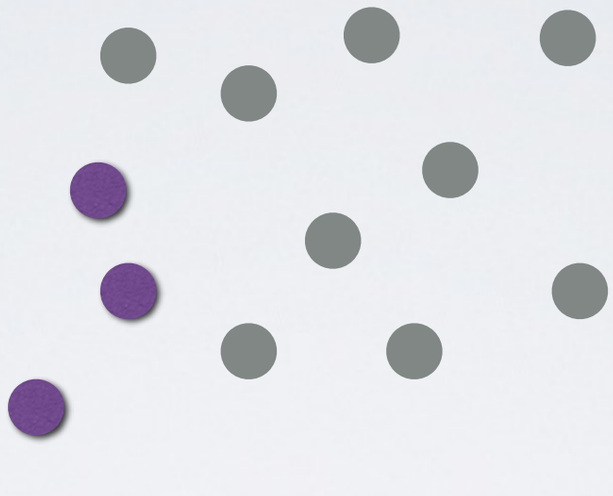

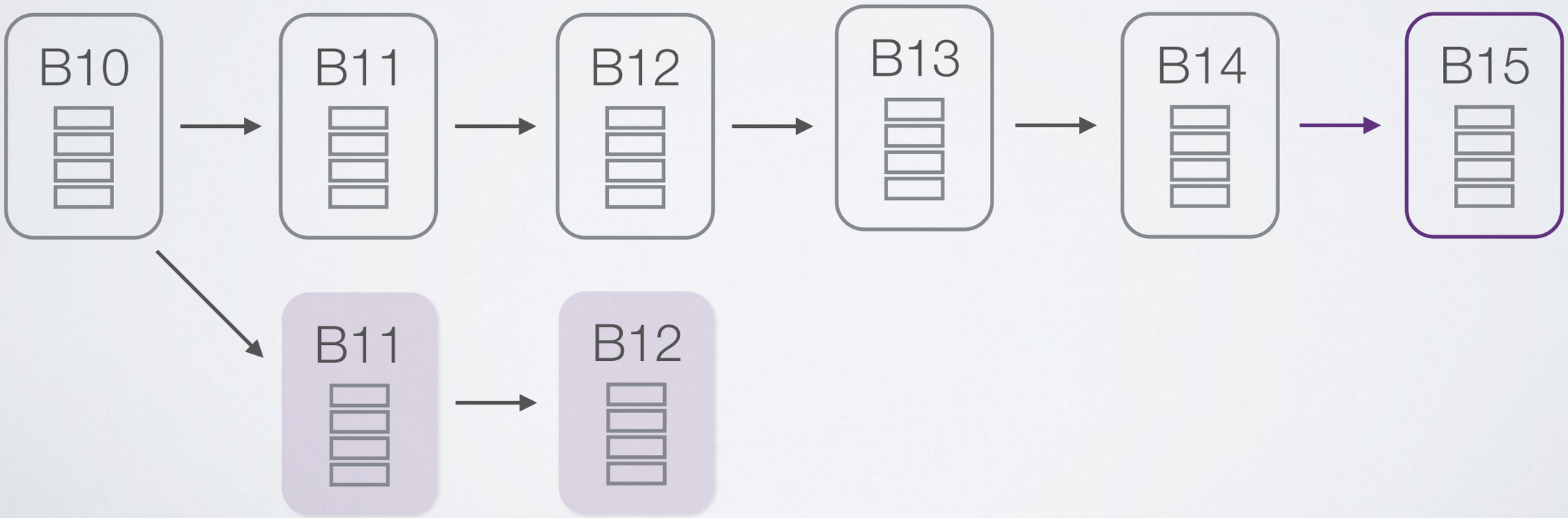
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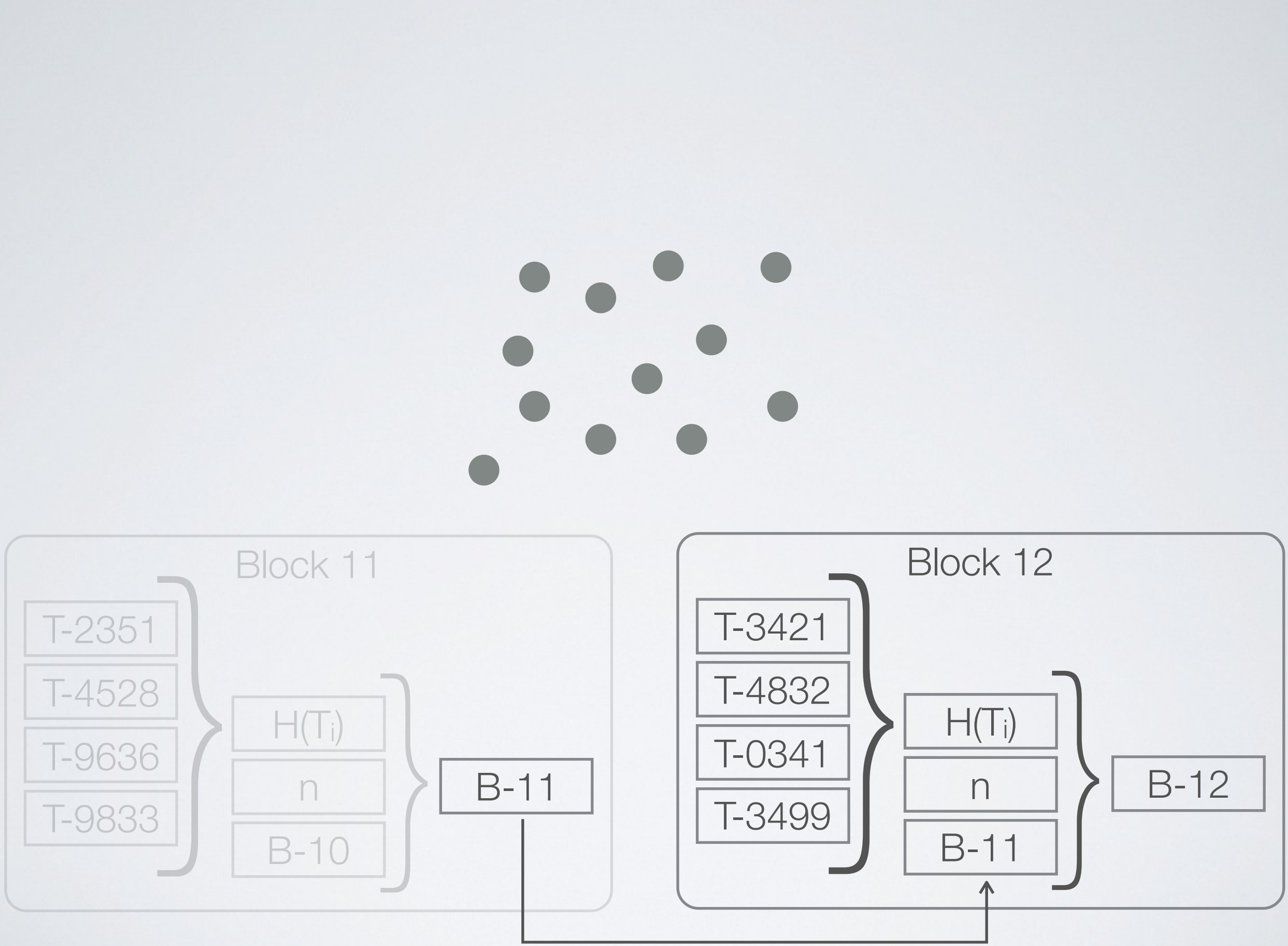
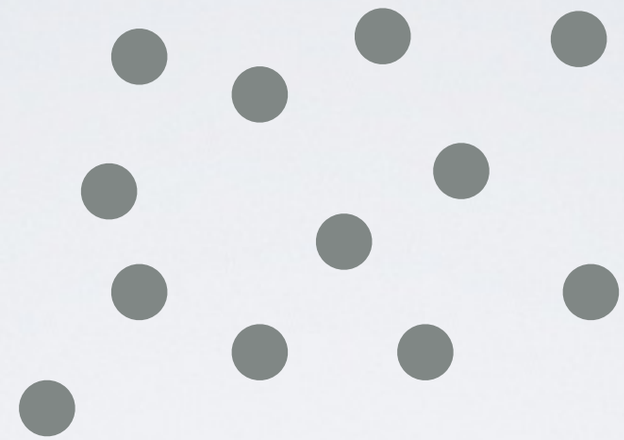
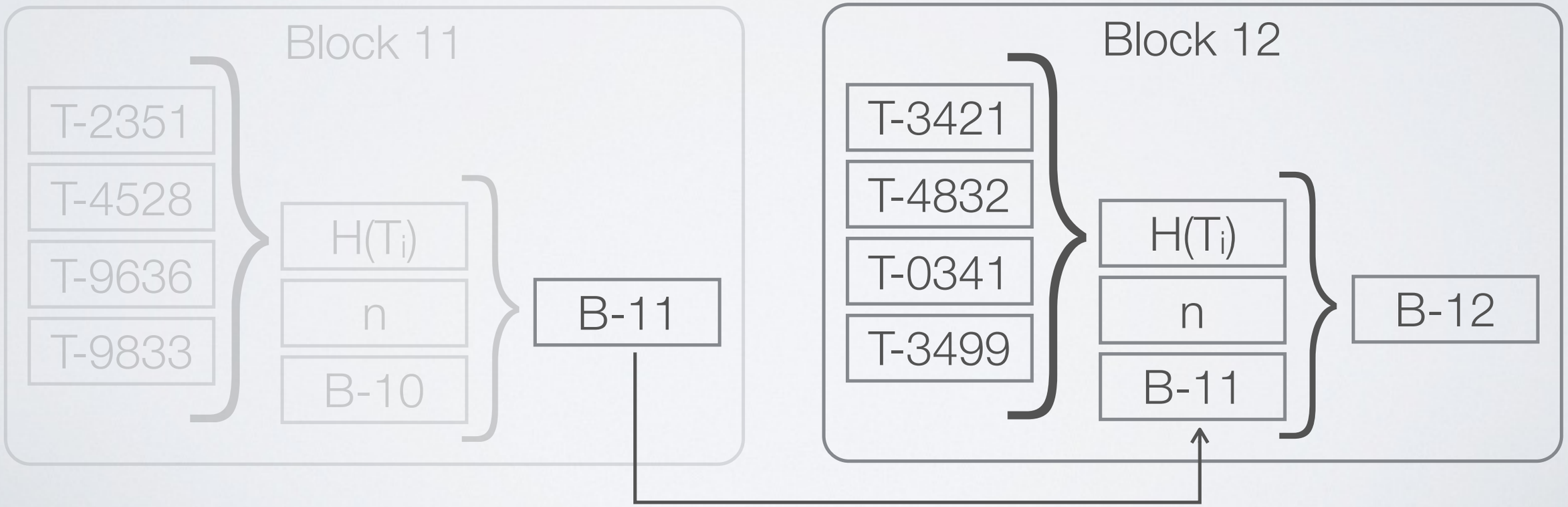

Block 11
T-2351
T-4528
T-9636
T-9833
H(Ti)
n
B-10
B-11
Block 12
T-3421
T-4832
T-0341
T-3499
H(Ti)
n
B-11
B-12

B-12 = H($H(T_i)$ || n || B-11)

= 00000000000XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

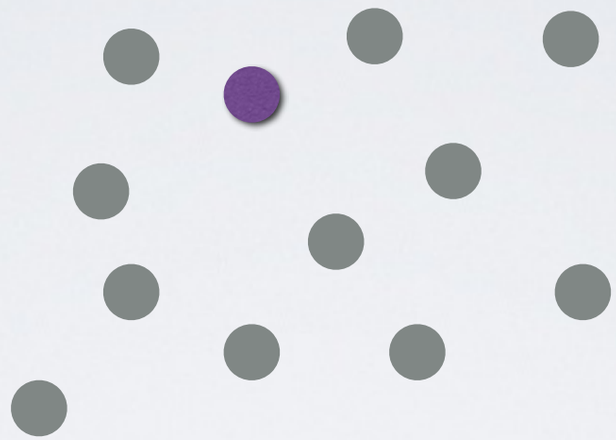
Work = (2^n)

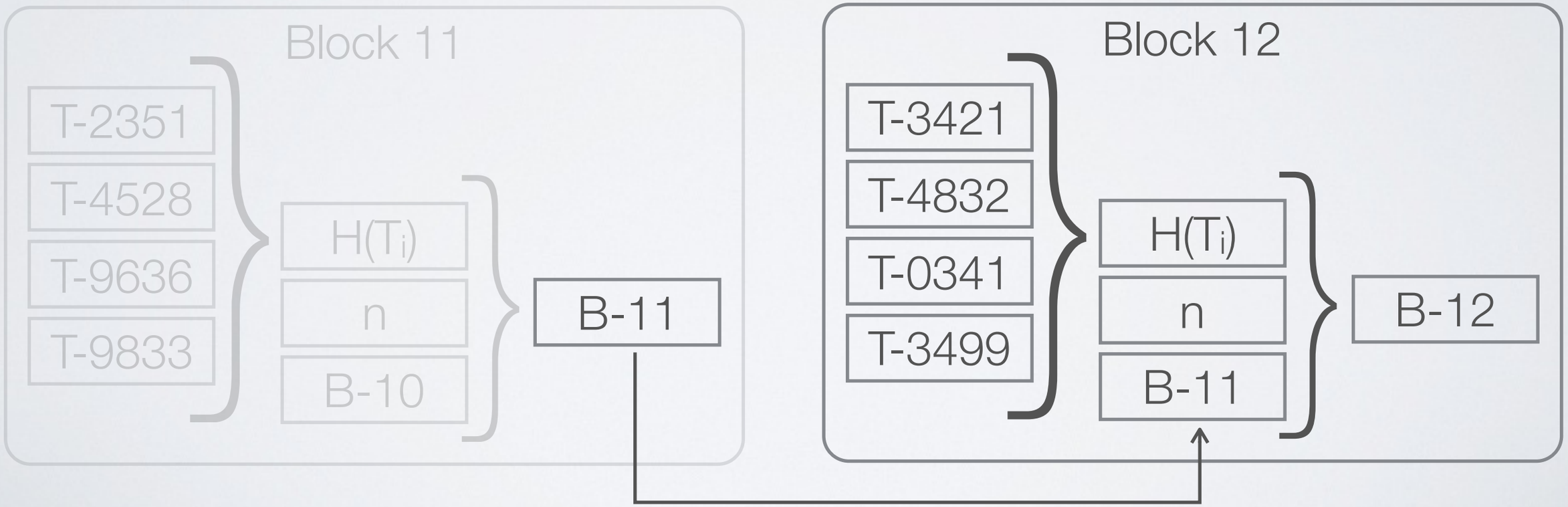




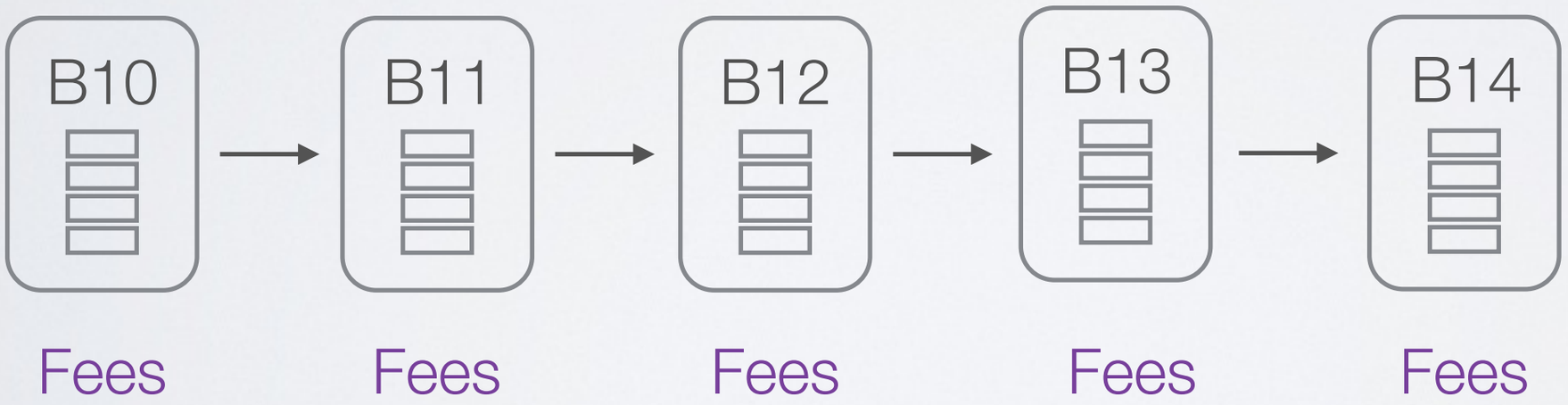
B-12 = H($H(T_i)$ || n || B-11)

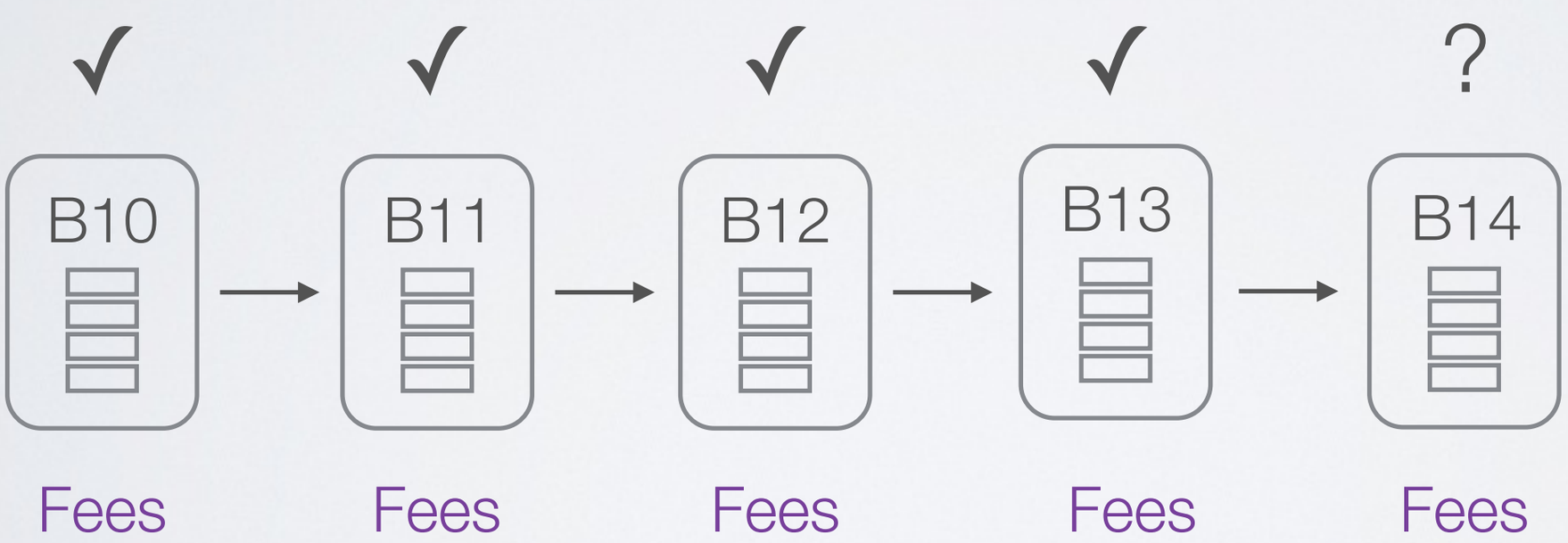
= 00000000000XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX





Incentive Compatibility

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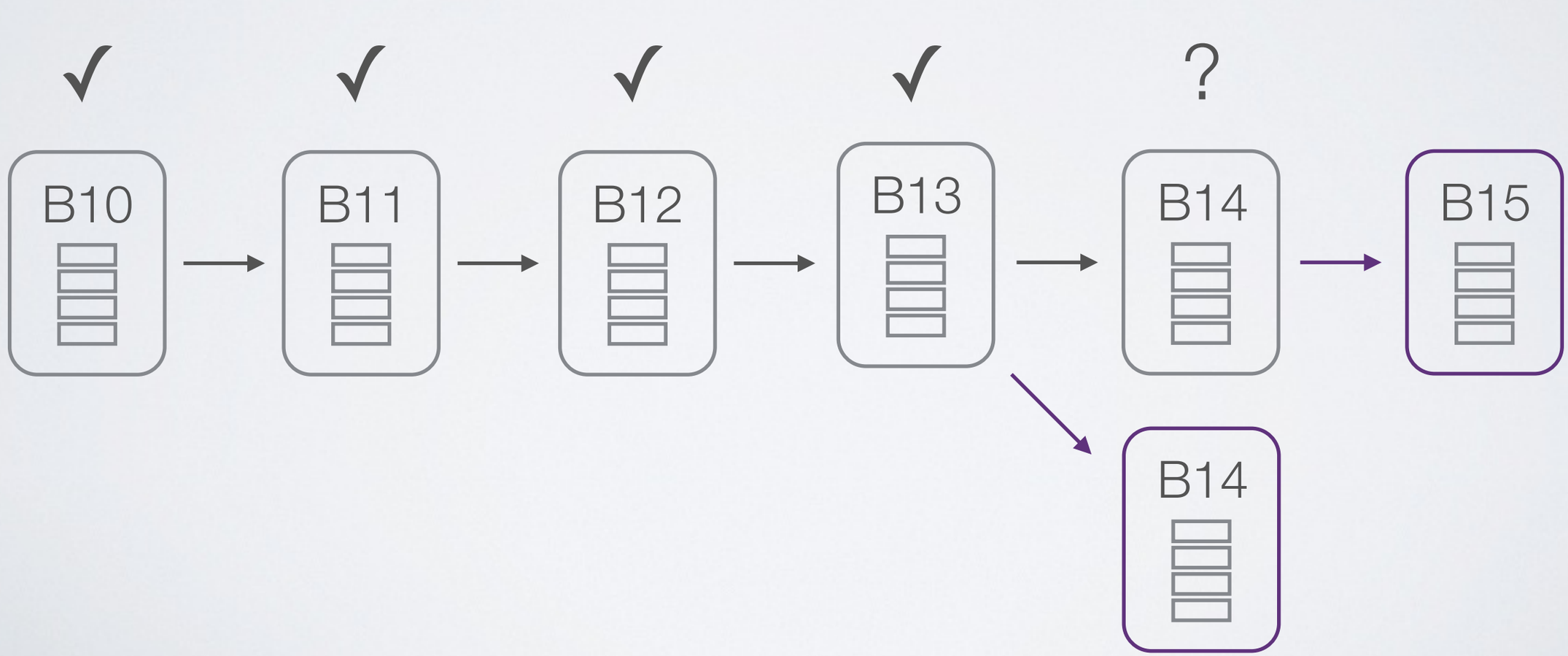
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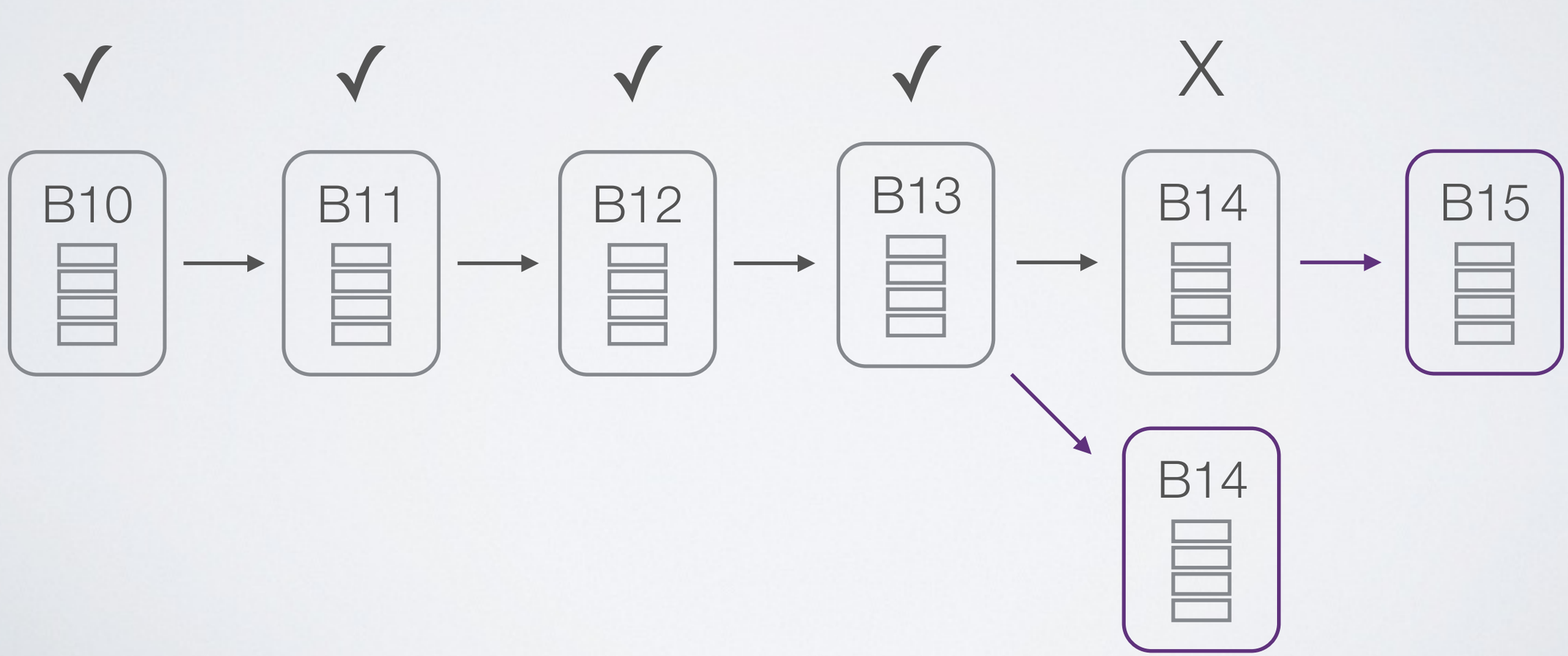
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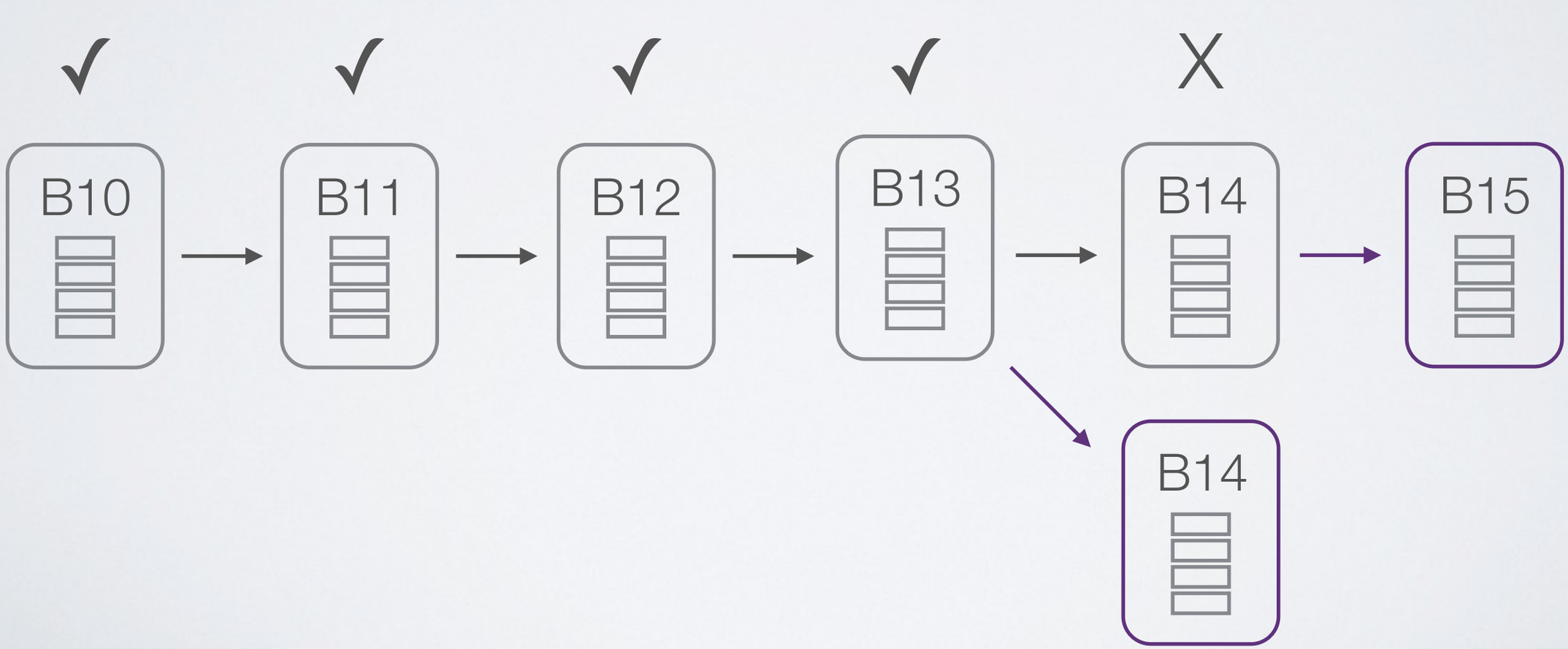
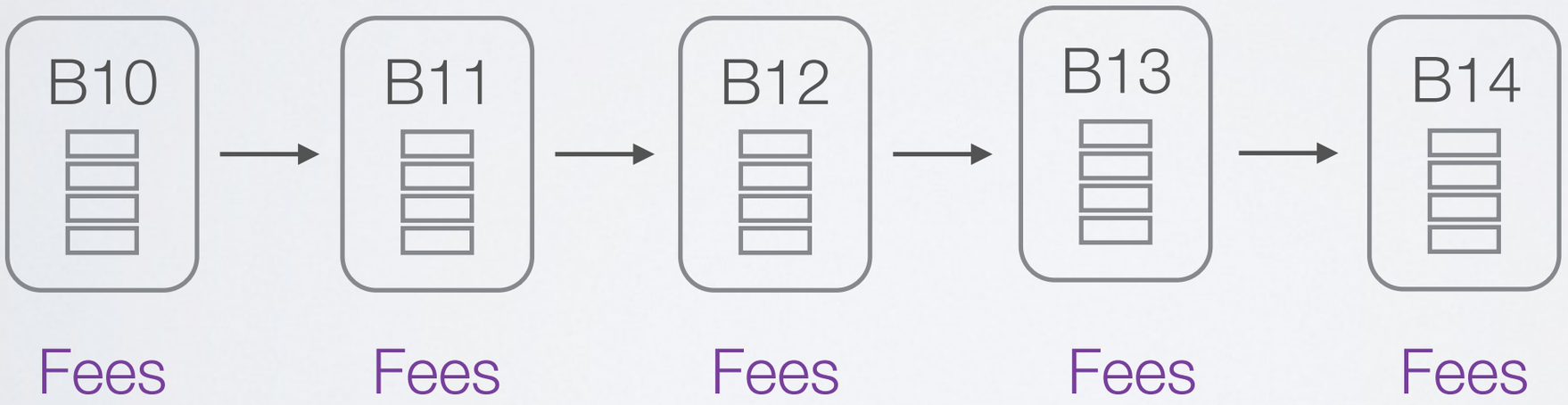
B14

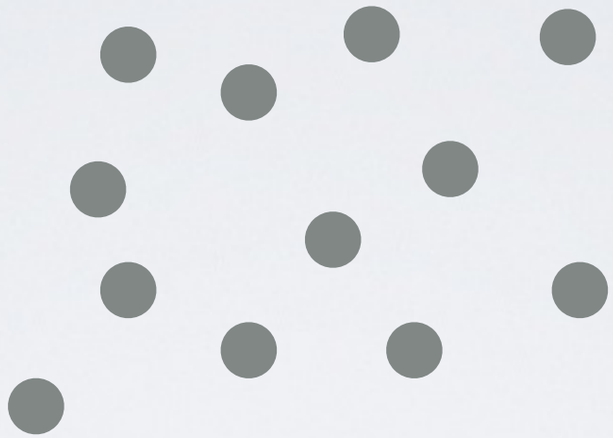
It pays to verify



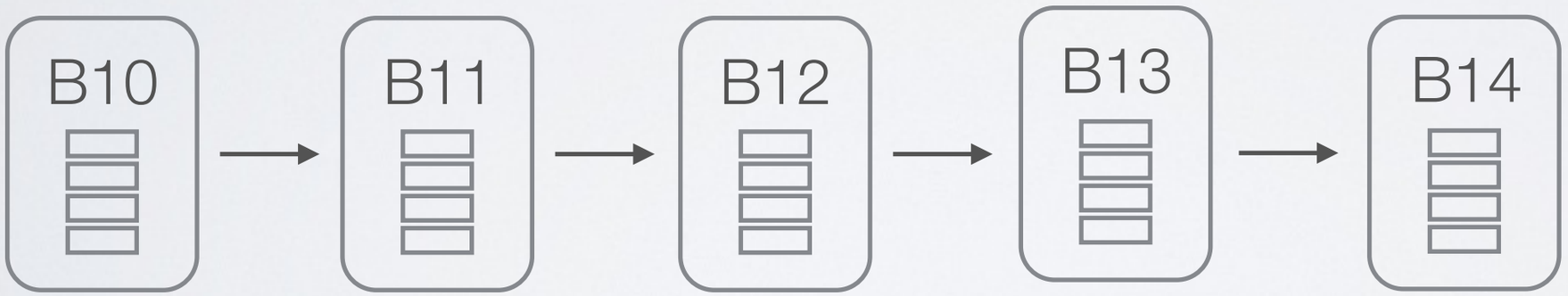
Initial Distribution (Minting)



Initial Distribution (Minting)



Nodes = “Miners”



Fees

Mint

Fees

Mint

Fees

Mint

Fees

Mint

Fees

Mint

Initial Distribution (Minting)

Newly minted coins offset expenses (seignorage)

This allows lower fees

Effectively: minted coins are distributed to the users in the form of lower fees

Circulation limited to 21M BTC (~Year 2140)

Challenge: Double Spend

Consider: two transactions are broadcast & both spend the same BTC

Which one will be included in blockchain?

Consensus will form but will take ~6 blocks (~1 hour) for high assurance. Too long to wait in some cases.

Discussion

The term blockchain

1) Bitcoin's protocol for achieving a distributed ledger maintained by an open network of profit-seeking nodes

2) Any distributed ledger

3) The philosophy behind Bitcoin: digitizing commodities, securities, deeds, contracts…

Blockchain v. Database

- Blockchains and (distributed) databases are similar and somewhat interchangeable
- The emphasis is on different things
- Blockchains are for small data (1MB every 10 min)
- Blockchains are for validated data
- Blockchains are not about complex queries (you download everything)
- Blockchains are secure against malicious nodes

Properties

1) Non-equivocation
   - Different people at different times see the same thing
   - Not just “see” but “have”
   - Your local copy is the golden copy

2) Mitigated trust-assumptions
   - Bitcoin operates in a trustless environment
   - Distributed ledgers exist on a spectrum of trust

3) Transparency
   - Validated records require disclosure
   - Useful for lit markets, challenge for proprietary ledgers

4) Efficiency
   - Digitized assets can be **settled:**
     - Minutes/hours without trust
     - Seconds with trust or collaterial
   - Distributed means no “clock on the wall”
     - Updates are “chunky” and no time priority
   - Computational effort required without trust

Key Challenges

Bitcoin is a poor store of value when unit of account, cutting out lending

Blockchains do not solve counter-party risk

Blockchains do not solve the problem of stapling real world entities to digital tokens

Endpoint security and key management is an old problem

Use Cases

Smart Contracts

A program (state machine) can be defined, initialized, and added to the blockchain

Anyone can invoke a state transition and each node will agree on how to update the state

“Public (no secrets) trusted third party” - Ari Juels

Research Perspectives and Challenges for Bitcoin and Cryptocurrencies. J Bonneau, A Miller, J Clark, A Narayanan, J Kroll, and EW Felten. IEEE Symp Sec & Priv 2015

Decentralized Markets

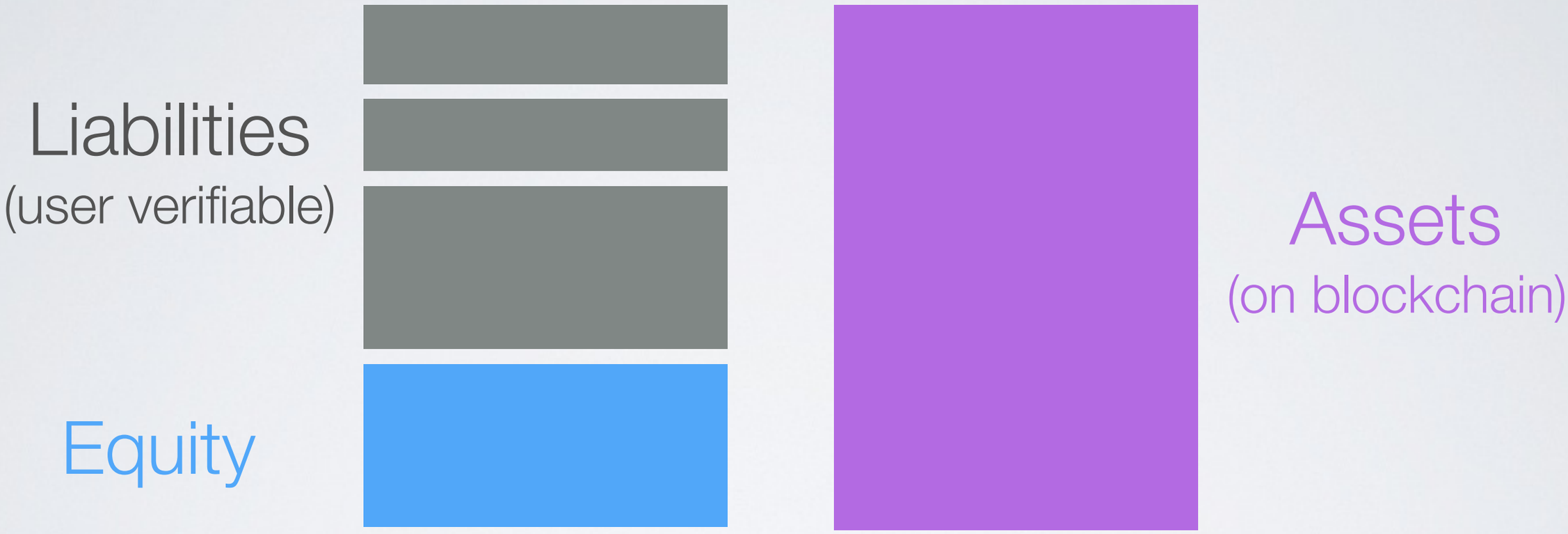
Excitement around replacing post-trade settlement for securities with a blockchain

We showed a design of decentralized order book based on a call market design

Nuances play a large roll: timing, speed, front-running, incentives

On Decentralizing Prediction Markets and Order Books.
J Clark, J Bonneau, EW Felten, JA Kroll, A Miller, A Narayanan. WEIS 2014

Solvency Proofs



ZKP: Equity = Assets - Liabilities >= 0

Provisions: Privacy-preserving proofs of solvency for Bitcoin exchanges.
G Dagher, B Bünz, J Bonneau, J Clark, D Boneh. CCS 2015

Questions?

@PulpSpy