비트코인 개념과 핵심기술

KAIST 디지털금융전문가 과정

IFC 여의도

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디지털금융전문가과정

DIGITAL FINANCE MASTERSHIP PROGRAM

2021 봄학기

- **블록체인과 디지털 자산**
  금융혁신과 신사업준비를 위하여 블록체인 분야에 특화된 기술 교육이 필요한 자
- **클라우드 컴퓨팅과 빅데이터 분석**
  금융 분야에서 클라우드 컴퓨팅 기반 기술 적용과 빅데이터 기획, 분석, 활용을 통한 가치 창출에 관심있는 금융 관련 종사자

2021 가을학기

- **디지털 트랜스포메이션**
  디지털금융/핀테크 분야 백그라운드가 없는 전통 금융 종사자 대상
- **인공지능과 기계학습**
  인공지능과 기계학습 분야를 중점적으로 이수하여 금융 산업에서 해당 분야의 전문가로 성장 하고 싶은 자

KAIST 정영대학

디지털금융전문가과정 Digital Finance Mastership Program

07326 서울특별시 영등포구 국제금융로 10 KAIST 디지털금융전문가과정
(One IFC 17층 KAIST 이의도 캠퍼스)
T. 02) 6274-6181~2 F. 02)6274-6194 E.kaistdfmp@kaist.ac.kr
www.business.kaist.ac.kr/executive

협력기관

서울특별시 금융위원회

QR 바로가기

440 x 280 mm

디지털금융전문가과정

BLOCKCHAIN & DIGITAL ASSETS

Digital Finance Mastership Program

2021년 교육일정 (2021. 3. 17 ~ 7. 14)

KAIST 정영대학

이흥노 교수 강의

교육 일자	일자	시간	시간	강의 주제	강사진	모듈
03월 31일	금	19:00~ 22:00	3H	블록체인 이코노미	이흥노 (GIST)	디지털금융과 블록체인
04월 14일	수	19:00~ 22:00	3H	비트코인 개념과 핵심 기술	이흥노 (GIST)	블록체인 플랫폼과 서비스

Agenda of this talk

- Bitcoin Consensus
- Other Consensuses
- Other Approaches

보유기술현황

보유기술

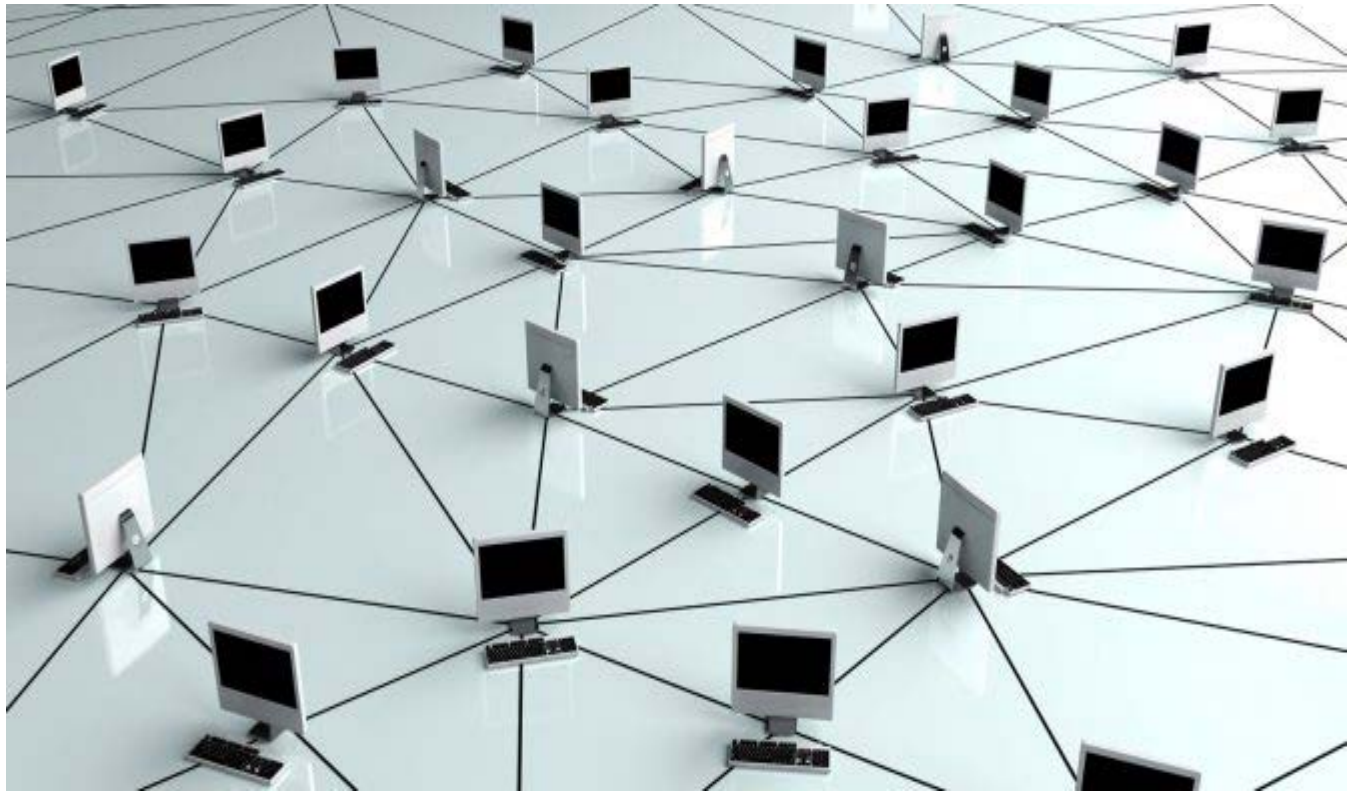
- GIST는 블록체인의 재중앙화 문제 해결을 위한 **부호-암호 기반의 작업증명** 방식 연구 및 특허 확보 및 출원한 **부호-암호 작업증명 특허**
  (GIST IP)를 기반으로 블록체인 시스템 개발

특허

특허	출원인	출원번호/등록일	핵심기술
부호-암호 화폐 시스템	광주과학기술원	10-2019-0151246 / 2019.11.12	블록체인의 재중앙화 문제 해결을 위한 핵심 기술
블록체인거버넌스	광주과학기술원	10-2019-0084800 / 2019-07-12	블록체인 거버넌스와 규제
블록체인의 거래검증시스템, 및 블록체인이 거래검증방법	광주과학기술원	10-2019-0120655 / 2019-09-30	블록체인거래검증

비트코인은 인터넷 위에서 동작

P2P 노드 네트워크 구성



멀리 떨어진 두 사람간의 거래

➢지급결제거래: A가 B에게 2 BTC를 보낸다.

A → B 2 BTC

미국에 있는
Adam

한국에 있는
Byungchul

Consensus

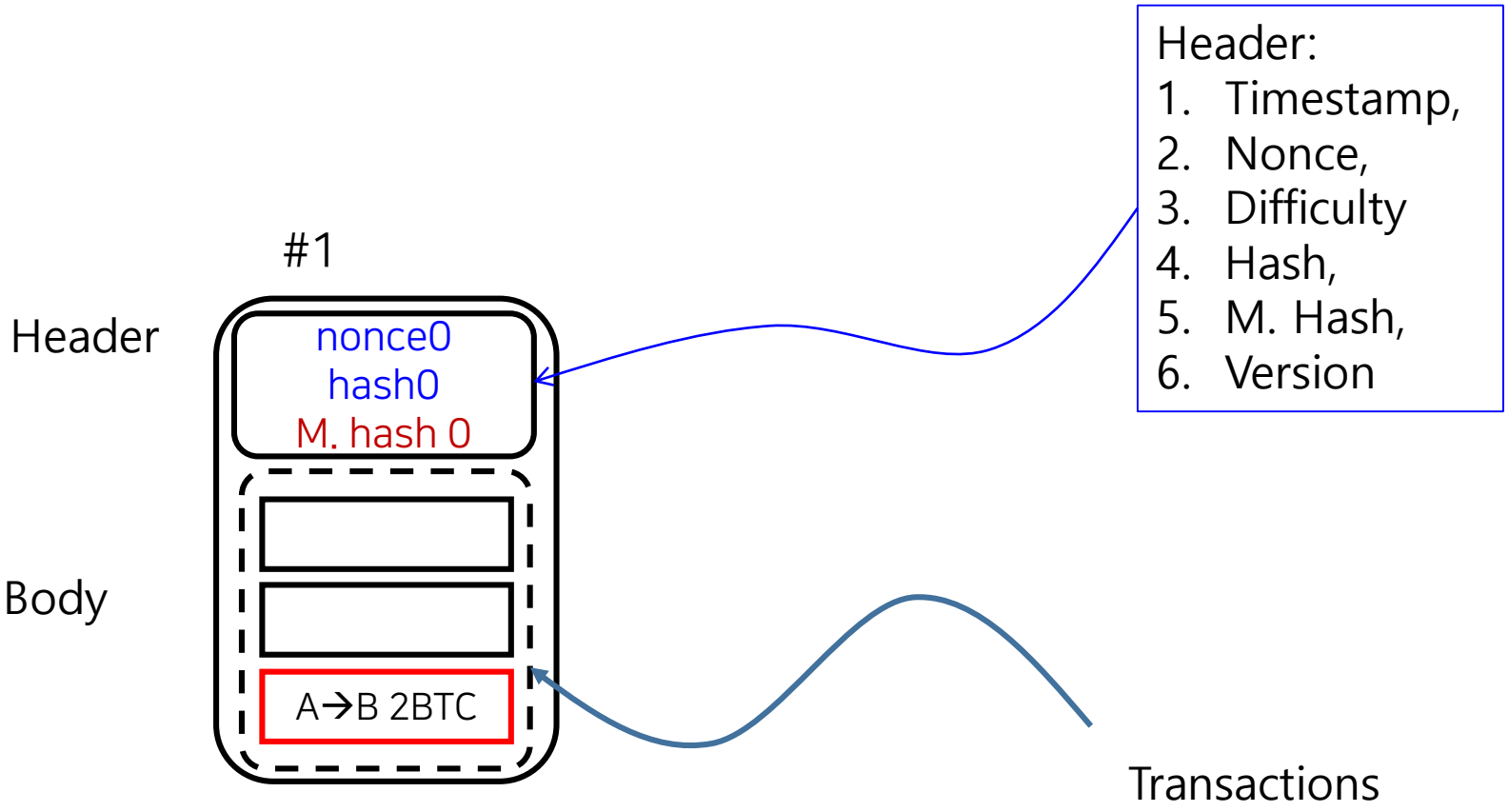
- **Goal: 하나의 동일한 원장 유지 관리**

- Nodes: 글로벌 영역에 분산되어 있는 노드 N개
  1. State: 각 노드의 현재 상태
     A. Work: (각자) 새로운 TXs 담아 블록 생성
     B. Announce: 발표
     C. Inspection: 검사
     D. Approval: 승인
  2. State Update: 새로운 블록을 기존 블록체인에 순서대로 추가

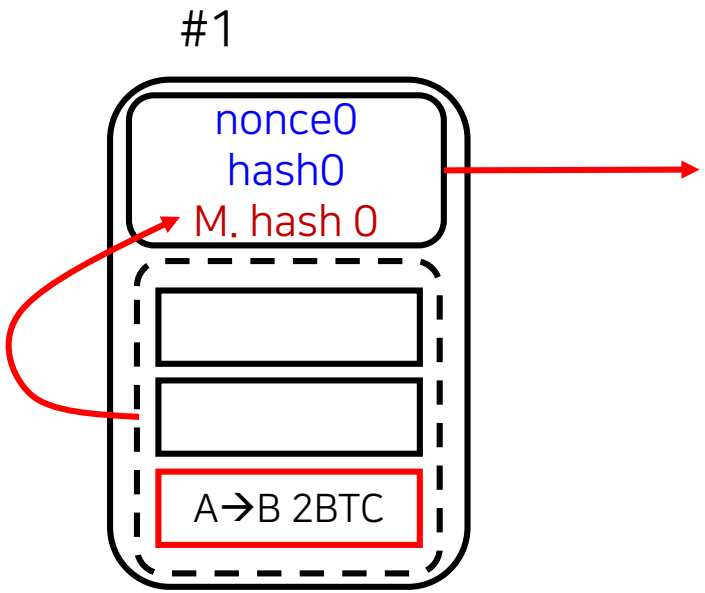
Consensus Algorithm설계의 어려움

- 노드들은 인터넷 상에서 협력하여 합의에 도달해야 함
- Open Source SW
- Cryptocurrency의 경우 다양한 공격 방법이 존재
  - Sybil Attack
  - DDoS Attack
  - Byzantine faults

Block: Header 와 Body



Secure Hash Function: 블록요약을 만드는 함수



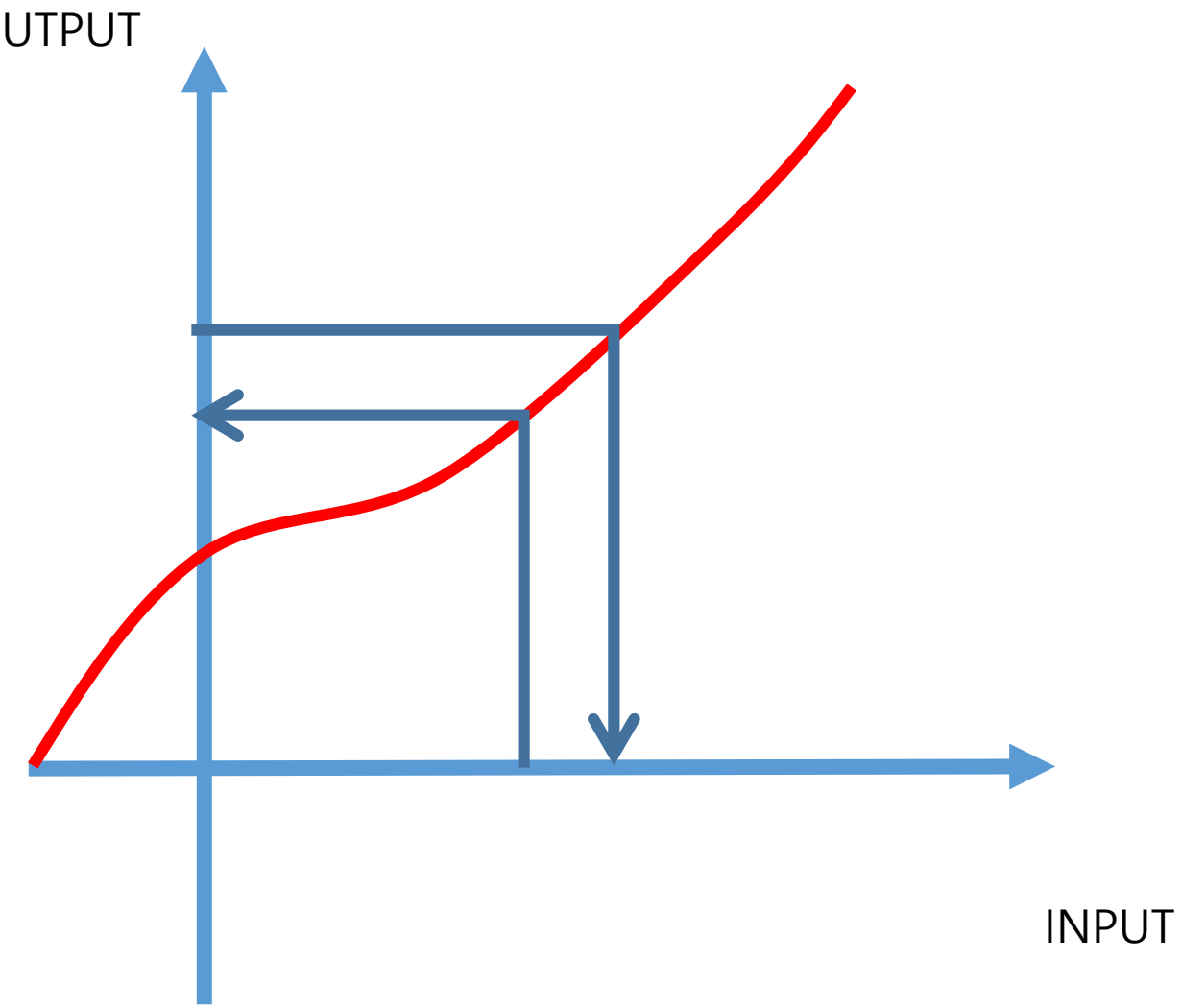
특징: Oneway 앞으로만 가는 함수.
뒤로 가려면 대입법 밖에 없다.

함수는 INPUT 을 받고 OUTPUT을 만든다
INPUT: 파일
OUTPUT: 256 bit 숫자

쓰이는 곳
1. 은행 서버는 Passwd의 hash값만 저장해 놓는다.
2. Spam mail 방지
3. PoW

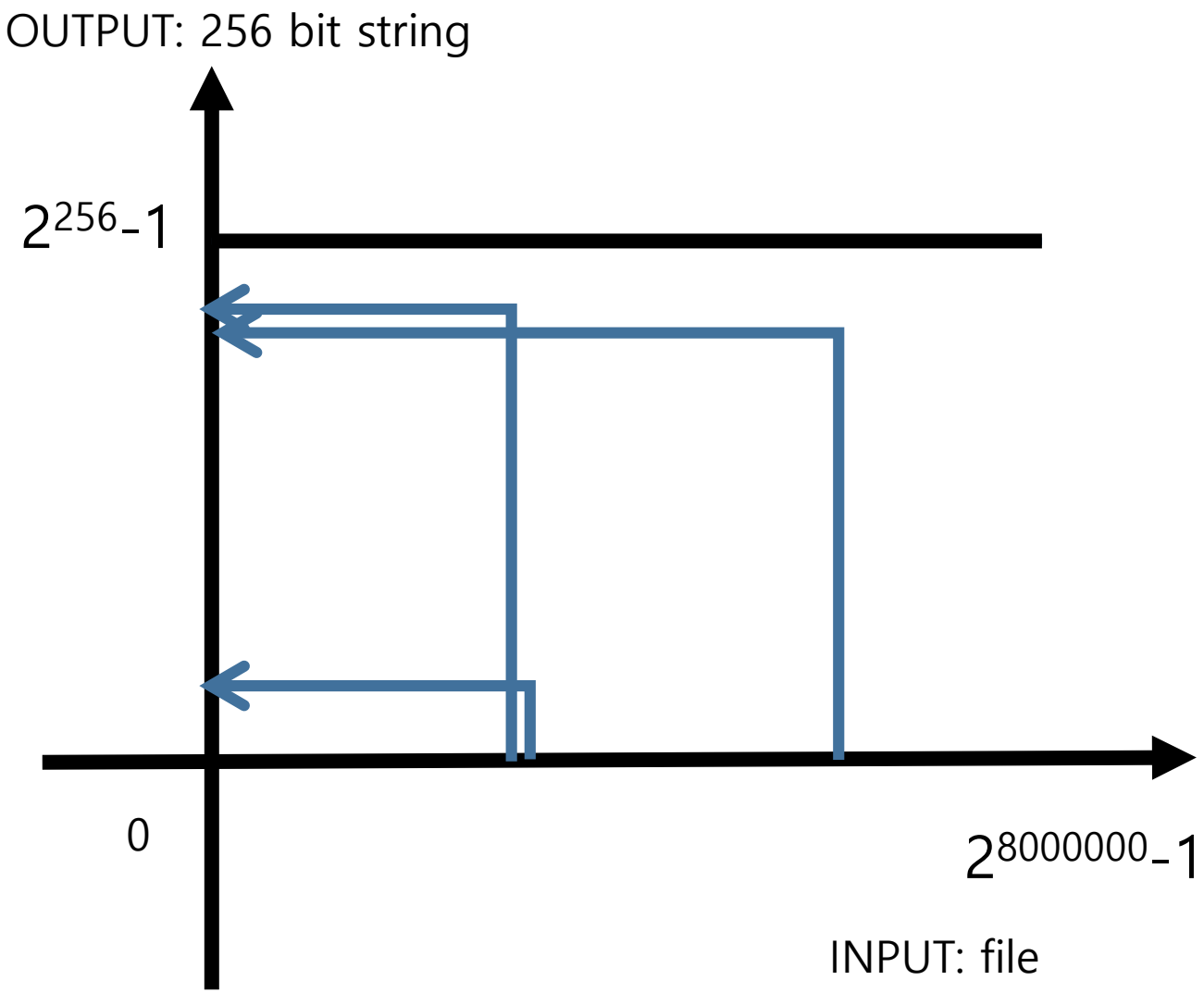
일반 함수

- Output을 본 후,
  Input 예측 가능함



SHA 함수

- 동일한 Input은 언제나 동일한 Output 출력.
- Input이 조금만 차이가 나도, 마치 무작위로 선택된 것 같은 Output을 줌.
- 결과: Output 값을 얻은 후 Input값을 전혀 예측 할 수 없게 됨.
- Many to 1 함수, but collision free!



Modulo Operation

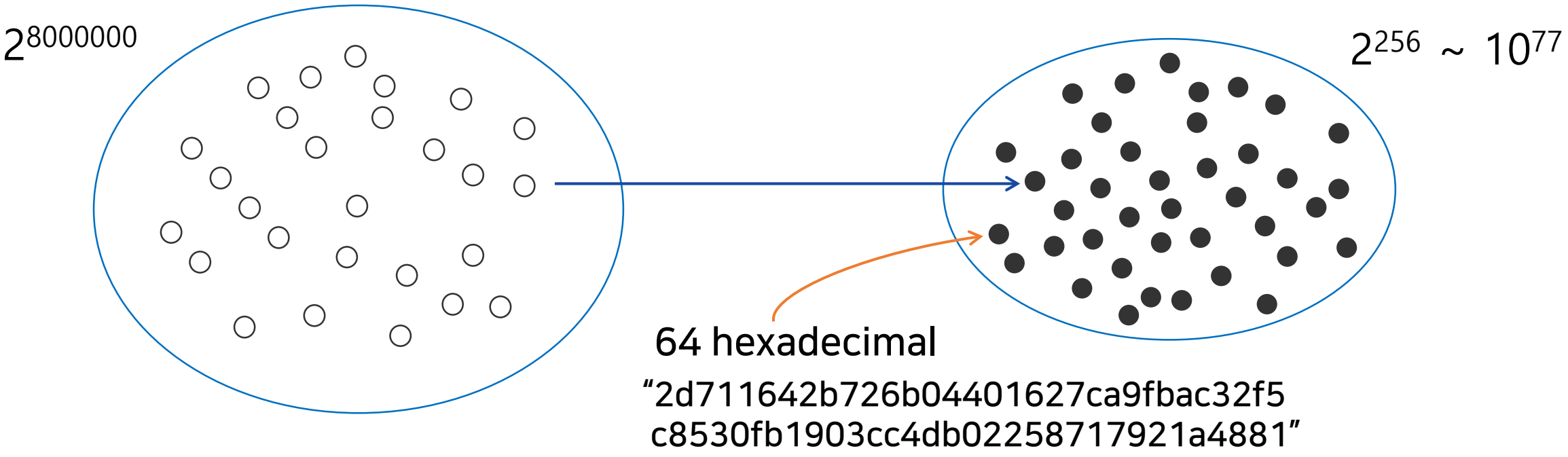
- F(x) = y
- F(x) = 7x + 6 mod 5

- Let x = 5. Then, y = 7*5 + 6 = 41 mod 5 = 1.
- Let x = 4. Then, y = 7*4 + 6 = 34 mod 5 = 4.

Hash 함수

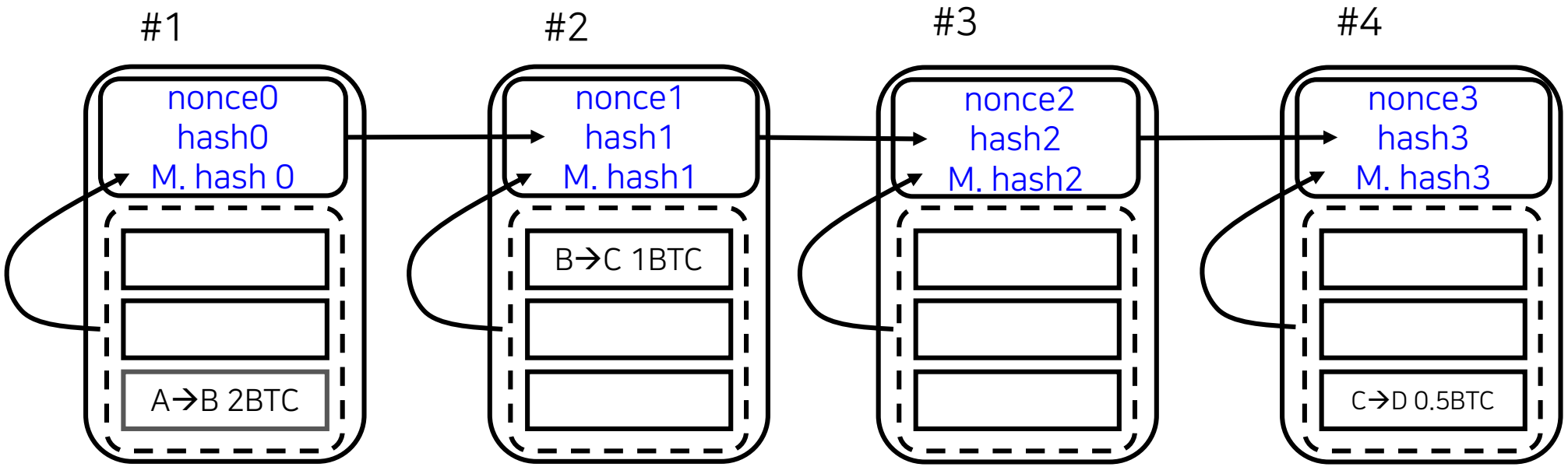
- SHA256, $F(x) = y$

$X = \{x | x$ is a message up to 1 Mbyte in size$\}$ $Y = \{y | y$ is a 256bit string$\}$

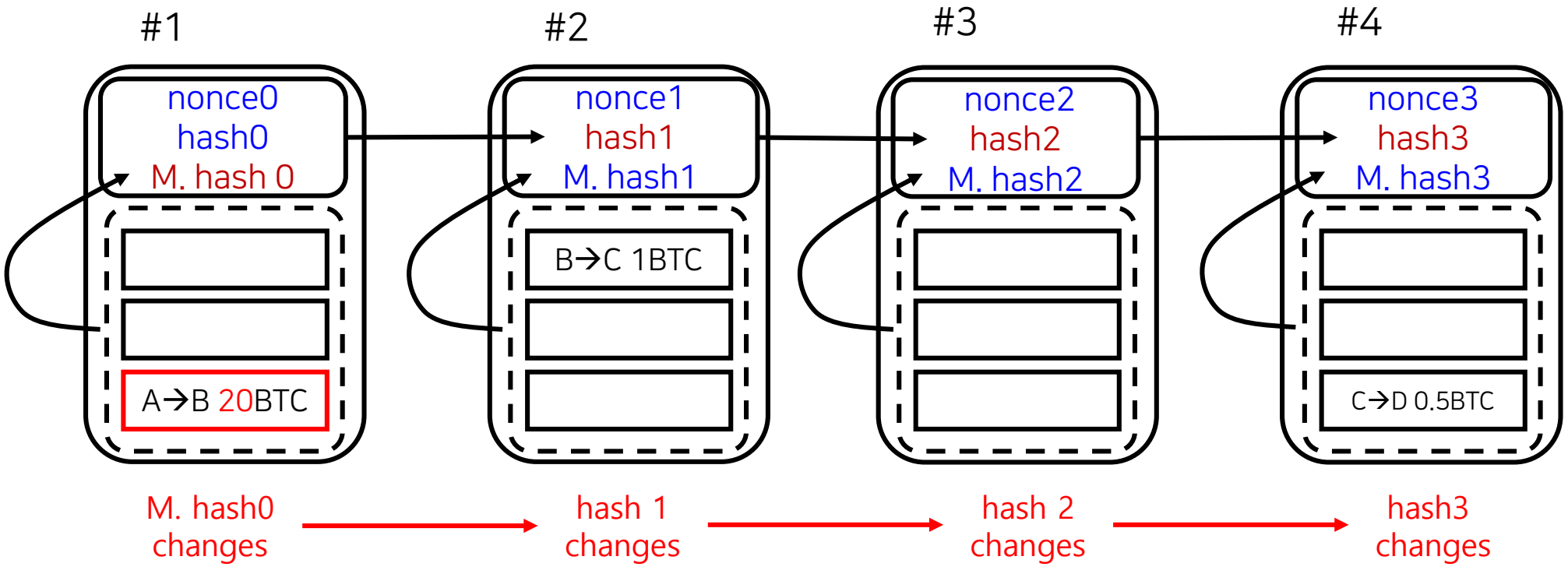


Blockchain이란?

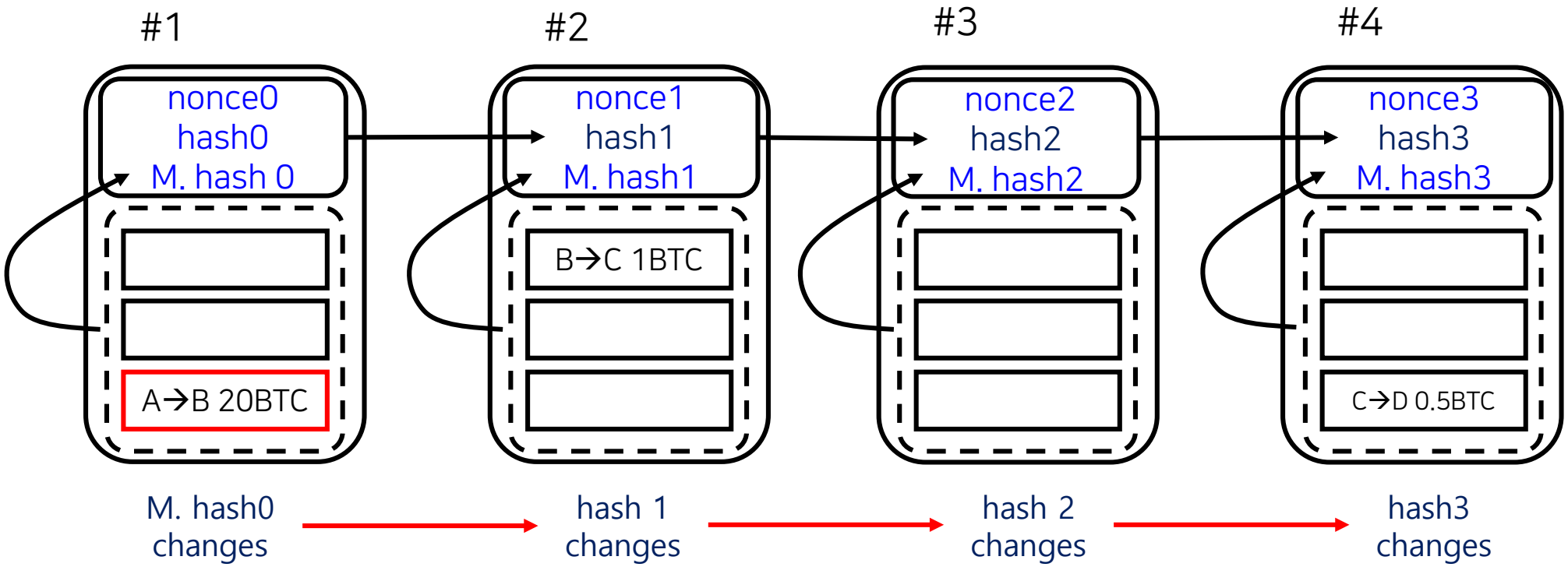
- Block body의 hash값을 Block header에 넣고
- Oneway function으로 block 과 block을 연결하는 것



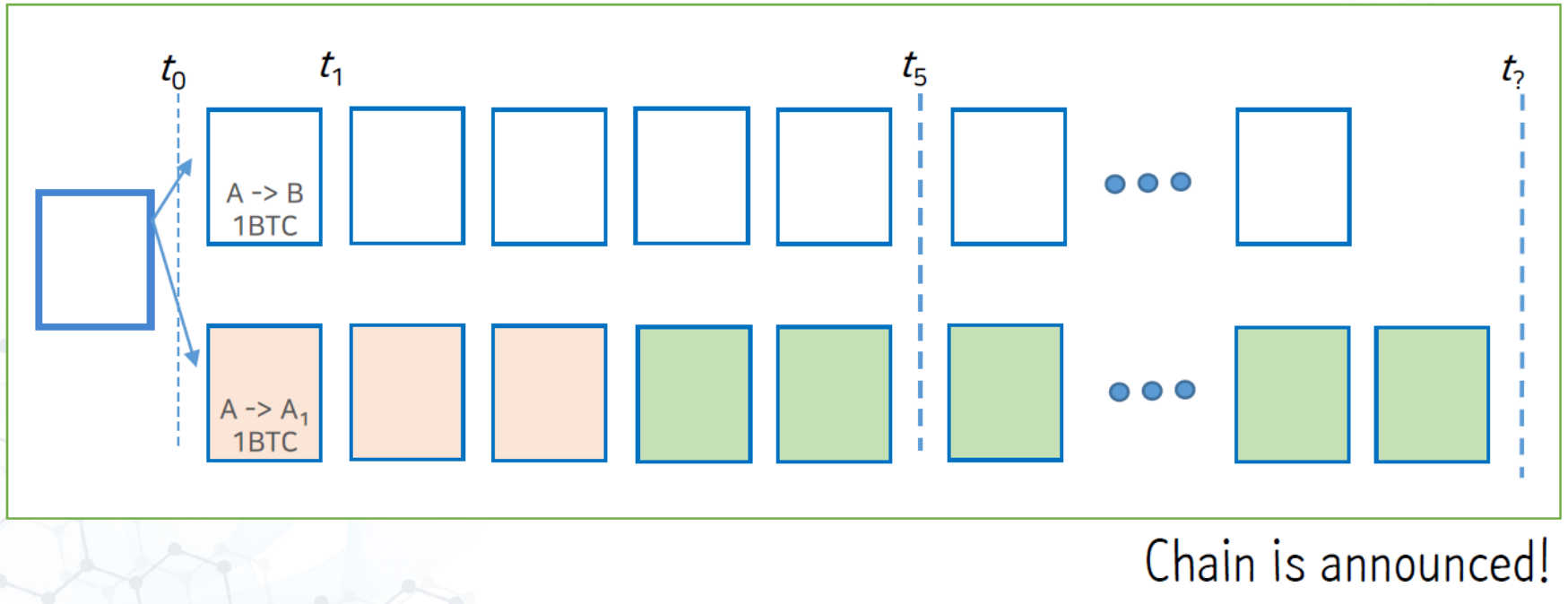
Block을 Chain으로 연결하여 얻는 효과는?



Block을 Chain으로 연결하면 컨텐츠를 못 바꿀까?

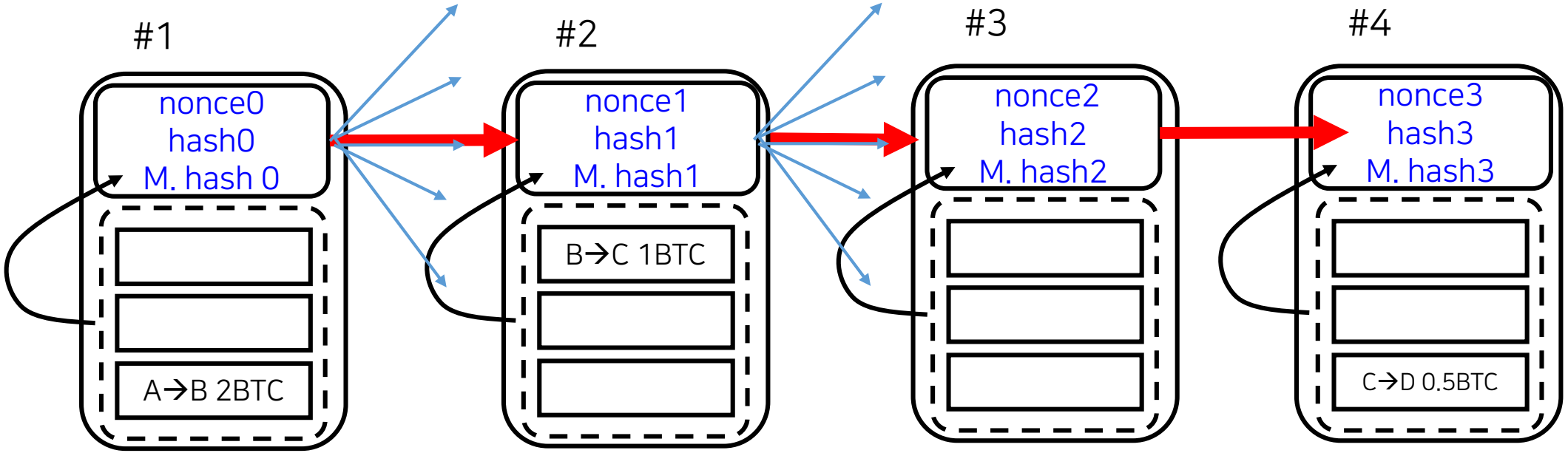


Double Spending이중지불은 어떻게 성립하는가? 방지하려면 무엇이 필요한가?



자세한 내용은 이 링크를 눌러 확인하세요 https://arxiv.org/abs/1903.01711

컨텐츠를 바꿀 수 없게 하려면 무엇이 필요한가?



- Block Chain + PoW
  - Revolutionary new idea!
    - Al-Im-To-Po Theory! https://infonet.gist.ac.kr/?page_id=8954
    - The more come to get involved, the safer the network becomes!
    - Reward
    - Fresh new race for each block.
    - Race means competition.

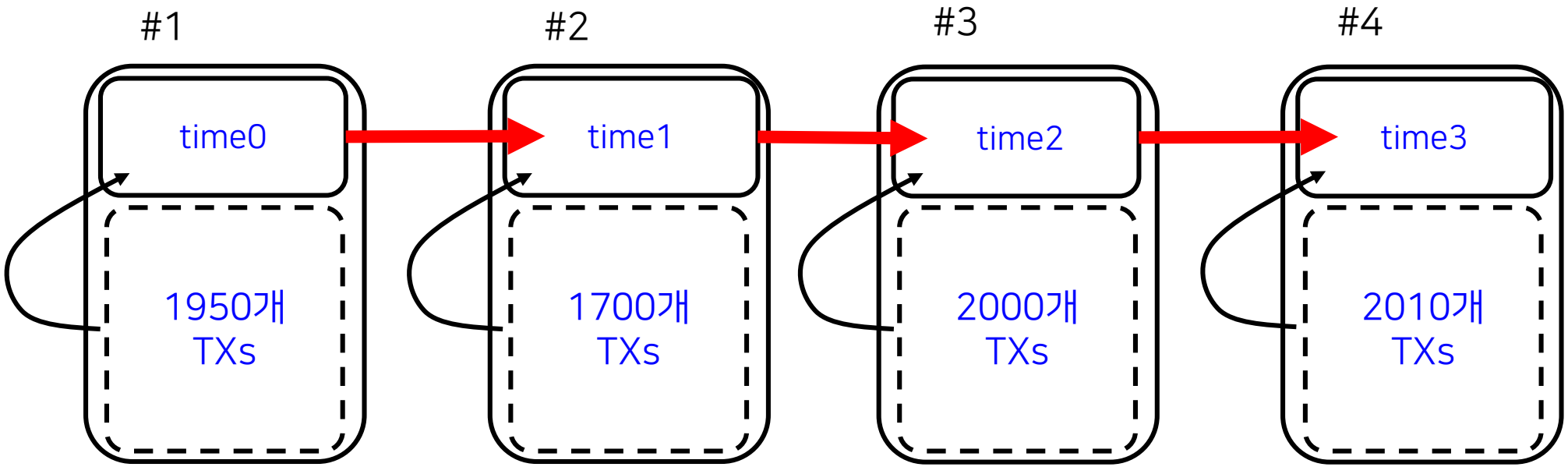
Block #613573

BlockHash 00000000000000000000288ae77f5b8b3c99784f55827431a23f524adf69d0e3a

Summary

Number Of Transactions	3170	**Difficulty**	14776367535688.639
Height	613573 (Mainchain)	**Bits**	17130c78
Block Reward	12.5 BTC	**Size (bytes)**	869316
Timestamp	Jan 20, 2020 1:15:17 AM	**Version**	1073733632
Mined by		**Nonce**	3774951927
Merkle Root	523c52ad89c6ac67bcc01a6...		
Previous Block	613572		

Block Interval, TXs/Block, TPS



TPS = TXs/Block / BI
= 2000 TXs/600초
= 3.3 TXs/sec

TPS제고 필요성 제기

- 인기가 많은 블록체인에만 해당
- TPS를 높이려면?
  1. 블록사이즈를 키우거나
  2. 블록인터벌을 줄이거나
  3. 둘 다 하거나

블록인터벌 **BI** 을 줄이려면?

- 노드 수를 줄이는 프로젝트들이 성행
  - 적은 수의 노드에서 잘 돌아가는 합의알고리즘 사용

  - 그러나 노드 수가 적으면
    - 탈 중앙화는????
    - DS 공격 취약성은???
    - Sybil Attack 취약성은???

블록인터벌 **BI** 을 줄이려면? (2)

- PoW도 Block Interval을 줄일 수 있음
  - Litecoin: 2.5분
  - ETH: Block Interval 14초

  - 수 많은 fork가 매 번 발생하는 문제 발생
    - DS 공격 취약성은???
    - 그러나, Profitable DS Attack분석으로 해결 가능 (See DeSecure블록체인)

PoW Puzzles

- Making PoW puzzles
  - Bitcoin uses SHA256.
  - SHA is *oneway* and *collision free*.
  - Difficulty and Nonce are in the BH.

2 PoW Puzzles

- Finding Good Block Summary
  - Function F takes input x and gives output y :

$$y = F(x)$$

  - x is block header (BH), i.e., F(BH) = hash.
  - Then, it can be written as

F(BH: nonce) < Target PoW Ineq.

  - For a block, find a nonce that satisfies the above inequality (Work)
  - Record the nonce in the block header. (Proof)

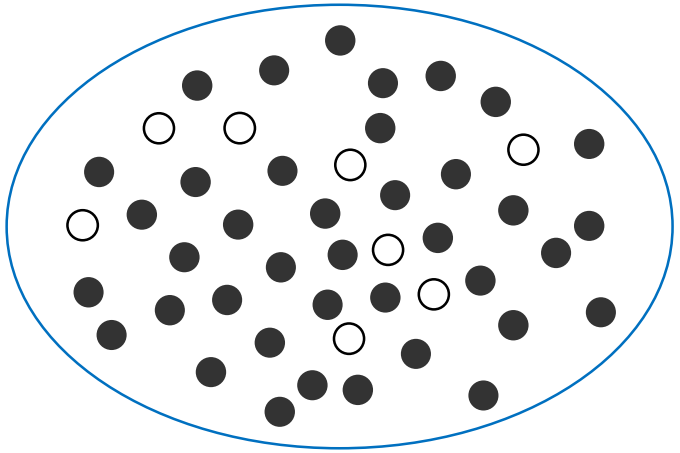
2 PoW Puzzles

- Toy puzzle
  - White and black balls.
  - There are 2^6 balls.
  - Balls are numbers, i.e., hashes.
  - Let Target be 2^3=8.
  - Pick a nonce and run SHA-256.

Total no. of balls $2^6 = 64$
Target = 2^3 0 0 1 0 0 0
White balls = {Balls < Target}
$2^3 - 1 = 7$ 0 0 0 1 1 1
6 0 0 0 1 1 0
5 0 0 0 1 0 1
…

What is the probability that a while ball is picked?

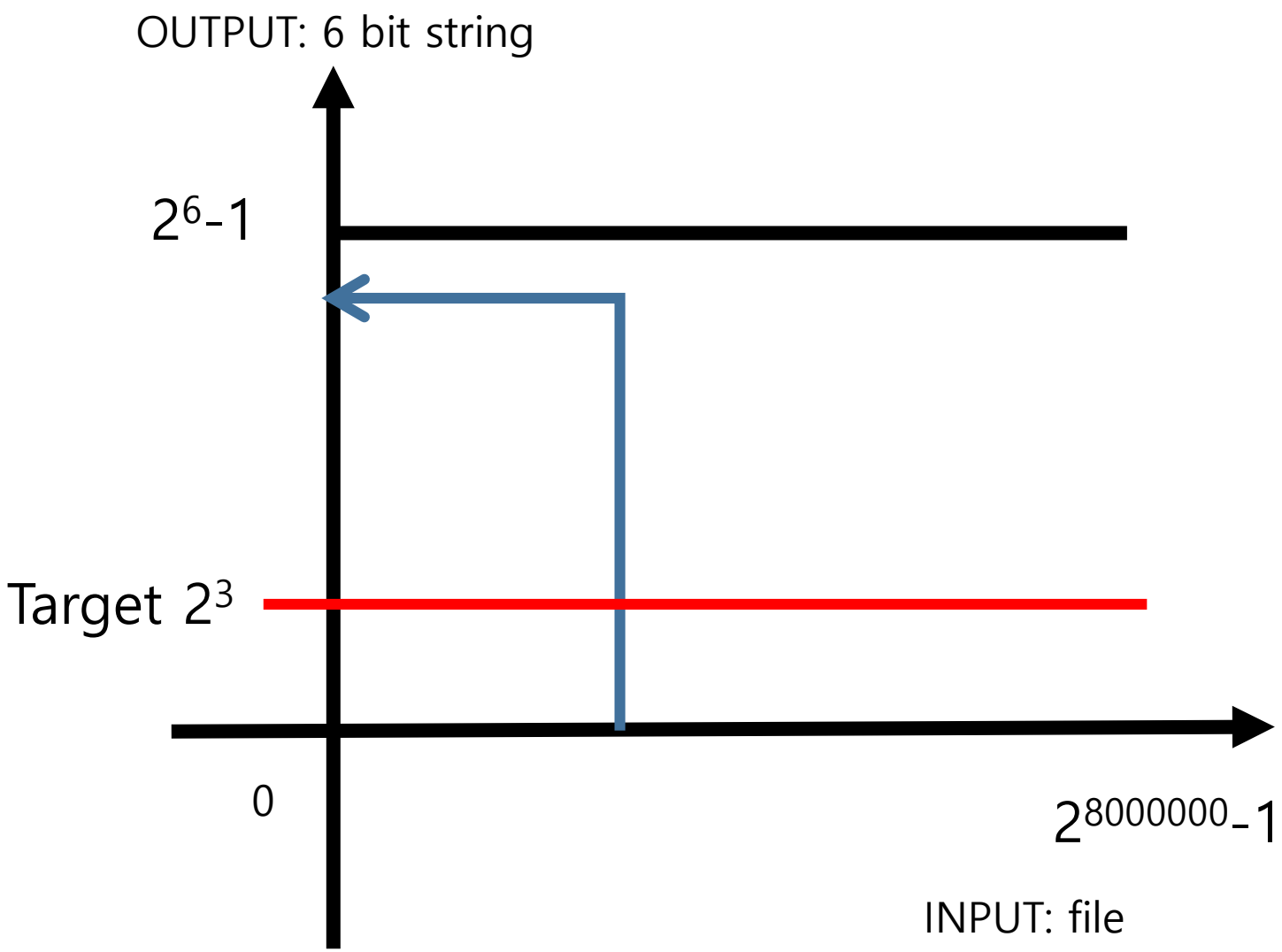
$$p = 2^3/2^6 = 1/8$$



Toy PoW 문제

- SHA-6 사용
- PoW 성공
  - Hash가 8 보다 작은 수가 되는 Input을 찾으면 성공
- 한번 뽑고 PoW 성공 확률?

$$p = 2^3/2^6 = 1/8$$



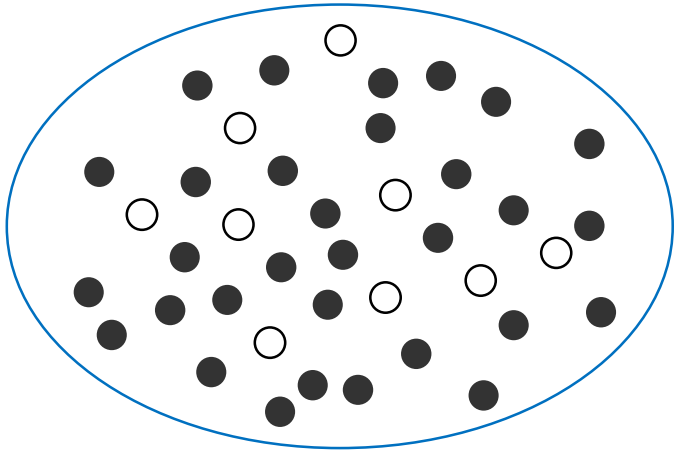
2 PoW Puzzles

- Bitcoin puzzle
  - Hashes are strings of 256 bits.
  - There are 2^{256} hashes in Y.
  - Let Target be $2^{256-16}=2^{240}$.

What is the probability that the hash satisfies the PoW?

$$p = 2^{240}/2^{256}$$
$$= 2^{-16}$$
$$= 1/64000$$

$$Y = \{y | y \text{ is a 256bit string}\}$$



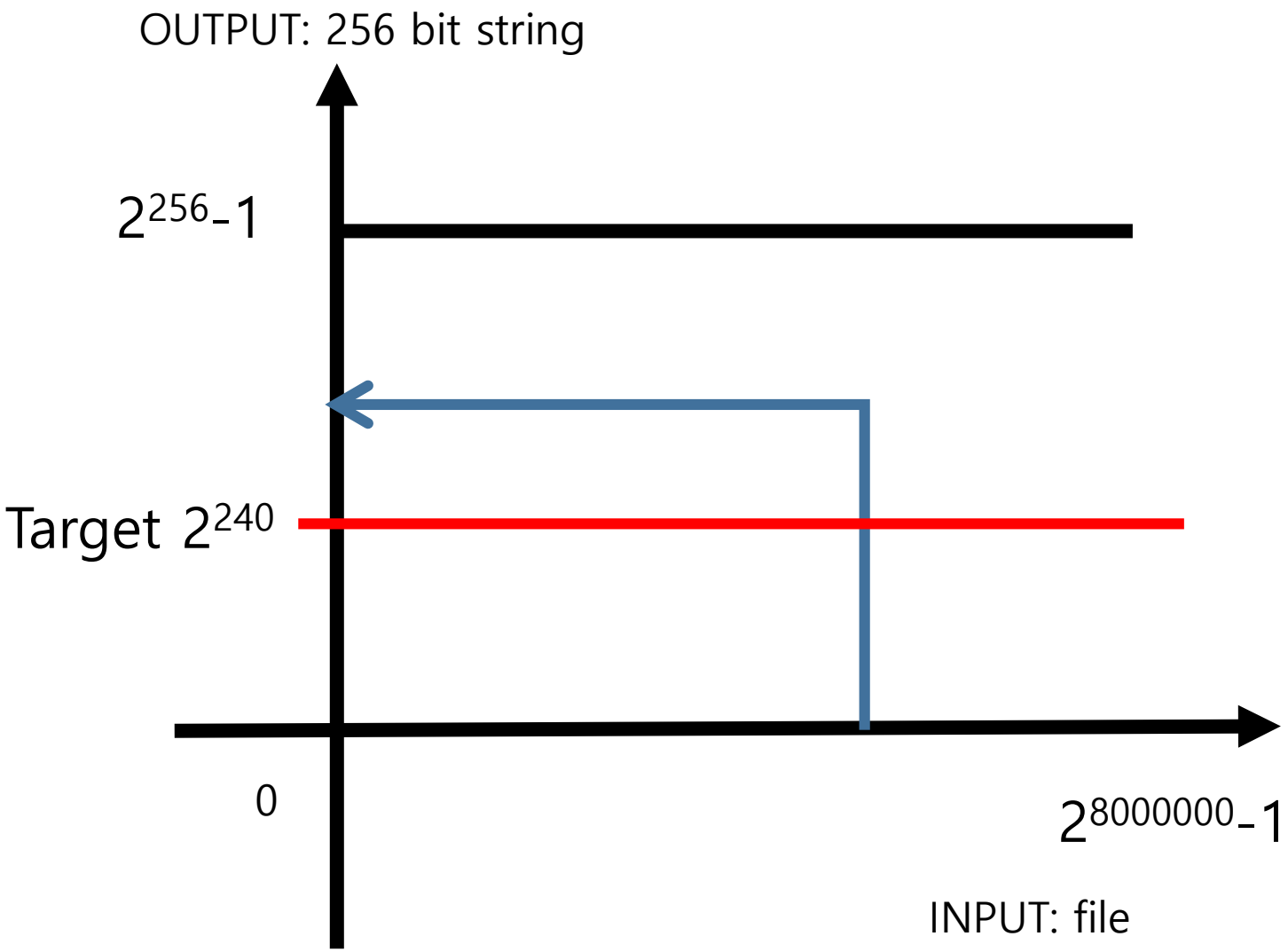
White balls are
64 hexadecimals with 4 leading zeros

"00001642b726b04401627ca9fbac32f5
c8530fb1903cc4db02258717921a4881"

PoW

- SHA-256 사용
- PoW 성공
  - Hash 값이 2^{240} 보다 작은 Input 을 찾으면 성공
- 한번 뽑고 PoW 성공 확률?

$$p = 2^{240}/2^{256}$$
$$= 2^{-16}$$
$$= 1/64000$$



4 Probability of Mining Success

- Given the difficulty p, we aim to find Probability of Mining Success.

- 한 번 뽑을 때 PoW성공 확률이 p 일 때,
  1. k 번째 뽑았을 때 비로서 성공할 확률은?
  2. 평균적으로 몇 번 뽑아야 성공할까?

4 Probability of Mining Success

- (PMF) What is the probability that a CPU solves PoW exactly at the k-th hash?

$$
\begin{aligned}
P_{pmf}(p,\ k) &:= P_p\{K \le k\} - P_p\{K \le k-1\} \\
&= P_p\{K = k\} \\
&= p + (1-p)\,p + (1-p)^2\ p + \cdots + (1-p)^{k-1}\ p \\
&\qquad -\left(p + (1-p)\,p + (1-p)^2\ p + \cdots + (1-p)^{k-2}\ p\right) \\
&= (1-p)^{k-1}\ p \qquad \text{for any } k = 1, 2, 3, \cdots
\end{aligned}
$$

4 Probability of Mining Success

- Average no. of hashes for a PoW success.
  - What is the average number of hashes for a PoW success at a given puzzle difficulty p?

$$\mathbb{E}\{K\} = \sum_{k=1}^{\infty} P_{pmf}(p,\ k)\ k$$

$$= \sum_{k=1}^{\infty} (1-p)^{k}\ p\ k$$

$$= \frac{1}{p}$$

$$= 2^{16} \quad [\text{hashes/block}]$$

Probability of Mining Success

- Definition: Hash Rate of CPU.
  - The hash rate of a CPU is defined as number hashes in a unit time.
  - For example, the hash rate of a CPU which can do 10^6 hash cycles per second is 10^6 hashes/sec.

4 Probability of Mining Success

- ASIC Mining Hardware

Bitcoin Mining Hardware Comparison

Pic	Miner	Hash Power	Price	Buy
	Antminer S9	14.0 TH/s	$3,000	
	Antminer R4	8.6 TH/s	$1,000	

출처: https://www.buybitcoinworldwide.com/mining/hardware/

Bitcoin 난이도 조절

- 평균 **BI**을 10분으로 유지하기 위해 Target값을 조절함

- 문제
- **마이너노드**의 수가 증가하면
  - Network Hash Rate이 낮아/높아 진다.
  - Block Interval이 줄어/길어 진다.
  - 평균 10분 BI을 유지하기 위해서는
  - Target을 크게/작게 해야 한다.

1 Bitcoin Difficulty

- Bitcoin Difficulty (D)

- The aim is to keep the average block generation time be 10 min.
  - Ex) The time span to mine 2016 blocks is set to take 2 weeks.
- Difficulty is adjusted for every 2016 block.
- Measure the time span, T [min], during which the past 2016 blocks were mined.
- Let T_D be 2 weeks [min], i.e., T_D = 2016x10 = 20160 [min].
- If T is different from T_D, adjust the Difficulty D :

$$D = D_{prev} \times \frac{T_D}{T}$$

In Bitcoin, initial D is set to 1 with 8 leading hexa zeros.

- Given a Target, one can determine the network hash rate.
- Suppose you bring your own mining chip.
- You can determine your chance of winning a puzzle.
- It is the ratio of your hash rate to the total hash rate:

$$= \frac{\text{Your Hash Rate}}{\text{Your Hash Rate} + \text{Network Hash Rate}}$$

Bitcoin Difficulty

Ex

- Target 이 2^{204}.
- 채굴에 1 Tera hash/sec mining chip을 구매하여 참여.
- 이때 내가 채굴에 성공할 확률은?
  - The network hash power is $2^{256-\log 2target}/600 = 2^{52}/600 = 7.51e12$ [hash/sec].
  - The hash rate percentage is:

$$= \frac{\text{Your Hash Rate}}{\text{Your Hash Rate} + \text{Network Hash Rate}}$$

$$= \frac{1.00e12}{1.00e12 + 7.51e12}$$

$$= 11.8\%$$

Bitcoin 실전 문제

Bitcoin Difficulty

- 블록 높이 516445 비트코인 블록체인 내 깊이 값 513445에서의 블록들

18 Leading Hexadecimal Zeros

요약	
높이	516445 (Main chain)
해시	00000000000000000004758013a1ed70036479f7d5038c19240afc9fd4710832b
이전 차단	
다음 블록	
시각	2018-04-03 12:40:12
수신 시간	
릴레이된 곳	
난이도	3,511,060,552,899.72
Bits	
거래 수	
출력 합계	
예상된 거래량	816.76804565 BTC
크기	1131.349 KB
번역	0x20000000
Merkle Root	5db080790c0433a7ec8c565932ea75fb7347b6873bc404b2e594f797d7762c10
해시 난수	1225863608
블록 보상	
거래 수수료	

해시 00000000000000000004758013a1ed70036479f7d5036c19240afc9fd4710832b

시간 2018년 4월 3일 12시 40분

난이도 3,511,060,522,899.72 → Log2Diff = 41.68
Target = 256 – (32+41.68) = 256 - 73.68 = $2^{182.32}$

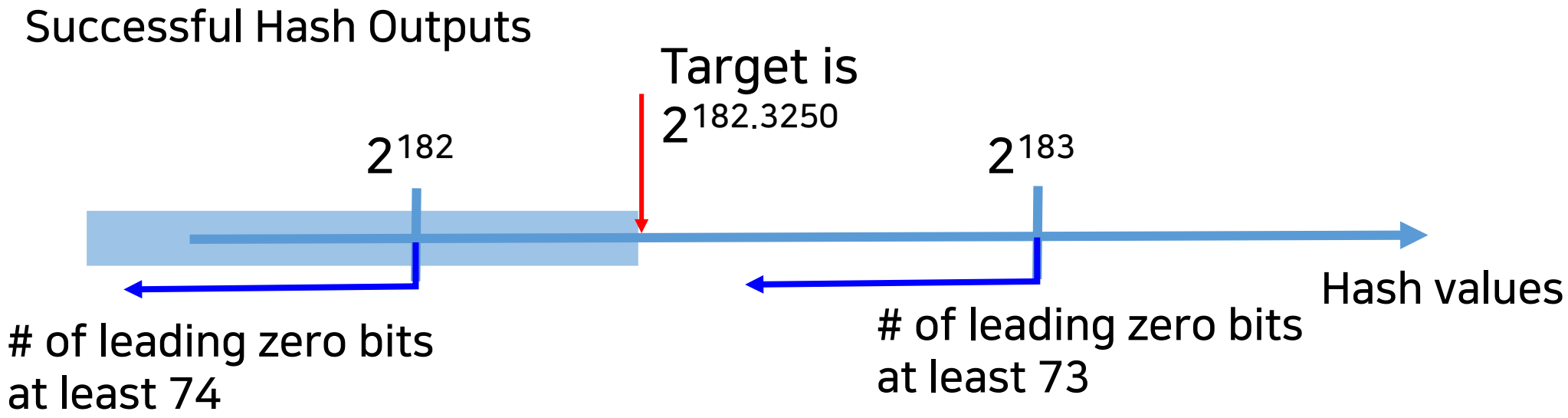
Nonce 1225863608

Bitcoin Difficulty

- Example of Difficulty and Target
  - Block #516445
  - BlockHash 0000 0000 0000 0000 0047 5801 … … … 832b
    - 18 hex zeros * 4 bits/hex + 1 bit = 72 + 1 = 73 zero bits
  - Difficulty D is 3,511,060,552,899.7197 = 3.5e12
  - New Target is $Target_0$ * (1/D)
    - Log2(D) = 41.68
    - Target = $2^{224.000}$ $2^{-41.675}$
      = $2^{182.325}$

Bitcoin Difficulty

Recall PoW Success
is
SHA Hash Output < Target



Bitcoin Difficulty

- Network Hash Rate : Block#516445
- With D=3.5e12, the probability p is about $2^{-(32+41.675)} = 2^{-73.6750}$.
- Then, it would take $1/p = 2^{73.6750} \sim$ 1.5080 e22 hashes to mine a single block.
- Dividing it by 10 min = 600 sec, the network hash rate is obtained, 25.13 Exa hash/sec.

Exa = 10^{18}

10% 해쉬 파워 확보를 위해 투자해야 할 돈은?

Ex

- Antminer S9s (14 Thps) 이 몇 개 필요할까, 만약 내가 hash power를 0.01 % 갖기를 원한다면?
- 네트워크 hash rate 은 25 Exa hash/sec 이다.

  - You need to bring at least 179 AS9 chips.

$$\text{Your Hash Rate} \geq \frac{0.01\% \;\; \text{Network Hash Rate}}{100\% - 0.01\%}$$

$$= \frac{1}{9999} 25e18 = 25e14$$

$$= 178.6(14e12)$$

- 179000개
- 단가 3000 USD
- 537 MUSD

문제

네트워크 hash rate은 25 Exa hash/sec 이다.

- 현재 네트워크에서 작동하는 마이닝 노드의 최소 개수는 몇 개인가?

답

네트워크 hash rate은 25 Exa hash/sec 이다.

- 현재 비트코인 네트워크에서 작동하는 마이닝 노드의 최소 개수는 몇 개인가?

$$\text{최소갯수} = \frac{\text{Net HR}}{\text{가장빠른칩 HR}}$$

$$= \frac{25 \times 10^{18}}{14 \times 10^{12}}$$

$$\sim 1.8 \times 10^{6}$$

문제

네트워크 hash rate은 25 Exa hash/sec 이다.

- 한개의 가장 빠른 마이닝칩으로 하나의 블록 작업증명에 성공하려면 걸리는 시간은?

문제

네트워크 hash rate은 25 Exa hash/sec 이다.

- 한개의 가장 빠른 마이닝칩으로 하나의 블록 작업증명에 성공하려면 걸리는 시간은?

$$\text{시간} = \frac{\text{Net HR} \times 600\text{초}}{\text{가장빠른칩 HR}}$$

$$= \frac{25 \times 10^{18}}{14 \times 10^{12}} \times 600\text{초}$$

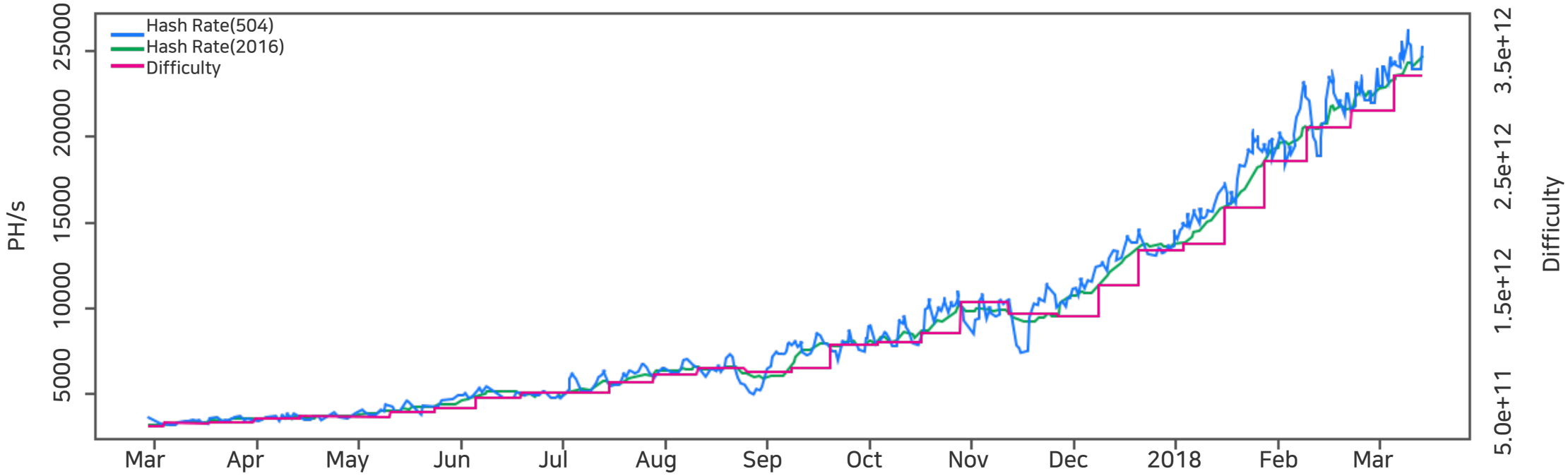
$$\sim 1.07 \times 10^{9}\text{초}$$

$$= 31.7 \text{ 년}$$

일년 = 3153만6천 초

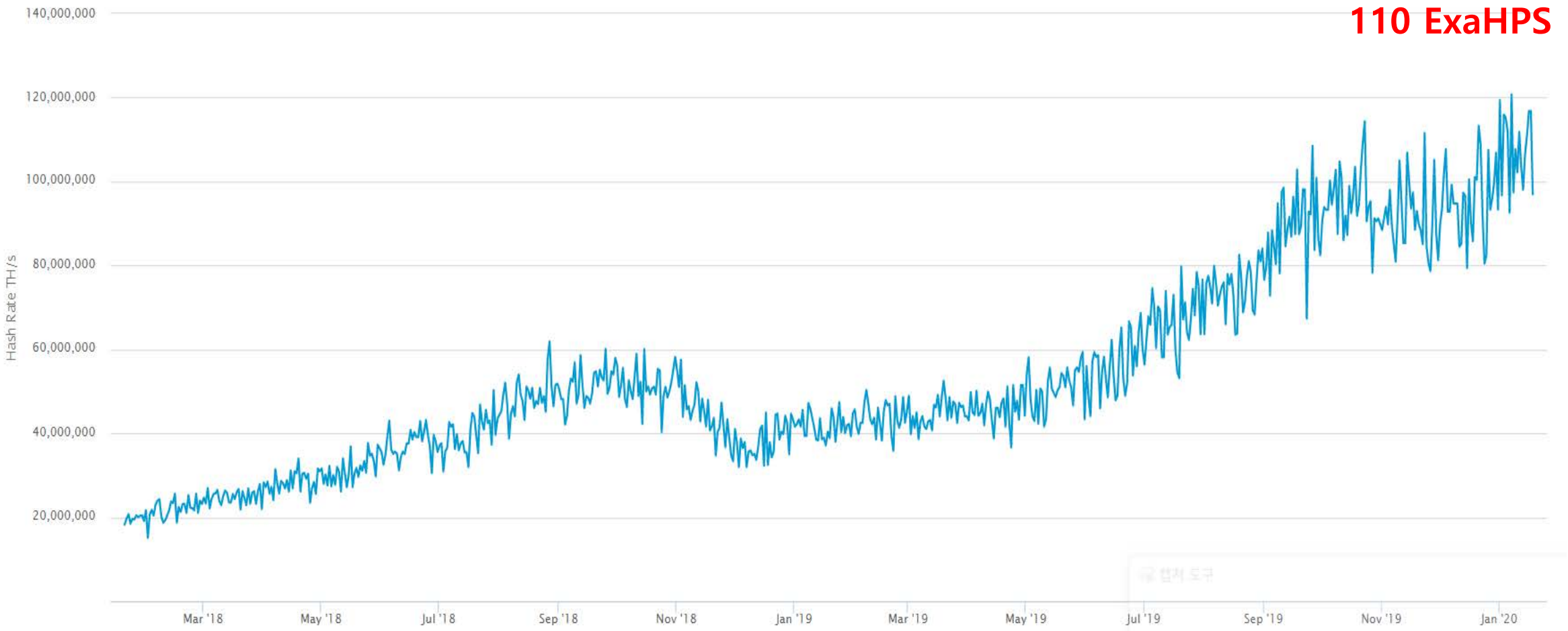
2 History of Bitcoin difficulty

- Bitcoin Hash Rate vs Difficulty (Mar/17 ~ Apr 18)



출처: https://bitcoinwisdom.com/bitcoin/difficulty

Network Hash Rate = 1/p



비트코인 PoW가 좋은 점

- PoW provides flexibility in TPS solutions!
  - Small difficulty → fast TPS
  - Large difficulty → slow TPS

- PoW is sufficient for data immutability!

- PoW and blockchain is a technological breakthrough.

PoW는 근본적인 보안성 해결방안

- 탈 중앙성과 보안성 모두 확보 가능한 해결방안!

- 주요 합의알고리즘은 탈 중앙성을 희생하여 보안성과 확장성을 얻으려 목표, 혹은 off-chain 정책에 의존함.
  - Staking, Delegation, Activity-checking, Leader Selecting, Random Selecting, etc.

- PoW의 현재 문제점을 새로운 기술로 해결하면 여전히 가장 좋은 해결방안이 됨!

블록생성과 검증이 분리되면 어떤 일이?

- 랜덤으로 선출된 자가, 지분을 많이 가진 자가, 활동이 많은 자가, 장군으로 선출된 자가, …

  블록을 생성하세요.

- 나머지는 검증을 하겠습니다.
- 선출 → 생성 → 검증 등 여러 단계로 분리 됨.
- 그러나, 각 단계에서 일이 제대로 되었을까?
  - Validators를 뽑아서 합시다. 보상은 나눕시다.
- 생성자 혹은 검증자가 일을 대충해서 좋지 않은 TX가 들어갈 경우?
  - 각 단계에서 혹시 실패한 경우가 발생할 경우는…
  - 평판도 측정, Staking 압수, …

PoW는 생성과 검증이 동시에 이루어짐

- 수 많은 노드가 생성과 검증을 경쟁적으로 (동시에) 함
- 끊김이 없이 블록이 생성됨
- 앞으로 전진만 있음
- 잘못된 TX이 포함될 경우 헛고생, 스스로 검증하고 생성함

Goal of this lecture note

- Bitcoin Script
- Tables of OP Codes
- Easy Script
- Pay-to-Public Key Hash (P2PKH) Script
- Multisignature and Smart Contracts Scripts

Bitcoin Script

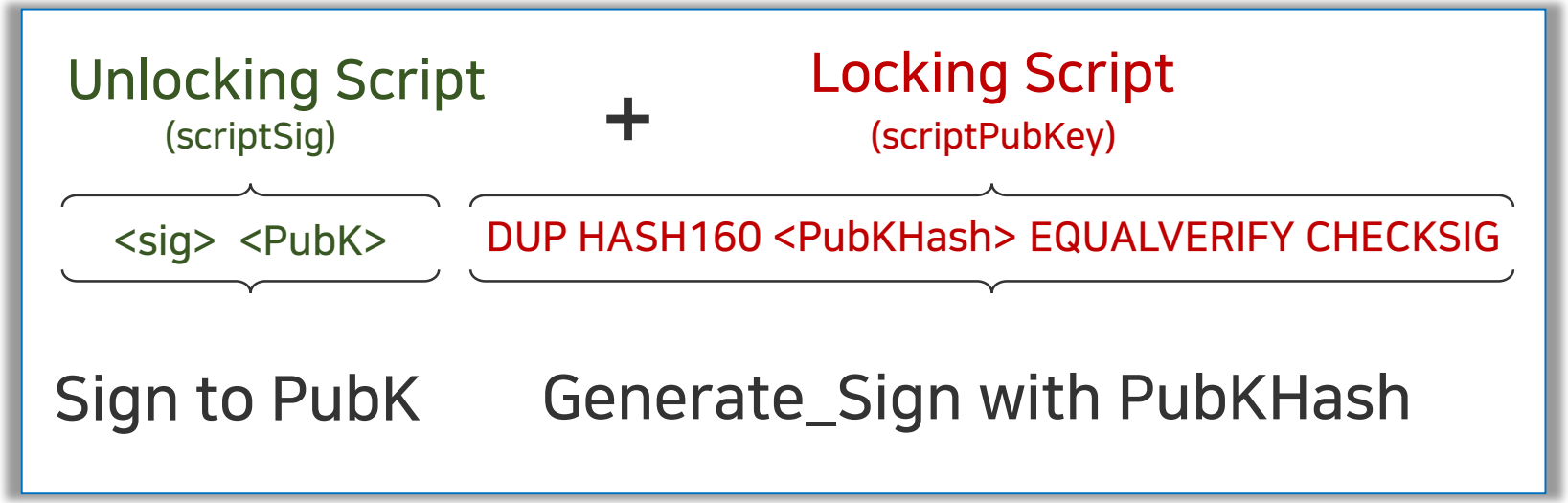
- Bitcoin Script
  - Bitcoin uses a scripting language for transactions.
  - A script is simple, stack-based, and processed from left to right.
  - It is intentionally not Turing-complete, with no loops.
  - A script is a list of instructions.
  - The payer locks the vout value to a payee's public address.
  - The payee unlocks the lock by providing the signature.

- Bitcoin Script
  - Payer uses a lock script to lock the `vout` value to a destination Bitcoin address and payee uses an unlock script to spend it.
    1. The `vout` value transferred to a destination address mapped from a public key is locked into the locking script, and
    2. A signature is embedded in the unlocking script which proves the ownership of the private key corresponding to the locked value.
  - Further reading from https://en.bitcoin.it/wiki/Script

- See if scriptSig unlocks scriptPubKey!
  - *Script Construction (Unlock+Lock)*
    - The locking script is called a *scriptPubKey*, because it contains a public key or a Bitcoin address.
    - The unlocking script is called *scriptSig* because it contains a digital signature.
    - When a correct unlocking script is provided to the locking script, the execution of the complete script comes out TRUE.
    - Then, the provider of scriptSig can spend the value.

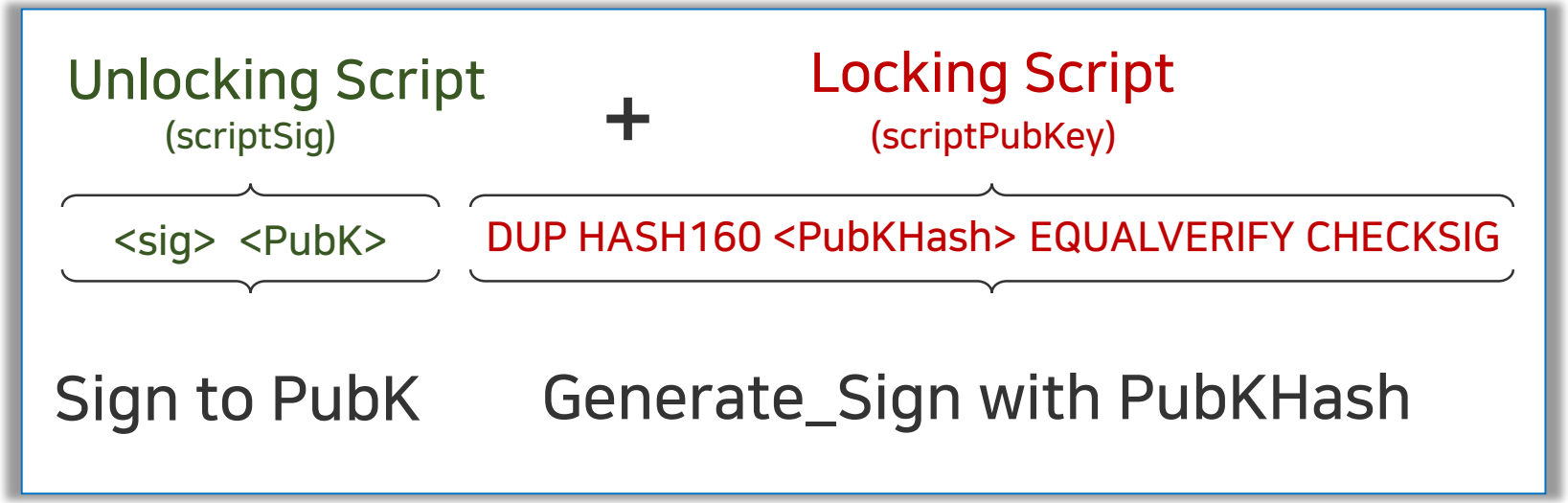
Bitcoin Script

- Pay to Public Key Hash
  - 시간 1: A's Sign (Priv. Key)→ Lock to Pub. Key of B 2.0BTC.
  - 시간 2: B's Sign (Priv. Key)→ Lock to Pub. Key of C 1.0BTC.
  - 시간 3: C's Sign (Priv. Key)→ Lock to Pub. Key of D 0.5BTC.



Bitcoin Script

- Values provided by users are given in < >.
- DUP, HASH160, EQUALVERIFY, CHECKSIG are Operations.



2 Tables of OP Codes

- Table C-7. Cryptographic and Hashing Operations

Symbol	Value(hex)	Description
OP_RIPEMD160	0xa6	Return RIPEMD160 hash of top item
OP_SHA1	0xa7	Return SHA1 hash of top item
OP_SHA256	0xa8	Return SHA256 hash of top item
OP_HASH160	0xa9	Return RIPEMD160(SHA256(x)) hash of top item
OP_HASH256	0xaa	Return SHA256(SHA256(x)) hash of top item
OP_CODESEPARATOR	0xab	Mark the beginning of signature-checked data

Appendix C of Mastering Bitcoin

2 Tables of OP Codes

- Table C-7. Cryptographic and Hashing Operations

Symbol	Value(hex)	Description
OP_CHECKSIG	0xac	Pop a public key and signature and validate the signature for the transaction's hashed data, return TRUE if matching
OP_CHECKSIGVERIFY	0xad	Same as CHECKSIG, then OP_VERIFY to halt if not TRUE
OP_CHECKMULTISIG	0xae	Run CHECKSIG for each pair of signature and public key provided. All must match. Bug in implementation pops an extra value, prefix with OP_NOP as workaround
OP_CHECKMULTISIGVERIFY	0xaf	Same as CHECKMULTISIG, then OP_VERIFY to halt if not TRUE

2 Tables of OP Codes

- Table C-3. Stack Operations

Symbol	Value(hex)	Description
OP_TOALTSTACK	0x6b	Pop top item from stack and push to alternative stack
OP_FROMALTSTACK	0x6c	Pop top item from alternative stack and push to stack
OP_2DROP	0x6d	Pop top two stack items
OP_2DUP	0x6e	Duplicate top two shack items
OP_3DUP	0x6f	Duplicate top three shack items
OP_2OVER	0x70	Copies the third and fourth items in the stack to the top
OP_2ROT	0x71	Moves the fifth and sixth items in the stack to the top
OP_2SWAP	0x72	Swap the two top pairs of items in the stack
OP_IFDUP	0x73	Duplicate the top item in the stack if it is not 0
OP_DEPTH	0x74	Count the items on the stack and push the resulting count

Appendix C of Mastering Bitcoin

2 Tables of OP Codes

- Table C-3. Stack Operations

Symbol	Value(hex)	Description
OP_DROP	0x75	Pop the top item in the stack
OP_DUP	0x76	Duplicate the top item in the stack
OP_NIP	0x77	Pop the second item in the stack
OP_OVER	0x78	Copy the second item in the stack and push it on to the top
OP_PICK	0x73	Pop value N from top, then copy the Nth item to the top of the stack
OP_ROLL	0x7a	Pop value N from top, then move the Nth item to the top of the stack
OP_ROT	0x7b	Rotate the top three items in the stack
OP_SWAP	0x7c	Swap the top three items in the stack
OP_TUCK	0x7d	Copy the top item and insert it between the top and second item

2 Tables of OP Codes

- Table C-6. Numeric Operators

Symbol	Value(hex)	Description
OP_1ADD	0x8b	Add 1 to the top item
OP_1SUB	0x8c	Subtract 1 from the top item
OP_2MUL	0x8d	Disabled (Multiply top item by 2)
OP_2DIV	0x8e	Disabled (Divide top item by 2)
OP_MEGATE	0x8f	Flip the sign of top item
OP_ABS	0x90	Change the sign of the top item to positive
OP_NOT	0x91	If top item is 0 or 1 boolean flip it, otherwise return 0
OP_ONOTEQUAL	0x92	If top item is 0 return 0, otherwise return 1
OP_ADD	0x93	Pop top two items, add them and push result

Appendix C of Mastering Bitcoin

2 Tables of OP Codes

- Table C-2. Conditional Flow Control

Symbol	Value(hex)	Description
OP_NOP	0x61	Do nothing
OP_VER	0x62	Halt – Invalid transaction unless found in an unexecuted OP-IF clause
OP_IF	0x63	Execute the statements following if top of stack is not 0
OP_NOTIF	0x64	Execute the statements following if top of stack is 0
OP_VERIF	0x65	Halt – Invalid transaction
OP_VERMPTIF	0x66	Halt – Invalid transaction
OP_ELSE	0x67	Execute only if the previous statements were not executed
OP_ENDIF	0x68	Ends the OP_IF, OP_NOTIF, OP_ELSE block
OP_VERIFY	0x69	Check the top of the stack, Halt and Invalidate transaction if not TRUE

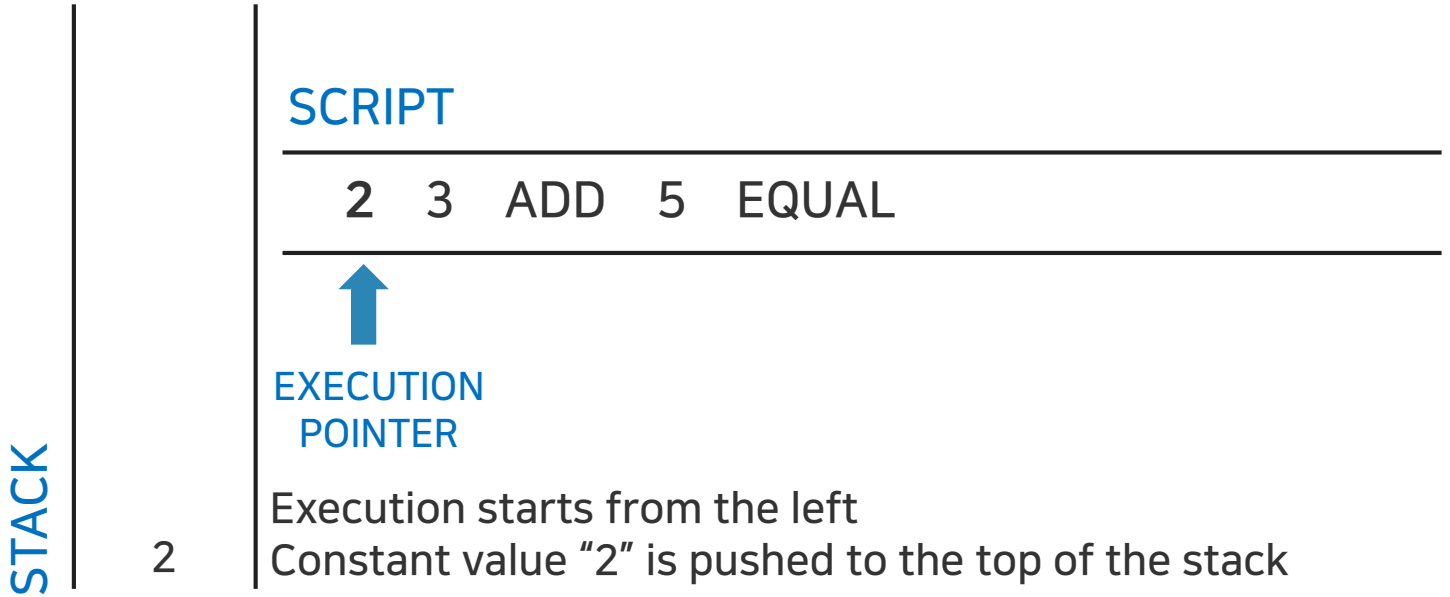
Appendix C of Mastering Bitcoin

Bitcoin opcodes

- Opcode가 뭔가요?
  - 일반 컴퓨터에서 실행되는 기본 프로그램
- 몇 개인가요?
  - 최 대 16 x 16, 즉 256개

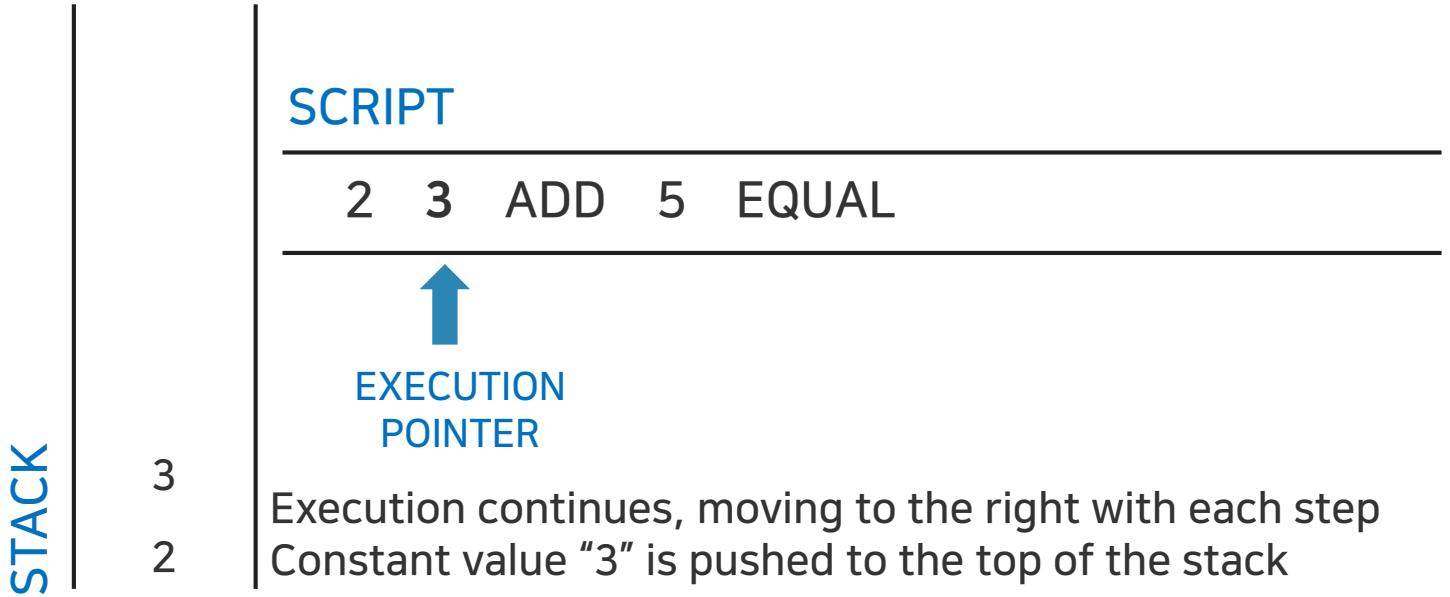
3 Easy Script

- Example script: 2 + 3 = 5



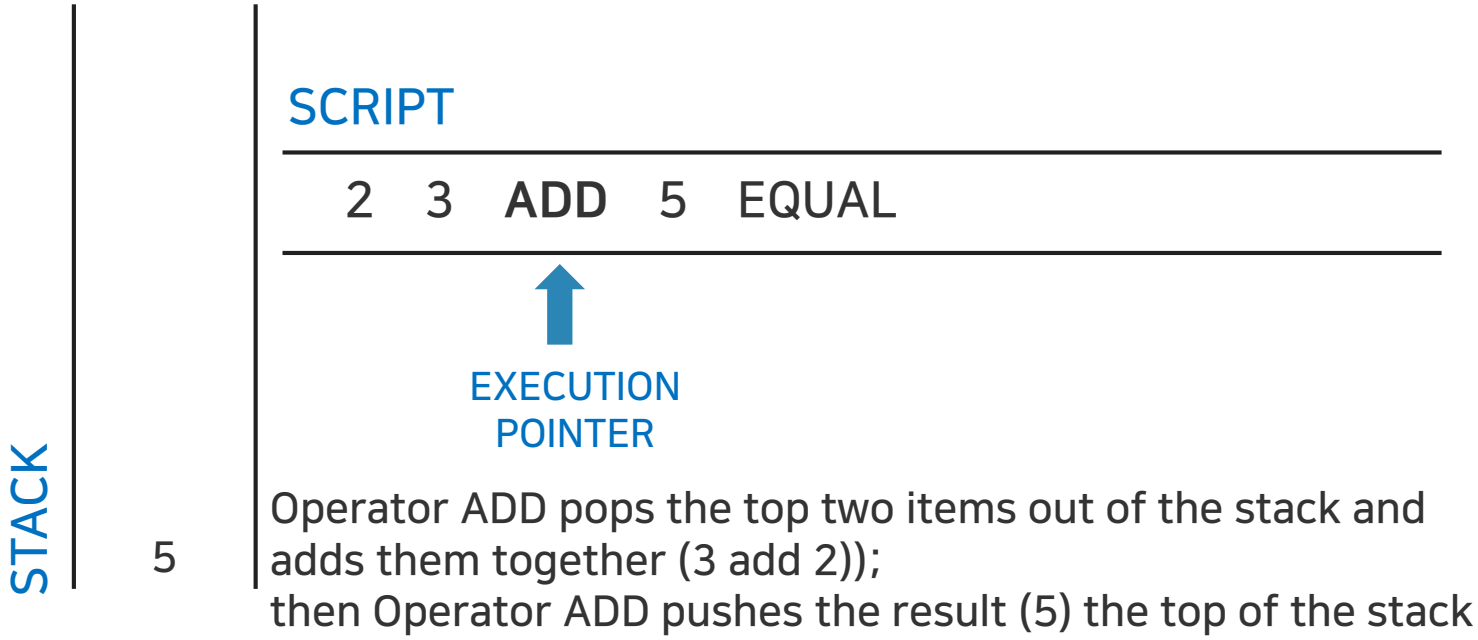
Easy Script

- Example script: 2 + 3 = 5



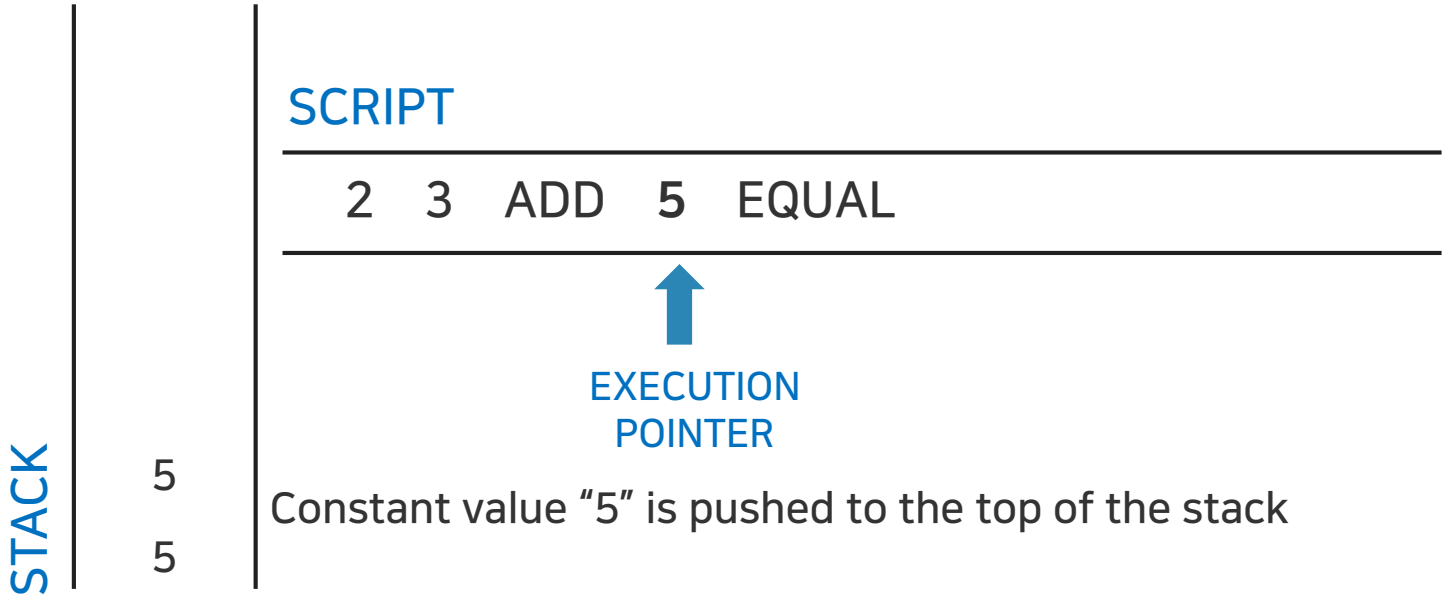
3 Easy Script

- Example script: 2 + 3 = 5



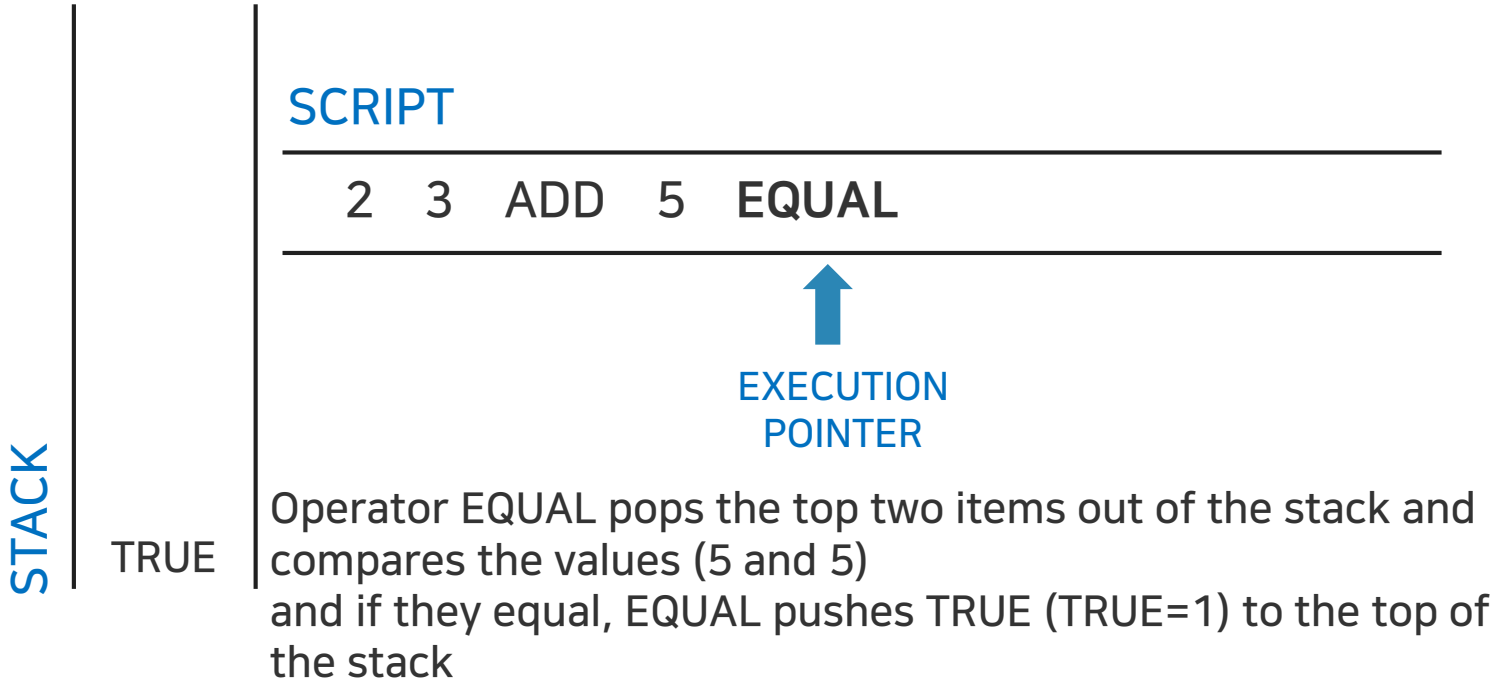
Easy Script

- Example script: 2 + 3 = 5



Easy Script

- Example script: 2 + 3 = 5



- Unlock + Lock Pair, shows a proof of ownership
  - Use a part of the arithmetic example script as the locking script:

    ```
    3 OP_ADD 5 OP_EQUAL
    ```

  - Which can be satisfied by a transaction containing an input with the unlocking script:

    ```
    2
    ```

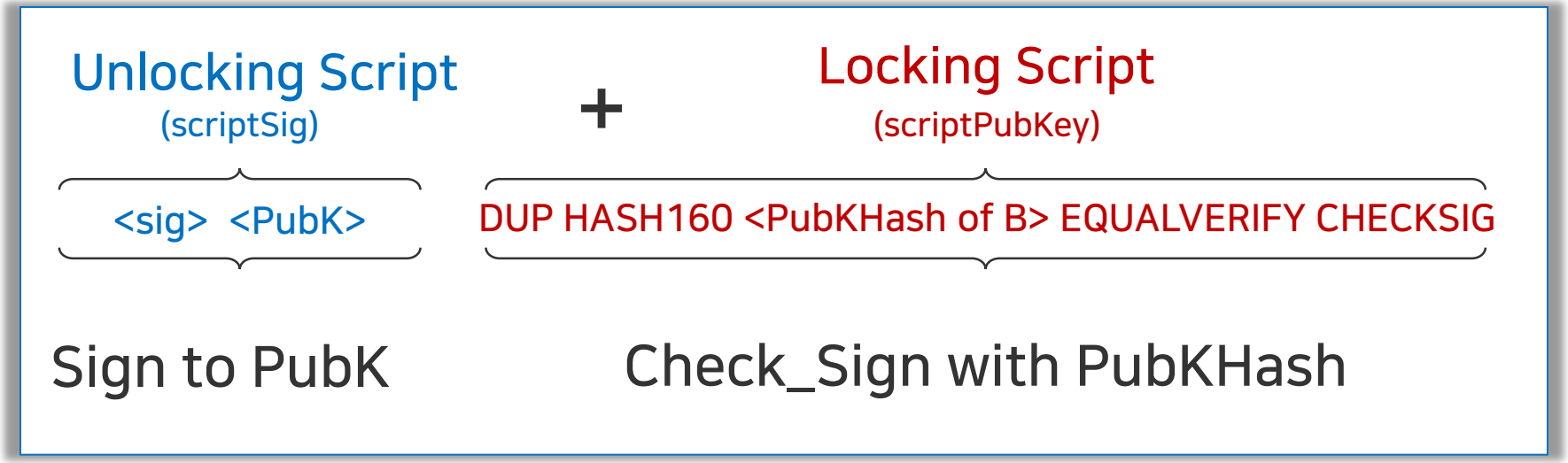
  - Put them together, we have the complete script.

    ```
    2 3 OP_ADD 5 OP_EQUAL
    ```

  - This pair will produce an outcome of TRUE.

4 P2PKH Script

- Now let us make a more realistic pair focusing on B.
  - 시간 1: A's Sign (Priv. Key)→ Lock to Pub. Key of B 2.0BTC.
  - 시간 2: B's Sign (Priv. Key)→ Lock to Pub. Key of C 1.0BTC.
  - the signature.



- P2PKH of B
  - Unspent value belongs to Pay to Public Key Hash(P2PKH) script.

```
OP_DUP OP_HASH160 <Public Key Hash of B> OP_EQUAL OP_CHECKSIG
```

  - Unlocking script is a digital sign created by corresponding private key.

```
<sig of B>  <PubK of B>
```

- Locking script with a single <input>
  - One input, four operations
  - `OP_DUP`: duplicate
  - `OP_Hash160`(x)= `RIPEMD`(`SHA256`(x))
  - `<Public Key Hash of B>`
  - `OP_EQUAL`: return TRUE if the two top most values are equal
  - `OP_CHECKSIG`: checks to see if the provided `sign` and `pubkey` are valid

4 P2PKH Script

- Locking script with <input>

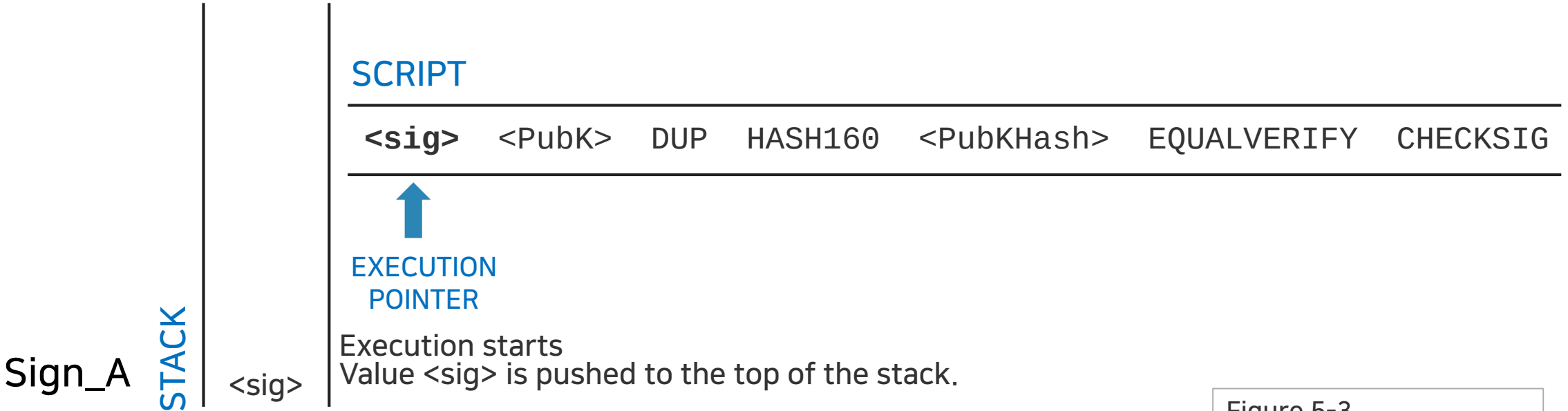


Figure 5-3.
Evaluating a script for a Pay-to-Public-Key-Hash transaction (Part 1 of 2)

4 P2PKH Script

- Locking script with <input>

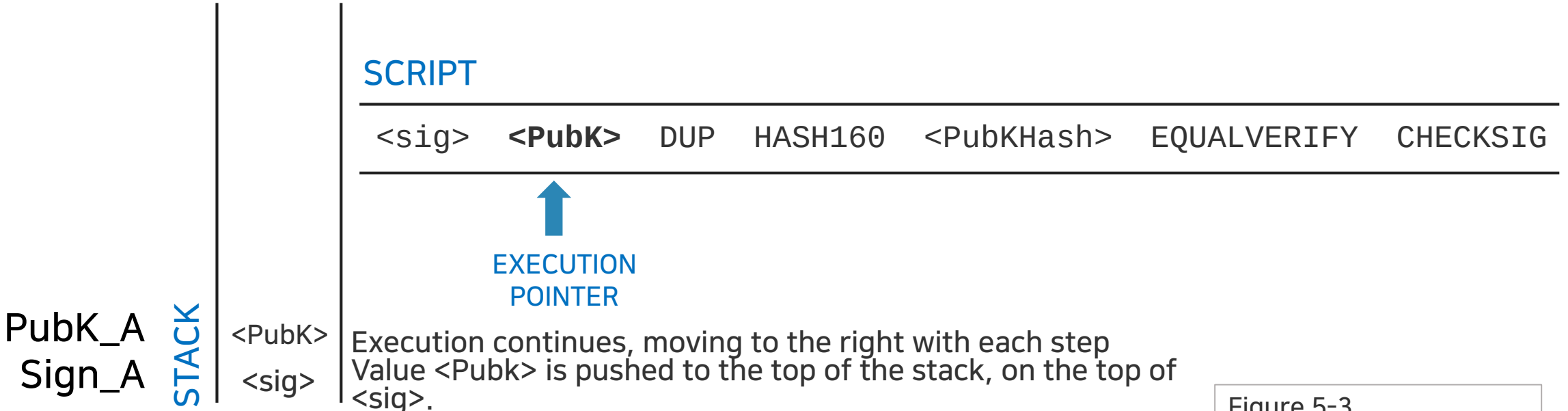


Figure 5-3.
Evaluating a script for a Pay-to-Public-Key-Hash transaction (Part 1 of 2)

4 P2PKH Script

- Locking script with <input>

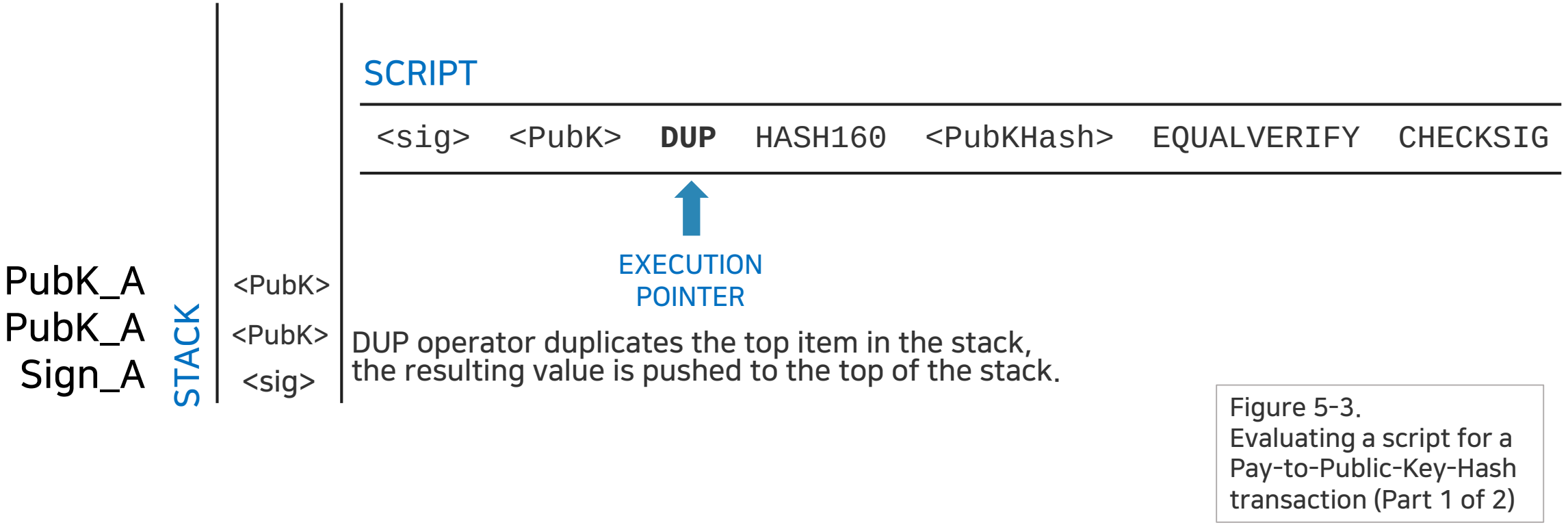


Figure 5-3.
Evaluating a script for a Pay-to-Public-Key-Hash transaction (Part 1 of 2)

4 P2PKH Script

- See if two PubKH_As match

PubKH_A
PubK_A
Sign_A

STACK

<PubK Hash>
<PubK>
<sig>

SCRIPT

<sig> <PubK> DUP **HASH160** <PubKHash> EQUALVERIFY CHECKSIG

EXECUTION POINTER

HASH160 operator hashes the top item in the stack with RIPEMD160(SHA256(PubK)).
the resulting value (PubKHash) is pushed to the top of the stack.

4 P2PKH Script

- See if the two PubKH_As match

PubKH_A
= ab3813c
PubKH_A
PubK_A
Sign_A

STACK

<PubK Hash>
<PubK Hash>
<PubK>
<sig>

SCRIPT

<sig> <PubK> DUP HASH160 **<PubKHash>** EQUALVERIFY CHECKSIG

EXECUTION POINTER

The value PubKHash from the script is pushed on top of the value PubKHash calculated previously from the HASH160 of the PubK.

4 P2PKH Script

- Check Signature

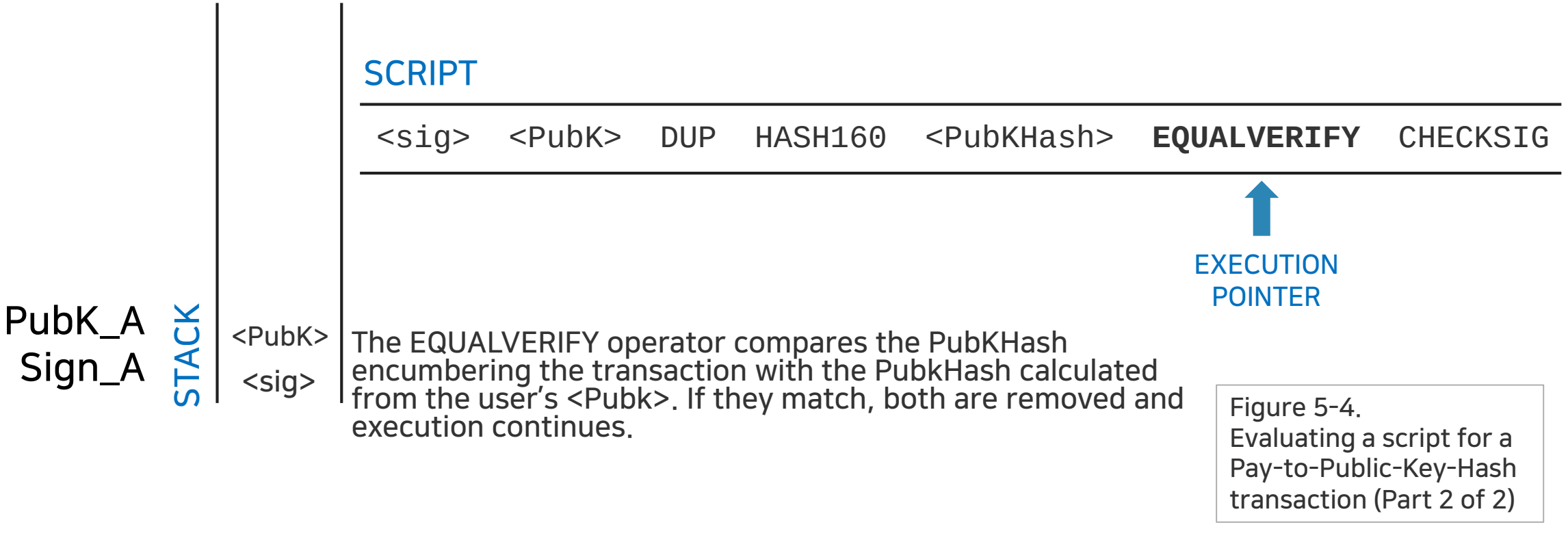


Figure 5-4.
Evaluating a script for a Pay-to-Public-Key-Hash transaction (Part 2 of 2)

- Recall `SignGenerate` and `isSignatureValid` routines
  - m = {`TXID`, output [n] = {value, a locking script with `PKH_A`}}
  - `Sign_A` = `SignGenerate` (m, `k_A`);
  - `isSignatureValid`(m, `Sign_A`, `PK_A`) = `TRUE/False`

P2PKH Script

- Check Signature

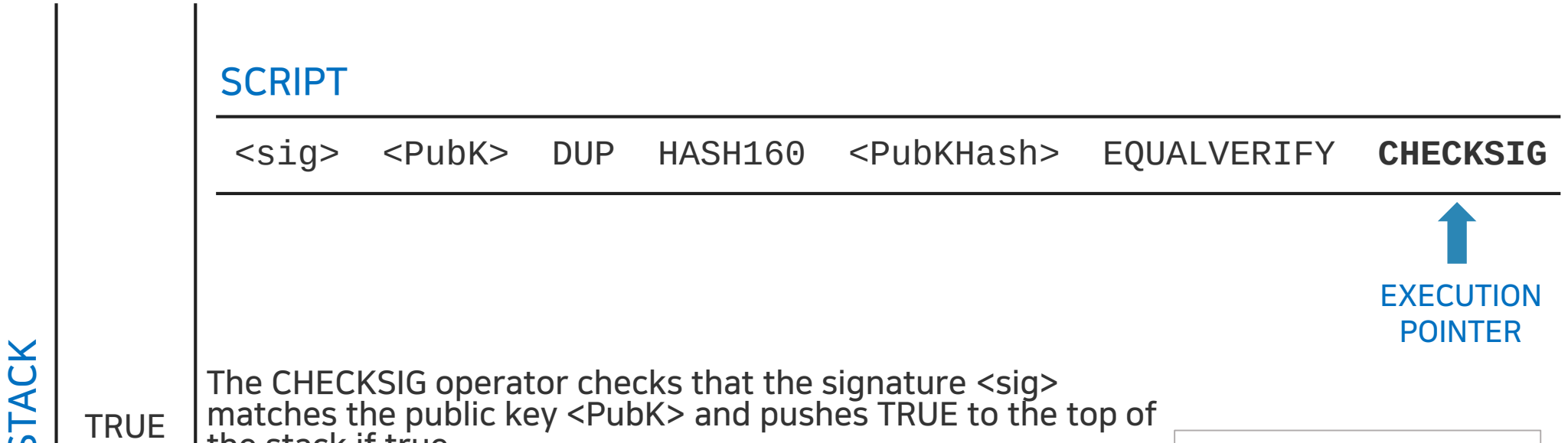


Figure 5-4.
Evaluating a script for a Pay-to-Public-Key-Hash transaction (Part 2 of 2)

Multisignature and Smart Contracts Scripts

- Other Scripts
  - Pay to Public Key (P2PK), introduced in the Bitcoin white paper.
  - Pay to Public Key Hash (P2PKH), used in the code by Satoshi Nakamoto.
  - Pay to Script Hash (P2SH), introduced winter of 2012.
    - These Bitcoin addresses are beginning with 3.
    - Hash of a script is the beneficiary.
    - It can be used for a `multisignature` script.
      - M out of N keys are needed to spend the value.
      - Useful for joint accounts

Multisignature and Smart Contracts Scripts

- Bitcoin uses scripts for Smart Contracts
  - There are many different possibilities that can be expressed with this scripting language.
  - Smart contracts can be programmed in to code which expresses more complex conditions for spending and how these conditions can be satisfied by unlocking scripts.
  - *This language allows for a nearly infinite variety of conditions to be expressed.*
  - *This is how bitcoin gets the power of "programmable money." (Mastering Bitcoin)*

Multisignature and Smart Contracts Scripts

- Bitcoin does not allow any loop for stable operations.
- Ethereum does.
  - `Jump` and `JumpTo` are used in the list of OP codes.
  - https://github.com/crytic/evm-opcodes.
- Bitcoin is more prudent and focuses on safety.

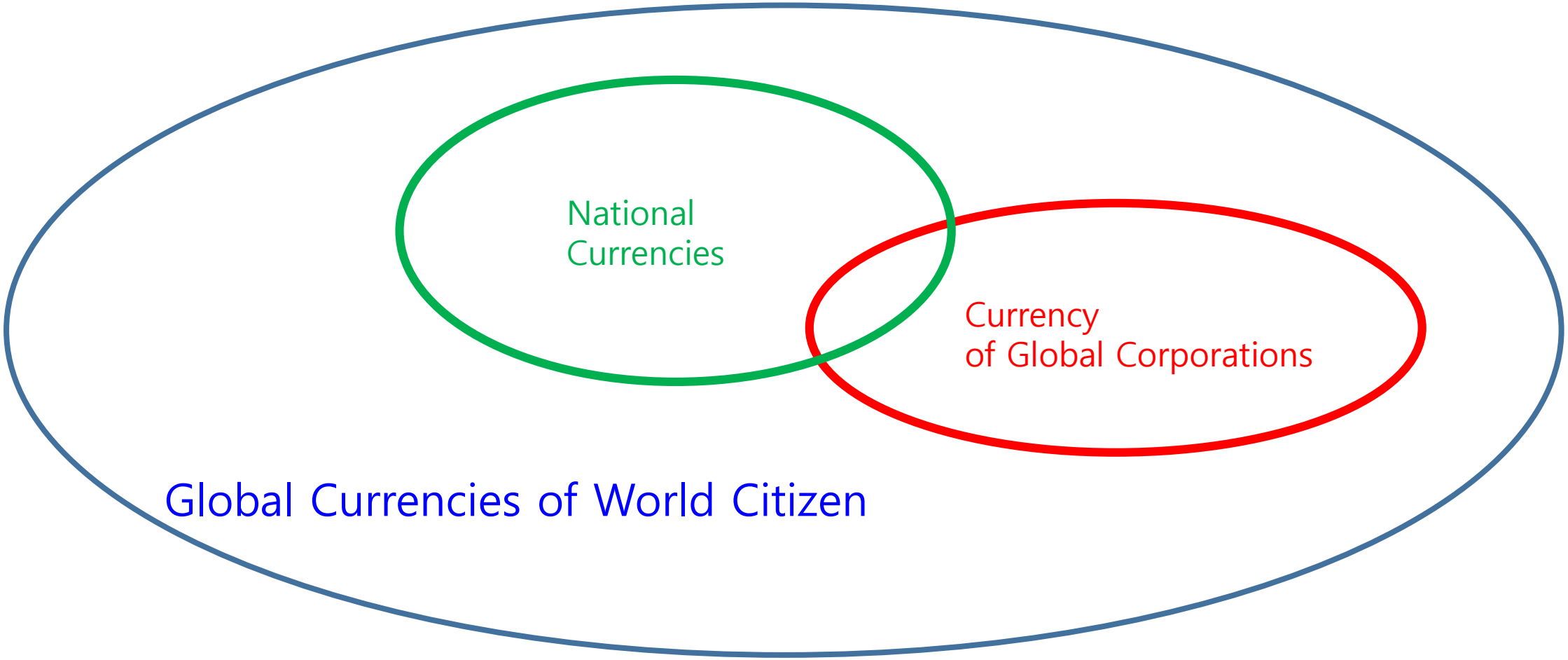
Bitcoin is money of people!

- We are people from the globe.
- We have our computers shared.
- This computer network maintains the book of transactions.
- This computer network mints coins.
- Currency is created by us the people.
- We the people get the seigniorage.
- Supply of this global currency is fixed.

Bitcoin provides honest money!

- It is a money freely traded worldwide.
- Supply is fixed.
- Participation is open.
- BIT-ECC is more decentralized than BIT.

10 years from now, competing currencies



Concluding Remarks

- Bitcoin is the currency of world citizen.
- PoW is fundamental to decentralization and security.
- Centralized altcoins are not as valuable as Bitcoin.
- DeSecure blockchains and multi-level blockchains provide new technological advance.
- It is inevitable to use cryptocurrencies.

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