Introduction to Cryptocurrencies

a tutorial

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An extended abstract of this tutorial (including the references) is available at: www.crypto.edu.pl/Dziembowski/talks/bitcointutorial.pdf.
These slides are available at www.crypto.edu.pl/Dziembowski/talks.

Outline

1. Introduction to Bitcoin
2. Bitcoin mining pools
3. Security of Bitcoin
4. Smart contracts
5. Other cryptocurrencies
6. Conclusion

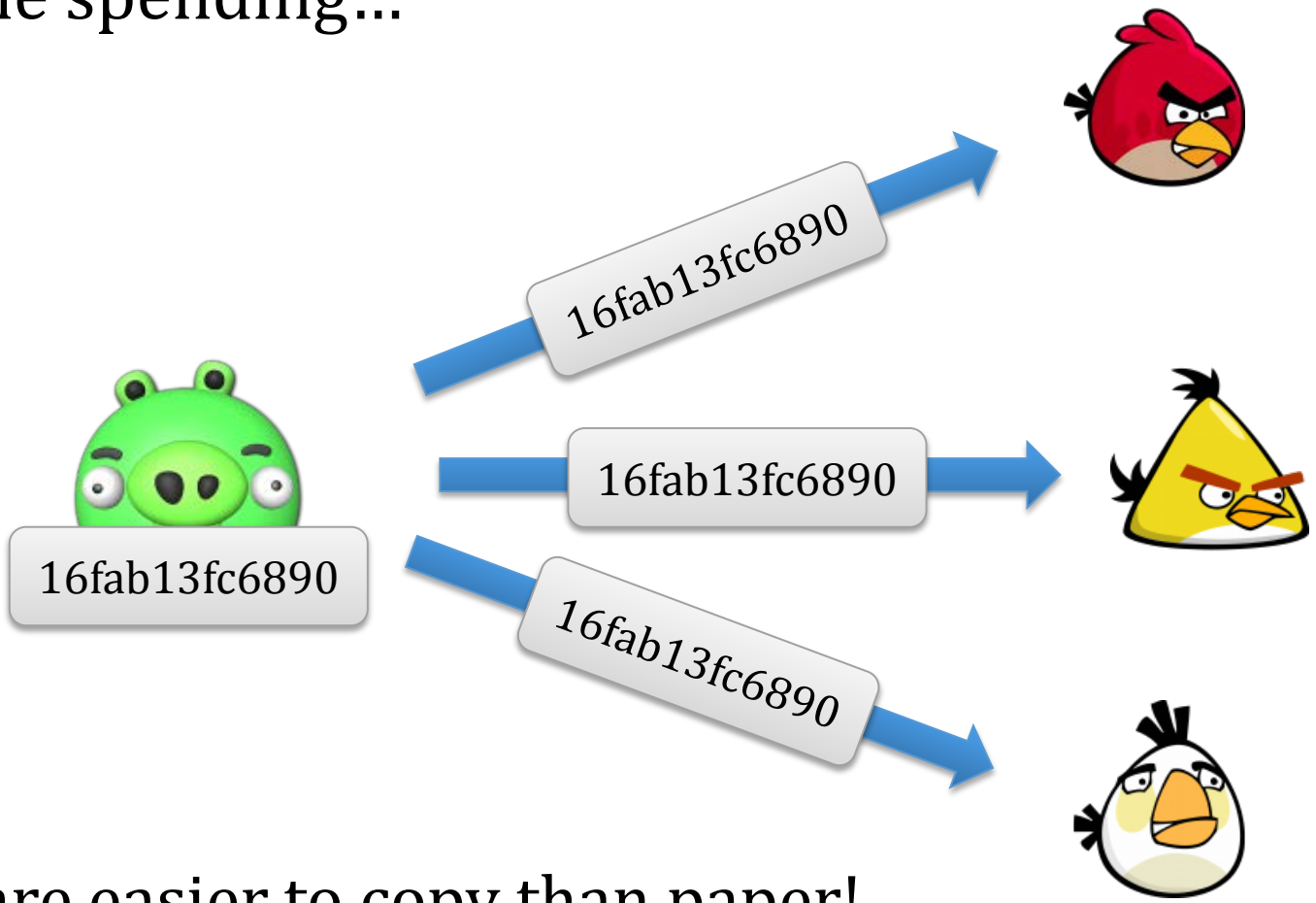
Part I

Introduction to Bitcoin

Main design principles

Main problem with the digital money

Double spending…



Bits are easier to copy than paper!

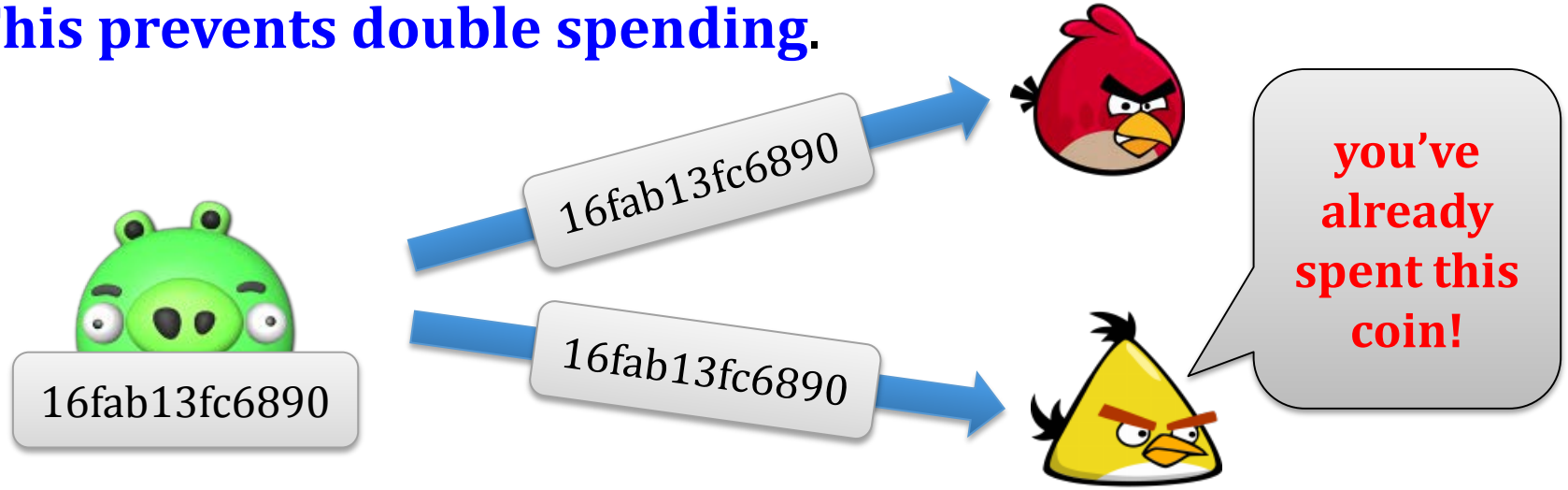
Bitcoin idea (simplified):

The users emulate a **public trusted bulletin-board** containing a list of transactions.

A transaction is of a form:

"User $\mathbf{P_1}$ transfers a coin #16fab13fc6890 to user $\mathbf{P_2}$"

This prevents double spending.



What needs to be discussed

1. How is the **trusted bulletin-board** maintained?
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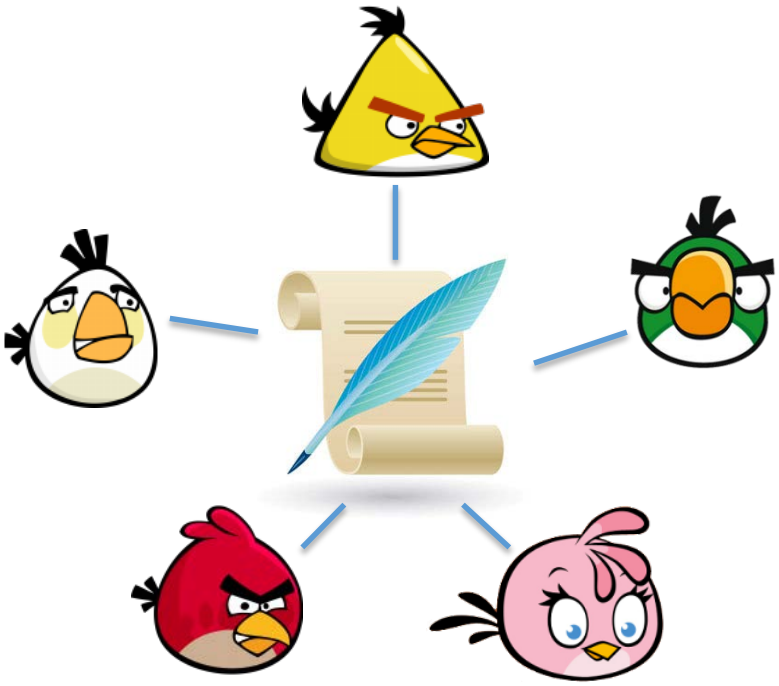
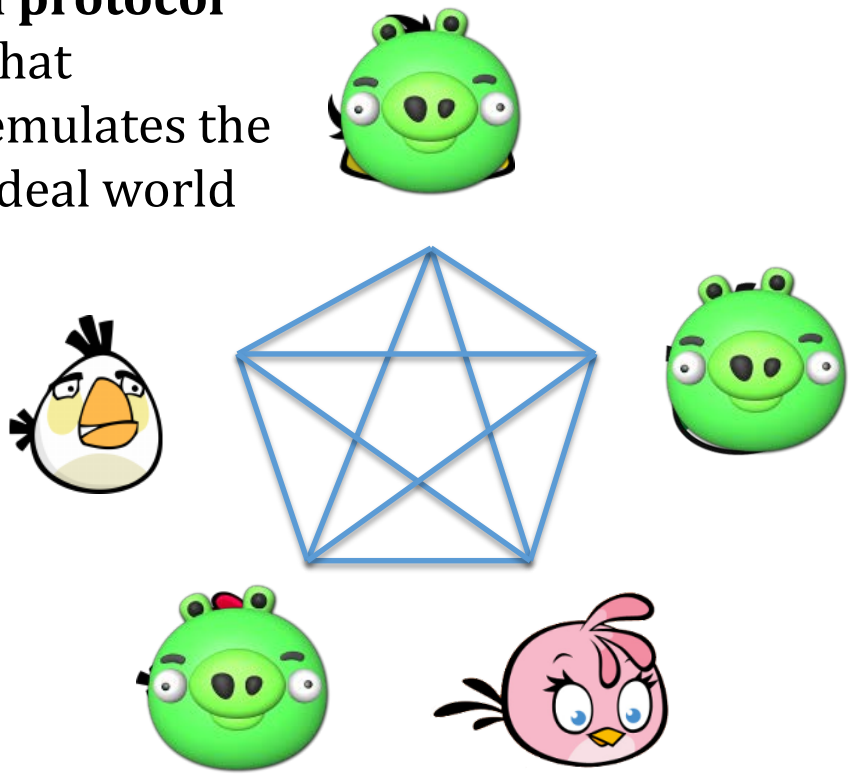
Trusted bulletin-board emulation

the "ideal" world



a **protocol** that emulates the ideal world



Main difficulty: Some parties can cheat.

Classical result: simulation is possible if the "majority is honest".

For example for **5** players we can tolerate at most **2** "cheaters".

Problem

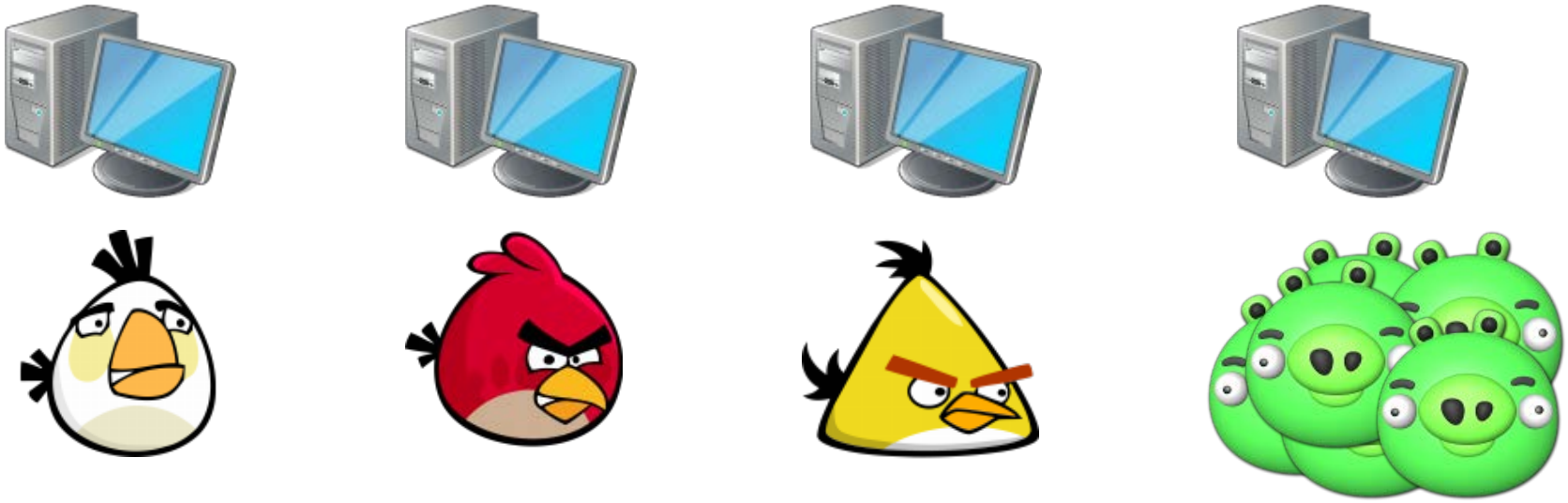
How to define "**majority**" in
a situation where
everybody can join the network?

The Bitcoin solution

Define the “majority” as

the majority of the computing power

Now creating multiple identities does not help!



How is this verified?

Main idea:

- use **Proofs of Work**
- **incentivize** honest users to constantly participate in the process

The honest users can use their **idle CPU cycles**.

Nowadays: often done on **dedicated hardware**.

Proofs of work

Introduced by **Dwork and Naor** [Crypto 1992] as a countermeasure against spam.

Basic idea:
Force users to do some computational work:

solve a **moderately difficult** "puzzle"

(checking correctness of the solution has to be fast)

A simple hash-based PoW

H -- a hash function whose computation takes time **TIME(H)**

random **x**

Prover
finds **s** such that
H(s,x) starts with **n** zeros (in binary)

s

Verifier
checks if
H(s,x) starts with **n** zeros

salt | "hardness parameter

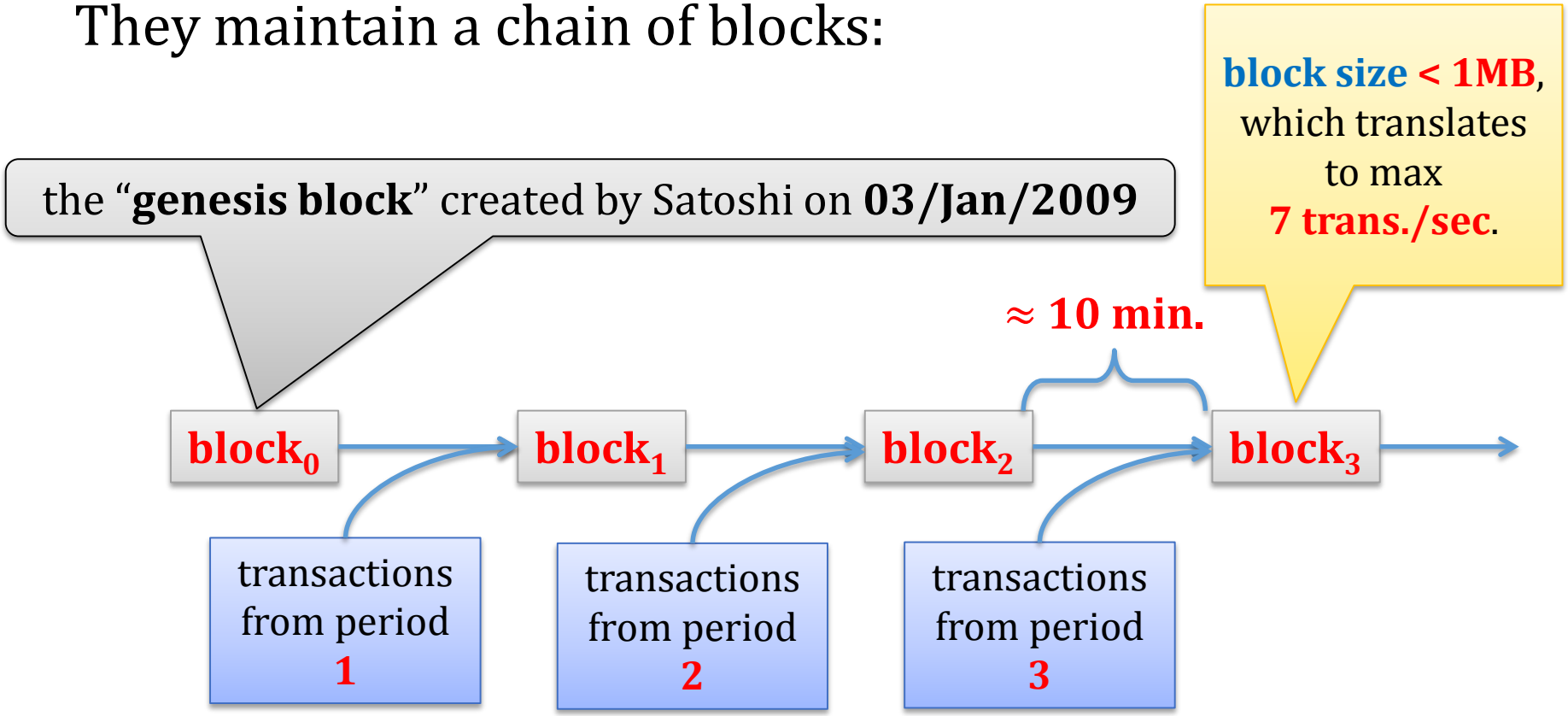
takes time $2^n \cdot$ **TIME(H)**

takes time **TIME(H)**

Main idea

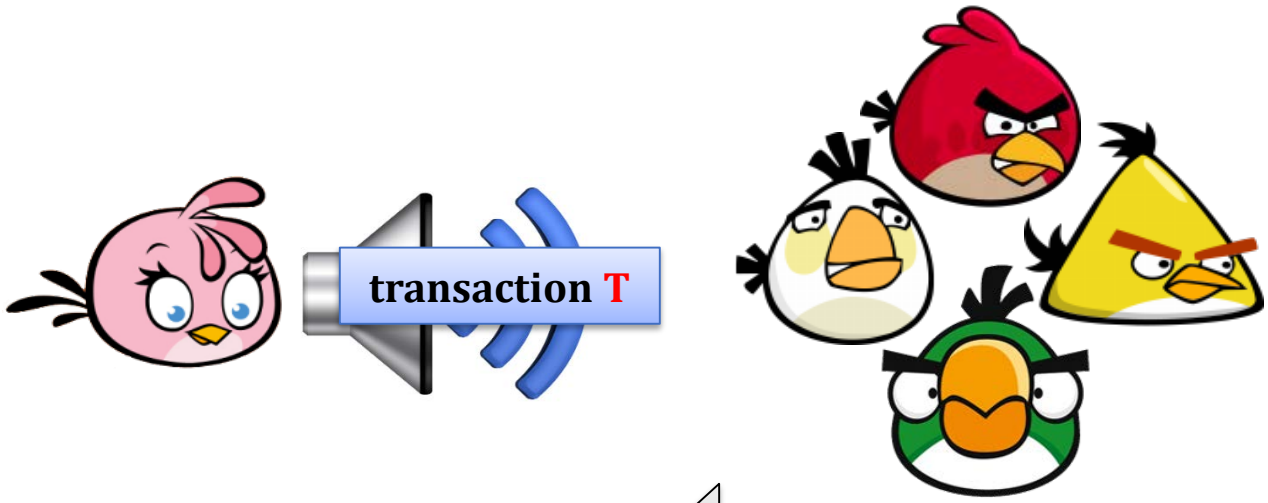
The users participating in the scheme are called the "miners".

They maintain a chain of blocks:



How to post on the board

Just broadcast (over the internet) your transaction to the miners.



And hope they will **add it to the next block.**

the miners are incentivized to do it.

Important:

They **never add an invalid transaction** (e.g. double spending)

a chain with an invalid transaction is **itself not valid**, so no rational miner would do it.

Main principles

1. It is **computationally hard** to extend the chain.

2. Once a miner finds an extension he **broadcasts it to everybody**.

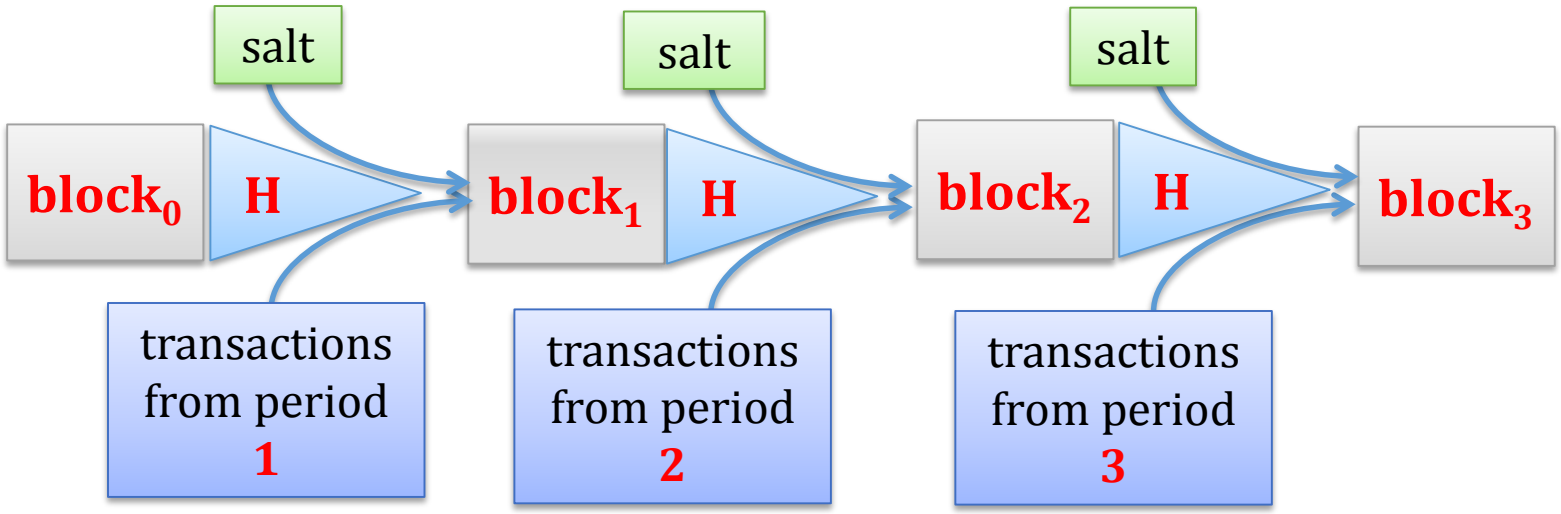
3. The users will always accept "**the longest chain**" as the valid one.

the system incentivizes them to do it

How are the PoWs used?

H – hash function

more concretely in Bitcoin: **H** is **SHA256**.



Main idea: to extend the chain one needs to find **salt** such that

H(salt, H(block$_i$),transactions) starts with some number **n** of **zeros**

"hardness parameter"

The hardness parameter is periodically changed

- The computing power of the miners **changes**.
- The miners should generate the new block **each 10 minutes** (on average).
- Therefore the hardness parameter **is periodically adjusted** to the mining power
- This happens once each **2016 blocks**.
- **Important**: the hardness adjustment is **automatic**, and depends on how much time it took to generate last 2016 blocks.

this is possible since every block contains a **time-stamp** produced by the miner who mined it

“Hashrate” = number of hashes computed per second

total hashrate over the last **2** years:

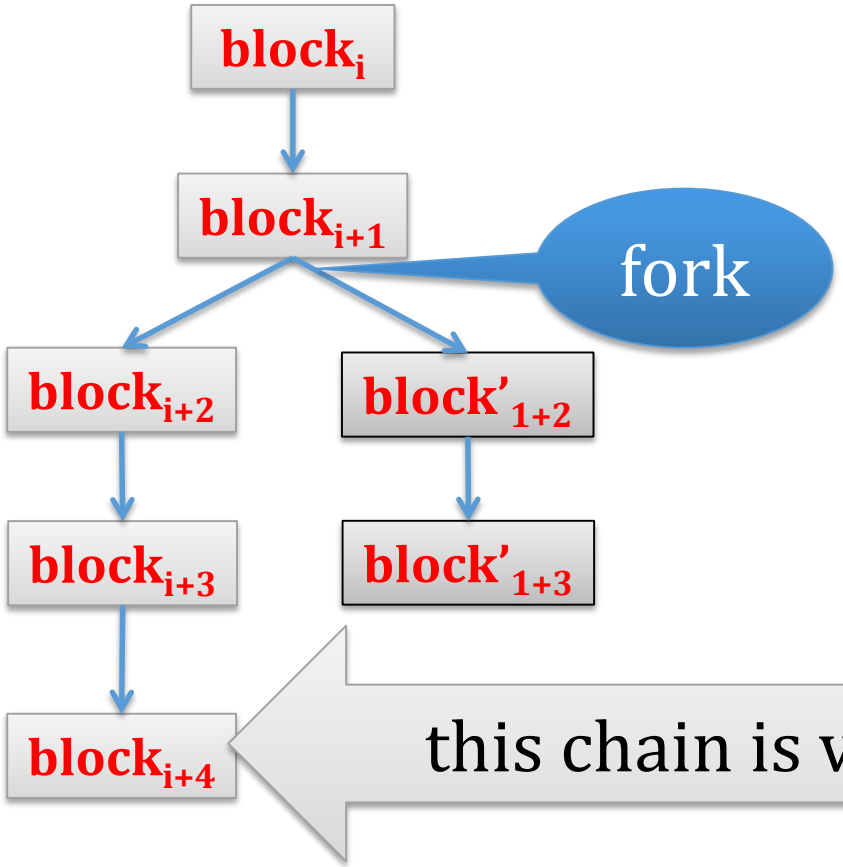
Note:

Sep 17 2013 :	990,986 GH/s
Sep 17 2014 :	280,257,530 GH/s
Sep 17 2015 :	385,067,688 GH/s

$\approx 2^{58}$ hash / second

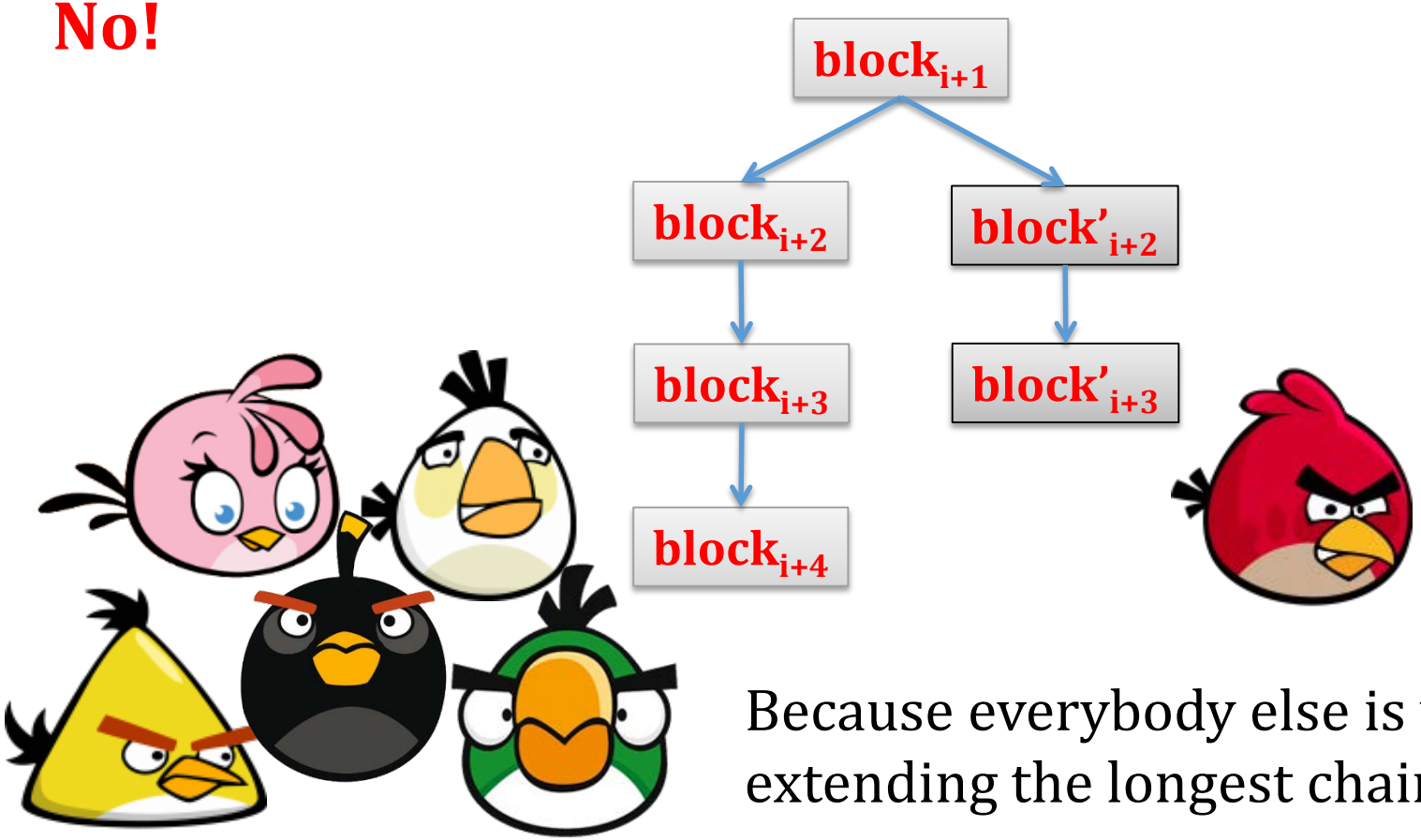
What if there is a “fork”?

For a moment let’s say: the “**longest**” chain counts.



Does it make sense to “work” on a shorter chain?

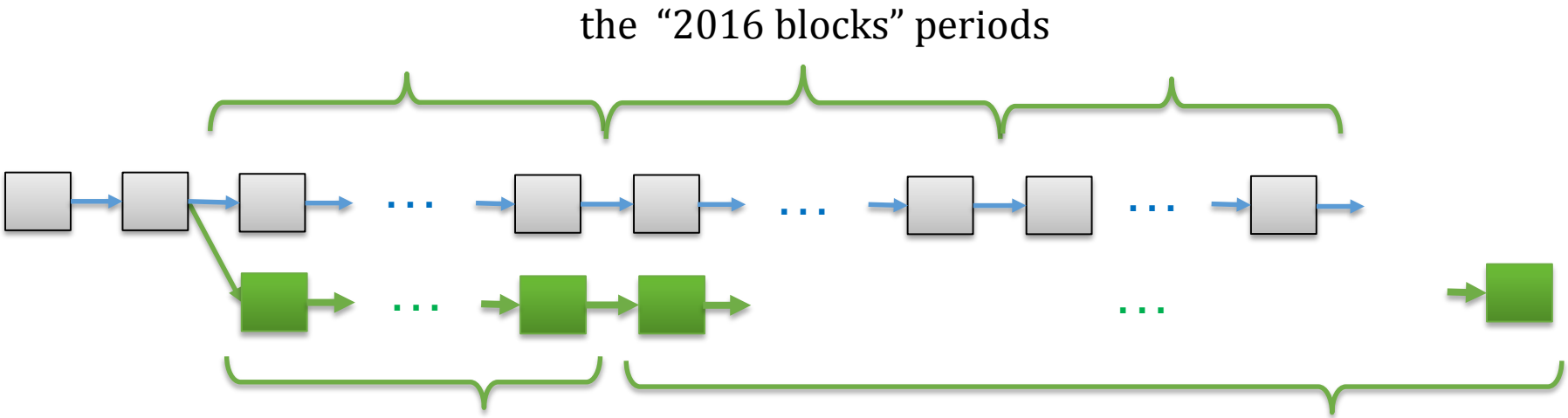
No!



Because everybody else is working on extending the longest chain.

Recall: we assumed that the majority follows the protocol.

Since hardness is adjusted thus the following attack might be possible



the adversary forks the chain:

(1)
he computes (secretly) another chain with **fake time-stamps** (indicating that it took zero time to produce it)

(2)
the difficulty drops dramatically, so he can quickly produce a chain longer than the valid one, and publish it.

Therefore

In Bitcoin it's not the **longest chain** but the **strongest chain** that matters.

The **strength of each block** is 2^{n}.

n – the hardness parameter in a given period

The **strength of the chain** is the sum of hardnesses of each block in it.

How are the miners incentivized to participate in this game?

Short answer: they are paid (in Bitcoins) for this.

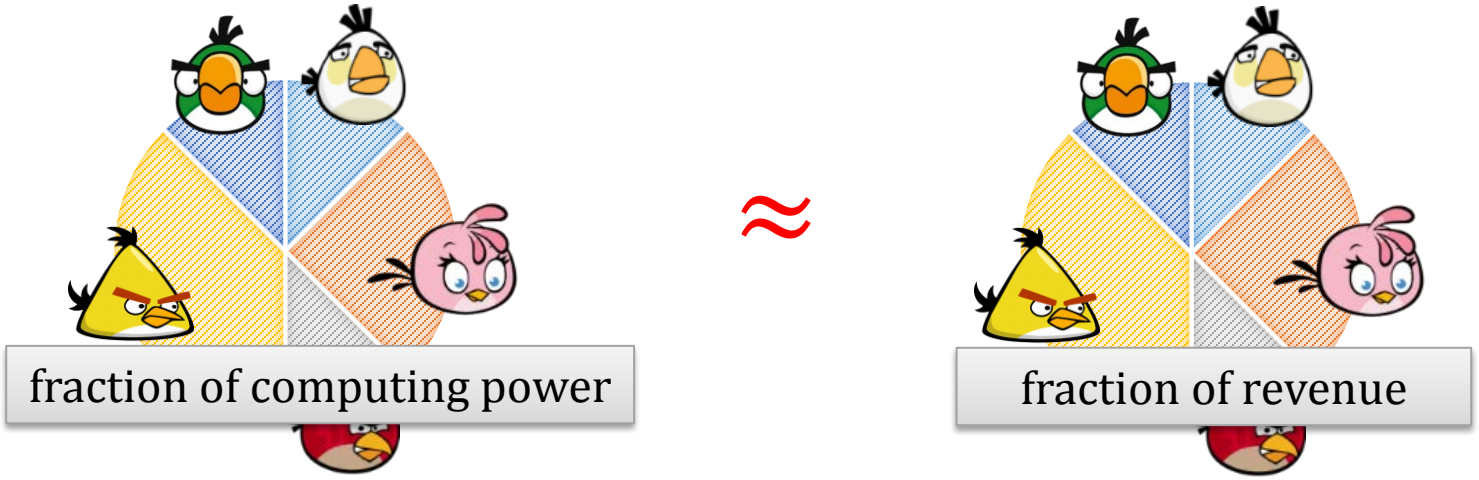
We will discuss it in detail later…

An important feature

Suppose everybody behaves according to the protocol

then:

every miner $\mathbf{P_i}$ whose **computing power is an α_i-fraction** of the total computing power **mines an α_i-fraction of the blocks**.



Intuitively this is because:

$\mathbf{P_i}$'s chances of winning are **<u>proportional to</u>**
the number of times $\mathbf{P_i}$ can compute $\mathbf{H}$ in a given time frame.

What is needed to decide which blockchain is valid?

In theory: one needs to know **only**:

- the **initial rules of the game**
- the **genesis block B_0**

This can take several hours.
Note: as of **Oct 13, 2015**: blockchain's size is **≈45MB**.

Then from many "candidate chains" choose the one that

- **verifies correctly** (starts B_0 and is satisfies all the rules)
- is **the strongest**.

One doesn't even need to have access to the communication history.

In practice: it's not that simple...

we will talk about it in a moment

Freshness of the genesis block

I didn't know the genesis block before Bitcoin was launched (**Jan 3, 2009**)

Here is a heuristic "proof":

Block$_0$ contained a hash of a title from a front page of the London Times on **Jan 3, 2009**


Chancellor on brink of second bailout for banks

A recent paper that shows how to generate the genesis block in a distributed way: **[Andrychowicz, D., CRYPTO'15]**.

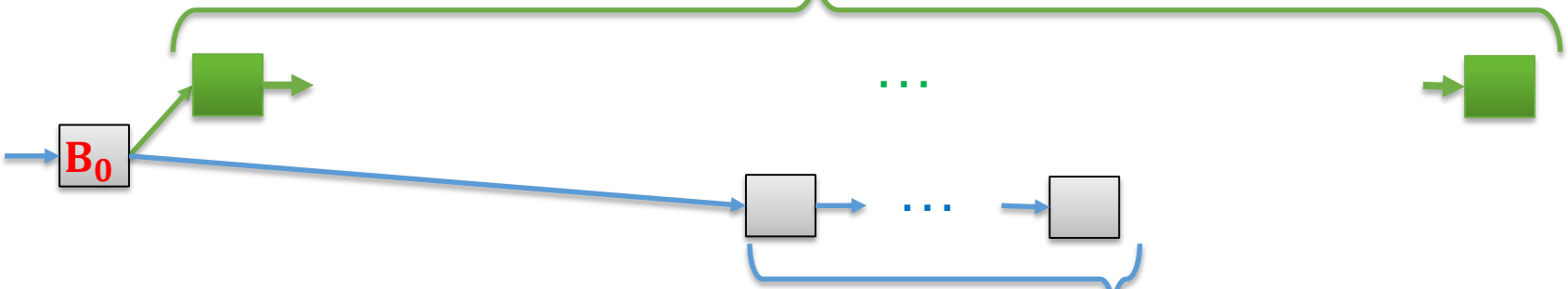
Why is this important?

Otherwise Satoshi could "pre-mine"

(mostly a theoretical threat today):

(1)
secretly start mining in **1980**, produce a very strong chain

(3)
On **Jan 03, 2010** publish your secret chain



(2)
honest miners start working on **Jan 03, 2009**.
They have **more computing power** but **less time**.
So, **after 1 year** their chain is still **weaker** than the one of Satoshi.

Checkpoints

Checkpoint – old block hash **hardcoded into Bitcoin software**.

From the **theoretical** point of view: ***not* needed**.

Moreover: they go against the "decentralized" spirit of Bitcoin.

Still they have some **practical advantages**:

- they prevent some **DoS attacks** (flooding nodes with unusable chains)
- they prevent attacks involving **isolating nodes** and giving them fake chains,
- they can be viewed as an **optimization** for the initial blockchain download.

Protocol updates

The Bitcoin protocol **can be updated**.

Proposals for the Bitcoin updates can be submitted to the **Bitcoin foundation** in the form of the **Bitcoin Improvement Proposals** (**BIPs**).

Then the foundation puts them at vote.

Only the miners can vote. The votes are included in the mined blocks.

Currently it is required that a proposal gets a **75% approval in the mined blocks** (over some period of time).

Note: **75% of blocks ≈ 75% of computing power**.

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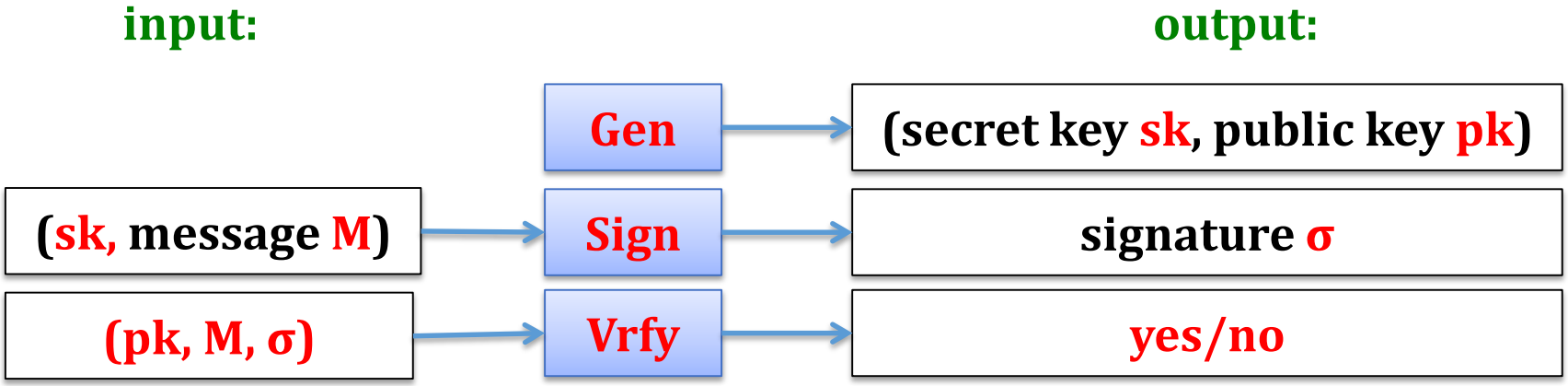
User identification

We use the digital signature schemes.

The users are identified by their public keys.

Digital signature schemes

A **digital signature scheme** consists of algorithms **Gen**, **Sign** and **Vrfy**, where:



Correctness:

for every **(sk,pk) := Gen()** and every **M** we have
Vrfy(pk,M,Sign(sk,M)) = yes

Security:

"without knowing **sk** it is infeasible to compute **σ** such that
Vrfy(pk,M,σ) = yes"

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Where does the money come from?

A miner who finds a new block gets a "reward" in **BTC**:

≈ 4 years

- for the first **210,000** blocks: **50 BTC**
- for the next **210,000** blocks: **25 BTC**
- for the next **210,000** blocks: **12.5 BTC**,

current reward

and so on…

Note: **$210{,}000 \cdot (50 + 25 + 12.5 + \cdots) \to 21{,}000{,}000$**

More details

Each block contains a transaction that **transfers the reward** to the miner.

Advantages:

1. It provides **incentives** to be a miner.
2. It also makes the miners interested in **broadcasting new block** asap.

this view was challenged in a recent paper:
Ittay Eyal, Emin Gun Sirer
Majority is not Enough: Bitcoin Mining is Vulnerable
(we will discuss it later)

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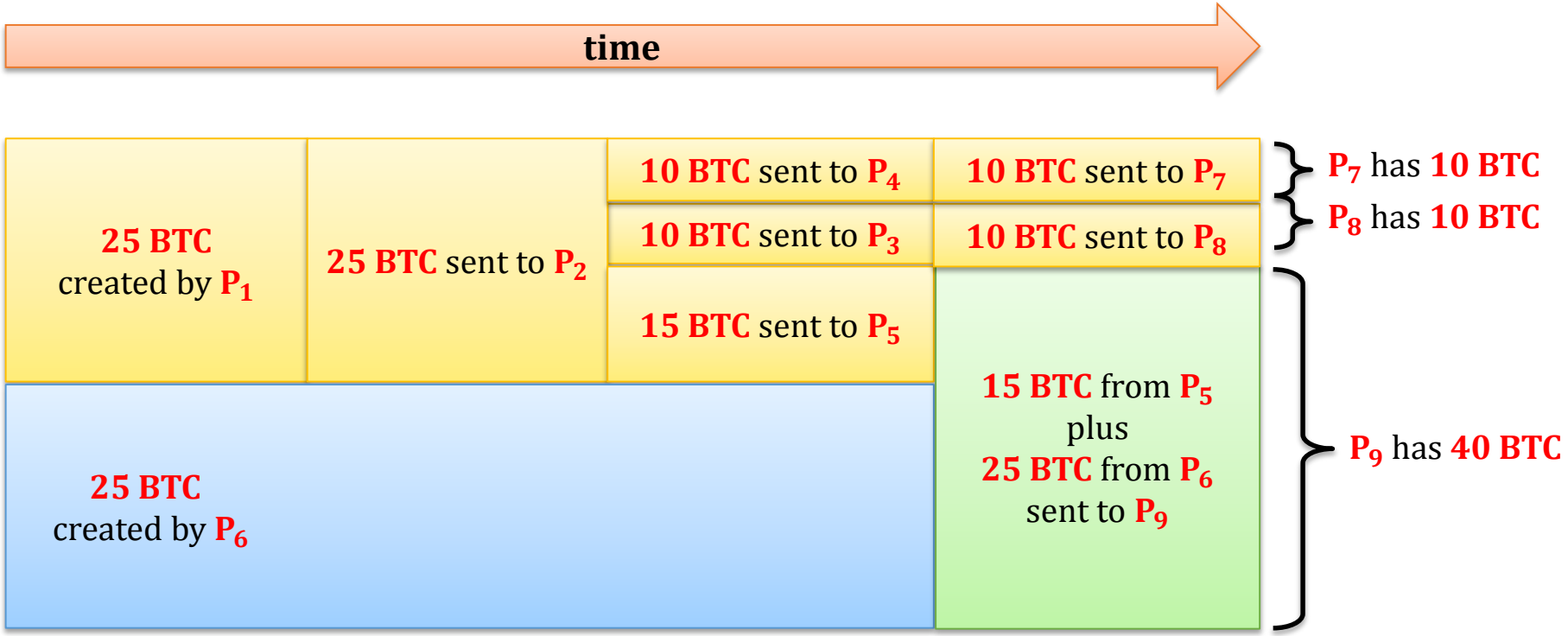
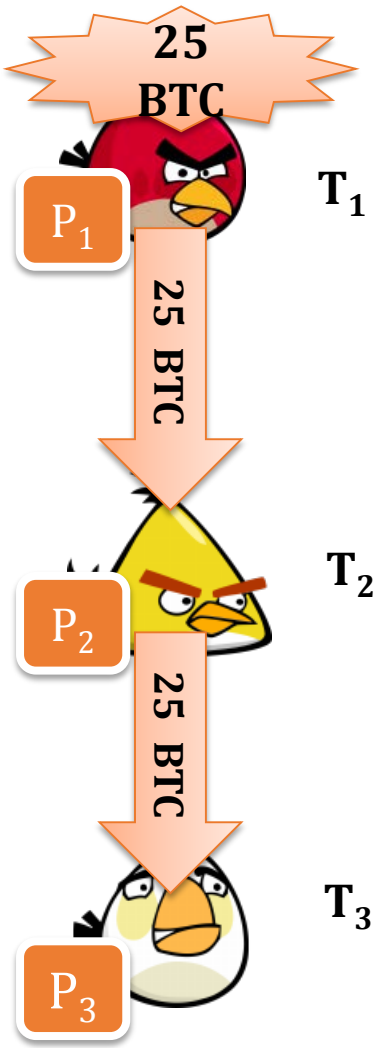
Bitcoin's money mechanics

Bitcoin is "transaction based".

Technically: there is no notion of a "coin" in Bitcoin.



Transaction syntax – simplified view



in the "mining process"

We say that T_3 **redeems** T_2

T_1 = (User P_1 creates **25 BTC**)

"value of T_2"

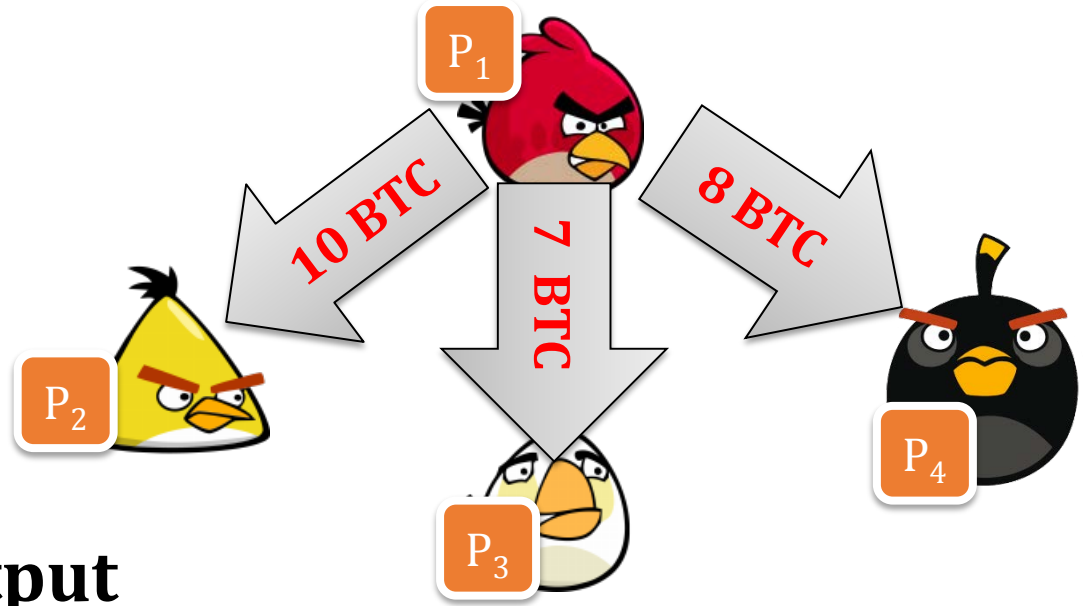
$[T_2]$

T_2 = (User P_1 sends **25 BTC** from T_1 to P_2 **signature of P_1 on $[T_2]$**)

$[T_3]$

T_3 = (User P_2 sends **25 BTC** from T_2 to P_3 **signature of P_2 on $[T_3]$**)

How to “divide money”?

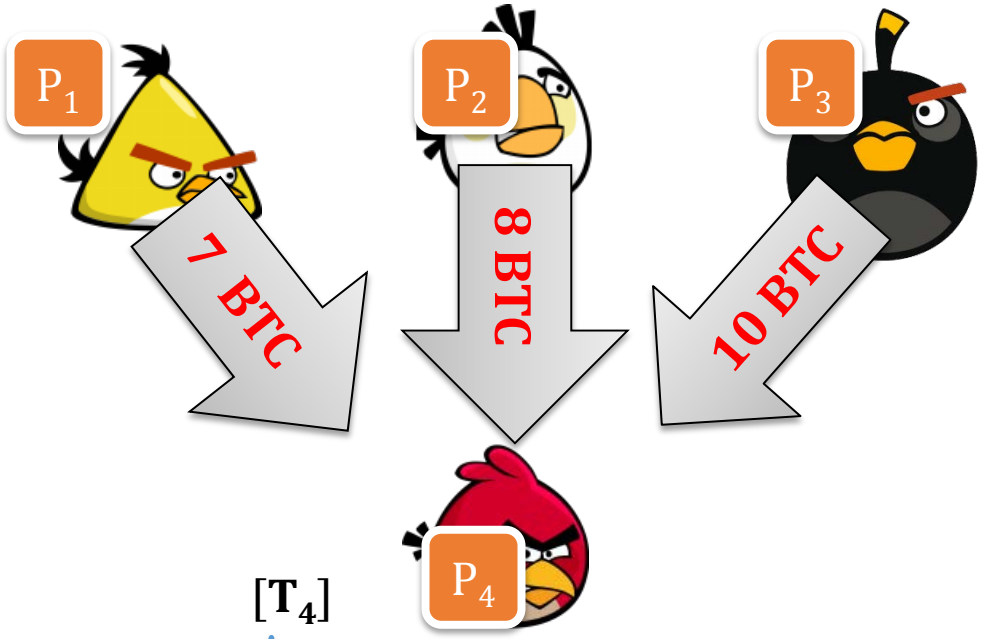


Multi-output transactions:

$[T_2]$

$T_2 =$ (User P_1 sends **10 BTC** from T_1 to user P_2, User P_1 sends **7 BTC** from T_1 to user P_3, User P_1 sends **8 BTC** from T_1 to user P_4 | **signature of P_1 on $[T_2]$**)

Multiple inputs



$[T_4]$

T_4 = (User P_1 sends **10 BTC** from T_1 to user P_4, User P_2 sends **7 BTC** from T_2 to user P_4, User P_3 sends **8 BTC** from T_3 to user P_4 | **signature of P_1 on $[T_4]$, signature of P_2 on $[T_4]$, signature of P_3 on $[T_4]$**)

all signatures need to be valid!

Time-locks

It is also possible to specify time **t** when a transaction becomes valid.