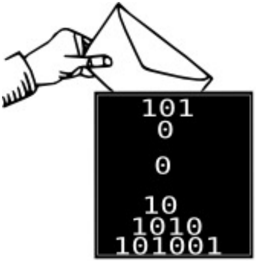
Securité et vérification fomrelle

Pascal Lafourcade

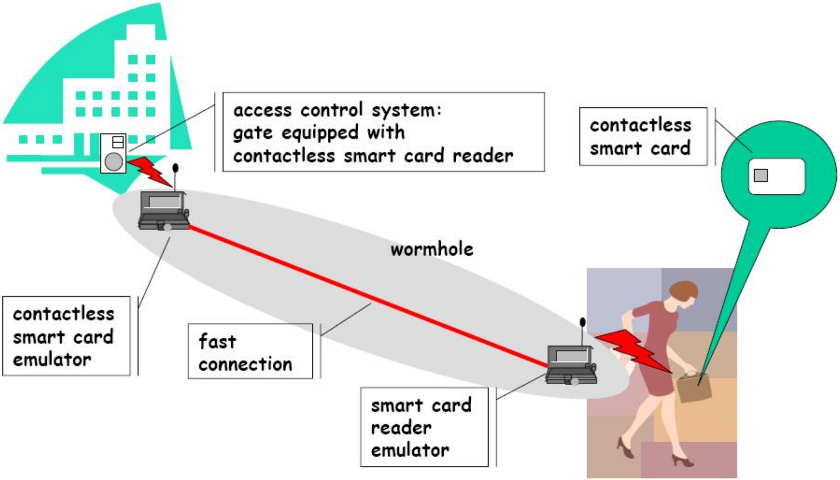
8 mars 2017

Nowadays Security is Everywhere!



Due to the succes of Computer Science.

Wormhole Attack



Paypal Attack

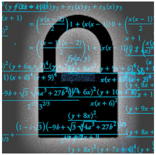
“Model-Based Vulnerability Testing of Payment Protocol Implementations”, Ghazi Maatoug, Frédéric Dadeau and Michael Rusinowitch, Hotspot 2014

Hacking Pacemakers:

Manufacturers are still not putting security first when designing implantable medical devices (2012)

Formal Verification Approaches

Designer



Attacker

Formal Verification Approaches

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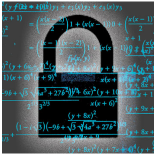

Attacker

Security Team

Formal Verification Approaches

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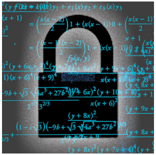
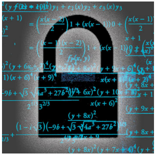


Attacker

Give a proof

Security Team

Formal Verification Approaches



Designer

Attacker

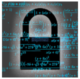
Give a proof

Find a flaw

Security Team

What is cryptography based security?

Cryptography:



- Primitives: RSA, Elgamal, AES, DES, SHA-3 ...
- Protocols: Distributed Algorithms

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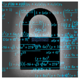

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Properties:

- Secrecy,
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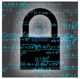

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- Active
- CPA, CCA ...

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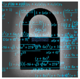

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Designing **secure** cryptographic protocols is **difficult**

Security of Cryptographic Protocols

How can we be convinced that a protocols is secure?

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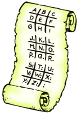    

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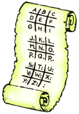    

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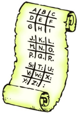    

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Computer-Aided Security

My Research Topics

- Formal analysis: e-exam, e-voting, e-eauction, SCADA
- Automatic analysis of cryptographic primitives
- WSN: Privacy, Secure Routing, Distance Bounding

Plan

Plan

Traditional security properties

- Common security properties are:
  - Confidentiality or Secrecy: No improper disclosure of information
  - Authentification: To be sure to talk with the right person. disclosure of information
  - Integrity: No improper modification of information
  - Availability: No improper impairment of functionality/service

Authentication

"On the Internet, nobody knows you're a dog."

Mechanisms for Authentication

KNOW	HAVE	ARE	DO
			
Passwords ID Questions Secret Images	Token (Smart) Card Phone	Face Iris Hand/Finger	Behavior Location Reputation

Other security properties

- Perfect Forward Secrecy (PFS) is s a property of key-agreement protocols that ensures that a session key derived from a set of long-term keys will not be compromised if one of the long-term keys is compromised in the future.
- Non-repudiation (also called accountability) is where one can establish responsibility for actions.
- Fairness is the fact there is no advantage to play one role in a protocol comparing with the other ones.
- Privacy

  Anonymity: secrecy of principal identities or communication relationships.

  Pseudonymity: anonymity plus link-ability.

  Data protection: personal data is only used in certain ways.

e-services :

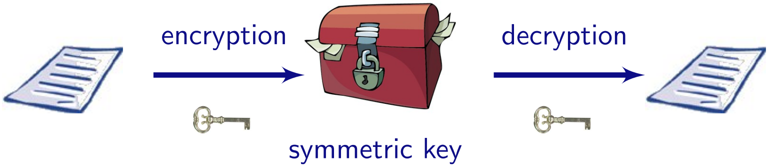
- e-voting
- e-auction
- e-examen
- e-reputation
- e-cash
- ...

Users except more properties and security with electronic services!

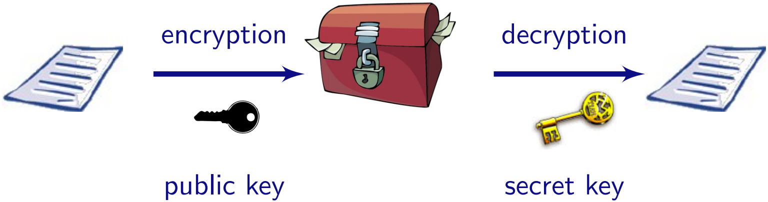
Plan

Symmetric vs Asymmetric Encryption

Symmetric Encryption (DES, AES)



Asymmetric Encryption (RSA, Elgamal ...)



3-pass Shamir

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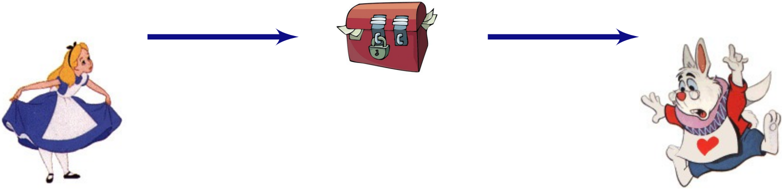

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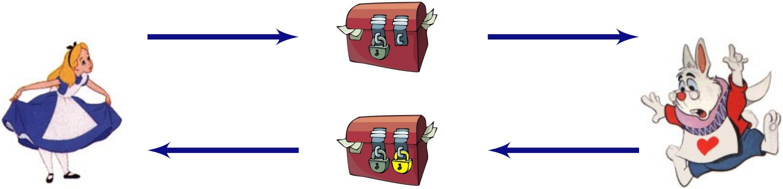

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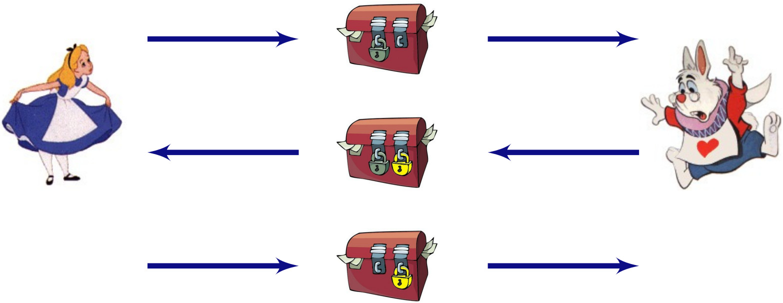

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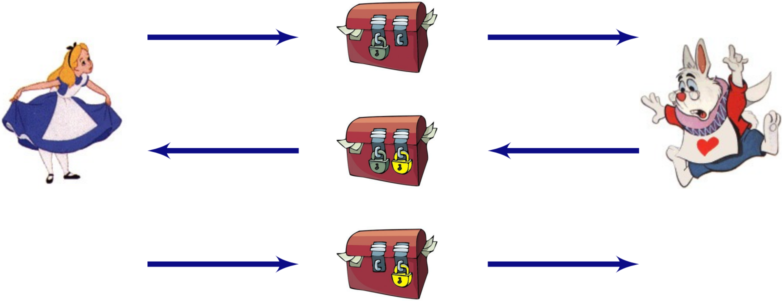
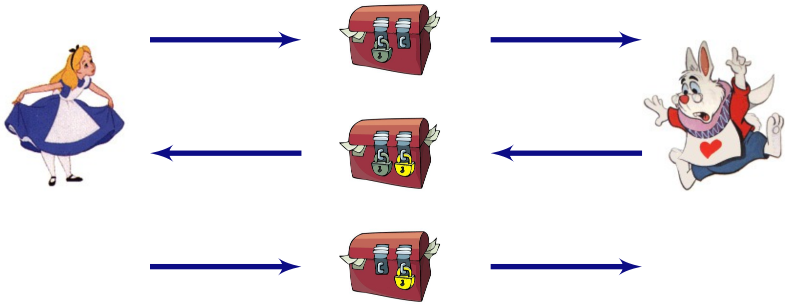


Abstract Representation

$$1 \quad A \rightarrow B : \{m\}_{K_A}$$

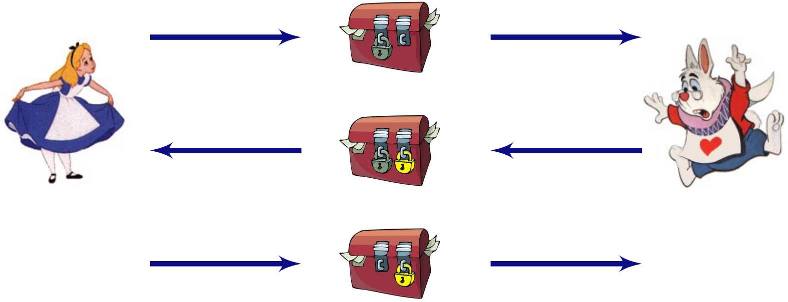
3-pass Shamir



Abstract Representation

$$
\begin{array}{lllll}
1 & A & \rightarrow & B & : \{m\}_{K_A} \\
2 & B & \rightarrow & A & : \{\{m\}_{K_A}\}_{K_B}
\end{array}
$$

3-pass Shamir



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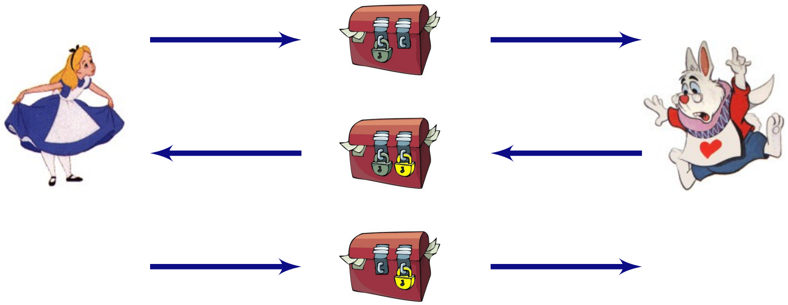
Commutative Encryption

3-pass Shamir



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$$

Commutative Encryption

Example

Needham Schroeder Key Echange 1976

$$A \rightarrow B : \{A, N_A\}_{Pub(B)}$$
$$B \rightarrow A : \{N_A, N_B\}_{Pub(A)}$$
$$A \rightarrow B : \{N_B\}_{Pub(B)}$$

- Use cryptography
- Small programs
- Distributed

Plan

Logical Attack on Shamir 3-Pass Protocol (I)

Perfect encryption one-time pad (Vernam Encryption)

$\{m\}_k = m \oplus k$

XOR Properties (ACUN)

- $(x \oplus y) \oplus z = x \oplus (y \oplus z)$ — **A**ssociativity
- $x \oplus y = y \oplus x$ — **C**ommutativity
- $x \oplus 0 = x$ — **U**nity
- $x \oplus x = 0$ — **N**ilpotency

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Vernam encryption is a commutative encryption :

$$\{\{m\}_{K_A}\}_{K_I} = (m \oplus K_A) \oplus K_I = (m \oplus K_I) \oplus K_A = \{\{m\}_{K_I}\}_{K_A}$$

Logical Attack on Shamir 3-Pass Protocol (II)

Perfect encryption one-time pad (Vernam Encryption)

$\{m\}_k = m \oplus k$

Shamir 3-Pass Protocol

$$
\begin{array}{llcll}
1 & A & \rightarrow & B: & m \oplus K_A \\
2 & B & \rightarrow & A: & (m \oplus K_A) \oplus K_B \\
3 & A & \rightarrow & B: & m \oplus K_B
\end{array}
$$

Passive attacker :

$$m \oplus K_A \qquad m \oplus K_B \oplus K_A \qquad m \oplus K_B$$

Logical Attack on Shamir 3-Pass Protocol (II)

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Shamir 3-Pass Protocol

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Passive attacker :

$$m \oplus K_A \oplus m \oplus K_B \oplus K_A \oplus m \oplus K_B = m$$

Cryptography is not sufficient !

Example : Needham Schroeder Key Echange

$$A \rightarrow B : \{A, N_A\}_{Pub(B)}$$

$$B \rightarrow A : \{N_A, N_B\}_{Pub(A)}$$

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$$A \rightarrow B : \{N_B\}_{Pub(B)}$$

Broken 17 years after, by G. Lowe

$$A \rightarrow I : \{A, N_A\}_{Pub(I)} \qquad I \rightarrow B : \{A, N_A\}_{Pub(B)}$$
$$B \rightarrow I : \{N_A, N_B\}_{Pub(A)} \qquad I \rightarrow A : \{N_A, N_B\}_{Pub(A)}$$
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Computer-Aided Security

Plan

Necessity of Tools

- Protocols are small recipes.
- Non trivial to design and understand.
- The number and size of new protocols.
- Out-pacing human ability to rigourously analyze them.

GOAL : A tool is finding flaws or establishing their correctness.

- completely automated,
- robust,
- expressive,
- and easily usable.

Existing Tools: AVISPA, Scyther, Proverif, Hermes, Casper/FDR, Murphi, NRL ...

Questions?

How can we find such attacks automatically?

- Models for Protocols
- Models for Properties
- Theories and Dedicated Techniques
- Tools
  - Automatic
  - Semi-automatic

Why is it difficult to verify such protocols?

- Messages: Size not bounded
- Nonces: Arbitrary number
- Intruder: Unlimited capabilities
- Instances: Unbounded numbers of principals
- Interleaving: Unlimited applications of the protocol.

Complexity

Complexity depends of intruder capabilities. In classical Dolev-Yao intruder model we (pair + encryption) we have the following results:

- Passive Intruder
  Problem is polynomial
- Bounded Number of sessions
  Problem is NP-complete
  Tools can verify 3-4 sessions: useful to finds flaws ! OFMC, Cl-Atse, SATMC, FDR, Athena...
- Unbounded Number of sessions
  Problem is in general undecidable
  Tools are corrects, but uncomplete (can find false attacks, can not terminate) Proverif, TA4SP, Scyther.

Which tool for what ?

	Proverif	Scyther	OFMC	Cl-atse	TA4SP	SAT-MC
Secrecy	X	X	X	X	X	X
Authentication	X	X	X	X	X	X
Equivalence Obs	X					
Bounded nb S		X	X	X	X	X
Unbounded nb S	X	X			X	
Xor	x		X	X		
DH	x		X	X		
Fast	X	X				
User friendly		X				

Success Story of Formal Verification

Tools based on different theories for several properties

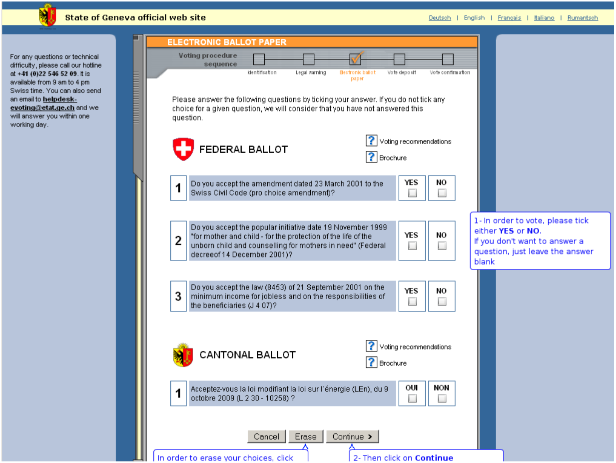
1995	Casper/FRD [Lowe]
2001	Proverif [Blanchet]
2003	Proof of certified email protocol with Proverif [AB]
	OFMC [BMV]
	Hermes [BLP]
	Flaw in Kerberos 5.0 with MSR 3.0 [BCJS]
2004	TA4SP [BHKO]
2005	SATMC [AC]
2006	CL-ATSE [Turuani]
2008	Scyther [Cremers]
	Flaw of Single Sign-On for Google Apps with SAT-MC [ACCCT]
	Proof of TLS using Proverif [BFCZ]
2010	TOOKAN [DDS] using SAT-MC for API
2012	Tamarin [BCM]

Plan

Internet voting

Available in

- Estonia
- France
- Switzerland
- ...



Security Properties of E-Voting Protocols

Fairness

Individual Verifiability

Eligibility

Universal Verifiability

Correctness

Privacy

Receipt-Freeness

Robustness

Coercion-Resistance

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Existing several models for Privacy, but they

- designed for a specific type of protocol
- often cannot be applied to other protocols

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Our Contributions [FPS'11, ICC'12 WS-SFCS,ESORICS'12]:

- Define **fine-grained** Privacy definitions to **compare** protocols
- Analyze **weighted votes** protocols
- **One coercer is enough**

4 Dimensions for Privacy [FPS'11, ICC'12 WS-SFCS]

Modeling in Applied π-Calculus

1. **Communication btwn the attacker & the targeted voter**

   [DKR09]  

   Vote-Privacy (VP) Receipt-Freeness (RF) Coercion-Resistance (CR)

2. **Intruder is controlling another voter**

   Outsider (O)  Insider (I)

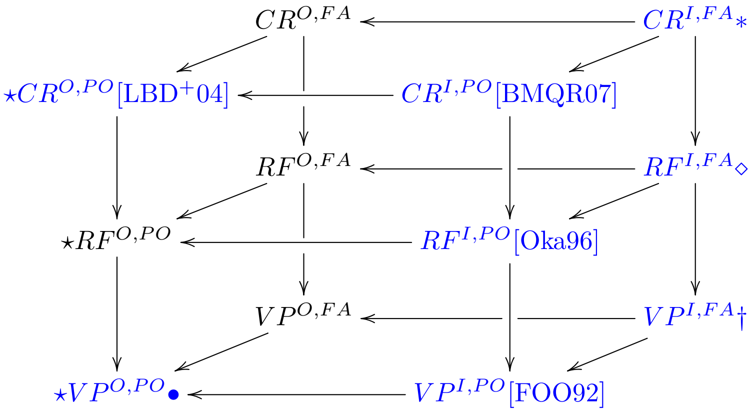
3. **Secure against Forced-Abstention**: (FA) or not (PO)

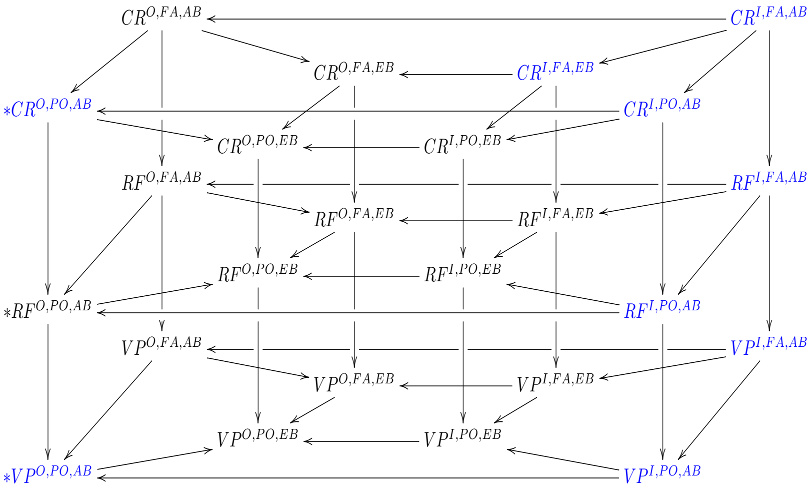
4. **Honest voters behavior**:

   $\exists$  $\forall$

Relations without ∃ and ∀ [FPS'11, ICC'12 WS-SFCS]



All relations among the notions [FPS'11, ICC'12 WS-SFCS]



Privacy for Weighted Votes [ESORICS'12]

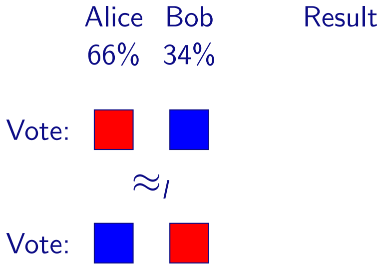
Alice Bob Result

Vote: (red) (blue)

$\approx_l$

Vote: (blue) (red)

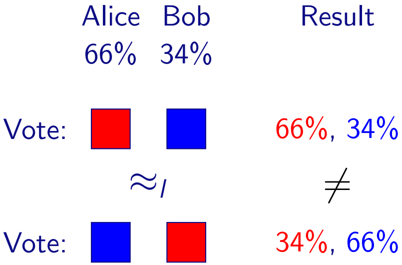
Privacy for Weighted Votes [ESORICS'12]



Privacy for Weighted Votes [ESORICS'12]

	Alice	Bob	Result
	66%	34%	
Vote:			66%, 34%
	$\approx_l$		
Vote:			34%, 66%

Privacy for Weighted Votes [ESORICS'12]



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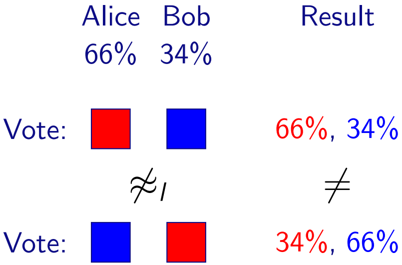
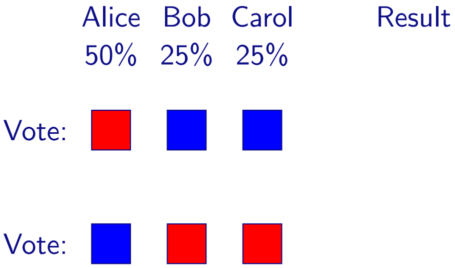


Privacy for Weighted Votes [ESORICS'12]

Still: Some privacy is possible!



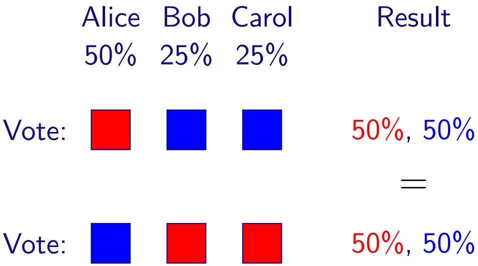
Privacy for Weighted Votes [ESORICS'12]

Still: Some privacy is possible!

	Alice	Bob	Carol	Result
	50%	25%	25%	
Vote:	■ (red)	■ (blue)	■ (blue)	50%, 50%
Vote:	■ (blue)	■ (red)	■ (red)	50%, 50%

Privacy for Weighted Votes [ESORICS'12]

Still: Some privacy is possible!



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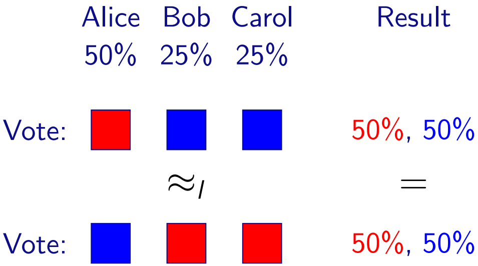


Vote-Privacy (VP) for weighted votes [ESORICS'12]

Idea: Two instances with the same result should be bi-similar

	Alice	Bob	$\cdots$		Result
Vote 1:	V_A^1	V_B^1	$\cdots$		Result 1
	$\approx_l$			$\Leftarrow$	$\stackrel{?}{=}$
Vote 2:	V_A^2	V_A^2	$\cdots$		Result 2

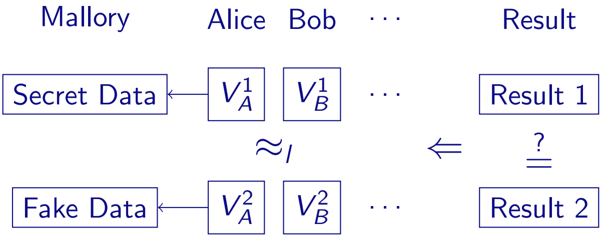
Single-Voter Receipt Freeness (SRF) [ESORICS'12]

Mallory	Alice	Bob	$\cdots$		Result
	V_A^1	V_B^1	$\cdots$		Result 1
	$\approx_l$			$\Leftarrow$	$\stackrel{?}{=}$
	V_A^2	V_B^2	$\cdots$		Result 2

Single-Voter Receipt Freeness (SRF) [ESORICS'12]

Mallory		Alice	Bob	$\cdots$		Result
Secret Data	$\longleftarrow$	V_A^1	V_B^1	$\cdots$		Result 1
		$\approx_l$			$\Leftarrow$	$\stackrel{?}{=}$
Fake Data	$\longleftarrow$	V_A^2	V_B^2	$\cdots$		Result 2

Single-Voter Receipt Freeness (SRF) [ESORICS'12]



If a protocol respects (EQ), then (SRF) and (SwRF) are equivalent.

Multi-Voter Receipt Freeness (MRF) [ESORICS'12]

...

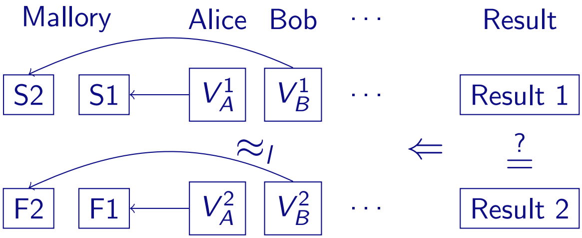
Mallory | Alice | Bob | $\cdots$ | Result

S1 $\leftarrow$ V_A^1 | V_B^1 | $\cdots$ | Result 1

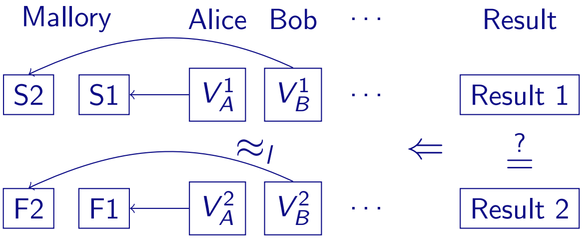
$\approx_l$ $\Leftarrow$ $\stackrel{?}{=}$

F1 $\leftarrow$ V_A^2 | V_B^2 | $\cdots$ | Result 2

Multi-Voter Receipt Freeness (MRF) [ESORICS'12]

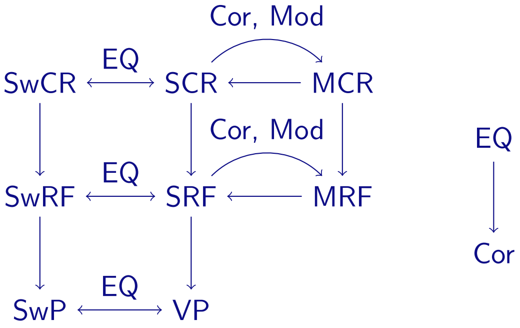


Multi-Voter Receipt Freeness (MRF) [ESORICS'12]



(MRF) implies (SRF) and (MCR) implies (SCR).

One Coerced Voter is enough! [ESORICS'12]



Unique decomposition of processes in the applied π-calculus.

Plan

Plan

e-Auctions

quicksales.com.au

Sotheby's

GUN BROKER.COM
The Bidding Starts Now

AutoBidsOnline.com
Don't Request a Quote, Set Your Price!

ricardo.ch

ebay

mercado Libre

hood.de

WineCommune Buy and Sell Fine Wine - Online!

Competing parties

Bidders/Buyers + 

Seller

Auctioneer ebay

Several e-Auctions

Many possible (complex) mechanisms:

- Sealed Bid
- English: open ascending price auction.
- Dutch: tulips market.
- First Price
- Second Price (Vickrey auction)
- ...

 e-Auctions: Security Requirements

[POST'13, ASIACCS'13]

Fairness

Verifiability

Non-Repudiation

Non-Cancellation

Security Requirements

Secrecy of Bidding Price

Receipt-Freeness

Coercion-Resistance

Anonymity of Bidders

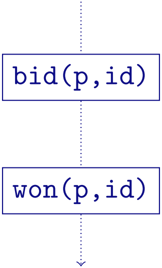
Events [POST'13]

To express our properties, we use the following events:

- `bid(p,id)`: a bidder `id` bids the price `p`
- `recBid(p,id)`: a bid at price `p` by bidder `id` is recorded by the auctioneer/bulletin board/etc.
- `won(p,id)`: a bidder `id` wins the auction at price `p`

Non-Repudiation [POST'13]

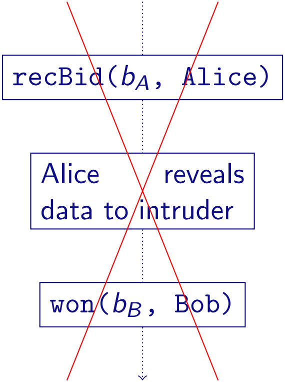
On every trace:



Non-Cancellation [POST'13]

Alice Bob

Bid b_A $>$ b_B



Strong Noninterference & Weak Noninterference [POST'13]

Definition (Strong Noninterference (SN))

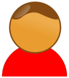
An auction protocol ensures *Strong Noninterference (SN)* if for any two auction processes AP_A and AP_B that halt at the end of the bidding phase (i.e. where we remove all code after the last `recBid` event) we have $AP_A \approx_l AP_B$.

Definition (Weak Noninterference (WN))

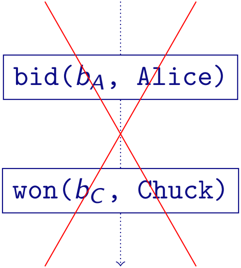
Like Strong Noninterference, but we consider only processes with the same bidders.

Highest Price Wins [POST'13]

Alice (honest)	Chuck (corrupted)

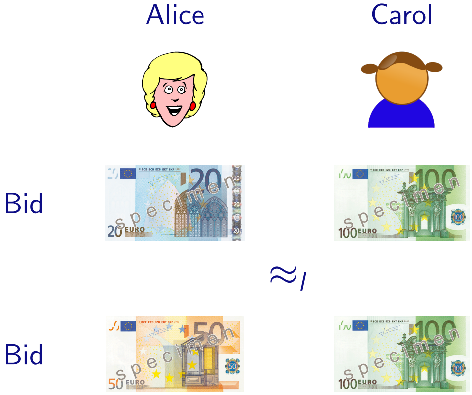


Bid b_A $>$ b_C



Strong Bidding-Price Secrecy (SBPS) [D10]

Main idea: Observational equivalence between two situations.



Bidding-Price Unlinkability (BPU) [POST'13]

The list of bids can be public, but must be unlinkable to the bidders.

	Alice	Bob	Carol
			
Bid			
		$\approx_l$	
Bid			

Strong Anonymity (SA) [POST'13]

The winner may stay anonymous.

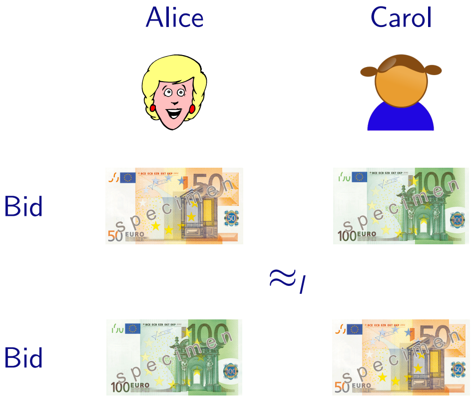
	Alice	Carol
		
Bid		

$$\approx_l$$

Bid		

Weak Anonymity (WA) [POST'13]

Unlinkability, but also for the winner.



e-Auctions: Hierarchy of Privacy Notions [POST'13]

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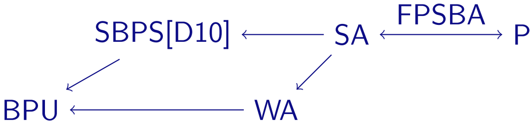
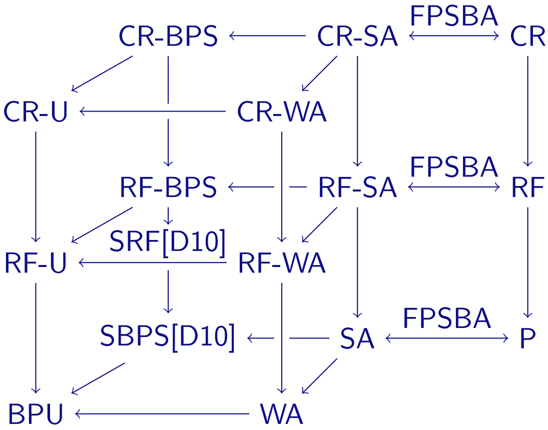


e-Auctions: Hierarchy of Privacy Notions [POST'13]



Protocol by Curtis et al.[C07]: Registration [POST'13]

Main idea: a registration authority (RA) distributes pseudonyms, which are then used for bidding.

Bidder

Registration Authority

Protocol by Curtis et al.[C07]: Registration [POST'13]

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Bidder

Registration Authority

, h(), 

Protocol by Curtis et al.[C07]: Registration [POST'13]

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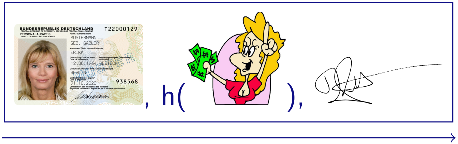
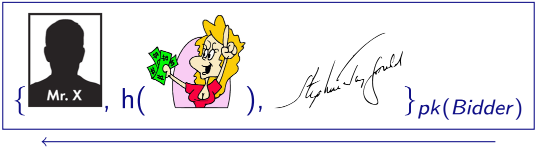
Bidder | Registration Authority





Bidding [POST'13]

The bidder uses his pseudonym to submit his bids.

Bidder

Registration Authority

Bidding [POST'13]

The bidder uses his pseudonym to submit his bids.

Bidder

Registration Authority

, {

}$_{pk(Auctioneer)}$,

Bidding [POST'13]

The bidder uses his pseudonym to submit his bids.

Bidder → Registration Authority

, {  }$_{pk(Auctioneer)}$, 

→

{  }$_{pk(Auctioneer)}$, 

←

Bidding Cont'd [POST'13]

The Registration Authority forwards the bids to the auctioneer, encrypted using a symmetric key k, which is revealed at the end.

Registration Authority

Auctioneer

Bidding Cont'd [POST'13]

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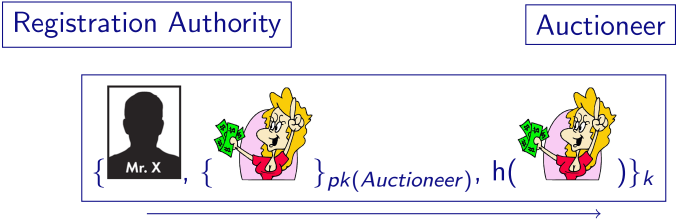

Bidding Cont'd [POST'13]

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Registration Authority → Auctioneer

{

, {$\}_{pk(Auctioneer)}$, h($)\}_k$

k, n

Completion [POST'13]

The auctioneer decrypts the bids using k and his secret key $sk(Auctioneer)$, and announces the winning pseudonym.

Registration Authority

Auctioneer

Completion [POST'13]

The auctioneer decrypts the bids using k and his secret key $sk(Auctioneer)$, and announces the winning pseudonym.

Analysis [POST'13]

Formal analysis using ProVerif:

- **Non-Repudiation:** ✗ attack, the messages from the RA to the auctioneer are not authenticated - anybody can impersonate the RA
- **Non-Cancellation:** ✗ same attack
- **Highest Price Wins:** ✗ same attack
- **Weak Noninterference:** (✓) OK if first message (hash of bid) is encrypted.
- **Privacy:** (✓) Weak Anonymity if first message is encrypted and synchronization is added

 Motivation: Three different perspectives [ASIACCS'13]

- A losing bidder:

- A winning bidder:

- The seller:

Registration and Integrity Verifiability [ASIACCS'13]

- Origination of all 

 and  ($rv_{submitted}$)
- Integrity of 

 and  (rv_w)

 The losing bidder verifies that he actually lost [ASIACCS'13]

- 

¡  (ov_l)

The winning bidder checks [ASIACCS'13]

- Correction of the computation of  i.e.

  $myBid =$  (ov_w)

The seller verifies [ASIACCS'13]

- b_{win} = 
- Correction of the computation of  (os_w)

Verification Test [ASIACCS'13]

Definition (Verification Test)

Efficient terminating algorithm: Data $\rightarrow$ Bool

- Input : data visible to a participant
- Output : Boolean value.

The protocol model [ASIACCS'13]

Definition (Auction protocol)

($\mathcal{B}$, S, $\mathbb{L}$, *getPrice*, *isReg*, *win*, *winBid*) where

- $\mathcal{B}$ is the set of bidders and S is the seller,
- $\mathbb{L}$ is a list of all submitted bids,
- $getPrice\colon EBid \mapsto Bid$
- $isReg\colon EBid \mapsto Bool$
- $win\colon List(Bid) \mapsto Index$
- *winBid* is a variable of the index of the winning bid at the end.

Verifiability for First-Price Auctions [ASIACCS'13]

Definition (Verifiability - 1st-Price Auctions)

($\mathcal{B}$, S, $\mathbb{L}$, *getPrice*, *isReg*, *win*, *winBid*) ensures *Verifiability* if the following Verification Tests rv_s, rv_w, ov_l, ov_w, ov_s are sound:

1. **Registration and Integrity Verifiability (RV)**:
   - $rv_s = true \rightarrow \forall b \in \mathbb{L}$: $isReg(b) = true$
   - $rv_w = true \rightarrow winBid \in Indices(\mathbb{L})$
2. **Outcome Verifiability (OV)**:
   - $ov_l = true \rightarrow myBid \neq win(getPrice(\mathbb{L}))$
   - $ov_w = true \rightarrow myBid = win(getPrice(\mathbb{L}))$
   - $ov_s = true \rightarrow winBid = win(getPrice(\mathbb{L}))$

And complete:

- If all participants follow the protocol correctly, the above tests succeed ($\Longleftarrow$).

Simple Example [ASIACCS'13]

1. All bidders publish their bids on a bulletin board[1].
2. At the end the auctioneer announces the winner.

Verification tests:

- ov_l, ov_w & ov_s: everybody can compute the winner on the public list of unencrypted bids
- rv_w: anyone can test if the winning bid is published
- rv_s: no sound test possible.

[1] not encrypted and not signed

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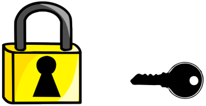
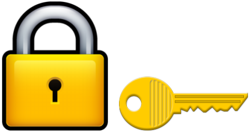
Verification tests:

- ov_l, ov_w & ov_s: everybody can compute the winner on the public list of unencrypted bids
- rv_w: anyone can test if the winning bid is published
- rv_s: no sound test possible. Solution: add signatures

[1] not encrypted and not signed

Protocol by Sako [S00][ASIACCS’13]

Each price corresponds to a pair of public and private keys.

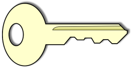
- Price 10 €: 
- Price 5 €: 
- Price 1 €: 

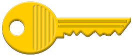
Set up [ASIACCS'13]

A public constant c

Bulletin Board

Authorities





Bidding Phase [ASIACCS'13]

Select a Price

- For 5 €:

- For 1 €:

Bidding Cont'd [ASIACCS'13]

The signed bids are published on the bulletin board:

Bid Opening [ASIACCS'13]

1. The signatures are checked.

Bid Opening [ASIACCS'13]

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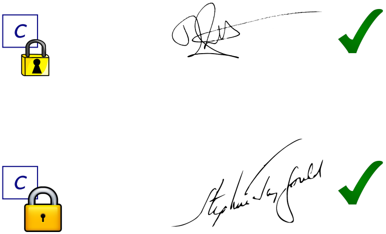
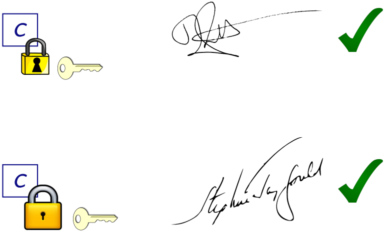


Bid Opening [ASIACCS'13]

1. The signatures are checked.
2. The bids are decrypted using the first private key.



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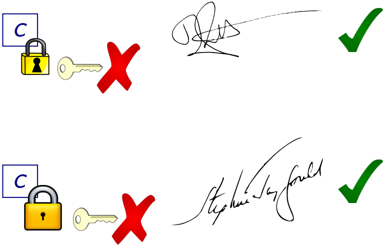

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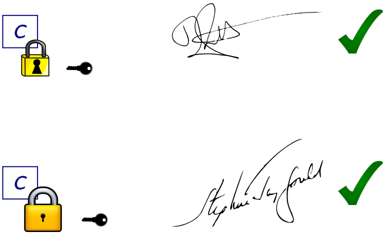

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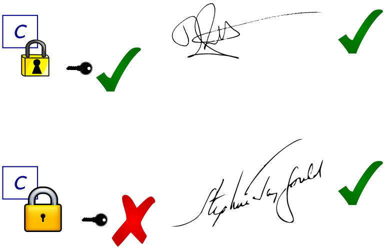

Registration Verification [ASIACCS'13]

1. rv_s: Anybody can verify the signatures.

2. rv_w: Anybody can check if the announced winning bid was published on the bulletin board.

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Outcome Verification (ov_l,ov_w,ov_s) [ASIACCS'13]

1. The authorities publish the used private keys, here keys 1  and 2 .
2. To verify the result, the parties check if the private keys correspond to the public keys:

3. They repeat the same decryptions as the authorities.

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3. They repeat the same decryptions as the authorities.

Analysis [ASIACCS'13]

The verification tests are sound and complete, proof using ProVerif and CryptoVerif.
Necessary hypotheses (CryptoVerif):

- A UF-CMA signature scheme
- A correct encryption scheme with the following properties:
  - A function `pkey` that computes the public key given the secret key.
  - Either of two private keys giving the same public key can be used to decrypt correctly.

Plan

Bitcoin : monnaie électronique

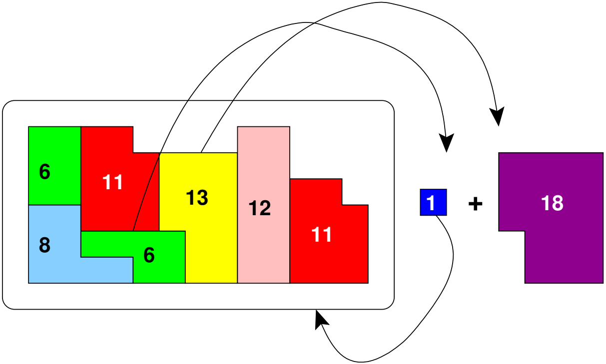
Créée en 2008 par Satoshi Nakamoto (1 BTC $\approx$ 945 euros)

1	BTC = 1 Bitcoin	
0,01	BTC = 1 cBTC	= 1 centiBitcoin (ou bitcent)
0,001	BTC = 1 mBTC	= 1 milliBitcoin
0,000 001	BTC = 1 μBTC	= 1 microBitcoin
0,000 000 01	BTC = 1 Satoshi	

Taux de change du bitcoin

Payer 18 BTC avec des pièces

Nous acceptons
Les **bitcoins**



Clef symétrique

Exemples

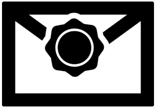
- DES
- AES

Chiffrement à clef publique

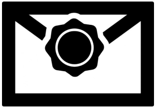
Exemples

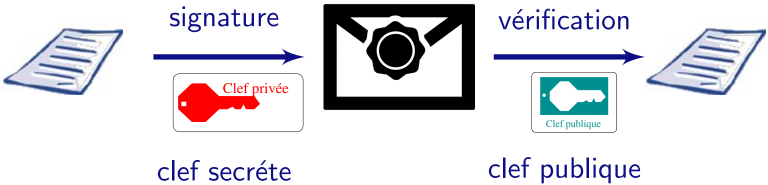
- RSA : $c = m^e \mod n$
- ElGamal : $c \equiv (g^r, h^r \cdot m)$

Signature



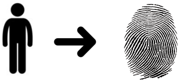
Signature





RSA: $m^d \mod n$

Fonction de Hachage (RIPEMD-160, SHA-256, SHA-3)



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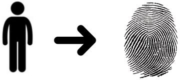
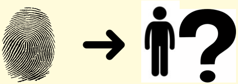


Propriétés de résitance

- Pré-image



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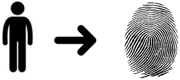

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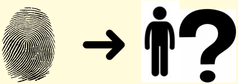
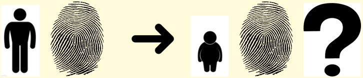


- Seconde Pré-image



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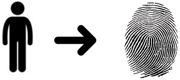

Propriétés de résitance

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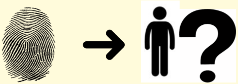

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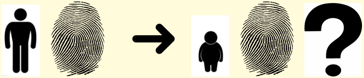


- Collision

Propriétés d'une monnaie électronique

- Non-Falsifiable (Unforgeable)

- Eviter la double dépense & identifiation fraudeur & "présemption d'innocence"

- Respect de la vie privée :
  - Anonymat faible : non identification d'un acheteur
  - Anonymat fort : non traçabilité d'un acheteur

Bitcoins : caractéristiques

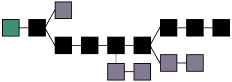
- Le nombre total de bitcoins est **fini**

21 millions BTC

- Les transactions utilisent des **PKI**
- Numéro de compte :

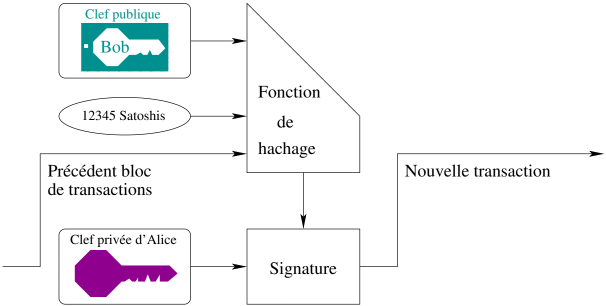
$$\text{RIPEMD-160}(\text{SHA-256}(\text{ECDSA}_{pub}))$$

- Toutes les transactions sont **publiques**
- **Blockchain** : un système pair-à-pair qui garantit la validité des transactions

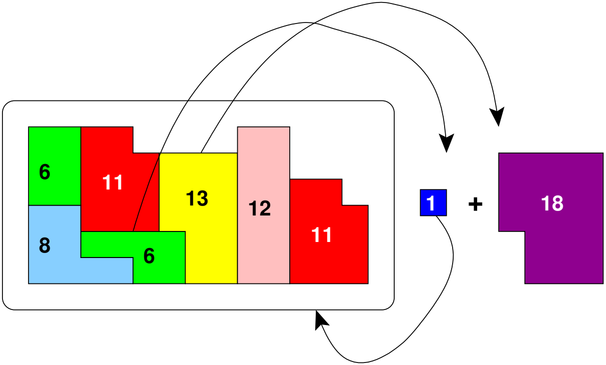


Comment faire une transaction?

Alice donne 12345 Satochis ($\approx 5c$) à Bob.



Payer 18 BTC avec des pièces

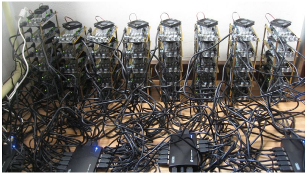


- Seuls des bitcoins possédés peuvent être dépensés

Miner des Bitcoins

Miner des Bitcoins

Les "*mineurs*" valident les transactions contre des bitcoins



Miner des Bitcoins

- Valider = résoudre un **objectif de hachage**
- Récompense initiale 50 BTC pour une validation
- Divisée par 2 tous les 210000 validations

$$\sum_{i=0}^{32} \frac{50}{2^i} \times 210\,000 = 21 \text{ millions BTC}$$

Miner : Objectif de hachage

Cible = 00000000000000000254845fa930deac4086b3e3bce21147e93f463b206d8076

Trouver une nombre n tel que

$$\text{SHA-256}(\text{SHA-256}(\text{Transactions}, n)) = x < Cible$$

Avoir un 0 plus de au début de x

Miner : Objectif de hachage

Cible = 00000000000000000254845fa930deac4086b3e3bce21147e93f463b206d8076

Trouver une nombre n tel que

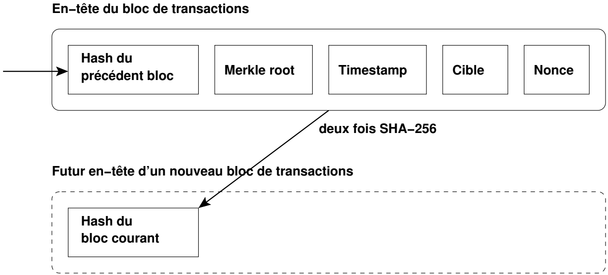
$$\text{SHA-256}(\text{SHA-256}(\text{Transactions}, n)) = x < \mathit{Cible}$$

Avoir un 0 plus de au début de x

Stratégie : brute force

Tester toutes les valeurs possibles de n

Miner : Proof of work



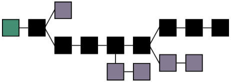
Avoir un zéro de plus au début

SHA-256(SHA-256(en-tête de bloc))

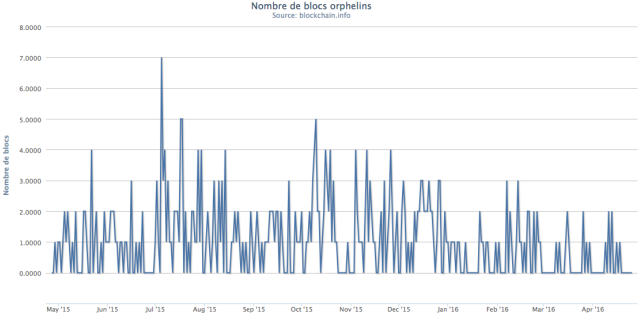
- les transactions passées (95 Go)
- les transactions à valider
- les secondes depuis 01/01/1970
- un nonce
- etc ...

Miner = Validation des transactions

Cible: 00000000000000000254845fa930deac4086b3e3bce21147e93f463b206d8076



- La chaîne la plus longue persiste (attaque 51 %)
- Validation toutes les 10 minutes (6 confirmations)



Autres crypto-monnaies

Classification des Altcoins

1. "Pourris coins"
2. Clônes de Bitcoin
3. Minage plus utiles, moins énergivores
4. Non-basés sur la preuve de travail
    - Proof of Stake (Peercoin)
    - Proof of Retreivability (Permacoin)
    - Proof of Capacity (Burstcoin)
    - Proof of Space (SpaceMint)

Bitcoin : Crypto-monnaie dématérialisée décentralisée

- Preuve de travail = Objectif de Hachage
- Création de la monnaie = récompense aux mineurs
- Miner = difficile + energivore



Bitcoin : Crypto-monnaie dématérialisée décentralisée

- Preuve de travail = Objectif de Hachage
- Création de la monnaie = récompense aux mineurs
- Miner = difficile + energivore

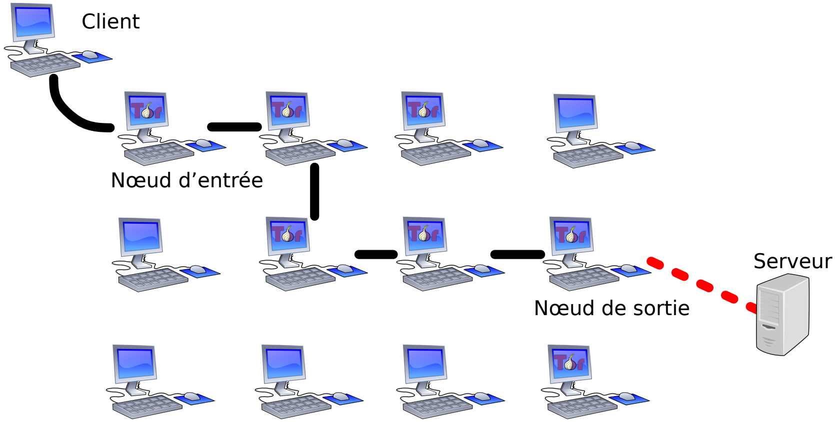


- Perte ou vol de la clef secrète = irréversible
- Monnaie anonyme et traçable



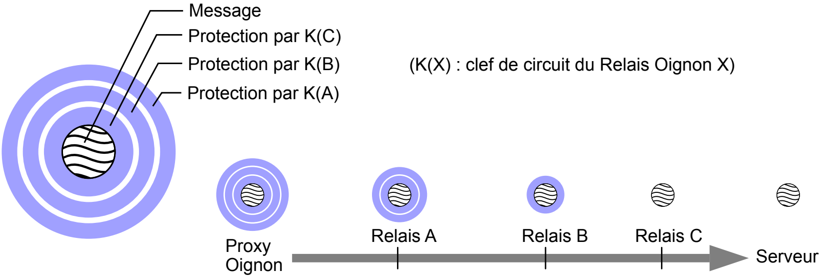
Plan

Application : The Onion Router (TOR)



https://www.torproject.org

Application : Tor



Plan

Merci pour votre attention.

Questions ?