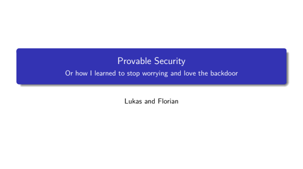
Provable Security

Or how I learned to stop worrying and love the backdoor

Lukas and Florian

2018-12-29

Provable Security


Provable Security
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- Thank you for waking up that early
- It's a great honor for us to give this talk, espessialy in the slot directly after djb and Tanja Lange
- Two points before, which might not get clear during this talk:
  - we like provable security
  - Oded Goldreich is a great cryptographer, who did amazing things for the field of cryptography

1. Motivation
2. Proofs and Modells
3. The struggles of Hash Functions
4. Universal composability

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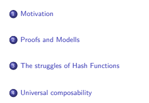
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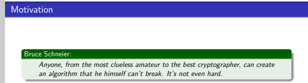
-
- Organisation of this talk:
  1. Motivation: Why do we want security **proven**
  2. Examples: What could get wrong and how to proof security of protocols
  3. 2 Examples Why modern crypto proofs are kind of weird

Motivation

Bruce Schneier:

> *Anyone, from the most clueless amateur to the best cryptographer, can create an algorithm that he himself can't break. It's not even hard.*



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- But you should be aware of the boundaries

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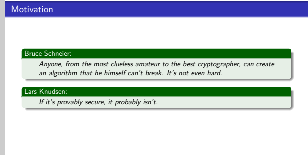

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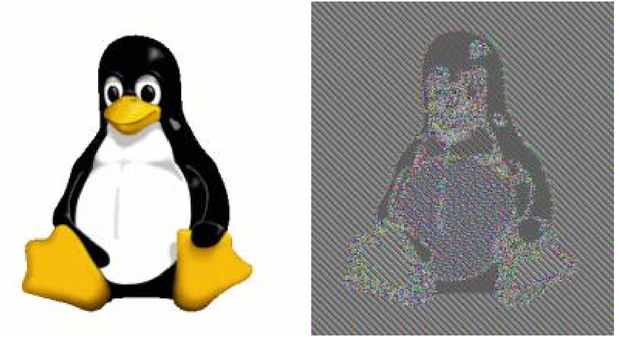
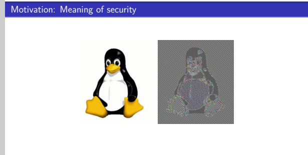
Motivation: Meaning of security

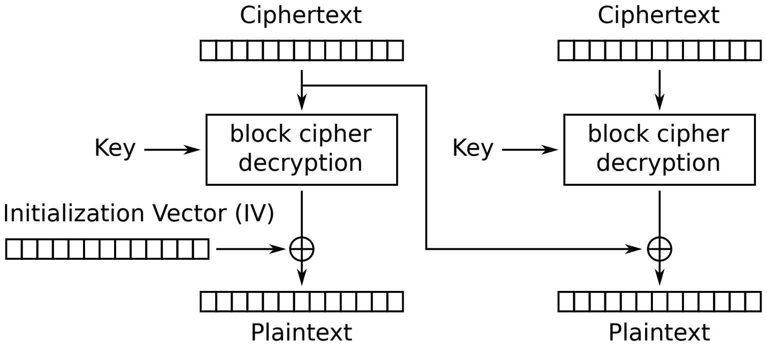


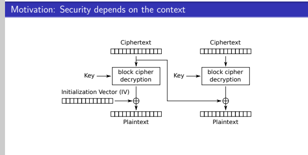


Motivation: Meaning of security

- most of you will know this example
- ECB (electronic codebook mode): mode for applying encryption defined on blocks of finite lenth to messages of arbitrary length
- each block (read: byte) is encypted in a secure way
- but deterministic
- Simply encypting each block is not a useful definition of security

Motivation: Security depends on the context




Motivation: Security depends on the context

- decryption of CBC (cipher block chaining) mode
- cipher is XORed on the output of the decryption
- deeper in the talk on TLS 1.3 by hanno

Excursus: Oracle

Oracles

- A protocol party
- takes well defined input
- answers with well defined output
- typicaly used to perform operations the “real” parties can’t

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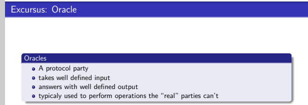
└Excursus: Oracle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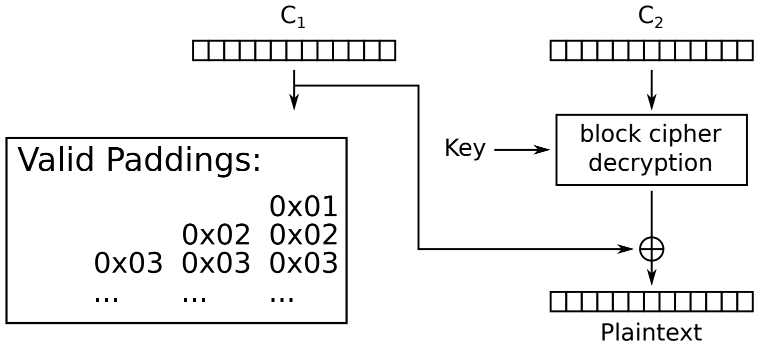
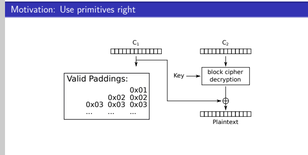
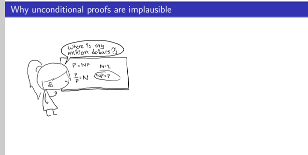



Motivation: Use primitives right

- CBC-Mode
- needs messages of specific lengths, i.e. a multiple of block size
- use padding
- excurse: Oracle
  - some magical instance
  - that takes input and
  - generates a specific Output
- Use Padding Oracle
- allows to break byte by byte
- Learn: Use your crypto right

Why unconditional proofs are implausible


Why unconditional proofs are implausible

- What is P vs. NP? **Millenium Problem**
- Asume that you have build up your protocol, so let's start to prove
- breaking a cipher should be hard, which mean it should be in $\mathcal{NP} \setminus \mathcal{P}$
- PAUSE
- recognising encryptions should be hard.
- if we proof this is difficulty, we would have a Problem in $\mathcal{NP} \setminus \mathcal{P}$
- so $\mathcal{NP} \neq \mathcal{P}$

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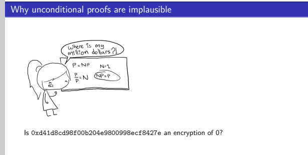
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How not to do it (RSA)

RSA

- Key-generation:
  - Public key: $n := p \times q,\ e := 3;\ p,\ q$ prime
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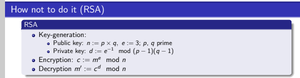

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RSA-Assumption

$\approx$ *It is impractical for a given public key to extract a randomly choosen plaintext from a ciphertext.*

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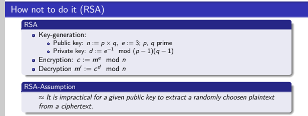

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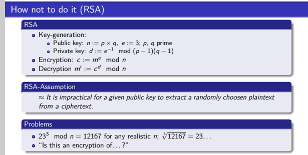
- $23^3 \mod n = 12167$ for any realistic n; $\sqrt[3]{12167} = 23\ldots$
- “Is this an encryption of…?”



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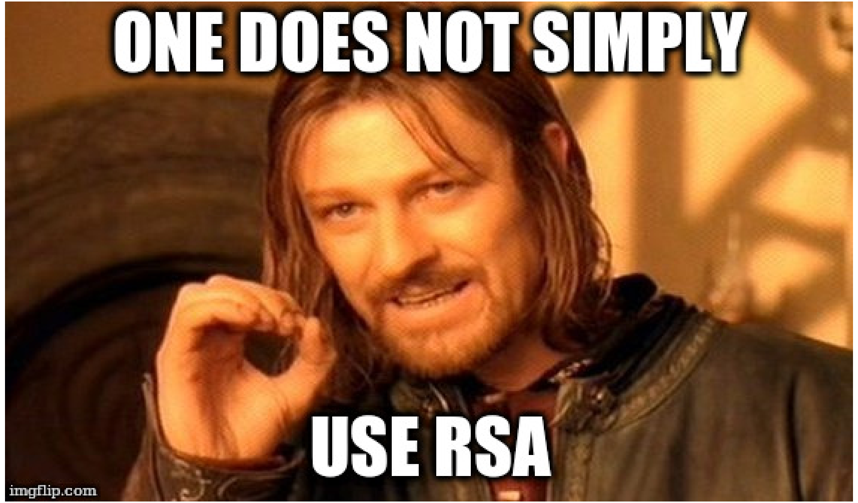

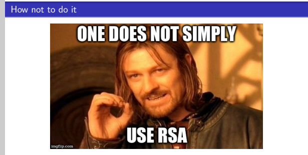
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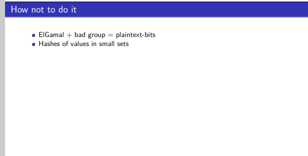
- ElGamal + bad group = plaintext-bits
- Hashes of values in small sets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Semantic Security and IND-CPA

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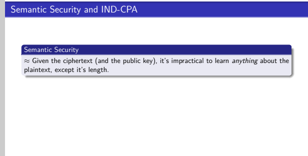

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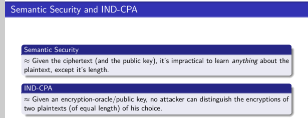
≈ Given an encryption-oracle/public key, no attacker can distinguish the encryptions of two plaintexts (of equal length) of his choice.



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Out-of-model-attacks

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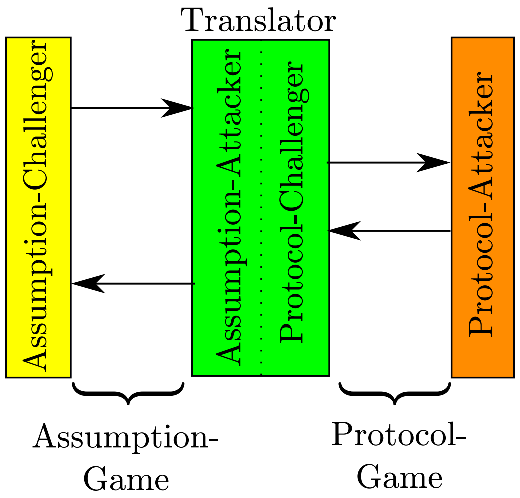
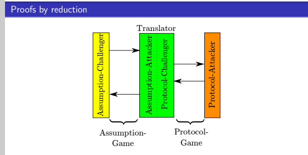
- We already mentioned Bleichenbacher
- There will be more. . .
- Side-channel-attacks
- Composition might give evil environments
- Often the hardest part in all of cryptography

Proofs by reduction




Proofs by reduction

- if we can give a translator, these assumptions contradict
- so either the assumption is wrong, or there is no adversary.

ElGamal

Prerequisites

- Let p, q be prime with $p = 2q + 1$ and $q > 2$
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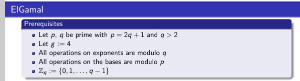
- $\mathbb{Z}_q := \{0, 1, \ldots, q - 1\}$



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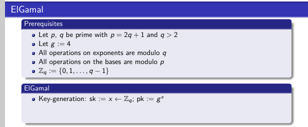

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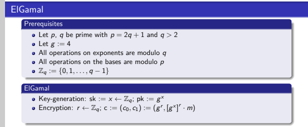

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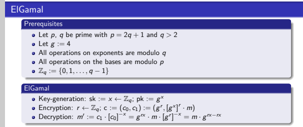

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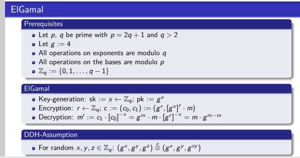
DDH-Assumption

- For random $x, y, z \in \mathbb{Z}_q$: $(g^x, g^y, g^z) \overset{c}{\equiv} (g^x, g^y, g^{xy})$



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Security-Proof of ElGamal

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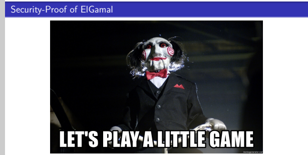
└─Proofs and Modells
└─Security-Proof of ElGamal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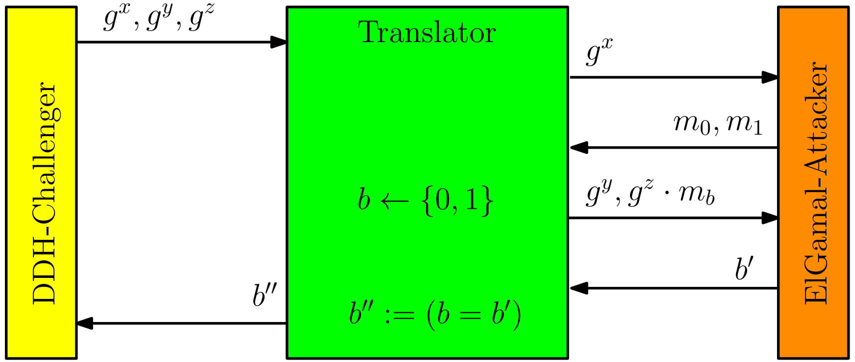

DDH-Challenger

Translator

ElGamal-Attacker

g^x, g^y, g^z

g^x

m_0, m_1

$b \leftarrow \{0,1\}$

$g^y, g^z \cdot m_b$

b'

b''

$b'' := (b = b')$

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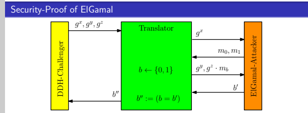
└Proofs and Modells

└Security-Proof of ElGamal



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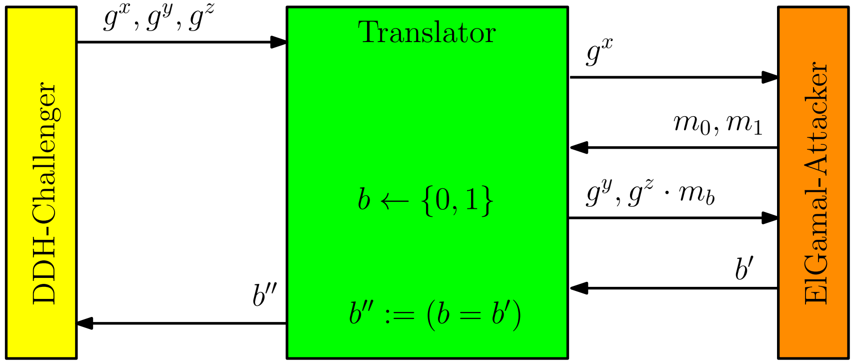

- Successrate of Attacker := $\frac{1}{2} + \epsilon$.
- If $xy = z$: perfect simulation, inherit $\frac{1}{2} + \epsilon$
- If $xy \neq z$: no correlation between c and m_b $\implies \frac{1}{2}$
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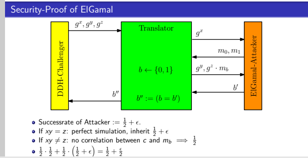
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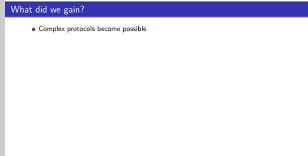
- Complex protocols become possible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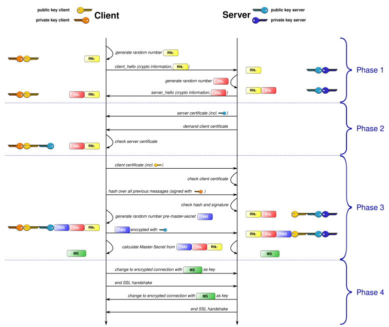
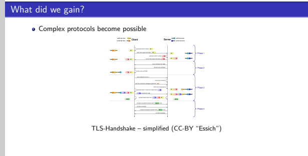

public key client
private key client
Client
Server
public key server
private key server
generate random number RNc
RNc
client_hello (crypto information, RNc)
generate random number RNs
server_hello (crypto information, RNs)
RNs RNc
Phase 1
server certificate (incl.)
demand client certificate
check server certificate
Phase 2
client certificate (incl.)
check client certificate
hash over all previous messages (signed with)
check hash and signature
generate random number pre-master-secret PMS
PMS encrypted with
calculate Master-Secret from PMS RNs RNc
MS
Phase 3
change to encrypted connection with MS as key
end SSL handshake
change to encrypted connection with MS as key
end SSL handshake
Phase 4

TLS-Handshake – simplified (CC-BY “Essich”)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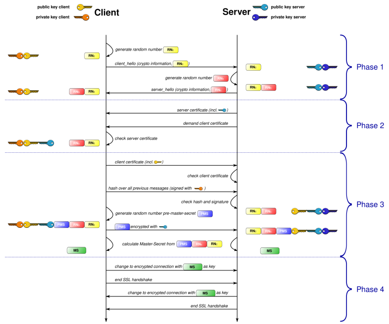
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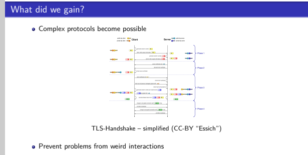
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Game-Based

- (Generally) easier proofs
- Often less intuitive meaning
- Does not scale

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- Proof that protocol can be simulated with output
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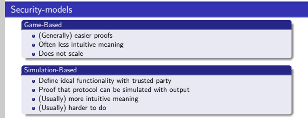

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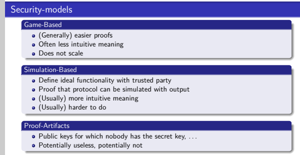
- Public keys for which nobody has the secret key, . . .
- Potentially useless, potentially not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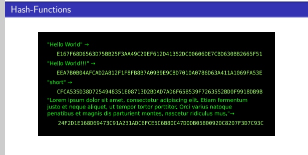
Hash-Functions

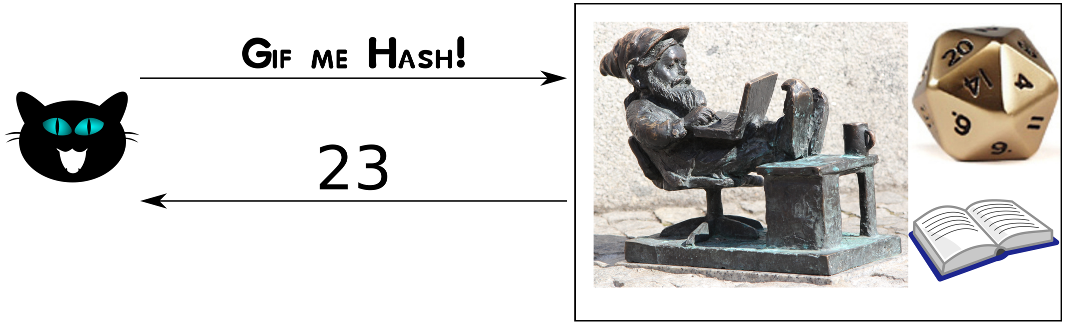
```
"Hello World" →
    E167F68D6563D75BB25F3AA49C29EF612D41352DC00606DE7CBD630BB2665F51
"Hello World!!!" →
    EEA7B0B04AFCAD2A812F1F8FB8B7A09B9E9C8D7010A0786D63A411A1069FA53E
"short" →
    CFCA535D38D7254948351E08713D2BDAD7AD6F65B539F7263552BD0F9918DB9B
"Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam fermentum
justo et neque aliquet, ut tempor tortor porttitor. Orci varius natoque
penatibus et magnis dis parturient montes, nascetur ridiculus mus."→
    24F2D1E168D69473C91A231ADC6FCE5C6B80C47D0DB05800920C8207F3D7C93C
```



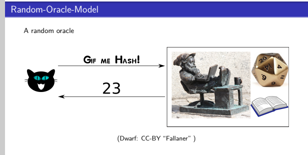
Used Hash-Function: SHA3-256

Random-Oracle-Model

A random oracle



(Dwarf: CC-BY "Fallaner")


Random-Oracle-Model
A random oracle
Gif me Hash!
23
(Dwarf: CC-BY "Fallaner")

- Hash functions are difficult to handle in proofs
- especially in an abstract way

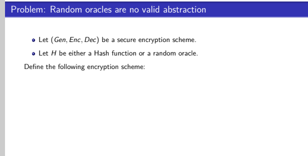
How a real Random oracle would look like:

- no one ever found a box with a dwarf
- those boxes would be difficult to handle
- ⇒ better use a hash function everyone can evaluate
- Problems:
  1. would be difficult to handle
  2. is not a valid abstraction

Problem: Random oracles are no valid abstraction

- Let (Gen, Enc, Dec) be a secure encryption scheme.
- Let H be either a Hash function or a random oracle.

Define the following encryption scheme:



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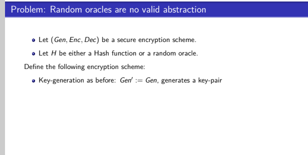

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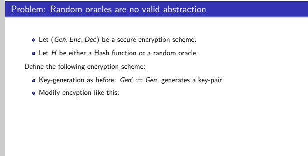

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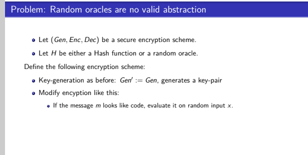

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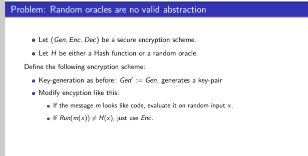

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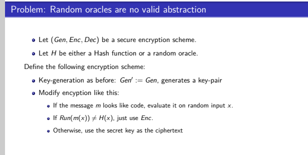

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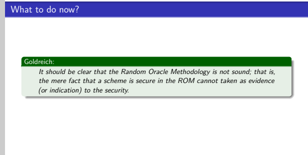
Goldreich:

> *It should be clear that the Random Oracle Methodology is not sound; that is, the mere fact that a scheme is secure in the ROM cannot taken as evidence (or indication) to the security.*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- authors came to harsh statements

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The Serpent of the Random Oracle Model

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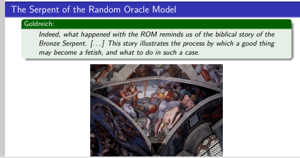

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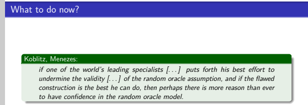
- spoiler alert: the snake had to be destroyed.
  - looking at the serpent healed snakebites; Hezekia destroyed it
- if you need to cite the bible as a cryptographer, you point may stand on feet of clay.

What to do now?

Koblitz, Menezes:

> *if one of the world's leading specialists [. . .] puts forth his best effort to undermine the validity [. . .] of the random oracle assumption, and if the flawed construction is the best he can do, then perhaps there is more reason than ever to have confidence in the random oracle model.*



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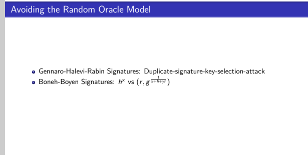
Avoiding the Random Oracle Model

- Gennaro-Halevi-Rabin Signatures: Duplicate-signature-key-selection-attack
- Boneh-Boyen Signatures: h^x vs $(r, g^{\frac{1}{x+h+yr}})$



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- For Gennaro-Halevi-Rabin Signatures it was shown that they have a strange Property: Duplicate-signature-key-selection-attacks.
- given a message and a signature, one can Calculate another key pair, such that the signature is valid for the same message under the new key
- Boneh-Boyen: Avoiding ROM made signatures twice as long and much more difficult to implement
- is this worth the effort?

Next:

- you might have noticed that we move more and more foreward into the beauty of proving-brain-fuck. For the next step I need to introduce another nice cryptographic tool called commitment schemes

A commitment scheme

Alice

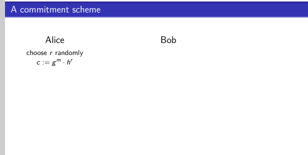
choose r randomly

$c := g^m \cdot h^r$

Bob

2018-12-29

Provable Security
└The struggles of Hash Functions
└A commitment scheme



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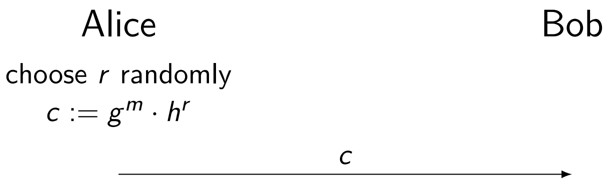

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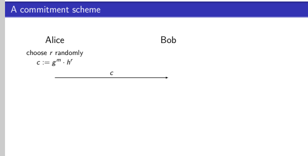
$\xrightarrow{c}$



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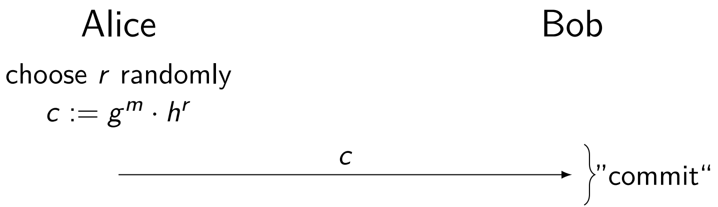

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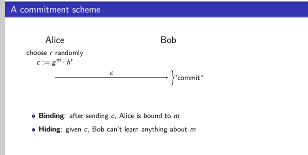
”commit“

- **Binding**: after sending c, Alice is bound to m
- **Hiding**: given c, Bob can't learn anything about m



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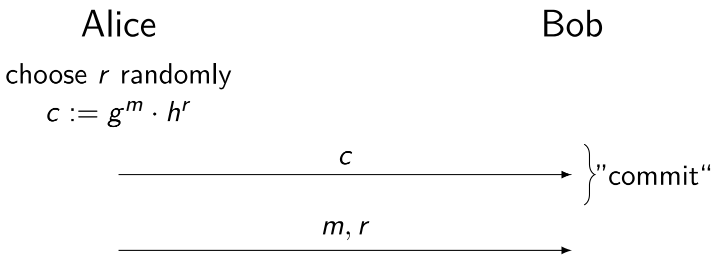

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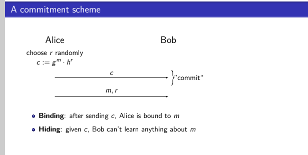

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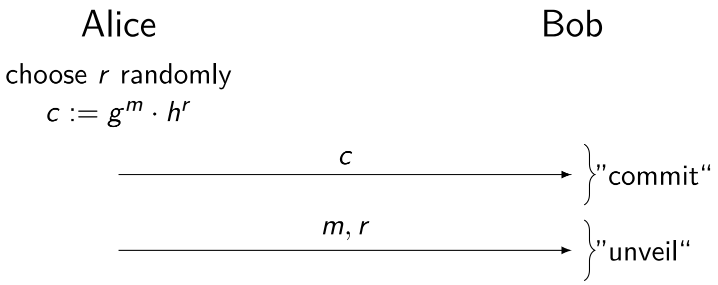

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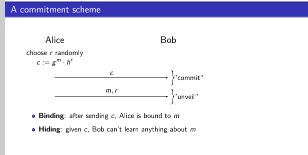

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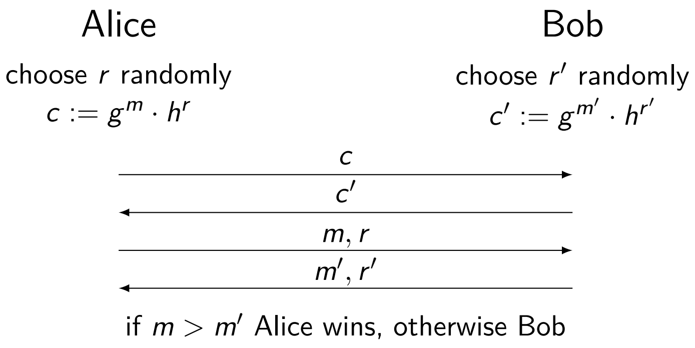

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choose r' randomly

$c' := g^{m'} \cdot h^{r'}$

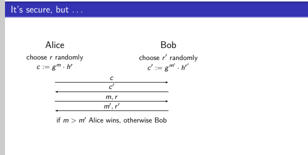
$\xrightarrow{c}$

$\xleftarrow{c'}$

$\xrightarrow{m, r}$

$\xleftarrow{m', r'}$

if $m > m'$ Alice wins, otherwise Bob



- auction szenario
- both parties commit on a price they want to pay
- higher value wins

Next:

- If Alice interacts with an evil party Mallory...

It's secure, but ...

Alice Mallory

choose r randomly

$c := g^m \cdot h^r$

$$\xrightarrow{\quad c \quad}$$

$$\xleftarrow{\quad c' := g \cdot c \quad}$$

$$\xrightarrow{\quad m, r \quad}$$

$$\xleftarrow{\quad m+1, r \quad}$$

Congratulations, Mallory

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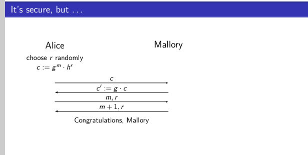
Provable Security

└The struggles of Hash Functions

└It's secure, but ...



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Composability

- Security definitions should contain *all* imaginable properties
- A protocol should be *secure*, regardless of the context.

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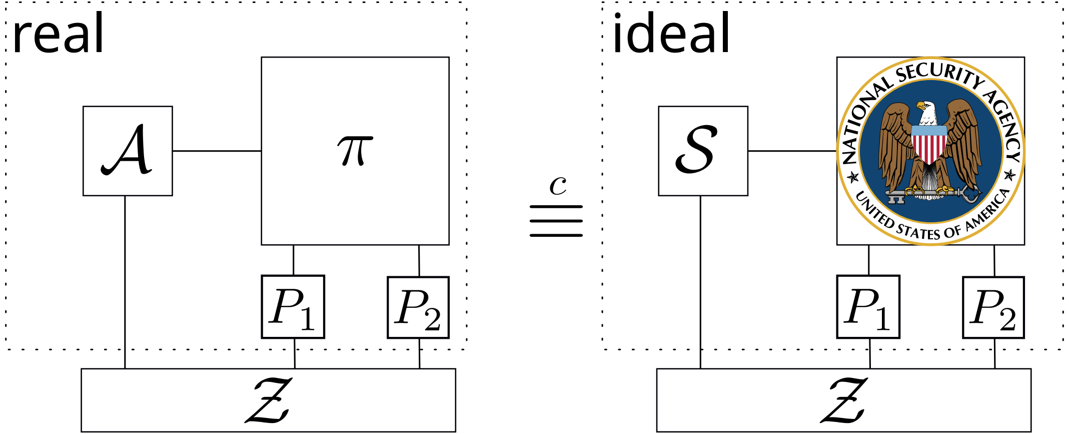
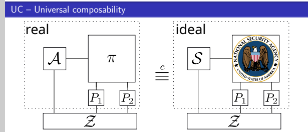
Composability

- Security definitions should contain *all* imaginable properties
- A protocol should be *secure*, regardless of the context.

There is a proving framework that offers this!

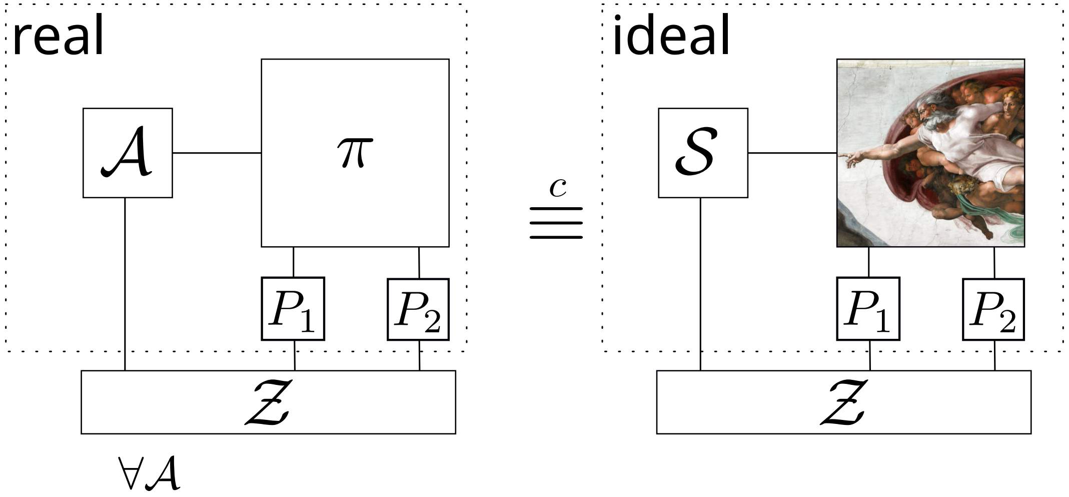
UC – Universal composability

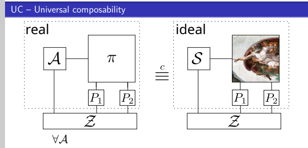




- Explain: F, Z, A, S

UC – Universal composability

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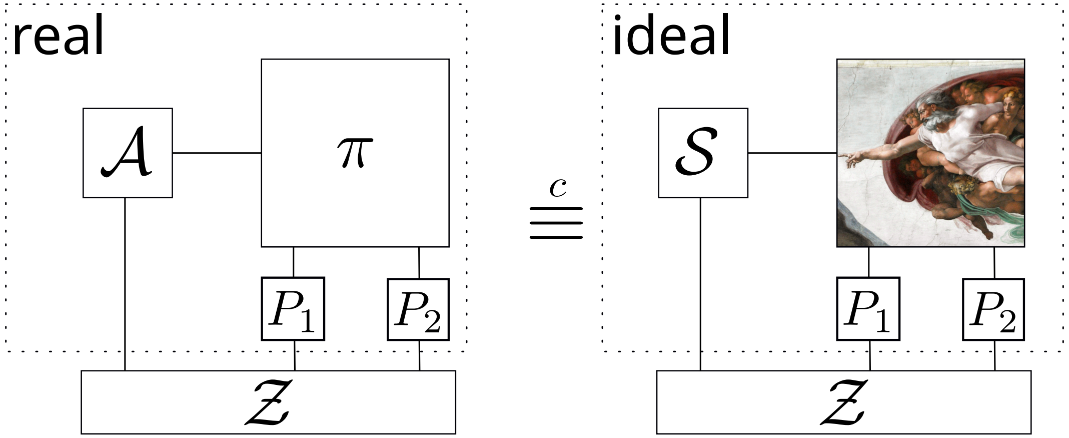
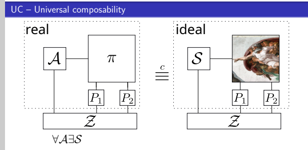


$\forall \mathcal{A} \exists \mathcal{S}$



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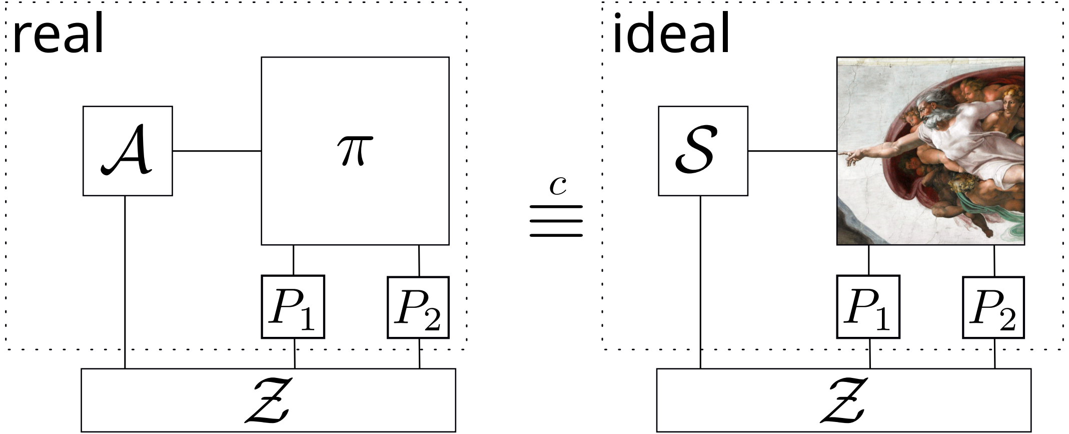
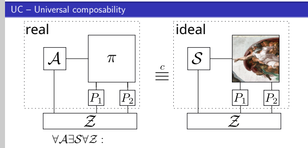


$\forall \mathcal{A} \exists \mathcal{S} \forall \mathcal{Z}$:



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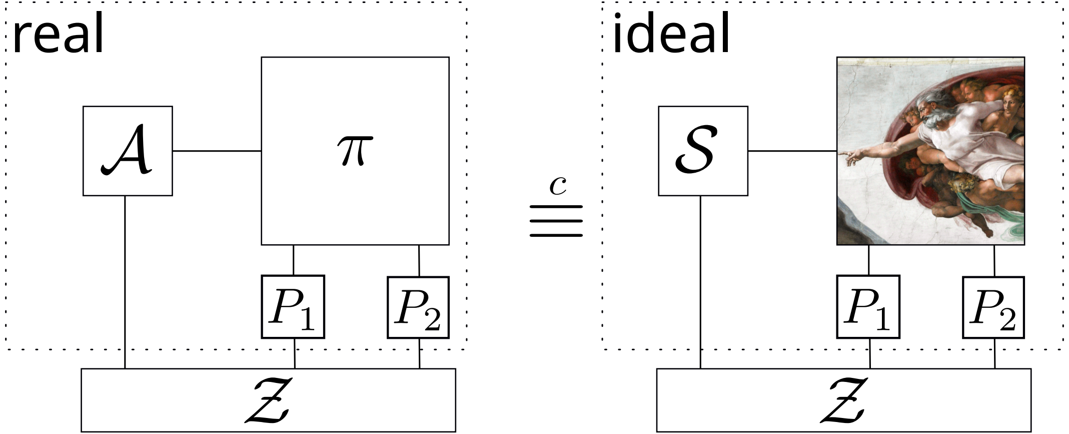
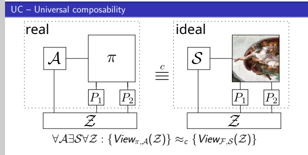


$$\forall \mathcal{A} \exists \mathcal{S} \forall \mathcal{Z} : \{View_{\pi,\mathcal{A}}(\mathcal{Z})\} \approx_c \{View_{\mathcal{F},\mathcal{S}}(\mathcal{Z})\}$$



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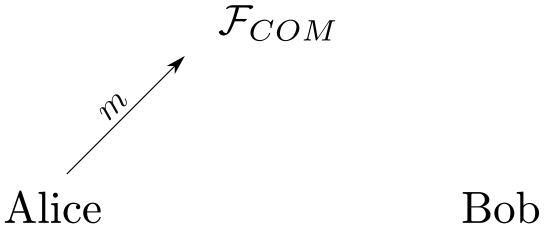
$\mathcal{F}_{Com}$



$\mathcal{F}_{COM}$

m

Alice

Bob

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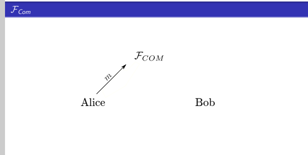
Provable Security

└Universal composability

└$\mathcal{F}_{Com}$



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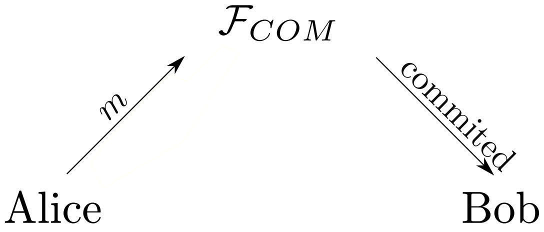
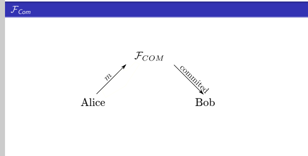
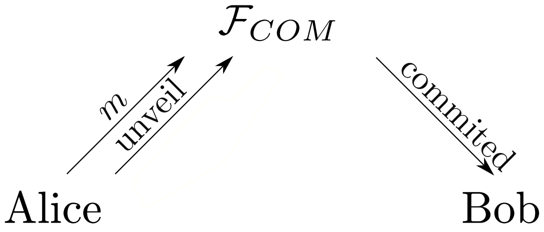



$\mathcal{F}_{Com}$
$\mathcal{F}_{COM}$
m
commited
Alice
Bob

$\mathcal{F}_{Com}$



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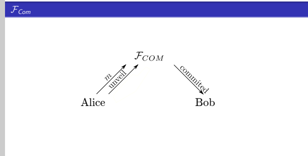
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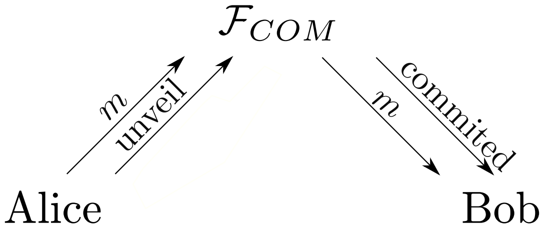


$\mathcal{F}_{COM}$

m

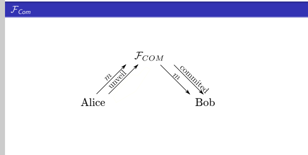
unveil

m

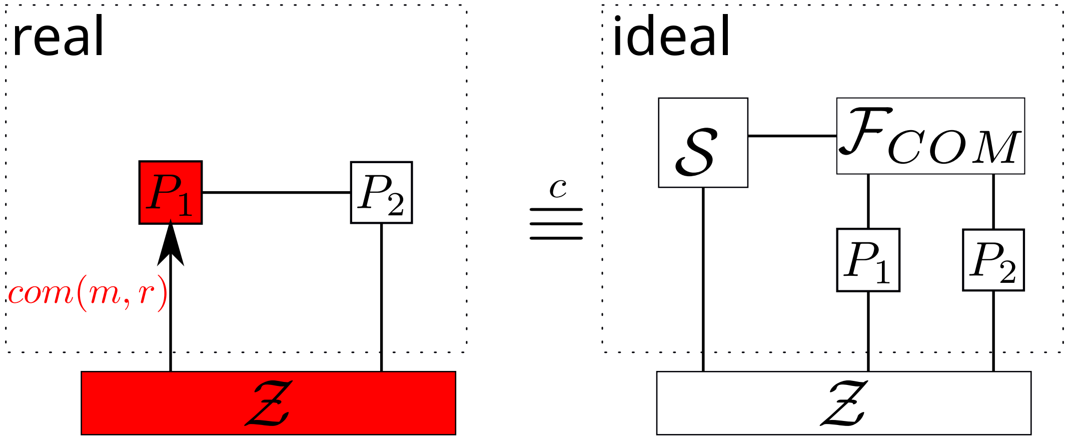
commited

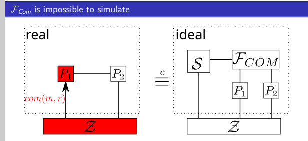
Alice

Bob



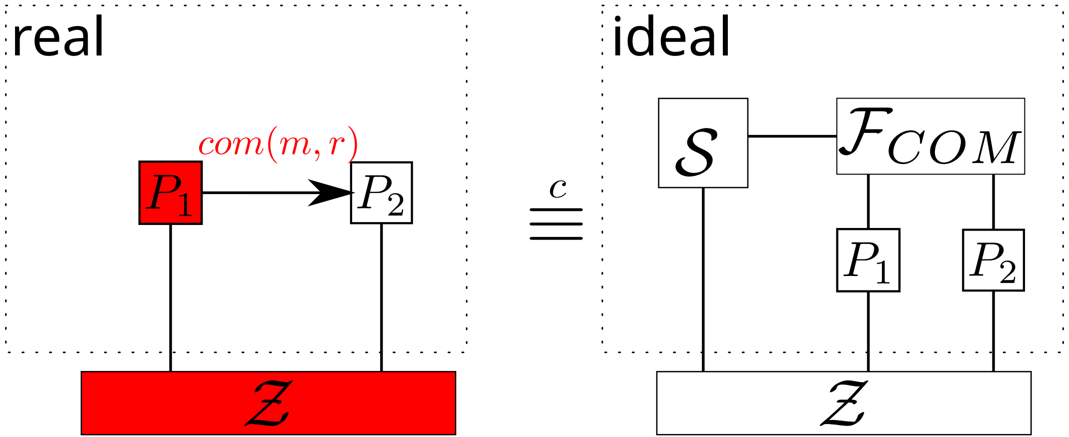
$\mathcal{F}_{Com}$ is impossible to simulate





- attacker and environment are working together
- simulator wants to mimic the atttacker such that Z can't distinguish

$\mathcal{F}_{Com}$ is impossible to simulate



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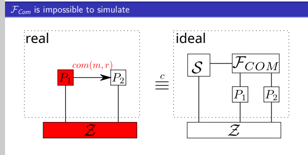

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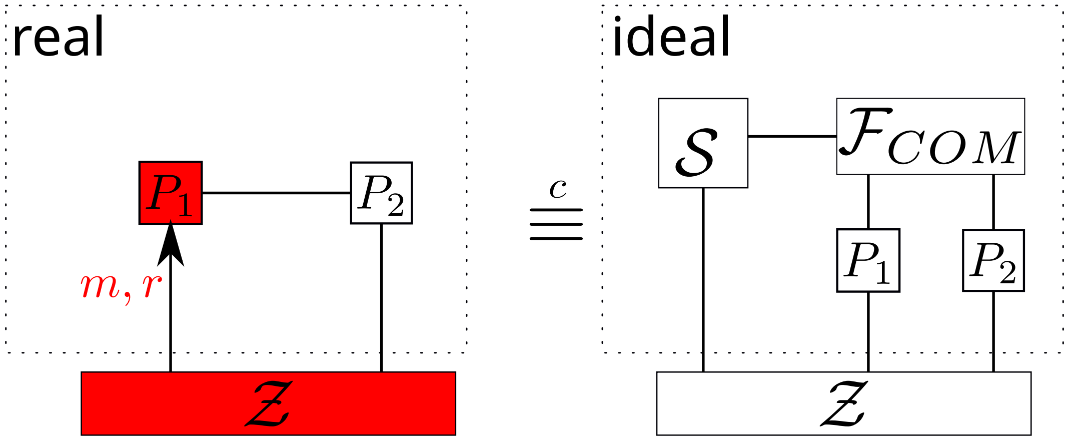

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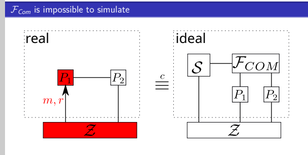
Provable Security

└Universal composability

└$\mathcal{F}_{Com}$ is impossible to simulate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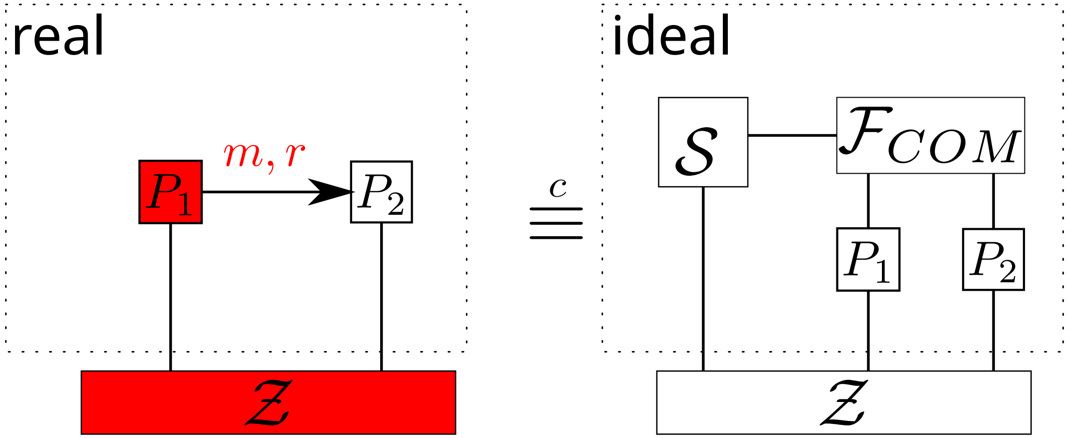

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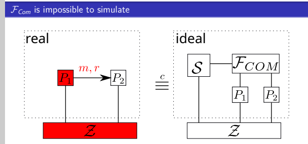

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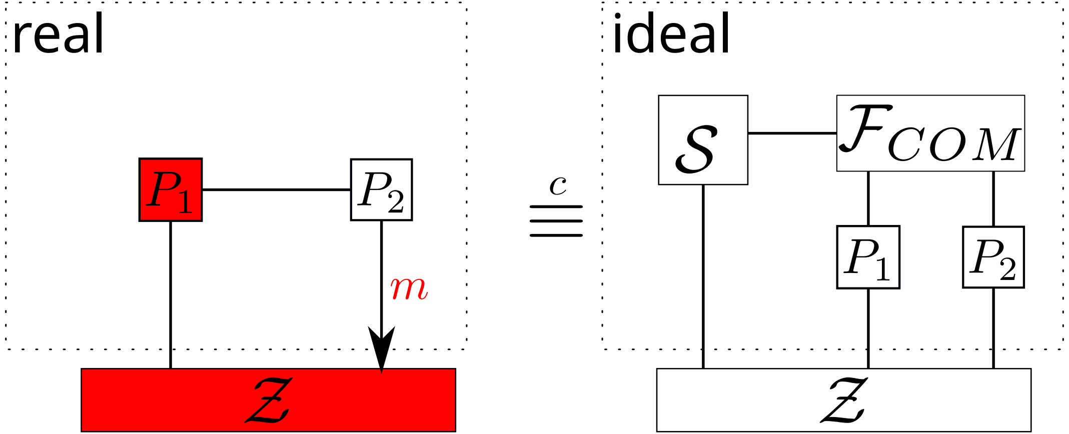

2018-12-29

Provable Security
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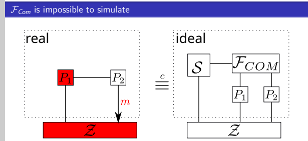
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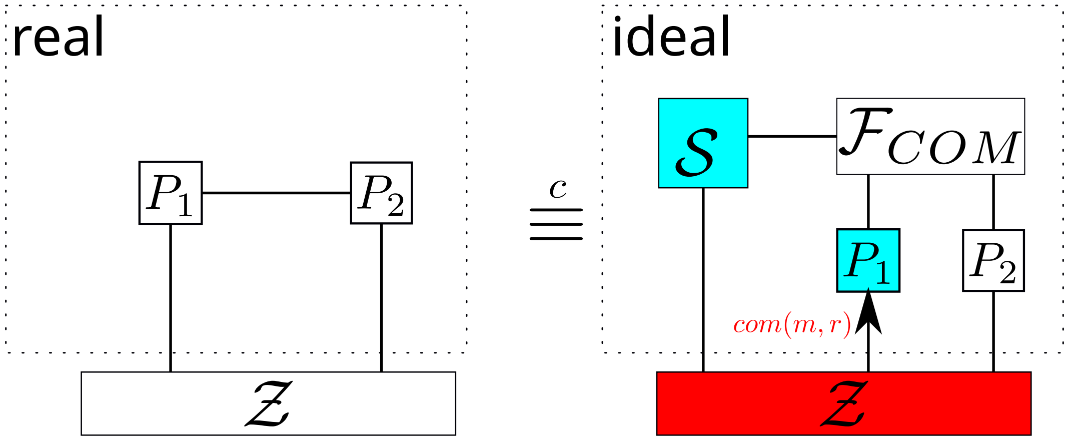

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Provable Security
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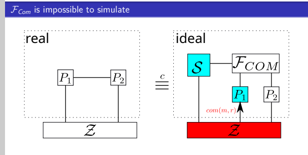

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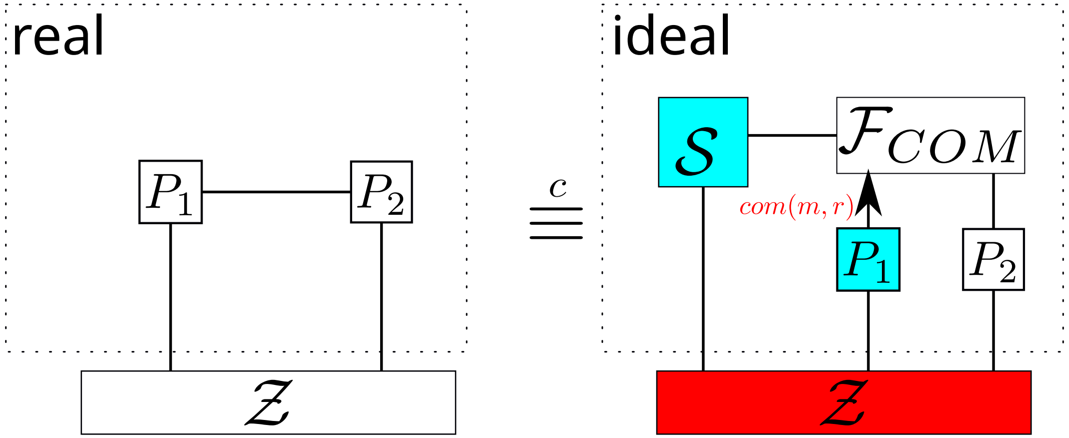

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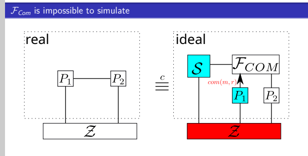

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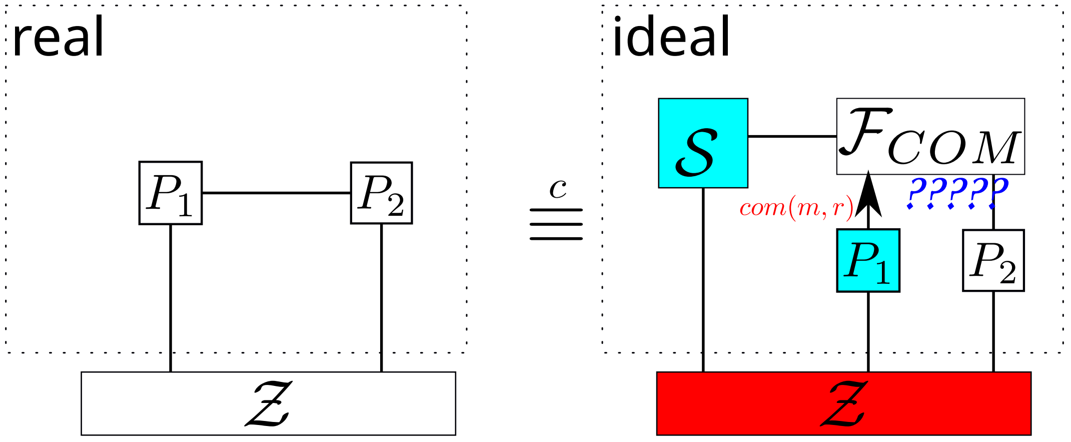
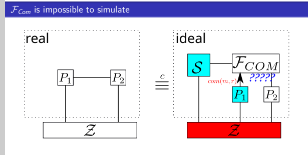
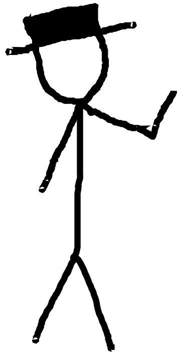




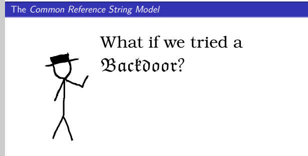
- Problem: $\mathcal{S}$ must provide a transcript
-
- A similar proof exists for the binding property.
-

⇒ No protocol can ever realize $\mathcal{F}_{Com}$.

The *Common Reference String Model*



What if we tried a Backdoor?



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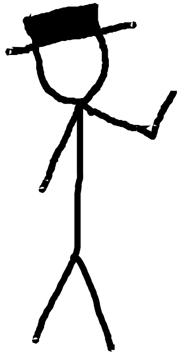

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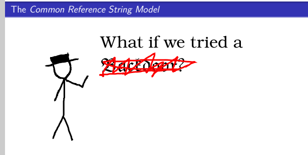

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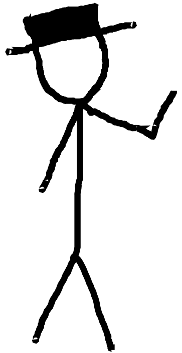

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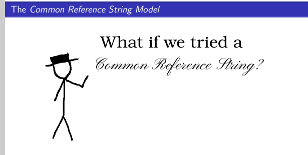

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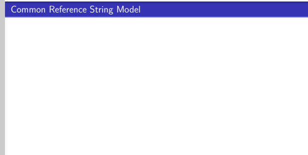
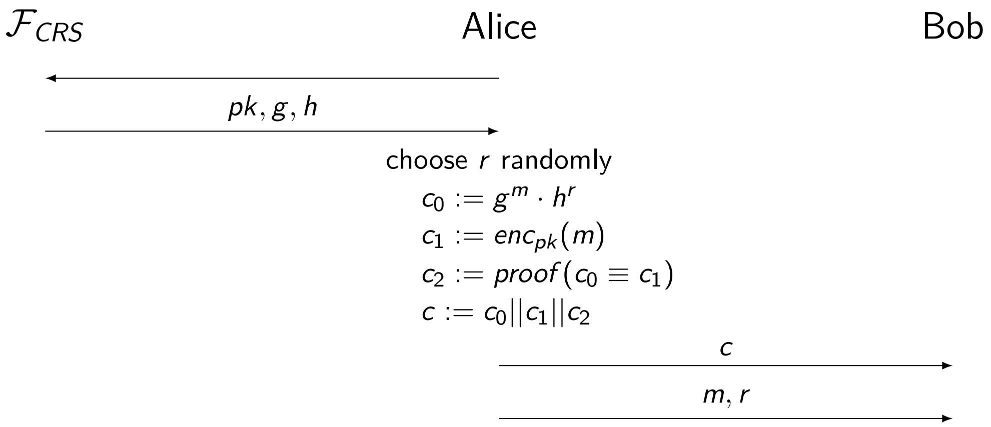


- Real: have a CRS
- Ideal: $\mathcal{S}$ simulates CRS

A *secure* Commitment Scheme



$\mathcal{F}_{CRS}$ Alice Bob

pk, g, h

choose r randomly

$c_0 := g^m \cdot h^r$

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$c_2 := proof(c_0 \equiv c_1)$

$c := c_0||c_1||c_2$

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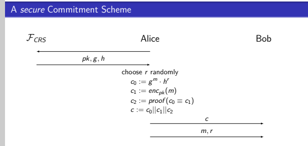
m, r

Provable Security
└Universal composability
└A *secure* Commitment Scheme



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Proof sketch

- $\mathcal{Z}$ needs to ask $\mathcal{A}$ (resp. $\mathcal{S}$) to get the public key.

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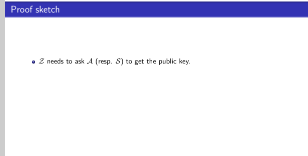
Provable Security
└Universal composability
└Proof sketch



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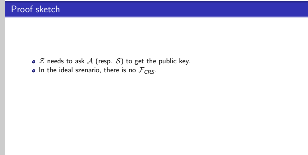

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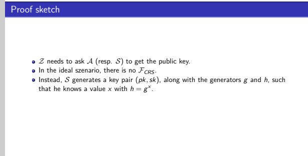

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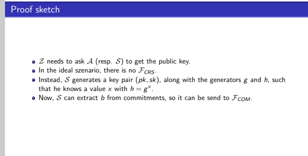

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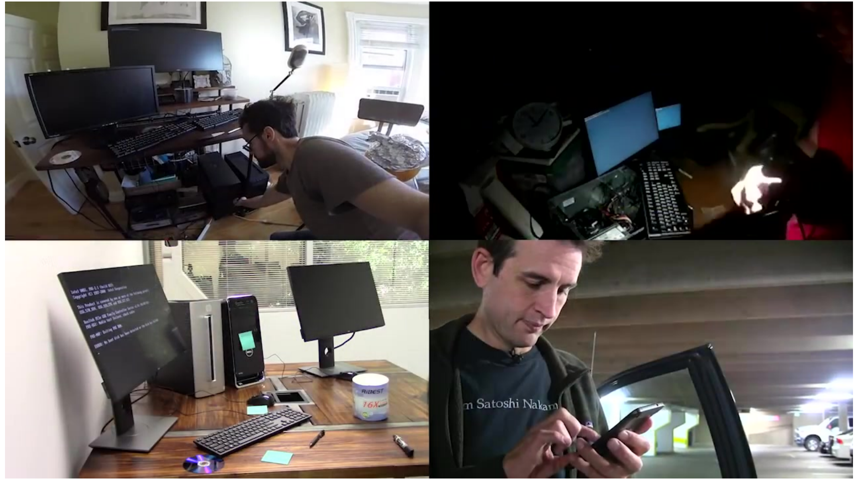
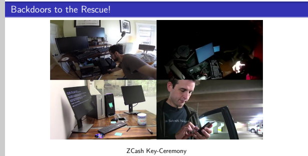
Backdoors to the Rescue!



ZCash Key-Ceremony


Backdoors to the Rescue!

ZCash Key-Ceremony

- ECDRBG (Elliptic Curve Deterministic Random Bit Generator) was only meant to provide extractability for UC-proofs, the NSA couldn't possibly have wanted to snoop

Too long, didn't watch

Rule #1

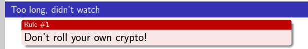
Don't roll your own crypto!

2018-12-29

Provable Security

└Universal composability

└Too long, didn't watch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- Good heuristics are better than nothing
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Questions?

Too long, didn't watch

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Questions?

Bonus-Slide: Security-Levels

Computational Security

- If Brute-Force is possible
- 128 Bit pre-quantum are fine

Statistical Security

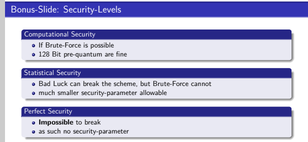
- Bad Luck can break the scheme, but Brute-Force cannot
- much smaller security-parameter allowable

Perfect Security

- **Impossible** to break
- as such no security-parameter

2018-12-29

Provable Security
└Universal composability
└Bonus-Slide: Security-Levels



Bonus-Slide: Security-Levels

Computational Security
- If Brute-Force is possible
- 128 Bit pre-quantum are fine

Statistical Security
- Bad Luck can break the scheme, but Brute-Force cannot
- much smaller security-parameter allowable

Perfect Security
- **Impossible** to break
- as such no security-parameter