Lecture 1: Course Overview

-COMP 6712 Advanced Security and Privacy

Haiyang Xue

haiyang.xue@polyu.edu.hk

2024/1/15

COMP 6712 Advanced Security and Privacy

- Hello
- It is the Second time this course is taught at PolyU.
- Last year, we have 16 students.
- I was expecting less students, but this year we have 45
- In the following 4 months, hope we will learn together….

Communication

- haiyang.xue@polyu.edu.hk find the instructor Haiyang XUE

- TA: Xun LIU, compxun.liu@connect.polyu.hk
- TA: Shenxing WEI, shenxing.wei@connect.polyu.hk

- Blackboard
  - We will use Blackboard for announcements
  - Use this to reach all course staff and students

- Zoom: the link and password posted in Blackboard

Course website

- https://haiyangxc.github.io/hyxue/teaching/comp6712-24.html
- Almost everything: syllabus, grading, final exam…
- I will continuously update slides/lecture notes/readings on the website

COMP6712 Advanced Security and Privacy
2023/24 Semester 2
Department of Computing, PolyU

General Information

- Venue: Y302
- Time: Monday, 18:30-21:20, week 1-13
- Instructor: Haiyang Xue, haiyang.xue@polyu.edu.hk
- TA:
  - xxx
  - xxx

Outline

This course will cover the most important features of security and privacy issues. The topics include network security, computer security and privacy-preserving computation (aka secure computation), and relevant knowledge cryptography and advanced privacy-enhancing technologies. A guest lecture on security and privacy in Blockchain is also included. Refer to the syllabus for details.

Updating Announcements

- Previous Course 2022/23-2

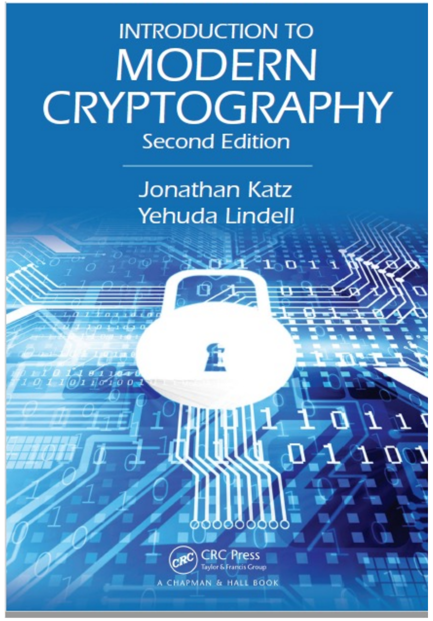
Syllabus

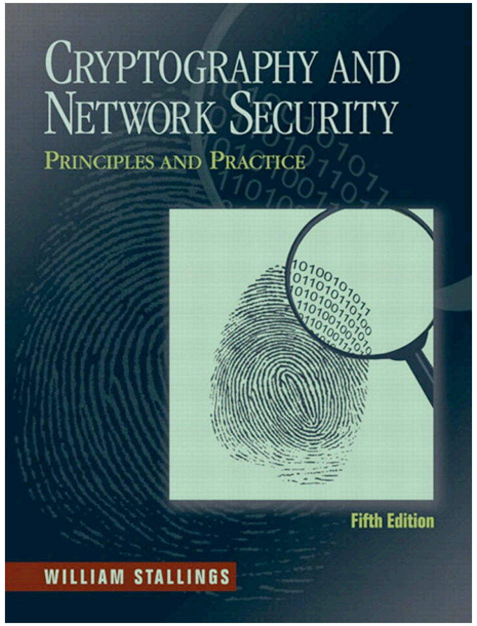
The syllabus [pdf] is subject to change, and I will continuously update it as the semester progresses.

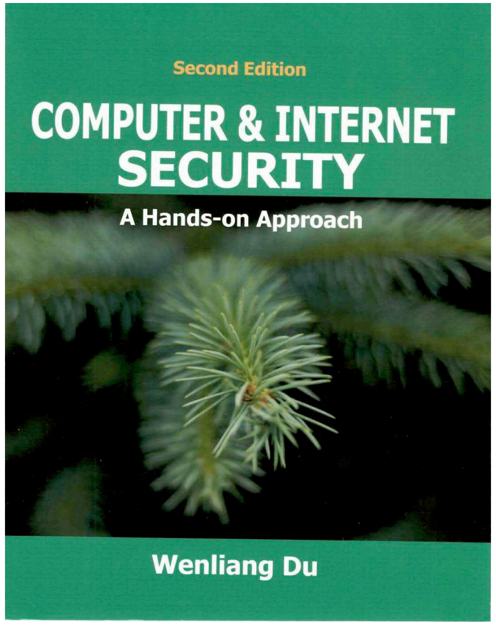
Date	Topics\slides	Outline	Readings	Lecture notes
Week 1: Jan 15	Course Overview [slides]	course plan, reading materials, grading, a brief introduction to every topic	[Sta] William Stallings, Cryptography and Network Security: Principles and Practice [Du] Wenliang Du, Computer Security: A Hands-on Approach [KPS] Charlie Kaufman, Radia Perlman, and Mike Speciner, Network Security: Private Communication in a Public World [KL] Jonathan Katz, and Yehuda Lindell, Introduction to Modern Cryptography	
Week 2: Jan 22	Basic Cryptography 1: Symmetric-key cryptography [slides]	symmetric encryption, one-time pad, blockcipher, hash function, MAC, authenticated encryption	[KL] Section 2-7 [Std] Chapter 3, 5, 6, 7, 11, 12 Goldreich, Foundation of Cryptography II, Section 5.3.1, 5.3.2, 5.3.3	Lecture 2 by Haiyang Xue

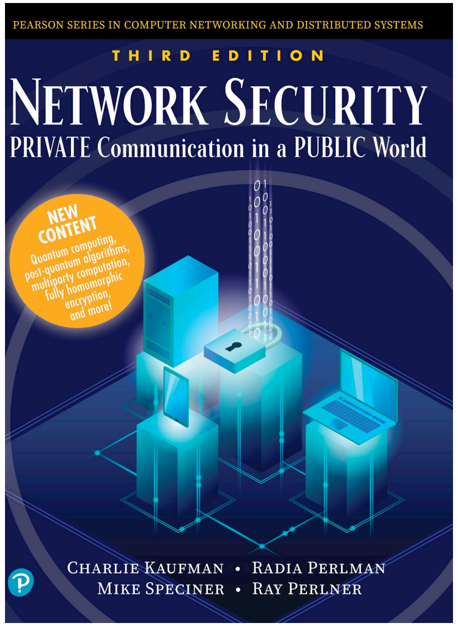
Course Materials: text books

- [KL] Jonathan Katz, and Yehuda Lindell, Introduction to Modern Cryptography
- [Sta] William Stallings, Cryptography and Network Security: Principles and Practice
- [Du] Wenliang Du, Computer Security: A Hands-on Approach
- [KPS] Charlie Kaufman, Radia Perlman, and Mike Speciner, Network Security: Private Communication in a Public World









Course Materials: lecture notes

- Google
  - Security and privacy + lecture notes or course or subject
  - Cybersecurity + lecture notes or course or subject
  - Computer security + …
  - cryptography+

- You may find
  - Jonathan Katz, Computer and Network Security
  - Ronald Rivest, Network and Computer Security
  - Etc.

Course Materials

- Some of my slides are also based on the lecture notes:
  - Jonathan Katz, Computer and Network Security
  - Yoshi Kohno, Computer Security
  - Dan Boneh and John Mitchell, Computer and Network Security
  - etc.…

- Thanks to Yoshi Kohno, Dan Boneh, Jonathan Katz, Håkon Jacobsen, and many others for sample slides and materials ...

- Please feel free to use and distribute my slides.

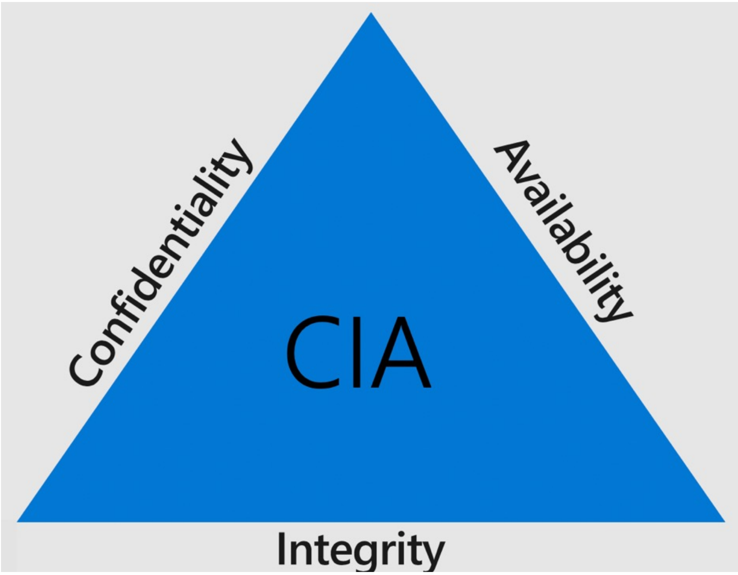
What is Security?

- System Correctness
  - Good input/behavior $\Rightarrow$ Desired output
  - It is better to have more features

- Security
  - Bad input/behaviors $\not\Rightarrow$ Bad output
  - Even attacker supplies unexpected input, system does not fail in certain ways
  - More features $\Rightarrow$ a higher chance of attacks

What is Security?

- Basic Goals (CIA)
  - **Confidentiality**: Information only available to authorized parties
  - **Integrity**: Information is precise, accurate, modified only in acceptable ways, consistent, meaningful, and usable
  - **Availability**: Services provide timely response, fair allocation of resources, quality of service



What is Security?

https://www.bicyclelaw.com/bicycle-safety/how-to-lock-your-bike/

What is Privacy?

- Generally, security concerns on protecting data from internal and external attackers,

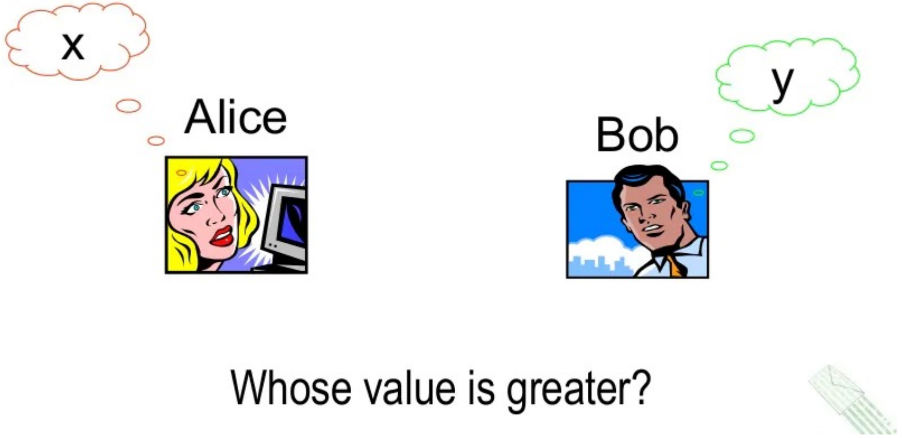
- While privacy focuses on the use and governance of (personal) data
  - Data is shared and used properly

https://www.varonis.com/blog/data-privacy

What is Privacy?

- Assume Alice is a millionaire; Bob is also rich

- Security
  - Who want to steal my money? And how
  - Who want to destroy my money? And how
  - How to protect the money?
- Privacy
  - They want to know who is richer,
  - but do not want to leak how much money they have (i.e., x, y)



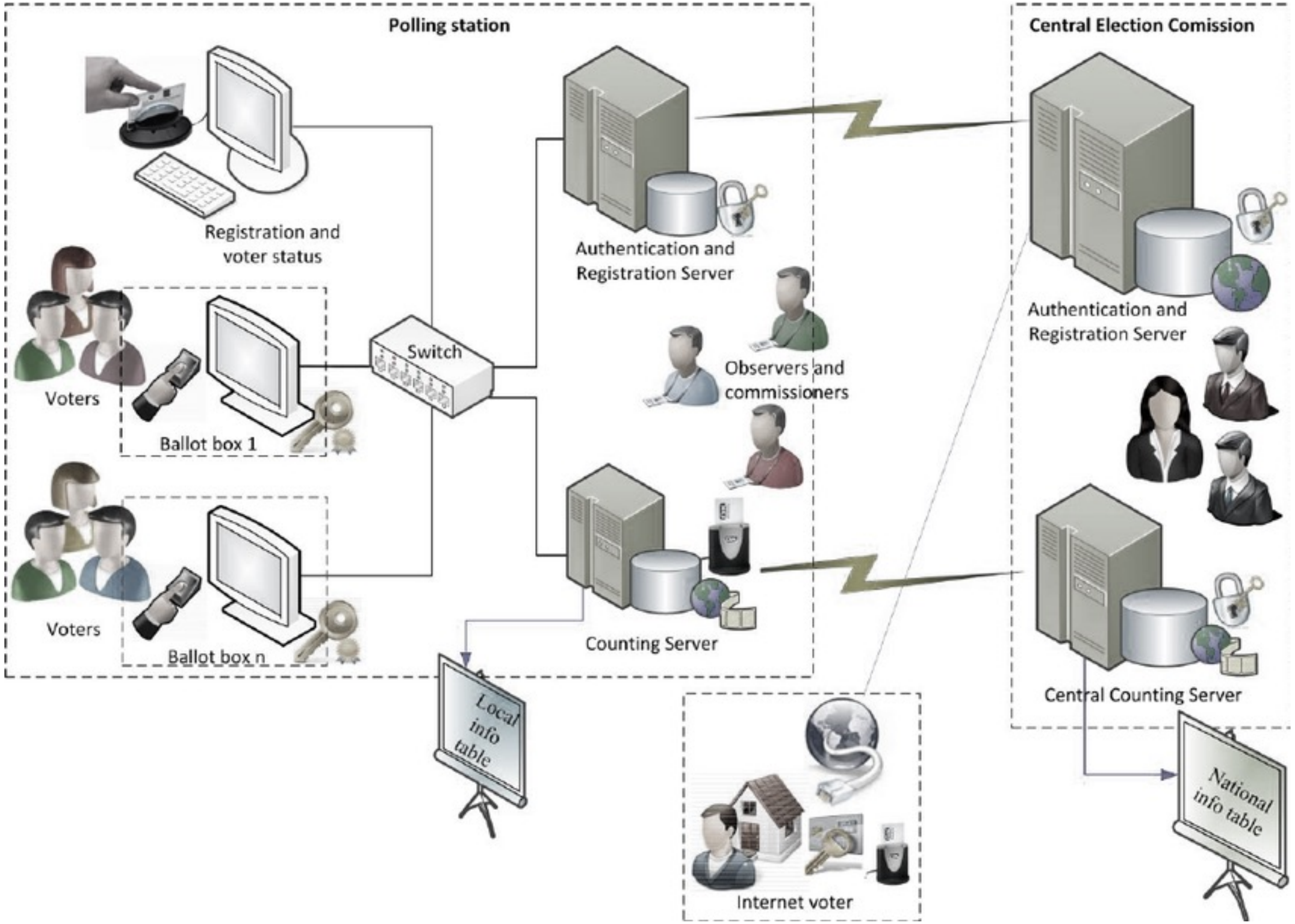
Security and Privacy

- Privacy and security are generally intertwined

- Security problem usually results in the leakage of data
  - Login in your Facebook, WeChat, WhatsApp account ---> (person info)
  - hack in your iphone ---> (private communication)
  - etc….

- Weakness of privacy may lead to efficient attacks
  - Face/fingerprint recognition ---> login iphone
  - Birthday, family number, ID ---> password of bank account

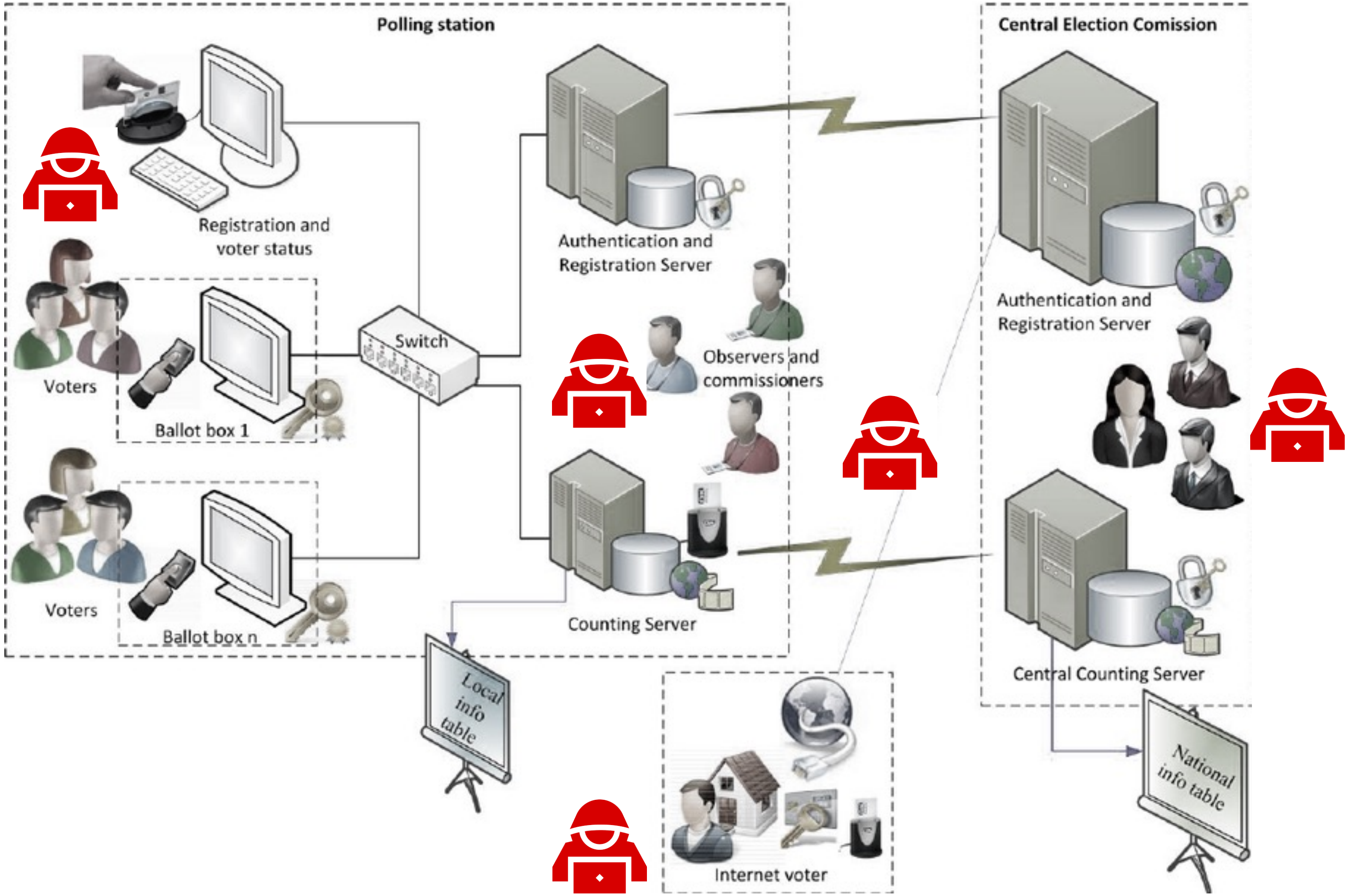
An Example: Electronic Voting (e-voting)



https://www.researchgate.net/figure/General-architecture-of-e-Voting-system_fig2_236693845

An Example: Electronic Voting (e-voting)

- Security



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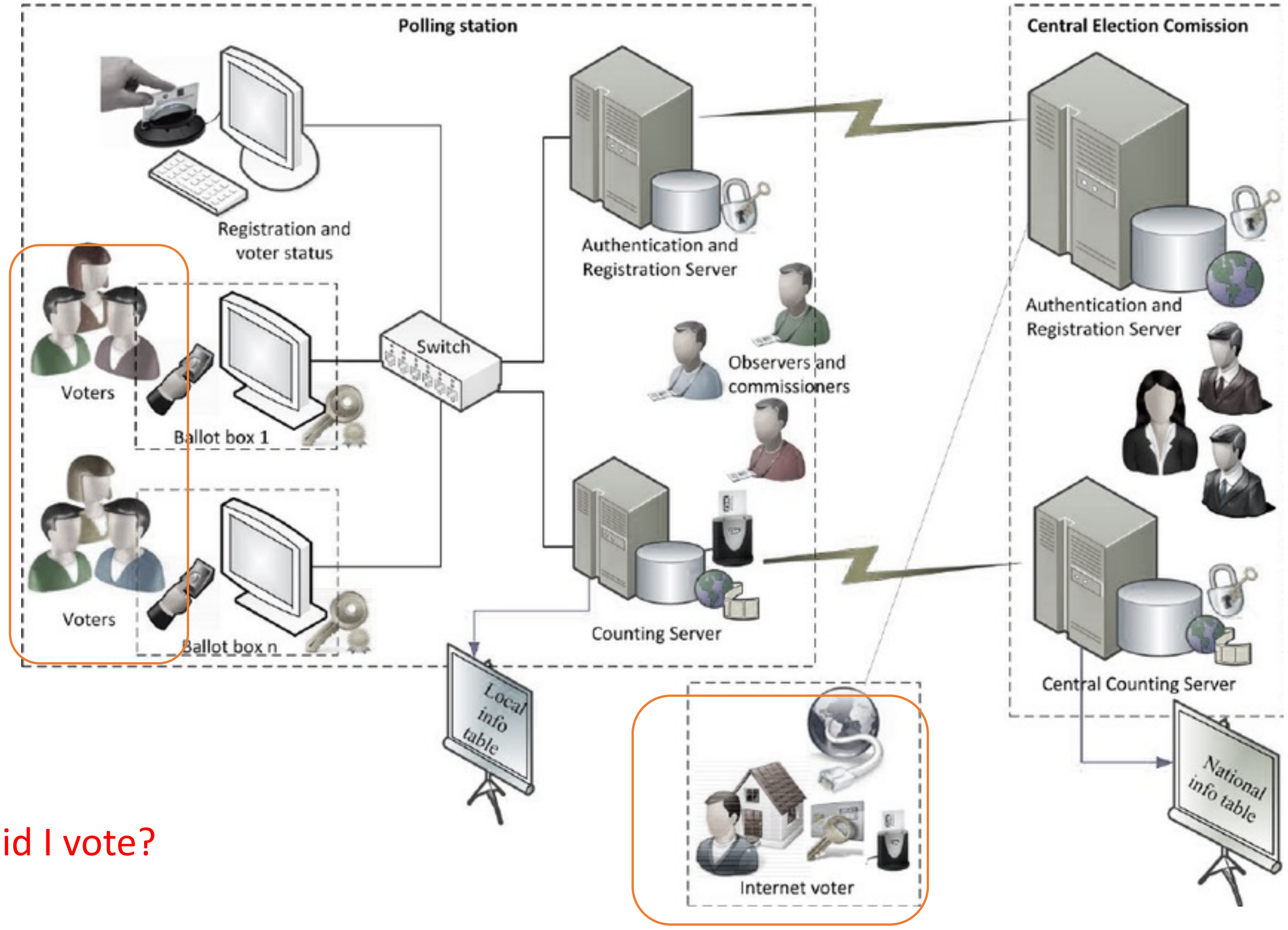
- Privacy



Who did I vote?

https://www.researchgate.net/figure/General-architecture-of-e-Voting-system_fig2_236693845

What this course is **NOT** about

- NOT a comprehensive course on security and privacy
  - security and privacy are broad topics.
  - Impossible to cover everything in a course
  - Encouraged to present a new topic

- NOT about all the latest attacks
  - We do not catch the latest attacks in this lecture
  - Encouraged to present new and great attacks

- NOT about ethical, legal, or economic issues

What this course is about

- Introduction to security and privacy
  - Basic tools and recent development to achieve security and privacy

- focus on “big-picture” principles and ideas
  - Basic cryptography
  - and network security
  - Advanced privacy-enhancing technologies

- Security and privacy problems in Blockchain
  - The hot topics in Blockchain

Course Plan

- Lectures
  - Lectures do not follow any textbooks
  - Include recent development

- A Guest Lecture (planned)
  - On the topic of security and privacy in the Blockchain

- Your final presentation
  - Every student gives a 10-minute presentation on any paper about S & P

Grading

- Assignments (20%)
  - I will post two assignments throughout the course
- Projects: (45%)
  - lecture notes and final presentation
- Final exam (35%)
  - ;) I will post a summary of what you should know about this on the website

Projects

- Final presentation
  - Give a 10-minute presentation for any paper from IEEE S&P 19-23, ACM CCS 19-23, USENIX 19-23, NDSS 19-23, CRYPTO 19-23, or EUROCRYPT 19-23
  - Send your choice to the TA on or before Mar 27
  - The presentation schedule will be given on April 1

- Lecture notes
  - I will give an example for week 2. I will also provide readings as a reference.
  - Lecture notes for week x should be submitted to TA and me on or before Tuesday of week x+4, $x \in \{3,4,5,6,7,8,9\}$
  - Every 3 students, as a team, should choose and write one lecture note. (45/7)
  - Revisions may be required.

What I want to cover

Network Security

Authentication

S & P in Blockchain

Multi-party Computation

Zero-Knowledge Proof

Basic Cryptography

Post-quantum Cryptography

Fully Homomorphic Encryption

Course syllabus

Date	Topics	Lecture notes
Week 1	Course Overview	N/A
Week 2	Basic Cryptography 1: Symmetric-key cryptography	Haiyang Xue
Week 3	Basic Cryptography 2: Public-key cryptography	Group 1 & Group 2
Week 4	Network Security Principles	Group 3 & Group 4
Week 5	Network Security in Practice	Group 5 & Group 6
Week 6	Authentication	Group 7 & Group 8 & Group 9
Week 7	Privacy-Enhancing technologies 1 post-quantum cryptography and fully-homomorphic encryption	Group 10 & Group 11
Week 8	Privacy-Enhancing technologies 2 zero knowledge proof	Group 12 & Group 13
Week 9	Privacy-Enhancing technologies 3 multiparty computation	Group 14 & Group 15
Week 10	Guest lecture on blockchain	N/A
Week 11	Easter	N/A
Week 12	Final presentation 1	N/A
Week 13	Final presentation 2	N/A

Before giving a brief intro to each topic,

I would like to give several helpful resources

Other Resources for learning security and privacy

- Top-tier conferences
  - IEEE Security & Privacy, ACM CCS, USENIX, NDSS
  - CRYPTO, EUROCRYPT, ASIACRYPT

- eprint
  - https://eprint.iacr.org/

- GitHub
  - https://github.com/sbilly/awesome-security
  - https://github.com/qazbnm456/awesome-web-security
  - https://github.com/matter-labs/awesome-zero-knowledge-proofs

In the rest of this lecture

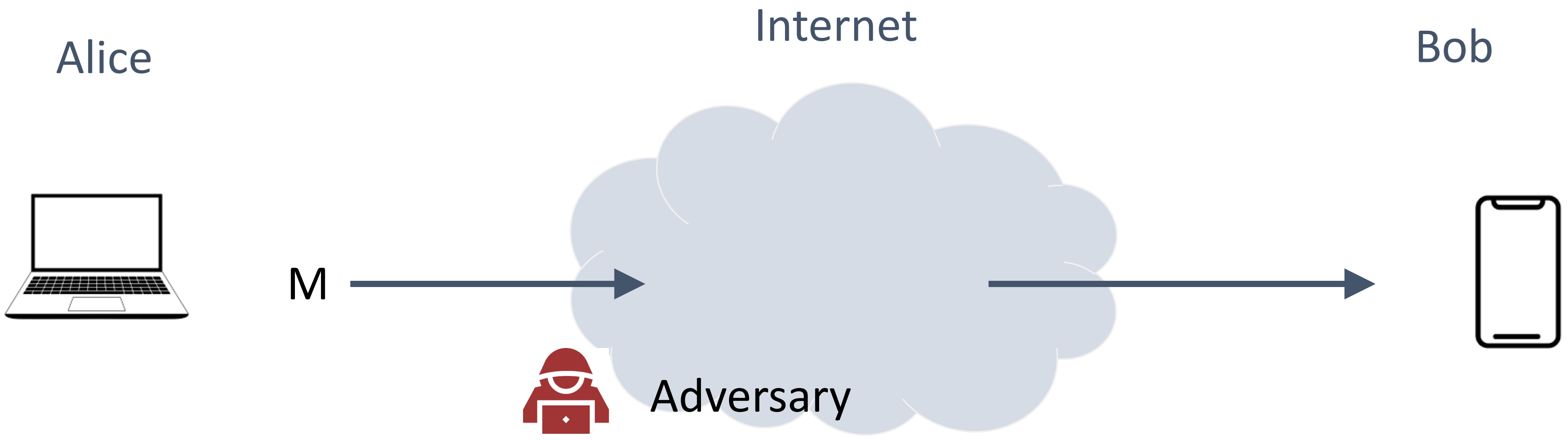
I will give a brief intro to each topic one by one

Please find which topic(s) you are interested in

Basic Cryptography 1: Symmetric-key cryptography

Date	Topics	Outline (tentative)	Lecture notes
Week 1	Course Overview	course plan, reading materials, grading, brief introduction to every topic	N/A
Week 2	Basic Cryptography 1: Symmetric-key cryptography	symmetric encryption, one-time pad, blockcipher, hash function, MAC, authenticated encryption.	Haiyang Xue
Week 3	Basic Cryptography 2: Public-key cryptography	RSA, Diffie-Hellman, public key encryption, Digital signature	??
Week 4	Network Security Principles	authenticated key exchange, PKI, and certification authorities	??
Week 5	Network Security in Practice	secure sockets layer (SSL), internet protocol security (IPSec), internet key exchange (IKE), virtual private network (VPN)	??
Week 6	Authentication	access control, password authentication, biometric authentication	??
Week 7	Privacy-Enhancing technologies 1	post-quantum cryptography; Fully-homomorphic encryption and applications	??
Week 8	Privacy-Enhancing technologies 2	commitment, zero-knowledge proofs;	??
Week 9	Privacy-Enhancing technologies 3	secure multiparty computation	??
Week 10	Guest lecture	security and privacy in Blockchain	N/A
Week 11			N/A
Week 12	Final presentation 1	papers from S&P, CCS, USENIX, NDSS, CRYPTO, or EUROCRYPT	N/A
Week 13	Final presentation 2	papers from S&P, CCS, USENIX, NDSS, CRYPTO, or EUROCRYPT	N/A

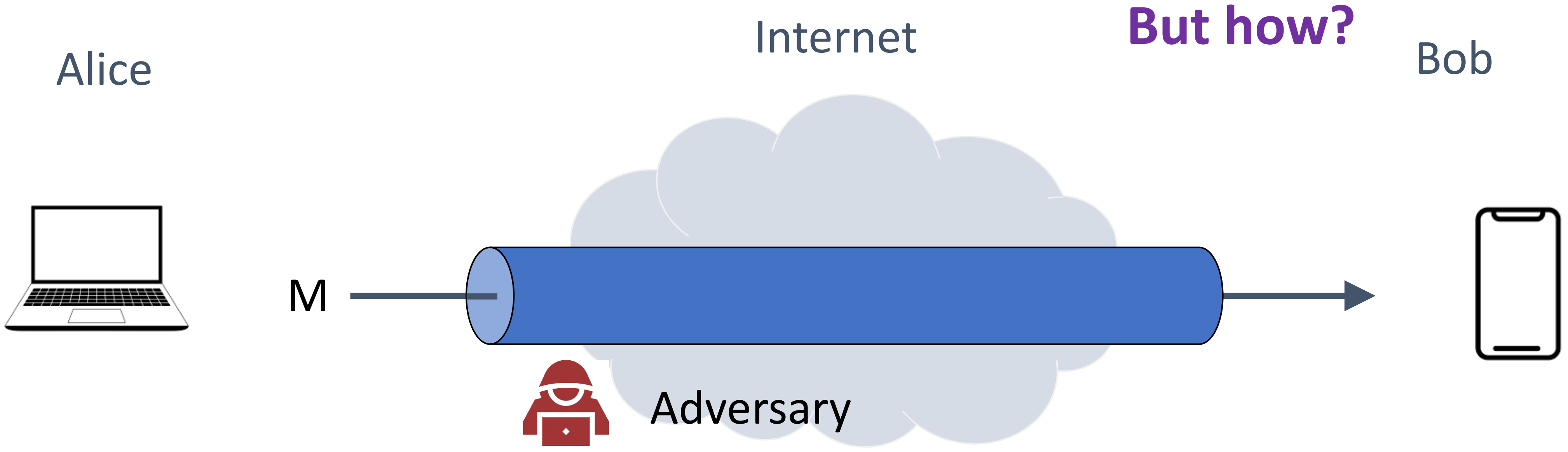
Lecture 2: Symmetric-key cryptography



Security goals:

- **Confidential:** adversary should not be able to read message M
- **Integrity:** adversary should not be able to modify message M
- **Authenticated:** message M really originated from Alice

Build secure channels



Security goals:

- **Confidential:** adversary should not be able to read message M
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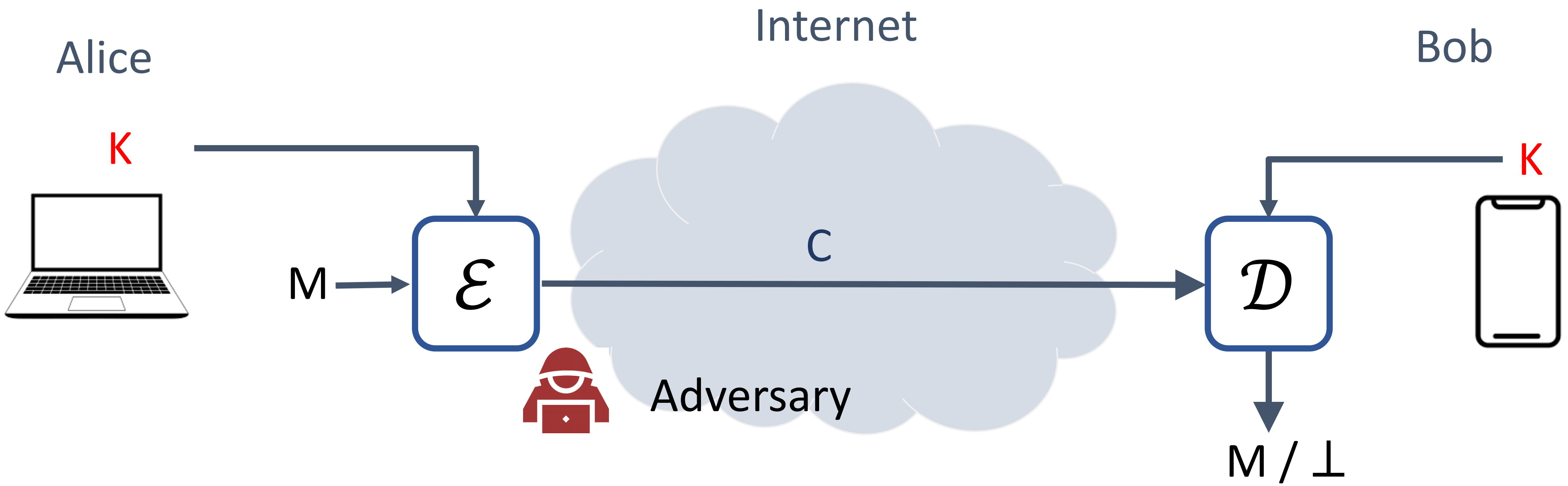
Lecture 2: Symmetric-key cryptography



$\mathcal{E}$: encryption algorithm (public)

$\mathcal{D}$: decryption algorithm (public)

K : shared key between Alice and Bob

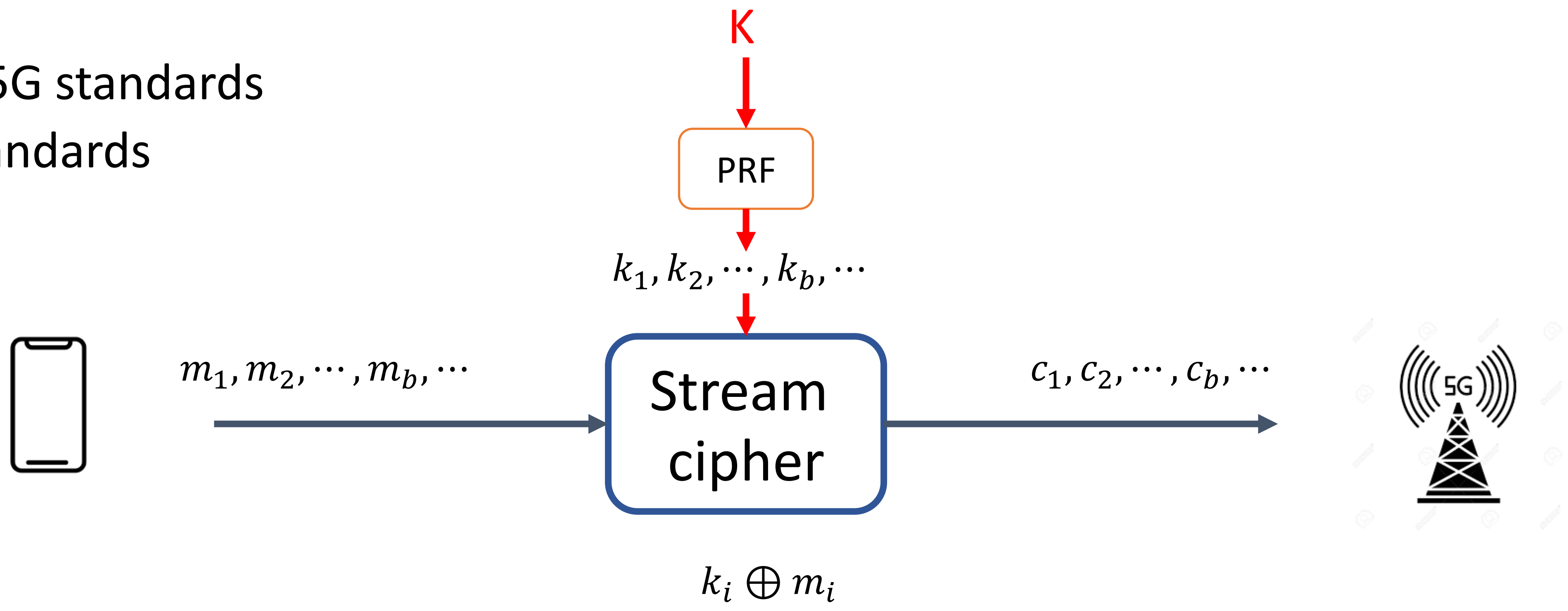
Ignore for now: How to achieve this??

Symmetric-key cryptography Stack

- Stream cipher
  - one-time pad
  - RC5; SNOW; ZUC
- Block cipher
  - 3DES, AES
- Hash function
- Message Authenticated Code (MAC)

Stream cipher

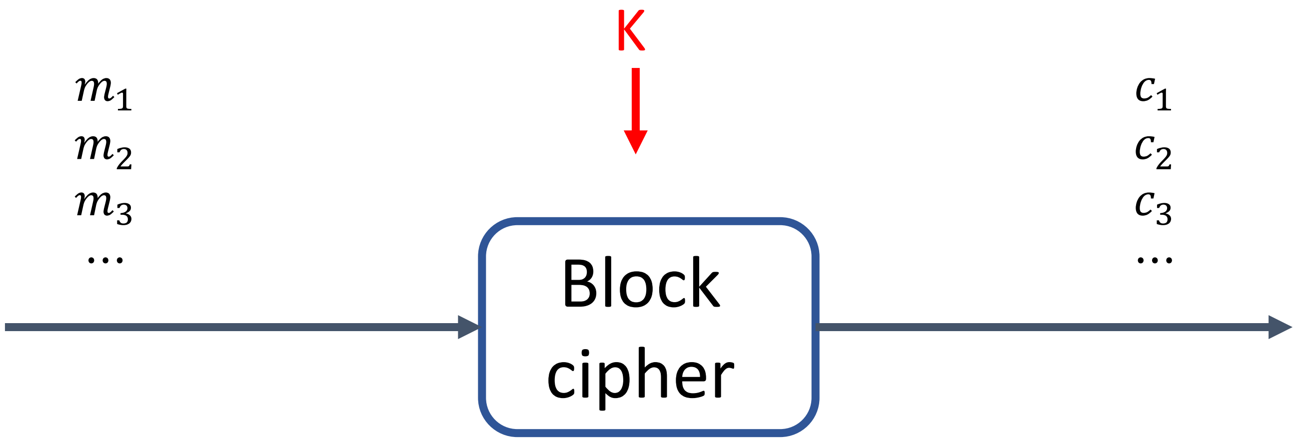
- Stream cipher
  - one-time pad
  - RC4: skype
  - SNOW 3G: 5G standards
  - ZUC: 5G standards
  - …



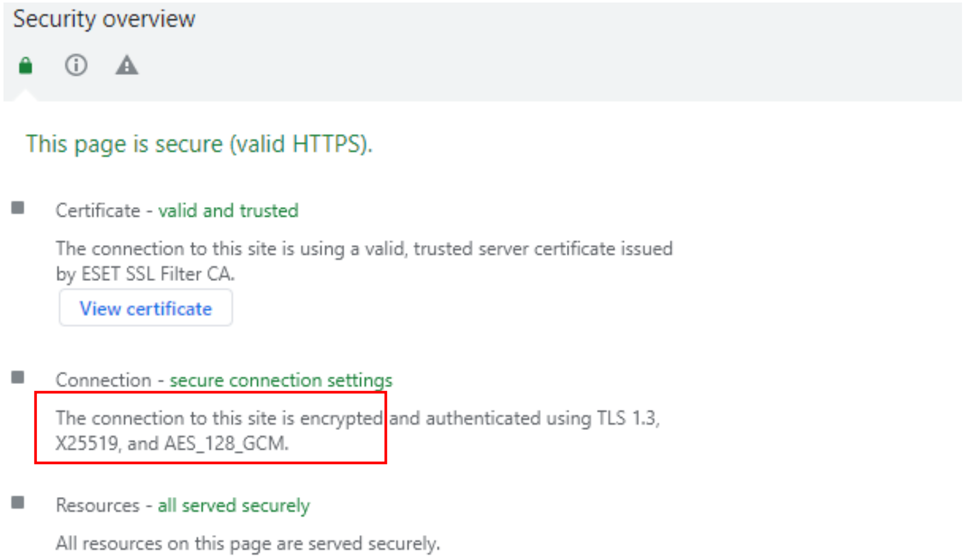
https://en.wikipedia.org/wiki/SNOW

Block cipher

- Block cipher
  - 3DES, AES-XXX



- Visit any https website



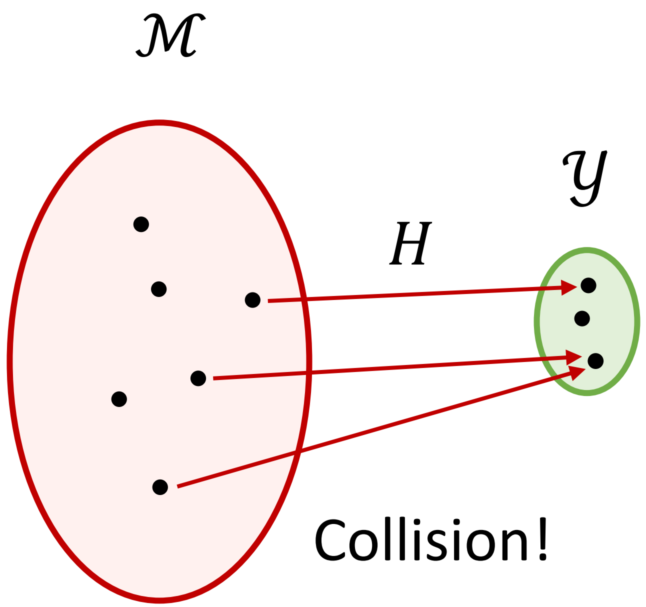
Hash functions

$H : \mathcal{M} \rightarrow \mathcal{Y}$

Keyless function

$|\mathcal{M}| \gg |\mathcal{Y}|$

Compressing



- SHA1 *: $\{0,1\}^{<2^{64}} \rightarrow \{0,1\}^{160}$
- $\text{SHA2}-256 : \{0,1\}^{<2^{64}} \rightarrow \{0,1\}^{256}$
- $\text{SHA3}-512 : \{0,1\}^{<2^{128}} \rightarrow \{0,1\}^{512}$

Collision Resistant

One way

* Insecure now. https://en.wikipedia.org/wiki/SHA-1#Attacks

Hash functions

- Store password in computer

- Blockchain Mining
  - SHA-256
  - $<2^{224}$

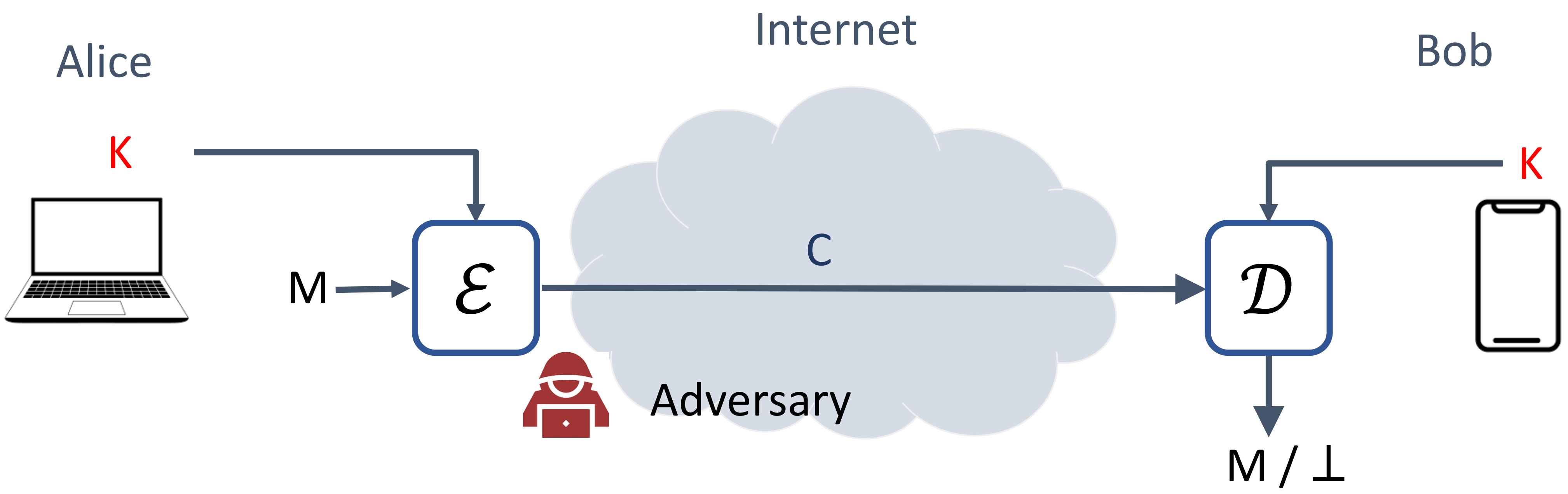
```
Block hash:
c5aa3150f61b752c8fb39525f911981e2f9982c8b9bc907c73914585ad2ef12b
Target:
0x00000000FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
Is the block hash less than the target?
False
```

- CA/APP fingerprint etc. example in CA

Symmetric-key cryptography Stack

- Stream cipher
  - one-time pad
  - RC5; SNOW; ZUC
- Block cipher
  - 3DES, AES
- Hash function
- Message Authenticated Code (MAC)

Challenge: Symmetric-key cryptography



$\mathcal{E}$: encryption algorithm (public)

$\mathcal{D}$: decryption algorithm (public)

K : shared key between Alice and Bob

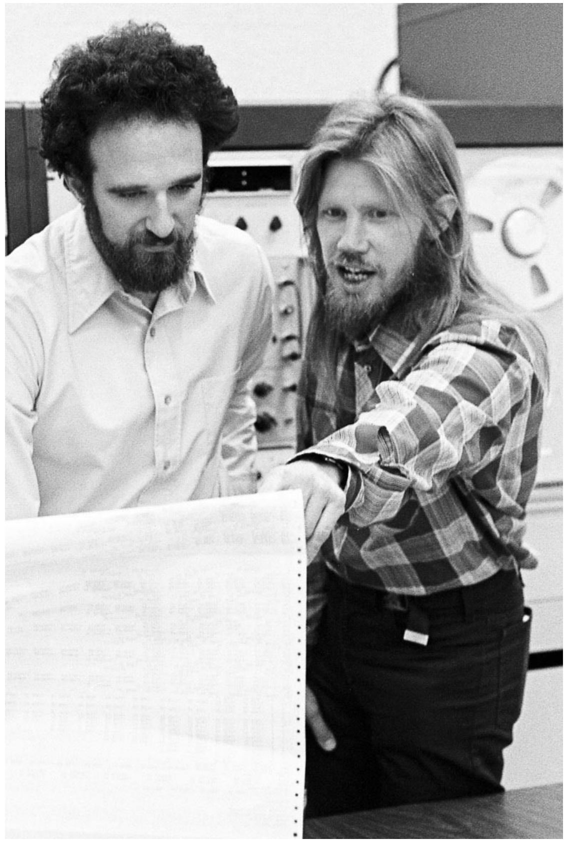
Challenge: How do they privately share a key?

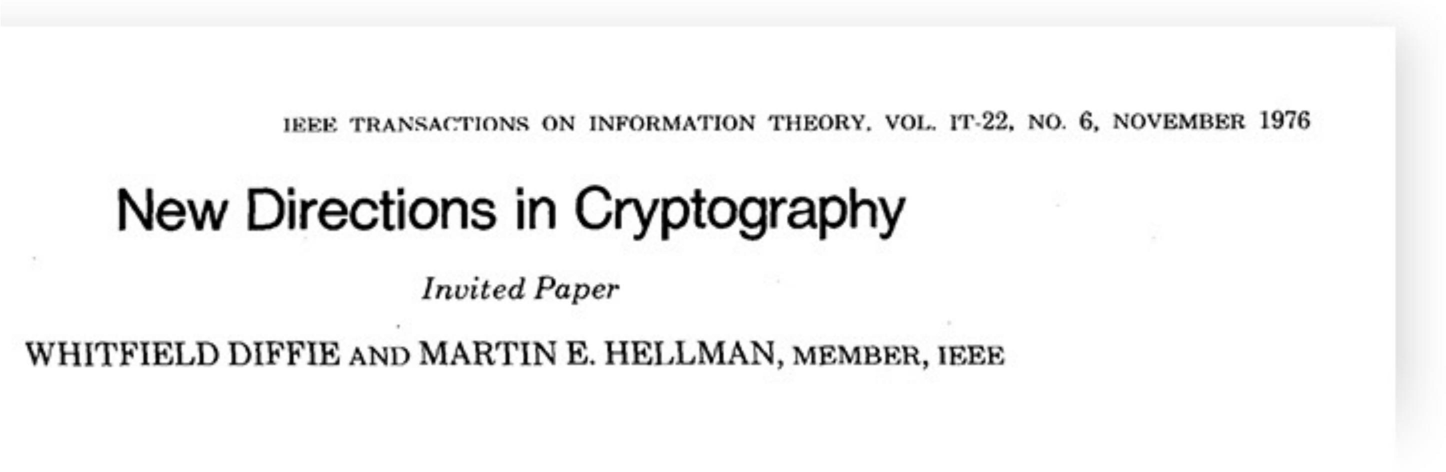
Basic Cryptography 2: Public-key cryptography

Date	Topics	Outline (tentative)	Lecture notes
Week 1	Course Overview	course plan, reading materials, grading, brief introduction to every topic	N/A
Week 2	Basic Cryptography 1: Symmetric-key cryptography	symmetric encryption, one-time pad, blockcipher, hash function, MAC, authenticated encryption.	Haiyang Xue
Week 3	Basic Cryptography 2: Public-key cryptography	RSA, Diffie-Hellman, public key encryption, Digital signature	??
Week 4	Network Security Principles	authenticated key exchange, PKI, and certification authorities	??
Week 5	Network Security in Practice	secure sockets layer (SSL), internet protocol security (IPSec), internet key exchange (IKE), virtual private network (VPN)	??
Week 6	Authentication	access control, password authentication, biometric authentication	??
Week 7	Privacy-Enhancing technologies 1	post-quantum cryptography; Fully-homomorphic encryption and applications	??
Week 8	Privacy-Enhancing technologies 2	commitment, zero-knowledge proofs;	??
Week 9	Privacy-Enhancing technologies 3	secure multiparty computation	??
Week 10	Guest lecture	security and privacy in Blockchain	N/A
Week 11			N/A
Week 12	Final presentation 1	papers from S&P, CCS, USENIX, NDSS, CRYPTO, or EUROCRYPT	N/A
Week 13	Final presentation 2	papers from S&P, CCS, USENIX, NDSS, CRYPTO, or EUROCRYPT	N/A

Lecture 3: Public-key cryptography

- Diffie-Hellman 1976 New Directions in Cryptography




IEEE TRANSACTIONS ON INFORMATION THEORY, VOL. IT-22, NO. 6, NOVEMBER 1976

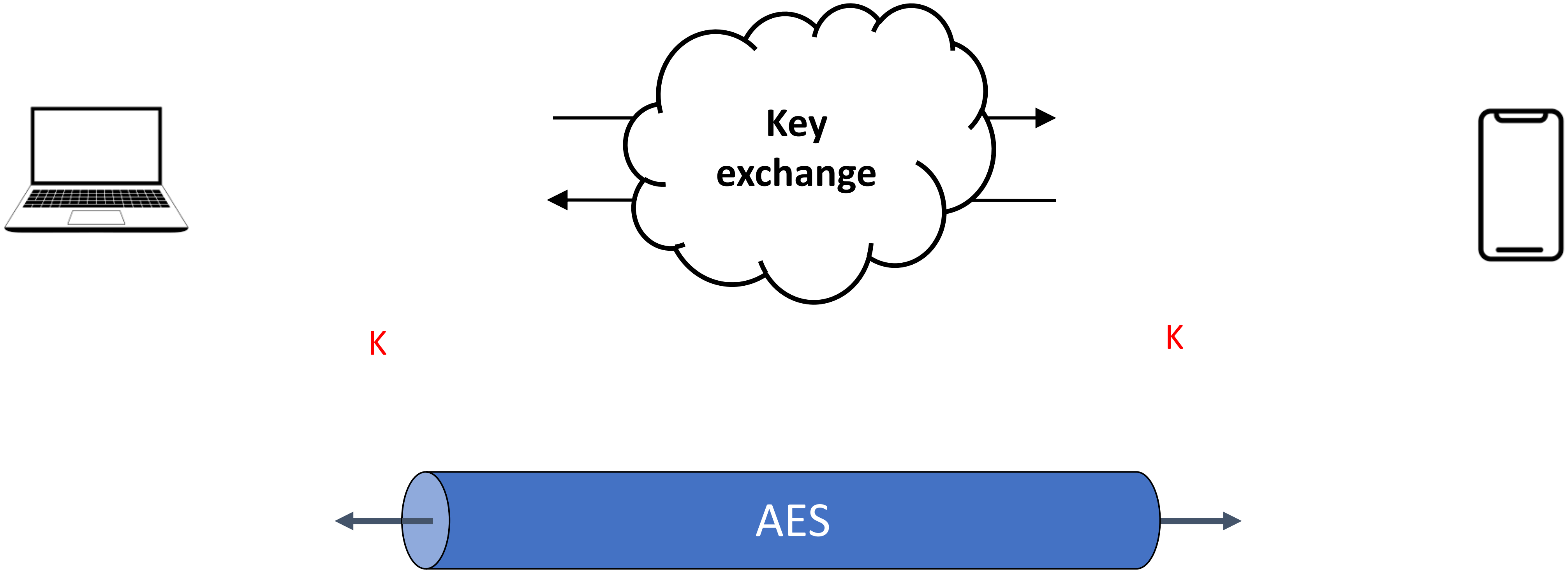
New Directions in Cryptography

Invited Paper

WHITFIELD DIFFIE AND MARTIN E. HELLMAN, MEMBER, IEEE

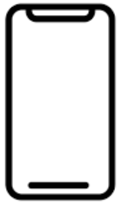
Lecture 3: Public-key cryptography

- DH key exchange



Diffie-Hellman Key Exchange

$G = \langle g \rangle$ ← public



$A = g^a$ →

← $B = g^b$

$a \overset{\$}{\leftarrow} \{1, \dots, |G|\}$

$b \overset{\$}{\leftarrow} \{1, \dots, |G|\}$

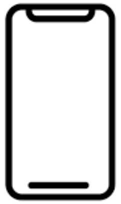
$\mathrm{K} \leftarrow B^a = g^{ab}$

$\mathrm{K} \leftarrow A^b = g^{ab}$

Diffie-Hellman Key Exchange

public

$G = \langle g = 5 \rangle$



$A = 4 = g^{a} \bmod 23$

$B = 10 = g^{b} \bmod 23$

$4 \xleftarrow{\$} \{1, \dots, |G|\}$

$3 \xleftarrow{\$} \{1, \dots, |G|\}$

$\mathrm{K} = 18 \leftarrow B^{a} = g^{ab}$

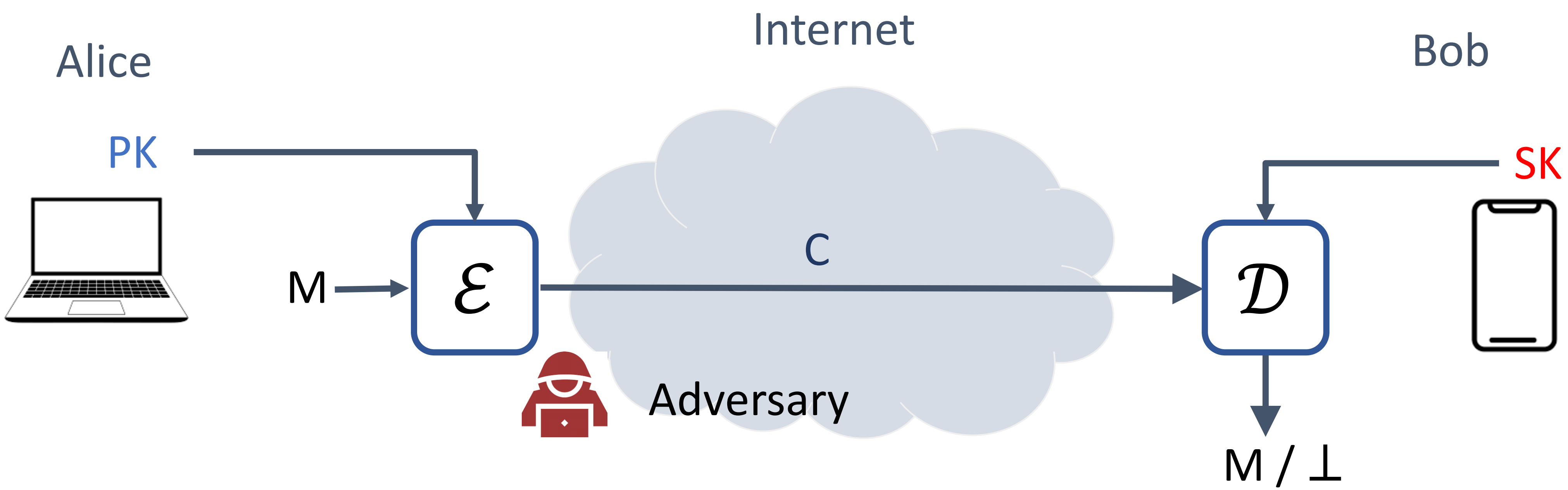
$\mathrm{K} = 18 \leftarrow A^{b} = g^{ab}$

Insecure Exp. $G = (\boldsymbol{Z}_p^*, \cdot), p = 23, g = 5$

To be secure: length p > 2048

https://www.rfc-editor.org/rfc/rfc2409#section-6.2; rfc3526#page-3

Is public-key cryptography possible???



$\mathcal{E}$: encryption algorithm (public)

$\mathcal{D}$: decryption algorithm (public)

PK : public key of Bob (public)

SK : secret key (secret)

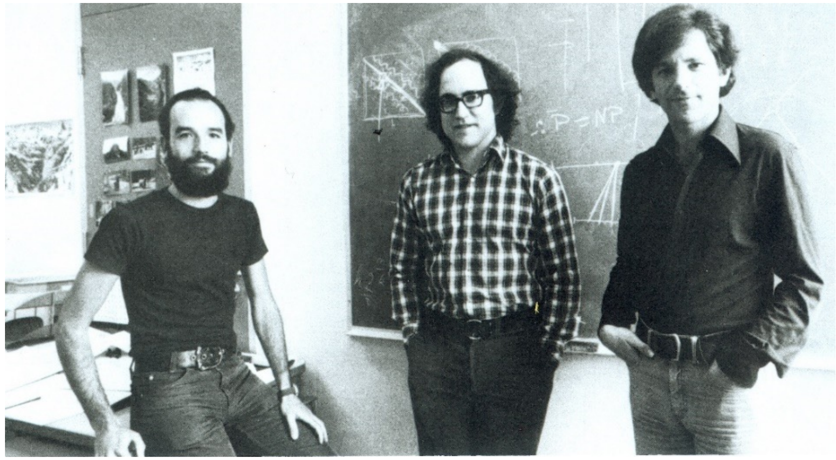
RSA said yes in 1977

- The RSA encryption scheme

$$c = E\,(m) = m^e\ (\text{mod}\, N)$$
$$m = D\,(c) = c^d\ (\text{mod}\, N)$$

PK: $N = pq, e$

SK: $d = e^{-1} mod\ \phi(N)$



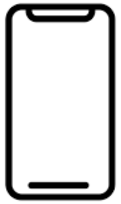
Adi Shamir Ron Rivest Leonard Adleman

Digital Signature

Alice

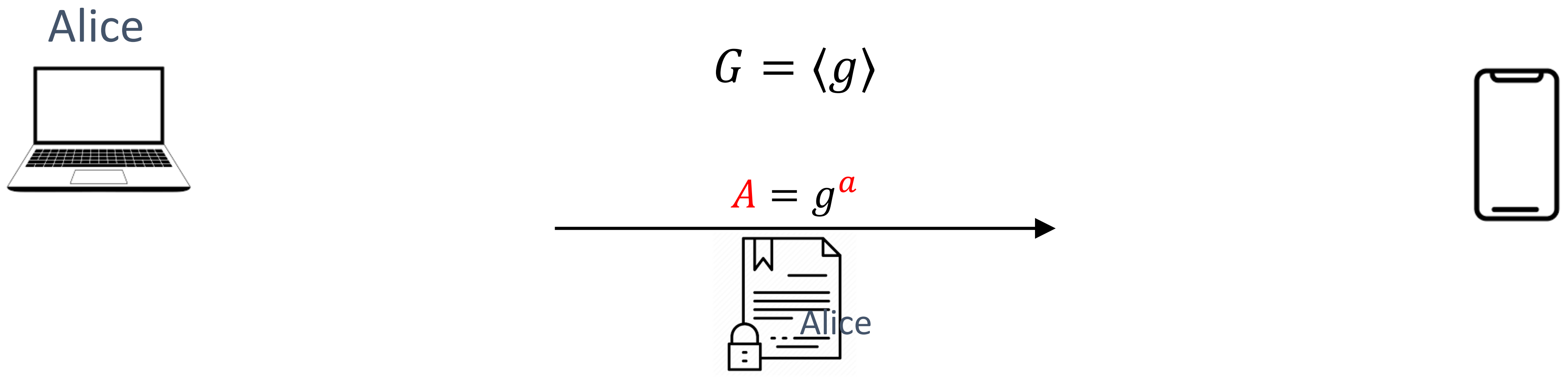
$G = \langle g \rangle$

$A = g^a$ →



Why should I believe A comes from Alice?
Most likely NO

Digital Signature



Why should I believe A comes from Alice?
Well, YES

Digital Signature

- ECDSA
  - Digital Signature Standard using Elliptic Curve Cryptography
  - Widely deployed in cryptocurrency, such as Bitcoin etc.
  - Standardized by NIST

- RSA Enc with hash
  - Roughly, the decryption is the signature
  - Roughly, the encryption is the verification

- Schnorr, etc

Digital Signature

- HTTPS / TLS certificates (any https)
- Software installation
- Bitcoin

A transaction in bitcoin looks like

Tr_1 :

Alice sends
$100 to Bob

h=hash (Tr_1)

Signature (sk_A, h)

Signature is the standard ECDSA proposed by NIST

Lecture 3: Public-key cryptography

- Diffie-Hellman key exchange

- PKE:
  - RSA

- Signature:
  - RSA, ECDSA, Shnorr

- Applications:
  - https, etc

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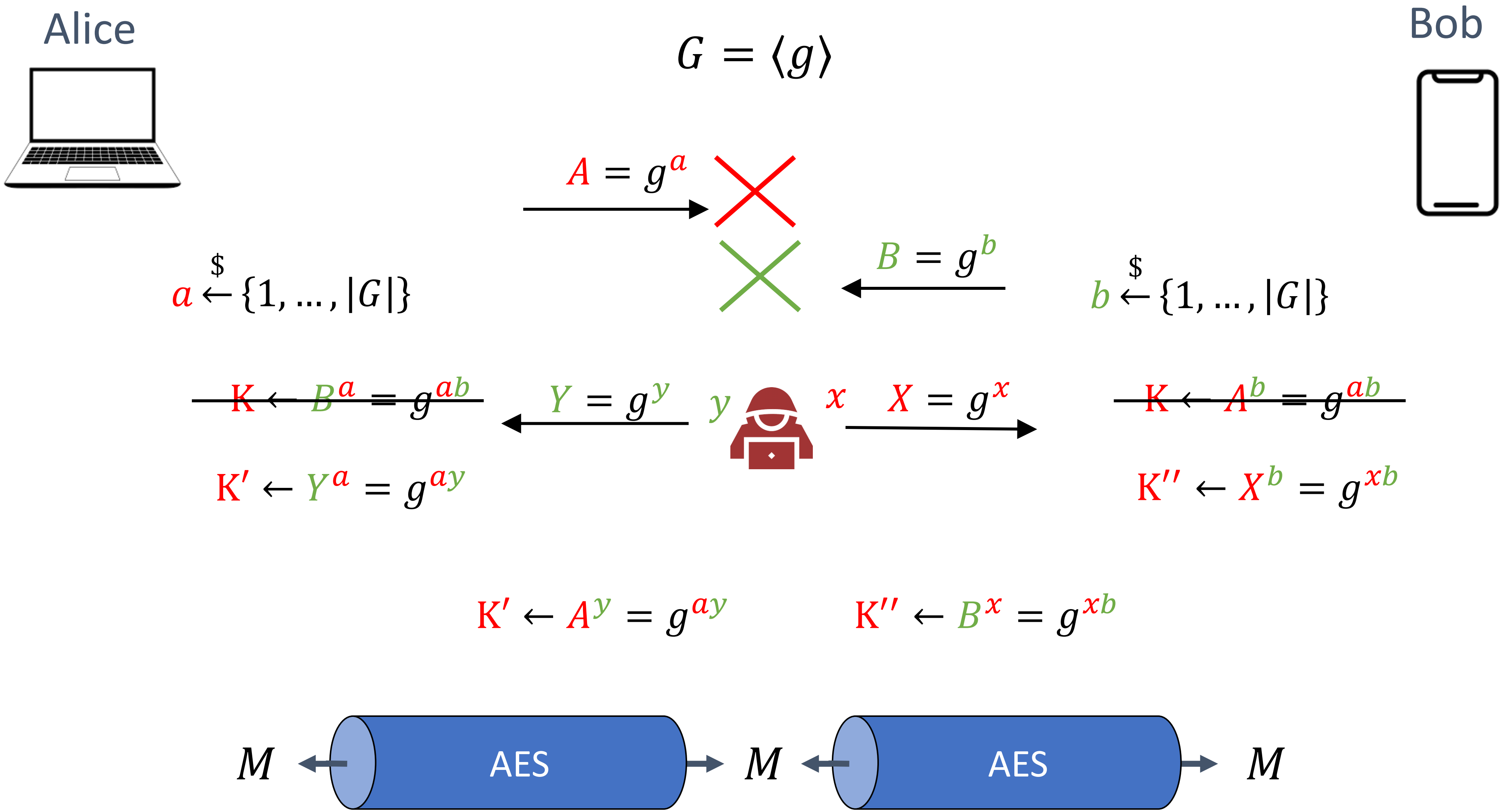
Week 13	Final presentation 2	papers from S&P, CCS, USENIX, NDSS, CRYPTO, or EUROCRYPT	N/A

Diffie-Hellman: man-in-the-middle attack

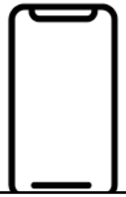


Ideal: Authenticated Key Exchange

Alice

Static Pub/Sec Key
pk_A/sk_A

Bob



Static Pub/Sec Key
pk_B/sk_B

$A = g^a$ $Sign\,(sk_A\,, A)$ →

← $B = g^b$ $Sign\,(sk_B\,, B)$

$\mathrm{K} \leftarrow B^a = g^{ab}$

$\mathrm{K} \leftarrow A^b = g^{ab}$

Ideal: Authenticated Key Exchange

Alice

Static Pub/Sec Key
pk_A/sk_A

There are many Alice's

Why should we believe pk_A belongs to Alice?

Need to **bind** public keys to entities

Public-key infrastructure (PKI)

Alice

Static Pub/Sec Key
pk_A/sk_A

Alice
pk_A

Sign(by Google)

Why do we believe pk_google is Google's pk (or verification key)?

Google
pk_google
Sign(by the ROOT)

A few Roots need to be trust

Certificate authority (CA)

- A way of binding a public key to an entity

- CA consists of:
  - The public key of the entity
  - A bunch of information identifying the entity
    - Name
    - Address
    - Occupation
    - URL
    - …

Certificate authority (CA)

Certificate

www.google.com | ESET SSL Filter CA

Subject Name

Common Name	www.google.com

Issuer Name

Common Name	ESET SSL Filter CA
Organization	ESET, spol. s r. o.
Country	SK

Validity

Not Before	Mon, 28 Nov 2022 08:19:01 GMT
Not After	Mon, 20 Feb 2023 08:19:00 GMT

Subject Alt Names

DNS Name	www.google.com

Public Key Info

Algorithm	Elliptic Curve
Key Size	256
Curve	P-256
Public Value	04:7E:F5:D4:A3:E7:83:25:34:E6:A8:96:FE:A8:14:F0:7A:4C:69:5B:D7:FB:48:5D:4D:01:4...

Miscellaneous

Serial Number	5B:C8:4B:3F:65:E6:5F:09:6A:40:A8:B6:AF:DF:C1:34

CA examples in chrome, safari, firefox

- Wiki, ECDSA Signature with SHA-384

- Polyu, PKCS #1 RSA Encryption

- Google,

Lecture 4: Network Security Principles

- Authenticated Key Exchange

- Public Key Infrastructure

- Certificate authority

Network Security in Practice

Date	Topics	Outline (tentative)	Lecture notes
Week 1	Course Overview	course plan, reading materials, grading, brief introduction to every topic	N/A
Week 2	Basic Cryptography 1: Symmetric-key cryptography	symmetric encryption, one-time pad, blockcipher, hash function, MAC, authenticated encryption.	Haiyang Xue
Week 3	Basic Cryptography 2: Public-key cryptography	RSA, Diffie-Hellman, public key encryption, Digital signature	??
Week 4	Network Security Principles	authenticated key exchange, PKI, and certification authorities	??
Week 5	Network Security in Practice	secure sockets layer (SSL), internet protocol security (IPSec), internet key exchange (IKE), virtual private network (VPN)	??
Week 6	Authentication	access control, password authentication, biometric authentication	??
Week 7	Privacy-Enhancing technologies 1	post-quantum cryptography; Fully-homomorphic encryption and applications	??
Week 8	Privacy-Enhancing technologies 2	commitment, zero-knowledge proofs;	??
Week 9	Privacy-Enhancing technologies 3	secure multiparty computation	??
Week 10	Guest lecture	security and privacy in Blockchain	N/A
Week 11			N/A
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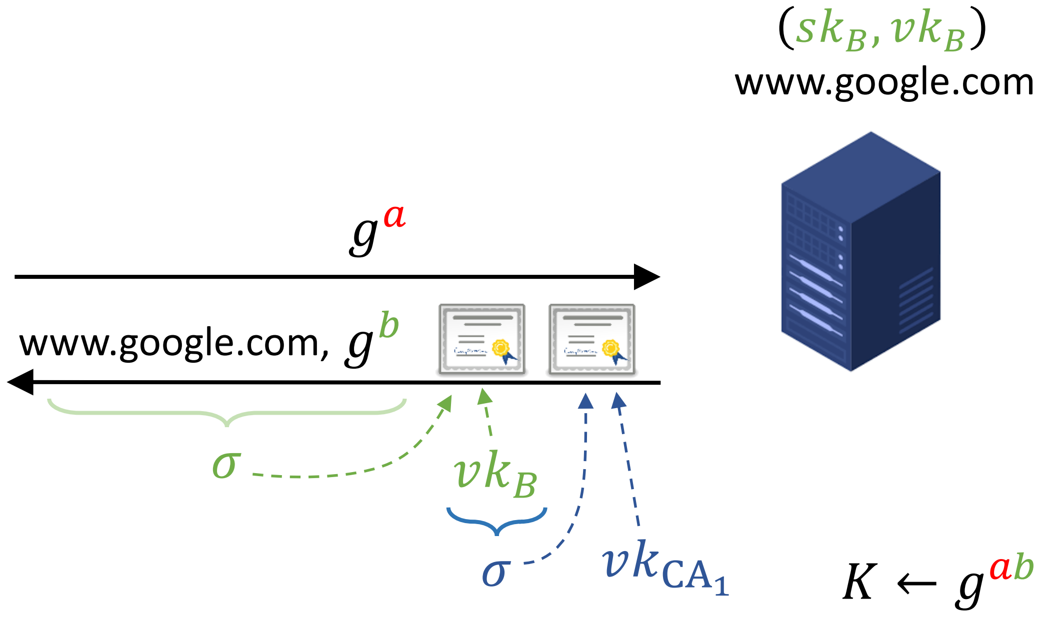
Lecture 5: Network Security in Practice

- HTTPS / TLS + PKI

vk_{CA_1}



if $\mathrm{Vrfy}(vk_B, \dots, \sigma) = 1$

and $\mathrm{Vrfy}(vk_{\mathrm{CA}_1}, \dots, \sigma) = 1$

$K \leftarrow g^{ab}$

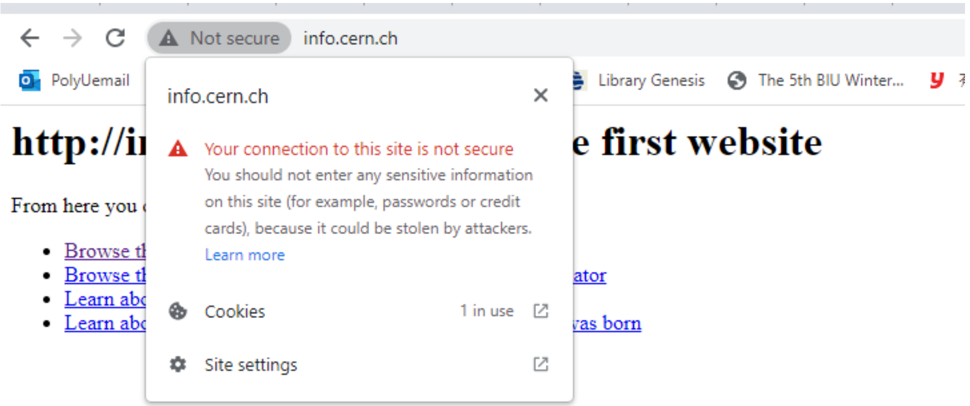
else

abort

From Håkon Jacobsen

HTTPS

http://info.cern.ch/



Web/Software Security

Date	Topics	Outline (tentative)	Lecture notes
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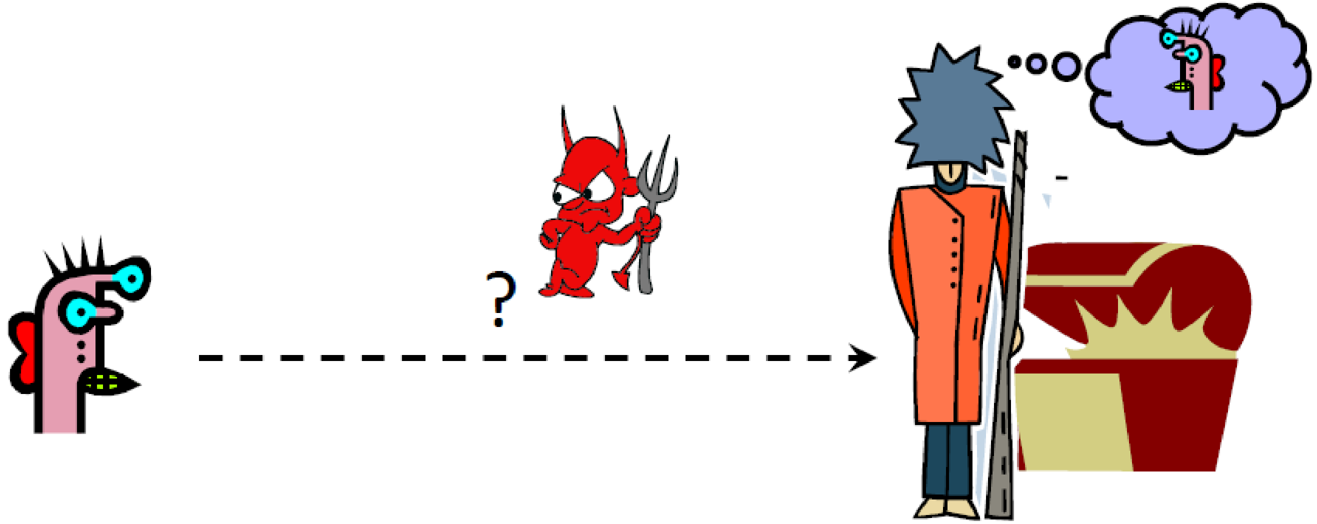
- Basic problem



How do you prove to someone you are who you claimed?

This needs to be solved for any access control system

Prove who you are

- What you know
  - Passwords
  - Answers to questions
- Where you are
  - IP address
- What you are
  - Biometrics
- What you have
  - Secure tokens, mobile devices

Password

- Authentication (& Identification)
    - Establishes that the user is who they say they are.
- Authorization
    - The process used to decide if the authenticated person is allowed to access specific information or functions.
- Access Control
    - Restriction of access (includes authentication & authorization)

How Can Passwords Be Stored?

- Filing System
- Clear text

- Encrypted
- Password + Encryption ?

- Hashed
- Password + Hash function ?

- Salted Hash
- (Username + Salt + Password) + Hash ?

What About Biometrics?

- Authentication: **What you are**

- Unique identifying characteristics to authenticate user or create
  - Biological and physiological: Fingerprints, face scan

- Advantages:
  - Do not need to remember
  - Can’t share (generally)

Attacking Biometrics

- An adversary might try to steal biometric info
  - Malicious fingerprint reader
    - Consider when biometric is used to derive a cryptographic key
  - Copy fingerprint on a glass

- Continuous news about trying to compromise biometrics

iPhone 6 vulnerable to TouchID fingerprint hack

By Allie Coyne
Sep 24 2014
9:03AM

1 Comment

But researcher not worried about attacks.

Apple's just-released iPhone 6 is vulnerable to the same TouchID fingerprint sensor attack as its iPhone 5s predecessor, a researcher who detailed the first security hole has found.

Principal researcher from security firm Lookout, Marc Rogers, followed the Chaos Computer Club biometrics hacking team late last year to demonstrate how the TouchID sensor in the iPhone 5s could be fooled by a fake set of fingerprints created by using household items.

Rogers this week decided to check whether Apple had

RELATED ARTICLES

Rackspace customer data taken in 'PLAY' ransomware attack

Authentication

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Shor's algorithm

1994

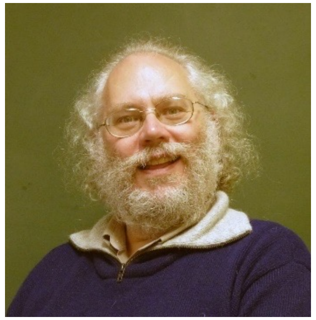
Polynomial-Time Algorithms for Prime Factorization and Discrete Logarithms on a Quantum Computer*

Peter W. Shor†

Abstract

A digital computer is generally believed to be an efficient universal computing device; that is, it is believed able to simulate any physical computing device with an increase in computation time by at most a polynomial factor. This may not be true when quantum mechanics is taken into consideration. This paper considers factoring integers and finding discrete logarithms, two problems which are generally thought to be hard on a classical computer and which have been used as the basis of several proposed cryptosystems. Efficient randomized algorithms are given for these two problems on a hypothetical quantum computer. These algorithms take a number of steps polynomial in the input size, e.g., the number of digits of the integer to be factored.

Keywords: algorithmic number theory, prime factorization, discrete logarithms, Church's thesis, quantum computers, foundations of quantum mechanics, spin systems, Fourier transforms

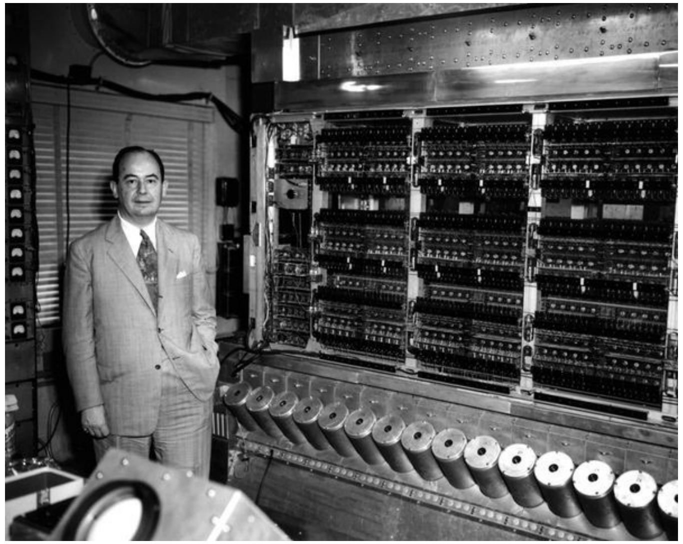


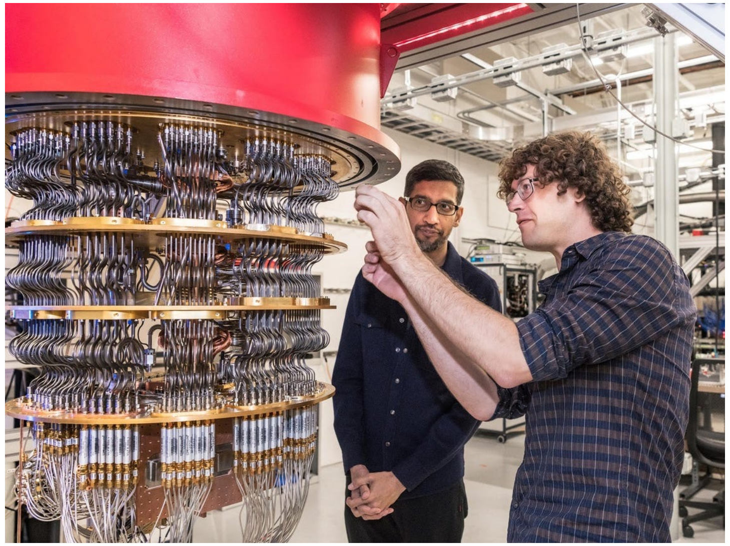
Quantum computer

While it is not sure when large-scale quantum computer could be built

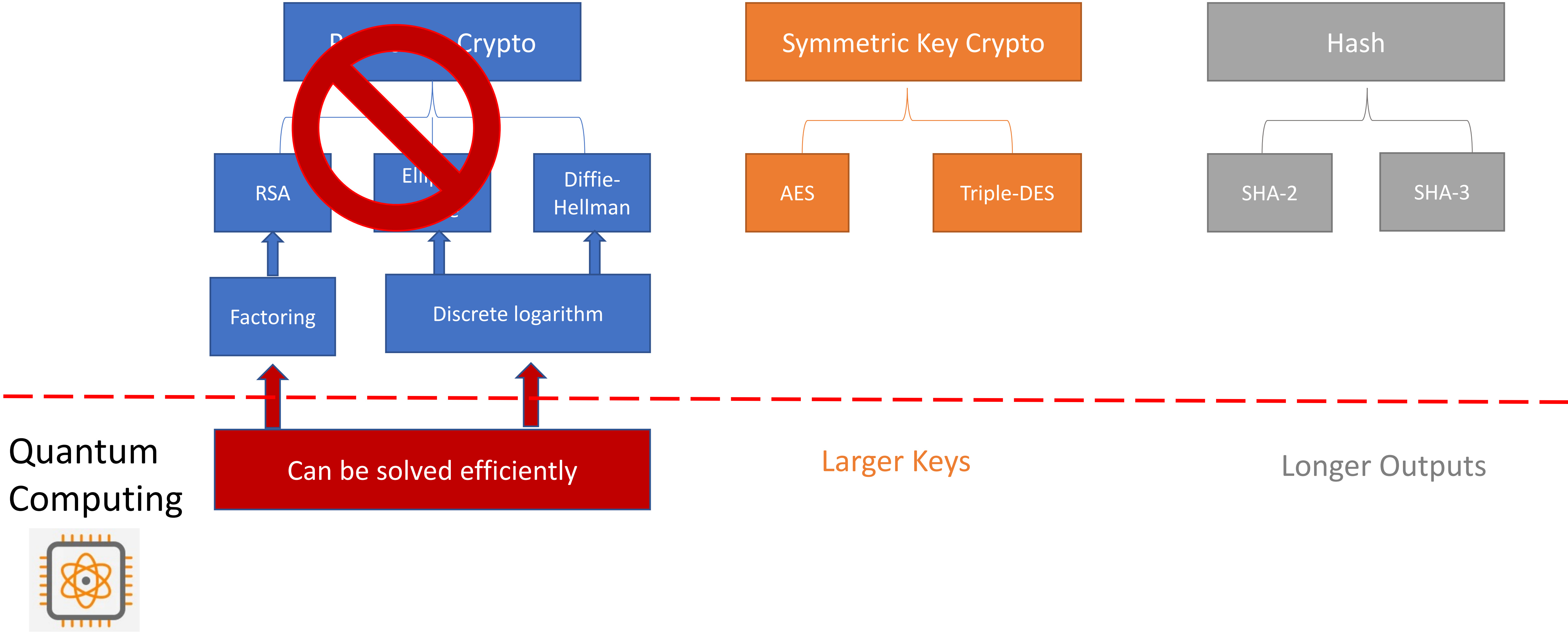
experts estimate it is possible in two decades*

*Quantum Threat Timeline Report: Global Risk Institute





Contemporary cryptography



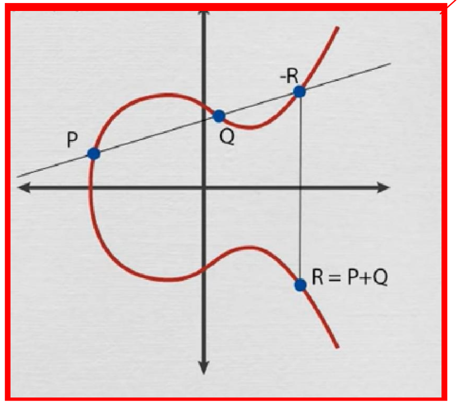
Quantum threats on Blockchain

Secret key vulnerability→financial loss

Private key		Public key		Bitcoin address
511BA35BED8201FEA838	→	3C5A8531F83893CD71C7	→	6C46FA854D39A52D50A

The private key is secret.
But the public key is public.

Elliptic Curve Digital Signature（ECDSA）



ECDSA is vulnerable to quantum computer, i.e., quantum adversary could steal your money.

National Institute of Standards and Technology (NIST)


NIST

Information Technology Laboratory

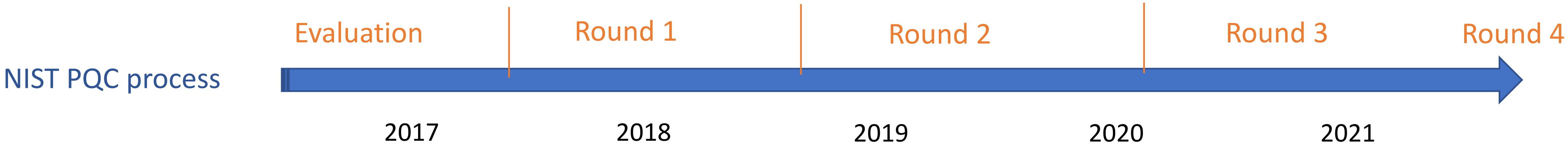
COMPUTER SECURITY RESOURCE CENTER

PROJECTS

Post-Quantum Cryptography PQC

Overview

The Candidates to be Standardized and Round 4 Submissions were announced July 5, 2022. NISTIR 8413, Status Report on the Third Round of the NIST Post-Quantum Cryptography Standardization Process is now available.



Hard problems believed to be quantum-resistant

Hash-based

- Signature

Code-based

- McEliece

Multivariate

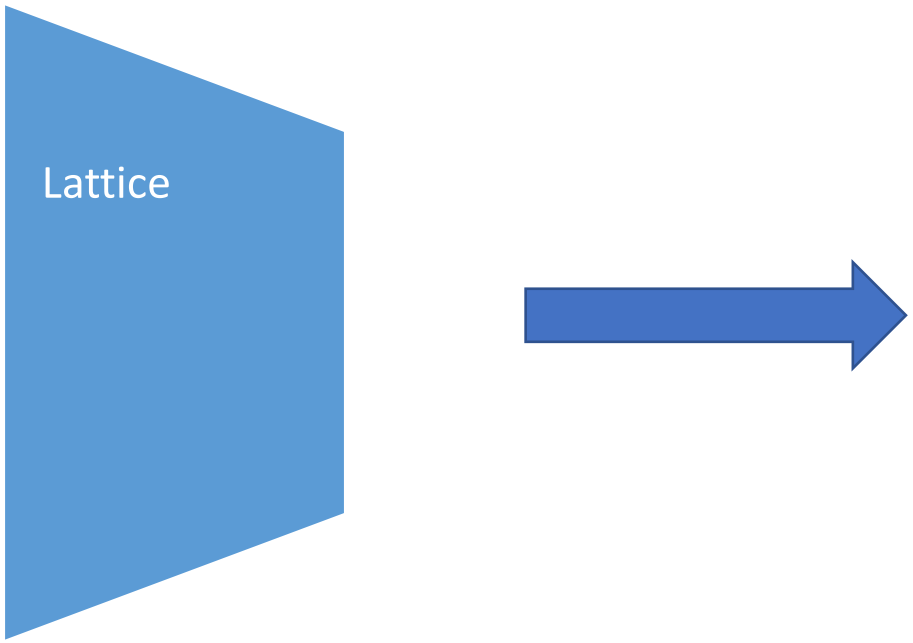
Lattice-based

- NTRU
- LWE
- RLWE

Isogenies

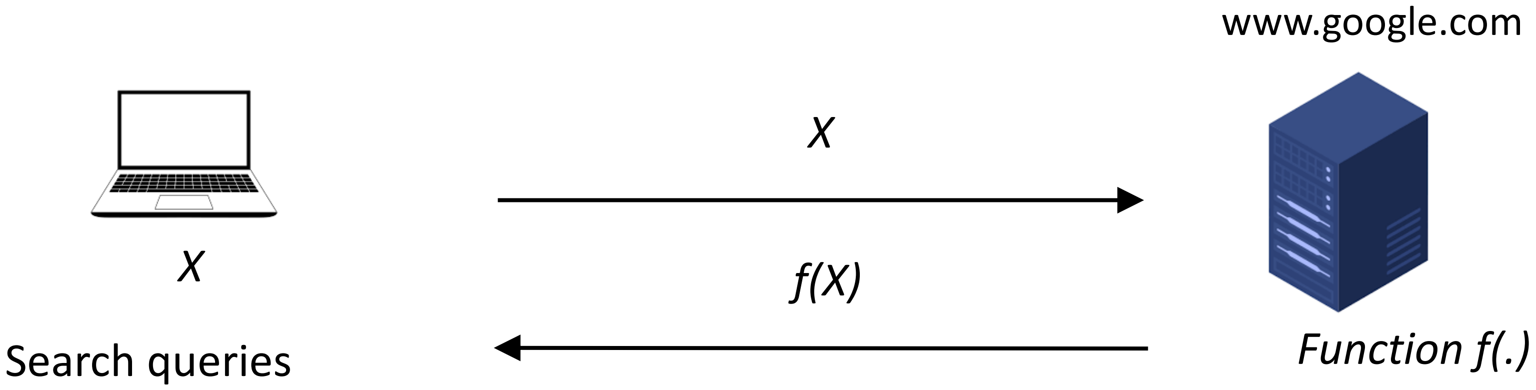
- Supersinular Isogeny （CSIDH）

Fully-homomorphic encryption (FHE)



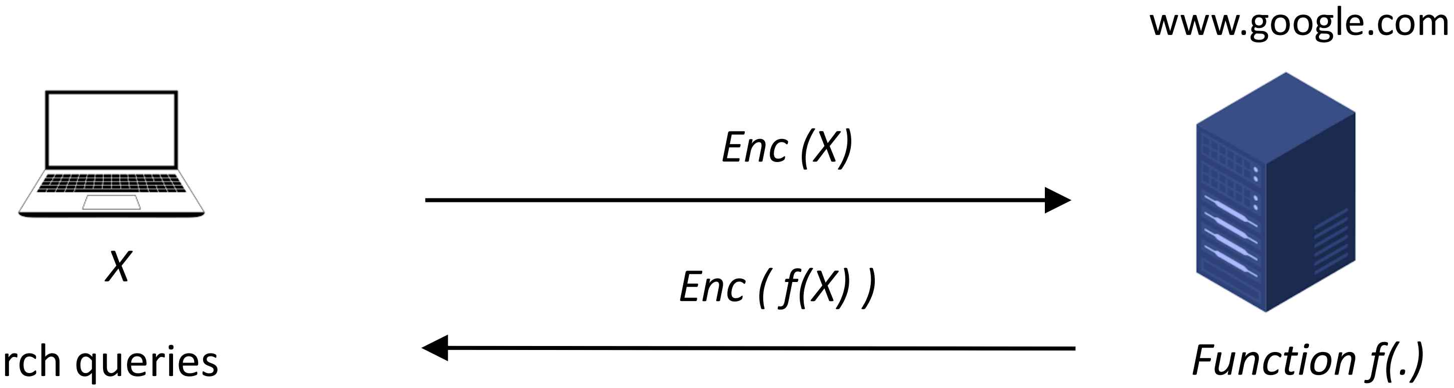
Fully-homomorphic encryption

What can we do with encrypted data, anyway?



WANT PRIVACY!

What can we do with encrypted data, anyway?



Google learns nothing

Some people noted the algebraic structure in RSA…

- RSA encryption E

$$E(m_1) = {m_1}^e \qquad E(m_2) = {m_2}^e$$

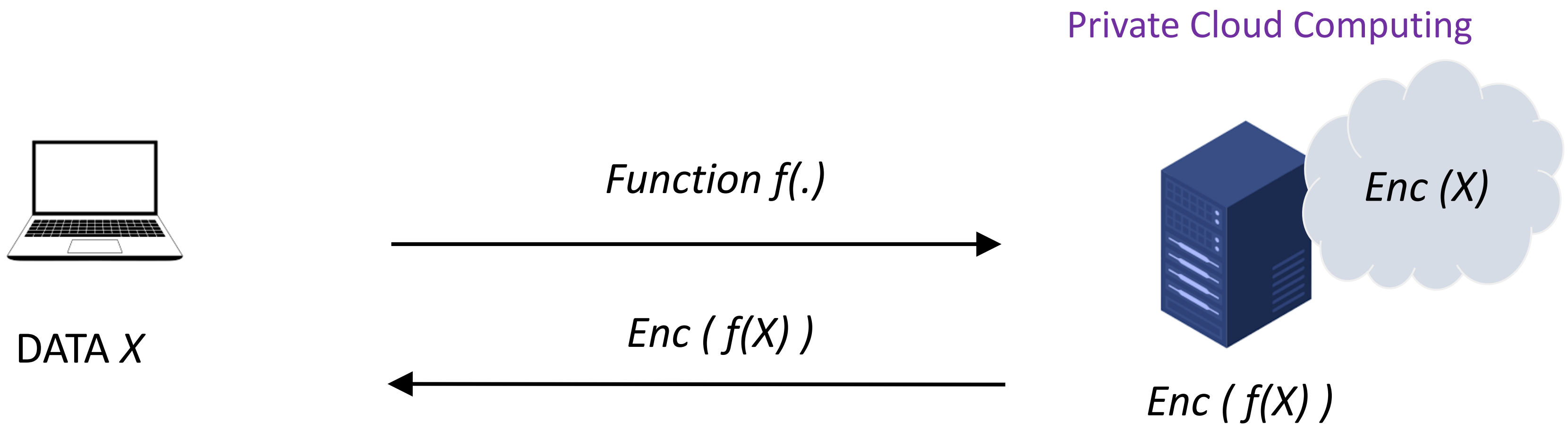
$$\begin{aligned} E(m_1)\times E(m_2) & \\ &= {m_1}^e \times {m_2}^e \\ &= (m_1 \times m_2)^e \\ &= E(m_1 \times m_2) \end{aligned}$$

f=Multiplication

$$E(m_1)\times E(m_2) = E(m_1 \times m_2)$$

What if f is any poly-time function?

f= arbitrary



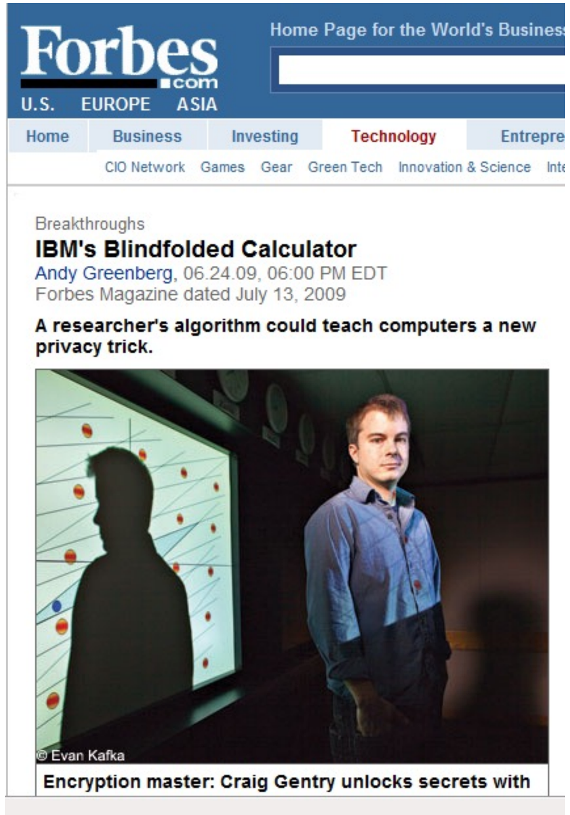
What if f is any poly-time function?

… until, in October 2008 …

… ***Gentry*** came up with the first

fully homomorphic encryption scheme …

… from Lattice…



How does it work?

What is the magic?

Privacy-Enhancing technologies 1: PQC and FHE

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Lecture 9: Privacy-Enhancing technologies 2: ZKP


Diffie

Rivest

Rivest

Yao

Goldwasser


Hellman

Shamir

Adelman

Adelman

Dertouzos

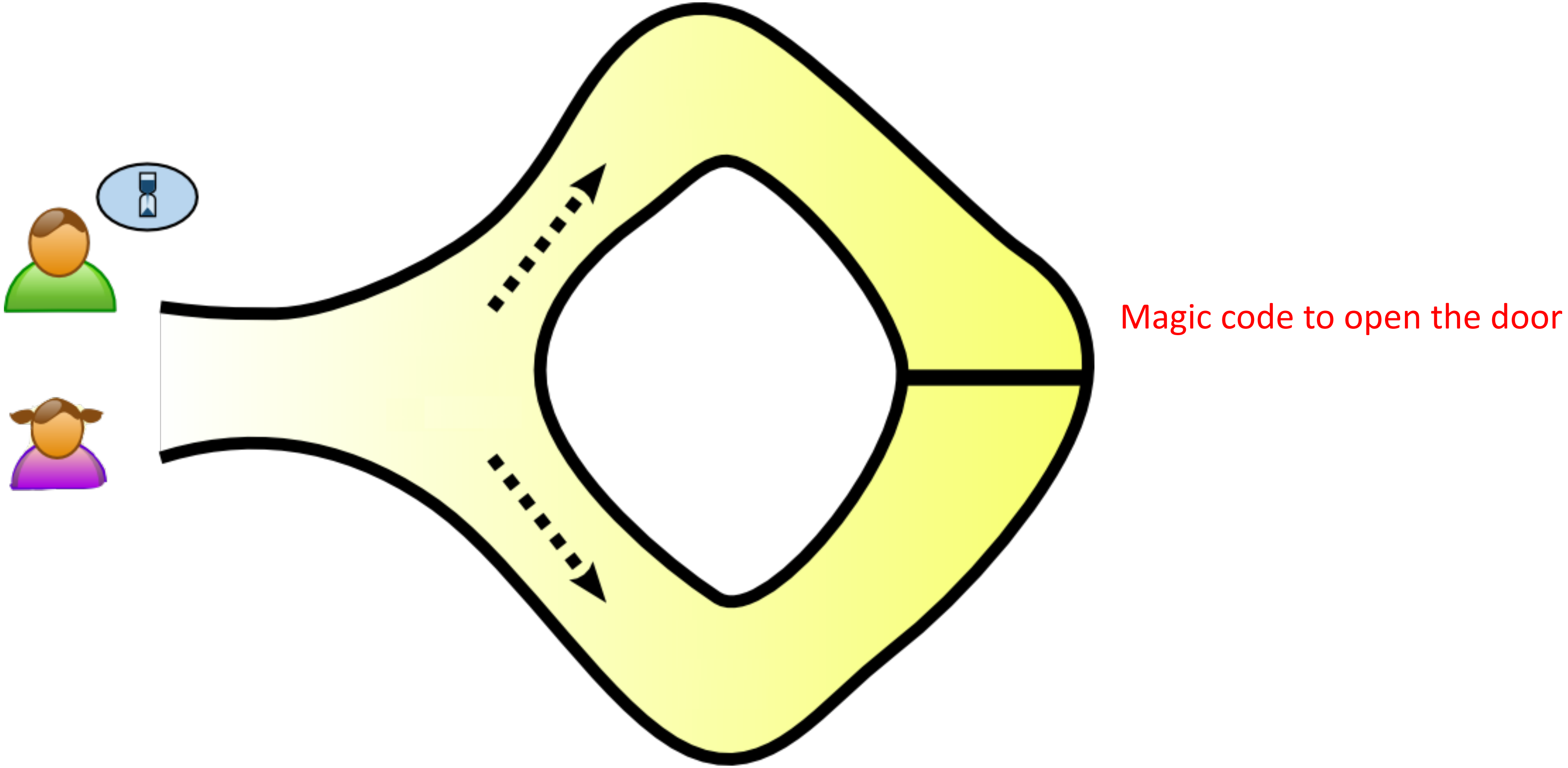
Micali

Rackoff

1976	1977	1978	1982	1985
New directions	RSA	Homomorphic Enc	MPC	Zero Knowledge

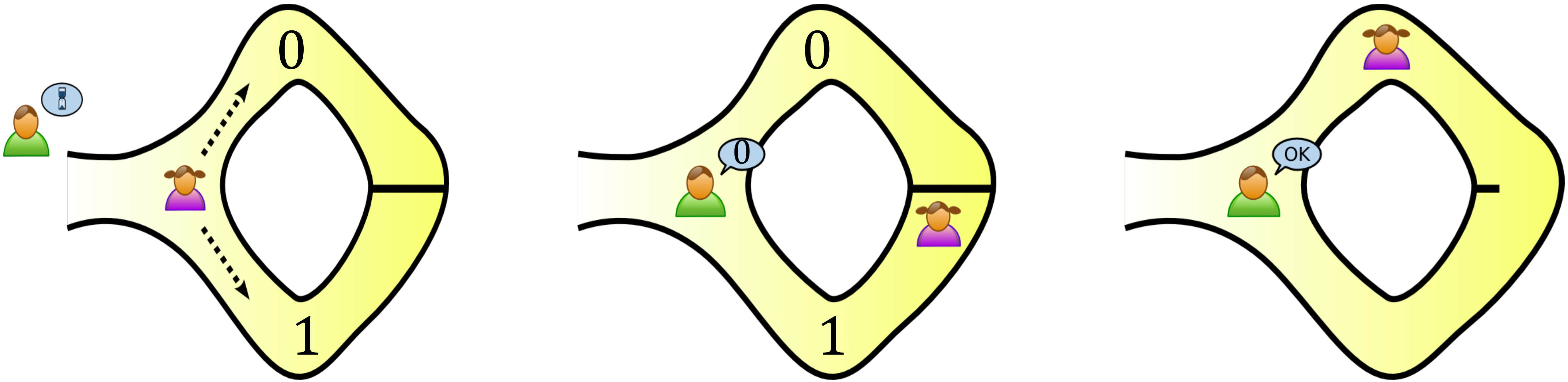
Turing Award

Zero Knowledge Proof



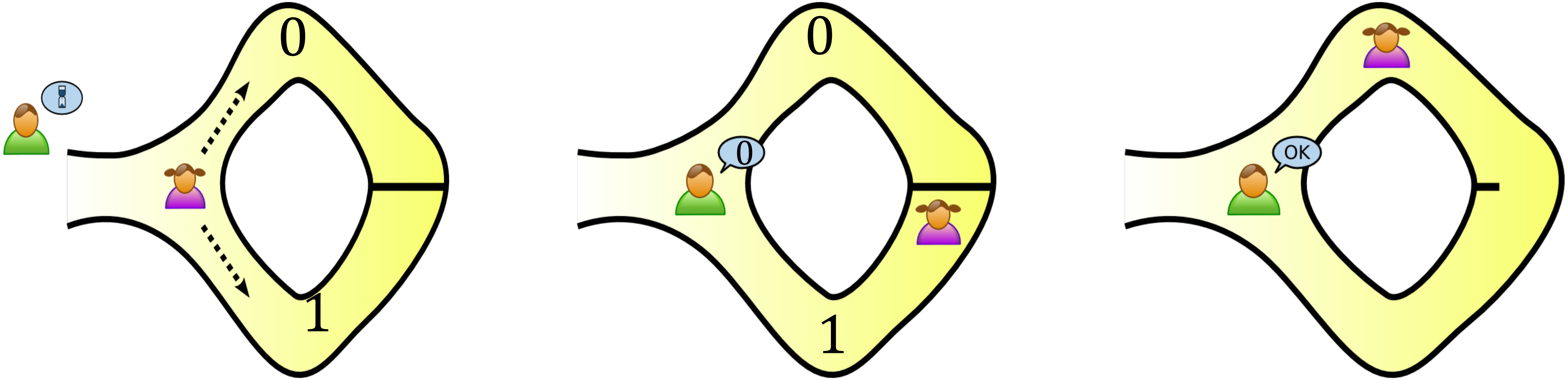
Goldwasser, Micali, Rackoff: The Knowledge Complexity of Interactive Proof-Systems (Extended Abstract)

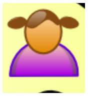
Alibaba Cave



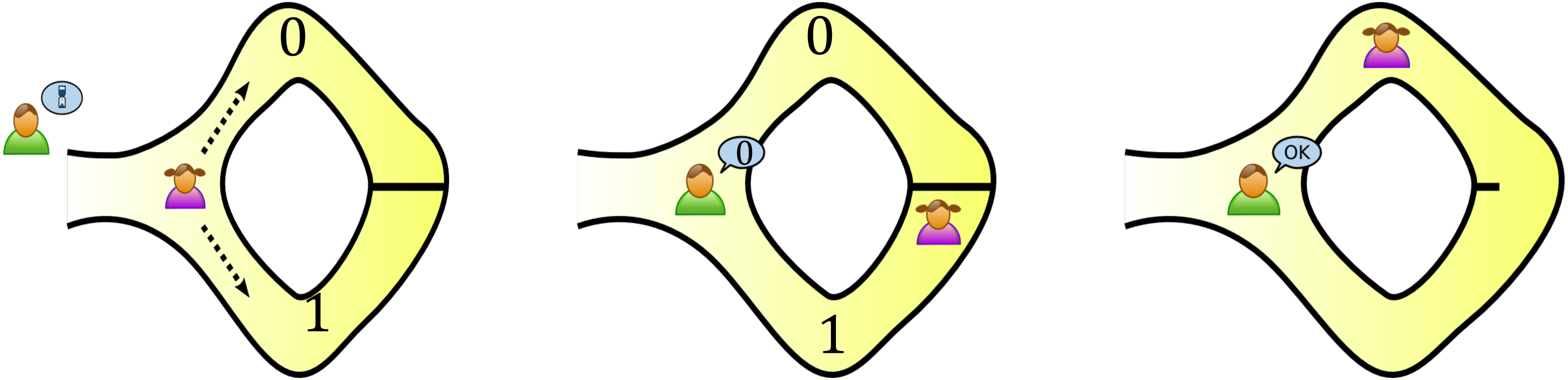
https://en.wikipedia.org/wiki/Zero-knowledge_proof

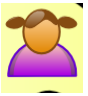
Alibaba Cave



-  does’t know the key, the proof was accepted with 1/2.
-  learns nothing about the magic code

Repeat the game n times



- if  does't know the key, the proof was accepted with $\frac{1}{2^n}$.
-  learns nothing about the magic code

Zero Knowledge Proof

- You want to show me you know the difference

- But do not want to show what the difference is.

- How?

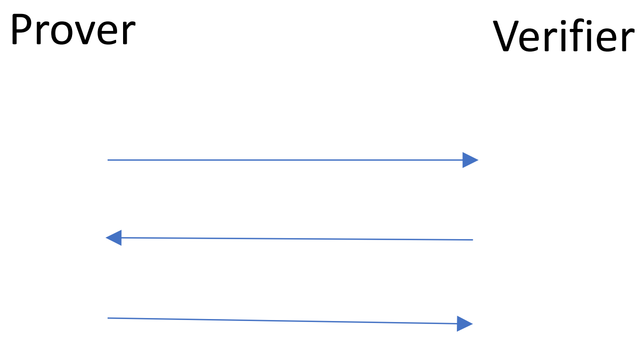
Zero Knowledge Proof for NP language

$x \in L$ if there exists a witness w s.t. $R(x, w) = 1$

$$L \coloneqq \{x | \exists\, w \text{ s.t. } R(x, w) = 1\}$$

Zero Knowledge Proof for NP

- Prover with input (x, w) wants to prove that $x \in L$



- if $x \in L$, verifier accept
- if $x \notin L$, for any (PPT) prover, the verifier will reject
- Zero-knowledge: verifier learns nothing about w

Zero Knowledge Proof (ZKP) for NP

Theorem [GMW86]
Commitment ---> ZKP for all of NP

Theorem [GMW86]
One-way function ---> ZKP for all of NP

zk-SNARK/STARK

- Consider the complexity of the Verifier.
- Could it be less than computing $R(x, w)$?????
- This is motivated by the applications in Blockchain.

YES!!!!

PCP Theorem [AS,ALMSS,Dinur]:
NP statements have polynomial-size PCPs in which the verifier reads only O(1) bits.

- Can be made ZK with small overhead [KPT97,IW04]

Lecture 9: Privacy-Enhancing technologies 2: ZKP

- ZKP various applications
  - outsource verifiable computing;
  - Honest behaviors

How does it work?

How to build efficient (and succinct) ZKP?

Privacy-Enhancing technologies 2: ZKP and MPC

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Lecture 9: Privacy-Enhancing technologies 3: MPC


Diffie


Rivest


Rivest


Yao


Goldwasser


Hellman


Shamir


Adelman


Adelman


Dertouzos


Micali


Rackoff

1976	1977	1978	1982	1985
New directions	RSA	Homomorphic Een	MPC	Zero Knowledge

Yao's Millionaires' Problem

Whose value is greater?

Andrew C. Yao , Protocols for Secure Computations.

Yao's Millionaires' Problem

$$F(x,y) = \begin{cases} (0,1), & x < y \\ (1,0), & x \geq y \end{cases}$$

Two-party computation

- x is Alice's input, a is her output
- y is Bob's input, b is his output

$$F(x, y) = (a, b)$$

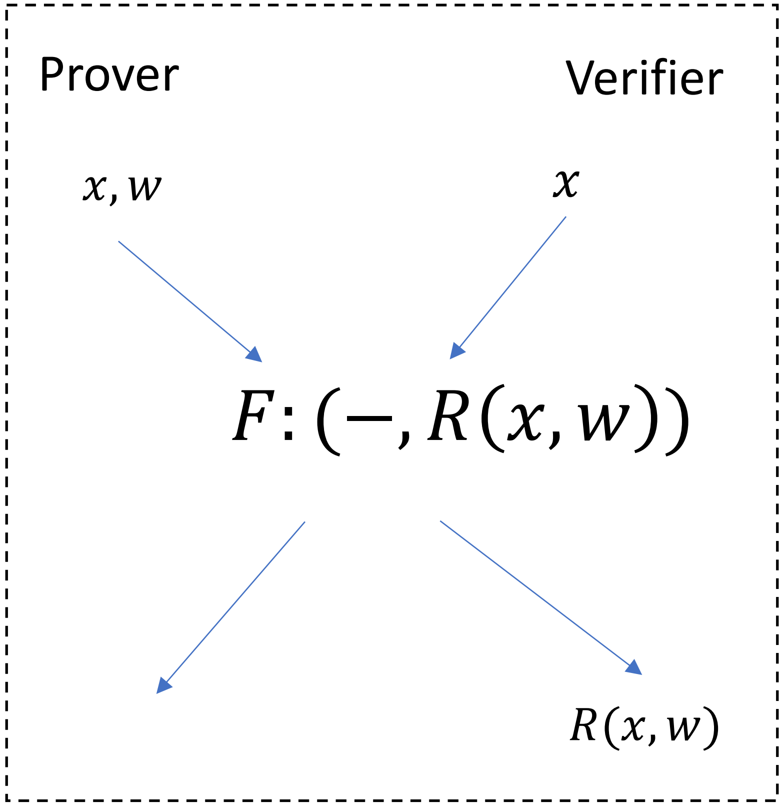
Zero-knowledge proof

$$F(x, y) = (a, b)$$

$$F((x, w), x) = (-, b), b = 1\ if\ x \in L$$

Zero-knowledge proof

$$F((x,w),x) = (-,b), b = R(x,w)$$



Multiparty Computation

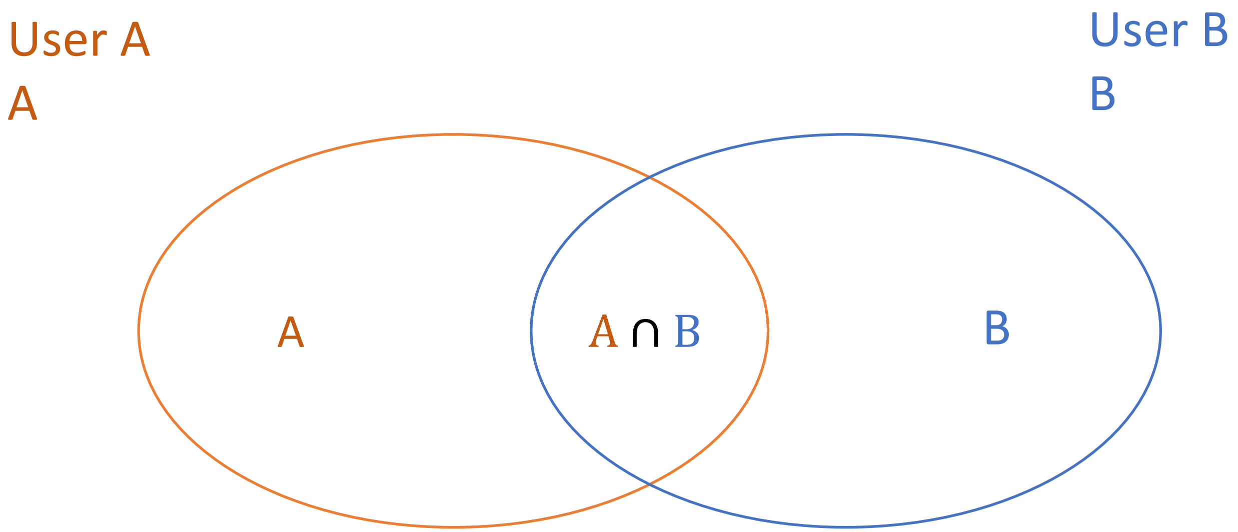
$$F(x_1, x_2, \cdots, x_n) = (y_1, y_2, \cdots y_n)$$

- Electronic voting
- Bidding
- Etc.

Multiparty Computation

Two or more parties want to perform some joint computation,
While guaranteeing “security” against “adversary behavior”

Example: Private set intersection



Chrome: password checkup

A is the set of your **Autofill** passwords, and B is the database of leaked accounts

Multi-party computation

How does it work?

How to build efficient MPC?

Case Studies 1: Blockchain

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Week 9	Privacy-Enhancing technologies 3	secure multiparty computation	??
Week 10	Guest lecture	security and privacy in Blockchain	N/A
Week 11			N/A
Week 12	Final presentation 1	papers from S&P, CCS, USENIX, NDSS, CRYPTO, or EUROCRYPT	N/A
Week 13	Final presentation 2	papers from S&P, CCS, USENIX, NDSS, CRYPTO, or EUROCRYPT	N/A

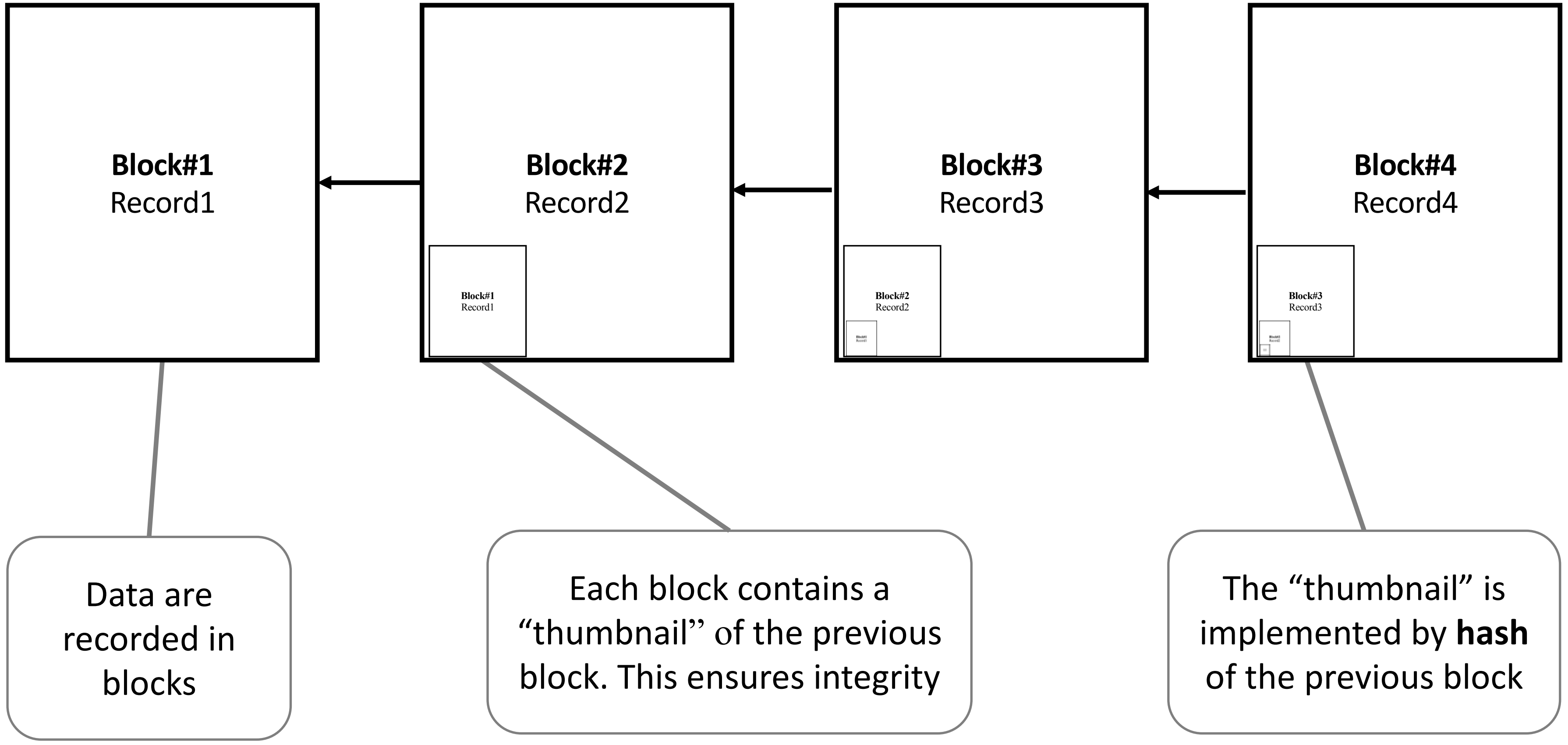
Lecture 11: Case Studies 1: Blockchain

- What is Blockchain

- Security in blockchain
  - Ex. Wallet security

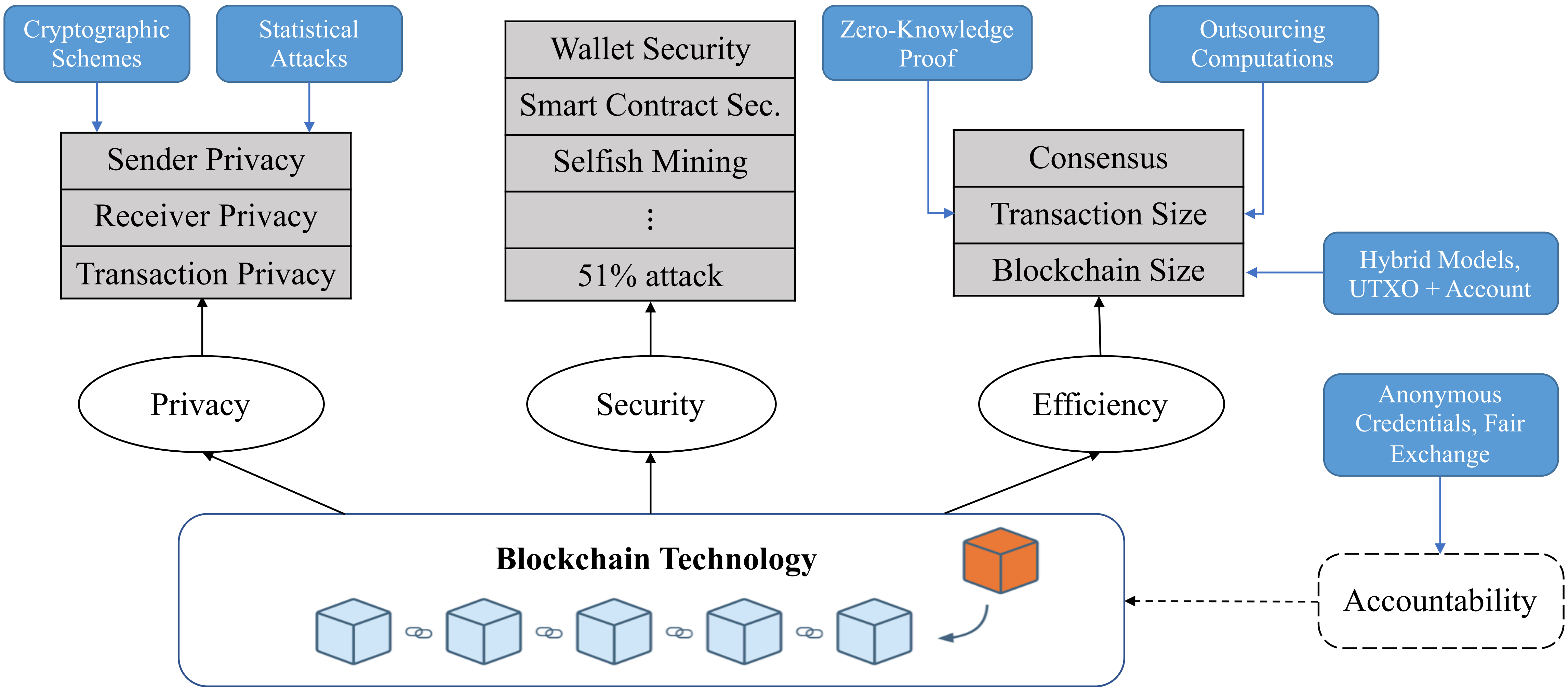
- Privacy in blockchain
  - Ex. private tx,

Blockchain: A public ledger



From Zuoxia Yu

Security and privacy issues



From Zuoxia Yu

Blockchain-based Cryptocurrency

>$ 381 B

The market capitalization of Bitcion is > $381 B

9000
70 x(>$1 B)

more than 70 had a market cap exceeding $1 billion

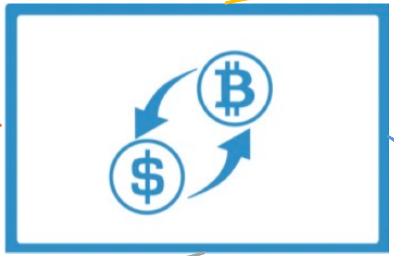
Cryptocurrency (wallet) security

>$ 381 B

The market cap of Bitcion is > $381 B

$ 2.66 B

$2.66 Billion has been stolen since 2012



70 x(>$1 B)

more than 70 had a market cap exceeding $1 billion

>46 Hacked

Since 2012, at least 46 cryptocurrencies have been hacked

List of Hacked Cryptocurrencies

Bitcoin's Biggest loss

At the beginning of 2014, Mt Gox was handling 70% of Bitcoin's transactions.

In Feb. 2014, Mt. Gox lost about 740,000 bitcoins (6% of all bitcoin in existence at the time) due to a "leak" in the wallet.

DATE	EXCHANGE	CAUSE OF HACK	AMOUNT STOLEN (USD)
2022, January 17	Crypto.com	Unknown	$34 million
2021, December 11	AscendEX	Obtained access to hot wallet	$80 million
2021, December 5	BitMart	Obtained access to hot wallet	$150 million
2021, August 19	Liquid	Obtained access to hot wallet	$97 million
2021, April 29	Hotbit	Obtained access to hot wallet	Nil
2020, December 23	Livecoin	Compromised system/servers	Unknown
2020, December 21	EXMO	Obtained access to hot wallet	$4 million
2020, December 1	BTC Markets	Internal staff error/mistake	270,000 user's private details
2020, September 25	KuCoin	Data leak	$275 million
2020, July 11	Cashaa	Malware	$3.1 million
2020, June 29	Balancer	Vulnerability in protocol	$500,000
2020, April 19	Lendf.me	Bugs and Re-entrancy attack	$24.5 million
2020, April 19	Uniswap	Bugs and Re-entrancy	$500,000

https://cryptosec.info/exchange-hacks/
https://www.hedgewithcrypto.com/cryptocurrency-exchange-hacks/

Loss of key = loss of money ☹

A transaction in bitcoin looks like

Tr_1 :

Alice sends $100 to Bob

h=hash (Tr_1)

Signature (sk_A, h)

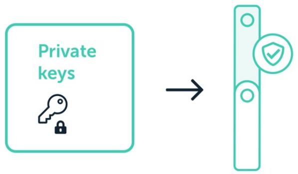
Signature is the standard ECDSA proposed by NIST

The private key sk_A is the only secret that Alice uses to generate this transaction

Lessons Learned

In cryptocurrency, we need to protect the private key

- **Cold Wallet:** a hardware wallet only stores and protects your **private key.**



- **Threshold Cryptography:** Distribute the trust

Blockchain: The need of privacy

- Supply chain privacy
  - A car company does not want to reveal how much it pays to its supplier

- Payment Privacy
  - A company wants to keep its employee's salaries private

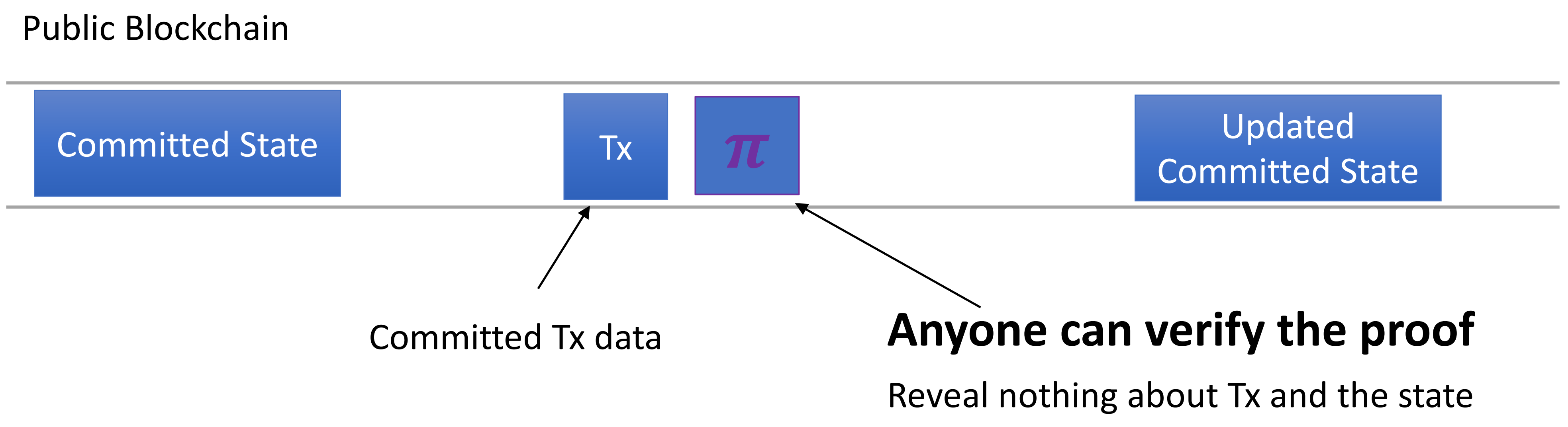
Blockchain: The need of privacy

Can we have private transactions over a public blockchain?

- Seems impossible
  - Universal verifiability --- > transaction data must be public
  - Otherwise, how can we verify the Tx

- Crypto magic
  - Crypto --- > Private Tx on a publicly verifiable blockchain

Blockchain: The need of privacy



- Committed data : short (hiding) commitment of data
- **Proof π**: short zero-knowledge proof that
  - Committed Tx data is consistent with the committed state
  - The updated committed state is correct

Lecture 12-13 Final presentation

Date	Topics	Outline (tentative)	Lecture notes
Week 1	Course Overview	course plan, reading materials, grading, brief introduction to every topic	N/A
Week 2	Basic Cryptography 1: Symmetric-key cryptography	symmetric encryption, one-time pad, blockcipher, hash function, MAC, authenticated encryption.	Haiyang Xue
Week 3	Basic Cryptography 2: Public-key cryptography	RSA, Diffie-Hellman, public key encryption, Digital signature	??
Week 4	Network Security Principles	authenticated key exchange, PKI, and certification authorities	??
Week 5	Network Security in Practice	secure sockets layer (SSL), internet protocol security (IPSec), internet key exchange (IKE), virtual private network (VPN)	??
Week 6	Authentication	access control, password authentication, biometric authentication	??
Week 7	Privacy-Enhancing technologies 1	post-quantum cryptography; Fully-homomorphic encryption and applications	??
Week 8	Privacy-Enhancing technologies 2	commitment, zero-knowledge proofs;	??
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Lecture notes

Date	Topics	Lecture notes
Week 1: Jan 10	Course Overview	N/A
Week 2: Jan 17	Basic Cryptography 1: Symmetric-key cryptography	Haiyang Xue
Week 3: Jan 31	Basic Cryptography 2: Public-key cryptography	??
Week 4: Feb 7	Network Security Principles	??
Week 5: Feb 14	Network Security in Practice	??
Week 6: Feb 21	Authentication	??
Week 7: Feb 28	Privacy-Enhancing technologies 1	??
Week 8: Mar 7	Privacy-Enhancing technologies 2	??
Week 9: Mar 14	Privacy-Enhancing technologies 3	??
Week 10: Mar 21	Security and Privacy in Practice 1	N/A
Week 11: Mar 28	Security and Privacy in Practice 2	N/A
Week 12: Apr 4	Final presentation 1	N/A
Week 13: Apr 11	Final presentation 2	N/A

Choose lecture notes

- Choose your lecture notes on/after Lecture 2

Thank you

and two more examples

Security Examples

https://kentonbrothers.com/generalinfo/1984/

An example from Yoshi Kohno

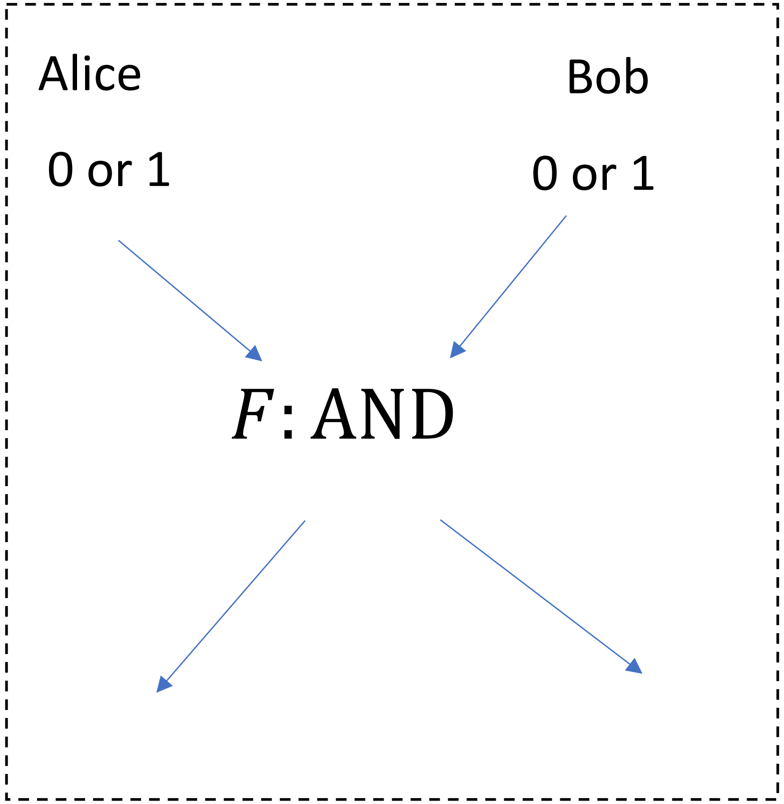
A fun privacy problem

- Bob and Alice want to check if they are interested in dating
  - If both are yes, the output is yes
  - If one is no, the output is no

- If Bob says NO, the output is always NO, no matter whether Alice said YES or NO.
  - Alice does not lose face.

<Pride and Prejudice>

A fun privacy problem



<Pride and Prejudice>

Lecture 3: Public-key cryptography

- Case studies
  - WhatsApp

Public Key Types

- `Identity Key Pair` – A long-term Curve25519 key pair, generated at install time.
- `Signed Pre Key` – A medium-term Curve25519 key pair, generated at install time, signed by the `Identity Key`, and rotated on a periodic timed basis.
- `One-Time Pre Keys` – A queue of Curve25519 key pairs for one time use, generated at install time, and replenished as needed.

Session Key Types

- `Root Key` – A 32-byte value that is used to create `Chain Keys`.
- `Chain Key` – A 32-byte value that is used to create `Message Keys`.
- `Message Key` – An 80-byte value that is used to encrypt message contents. 32 bytes are used for an AES-256 key, 32 bytes for a HMAC-SHA256 key, and 16 bytes for an IV.

https://faq.whatsapp.com/820124435853543