EECS 575: Advanced Cryptography
Fall 2022
Lecture 1

Paul Grubbs

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Beyster 4709

Agenda for this lecture

- Introductions
  - Who are your course staff? Who are you all?
- Course policies and syllabus
- Motivation, course overview, and information-theoretic security

About Me

- Just finished first year of faculty
- Did a postdoc at NYU before joining UMich
- PhD Cornell (2020), undergrad at Indiana
- Worked as a cryptography engineer
- website: https://web.eecs.umich.edu/~paulgrub/
- he/him/his pronouns
- Research: applied cryptography, security, systems
  - Managing encrypted data, searchable encryption, authenticated encryption, attacks, provable security, messaging, zero-knowledge proofs, etc…
- Outside of work:
  - Reading about history, pandemics, social issues, politics, languages…
  - watching sitcoms/movies (currently: re-watch of Fast+Furious series)
  - playing Switch (Overwatch)

About Our GSI

Alexandra Veliche
aveliche@umich.edu

- PhD candidate in CSE, advised by Mahdi Cheraghchi
  - Research interests in coding theory, theoretical cryptography, complexity theory
- Art projects
- Hiking
- Reading
- Experimental baking (!?)

About You!

Go around the room and introduce yourself to us:

- Name, preferred pronouns
- one thing you want to get out of this class, or a topic you’re excited about
- an interesting fact about yourself

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Course Setup

- Lecture-based course. I will give lectures.
  - Monday and Wednesday, 9-10:30am DOW 1005
- One discussion per week, led by Alexandra.
  - Friday 1:30-2:30pm, DOW 1005
  - I may or may not attend
- Several office hours throughout the week (see syllabus)
- If you need to email the course staff, include [EECS575FA22] in the subject line

Course Materials

- Lecture notes: https://github.com/pag-crypto/EECS575-fall22
  - Chris’s notes from past semesters: https://github.com/cpeikert/TheoryOfCryptography
- Canvas: https://umich.instructure.com/courses/546123
- Piazza: https://piazza.com/class/l79a7bug761mw
- Gradescope: https://www.gradescope.com/courses/429591
- No required textbook, but you’ll likely find the optional textbook useful

COVID Accommodations

- All lectures and discussions will be recorded and made available online.
- PDFs of slides with markups will also be available on the Github.
- Students are recommended to wear masks in class. Make sure to complete your ResponsiBLUE screenings as well. **If you feel sick, do not come to class.**

Grading

- Your final grade will have three components:
  - 50%: homework assignments, Canvas peer review of others' solutions, and class participation
  - 25%: Take-home exam #1
  - 25%: Take-home exam #2
- All homework and exam solutions *must* be typeset in LaTeX.
- Collaboration and external sources are allowed for homeworks, with some caveats (see syllabus) but not for exams. Must list collaborators on HWs
- Some lectures are not yet typeset. If you feel you need extra credit, you may be able to get it for writing good scribe notes for these lectures. Contact me for info.
- Grades in grad school really don't matter, so don't worry too much about them.

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Motivating our topic of study

This class is about *cryptography.*

Anyone want to try to define cryptography, in their own words?

Why study cryptography?

I'm going to try to answer this question two ways…

1. Standard answer I've often heard, but find incomplete
2. More satisfying answer

Answer #1

Cryptography, an ancient discipline whose origins predate digital computers by centuries, is compelling and exciting because of how it leverages deep mathematical and complexity-theoretic insights to make computers more secure.

Why I find it unsatisfying

This motivates cryptography, but many other things as well…

Cryptography, an ancient discipline whose origins predate digital computers by centuries, is compelling and exciting because of how it leverages deep mathematical and complexity-theoretic insights to make computers more secure.

This describes:
- number theory
- statistics (i.e., ML)
- algorithms

This describes:
- coding theory
- machine learning
- programming languages

This describes:
- static analysis
- distributed systems
- turning the computer off
- destroying the computer

Answer #2

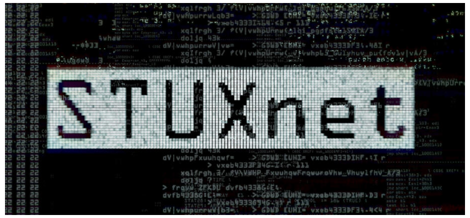
We live in an Information Age.
In our world, information is…

Money

Political influence

How the Russians hacked the DNC and passed its emails to WikiLeaks

Weaponry



Identity

AADHAAR

Protest

me too.

Answer #2

Cryptography is a means to control information;
thus, cryptography is inextricably linked to power.

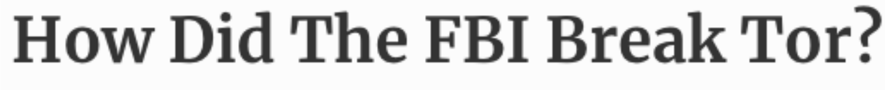
We live in an Information Age.
In our world, information is…

⚡ Power! ⚡

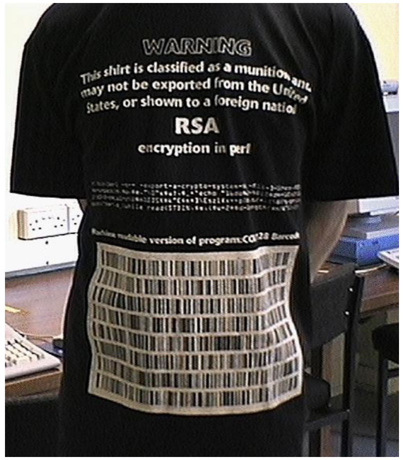
“Cryptography rearranges power: it configures who can do what, from what. This makes cryptography an inherently political tool, and it confers on the field an intrinsically moral dimension.”
– Rogaway, “The Moral Character of Cryptographic Work”

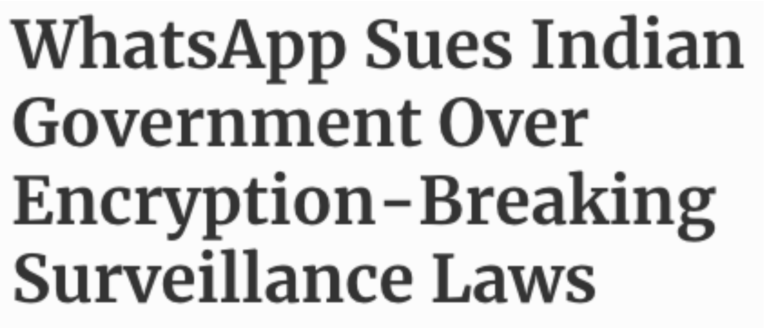
Answer #2

Governments try to subvert and/or ban strong cryptography *all the time…!*

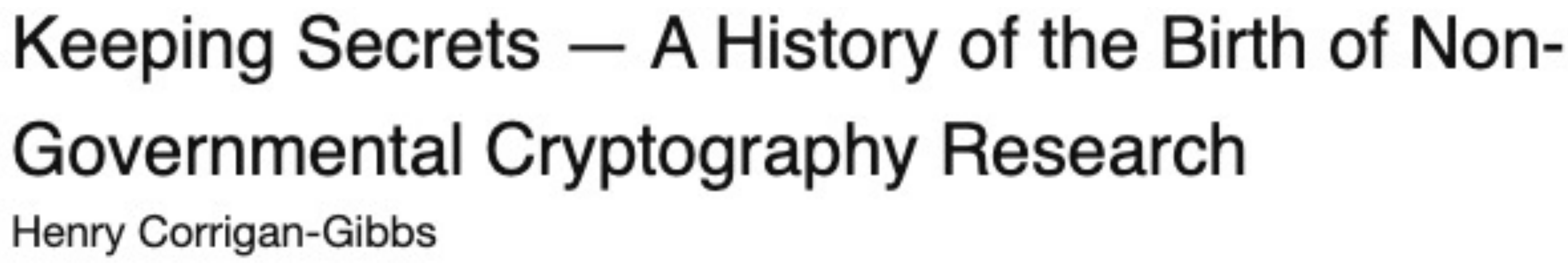


How Did The FBI Break Tor?


WARNING
This shirt is classified as a munition and may not be exported from the United States, or shown to a foreign national
RSA
encryption in perl
Machine readable version of program: CODE128 Barcode



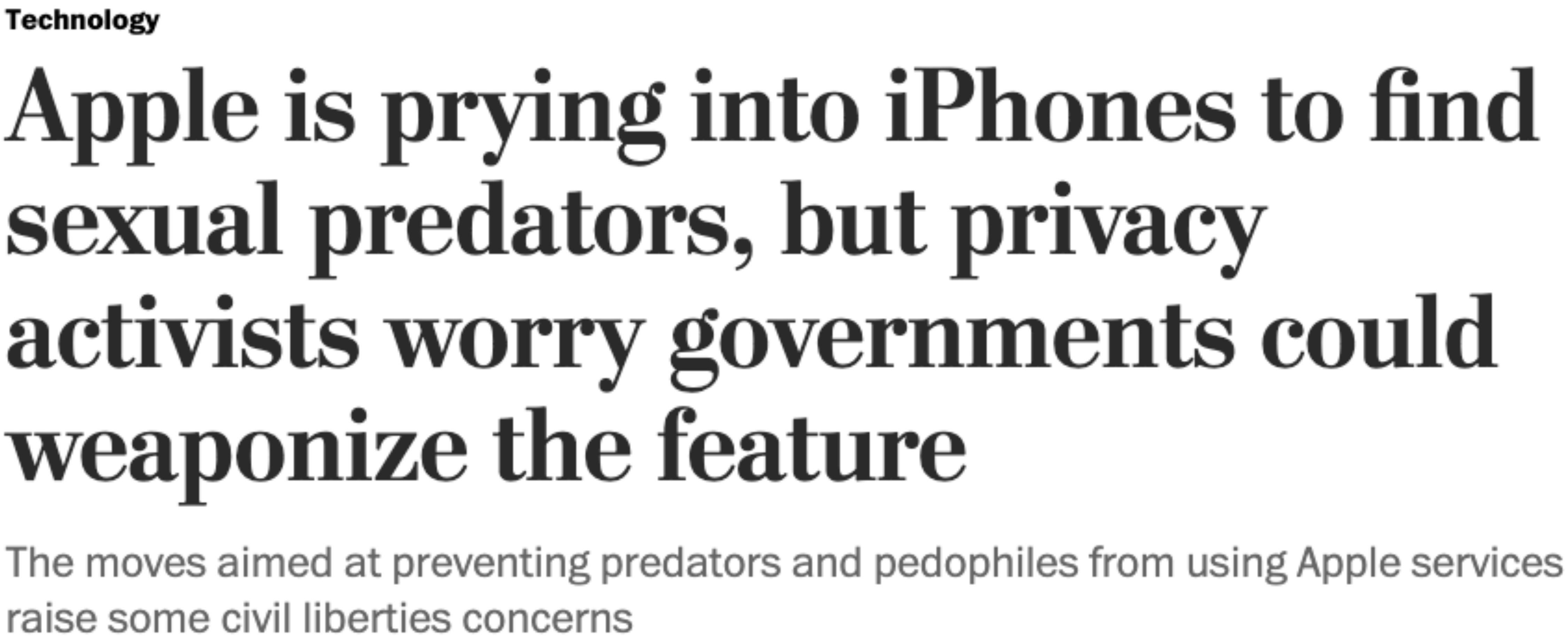
WhatsApp Sues Indian Government Over Encryption-Breaking Surveillance Laws



Keeping Secrets — A History of the Birth of Non-Governmental Cryptography Research

Henry Corrigan-Gibbs

Answer #2



Technology

Apple is prying into iPhones to find sexual predators, but privacy activists worry governments could weaponize the feature

The moves aimed at preventing predators and pedophiles from using Apple services raise some civil liberties concerns

Answer #2

Cryptography is compelling, exciting, and worthwhile for all the reasons listed above, but also (especially) because in the Information Age, controlling information is exercising power.

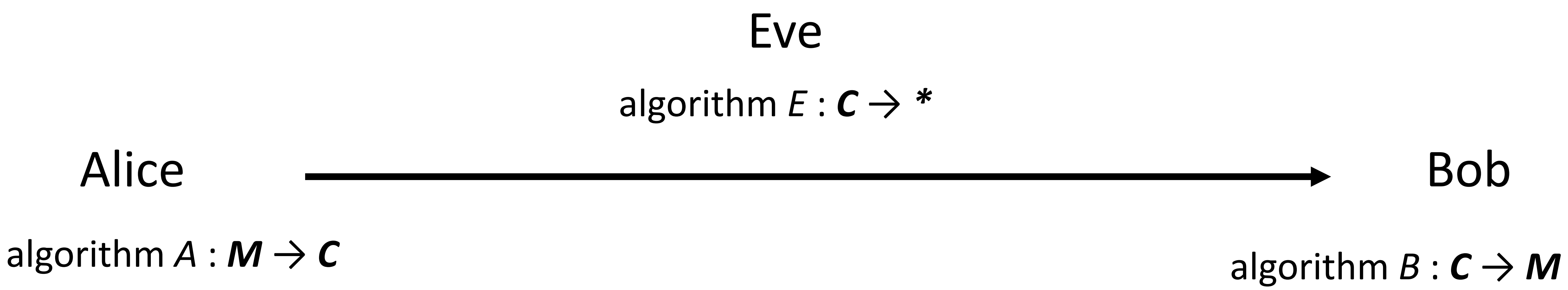
Course Overview

- **Information-theoretic security:** Perfect secrecy. The one-time pad.
- **Symmetric cryptography:** one-way functions, computational security, pseudorandomness, encryption, message authentication, authenticated encryption, hash functions
- **Asymmetric cryptography:** Number-theoretic background. Public-key encryption. Digital signatures. Elliptic curve cryptography
- **Protocols:** Commitment, identification schemes, secret sharing, zero-knowledge proofs.
- **Applications/Special Topics:** blockchains and cryptocurrencies, private information retrieval, secure messaging

In studying these, we'll follow the *cryptographic methodology:*

1. Form a precise mathematical model of the problem
2. Define the desired functionality and security properties of a solution
3. Construct a candidate solution with the desired functionality
4. Analyze the solution and rigorously prove it satisfies the security properties

Modelling Secure Communication



Eve

algorithm $E : \boldsymbol{C} \to \boldsymbol{*}$

Alice

Bob

algorithm $A : \boldsymbol{M} \to \boldsymbol{C}$

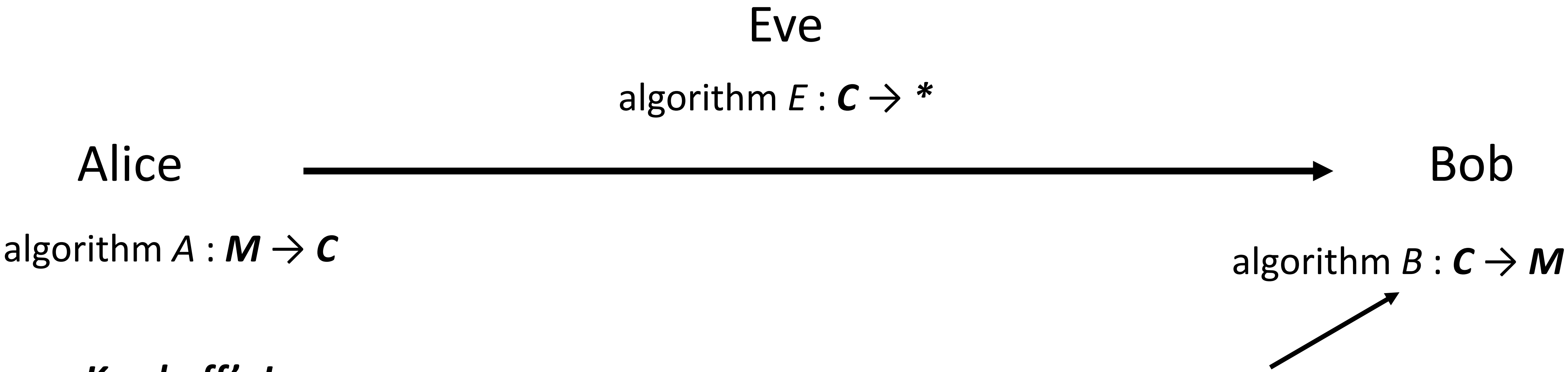
algorithm $B : \boldsymbol{C} \to \boldsymbol{M}$

Desired functionality: for any m in $\boldsymbol{M}$, $B(A(\mathrm{m})) = \mathrm{m}$

Desired security?

Can just set $E = B$ and learn any message. Hmm…

Fixing the Model



Eve

algorithm E : $\boldsymbol{C} \to \boldsymbol{*}$

Alice

Bob

algorithm A : $\boldsymbol{M} \to \boldsymbol{C}$

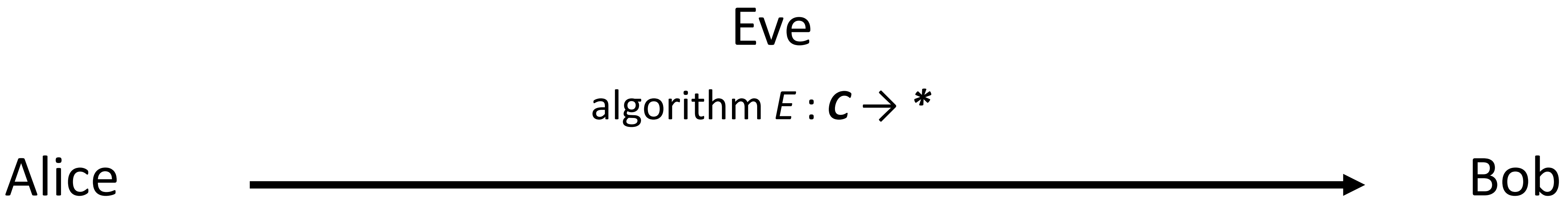
algorithm B : $\boldsymbol{C} \to \boldsymbol{M}$

What if the algorithm *B* was secret?

Security through obscurity

Kerchoff’s Law:
A cryptographic algorithm should be secure even if its description is public.

Symmetric-Key Encryption



Eve

algorithm $E : \boldsymbol{C} \to \boldsymbol{*}$

Alice

Bob

Enc : $\boldsymbol{K} \times \boldsymbol{M} \to \boldsymbol{C}$

Dec : $\boldsymbol{K} \times \boldsymbol{C} \to \boldsymbol{M}$

Instead, allow both Enc and Dec to take a ***key*** k.
K is generated by a randomized algorithm Gen

Desired functionality: for any m in $\boldsymbol{M}$ and k in $\boldsymbol{K}$, Dec(k, Enc(k, m)) = m

Questions:

- In this model, how must $|\boldsymbol{M}|$ and $|\boldsymbol{C}|$ be related?
- Can we infer anything about $|\boldsymbol{K}|$ in relation to $|\boldsymbol{M}|$ or $|\boldsymbol{C}|$?

Security of Symmetric-Key Encryption

What security properties might we want here?

Eve

algorithm $E : \boldsymbol{C} \to \boldsymbol{*}$

Alice

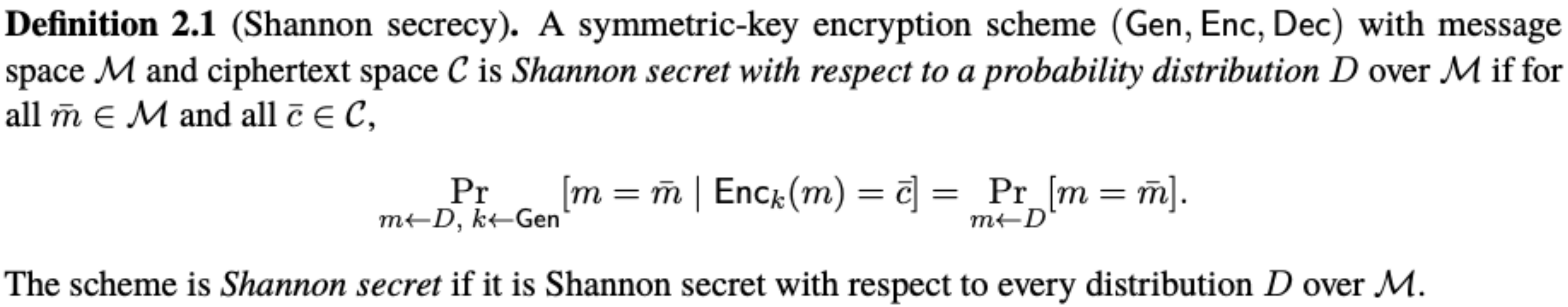
Bob

Enc : $\boldsymbol{K} \times \boldsymbol{M} \to \boldsymbol{C}$

Dec : $\boldsymbol{K} \times \boldsymbol{C} \to \boldsymbol{M}$

Seeing the ciphertext should be no better than seeing *nothing at all*

Shannon Secrecy

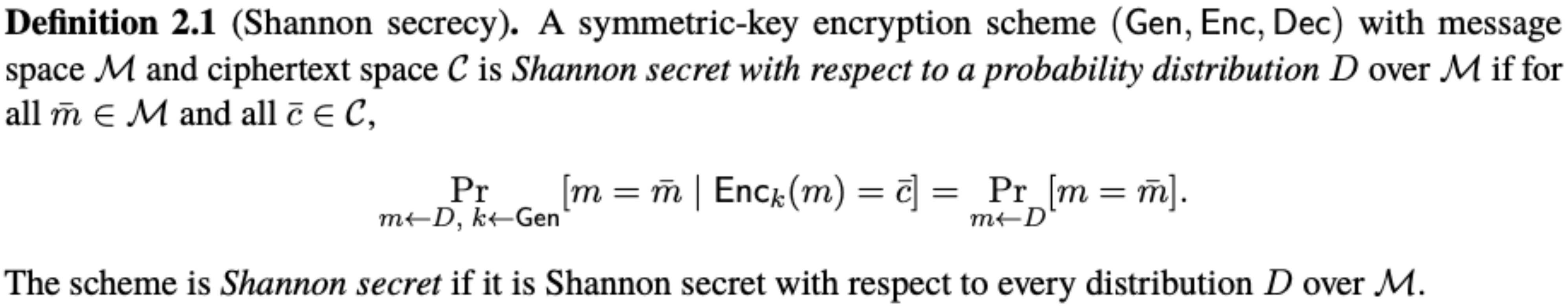


Definition 2.1 (Shannon secrecy)**.** A symmetric-key encryption scheme $(\mathsf{Gen}, \mathsf{Enc}, \mathsf{Dec})$ with message space $\mathcal{M}$ and ciphertext space $\mathcal{C}$ is *Shannon secret with respect to a probability distribution D over $\mathcal{M}$* if for all $\bar{m} \in \mathcal{M}$ and all $\bar{c} \in \mathcal{C}$,

$$\Pr_{m \leftarrow D,\ k \leftarrow \mathsf{Gen}}[m = \bar{m} \mid \mathsf{Enc}_k(m) = \bar{c}] = \Pr_{m \leftarrow D}[m = \bar{m}].$$

The scheme is *Shannon secret* if it is Shannon secret with respect to every distribution D over $\mathcal{M}$.

Rewriting Shannon Secrecy

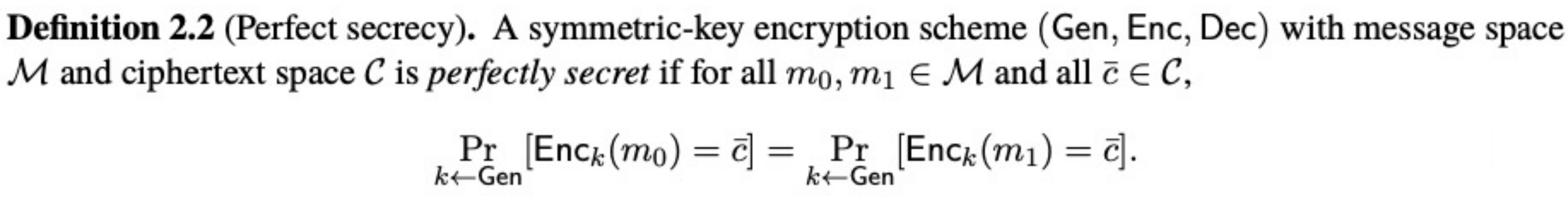


Definition 2.1 (Shannon secrecy)**.** A symmetric-key encryption scheme $(\mathsf{Gen}, \mathsf{Enc}, \mathsf{Dec})$ with message space $\mathcal{M}$ and ciphertext space $\mathcal{C}$ is *Shannon secret with respect to a probability distribution* D over $\mathcal{M}$ if for all $\bar{m} \in \mathcal{M}$ and all $\bar{c} \in \mathcal{C}$,

$$\Pr_{m \leftarrow D,\, k \leftarrow \mathsf{Gen}}[m = \bar{m} \mid \mathsf{Enc}_k(m) = \bar{c}] = \Pr_{m \leftarrow D}[m = \bar{m}].$$

The scheme is *Shannon secret* if it is Shannon secret with respect to every distribution D over $\mathcal{M}$.

Perfect Secrecy

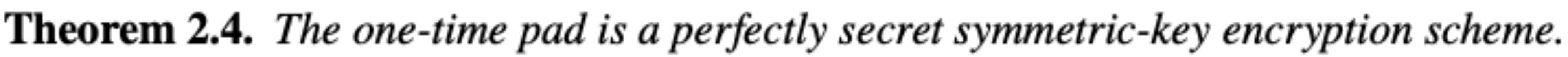


Definition 2.2 (Perfect secrecy)**.** A symmetric-key encryption scheme $(\mathsf{Gen}, \mathsf{Enc}, \mathsf{Dec})$ with message space $\mathcal{M}$ and ciphertext space $\mathcal{C}$ is *perfectly secret* if for all $m_0, m_1 \in \mathcal{M}$ and all $\bar{c} \in \mathcal{C}$,

$$\Pr_{k \leftarrow \mathsf{Gen}}[\mathsf{Enc}_k(m_0) = \bar{c}] = \Pr_{k \leftarrow \mathsf{Gen}}[\mathsf{Enc}_k(m_1) = \bar{c}].$$

The One-Time Pad

Perfect Secrecy of the One-Time Pad



Theorem 2.4. *The one-time pad is a perfectly secret symmetric-key encryption scheme.*

Proof:

Questions to think about

If we replaced XOR with AND in the one-time pad, would it still be a valid encryption scheme? Would it be perfectly secret?

Can you think of some other ways cryptography is related to power? Do you agree that cryptography is *inherently* political?