CNT 4406, Spring 2024

Cryptography

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Agenda

1. Crypto Usage & Goal

2. Classical Crypto

3. One-time Pad & Perfect Secrecy

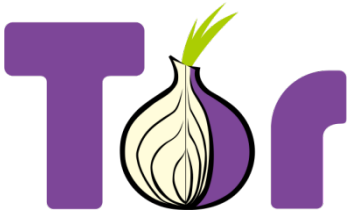
4. Modern Crypto

Crypto Use Is Ubiquitous

HTTPS

Secure messaging

Bitcoin



A Classical Crypto Goal: Privacy

Transfer $5 to account 12345

K_e

K_d

Privacy: Adversary can't learn anything from the content that it eavesdrops.

A Classical Crypto Goal: Privacy

1100000100101
0101011110111

K_e

K_d

Private-key setting: $K_e = K_d$

secret

Public-key setting: $K_e \neq K_d$

public secret

But Privacy Alone Is Not Enough

K_e

Transfer $5 to account 12345

K_e

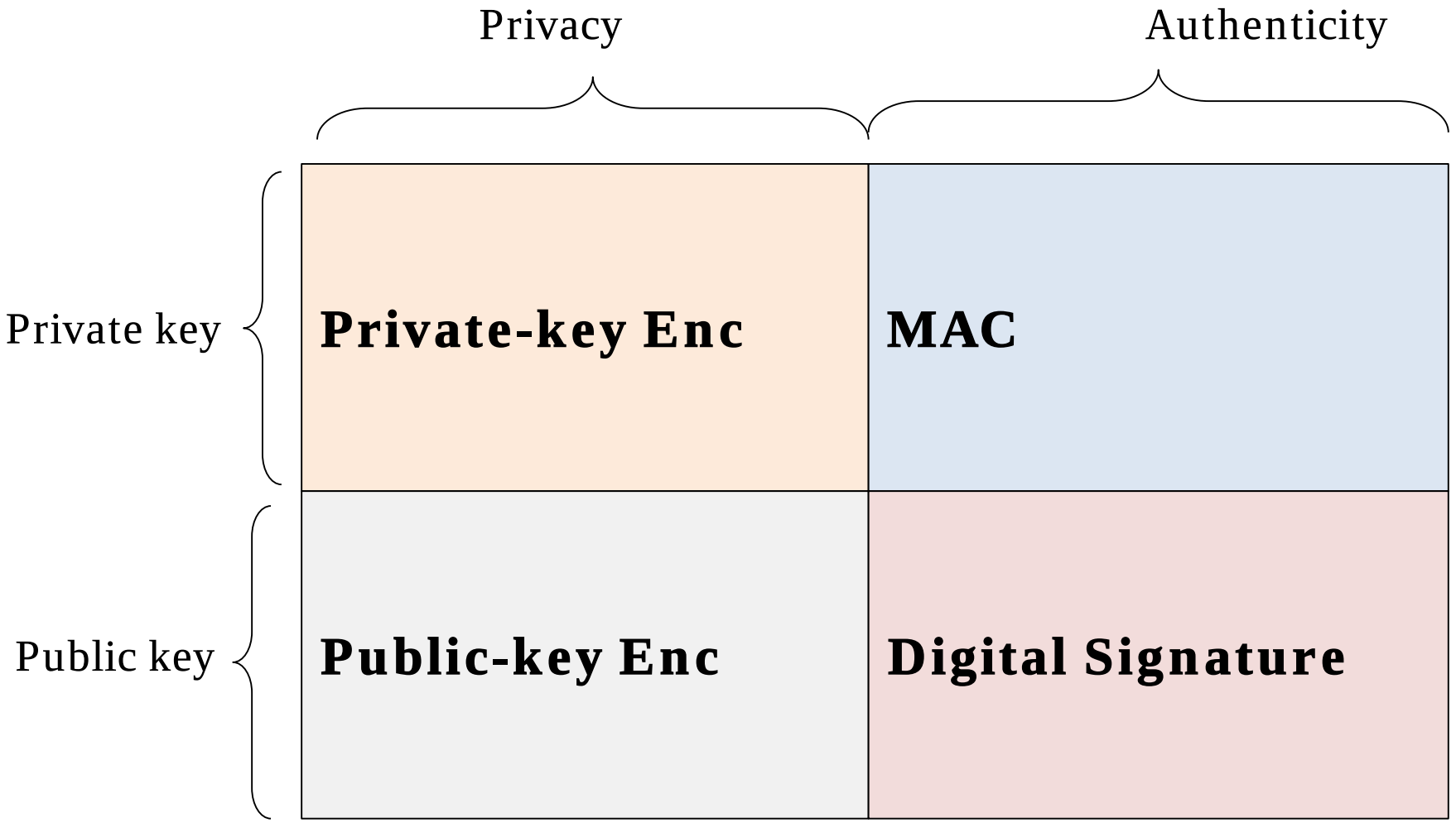
K_d

Transfer $1000 to account 99999

K_e

Authenticity: Adversary can't forge valid ciphertexts

Four Fundamental Cryptographic Problems



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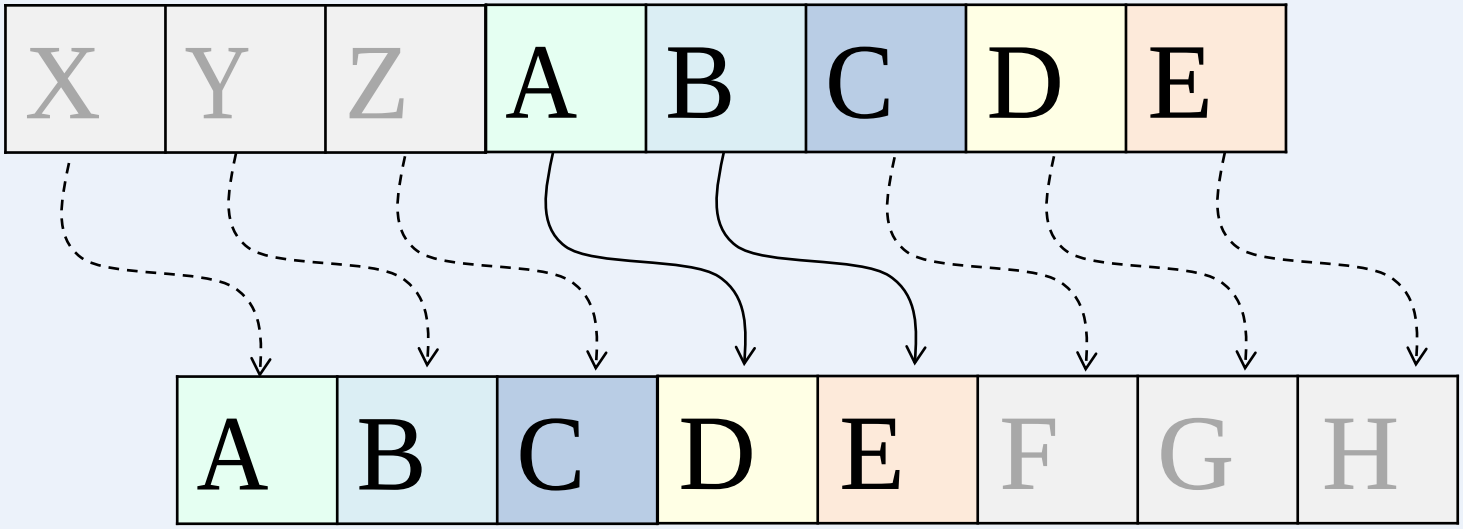
Caesar Cipher



No key

Broken once scheme is known

Caesar Cipher In The Wild

The Register®

This article is more than **1 year old**

Mafia boss undone by clumsy crypto

Little Caesar

John Leyden Wed 19 Apr 2006 // 14:14 UTC

Clues left in the clumsily encrypted notes of a Mafia don have helped Italian investigators to track his associates and ultimately contributed to his capture after years on the run.

The Register®

This article is more than **1 year old**

BA jihadist relied on Jesus-era encryption

30 years for airline bomb plot

Team Register Tue 22 Mar 2011 // 11:52 UTC

An IT worker from British Airways jailed for 30 years for terrorism offences used encryption techniques that pre-date the birth of Jesus.

Shift Cipher

Use a secret key $K \in \{0, \ldots, 25\}$

Same as Caesar cipher, but shift K positions, instead of 3.

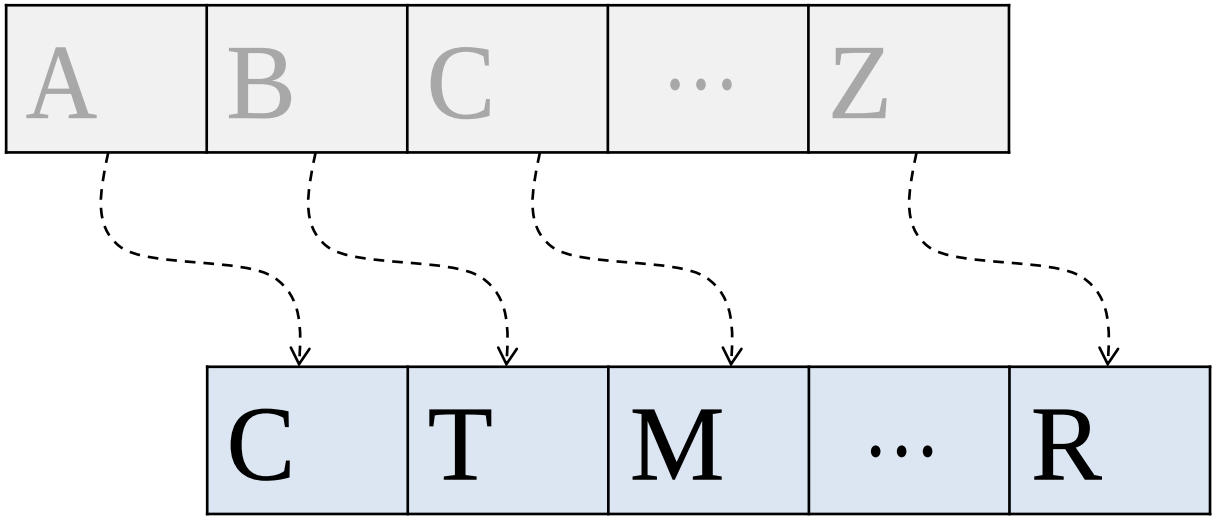
Small Keyspace

Broken by brute force

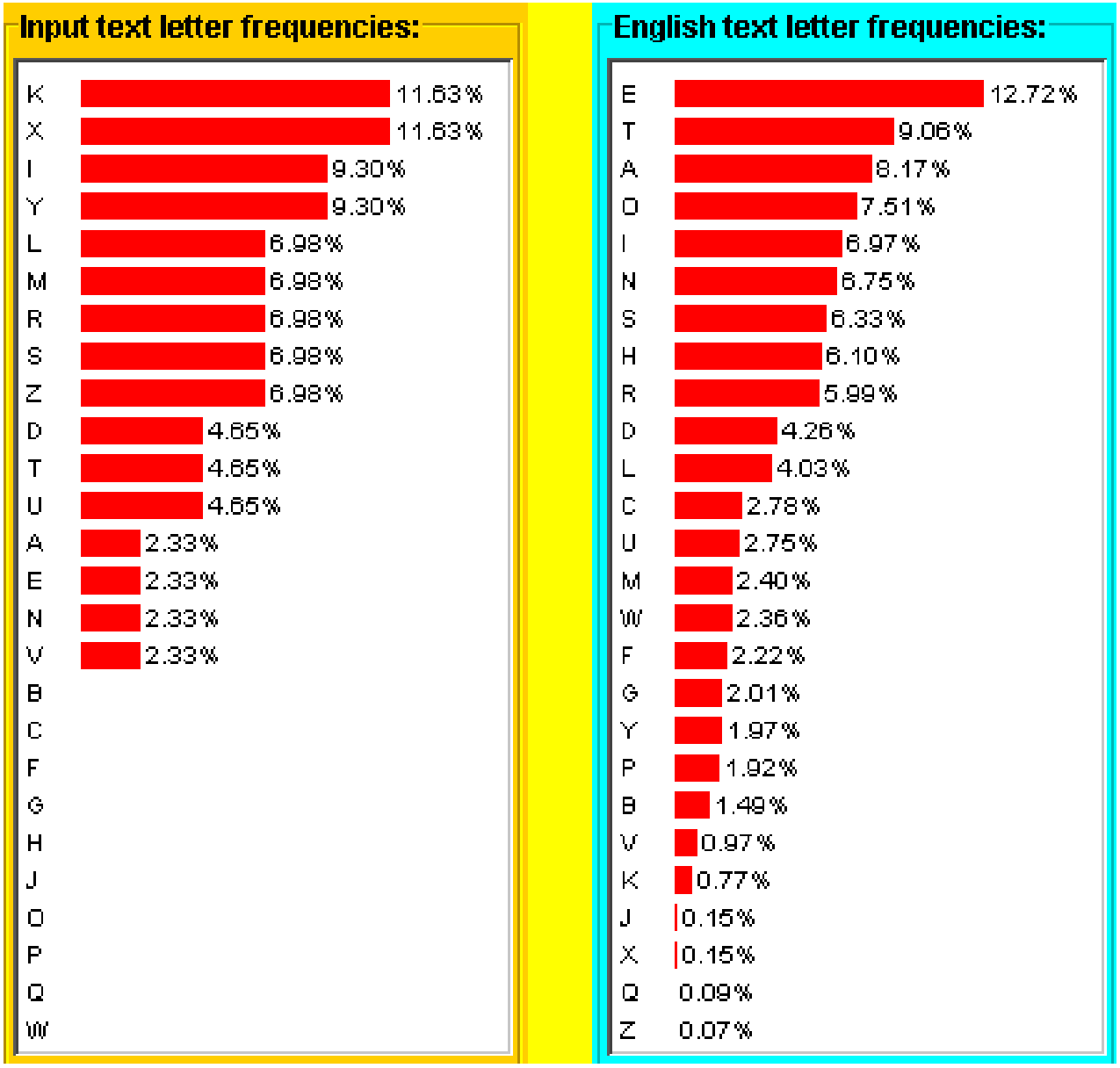
Substitution Cipher

Key: a permutation $\pi : \Sigma \to \Sigma$

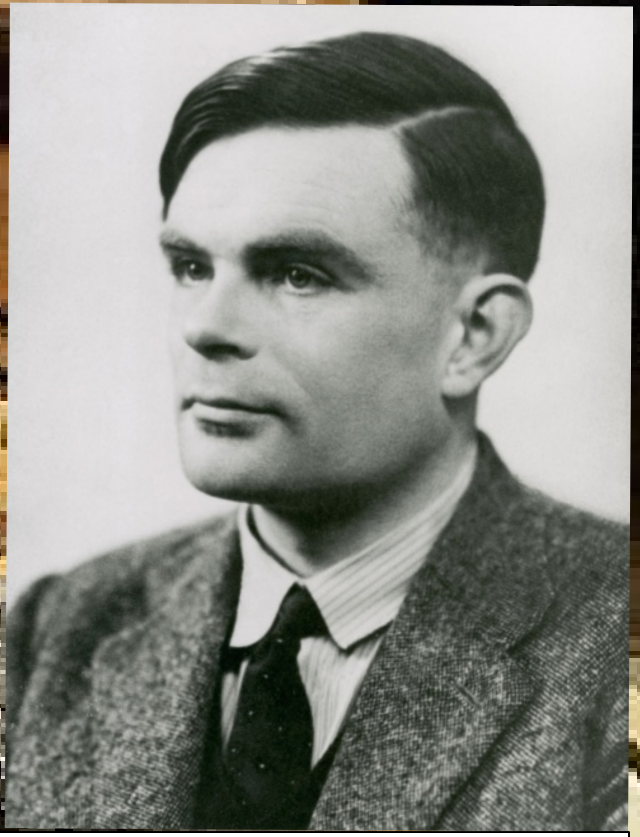
Example: $\Sigma = \{\mathrm{A}, \mathrm{B}, \mathrm{C}, \ldots, \mathrm{Z}\}$



Break Substitution Cipher: Frequency Analysis



The Enigma



Broken by British

in an effort led by Turing

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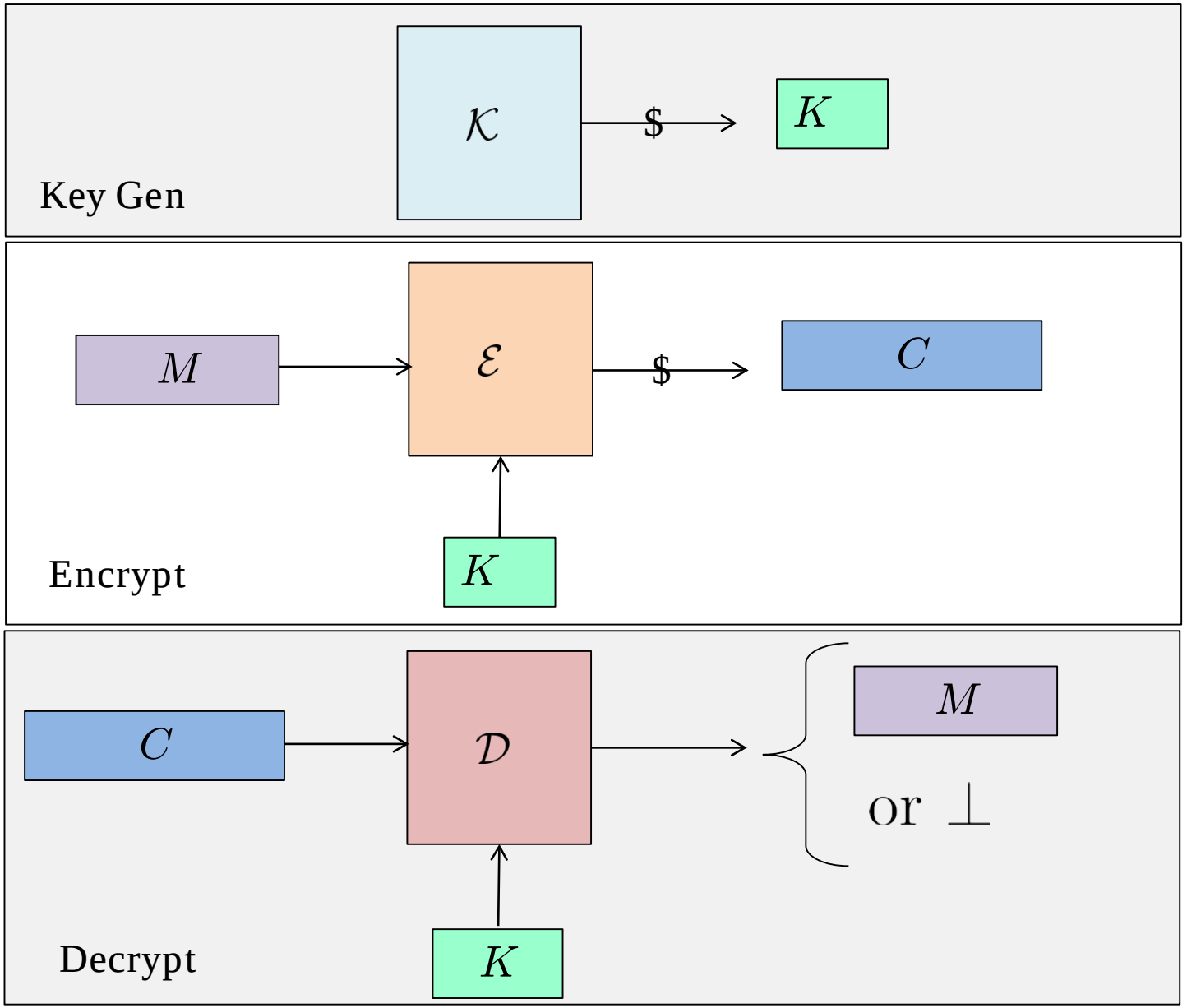
Encryption Syntax



Define security?

Perfect Secrecy

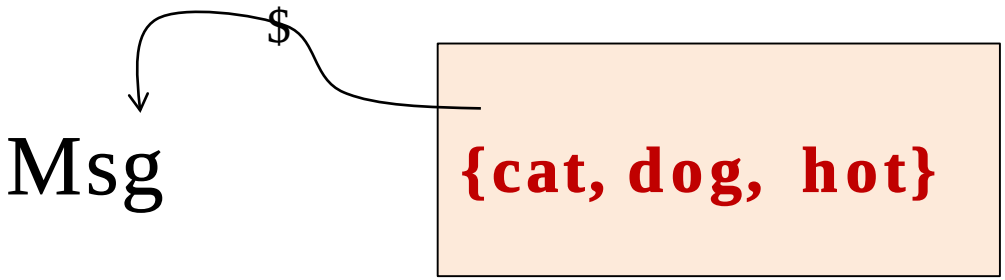
Intuition: Ciphertext should reveal **no additional info** about plaintext

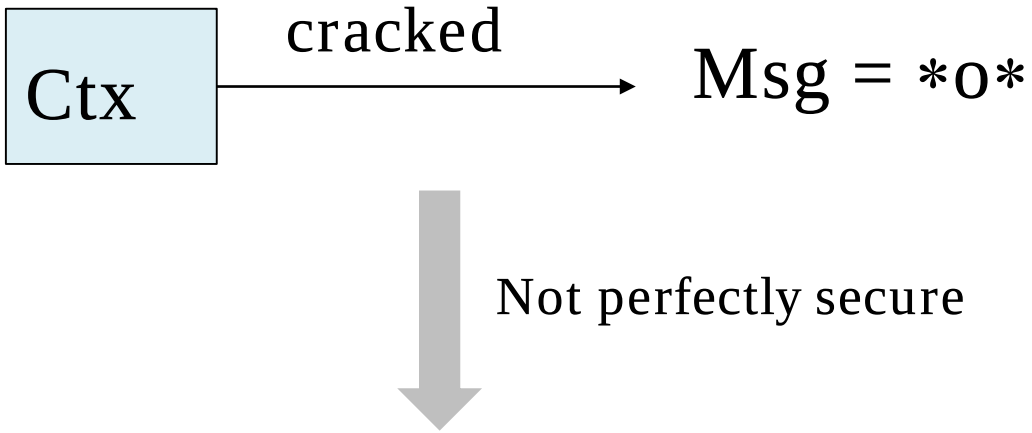
For every m and c:

$$\Pr_{K \xleftarrow{\$} \mathcal{K}}[\mathrm{Msg} = m \mid \mathcal{E}_K(\mathrm{Msg}) = c] = \Pr[\mathrm{Msg} = m]$$

Common case: Ciphertext is uniformly random, independent of msg

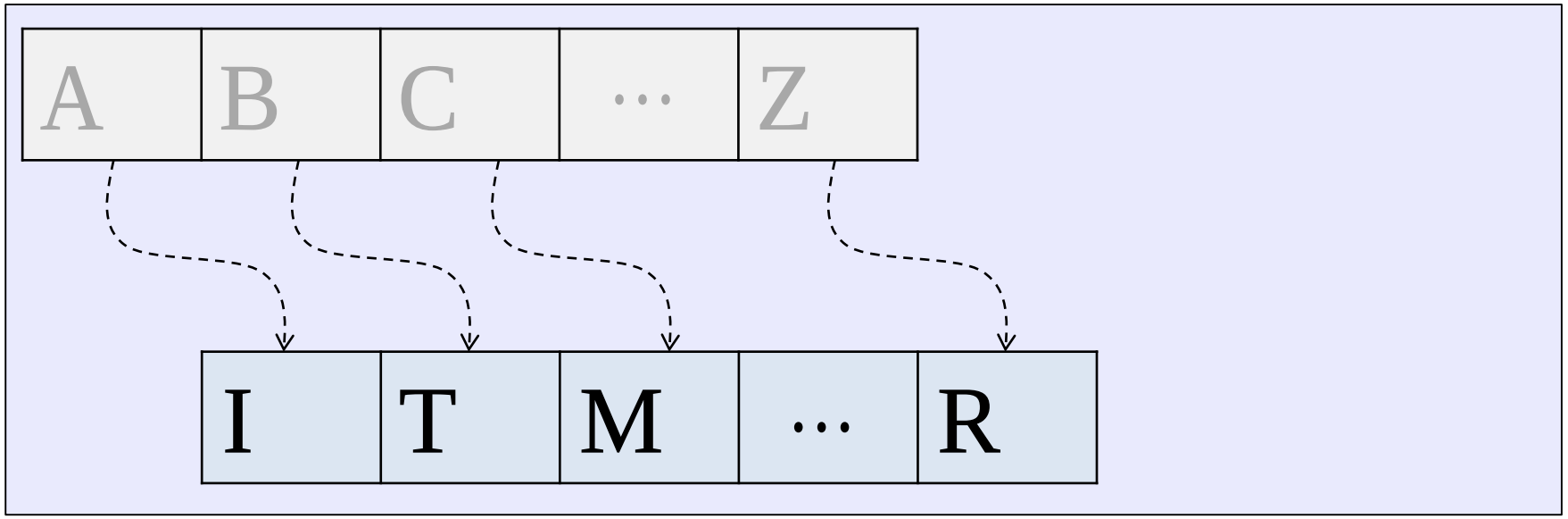
An Example





$$\Pr[\text{Msg} = \text{dog} \mid \text{Ctx}] = \frac{1}{2} \neq \Pr[\text{Msg} = \text{dog}] = \frac{1}{3}$$

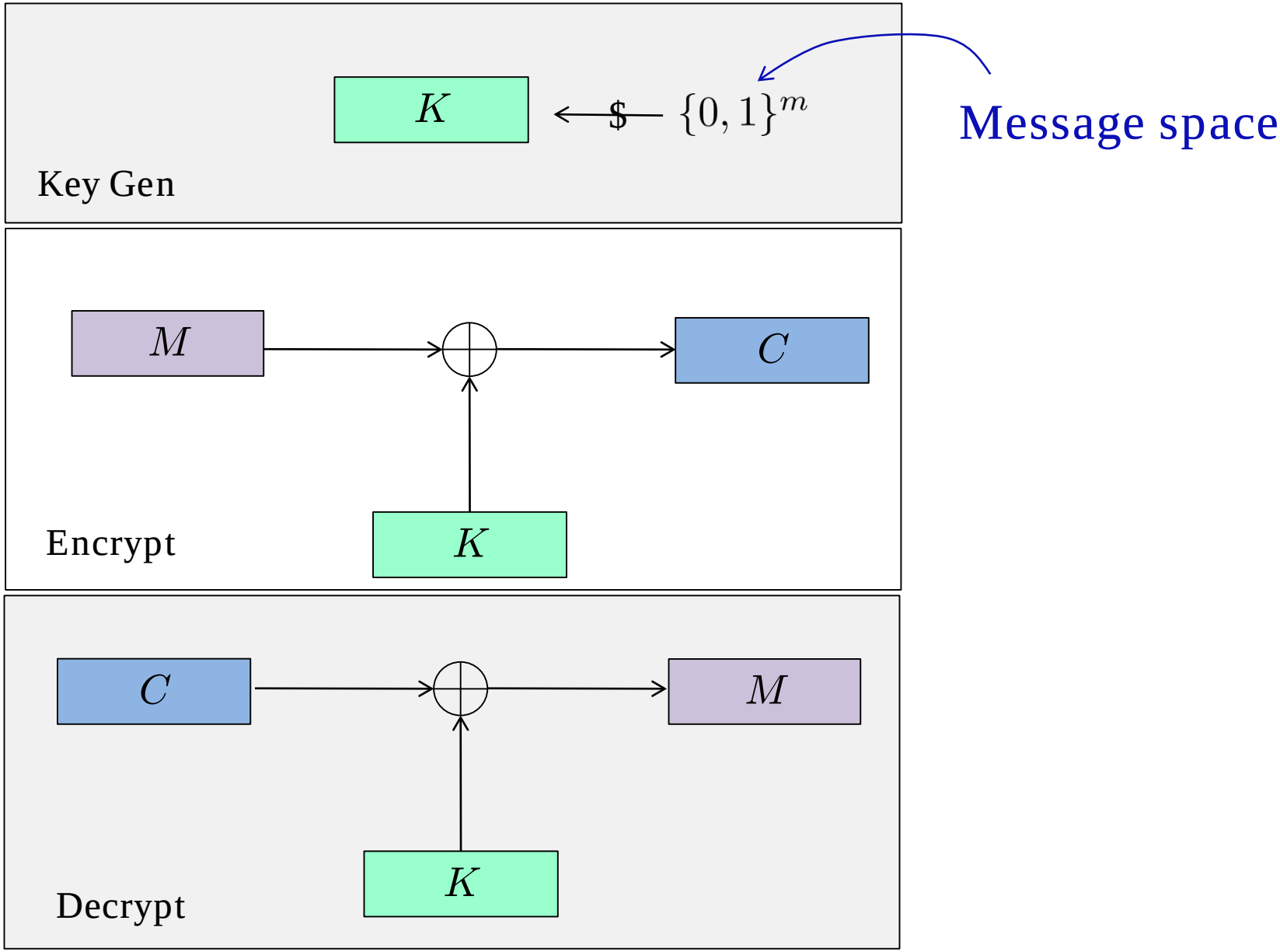
Substitution Cipher Is Not Perfectly Secret



Ctx = “tic tok”

$$\Pr[\text{Msg} = \text{bad boy} \mid \text{Ctx}] = 1 \neq \Pr[\text{Msg} = \text{bad boy}] = 1/2$$

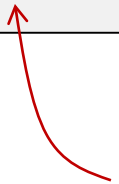
Achieving Perfect Secrecy: One-time Pad



Behind Every Notion, There Is An Assumption

For every m and c:

$$\Pr_{K \xleftarrow{\$} \mathcal{K}}[\mathrm{Msg} = m \mid \mathcal{E}_K(\mathrm{Msg}) = c] = \Pr[\mathrm{Msg} = m]$$



It's **assumed** that you pick a fresh key for each encryption

Reusing One-time Pad Breaks Security

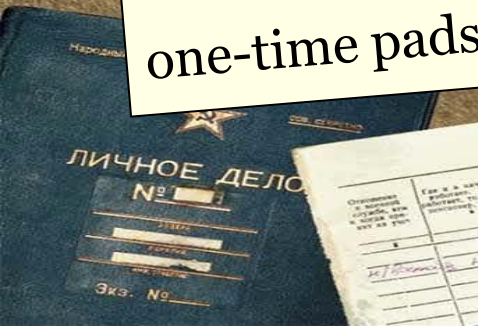
One can obtain $M \oplus M'$ via $C \oplus C'$

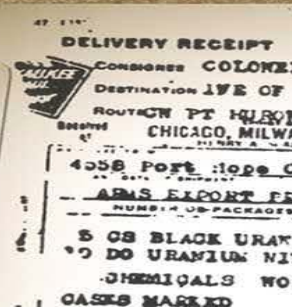
Can recover both M and M' if the messages are English texts and long enough

THE VENONA SECRETS

The Definitive Exposé of Soviet Espionage in America

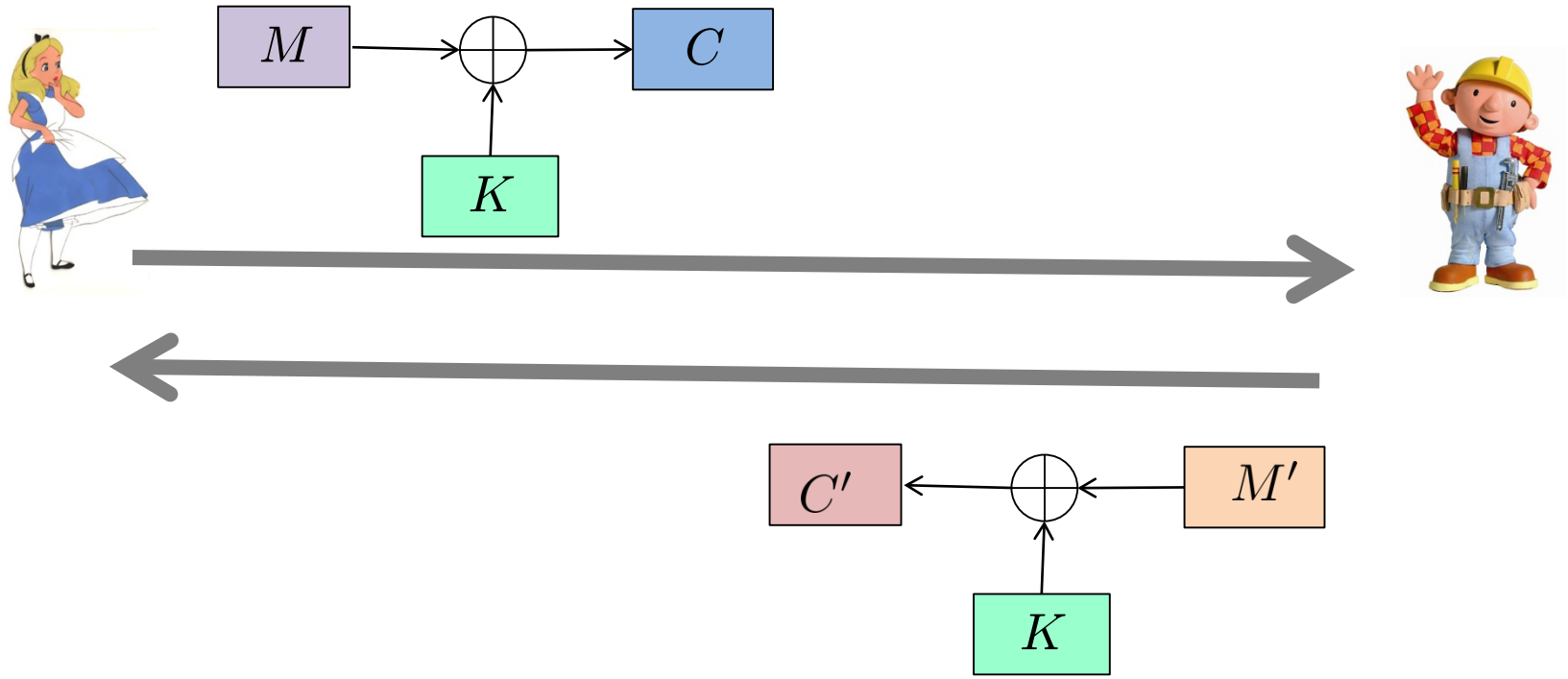
Bad Usage of One-time Pad: USSR's reusing of one-time pads led to the decryption of 2900 messages.

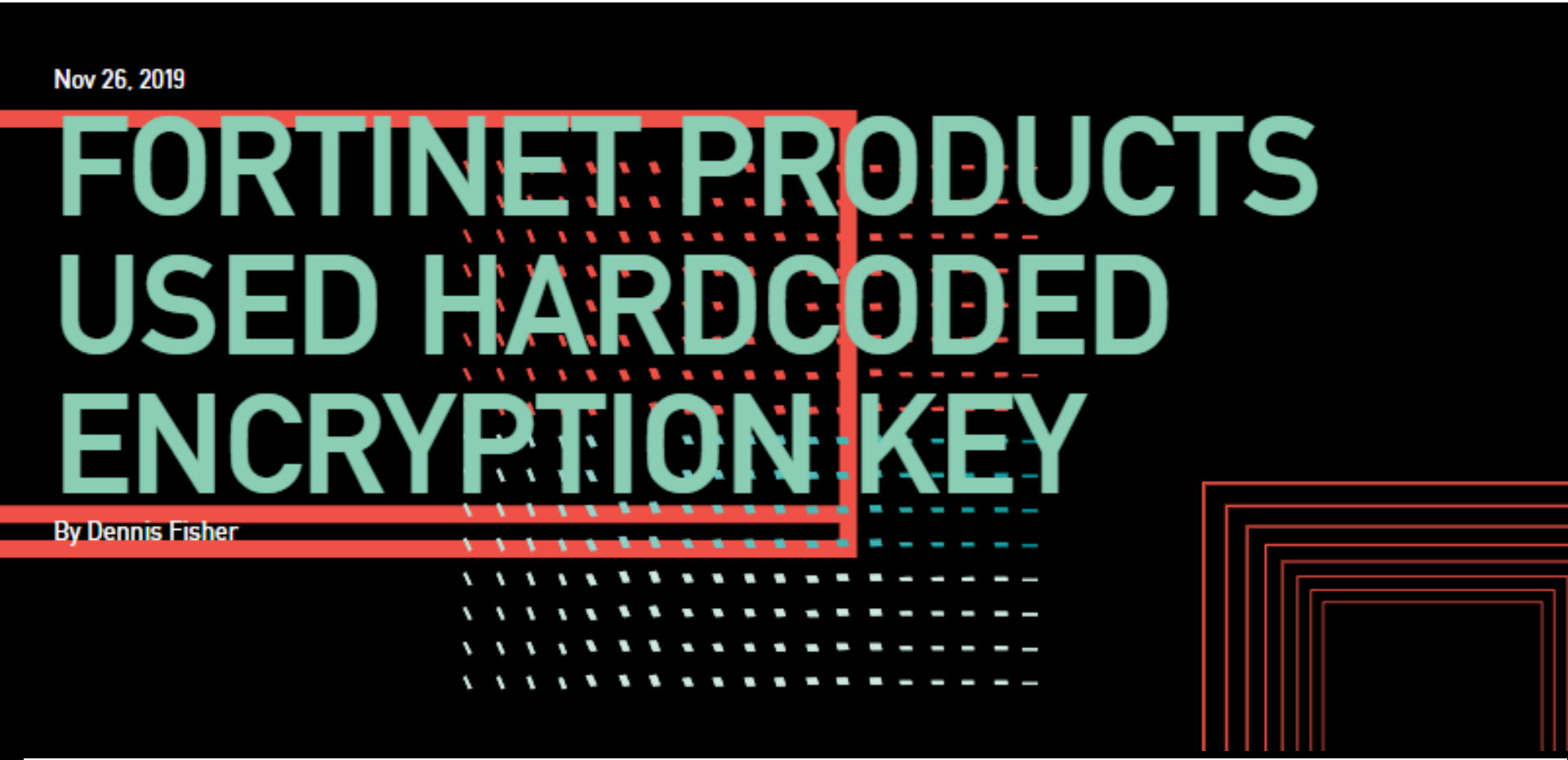




Bad Usage of One-time Pads:

PPTP protocol in Windows NT





Fortinet’s blunder led them to reuse a one-time pad several times

Limitation of Perfect Secrecy

If $|\mathcal{M}| > |\mathcal{K}|$ then **no** scheme is perfectly secret

Impractical

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4. **Modern Crypto**

Lego Approach

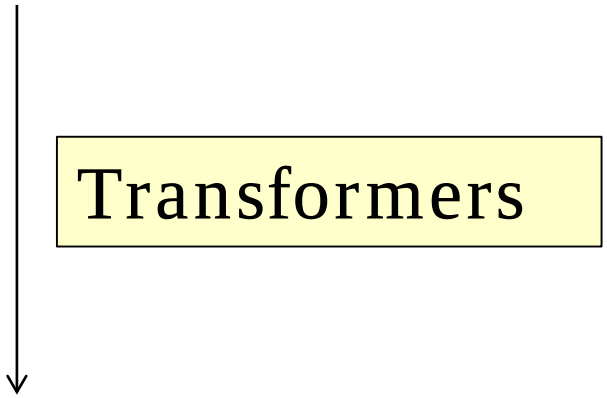
Computational Science

Modern Crypto

Provable Security

Modern Crypto: A Lego Approach

Primitives: AES | SHA-2 | Factoring | ...



Applications: Encryption | MAC | Digital Signature

Modern Crypto: A Computational Science

- Assume **computational** hardness of **a few** primitives

AES | SHA-2 | Factoring | ...

- Confidence by cryptanalysis

Modern Crypto: Provable Security

- **Define** security notions for applications
- **Prove** the transformer meets the notions