CIS 4360, Spring 2026

Blockcipher

Viet Tung Hoang

Some slides are based on material from Prof. Mihir Bellare (UCSD) and Prof. Stefano Tessaro (UW)

Agenda

1. Blockciphers

2. Birthday Attack

3. App: TCP Sequence Number

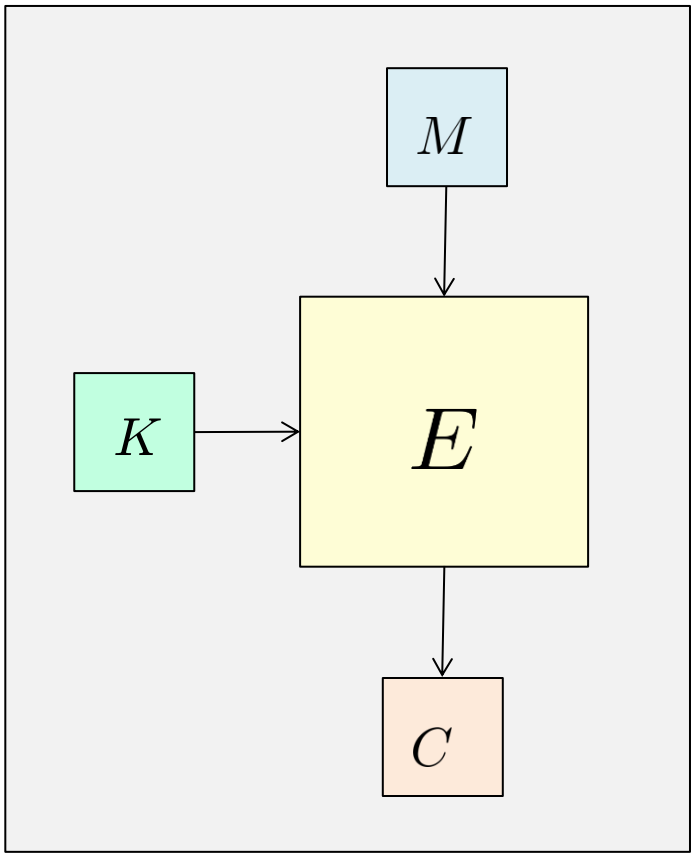
4. App: One-time Password

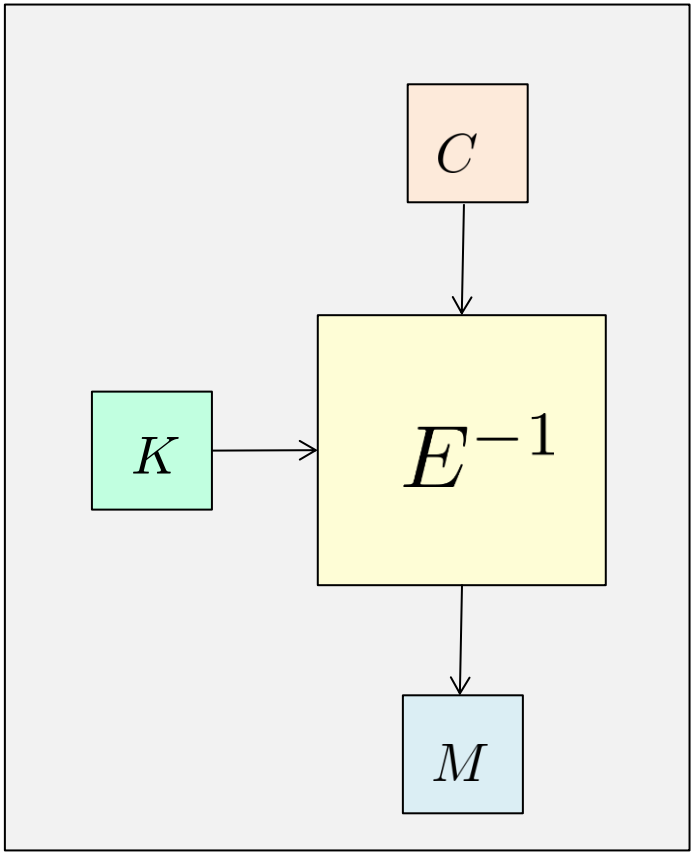
5. App: Challenge-Response Protocol

Blockcipher

$$E : \underbrace{\{0,1\}^k}_{\text{Key space}} \times \underbrace{\{0,1\}^n}_{\text{Domain}} \to \{0,1\}^n$$

efficiently invertible given the key





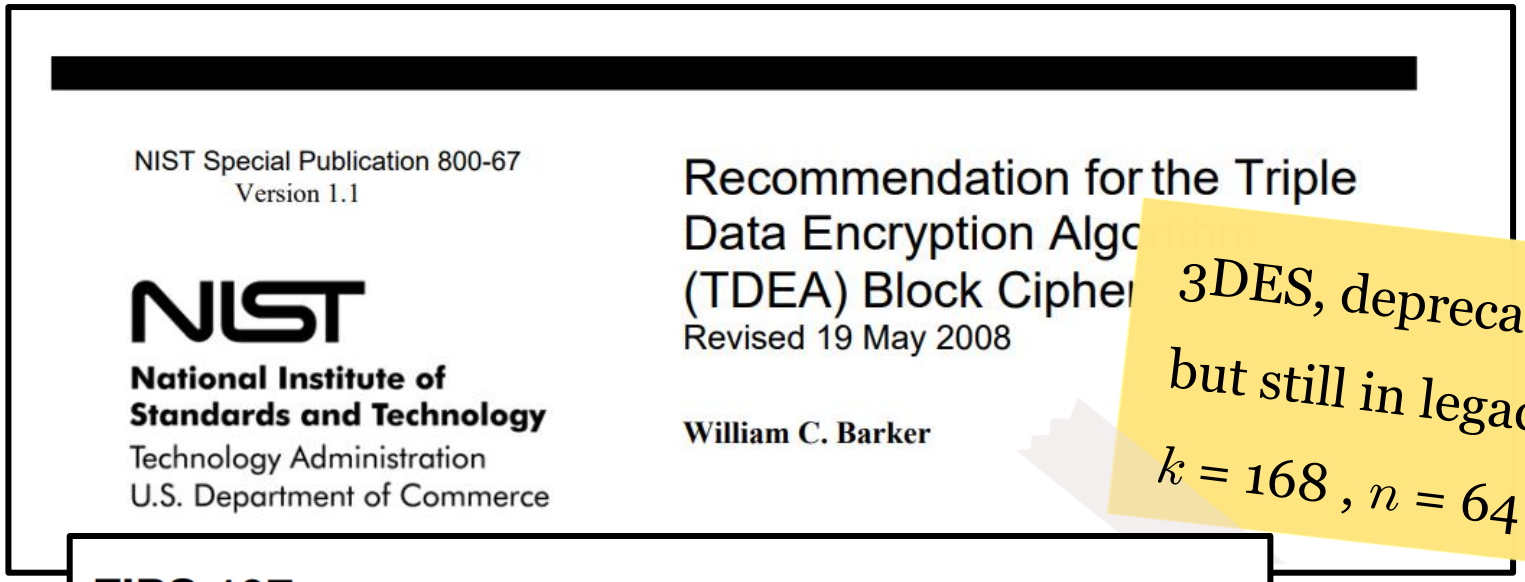
Blockcipher Usage

$C_1 \leftarrow E_K(M_1)$ ... $C_q \leftarrow E_K(M_q)$

K K

Random key K is known to both parties, but not given to adversary A

Real-world Blockciphers



NIST Special Publication 800-67
Version 1.1

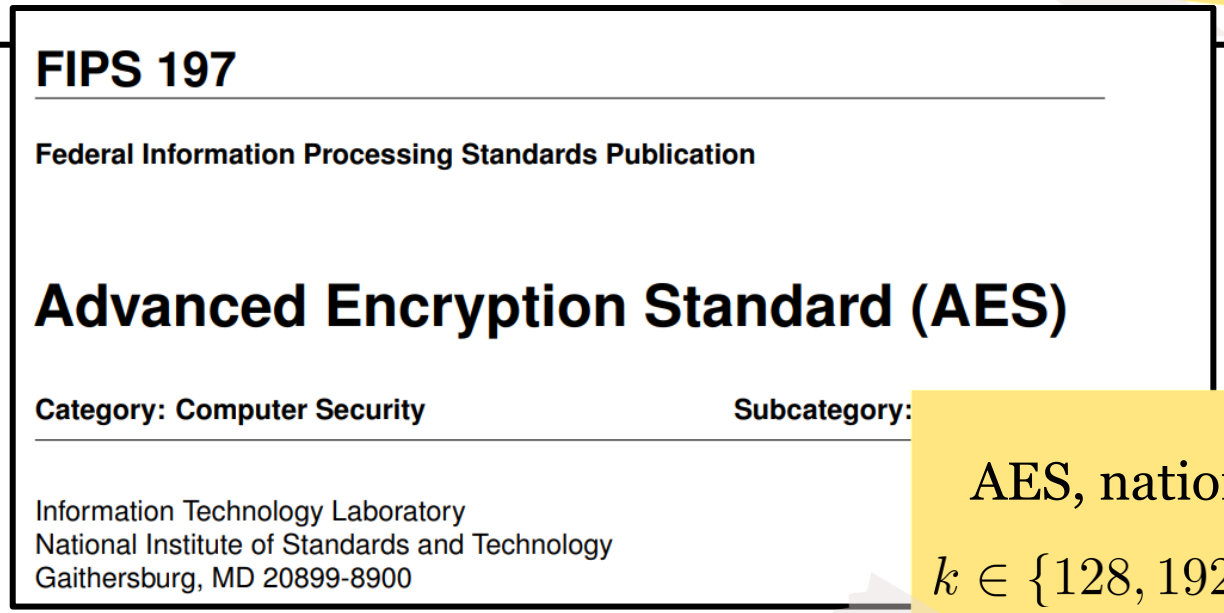
NIST
National Institute of Standards and Technology
Technology Administration
U.S. Department of Commerce

Recommendation for the Triple Data Encryption Algo
(TDEA) Block Cipher
Revised 19 May 2008

William C. Barker

3DES, deprecated since 2017 but still in legacy software

$k = 168$, $n = 64$



FIPS 197

Federal Information Processing Standards Publication

Advanced Encryption Standard (AES)

Category: Computer Security Subcategory:

Information Technology Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899-8900

AES, national standard

$k \in \{128, 192, 256\}, n = 128$

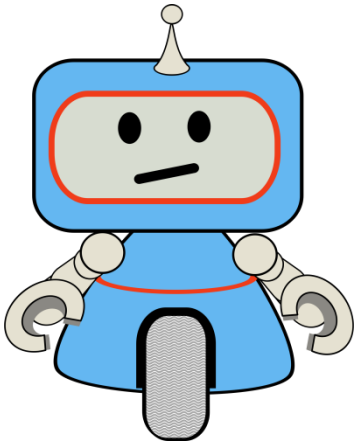
Defining Security for Blockcipher

Possible Properties	**Necessary**	**Sufficient**
Hard to recover the key	Yes	No
Hard to find M given $C \leftarrow E_K(M)$	Yes	No
…		

Want: a single "master" property that is sufficient to ensure security of common usage of blockcipher.

An Analogy: Turing Test

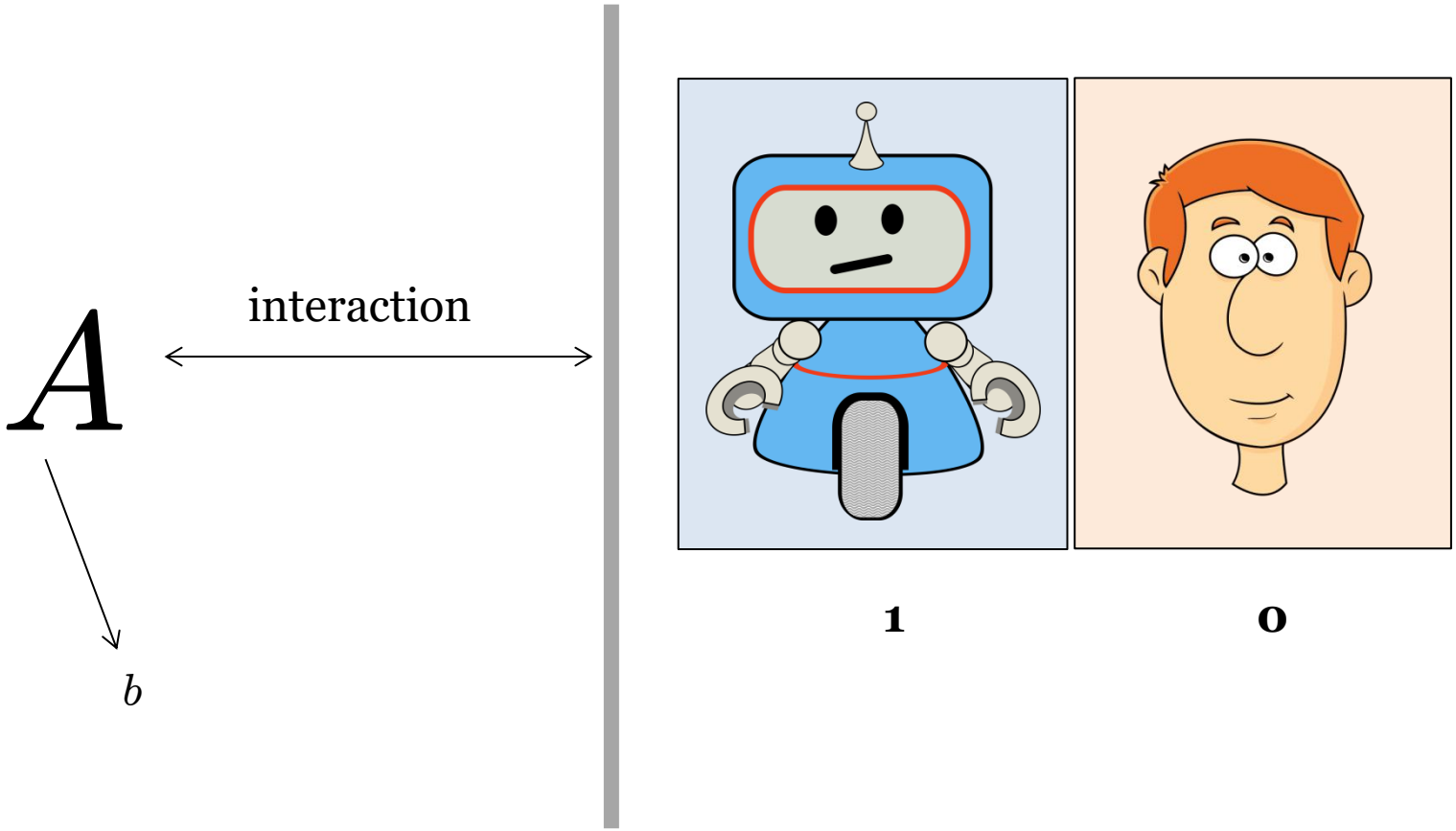
What does it mean for a machine to be “intelligent”?



Possible Answers
It can be happy
It recognizes pictures
…

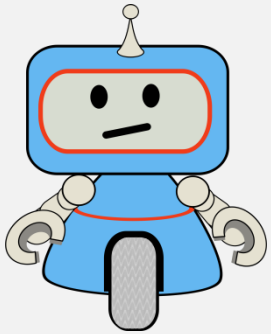
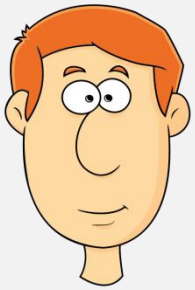
But no such list is satisfactory

An Analogy: Turing Test



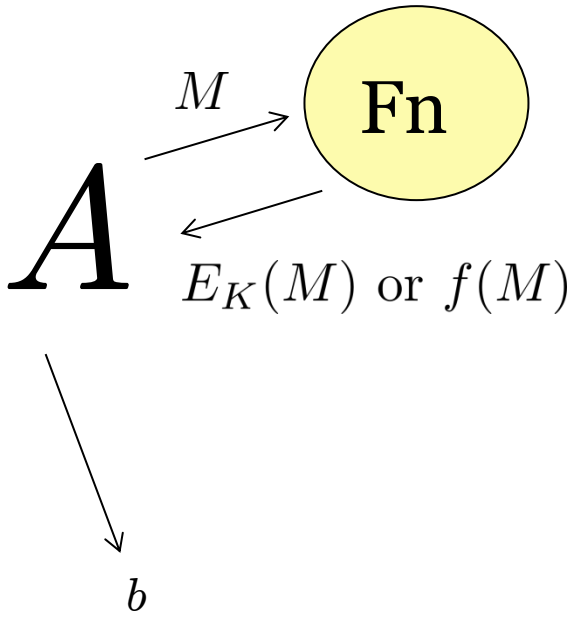
Man (0) or Machine (1)?

Real versus Ideal

Notion	Real object	Ideal object
Intelligence		
PRF	E_K	Random function

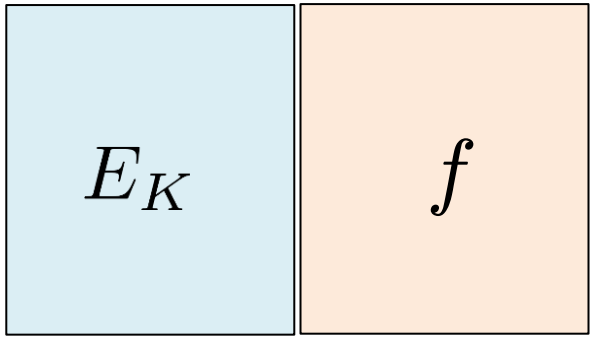
Informal View of PRF Security

$$E : \{0,1\}^k \times \{0,1\}^n \rightarrow \{0,1\}^n$$



Sample random $f : \{0,1\}^n \rightarrow \{0,1\}^n$

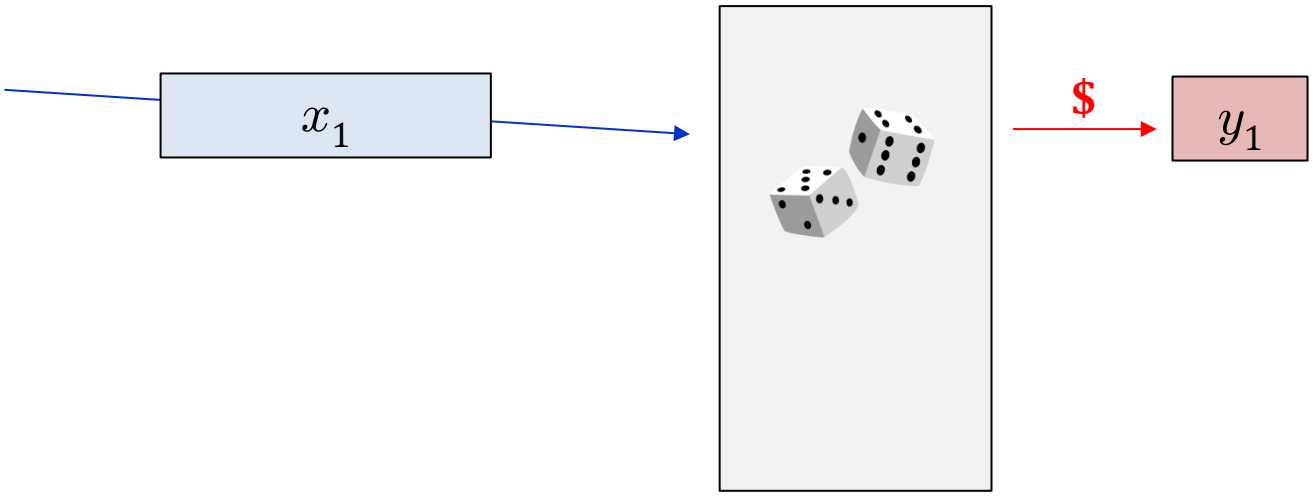
$K \xleftarrow{\$} \mathcal{K}$



Adversary doesn't know K or f

Defining Random Function: Lazy Sampling

Want: a random function $f : \{0,1\}^n \to \{0,1\}^m$



Pick a fresh random answer for a new query, and remember the answer

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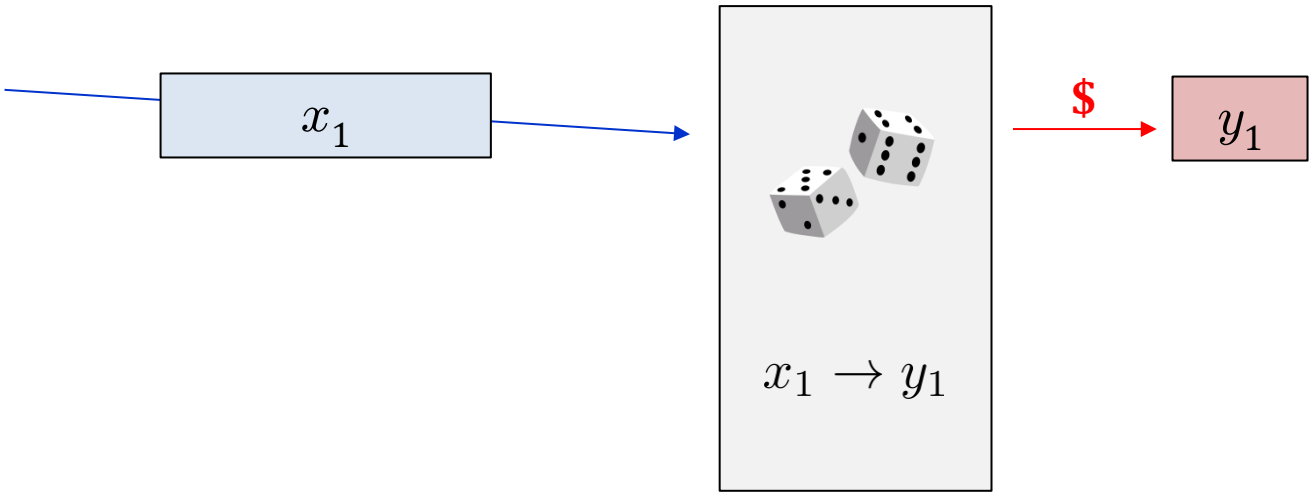

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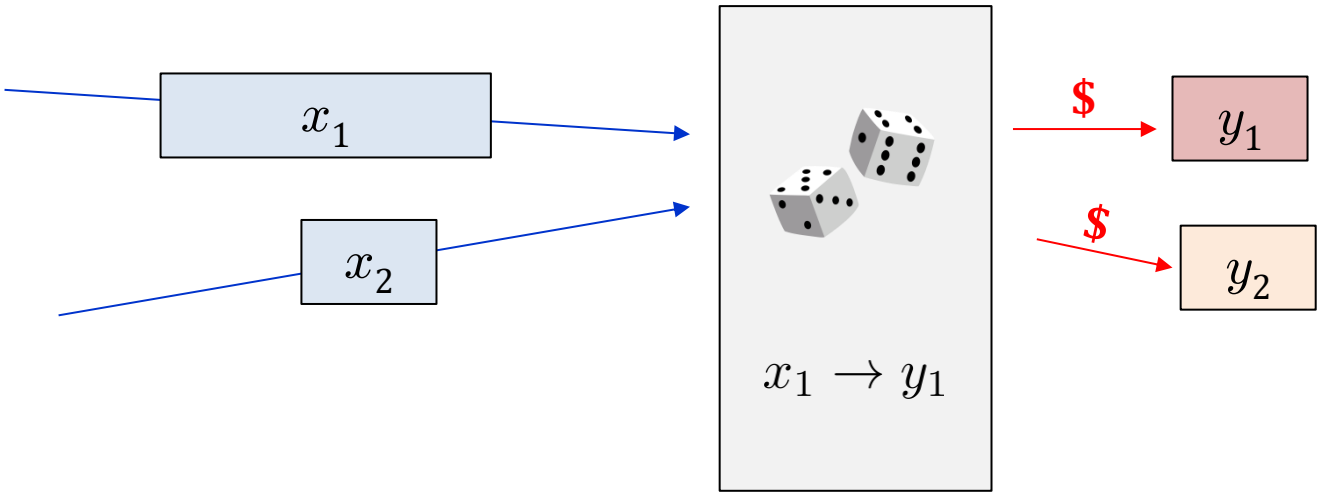

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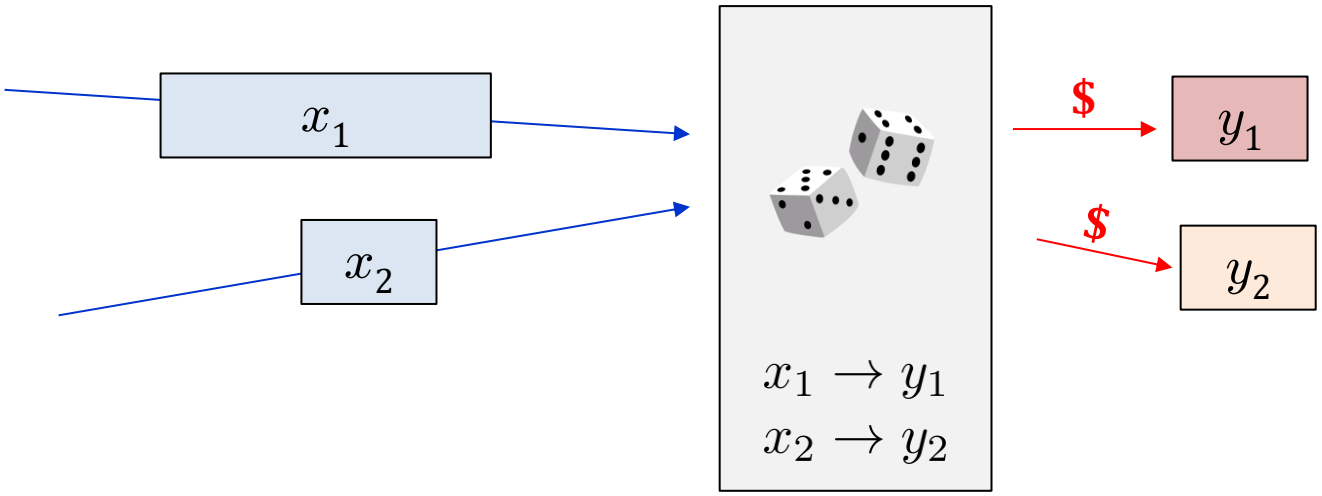
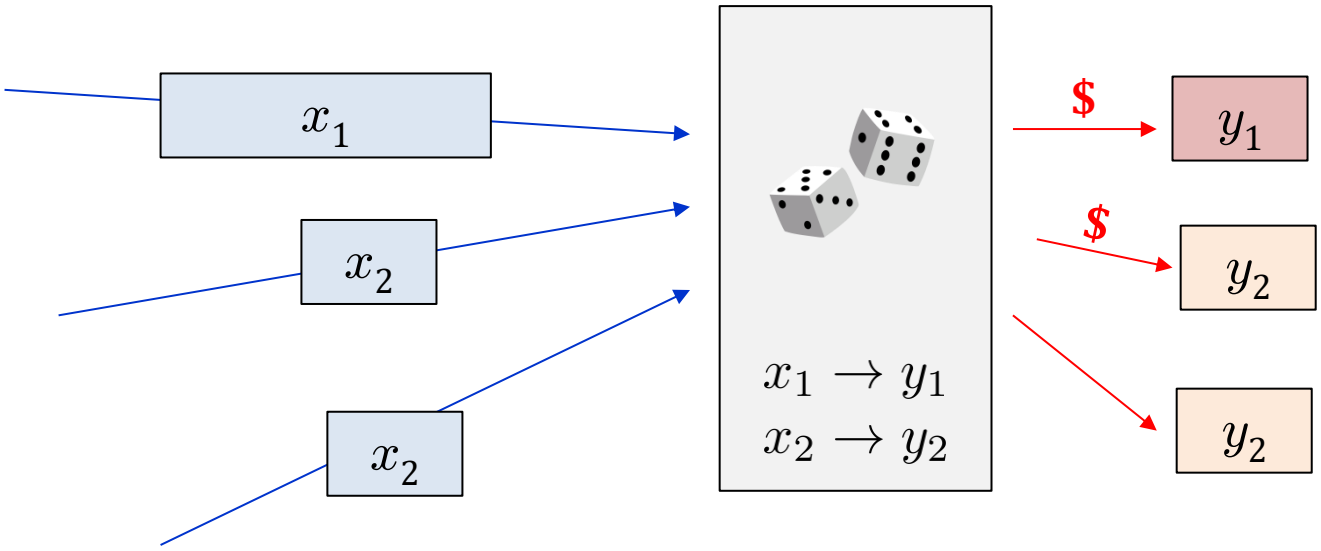


Pick a fresh random answer for a new query, and remember the answer

Reuse Prior Answer for Old Query

Want: a random function $f : \{0,1\}^n \to \{0,1\}^m$



Putting Things in Code

Game Real_E

procedure Initialize()

$K \xleftarrow{\$} \mathcal{K}$

procedure Fn(M)

return $E_K(M)$

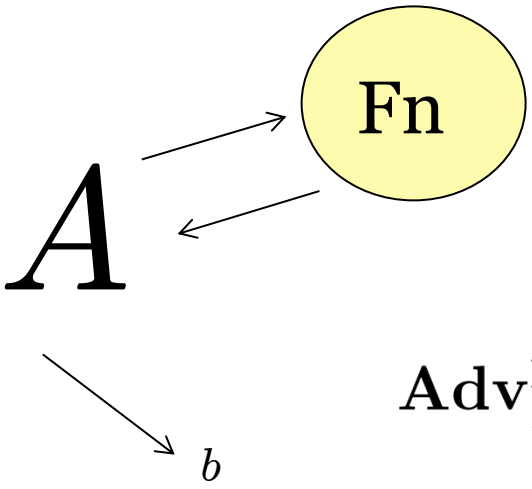
Game Rand_E

string array $T = \{\}$ // Global variable

procedure Fn(M)

If $T[M] = \perp$ then $T[M] \xleftarrow{\$} \{0,1\}^n$

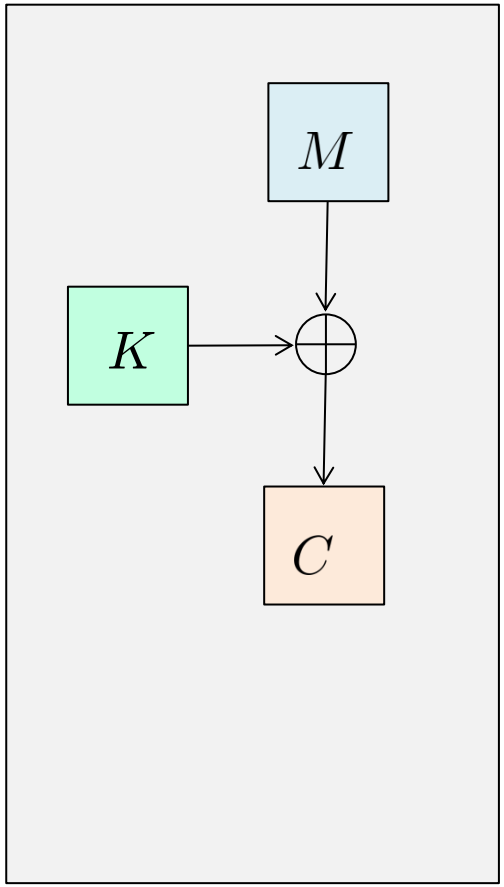
return $T[M]$



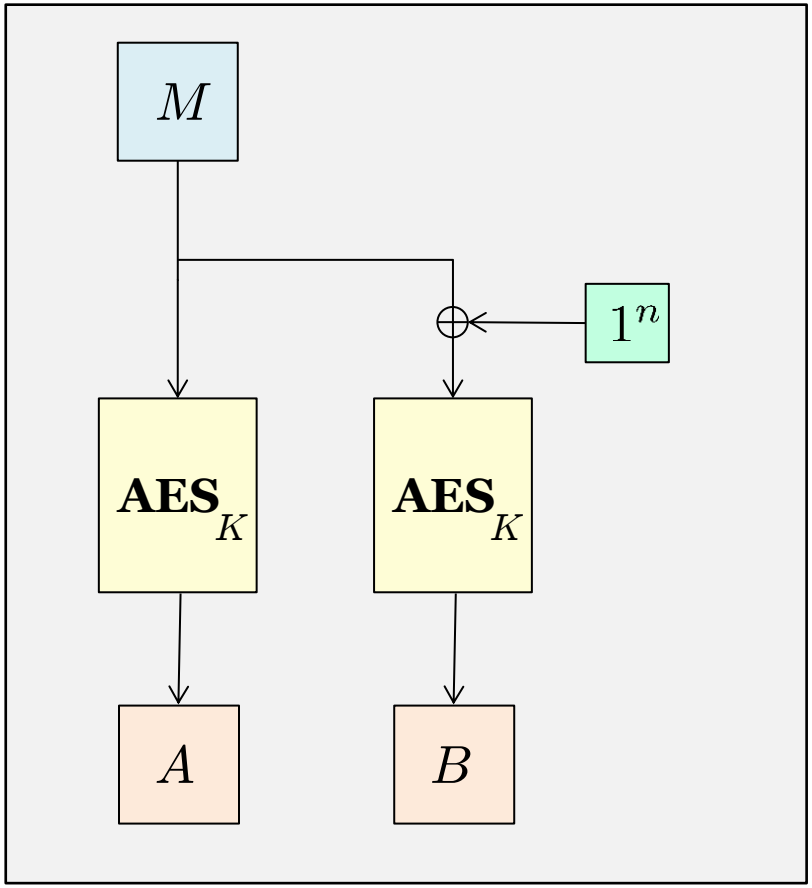
$$\mathbf{Adv}^{\text{prf}}_E(A) = \Pr[\text{Real}^A_E \Rightarrow 1] - \Pr[\text{Rand}^A_E \Rightarrow 1]$$

Exercise: PRF Attacks

$E_K(M) = M \oplus K$



$E_K(M) = \mathbf{AES}_K(M) \| \mathbf{AES}_K(\overline{M})$



Agenda

1. Blockciphers

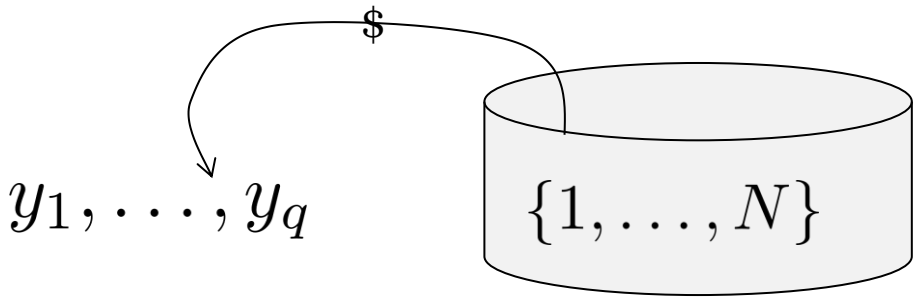
2. Birthday Attack

3. App: TCP Sequence Number

4. App: One-time Password

5. App: Challenge-Response Protocol

Birthday Problem

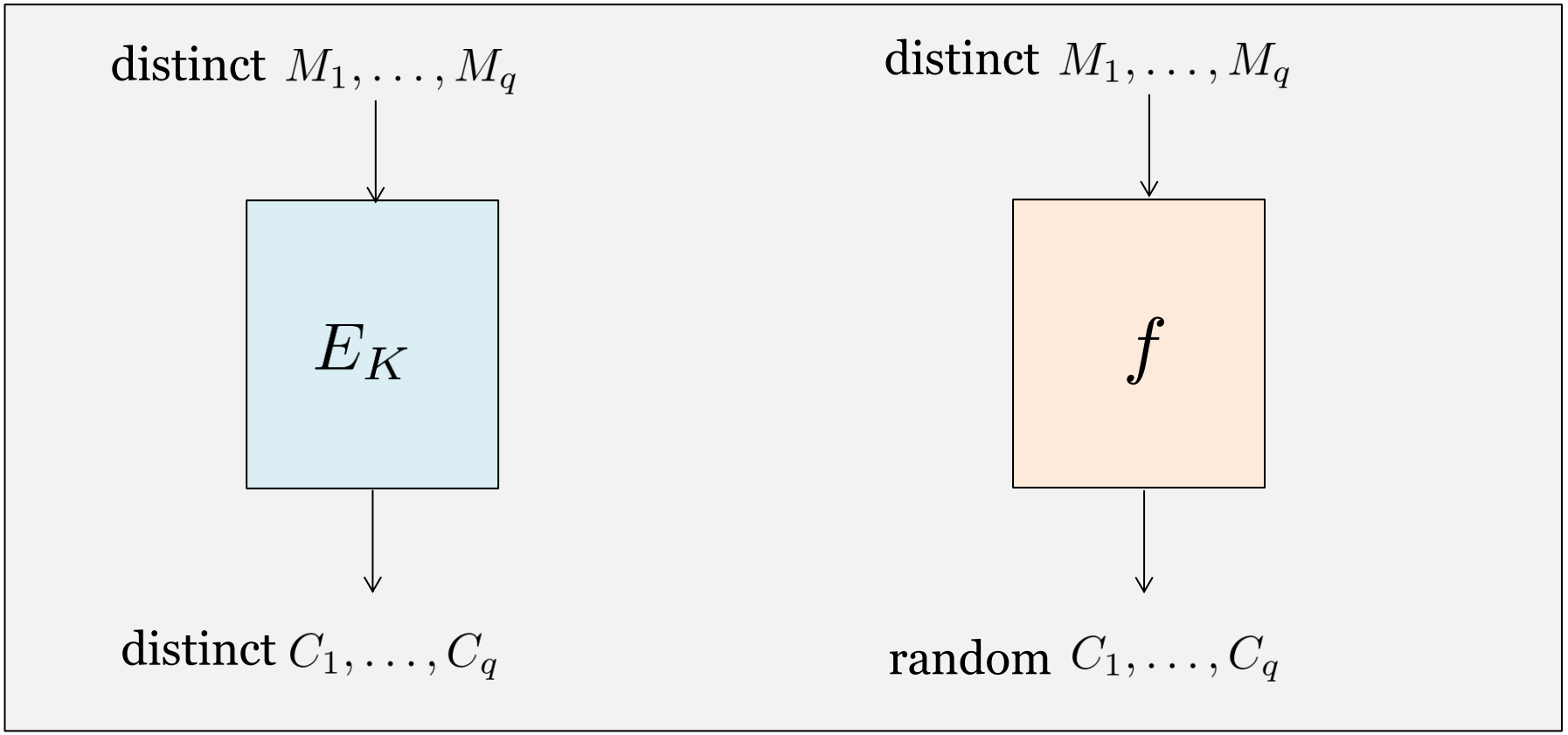


$$C(N, q) = \Pr[y_1, \ldots, y_q \text{ not distinct}]$$

Fact: For $q \leq \sqrt{2N}$,

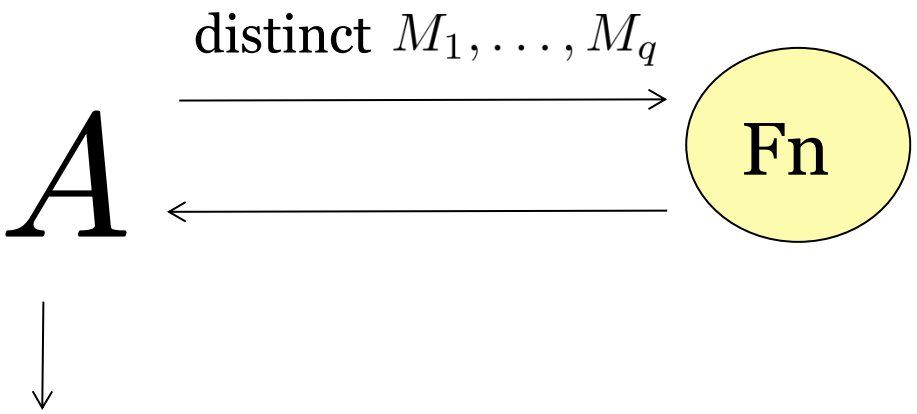
$$\frac{q(q-1)}{4N} \leq C(N, q) \leq \frac{q(q-1)}{2N}$$

Birthday Attack on PRF Security



Birthday Attack on PRF Security

$$E : \{0,1\}^k \times \{0,1\}^n \rightarrow \{0,1\}^n$$



$$\mathbf{Adv}_E^{\mathrm{prf}}(A) = C(2^n, q) \approx \frac{q^2}{2^n}$$

Need $2^{n/2}$ queries to break PRF security

Blockcipher	n	$2^{n/2}$	**Status**
3DES	64	2^{32}	Insecure
AES	128	2^{64}	Secure

Does It Matter In Practice?

Sweet32: Birthday Attacks on 64-bit Blockciphers in TLS and OpenVPN [Bhargavan, Leurent 16]

HTTPS encryption via 3DES

Recover cookie after capturing 785GB

Agenda

1. Blockciphers

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3. App: TCP Sequence Number

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5. App: Challenge-Response Protocol

Recap: TCP Reset Attack

Session data

Need to guess seq #

Reset, source=Alice

Want: Seq # is hard to guess if adversary can't sniff packets

First Attempt: Random Sequence Number

Backward Compatibility Issue

End with seq # X

Port 1324 → Port 80

Start with seq # Y

Port 1324 → Port 80

Requirement: If two connections of same IP addresses and ports are within a small window, must have $X < Y$ to avoid interference from delayed packets

Generating TCP Sequence Numbers with PRF

Port 1234, IP A

Port 80, IP S

timer

T

K

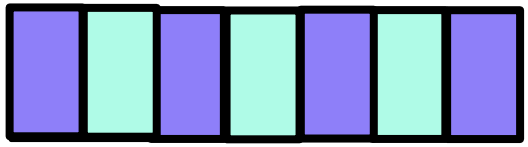
Not shared with Alice

$$\text{Server's Seq \#} = T + F_K(A\|1234\|S\|80)$$

Recap: TCP SYN Flood

SYN requests with
random IPs

SYN Queue



Countermeasure: TCP SYN Cookie

Port 1234, IP A

Port 80, IP S

SYN

SYN/ACK

No queue

$$\text{Server's Seq \#} = T \| M \| F_K(A \| 1234 \| S \| 80 \| T \| M)$$

5-bit global timer

3-bit encoding of maximum segment size

Agenda

1. Blockciphers

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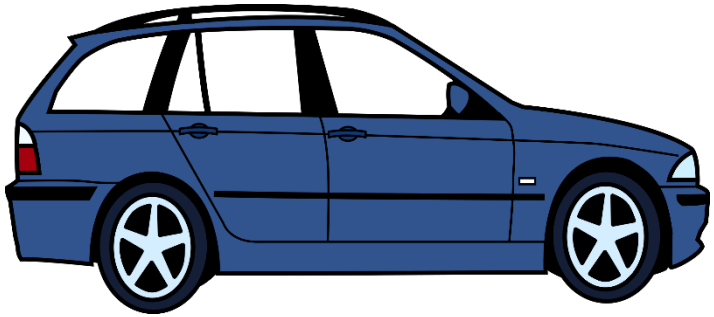
Motivation

identify



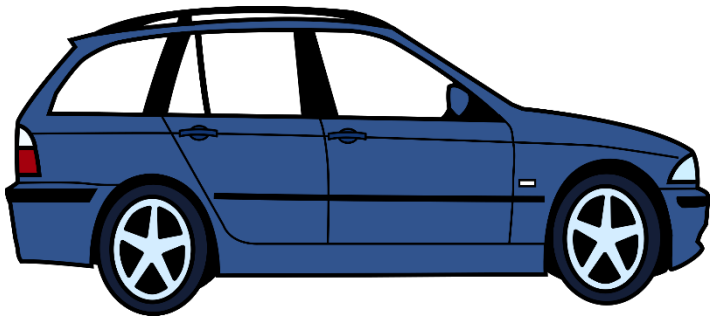
K

K

Goal: An eavesdropper cannot later open the car

A Wrong Solution

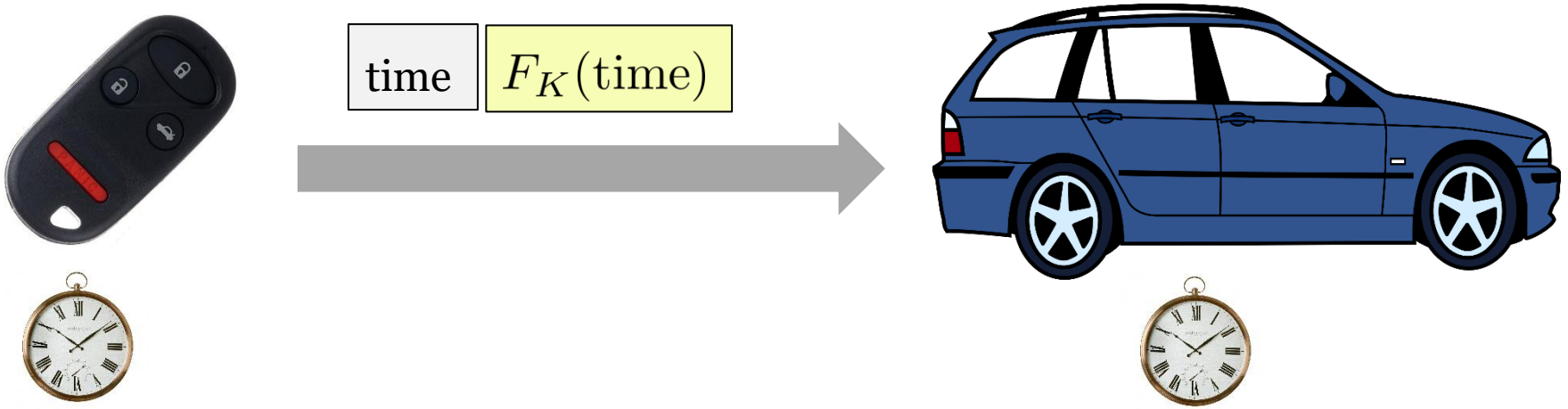
"Open the door"



Question: Why is it bad?

One-Time Password Via PRF

https://tools.ietf.org/html/rfc6238



Should allow time drift, and accept for slightly outdated time

(Stateful) alternative: Run the PRF on a synchronized counter

https://tools.ietf.org/html/rfc4226

A Real-world Example: RSA's SecureID

The Register

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

SecurID breach cost RSA $66m

In 2nd quarter alone

Dan Goodin

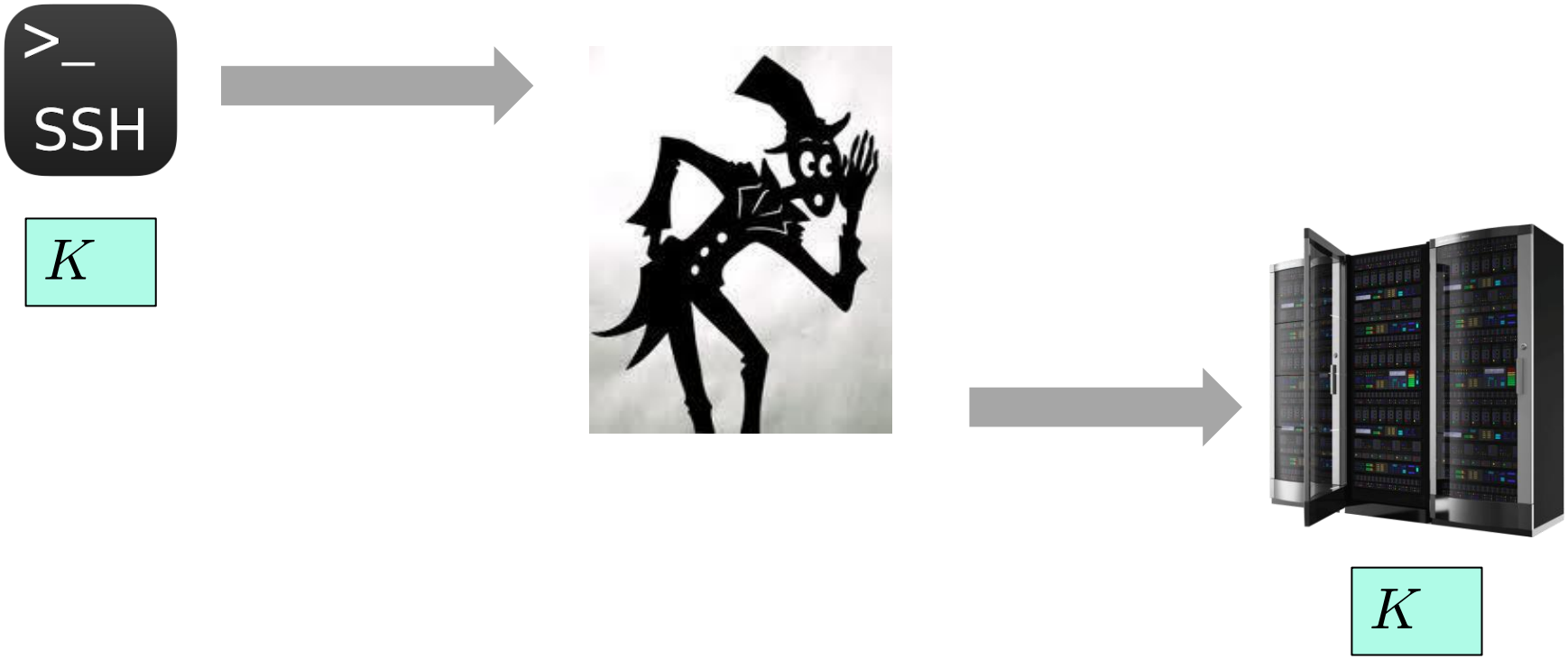
Wed 27 Jul 2011 // 17:17 UTC

But it's disastrous if the key is stolen

Agenda

1. Blockciphers
2. Birthday Attack
3. App: TCP Sequence Number
4. App: One-time Password
5. **App: Challenge-Response Protocol**

Motivation: Man-In-The-Middle Attack



Question: Does one-time password work here?

Solution: Challenge-Response

Nonce: a string that should never repeat