CIS 4360: Computer Security Fundamentals

Blockcipher

Viet Tung Hoang

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

Agenda

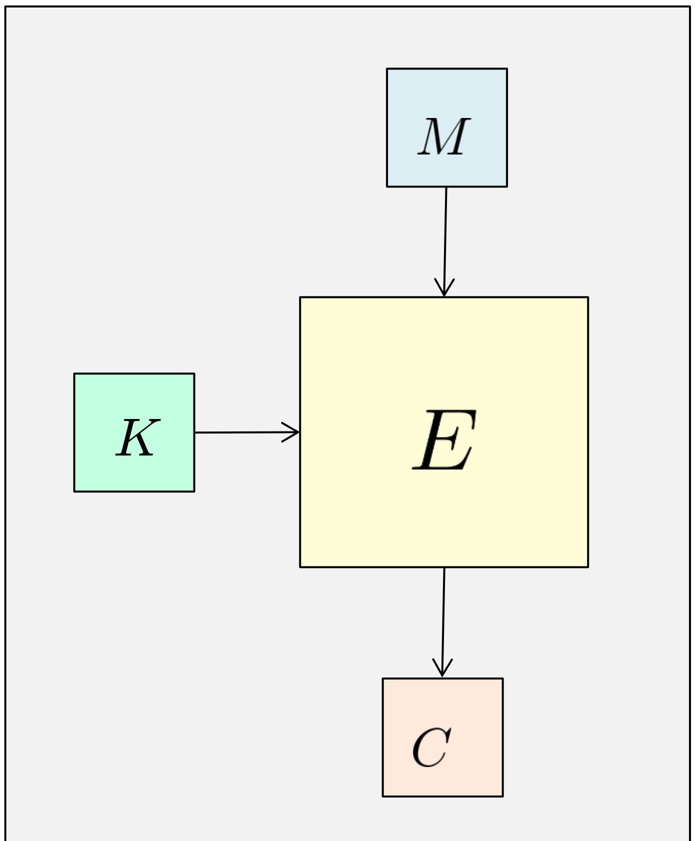
1. **Blockciphers**

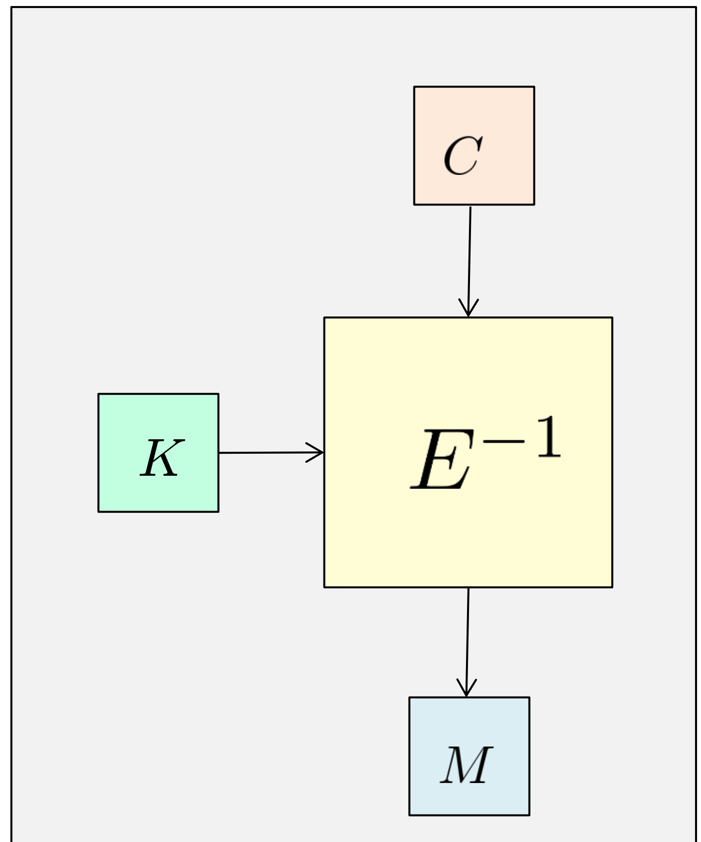
2. Birthday Attack

Blockcipher

efficiently invertible given the key

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





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

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

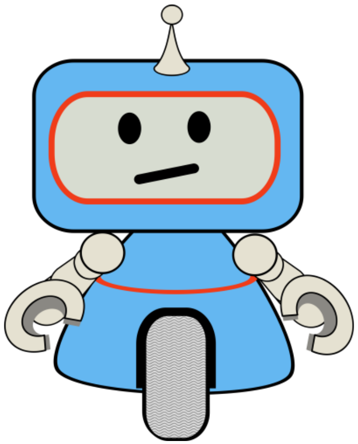
Defining Security for Blockcipher

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

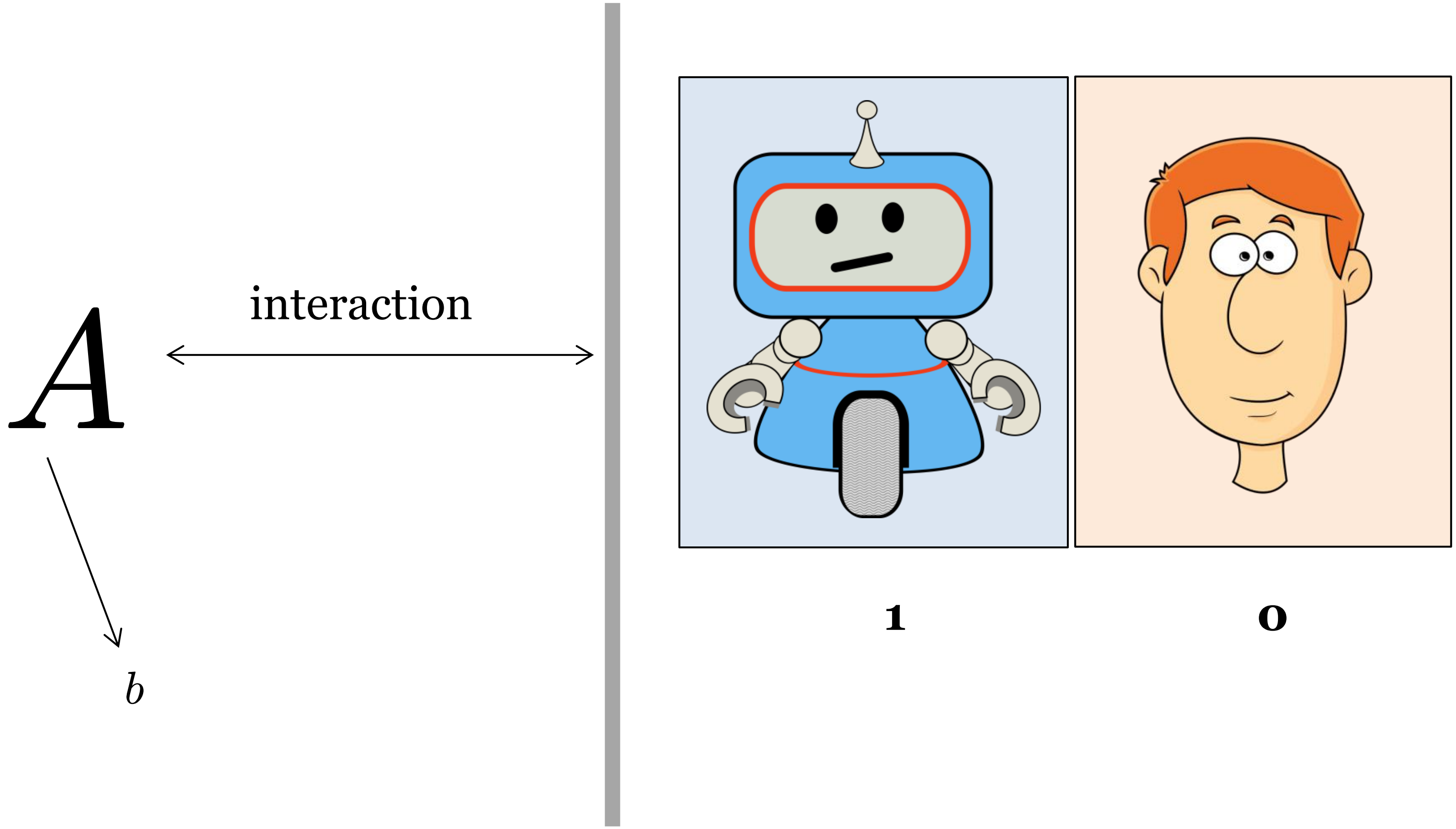
What does it mean for a machine to be “intelligent”?



Possible Answers
It can be happy
It recognizes pictures
…

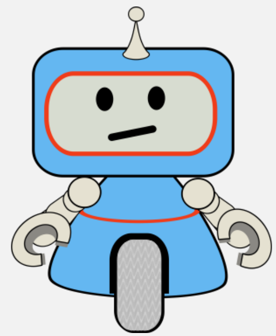
But no such list is satisfactory

An Analogy: Turing Test



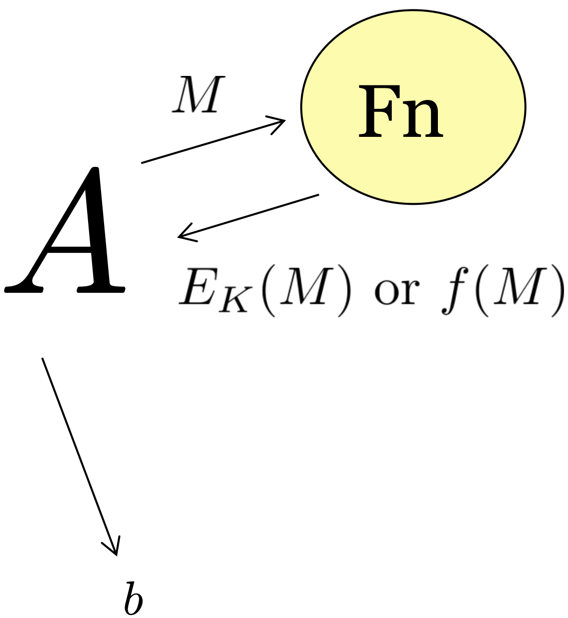
Man (0) or Machine (1)?

Real versus Ideal

Notion	Real object	Ideal object
Intelligence		
PRF	E_K	Random function

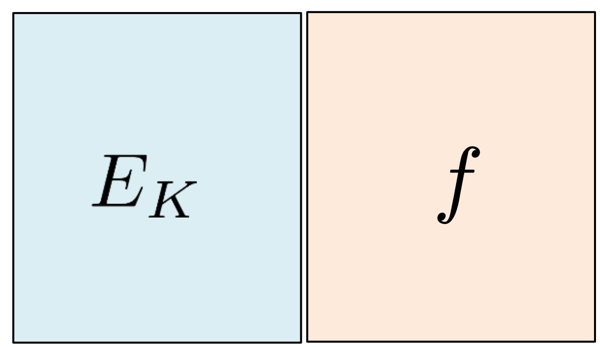
Informal View of PRF Security

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



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

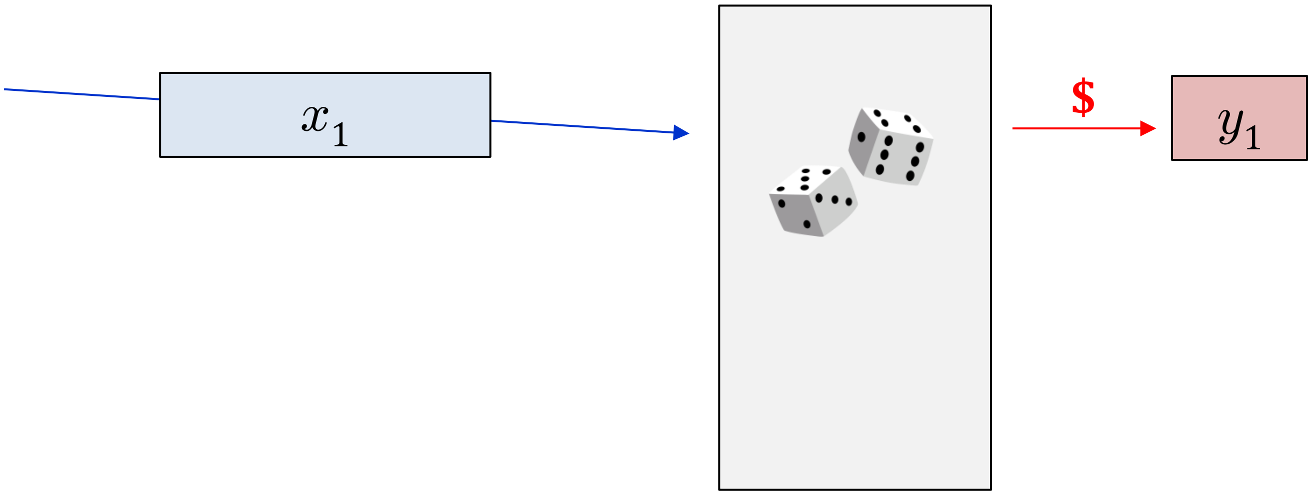
$K \xleftarrow{\$} \mathcal{K}$



Adversary doesn't know K or f

Defining Random Function: Lazy Sampling

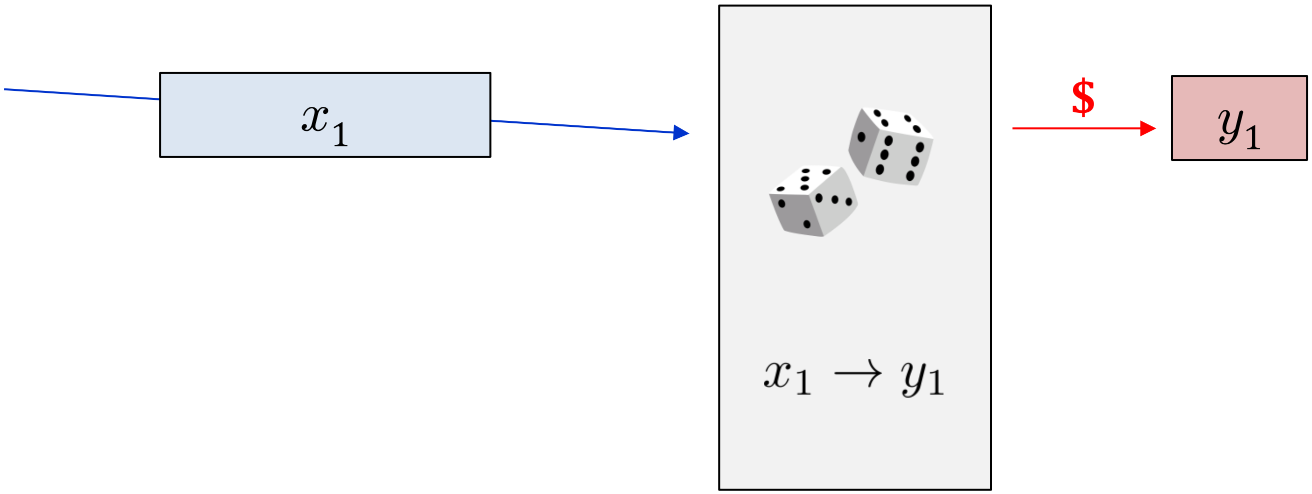
Want: a random function $f : \{0,1\}^n \to \{0,1\}^m$



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

Defining Random Function: Lazy Sampling

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



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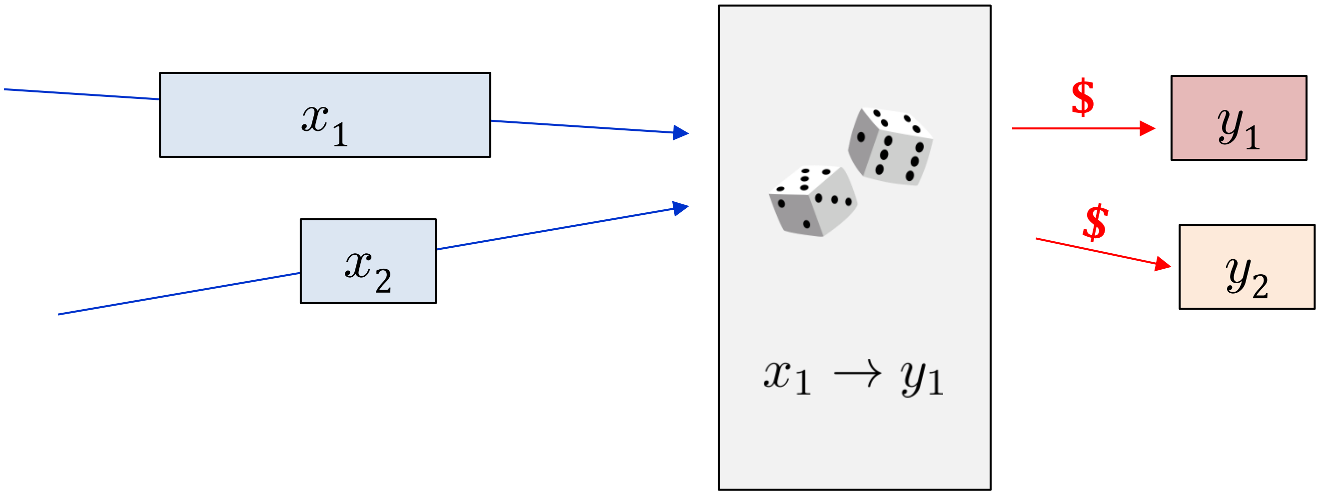

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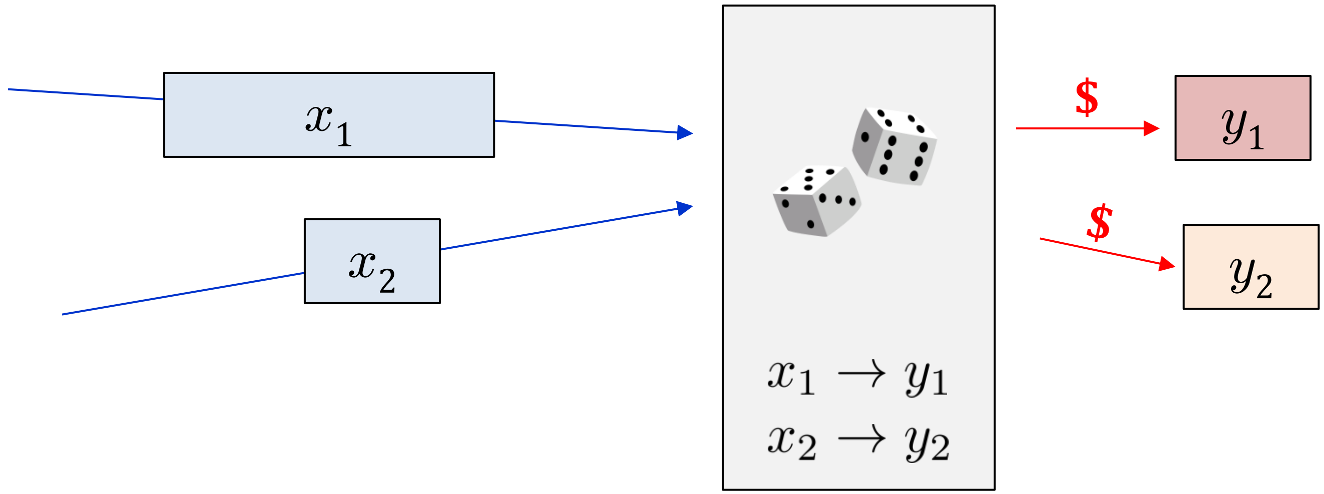
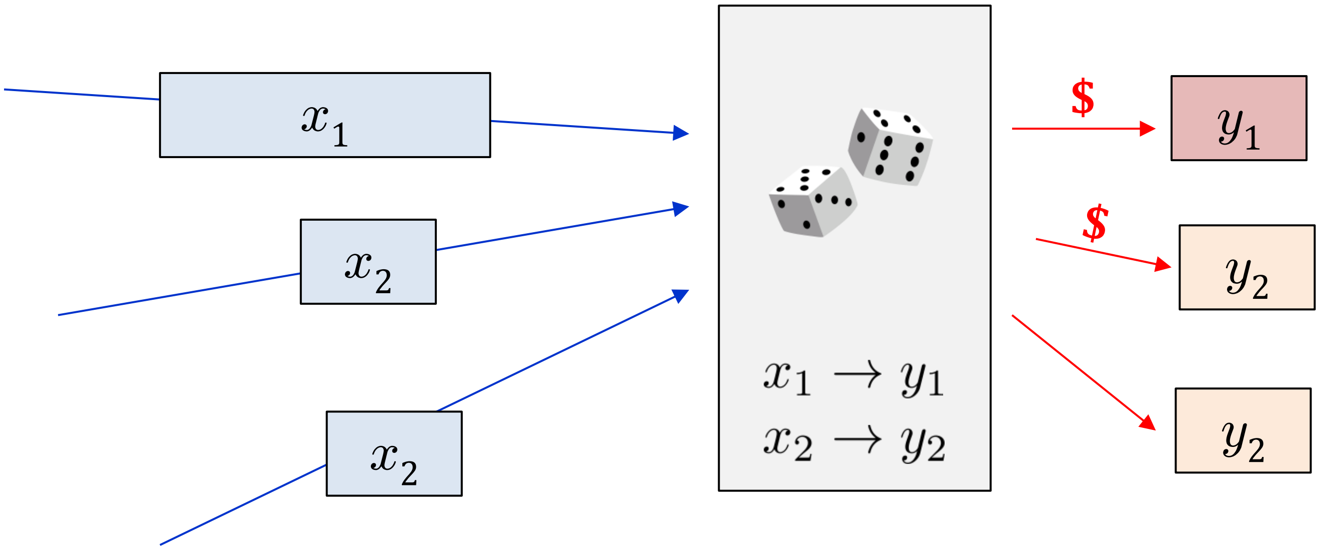


Pick a fresh random answer for a new query, and remember the answer

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 $E_K(M)$

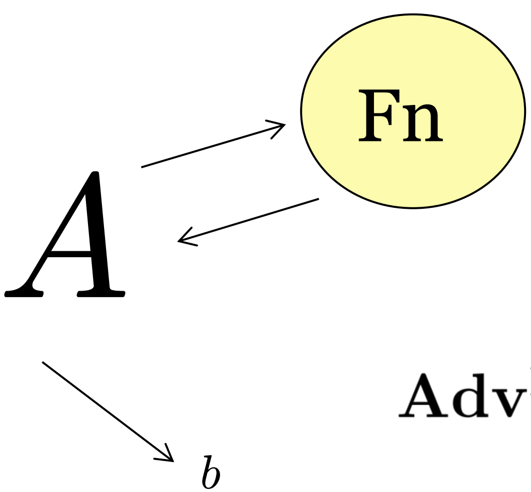
Game Rand_E

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

procedure Fn(M)

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

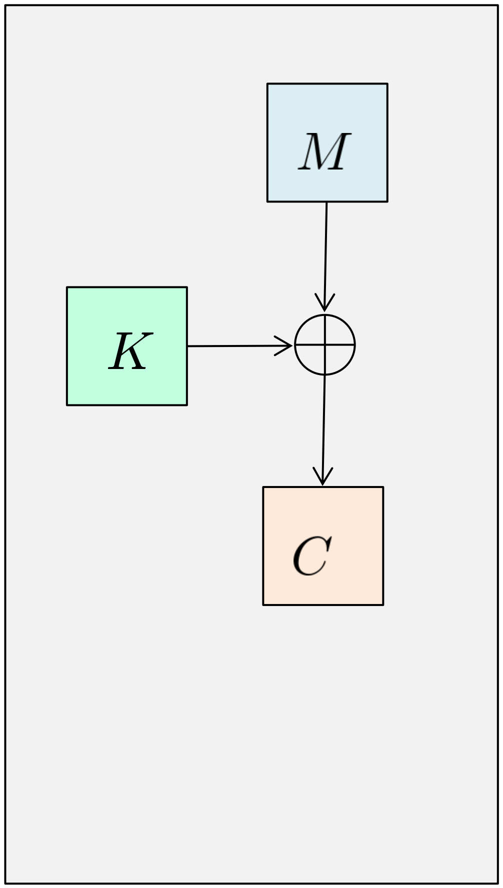
return $T[M]$



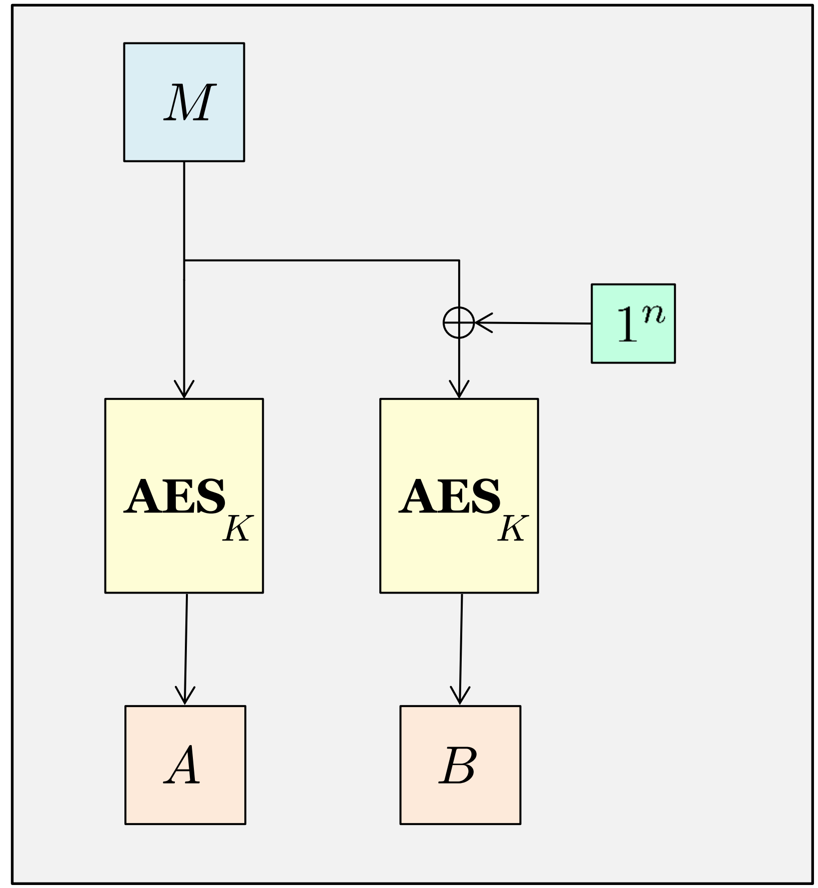
$$\mathbf{Adv}_E^{\mathrm{prf}}(A) = \Pr[\mathrm{Real}_E^A \Rightarrow 1] - \Pr[\mathrm{Rand}_E^A \Rightarrow 1]$$

Exercise: PRF Attacks

$$E_K(M) = M \oplus K$$



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

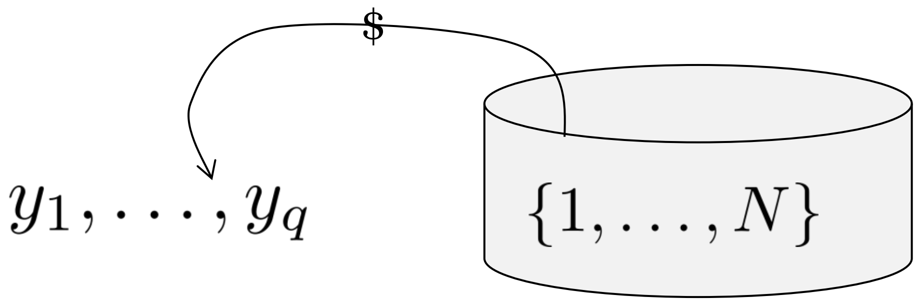


Agenda

1. Blockciphers

2. **Birthday Attack**

Birthday Problem

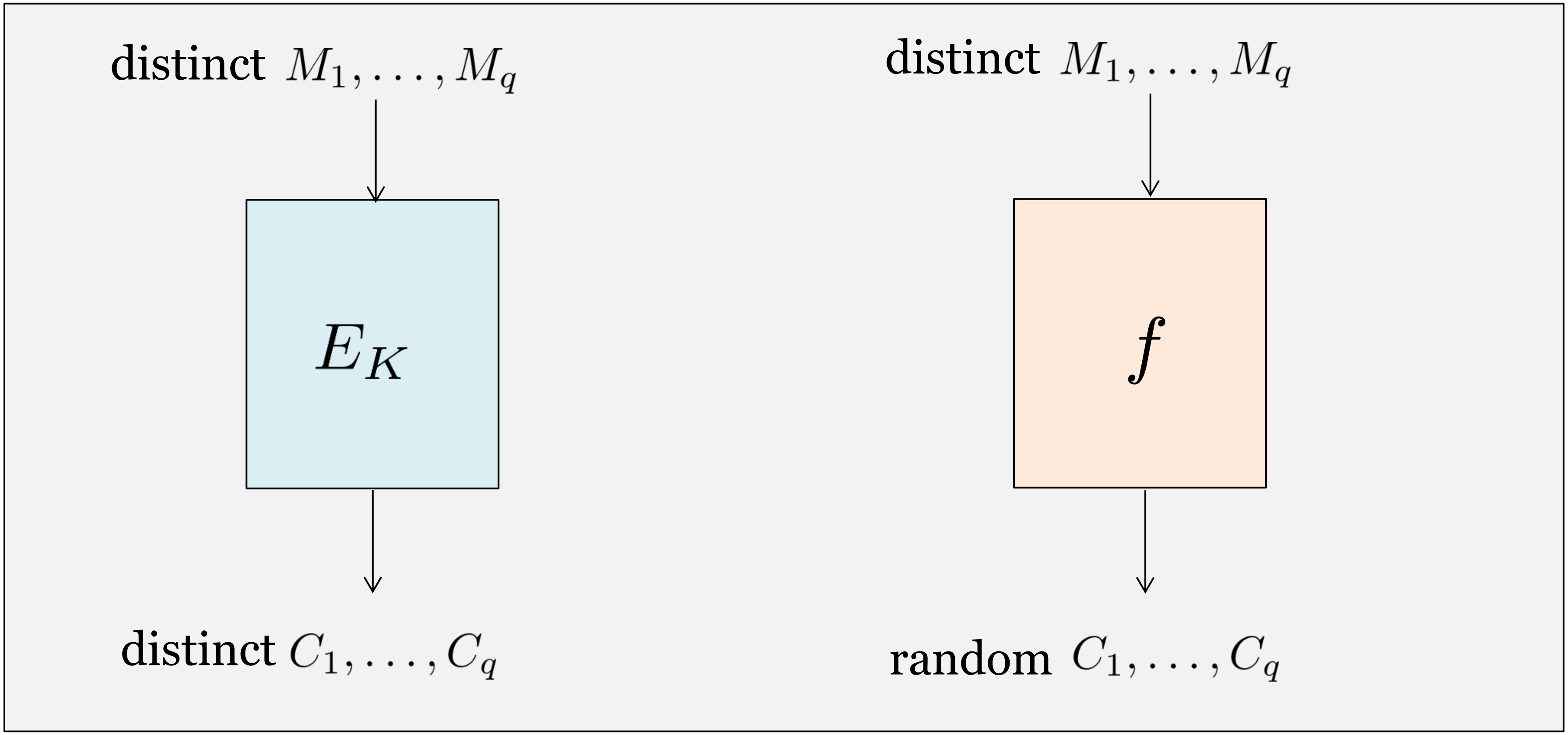


$$C(N, q) = \Pr[y_1, \ldots, y_q \text{ not distinct}]$$

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

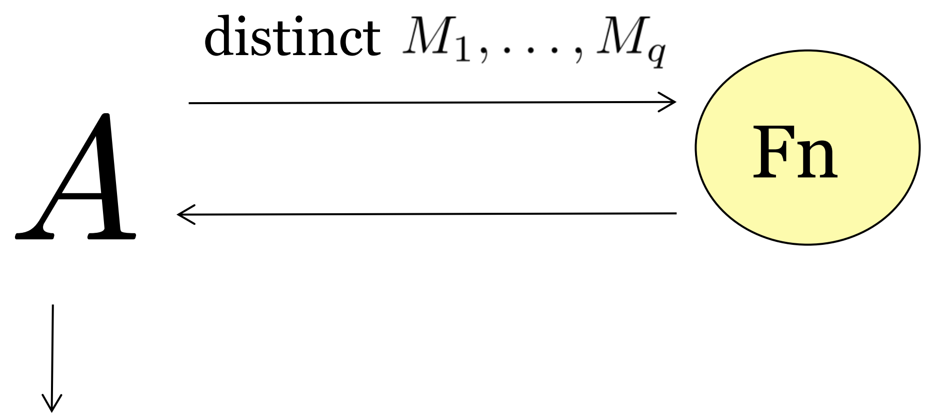
$$\frac{q(q-1)}{4N} \leq C(N, q) \leq \frac{q(q-1)}{2N}$$

Birthday Attack on PRF Security



Birthday Attack on PRF Security

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



Output 1 if $C_1, \ldots, C_q$ are distinct

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

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