CS 5830
Cryptography

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bjqhtrj yt ymj jchnynsl btwqi tk hwduytlwfumd

CORNELL TECH
HOME OF THE JACOBS INSTITUTE

Who am I? https://rist.tech.cornell.edu

- Academic computer security researcher
  - ~7 years of grad school at UC Davis & UC San Diego
  - 4.5 years as professor at University of Wisconsin-Madison
  - 6+ years as professor at Cornell Tech
  - Consulting with industry on applied crypto
    - Skyhigh Networks previously
    - Cloudflare

- Applied & theoretical cryptography, cloud computing security, machine learning privacy, user authentication, abuse

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Computer security

understanding and improving the behavior of
computing technologies in the presence of adversaries

Attackers
(aka adversaries)

Target/victim
computing
systems

Defenders
(designers, engineers,
lawyers, etc.)

This class is on cryptography, class of mechanisms for helping achieve security

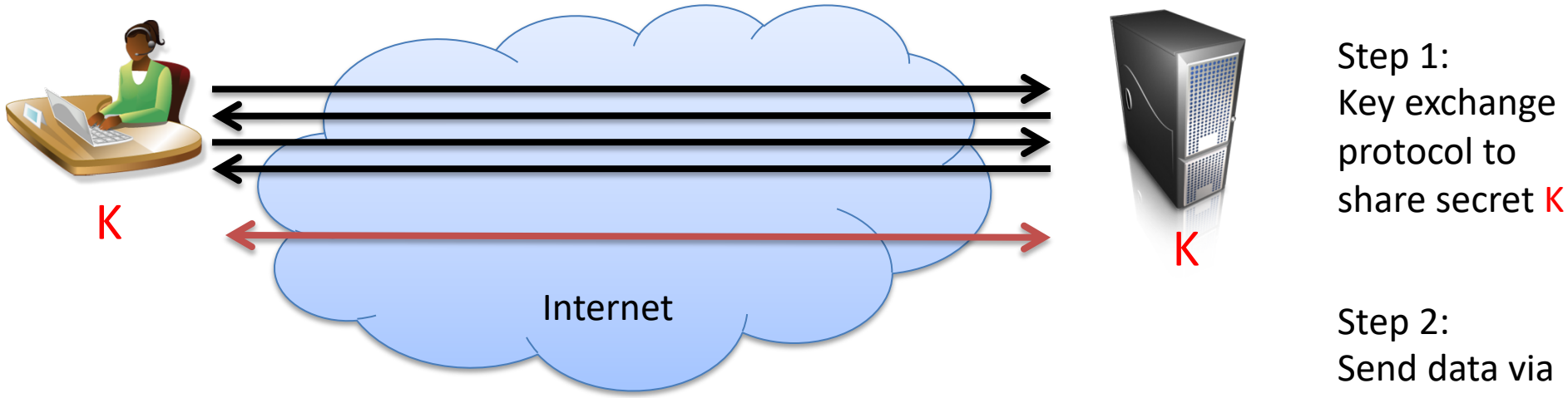
Cryptography: “Hidden writing”

- Study and practice of building security protocols that resist adversarial behavior
  - Not ***just*** encryption
- Blend of mathematics, engineering, computer science

- Cryptanalysis: breaking cryptography

Crypto = cryptography (not cryptocurrencies)

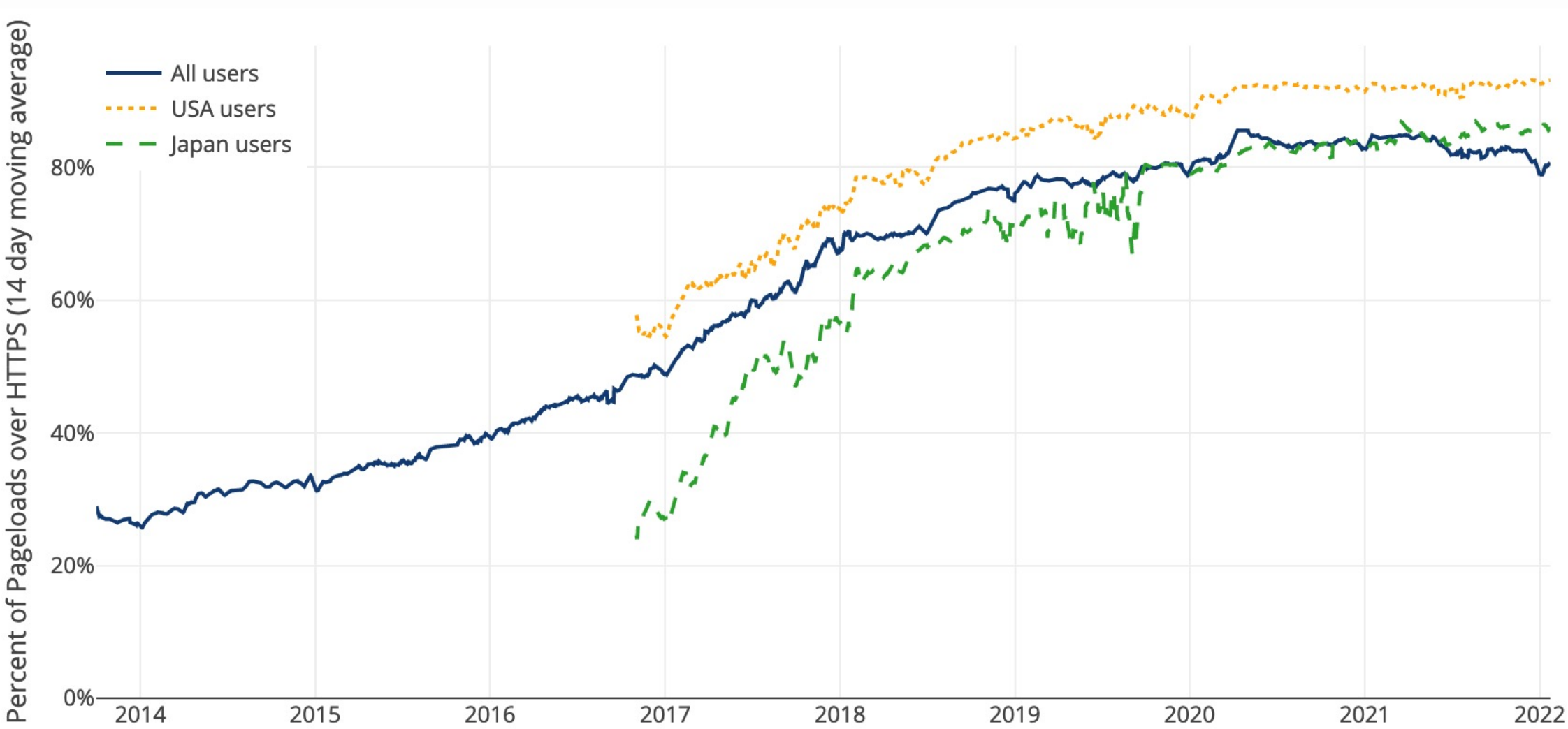
Cryptography use cases



TLS (Transport Layer Security) protects web traffic “in flight”

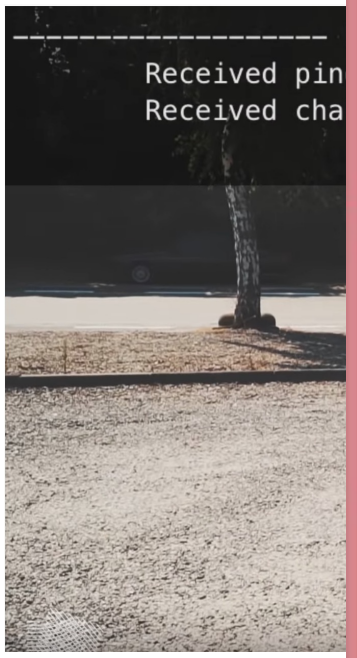
- Passwords
- Credit card numbers
- Personal information
- …

Cryptography use cases

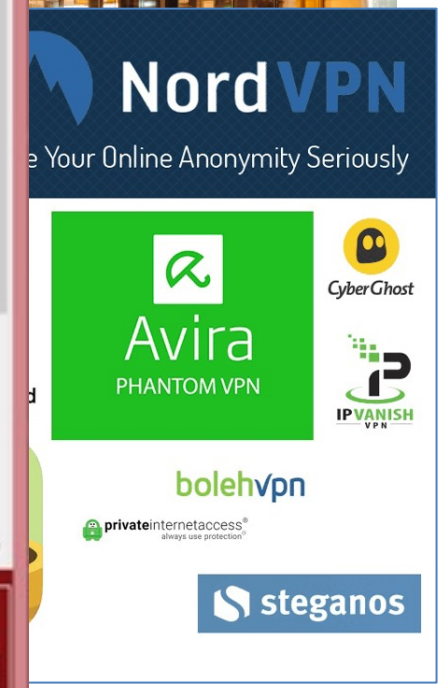


Statistics from Firefox
https://letsencrypt.org/stats/

Cryptography use cases



https://www



.com/blog/vpn-beginners-guide/

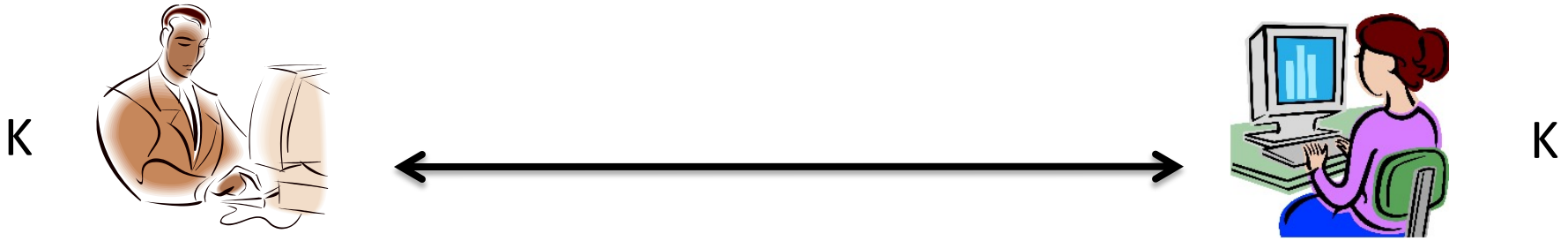
Crypto changes power relationships

- WW2 cryptanalysis
- CryptoAG backdoor
- Crypto wars of 1990s through today (United States)
  - RSA invented by intelligence agencies (GCHQ) before RSA
  - Late 1970s, early 1980s surge in public-sector cryptography
  - Clipper Chip (1990s)
  - Export restrictions on cryptography (treated as “munition”)
  - US intelligence efforts on surreptitious backdoors
- Law enforcement and lawful access debate
  - Child sexual abuse media (CSAM), encrypted phones

Some goals for course

- **Learning to "speak" crypto**
  - What different primitives are for
  - What are the security goals associated with them
  - How do cryptographers reason about security
- **Current best practices** for cryptographic constructions you are likely to encounter
  - Understand why they are considered best
  - Know how to break some inferior choices

Symmetric encryption uses shared secret key K



Scheme SE = (Kg,Enc,Dec) has three algorithms:

- Key generation (Kg), Encryption (Enc), Decryption (Dec)

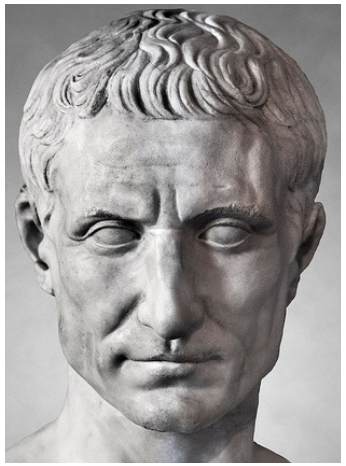
Functionality (correctness)

- Decryption should reverse encryption (for same key)
- Should be efficient to run all three algorithms

Security

- Capabilities and goals of attacker

Substitution cipher (aka Caeser cipher)



Kg():
K <-$ {a,b,c,…,z}

Pick a random English letter from [a-z]

Enc(K,M):
Split M into characters $M_1,M_2,\ldots,M_m$
For i = 1 to m do
C_i <- M_i + K mod 26
Return $C_1||C_2||\ldots||C_m$

Assume M is string of English lower-case letters
Plus '+' interprets letters as numbers (a = 0, b = 1, …), adds mod 26, then converts back to letter

Dec(K,C):
Split C into characters $C_1,C_2,\ldots,C_m$
For i = 1 to m do
C_i <- M_i - K mod 26
Return $M_1||M_2||\ldots||M_m$

Assume C is string of English lower-case letters

Threat models for symmetric encryption

C

C <- Enc(K,M)

M <- Dec(K,C)

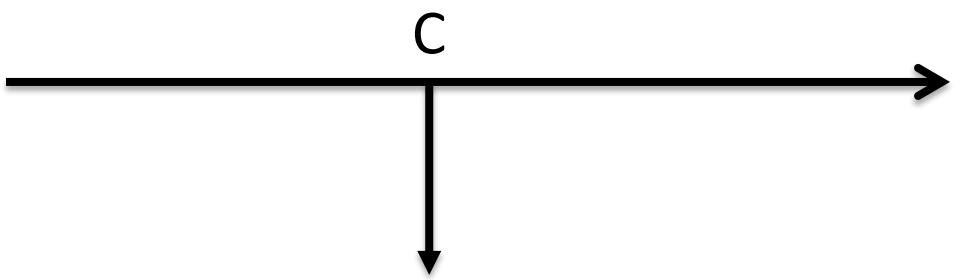
Threat model captures:

1. Adversary's goals
2. Adversary's capabilities

What are example adversarial goals?
What are potential capabilities?

Threat models for symmetric encryption

C



C <- Enc(K,M)

Adversary

M <- Dec(K,C)

Can the adversary recover M from C? Message/plaintext recovery attack

Can the adversary recover K from C? Key recovery attack

What does adversary know about Enc?

Auguste Kerckhoffs' (Second) Principle

(circa 1883)

"The system must not require secrecy and can be stolen by the enemy without causing trouble"

A cryptosystem should be secure even if its algorithms, implementations, configuration, etc. is made public --- the only secret should be a key

Why?

Threat models in cryptography

In general, we want to build cryptography that is secure:

- even for seemingly “weak” goals
- against adversaries with strong capabilities

Crypto design

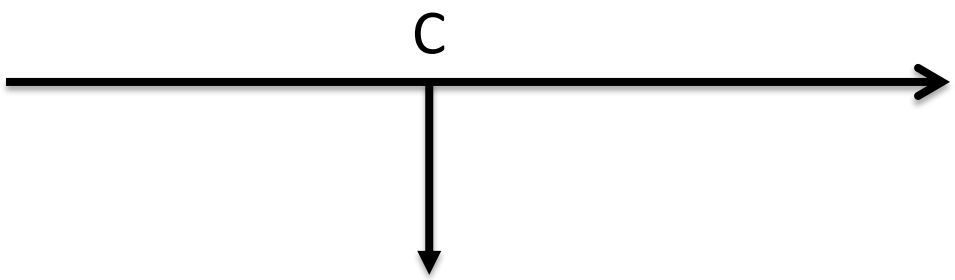
For cryptanalysis we want to build attacks that:

- are as damaging as possible
- assume as few capabilities as possible

Cryptanalysis

Substitution cipher

C



C <- Enc(K,M)

Adversary

M <- Dec(K,C)

Partial message recovery:
Adversary obtains a single ciphertext, attempt to recover one bit of M

Message recovery:
Adversary obtains a single ciphertext, attempt to recover all of M

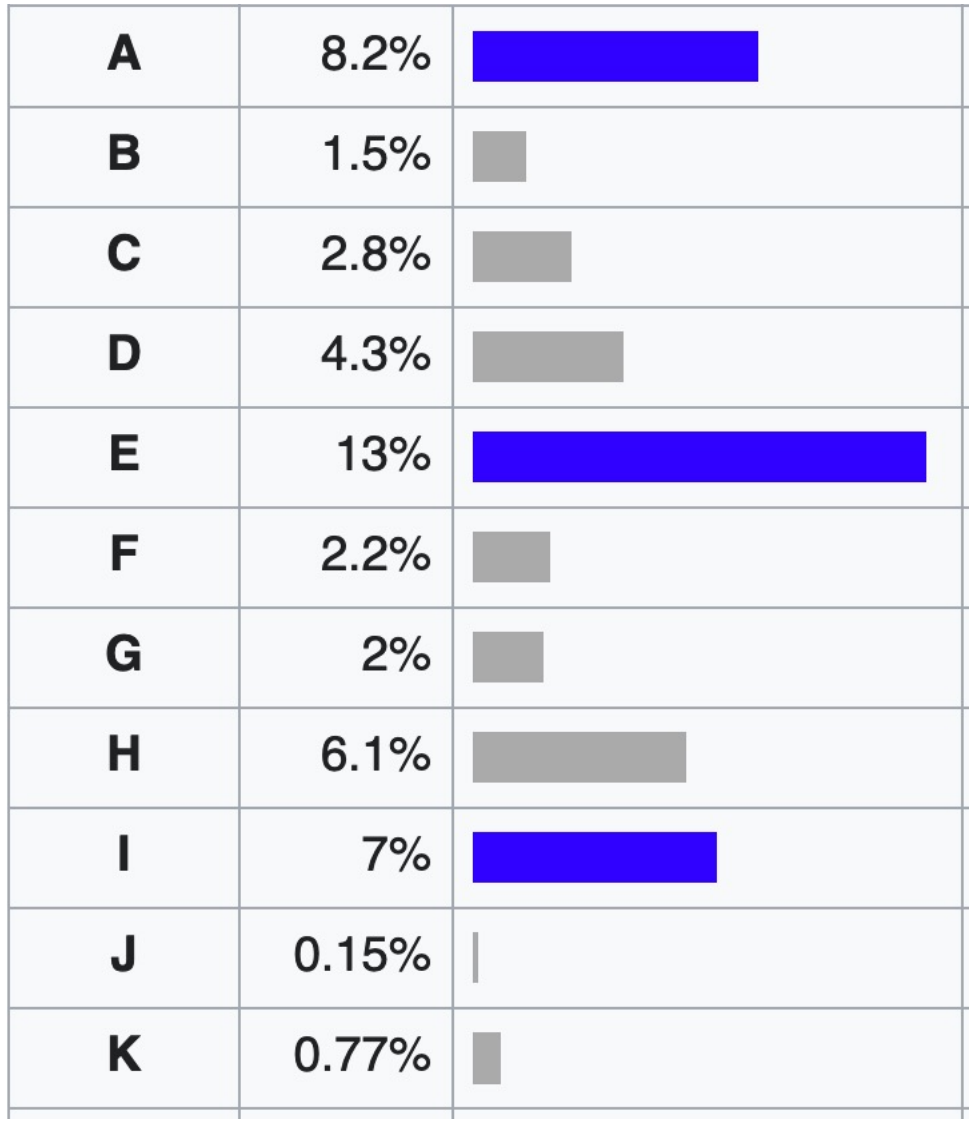
Key recovery:
Adversary obtains a single ciphertext, attempts to recover K

Let’s do some cryptanalysis (breakouts)

bjqhtrj yt ymj jchnynsl btwqi tk hwduytlwfumd

Frequency analysis

- English language has patterns
- Can exploit, why?
  - Substitution cipher ***preserves*** frequency of plaintext
  - Need to not leak this information



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


ENIGMA

Shannon's security notion (1949)

Def. A symmetric encryption scheme Enc is perfectly secure if for all messages M, M' and ciphertexts C

$$\Pr[\,Enc(K,M) = C\,] = \Pr[\,Enc(K,M') = C\,]$$

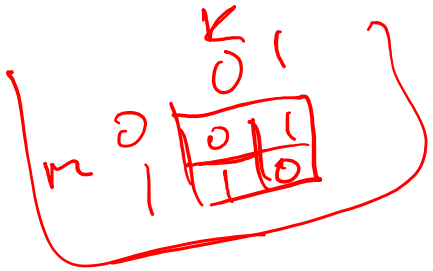
where probabilities are over choice of K

In words:
each message is equally likely to map to a given ciphertext

In other words:
seeing a ciphertext leaks nothing about what message was encrypted

Does a substitution cipher meet this definition? No!

One-time pad (OTP)



Kg():
K <-$ {0,1}^L

Pick a random bit string

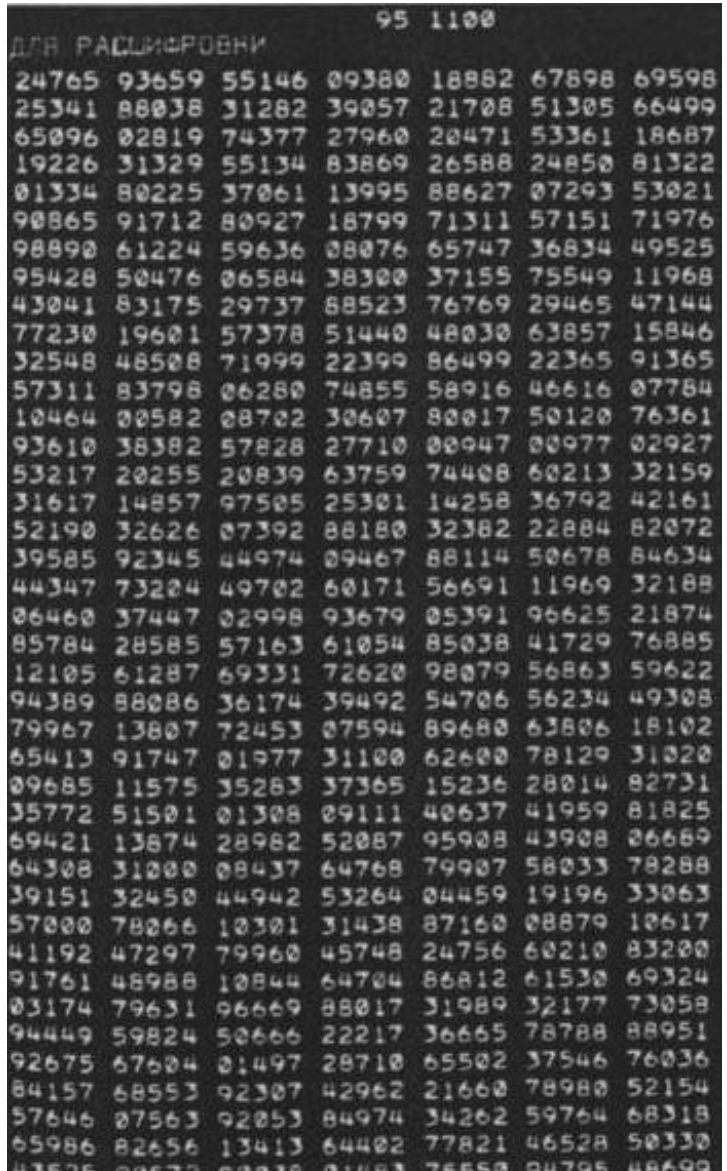
Enc(K,M):
Return M ⊕ K

Assume M is L-bit string

Dec(K,C):
Return C ⊕ K

Assume C is L-bit string

Part of a CIA OTP used by Soviet diplomat spying for CIA



95 1100

ДЛЯ РАСШИФРОВКИ

24765	93659	55146	09380	18882	67898	69598
25341	88038	31282	39057	21708	51305	66499
65096	02819	74377	27960	20471	53361	18687
19226	31329	55134	83869	26588	24850	81322
01334	80225	37061	13995	88627	07293	53021
90865	91712	80927	18799	71311	57151	71976
98890	61224	59636	08076	65747	36834	49525
95428	50476	06584	38300	37155	75549	11968
43041	83175	29737	88523	76769	29465	47144
77230	19601	57378	51440	48030	63857	15846
32548	48508	71999	22399	86499	22365	91365
57311	83798	06280	74855	58916	46616	07784
10464	00582	08702	30607	80017	50120	76361
93610	38382	57828	27710	00947	00977	02927
53217	20255	20839	63759	74408	60213	32159
31617	14857	97505	25301	14258	36792	42161
52190	32626	07392	88180	32382	22884	82072
39585	92345	44974	09467	88114	50678	84634
44347	73204	49702	60171	56691	11969	32188
06460	37447	02998	93679	05391	90625	21874
85784	28585	57163	61054	85038	41729	76885
12105	61287	69331	72620	98079	56863	59622
94389	88086	36174	39492	54706	56234	49308
79967	13807	72453	07594	89680	63806	18102
65413	91747	01977	31100	62600	78129	31020
09685	11575	35283	37365	15236	28014	82731
35772	51501	01308	09111	40637	41959	81825
69421	13874	28982	52087	95908	43908	06669
64308	31000	08437	64768	79907	58033	78288
39151	32450	44942	53264	04459	19196	33063
57000	78066	10301	31438	87160	08879	10617
41192	47297	79960	45748	24756	60210	83200
91761	48988	10844	64704	86812	61530	69324
03174	79631	96669	88017	31989	32177	73058
94449	59824	50666	22217	36665	78788	88951
92675	67604	01497	28710	65502	37546	76036
84157	68553	92307	42962	21660	78980	52154
57646	07563	92053	84974	34262	59764	68318
65986	82656	13413	64402	77821	46528	50330

Shannon's security notion (1949)

Def. A symmetric encryption scheme Enc is perfectly secure if for all messages M, M' and ciphertexts C

$$\Pr[\,Enc(K,M) = C\,] = \Pr[\,Enc(K,M') = C\,]$$

where probabilities are over choice of K

Thm. OTP is perfectly secure

For any C and M of length L bits

$$\Pr[\,K \oplus M = C\,] = 1 / 2^L$$

$$\Pr[\,K \oplus M = C\,] = \Pr[\,K \oplus M' = C\,]$$

Shannon's security notion (1949)

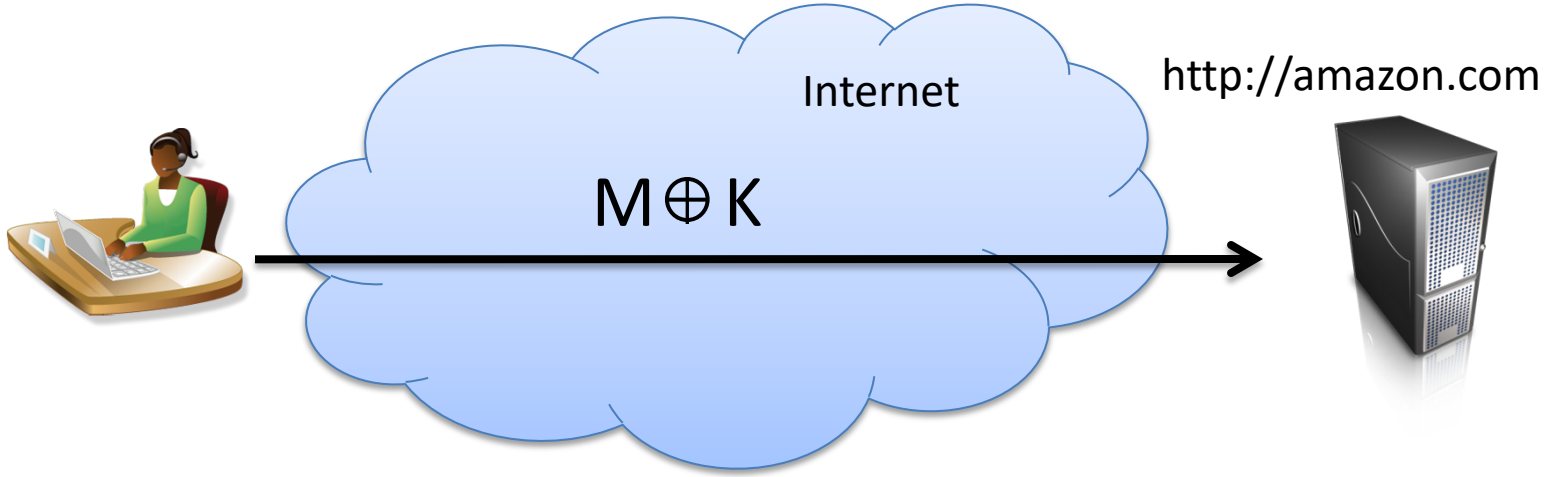
Def. A symmetric encryption scheme Enc is perfectly secure if for all messages M, M' and ciphertexts C

$$\Pr[\,Enc(K,M) = C\,] = \Pr[\,Enc(K,M') = C\,]$$

where probabilities are over choice of K

Thm. OTP is perfectly secure

Thm. Perfectly secure encryption requires $|K| \geq |M|$



Does OTP suffice for securing communications online?

Integrity easily violated

Reuse of K for messages M,M’ leaks M ⊕ M’

Encrypting same message twice under K leaks the message equality

K must be as large as message

Message length revealed

Formal security notions are hard to get right

Simplifying abstraction to allow rigorous analysis

Amount of deployment details needed to capture attacks

How do cryptographers *evaluate* crypto?

- Cryptanalysis
  - Try to break it. Bonus points if it's an implementable attack
- Formal analyses by hand
  - Give rigorous definition of security, prove manually that scheme meets it (usually via reduction to underlying hard problem)
- Automated protocol analysis tools
  - Build software tools to analyze protocols for bugs
- Implementation analysis tools
  - Build software tools to analyze implementations

How do cryptographers *design* crypto?

- Avoid security through obscurity:
  - Public designs and evaluation
- Public competitions
  - Set out requirements document, solicit submissions and then have several years of people trying to break stuff
- Standardization processes (IETF / ISO)
  - Write down protocols as RFCs (Request for Comments)
  - Sometimes this is design-by-committee
- No single person can design good crypto. Community effort

The game plan

- Planned topics
  - Stream ciphers, block ciphers
  - Symmetric encryption (block cipher modes of operation)
  - Authenticated encryption & hashing
  - TLS overview and public key encryption (RSA)
  - PKI, Diffie-Hellman, Elliptic curve cryptography
  - Encrypted messaging & “backdoors”
  - Random number generation
  - Misc. topics

The game plan

- Targeting 4 homework assignments
  - Mix of Python programming, short answer
  - Hope to get full homework schedule up in next few days
- One final exam (take-home)
  - Like the short answer questions from homeworks
- Will try to have some extra credit opportunities

The game plan

- First two weeks must be online
  - Afterwards: ???
  - Schedule will be kept up to date with remote vs. in-person
- In-person should be (fingers crossed) remotely viewable
- Will try to make recordings available, as well

Enrollment

- If you had trouble enrolling, or know friends who had trouble, just have them email me and we will sort it out

Questions? Comments?