UCS1505 INTRODUCTION TO CRYPTOGRAPHIC TECHNIQUES

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Course Objectives

- To understand the classical and symmetric cryptographic techniques
- To study about message authentication and hash functions
- To learn number theory fundamentals needed by cryptographic algorithms
- To understand the various key distribution and management schemes
- To understand the concepts of Public key cryptography and digital signatures.

Course Outcome

- On successful completion of this course, the student will be able to:
- Describe and implement classical and symmetric ciphers (K2)
- Describe the authentication schemes and hash algorithms (K2)
- Understand the number theoretic foundations of cryptography (K3)
- Compare and contrast various Public key cryptographic techniques (K3)
- Illustrate various Public key cryptographic techniques (K3).

History of Cryptography

hieroglyphs - around 2000 B.C.

漢字 汉字

ideogram - ancient Chinese

Clay tablets from Mesopotamia

ABCDEFGHIJKLMNOPQRSTUVWXYZ
ZYXWVUTSRQPONMLKJIHGFEDCBA

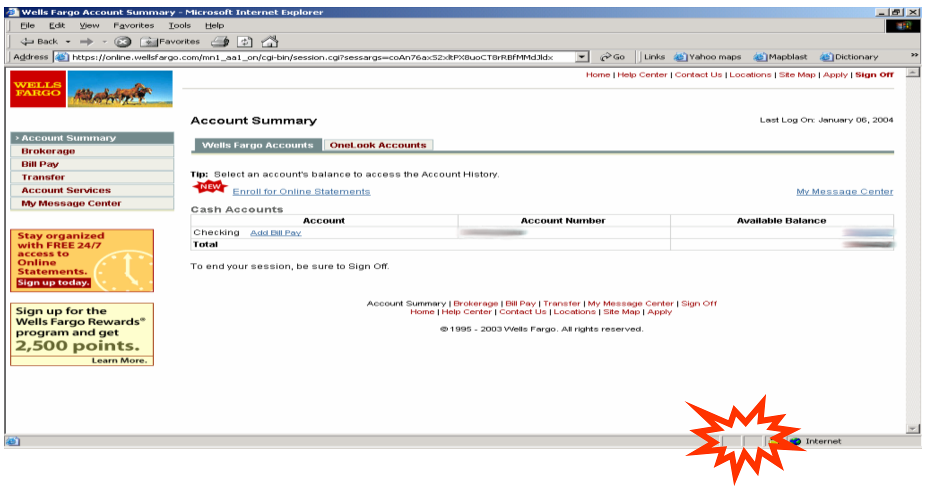
Atbash cipher - around 500 to 600 BC

Scytale - Spartan

	1	2	3	4	5
1	A	B	C	D	E
2	F	G	H	I	J
3	K	L	M	N	O
4	P	Q	R	S	T
5	U	V	W	X	Y/Z

Polybius Square - Greek method

Secure communication



HTTPS

no eavesdropping
no tampering

Secure Sockets Layer / TLS

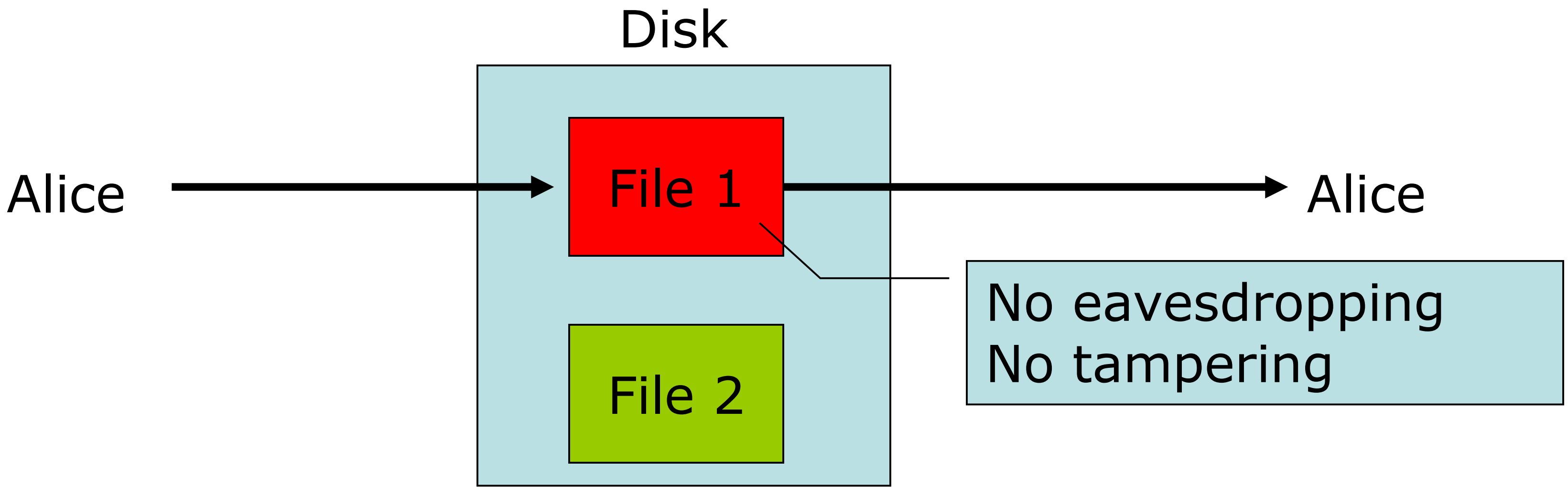
Two main parts

1. Handshake Protocol: **Establish shared secret key using public-key cryptography** (2nd part of course)

2. Record Layer: **Transmit data using shared secret key**

   Ensure confidentiality and integrity (1st part of course)

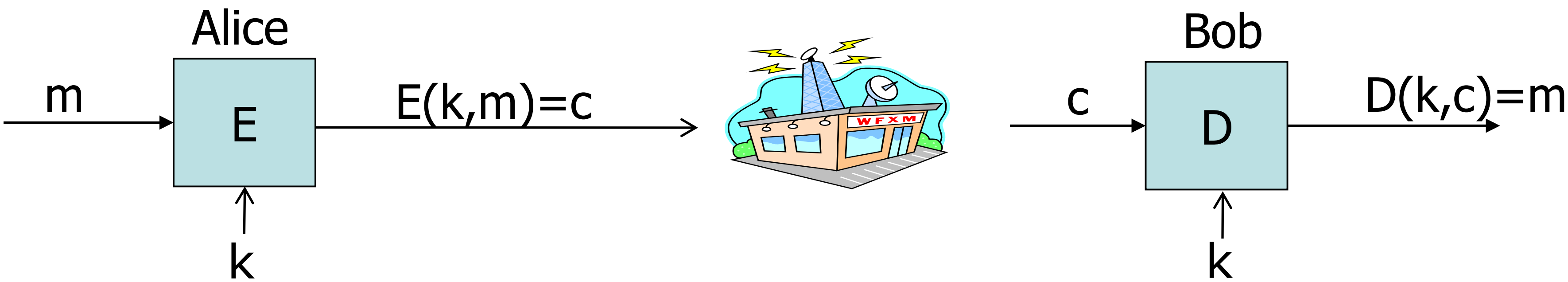
Protected files on disk



Analogous to secure communication:

Alice today sends a message to Alice tomorrow

Building block: sym. encryption



E, D: cipher k: secret key (e.g. 128 bits)
m, c: plaintext, ciphertext

Encryption algorithm is publicly known

- Never use a proprietary cipher

Things to remember

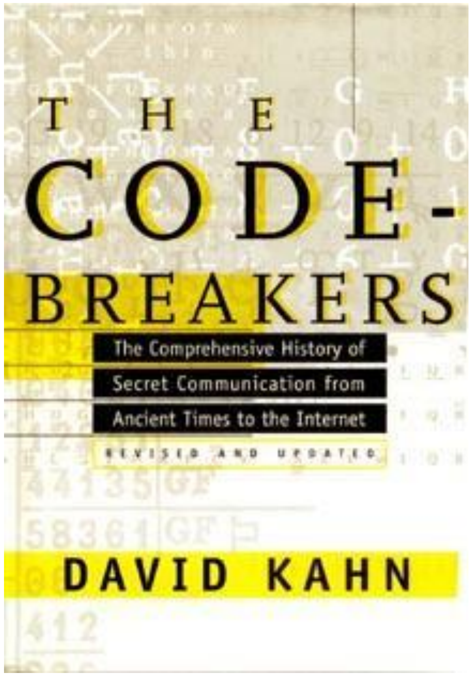
Cryptography is:

- A tremendous tool
- The basis for many security mechanisms

Cryptography is not:

- The solution to all security problems
- Reliable unless implemented and used properly
- Something you should try to invent yourself
  - many many examples of broken ad-hoc designs

- David Kahn, “The code breakers” (1996)



Price Water Cooper

Increased Security Breaches

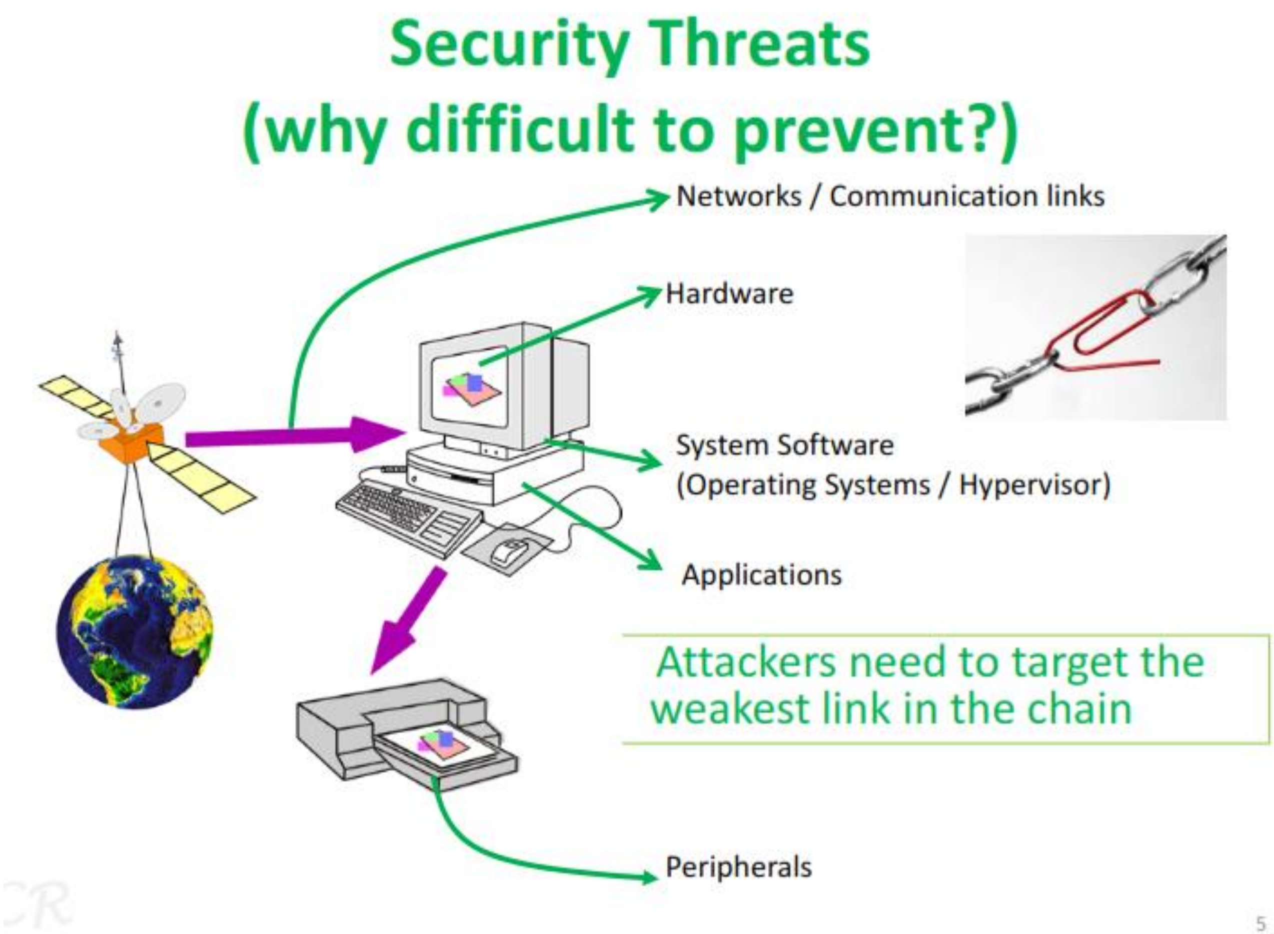
81% more in 2015

90% of large organisations
74% of small businesses
had a security breach.
▲ Up from 81% a year ago.
▲ Up from 60% a year ago.

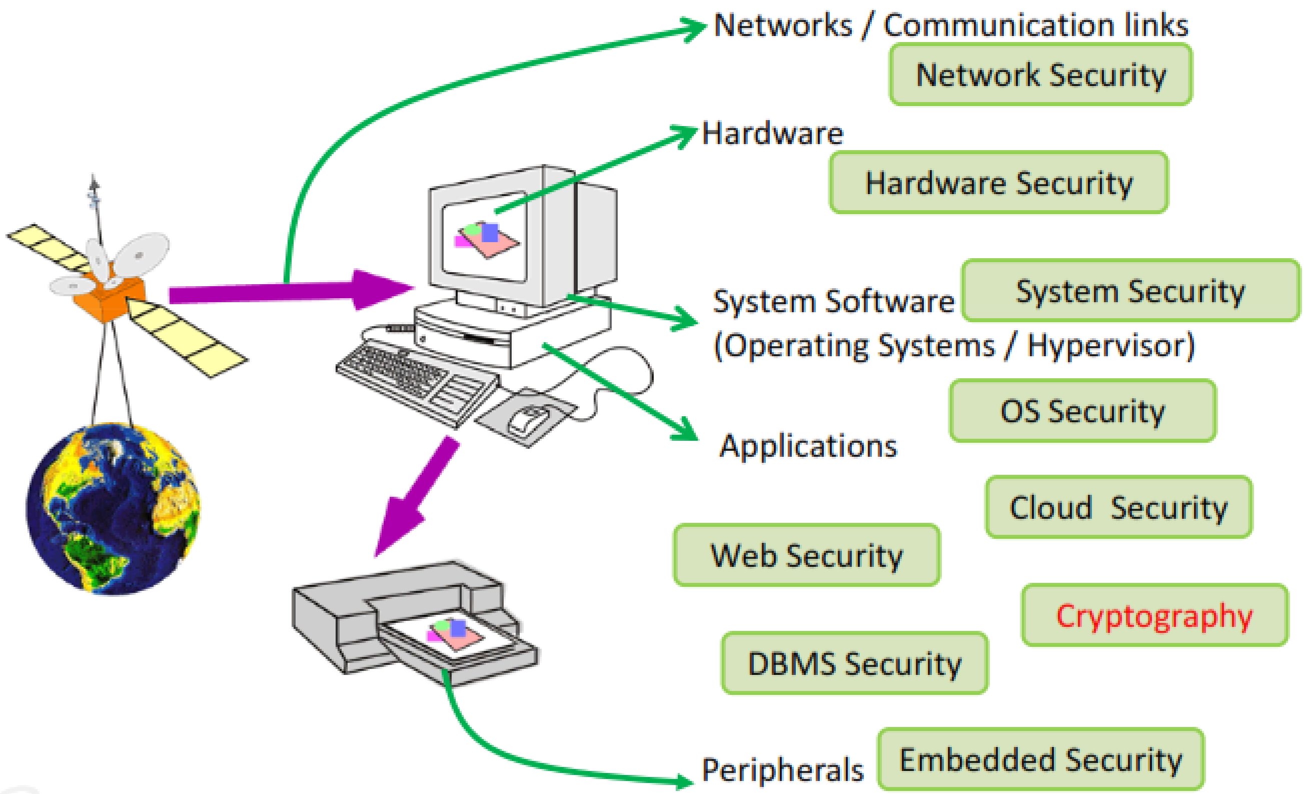
£1.46m - £3.14m is the average cost to a large organisation	**£75k - £311k** is the average cost to a small business

44% of large organisations
44% of small businesses
increased information security spend in the last year.

Security Threats

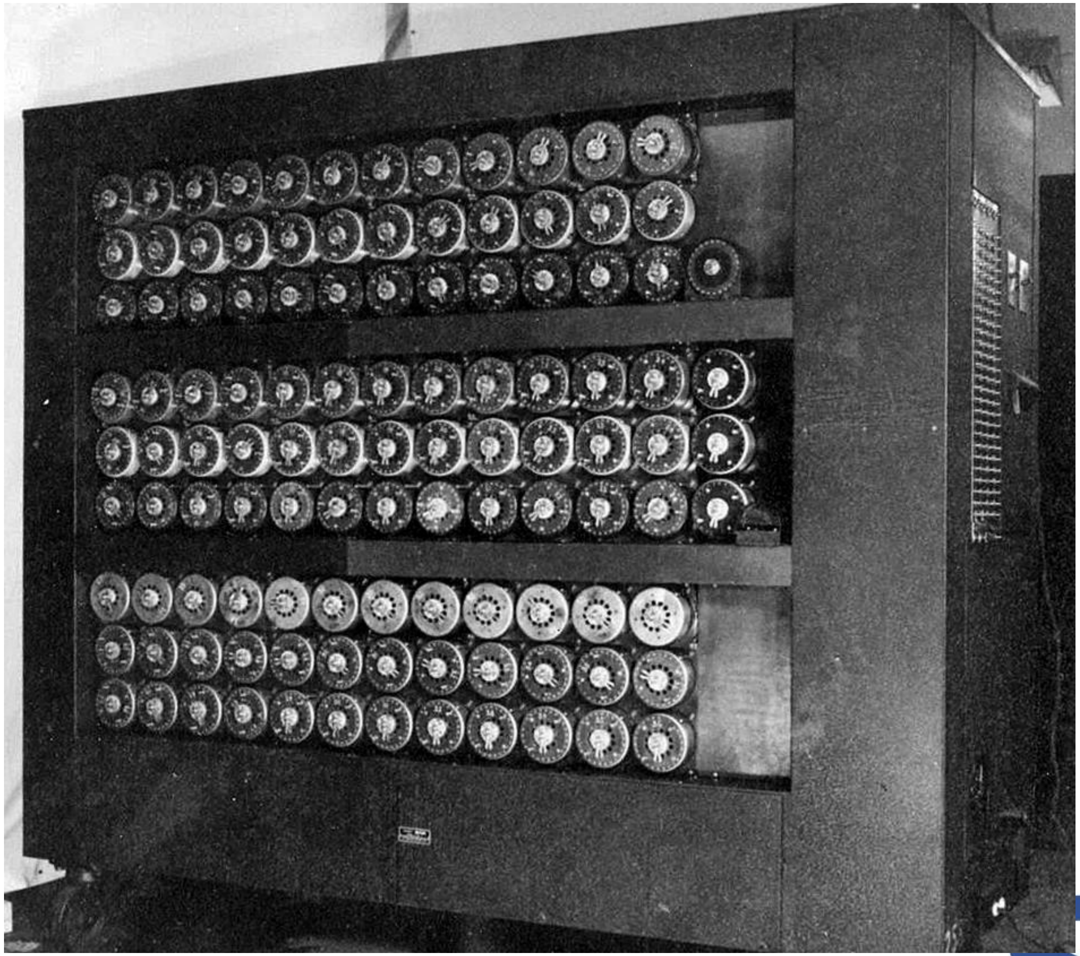


Security Study



Enigma

Bombe



Turing Award

Increased Security Breaches (PWC)

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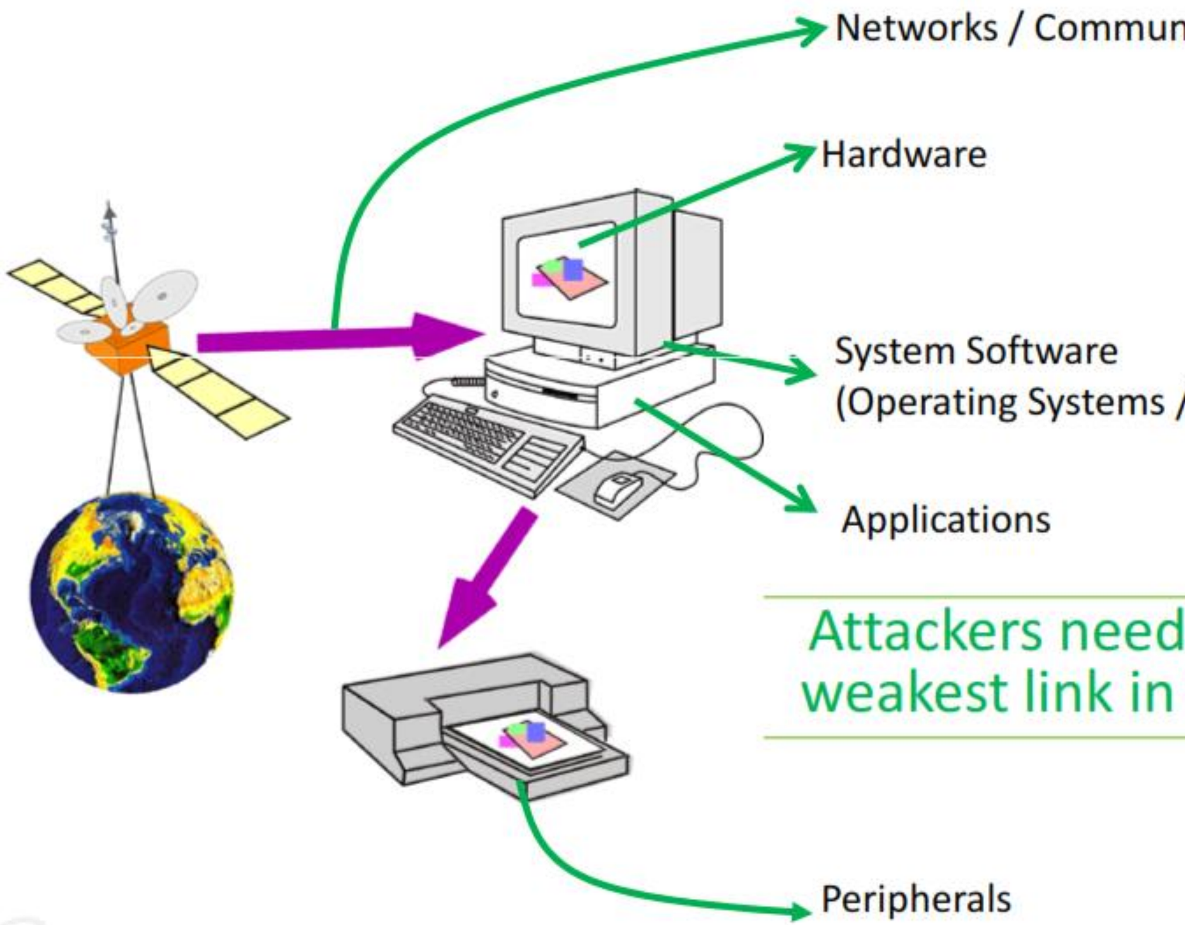
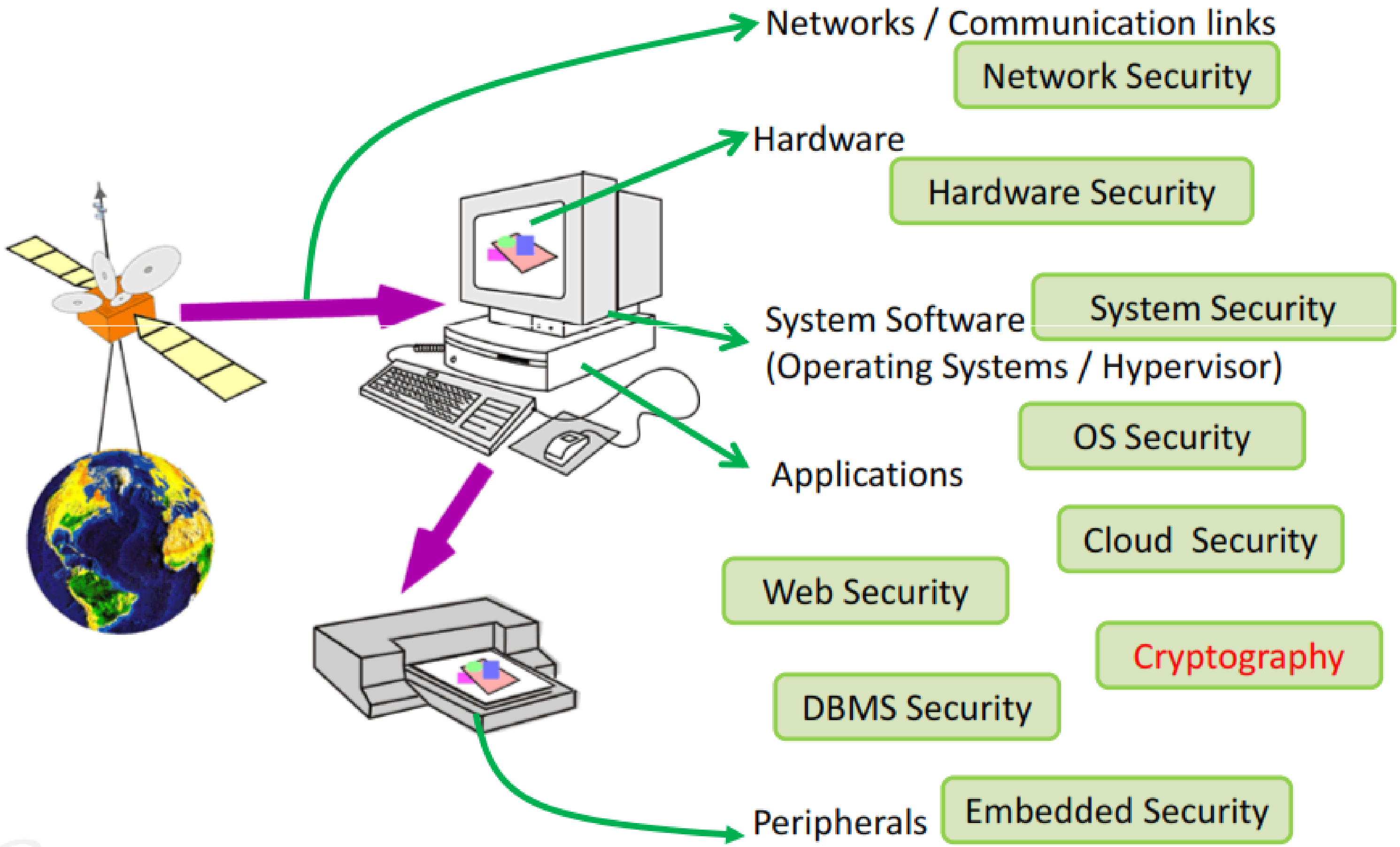


Attackers need to target the weakest link in the chain

Security Studies



Cryptography (historically)

"...the art of writing or solving codes…"

- Historically, cryptography focused exclusively on ensuring *private communication* between two parties sharing secret information in advance (using "codes" aka *private-key encryption*)

Modern cryptography

- Much broader scope!
  - Data integrity, authentication, protocols, …
  - The *public-key setting*
  - Group communication
  - More-complicated trust models
  - Foundations (e.g., number theory, quantum-resistance) to systems (e.g., electronic voting, cryptocurrencies)

Modern cryptography

Design, analysis, and implementation of ***mathematical techniques*** *for securing information, systems, and distributed computations against adversarial attack*

Modern cryptography

- Cryptography is ubiquitous
  - Passwords, password hashing
  - Secure credit-card transactions over the internet
  - Encrypted WiFi
  - Disk encryption
  - Digitally signed software updates
  - Bitcoin
  - …

Cryptography (historically)

"…the art of writing or solving codes…"

- Historically, cryptography was an *art*
  - Heuristic, unprincipled design and analysis
  - Schemes proposed, broken, repeat…

Modern cryptography

- Cryptography is now much more of a *science*
  - Rigorous analysis, firm foundations, deeper understanding, rich theory
- The “crypto mindset” has permeated other areas of computer security
  - Threat modeling
  - Proofs of security

Rough course outline

	Secrecy	**Integrity**
Private-key setting	Private-key encryption	Message authentication codes
Public-key setting	Public-key encryption	Digital signatures

- Building blocks
  - Pseudorandom (number) generators
  - Pseudorandom functions/block ciphers
  - Hash functions
  - Number theory

Cryptography

- A crucial component in all security systems
- Fundamental component to achieve
  - Confidentiality
  - Data Integrity
  - **Authentication**
  - Non-Repudiation

Cryptography helps prove identities

Classical Cryptography

Motivation

- Allows us to “ease into things…,” introduce notation
- Shows why unprincipled approaches are dangerous
- Illustrates why things are more difficult than they may appear

Classical cryptography

- Until the 1970s, exclusively concerned with ensuring *secrecy* of communication
- i.e., *encryption*

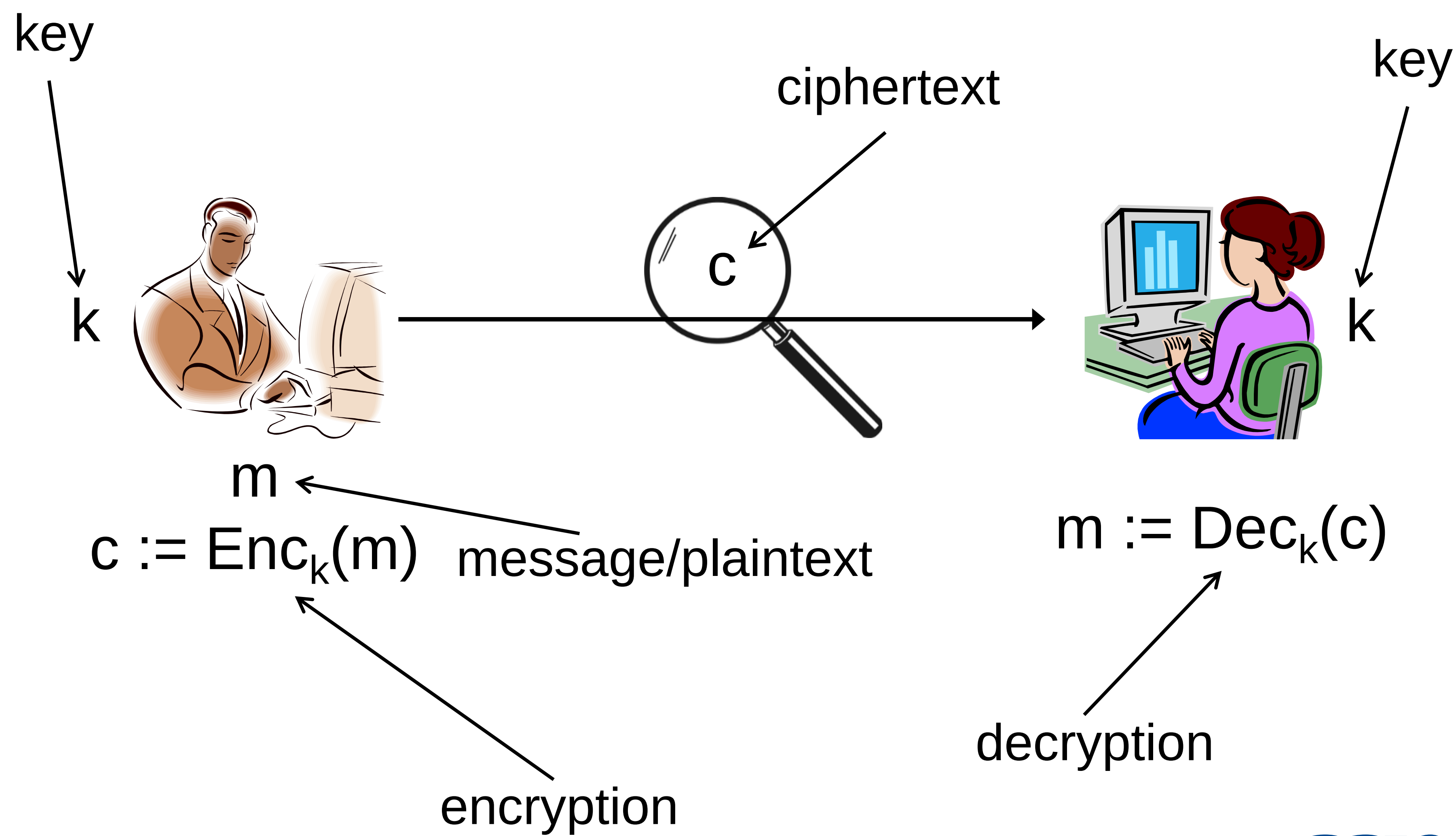
Classical Cryptography

- Until the 1970s, relied exclusively on secret information (a *key*) shared in advance between the communicating parties

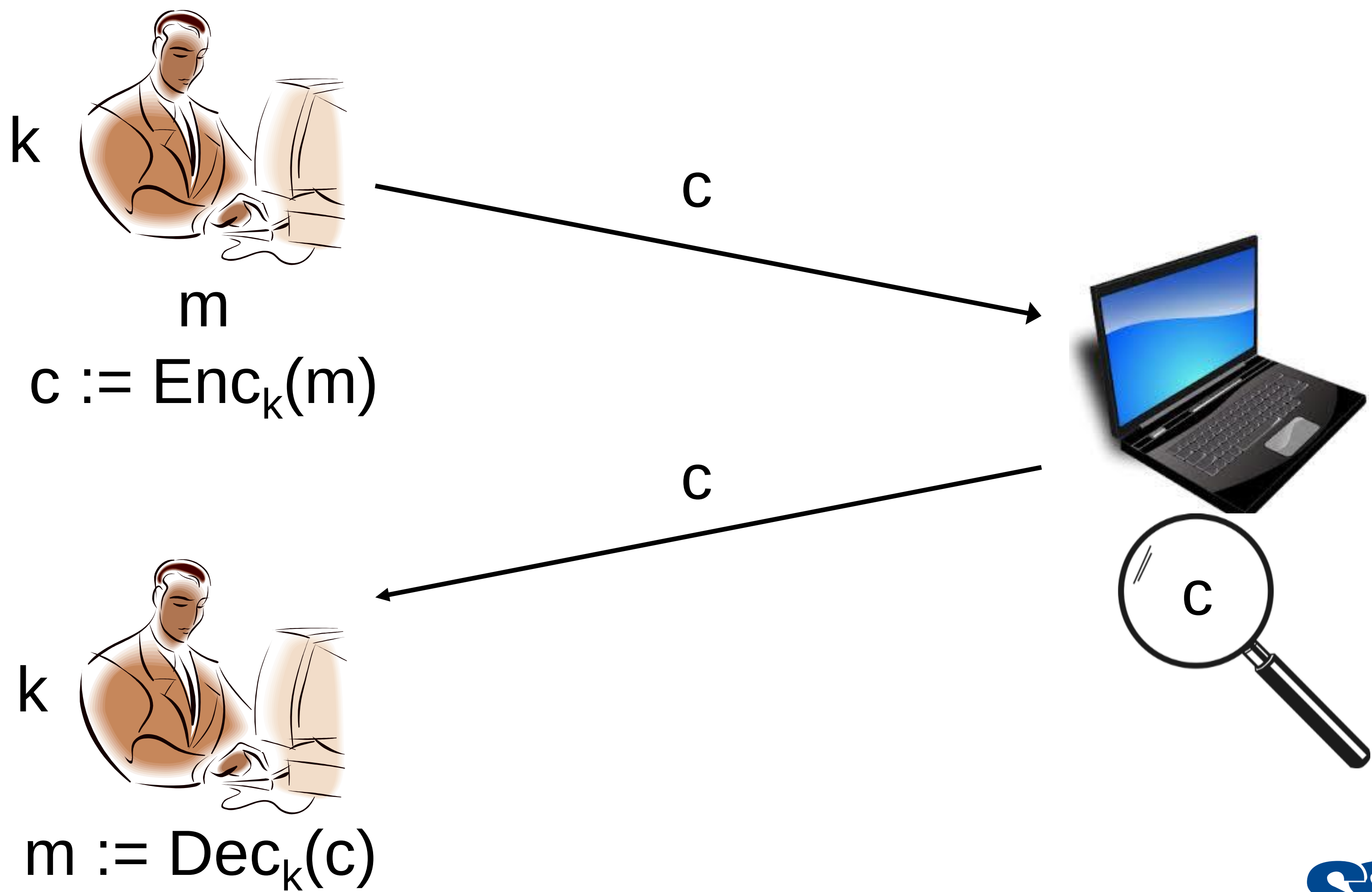
Private-key cryptography

- – aka secret-key / shared-key / symmetric-key cryptography ssn

Private-key encryption



Private-key encryption



Private-key encryption

- A *private-key encryption scheme* is defined by a message space $\mathcal{M}$ and algorithms (Gen, Enc, Dec):
  - Gen (key-generation algorithm): outputs $k \in \mathcal{K}$
  - Enc (encryption algorithm): takes key k and message $m \in \mathcal{M}$ as input; outputs ciphertext c
    $$c \leftarrow Enc_k(m)$$
  - Dec (decryption algorithm): takes key k and ciphertext c as input; outputs m or "error"

For all $m \in \mathcal{M}$ and k output by Gen,

$$Dec_k(Enc_k(m)) = m$$

Kerckhoffs's principle

- *The encryption scheme* is not secret
  - The attacker knows the encryption scheme
  - The only secret is the *key*
  - The key must be chosen at random; kept secret

- Some arguments in favor of this principle
  - Easier to keep *key* secret than *algorithm*
  - Easier to change *key* than to change *algorithm*
  - Standardization
    - Ease of deployment
    - Public validation

The shift cipher

- Consider encrypting English text
- Associate ‘a’ with 0; ‘b’ with 1; …; ‘z’ with 25
  - $k \in \mathcal{K} = \{0, \ldots, 25\}$

```
helloworldz
ccccccccccc
-----------
jgnnqyqtnfb
```

- To encrypt using key k, shift every letter of the plaintext by k positions (with wraparound)
- Decryption just does the reverse

Substitution Technique

- Is one in which the letters of plaintext are replaced by other letters or by numbers or symbols
- If the plaintext is viewed as a sequence of bits, then substitution involves replacing plaintext bit patterns with ciphertext bit patterns

Caesar Cipher

- Simplest and earliest known use of a substitution cipher
- Used by Julius Caesar
- Involves replacing each letter of the alphabet with the letter standing three places further down the alphabet
- Alphabet is wrapped around so that the letter following Z is A

plain: meet me after the toga party

cipher: PHHW PH DIWHU WKH WRJD SDUWB

Caesar Cipher Algorithm

- Can define transformation as:

a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z
D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C

- Mathematically give each letter a number

a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

- Algorithm can be expressed as:

$$c = \mathrm{E}(3, p) = (p + 3) \bmod (26)$$

  - A shift may be of any amount, so that the general Caesar algorithm is:

$$C = E(k , p) = (p + k) \bmod 26$$

- Where k takes on a value in the range 1 to 25; the decryption algorithm is simply:

$$p = D(k , C) = (C - k) \bmod 26$$