CS306: Introduction to IT Security

Fall 2020

Lecture ption

Instructor: **Nikos**

September 8, 2020

STEVENS
INSTITUTE *of* TECHNOLOGY
THE INNOVATION UNIVERSITY®

CS306: Staff

- Instructor
  - Nikos Triandopoulos, ntriando@stevens.edu
  - course organization / management, lectures, assignments, grades, …
    - all mistakes will b
  - office hours: **Thursd** **2**) or by appointment
- **Teaching assistants**
  - **Dean Rodman (drodman@stevens.edu), Devharsh Trivedi (dtrived5@stevens.edu), Joseph Iervasi (jiervasi@stevens.edu), Mohammad Khan (mkhan13@stevens.edu), Joshua Mimer (jmimer@stevens.edu), Uday Samavenkata (usamaven@stevens.edu)**
  - **assistance w/ labs, assignments, help sessions, grading, demos, …**

CS306: TA hours

- Standard schedule, starting from tomorrow

SAME ZOOM ID

Day	Monday	Tuesday	Wednesday	Thursday	Friday
time	13:00 – 14:00	13:00 – 14:00	13:00 – 14:00	13:00 – 14:00	13:00 – 14:00
Zoom ID	91463728672			728672	91463728672
staff	Dean			**Nikos**	Uday

- Additional TA hours to be added for homework assignments or before exams

CS306: Lectures & labs

CS306 is offered in **2 required sessions**, each offered in **multiple sections**

- lectures
  - CS306-A Tue 2:00pm - 4:30pm **Online** 67 / 69
  - CS306-B Tue 6:30pm - 9:00pm **Online** 63 / 69
- labs
  - CS306-Lx Thursdays

last week

x	A	B	C		E	F
time	8 - 8:50	9:30 - 10:20	11:00 - 11:50	12:30 - 13:20	2:00 - 2:50	3:30 - 4:20
enrollment	1	18	29	29	29	24

CS306: Lectures & labs (continued)

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CS306: Lectures & labs (continued)

- Lecture/lab sections will cover the same materials
- Changes in lecture or lab sections
  - **allowed** (if need be) but **generally discouraged** (for planning purposes)
- In any case, if a secti
  - **students must let th** **ance**

Our on-going semester-long project…

- Lectures take place in 2.5h slots
  - CS306-A Tue 2:00pm - 4:30pm **Online** 67 / 69
  - CS306-B Tue 6:30pm - 9:00pm **Online** 62 / 69
- Highly problematic s & instructor
  - unfortunately unav g restrictions
- **Tentative countermeasures**
  - **two ~10-min breaks**
  - **Spending last 30min with demos, special topics of interest or offline materials**

Please provide suggestions on what can make class experience better despite 2.5h lectures

CS306: Lab sections schedule

- labs
  - CS306-Lx Thursdays

ZOOM ID: LAB SPECIFIC!

x	B			E	F
time	9:30 - 10:20			:00 - 14:50	15:30 - 16:20
Zoom ID	91573945614	93061161569	9497	271191	94520991826
TAs	Dean, Joseph, Joshua, Uday	Dean, Devharsh, Joseph, Joshua	Dean/Devharsh, Joshua, Mohammad, Uday	Devharsh, Joseph, Mohammad, Uday	Dean, Joseph, Mohammad, Uday

CS306: Other announcements

- Canvas course materials are now updated
- Lab sessions start this week
- TA hours & office hours start tomorrow

CS306: Tentative Syllabus

Week	Date	Topics	Reading	Assignment
1	Sep 1	Introduction	Lecture 1	-
2	Sep 8	Symmetric-key crypto I		
3	Sep 15			
4	Sep 22			
5	Sep 29	Public-key cr		
6	Oct 6	Access control & authentication		
-	Oct 13	**No class (Monday schedule)**		
7	Oct 20	**Midterm**	All materials covered	

CS306: Tentative Syllabus (continued)

Week	Date	Topics	Reading	Assignment
8	Oct 27	Software & Web security		
9	Nov 3	Network security		
10	Nov 10			
11	Nov 17			
12	Nov 24	Privacy		
13	Dec 1	Economics		
14	Dec 8	Legal & ethical issues		
15	Dec 10 (or later)	**Final** (closed "books")	All materials covered*	

* w/ focus on what covered after midterm

CS306: Course outcomes

- Terms
  - describe common security terms and concepts
- Cryptography
  - state basics/fundamentals about secret and public key cryptography concepts
- Attack & Defense
  - acquire basic understanding for attack techni mechanisms
- Impact
  - acquire an understanding for the broader impact of security and its integral connection to other fields in computer science (such as software engineering, databases, operating systems) as well as other disciplines including STEM, economics, and law
- Ethics
  - acquire an understanding for ethical issues in cyber-security

Questions?

- Please ask questions during class!

Last week

- Course logistics
  - topic of study, enrollment eligibility, sessions
  - staff, learning materials, course organization
  - expectations, gradi
  - syllabus overview,
- Introduction to the field of IT security
  - in-class discussion with a real-world example

Today

- Introduction to the field of IT security
  - Basic concepts and terms
  - Symmetric encryption

What is IT security?

IT security is the prevention of, or protection against

- access to information by unauthorized recipients
- intentional but unauthorized destruction or alteration of that information

m *Dictionary of Computing,* Fourth Ed. Oxford: Oxford University Press 1996).

IT security (informal definition)

- the protection of information systems from
  - theft or damage to the hardware, the software, and to the information on them, as well as from disruption or misdirection of the services they provide
  - any possible threat

The ‘IT-security’ game: What’s at stake?

- Computer systems comprise assets that have (some) **value**
  - e.g., laptops store vast personal or important information (files, photos, email, …)
  - personal, time-dependent and often imprecise (e.g., monetary Vs. emotional)
- Valuable assets des
  - to **preserve** their **v** d as a **security property**
    - e.g., personal photos should always b their owner
  - or to **prevent** (undesired) **harm**  examined as a concrete **attack**
    - e.g., permanent destruction of irreplaceable photos

The ‘IT-security’ game: Who are the players?

- **Defenders**
  - system owners (e.g., users, administrators, etc.)
  - seek to **enforce** one or more **security properties** **property-based view**
    or **defeat** certain **at**
- **Attackers**
  - external entities (e.g., hackers, other us
  - seek to launch attacks that **break** a **security property**
    or **impose** the system to certain **threats**  **attack-based view**

Security properties

- General statements about the value of a computer system
- Examples
  - The C-I-A triad
    - **confidentiality**,
  - (Some) other pro
    - **authentication / authenticity**
    - **non-repudiation / accountability / auditability**
    - **anonymity**

The C-I-A triad

- Captures the three fundamental properties that make any system valuable

Computer security seeks to prevent unauthorized viewing (confidentiality) or modificatio rving access (availability)

Confidentiality

- An asset is viewed only by authorized parties
  - e.g., conforming to originally-prescribed “read” rules <subject, object, access mode, policy> via access control
  - some other tools
    - encryption, obfusc

Integrity

- An asset is modified only by authorized parties
  - beyond conforming to originally-prescribed “write” access-control rules
  - precise, accurate, unmodified, modified in acceptable way by authorized people or processes, consist
  - authorized actions, s es, error detection & correction
  - some tools
    - hashing, MACs

Availability

- An asset can be used by any authorized party
  - usable, meets service's needs, bounded waiting/completion time, acceptable outcome
  - timely response, fairness, concurrency, fault tolerance, graceful cessation (if needed)
  - some tools
    - redundancy, fault es

Authenticity

- The ability to determine that statements, policies, and permissions issued by persons or systems are genuine
  - some tools
    - digital signature to allow entities to commit to the authenticity
      - achieve non-repudiation (authenticity by some person or system cannot be denied)

Anonymity

- The property that certain records/transactions cannot be attributed to any individual
- some tools
  - aggregation
    - disclosure of statis individuals that cannot be tied to any individual
  - proxies
    - trusted agents interacting on behalf on an individual in untraceable way
  - pseudonyms
    - fictional identities, known only to a trusted party, that fill in for real identities

Discussion

1. Cloud-based storage
2. e-banking
   - What is a **valued asset**?
   - What does it mean
   - What is a correspo
   - What is a **harm** that must be prevented?

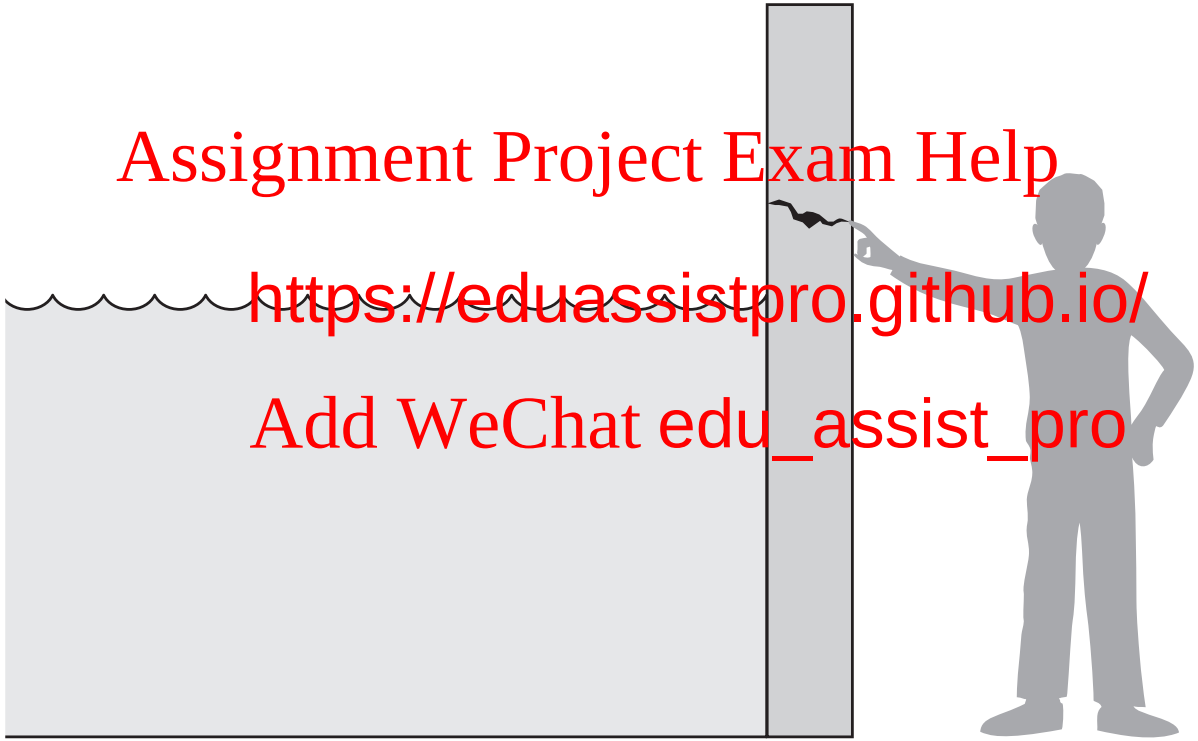
The “Vulnerability - Threat - Control” paradigm

- A **vulnerability** is a weakness that could be exploited to cause harm
- A **threat** is a set of circumstances that could cause harm
- A **security control** is a mechanism that protects against harm
  - i.e., countermeasur m exercising vulnerabilities

Thus

- **Attackers** seek to **exploit** vulnerabilitie **pose** threats
- **Defenders** seek to **block** these threats by **controlling** the vulnerabilities

A “Vulnerability - Threat - Control” example



Example of threat

- **Eavesdropping:** the interception of information intended for someone else during its transmission over a communication channel

Example of threat

- **Alteration:** unauthorized modification of information
  - **Example:** the man-in-the-middle attack, where a network stream is intercepted, mo and retransmitted

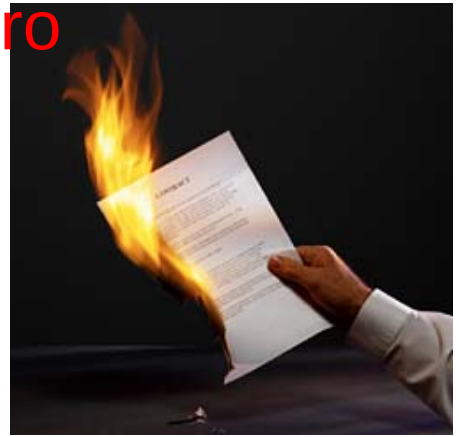
Example of threat

- **Denial-of-service:** the interruption or degradation of a data service or information access
  - **Example:** email spam, to the degree that it to simply fill up a ma and slow down an

Examples of threats

- **Masquerading**: the fabrication of information that is purported to be from someone who is not actually the author
  - e.g., IP spoofing att
    the source IP addre

- **Repudiation:** the denial of a commitme eipt
  - this involves an attempt to back out of a contract/protocol that, e.g., requires the different parties to provide receipts acknowledging that data has been received



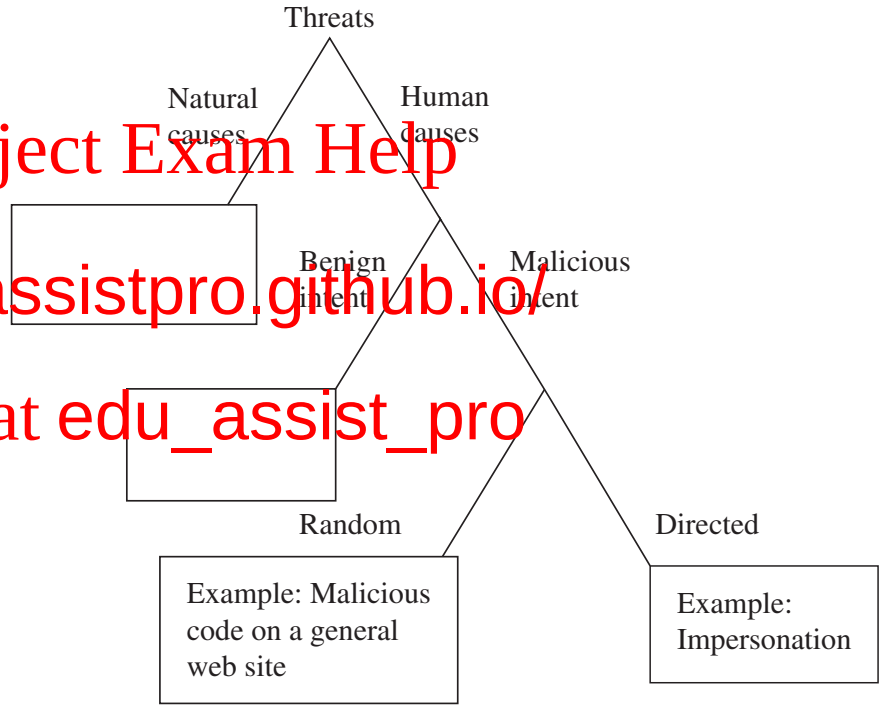
Example of vulnerability

- **Software bugs:** Code is not doing what is supposed to be doing
  - **Example:** Some application code is mistakenly using an algorithm for encryption that has been broken
  - **Example:** There is n

An hard-to-win game: Varied threats

Threats

- from natural to human
- from benign to malicious
- from random to targe



A hard-to-win game: Unknown enemy

Attackers

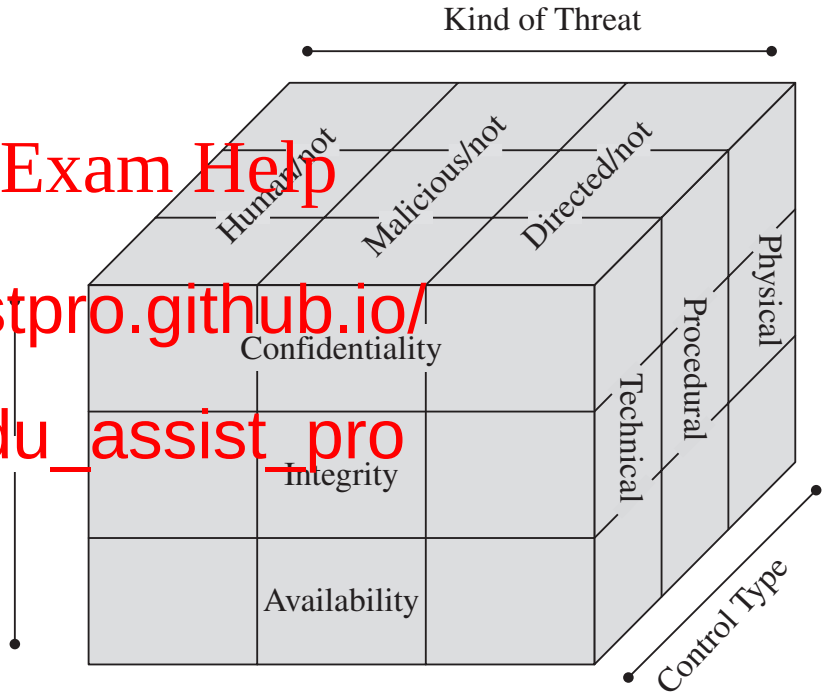
- beyond isolated “crazy” hackers
- organized groups/crime
  - may use computer (e.g., stealing CC#s) to finance other crimes
- terrorists
  - computers/assets as target, method, enabler, or enhancer

A hard-to-win game: Choose your battle

Risk management

- choose priorities
  - which threats to control
    - estimate possible
  - what / how many res
    - estimate solution cost & protection lev
- consider trade-offs balancing cost vs. benefit
- compute the residual risk
  - decide on transfering risk or doing nothing

Never a “one-shot” game



A hard-to-win game: Best-effort approach

Deciding on controls relies on incomplete information

- likelihood of attack and impact of possible harm is impossible to measure perfectly
- full set of vulnerabilities is often unknown
  - weak authenticatio programs, etc.
- system's attack surface i
  - physical hazards, malicious attacks, stea iders, benign mistakes, impersonations, etc.

A useful strategy: The "method – opportunity – motive" view of an attack

- **deny any of them and the attack will (likely) fail**

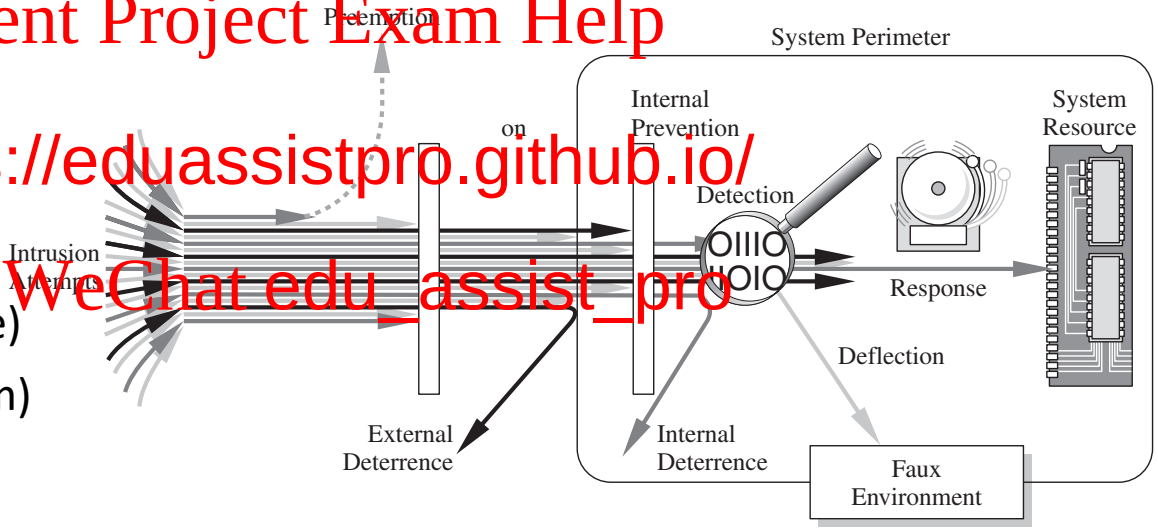
A hard-to-win game: Best-effort approach (continued)

Controls offer a wide range of protection level / efficacy

- they counter or neutralize threats or remove vulnerabilities in different ways

Types of controls

- prevent (attack is blocke
- deter (attack becomes ha
- deflect (change target of attack)
- mitigate (make impact less severe)
- contain (stop propagation of harm)
- detect (real time/after the fact)
- recover (from its effects)



Hard to balance cost/effectiveness of controls with likelihood/severity of threats

Example of control: HTTPS protocol

Hypertext Transfer Protocol Secure (HTTPS)

- Confidentiality
- Integrity
- Availability
- Authenticity
- Anonymity

Example of control: RAID technology

Redundant Array of Independent Disks (RAID)

- Confidentiality
- Integrity
- Availability
- Authenticity
- Anonymity

Example of controls: TOR protocol

- Confidentiality
- Integrity
- Availability
- Authenticity
- Anonymity

As we will see: Exciting times to study (or work in) IT Security!

Relevance to practice & real-world importance

- plethora of real-world problems & real needs for security solutions
- combination of different research areas within CS and across other fields
- multi-dimensional top
  - protocol design, system building, user e l/economic aspects
- wide range of perspectives
  - practical / systems – foundations / theory, attacker's Vs. defender's view

Recall: Confidentiality

Fundamental security property

- **an asset is viewed only by authorized parties**
- "C" in the CIA triad

"computer security
or modification

viewing (confidentiality)
g access (availability)"

Eavesdropping

- main threat against confidentiality of **in-transit** data

defender **defender**

attacker

Problem setting: Secret communication

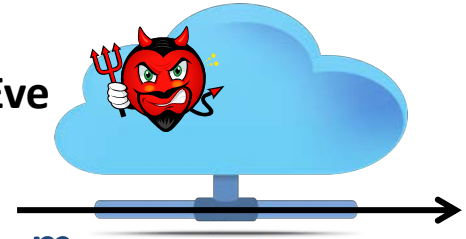
Two parties wish to communicate over a channel

- Alice (sender/source) wants to send a message m to Bob (recipient/destination)

Underlying channel is unprotected

- Eve (attacker/adversary)
- e.g., packet sniffing ov ications

Alice m

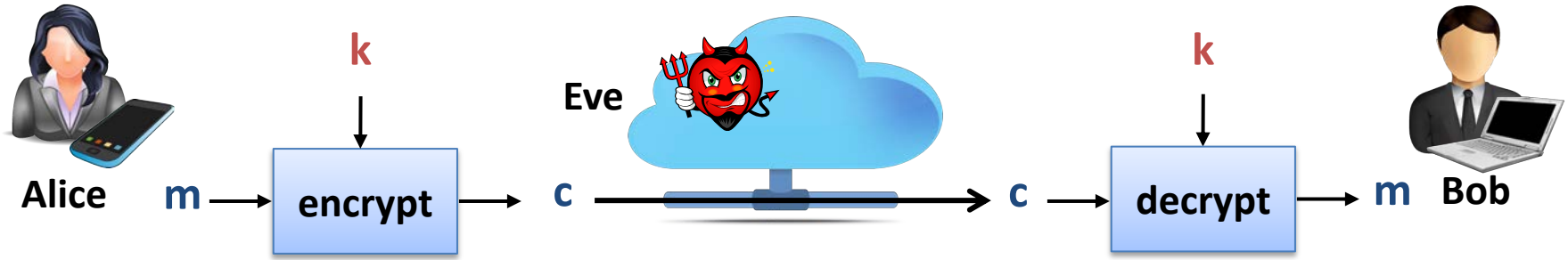


m Bob

Solution concept: Symmetric-key encryption

Main idea

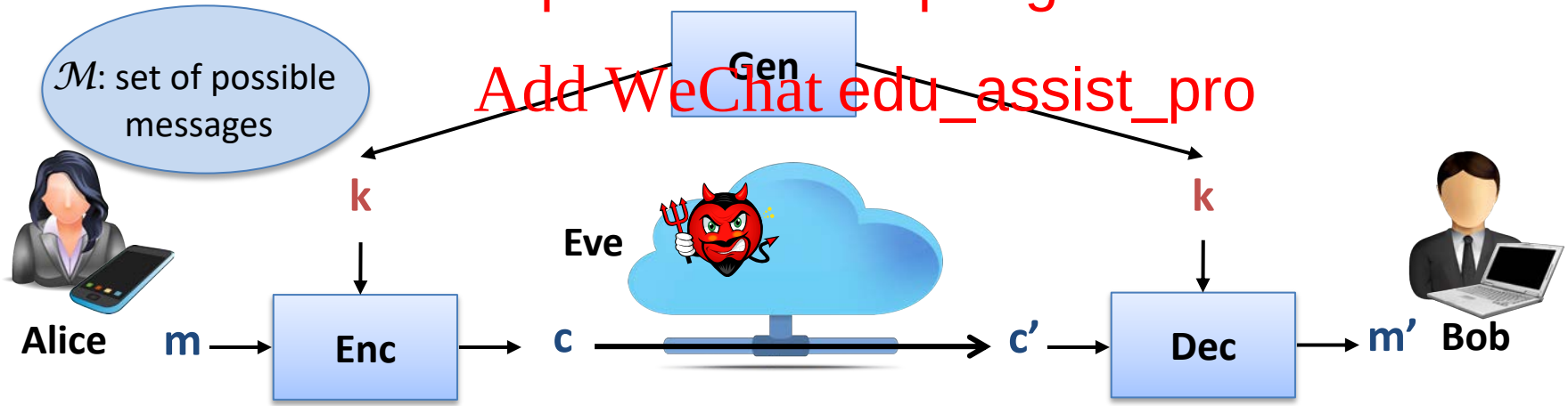
- secretly transform message so that it is **unintelligible** while in transit
  - Alice **encrypts** her message m to **ciphertext c**, which is sent instead of **plaintext m**
  - Bob **decrypts** receiv
  - Eve can intercept c bu
  - Alice and Bob share a **secret key k** that is used for message transformations



Security tool: Symmetric-key encryption scheme

Abstract cryptographic primitive, **a.k.a. cipher**, defined by

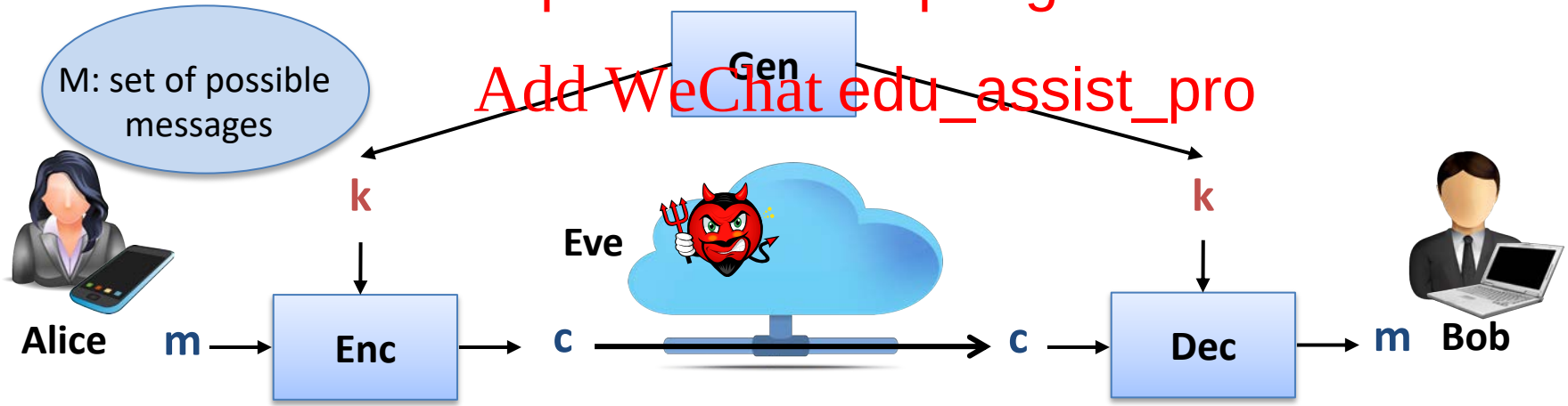
- a **message space** $\mathcal{M}$; and
- a triplet of algorithms **(Gen, Enc, Dec)**
  - Gen, Enc are probabilistic algorithms, whereas Dec is deterministic
  - Gen outputs a unif ey space $\mathcal{K}$)



Desired properties for symmetric-key encryption scheme

By design, any symmetric-key encryption scheme should satisfy the following

- **efficiency**: key generation & message transformations "are fast"
- **correctness**: for all m and k, it holds that Dec(Enc(m, k), k) = m
- **security**: one " hertext c



Kerckhoff's principle

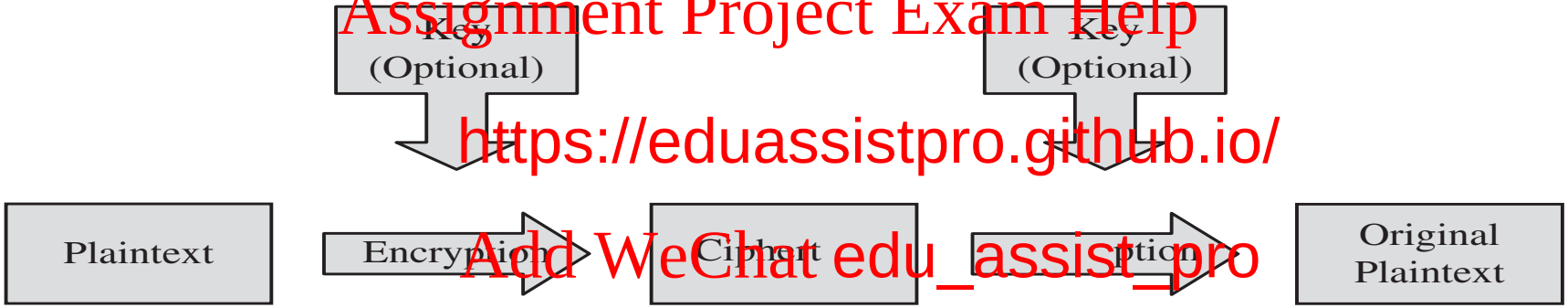
"The cipher method must not be required to be secret, and it must be able to fall into the hands of the enemy without inconvenience."

Reasoning

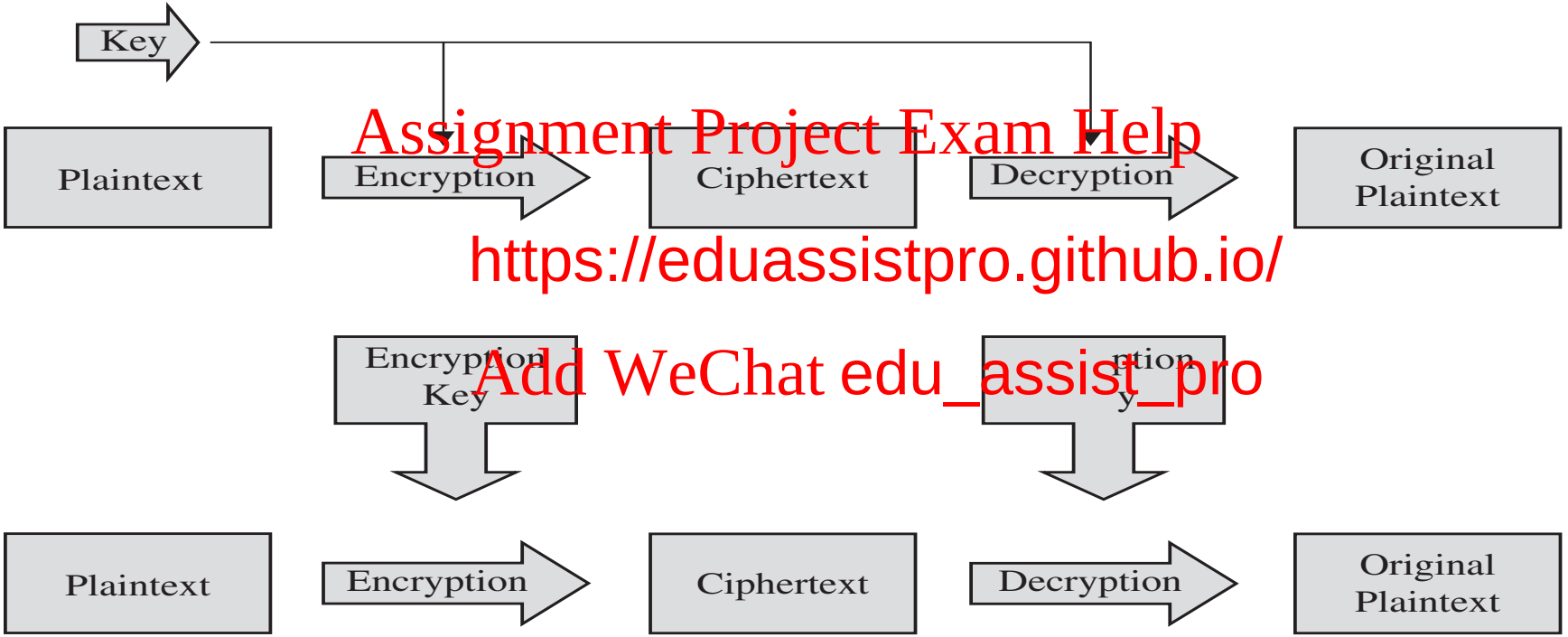
- due to security & cor some secret info
- if no shared key capt aptured by Enc, Dec
- but keeping Enc, Dec secret is problemati
  - harder to keep secret an algorithm than a short key (e.g., after user revocation)
  - harder to change an algorithm than a short key (e.g., after secret info is exposed)
  - riskier to rely on custom/ad-hoc schemes than publicly scrutinized/standardized ones

Symmetric-key encryption

- Also referred to as simply “symmetric encryption”



Symmetric Vs. Asymmetric encryption



(b) Asymmetric Cryptosystem

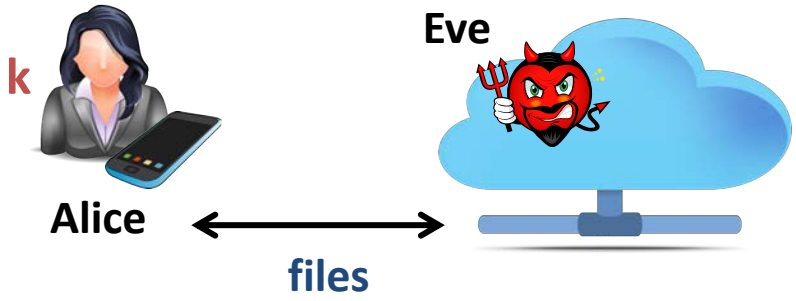
Main application areas

Secure communication

- **encrypt messages** sent among parties
- assumption
  - Alice and Bob **securel distribute & store sh**
  - attacker does not learn key k

Secure storage

- **encrypt files** outsourced to the cloud
- **ly generates & stores key k**
- not learn key k



Brute-force attack

Generic attack

- given a captured ciphertext c and known key space $\mathcal{K}$, Dec
- strategy is an **exhaustive search**
  - for all possible keys k
    - determine if Dec
- **requires some knowledge on the message space**
  - i.e., structure of the plaintext (e.g., PDF file or email message)

Countermeasure

- key should be a **random** value from a **sufficiently large** key space $\mathcal{K}$ to make exhaustive search attacks **infeasible**

Substitution ciphers

Large class of ciphers

- each letter is uniquely replaced by another
- there are 26! possible substitution ciphers
  - e.g., one popular su
    for some Internet po
- historically
  - all classical ciphers are of this type

General structure of classical ciphers

Based on letter substitution

- message space $\mathcal{M}$ is "valid words" from a given alphabet
  - e.g., English text without spaces, punctuation or numerals
  - characters can be r
- encryption
  - mapping each plain ter
  - character mapping is typically defined as a ntext character by a number of positions in a canonical orde cters in the alphabet
  - character shifting occurs with "wrap-around" (using mod 26 addition)
- decryption
  - undo character shifting with "wrap-around" (using mod 26 subtraction)

Limitations of substitution ciphers

Generally, susceptible to frequency (and other statistical) analysis

- letters in a natural language, like English, are not uniformly distributed
- cryptographic attacks against substitution ciphers are possible
  - e.g., by exploiting k cluding pairs and triples

Letter frequency in (sufficiently large) English text

Classical ciphers – examples

Caesar's cipher

- shift each character in the message by 3 positions
  - or by 13 positions in ROT-13
- cryptanalysis
  - **no secret key is us** ty”
  - thus the code is trivially insecure once kn c)

Classical ciphers – examples (II)

Shift cipher

- **keyed extension** of Caesar's cipher
- randomly set key k in [0:25]
  - shift each character
- cryptanalysis
  - **brute-force attacks** are effective given t
    - **key space is small** (26 possibilities or, actually, 25 as 0 should be avoided)
    - message space M is **restricted to "valid words"**
      - e.g., corresponding to valid English text