CS 798
Privacy in Computation and Communication

Module 1
What is Privacy?

Fall 2025

Instructor

Ian Goldberg

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- https://cs.uwaterloo.ca/~iang/
- Online office hours: Thursdays 11:00 am–noon (or by appointment)
- Office hours link on LEARN

Course personnel

TA:

- Vecna (they/them)

Office hours:
Mondays, 1–2 pm, DC 3333A
(or online, by request)

Special course personnel:

- Luna

(Come to Prof. Goldberg's office hours)

First in-person offering

- This is first time this course is being offered in an in-person format
- Things may not go perfectly smoothly
- We'll do our best, but please be understanding :-)
- And feedback on what is and is not working will be very helpful!
    - Throughout the term, not just in the course perception surveys at the end
- Videos of the previous (online) offering are available online
    - That content is not exactly the same as this year's offering, however

Course mechanics

- LEARN: course info, assignments, grades, etc.
- Piazza: Q&A, general discussions
- BigBlueButton (BBB): office hours (no need to make an account!)
- Course website: course outline (also see outline.uwaterloo.ca), slides, public materials
- uWaterloo GitLab: assignment submission

All links to the above are on LEARN.

Communication channels

- Important course announcements will be made on Piazza
  - Please keep up with the information there

- Use discussion forums in Piazza for all communication
  - Use a private question for questions not of general interest

- Use email only as a last resort, and then it must be from your uwaterloo.ca email address.

- Some communication might be sent *to* your uWaterloo email address
  - Check it regularly

Grades

- There will be four graded assignments in this course, each worth 25% of your course grade
- Three due during the term, the fourth during the final exam period
- Deadlines are already posted to LEARN and the course website
- Assignments are to be done individually
    - No sharing code or text
    - General rule: discussion with your classmates is fine, but don't write anything down during it
    - That will help avoid academic integrity issues

Assignment 0

- There is an additional *ungraded* assignment (available now!) that will help walk you through getting set up with git and docker (the tools you will use to submit all assignments)
- Collaboration on Assignment 0 is *encouraged*; indeed, please do so on Piazza so that everyone can benefit!

Assignments

- To do the assignments, you will minimally need:
    - A desktop or laptop on which you can install and run git and docker
    - The ability to write programs in at least one of Rust, C++, Python 3
    - A tool to produce written documents as PDFs (pdflatex preferred, but really anything is fine)
- You will submit your assignments as git repositories you will create (as part of Assignment 0) on uWaterloo's GitLab https://git.uwaterloo.ca.

Other readings

- From time to time, there will be additional assigned readings
- Links will be provided from the class schedule page in LEARN
- They will mostly be supplementary material, but some may be important to completing the assignments

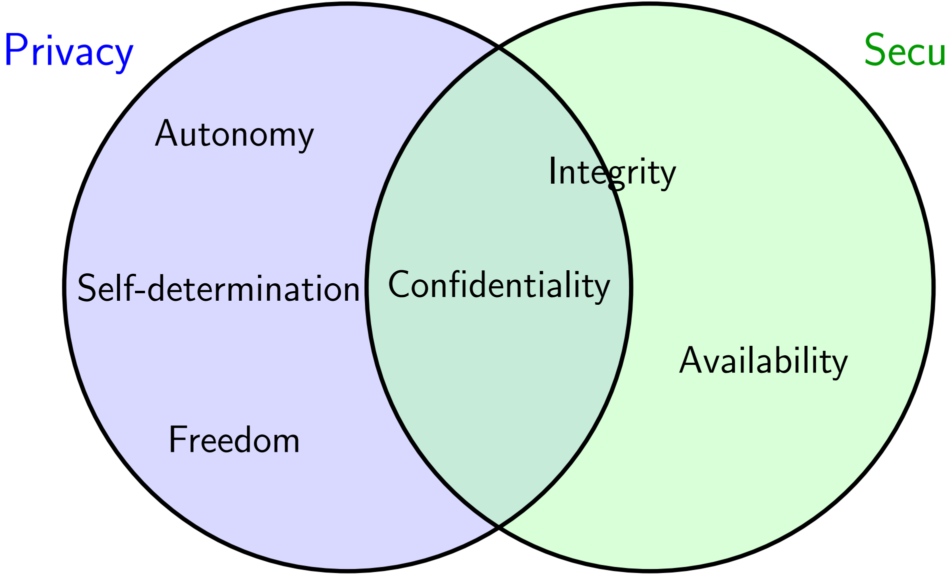
Modules

1. What is privacy?
2. Background
3. Privacy in computation: distributed trust
4. Privacy in computation: trusted hardware
5. Privacy in computation: homomorphic encryption
6. Privacy in communication: protecting metadata
7. Privacy in communication: censorship resistance

What is privacy?

- Surprisingly hard to concisely define
- Hiding personal information from others?
- Controlling who can do what with information about you?
- Being able to make decisions without undue external influence?

Comparing privacy with security



Privacy

Security

Autonomy

Self-determination

Freedom

Confidentiality

Integrity

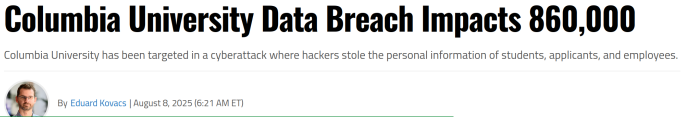
Availability

The importance of privacy

- Treating people with dignity as individuals
- When you lose privacy:
  - Surveillance and censorship
  - Coercion and social sorting
  - Subversion of democracy
- Privacy is a social good, not just an individual good
- Synergy between computer science and social science
  - CS 858 / SOC 701 “Surveillance and Privacy”

Privacy in computation

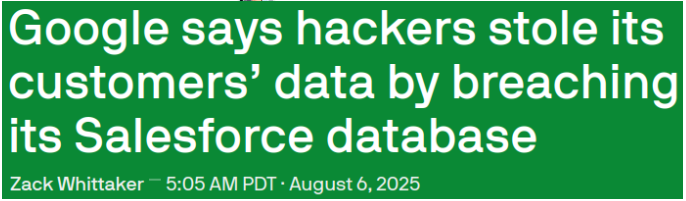
- Data breaches are exceptionally common



Columbia University Data Breach Impacts 860,000

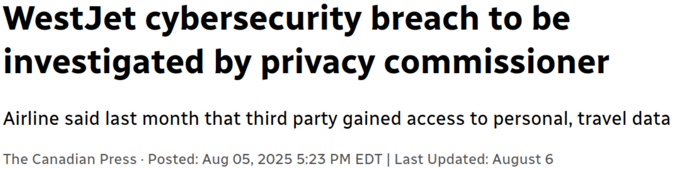
Columbia University has been targeted in a cyberattack where hackers stole the personal information of students, applicants, and employees.

By Eduard Kovacs | August 8, 2025 (6:21 AM ET)



Google says hackers stole its customers' data by breaching its Salesforce database

Zack Whittaker — 5:05 AM PDT · August 6, 2025



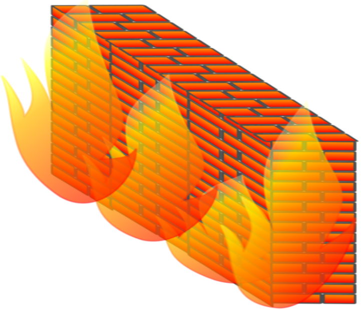
WestJet cybersecurity breach to be investigated by privacy commissioner

Airline said last month that third party gained access to personal, travel data

The Canadian Press · Posted: Aug 05, 2025 5:23 PM EDT | Last Updated: August 6

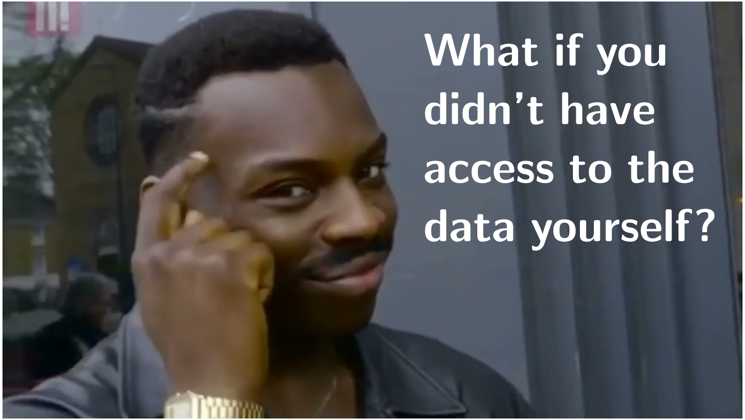
Why is computer security failing?

- Large, complex systems
- Large, complex trusted computing bases (TCB)
- “Tootsie pop” security



A modest proposal

- If you are a company and don't want to have your customer / user / data subject information stolen from you...



Privacy in computation

- Goal: be able to process information without having access to the information itself

- Obviously impossible?

- Perhaps not...

Privacy in computation

- Three approaches:
  - Distributed trust
  - Trusted hardware
  - Homomorphic encryption

Distributed trust

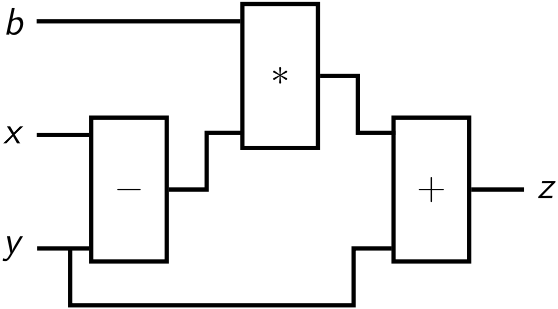
- Key idea: split the information across multiple servers
- Not that each server has a subset of the data
- For example, you could have two servers, where server 1 holds R and server 2 holds S such that $R + S =$ the original data
  - Each of R and S is completely random, and contains *no information* about the original data
  - In a very strong mathematical sense
  - This is called *secret sharing*; we'll see more about it in Module 2
- So if either server is compromised, *no information* is leaked to the attacker
  - But if *both* are, you're out of luck!

Distributed trust

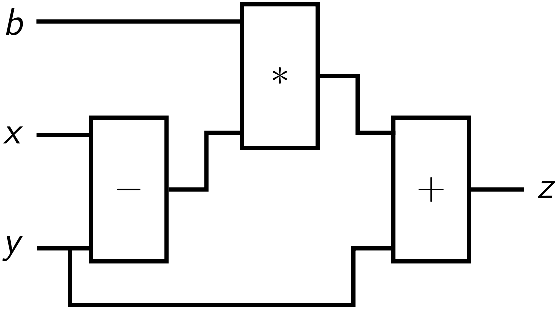
- Compile the program P you want to run on the data into a "circuit" consisting of binary or arithmetic gates

- Note that you cannot have conditional execution like "if statements", since the servers *cannot see the data!*
  - Oblivious algorithms

Oblivious computation



Oblivious computation



$$z = \begin{cases} y & \text{if } b = 0 \\ x & \text{if } b = 1 \end{cases}$$

Secure multiparty computation

- Perform Secure Multiparty Computation (MPC) to evaluate the circuit
- In MPC, multiple parties each have an input to a computation, and they execute some protocol to compute the output of some program over all of their inputs, without any party learning any other party's input
- Typically, "linear" operations (like addition of two variables or multiplying a variable by a constant) are extremely easy *local* operations, but more complex operations (like multiplying two variables) require parties to communicate
- Reading or writing to a secret-shared memory *at a secret-shared location* is one of the most complex operations

Trusted hardware

- Trusted Execution Environments (TEEs)
  - Intel SGX, AMD SEV, ARM TrustZone, etc.
  - What does "Trusted" mean here?
- Encrypt the data to a key inside the CPU
- The CPU can decrypt and process the data
- The rest of the computer, including the operating system, **cannot** see the data
  - But watch out for **side channels**
  - Also requires *oblivious algorithms* to maintain privacy

Trusted hardware

- On Intel SGX for example, each program can have its own *enclave*, and data encrypted for one enclave cannot even be decrypted by any other enclave.

- There is also a facility so that other programs running on the same machine ("local attestation") or a different machine ("remote attestation") can be assured they are communicating with, or encrypting data to, the enclave running a particular program, or one signed/authorized by a particular entity.

Trusted hardware

- TEEs decrypt and process the data (and typically re-encrypt the result)
  - But there's a lot of trust required in the hardware design
  - And the side channels to be managed, since the CPU *does* see the decrypted data

- What if the server could process the encrypted data *without decrypting it at all*?

Homomorphic encryption

- In 2009, a new kind of cryptography was discovered
  - Fully homomorphic encryption (FHE)
- Since then, there have been substantial improvements
  - Also implementations, libraries, etc.

- What does it do?
- I have some data x, you have a program P. I want you to compute $P(x)$ for me, but I don't want you to learn x (and often, you don't want me to learn P).
- With FHE, I send you $E(x)$, and with P and $E(x)$, you can compute $E(P(x))$ and send it back to me.

Homomorphic encryption

- General idea: be able to support a handful of simple operations on encrypted data
    - Minimally, be able to compute $E(x+y)$ and $E(x \cdot y)$ from $E(x)$ and $E(y)$
- Then (as with MPC) turn your program P into a circuit consisting of these simple operations
- Again, you can't have "if statements", since the server can't see the data
    - Oblivious algorithms come up again

Homomorphic encryption

- There are several current FHE protocols, with slightly different properties

- We will **not** be discussing *how* the FHE algorithms work (i.e., the math under the hood)

- We **will** be discussing what you can *do* with them

Privacy in communication

- The next set of modules will discuss privacy in communication
- Who can see what when people communicate online?
- What might you want to protect?
  - The *contents* of a message
  - The *metadata* of a message
  - The *existence* of a message
  - *Proof* of any of the above

Protect those things from whom?

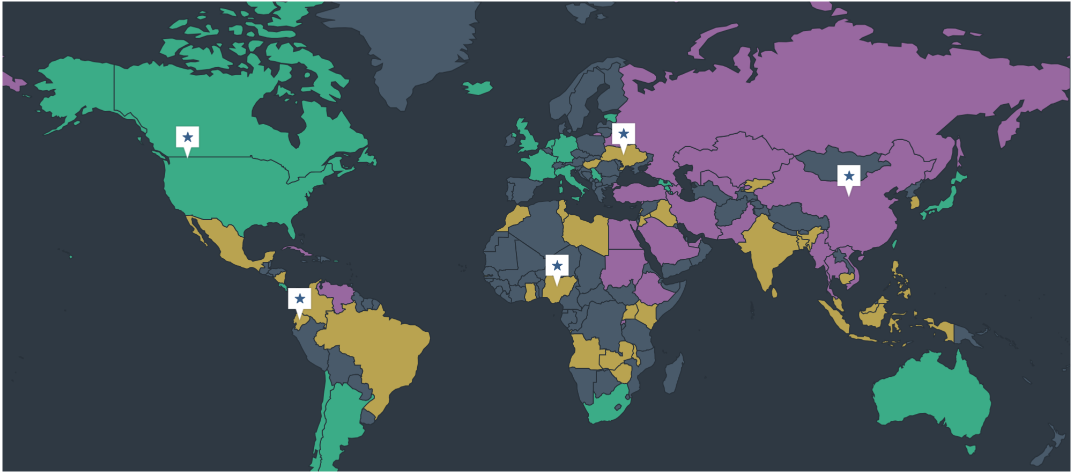
- Third parties
    - ISPs, eavesdroppers (local or global), governments
- Servers facilitating the message delivery
    - Apple, Signal, etc.
- The people you're communicating with
    - One-on-one or in a group
- Malware running on your own device
    - Tough to do?

Protecting metadata

- We'll look at various technologies to protect communication:
- Messaging apps (and their shortcomings)
- Tor (and its shortcomings)
- Metadata-Protecting Communication Systems (active research area)

Internet censorship

- Many countries censor the Internet



https://freedomhouse.org/explore-the-map?type=fotn&year=2024

Internet censorship

- What is it?
- Why does it happen?
- What technologies can people use to evade Internet censorship?
- Why is this a *privacy* issue?