Lecture 21: Differential Privacy

CS 181S

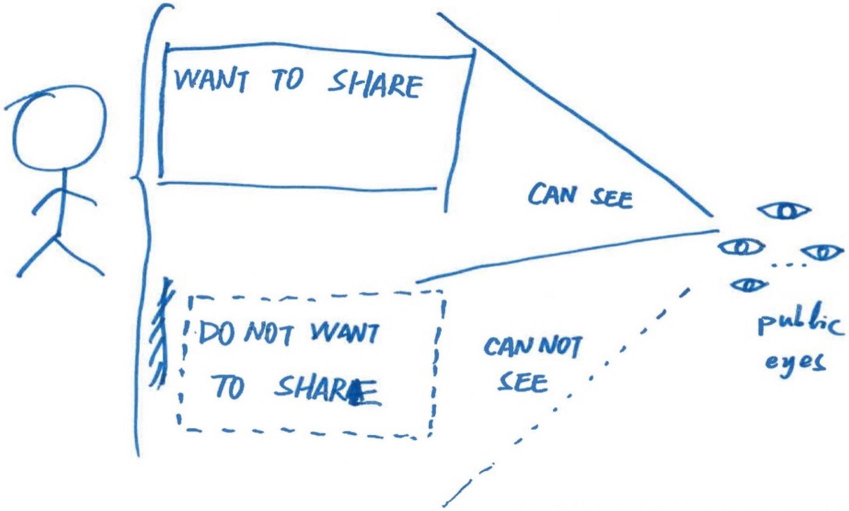
Spring 2024

What is Privacy?

Privacy

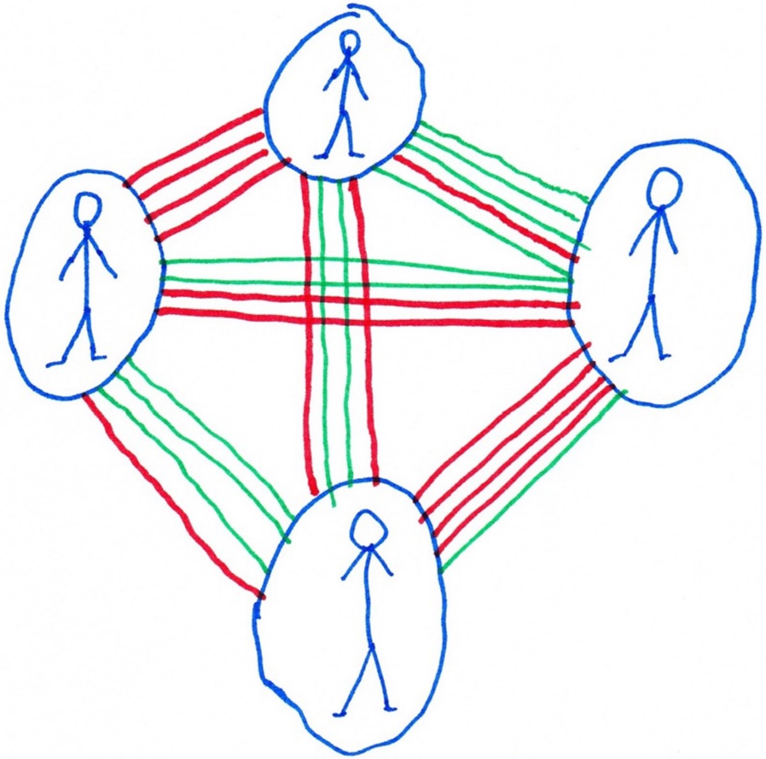
Privacy concerns information about individuals (people, organizations, etc.)

- Often construed as legal right
- *Privacy* is not a synonym for confidentiality or for secrecy



People have right to keep what they do not want to share invisible.

– AC, age 24



Privacy is a network: I share what I want with whom I want and trust and what matches with those in the network….

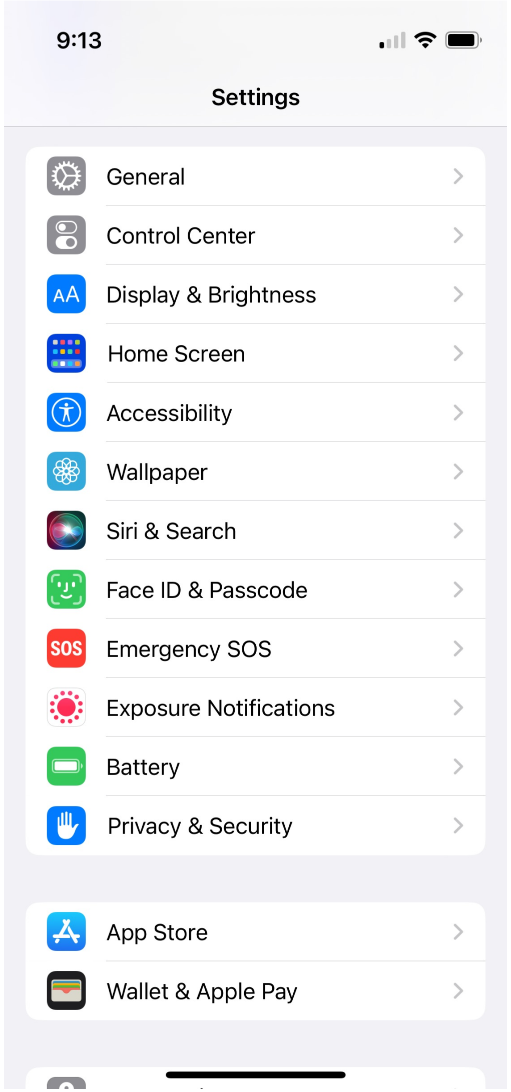
Green = share.
Red = don't.

Privacy and Freedom (1967)

Privacy is the claim of individuals, groups or institutions to determine for themselves when, how, and to what extent information about them is communicated to others.

– Alan Westin

Privacy Settings



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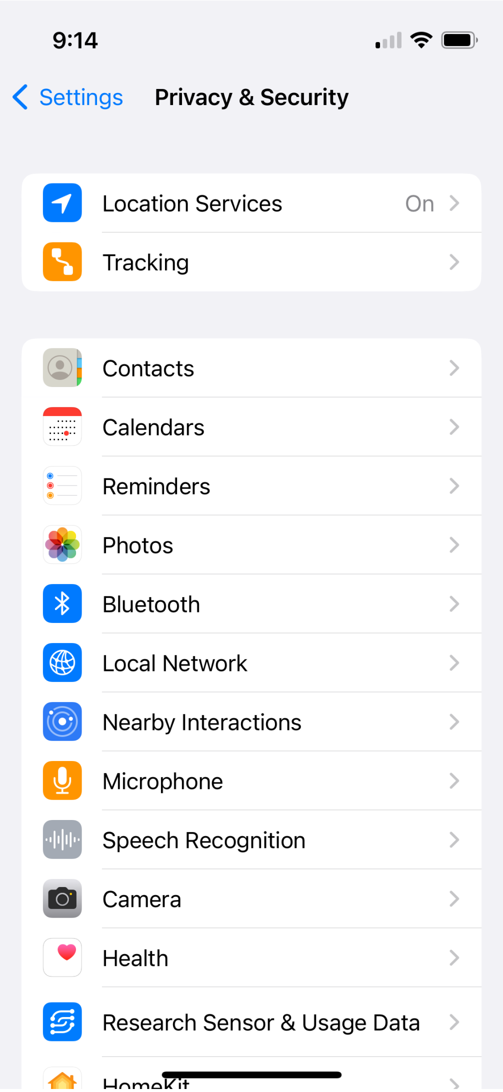
Settings

- General
- Control Center
- Display & Brightness
- Home Screen
- Accessibility
- Wallpaper
- Siri & Search
- Face ID & Passcode
- Emergency SOS
- Exposure Notifications
- Battery
- Privacy & Security

- App Store
- Wallet & Apple Pay



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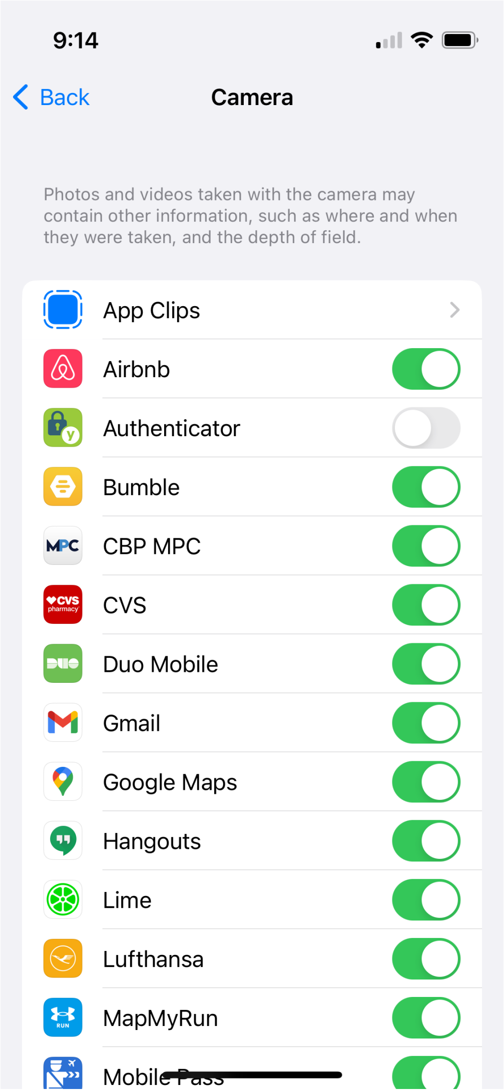
< Settings **Privacy & Security**

- Location Services On
- Tracking

- Contacts
- Calendars
- Reminders
- Photos
- Bluetooth
- Local Network
- Nearby Interactions
- Microphone
- Speech Recognition
- Camera
- Health
- Research Sensor & Usage Data
- HomeKit



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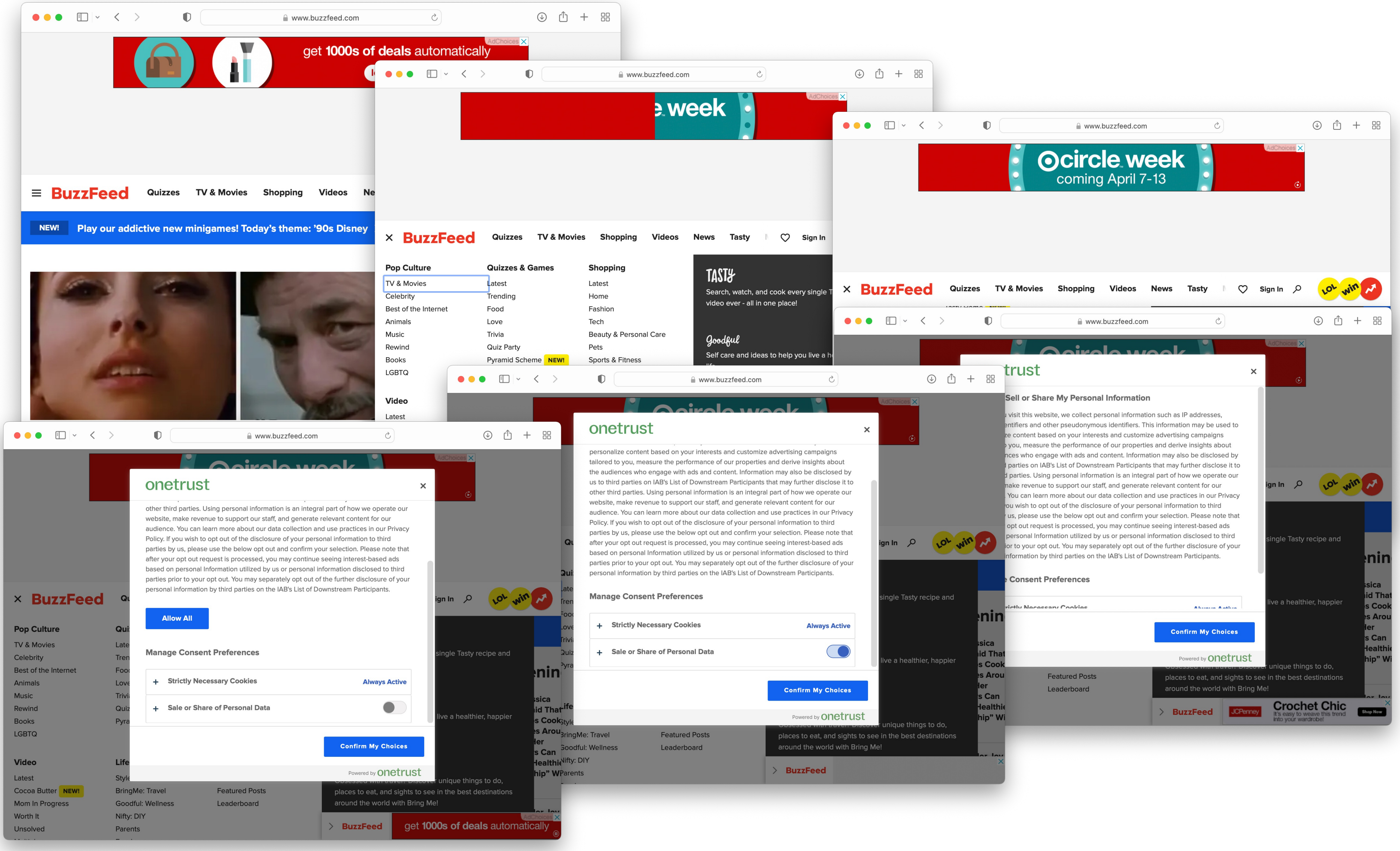
< Back **Camera**

Photos and videos taken with the camera may contain other information, such as where and when they were taken, and the depth of field.

- App Clips
- Airbnb ☑
- Authenticator ☐
- Bumble ☑
- CBP MPC ☑
- CVS ☑
- Duo Mobile ☑
- Gmail ☑
- Google Maps ☑
- Hangouts ☑
- Lime ☑
- Lufthansa ☑
- MapMyRun ☑
- Mobile Pass ☑

Opt-outs



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+ Sale or Share of Personal Data	○

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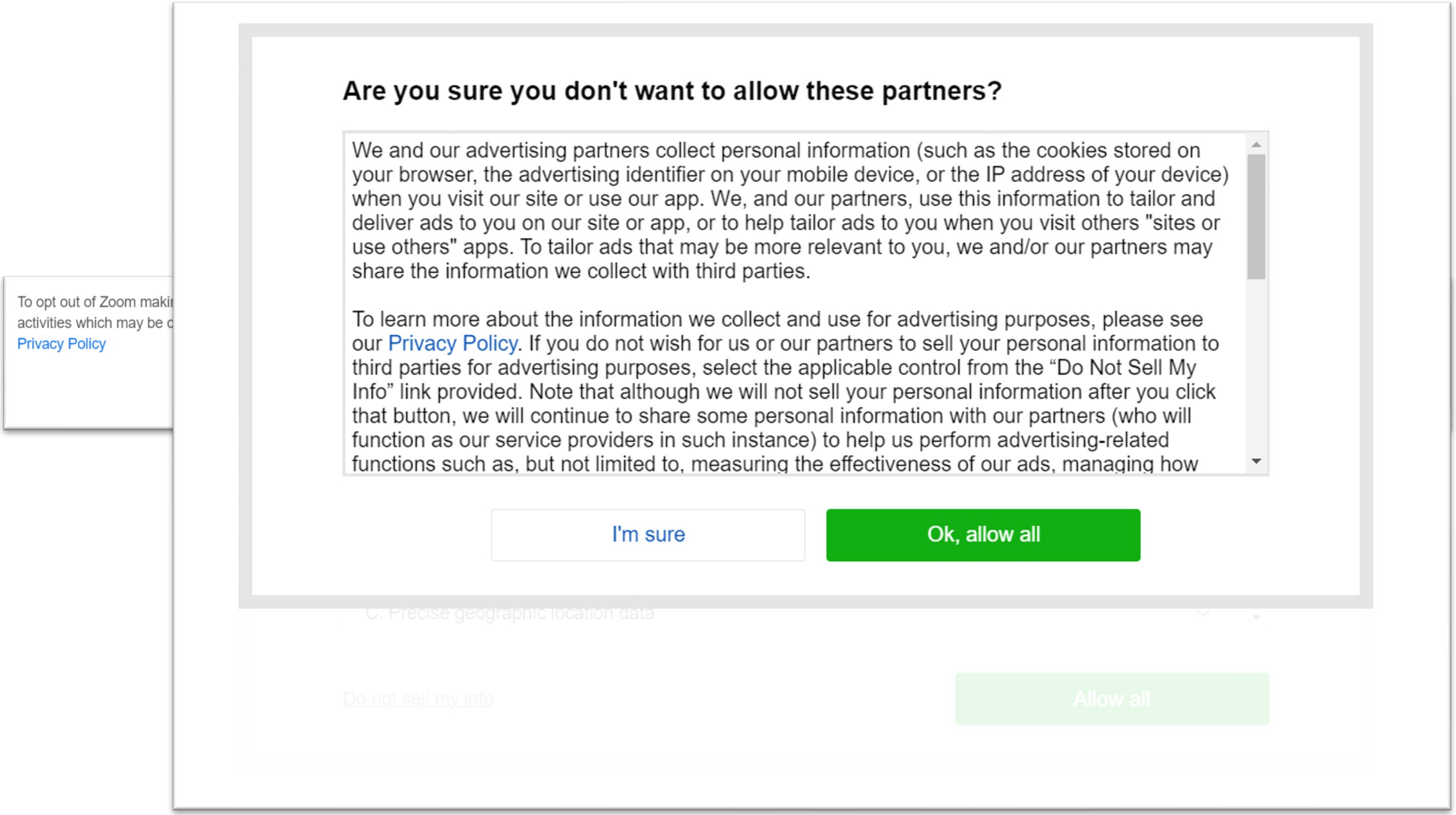
Opt-outs



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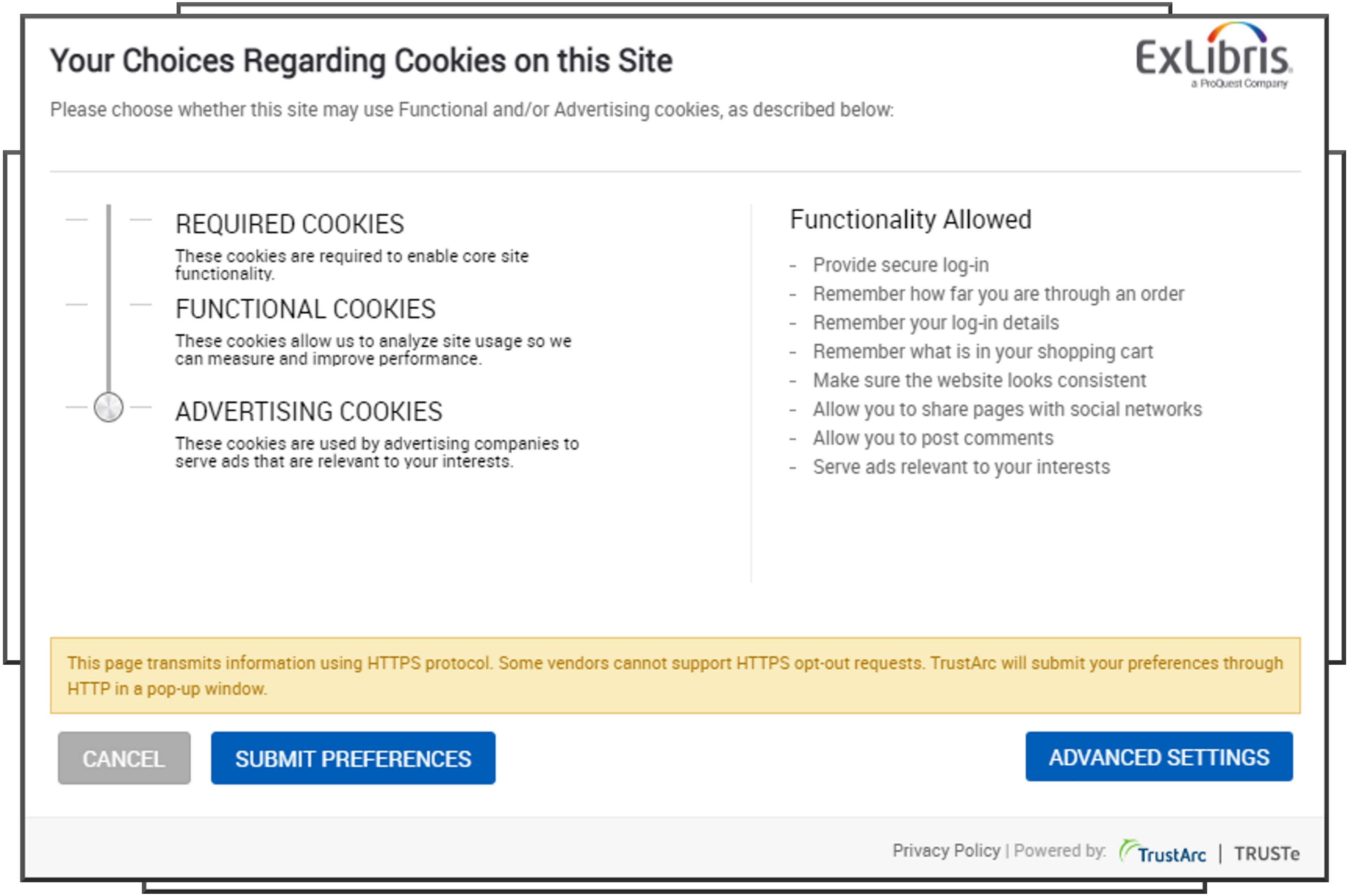

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These cookies allow us to analyze site usage so we can measure and improve performance.

ADVERTISING COOKIES

These cookies are used by advertising companies to serve ads that are relevant to your interests.

Functionality Allowed

- Provide secure log-in
- Remember how far you are through an order
- Remember your log-in details
- Remember what is in your shopping cart
- Make sure the website looks consistent
- Allow you to share pages with social networks
- Allow you to post comments
- Serve ads relevant to your interests

This page transmits information using HTTPS protocol. Some vendors cannot support HTTPS opt-out requests. TrustArc will submit your preferences through HTTP in a pop-up window.

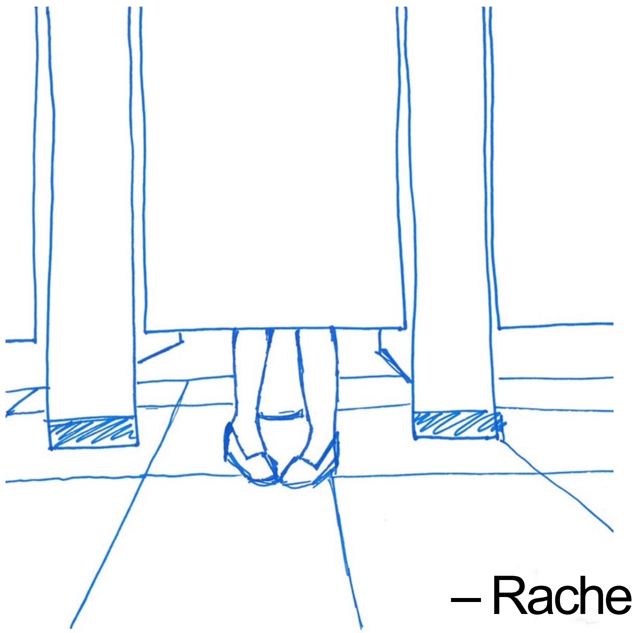
Manipulation of privacy behavior

A few common examples of manipulative design in privacy-related interfaces

- Defaults are not privacy protective
- Buttons have confusing labels
- Framing - including wording
  that shames users to influence their decisions
  or makes them feel like they will be missing out
- Highlighting – visually emphasizing opt-in
- Cumbersome privacy choices - more
  difficult to choose privacy options

Your room is private.

– Alexia, age 11



– Rachel, age 20

Contextual Integrity

- defines privacy relative to appropriate context
- considers information type, time, location, purpose, principals involved (subject, sender, receiver)
- dependent on social norms
- norms can change over time

General Guidelines

The FTC's Fair Information Practice Principals (FIPPs) are the most broadly recognized guidelines for handling private data in information systems

- Seek consent
- Minimize data use
- Limit storage
- Avoid linking

General Data Protection Regulation

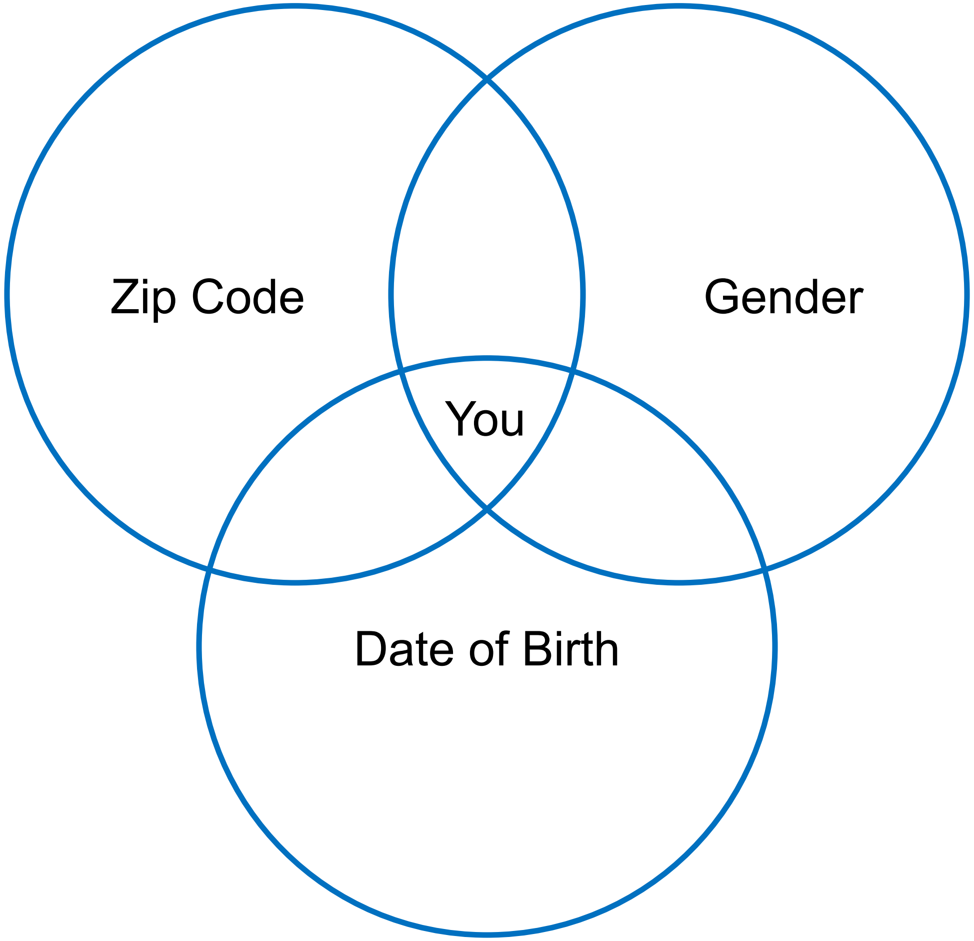
Goal: Codify fundamental right to protection of personal data.

- Introduced individual rights
  1. The right to transparency
  2. The right to access
  3. The right to correct
  4. The right to delete
  5. The right to data portability
  6. The right to withdraw consent
  7. The right to object

- Additional obligations
  - Legal basis for processing
  - Purpose limitation
  - Data Minimization
  - Storage limitation
  - Security requirements
  - Privacy by design

- Adopted: April 14, 2016
- Effective: May 25, 2018

Deanonymization



Deanonymization

k-Anonymity

Name	Pronouns	Year	Grade
Alice	she/her	2025	95
Bob	he/him	2025	80
Charlie	they/them	2025	95
David	he/him	2025	60
Edward	he/him	2026	80
Flora	she/her	2026	99
Georgia	she/her	2026	60

- **Quasi-identifiers (QIs)** are sets of attributes that can be exploited for linking
- A database is **k-anonymous** if each QI maps to at least k different individuals
- Techniques: suppression and generalization

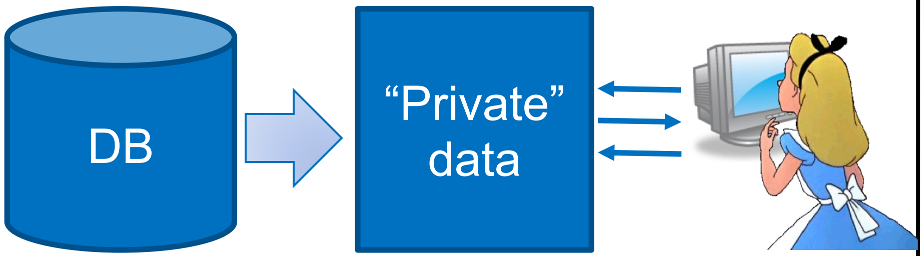
Exercise 2: k-anonymity

- Modify this dataset to make it 2-anonymous with respect to Race/DOB/Sex

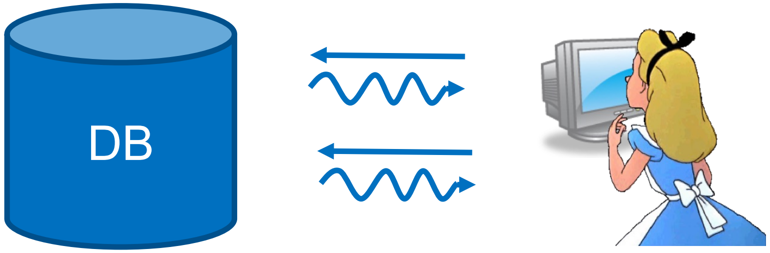
Race	DOB	Sex	Marital Status	Health Issues
asian	9/27/00	female	divorced	hypertension
asian	9/30/00	female	divorced	obesity
asian	4/18/00	male	married	chest pain
asian	4/15/00	male	married	obesity
black	3/13/99	male	married	hypertension
black	3/18/99	male	married	shortness of breath
black	9/13/00	female	married	shortness of breath
black	9/07/00	female	married	obesity
white	5/14/01	male	single	chest pain
white	4/08/01	male	single	obesity
white	9/15/01	female	married	shortness of breath

Database Privacy

Offline Privacy

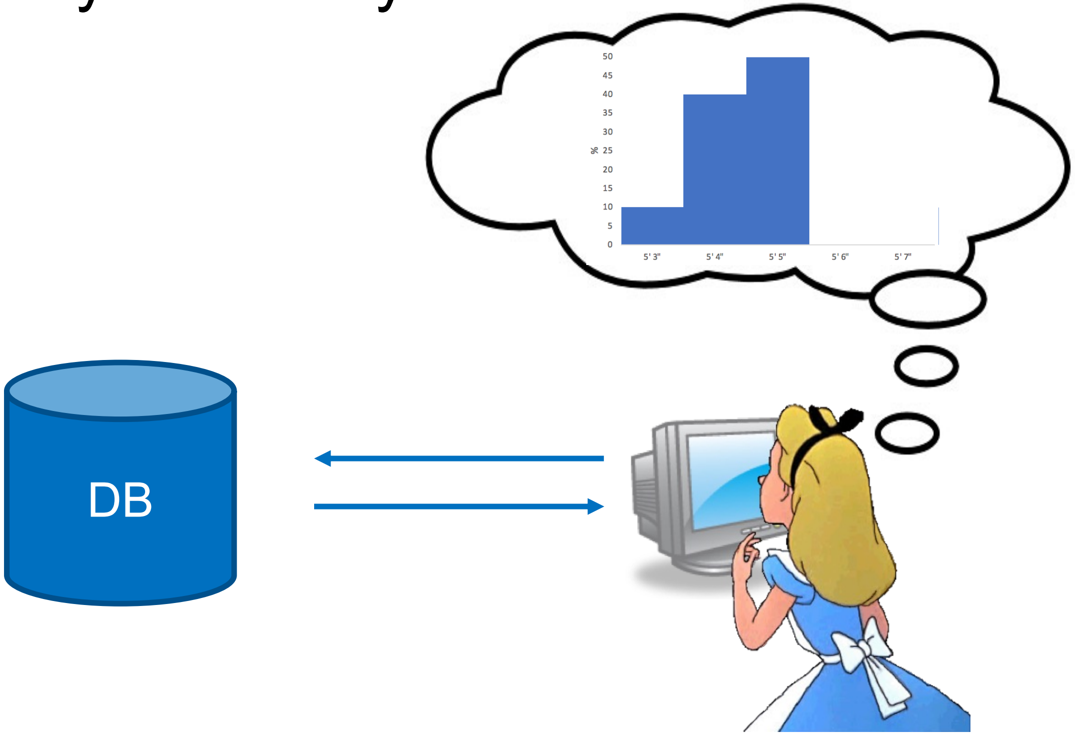


Online Privacy

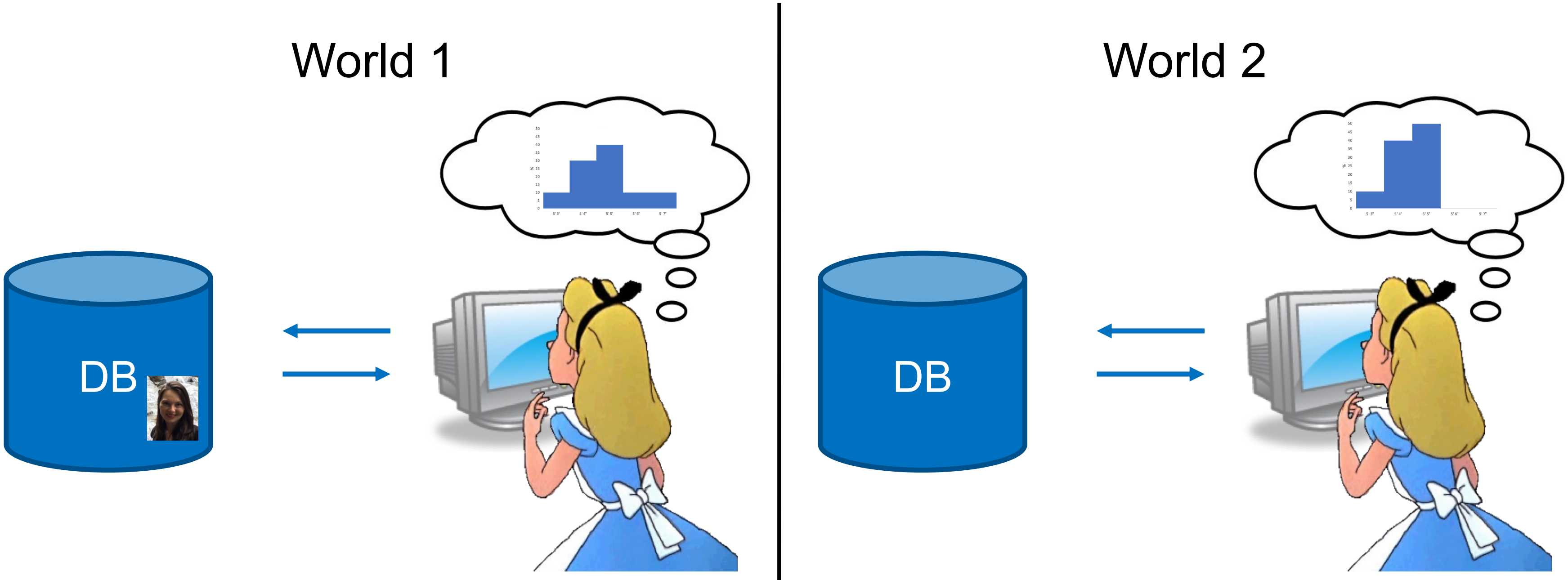


Defining Privacy: Try #1

- You don't know anything more after interacting with the database then you already knew



Differential Privacy



A query Q is ϵ-differentially private if $\forall D, r \in D$,
$\Pr[Q(D) = x] \le e^{\epsilon} \cdot \Pr[Q(D - r) = x]$

Sensitivity

- The sensitivity Δ of a query Q is the maximum the answer to Q can possibly change between two databases that differ only by one person

- Q = number of people taller than 6 ft $\Delta = 1$
- Q = maximum height of a person $\Delta = 48$

Exercise 3: Sensitivity

- Assume you have a database containing the heights of 100 users specified in inches. You may assume that all heights are between 48 in and 96in.

- What is the sensitivity of the following queries?
  1. The number of people who are 5' 4"
  2. The median height in the dataset
  3. The mean height in the dataset

Exercise 3: Sensitivity

- Assume you have a database containing the heights of 100 users specified in inches. You may assume that all heights are between 48 in and 96in.

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  1. The number of people who are 5' 4"
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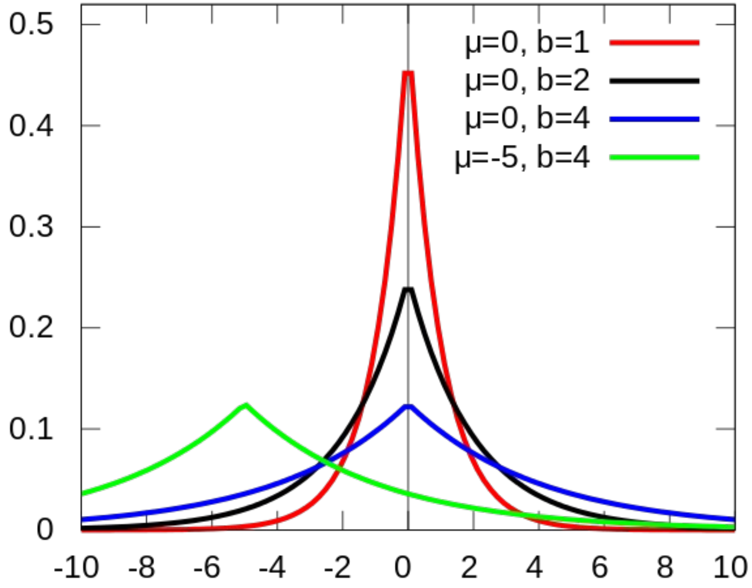
Laplacian Distribution

- Lap(b) is the probability distribution with the property that

$$\Pr[\,Lap(b) = x] = \frac{1}{2b} \cdot e^{-\frac{|x|}{b}}$$



Laplacian Mechanism

- Given a query Q on a database D that has sensitivity Δ, respond with Q(D)+Y where Y is drawn from the distribution $Lap(\frac{\Delta}{\epsilon})$
- Theorem: this mechanism satisfies ϵ-differential privacy

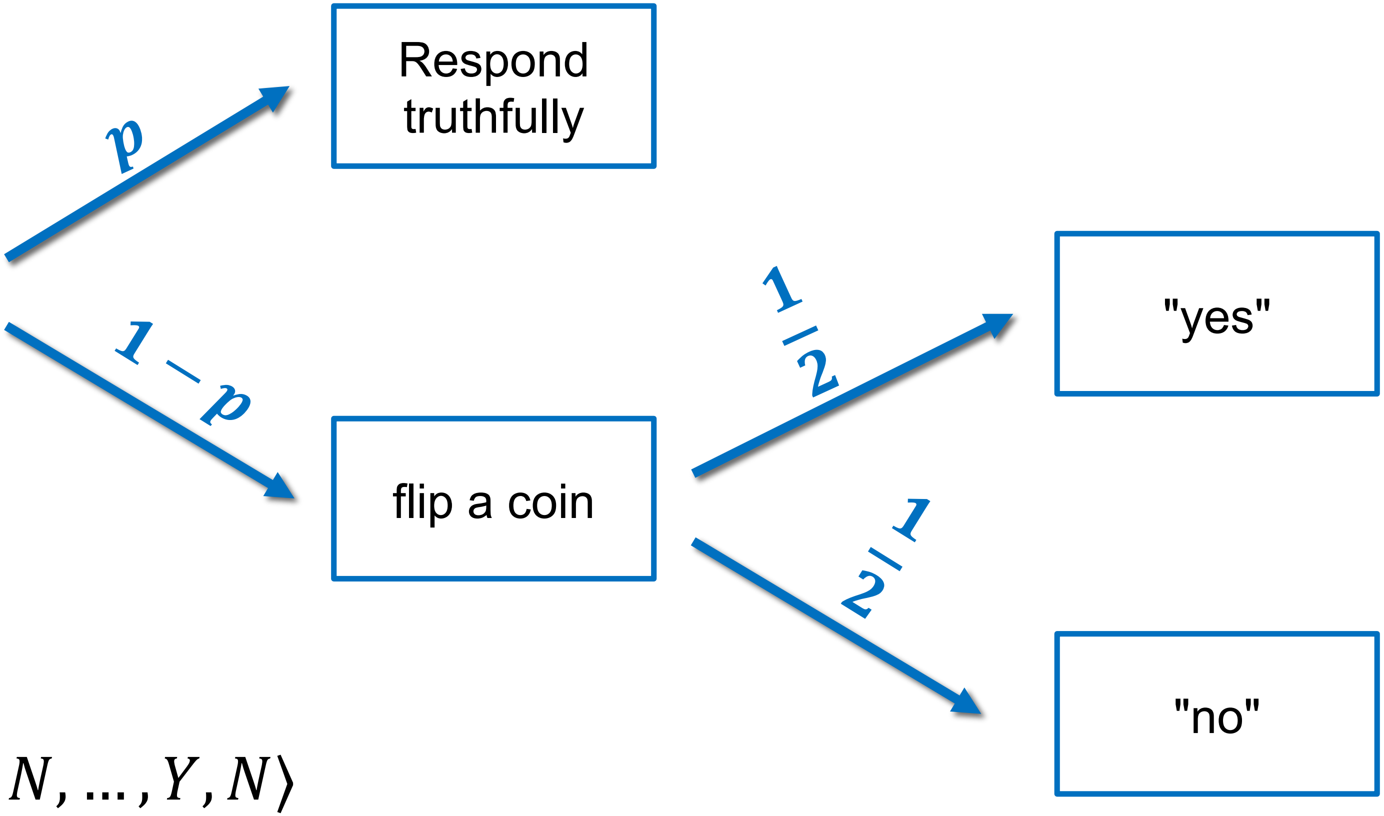
$$\frac{\Pr[\,Q(D) + Y = x]}{\Pr[Q(D-r) + Y = x]} = \frac{\Pr[\,Y = x - Q(D)]}{\Pr[Y = x - Q(D-r)]} = \frac{\frac{1}{2(\Delta/\epsilon)}\cdot e^{-\frac{|x-Q(D)|}{\Delta/\epsilon}}}{\frac{1}{2(\Delta/\epsilon)}\cdot e^{-\frac{|x-Q(D-r)|}{\Delta/\epsilon}}} = \frac{e^{-\frac{|x-Q(D)|}{\Delta/\epsilon}}}{e^{-\frac{|x-Q(D-r)|}{\Delta/\epsilon}}}$$

$$= e^{\frac{|x-Q(D-r)|}{\Delta/\epsilon}-\frac{|x-Q(D)|}{\Delta/\epsilon}} = e^{\left(\frac{\epsilon}{\Delta}\right)\cdot(|x-Q(D-r)|-|x-Q(D)|)}$$

$$\le e^{\left(\frac{\epsilon}{\Delta}\right)\cdot(|x-Q(D-r)-x+Q(D)|)} = e^{\left(\frac{\epsilon}{\Delta}\right)\cdot(|Q(D)-Q(D-r)|)}$$

$$\le e^{\left(\frac{\epsilon}{\Delta}\right)\cdot\Delta} = \mathrm{e}^{\epsilon}$$

Randomized Response



Respond truthfully

flip a coin

"yes"

"no"

p

$1-p$

$1/2$

$1/2$

$\langle Y, N, \mathbf{Y}, Y, Y, N, \ldots, Y, N \rangle$

Theorem: this mechanism satisfies ϵ-differential privacy

Randomized Response

- Theorem: this mechanism satisfies ϵ-differential privacy

$$\frac{\Pr[\langle Y, N, \boldsymbol{Y}, Y, Y, N, \ldots, Y, N\rangle \mid f(\mathrm{Bob}) = Y]}{\Pr[\langle Y, N, \boldsymbol{Y}, Y, Y, N, \ldots, Y, N\rangle \mid f(\mathrm{Bob}) = N]}$$

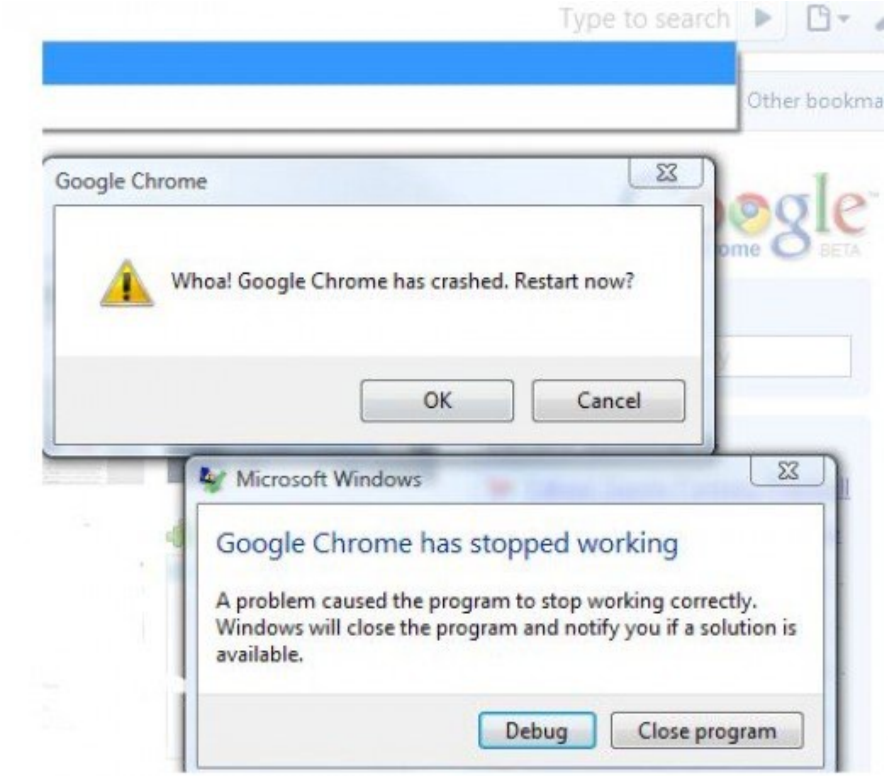
$$= \frac{\Pr[Y \mid f(P_0)] \cdot \Pr[\mathrm{N} \mid f(P_1)] \cdot \Pr[Y \mid f(Bob) = Y] \cdot \ldots \cdot \Pr[\mathrm{N} \mid f(P_{n-1})]}{\Pr[Y \mid f(P_0)] \cdot \Pr[\mathrm{N} \mid f(P_1)] \cdot \Pr[Y \mid f(Bob) = N] \cdot \ldots \cdot \Pr[\mathrm{N} \mid f(P_{n-1})]}$$

$$= \frac{\Pr[Y \mid f(Bob) = Y]}{\Pr[Y \mid f(Bob) = N]}$$

$$= \frac{p \cdot 1 + (1-p) \cdot \frac{1}{2}}{p \cdot 0 + (1-p) \cdot \frac{1}{2}} = \frac{(1+p) \cdot \frac{1}{2}}{(1-p) \cdot \frac{1}{2}} = \frac{(1+p)}{(1-p)}$$

$$= \mathrm{e}^{\ln(\frac{1+p}{1-p})}$$

DP in action…



Whoa! Google Chrome has crashed. Restart now?

Google Chrome has stopped working

A problem caused the program to stop working correctly. Windows will close the program and notify you if a solution is available.