

Ensuring (Statistical) Privacy

Daniel Alabi

Ph.D. student in the Theory of Computation group

@ Harvard SEAS (School of Engineering and Applied Sciences)

Advised by Salil Vadhan

Code for this talk: https://github.com/alabid/pre_college_2019

See full course materials here: <http://people.seas.harvard.edu/~salil/cs208/>

My email: alabid@g.harvard.edu



Table of Contents

- Motivations
 - Reidentification via Linkage Attacks
 - Reconstruction and Inference Attacks
- Definitions
 - K-anonymity
 - Differential Privacy
- Mechanisms
 - Laplace Mechanism
- Code Demonstrations
 - Python Code



The Problem

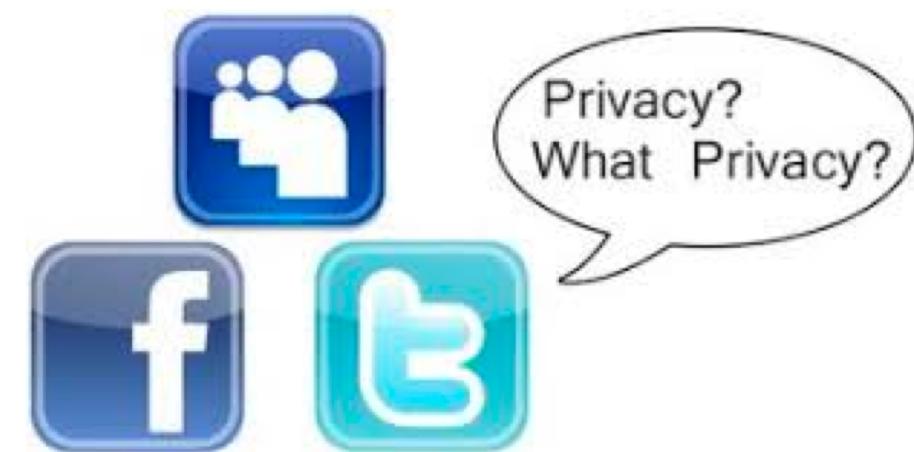
We have a dataset with sensitive information, such as:

1. Health records (e.g. reveals which disease a patient has)
2. Census data (e.g. reveals income range)
3. Social network activity (e.g. which pages you like)



How can we:

1. Allow the use of the data?
2. Protect the privacy of the data subjects?
3. Achieve both (1) and (2)?



Some Approaches to Solve the Problem

Encrypt the Data:

Name	Sex	Blood	...	HIV?
James	M	B	...	N
Peter	M	O	...	Y
...
Paul	M	A	...	N
Eve	F	B	...	Y

Some Approaches to Solve the Problem

Encrypt the Data:

Name	Sex	Blood	...	HIV?
James	M	B	...	N
Peter	M	O	...	Y
...
Paul	M	A	...	N
Eve	F	B	...	Y



Name	Sex	Blood	...	HIV?
10101	01010	01000	...	00001
11010	01101	10111	...	10111
...
10100	10000	11101	...	01111
11000	10001	11110	...	10001

Some Approaches to Solve the Problem

Encrypt the Data: Are we happy with this solution? Why or why not?

Name	Sex	Blood	...	HIV?
James	M	B	...	N
Peter	M	O	...	Y
...
Paul	M	A	...	N
Eve	F	B	...	Y



Name	Sex	Blood	...	HIV?
10101	01010	01000	...	00001
11010	01101	10111	...	10111
...
10100	10000	11101	...	01111
11000	10001	11110	...	10001

Some Approaches to Solve the Problem

“Anonymize the Data”: Are we happy with this solution? Why or why not?

Name	Sex	Blood	...	HIV?
James	M	B	...	N
Peter	M	O	...	Y
...
Paul	M	A	...	N
Eve	F	B	...	Y

Name	Sex	Blood	...	HIV?
XXXXX	M	B	...	N
XXXXX	M	O	...	Y
...
XXXXX	M	A	...	N
XXXXX	F	B	...	Y

Some Approaches to Solve the Problem

“Anonymize the Data”: Not sufficient because of linkage attacks!

87% of US population have unique date of birth, gender, and postal code!

[Golle and Partridge ‘09]

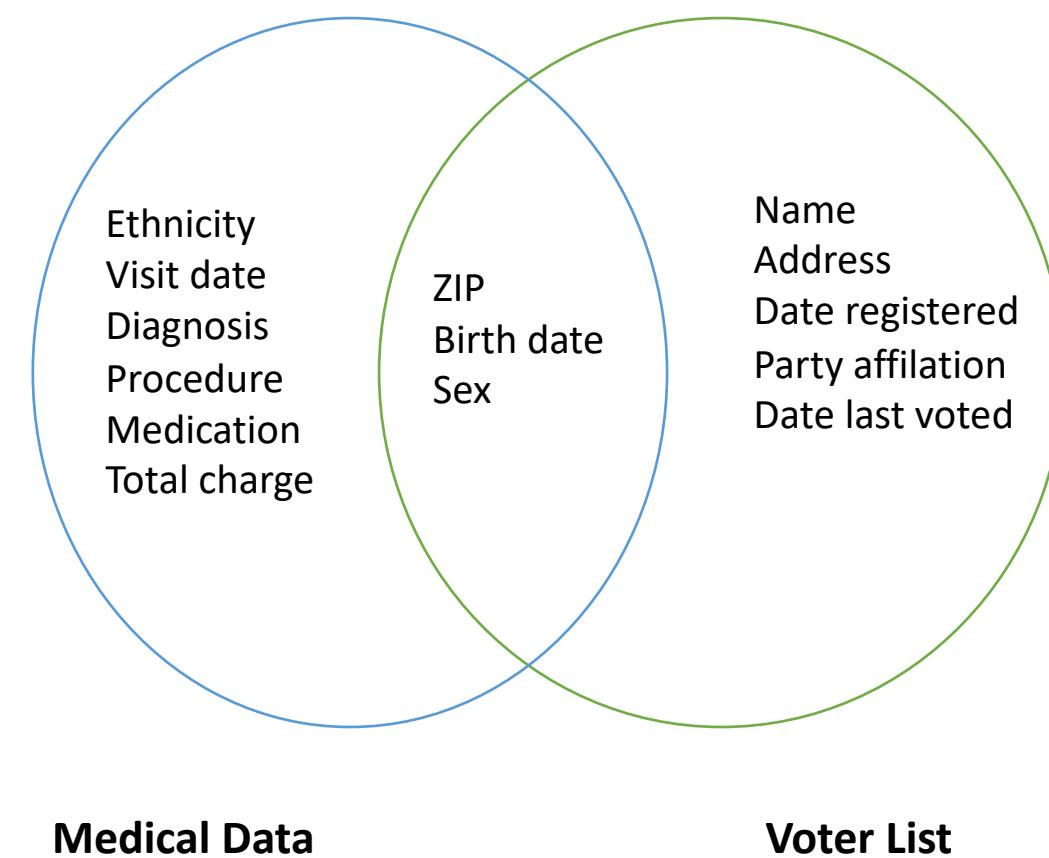


Some Approaches to Solve the Problem

“Anonymize the Data”: Reidentification via Linkage

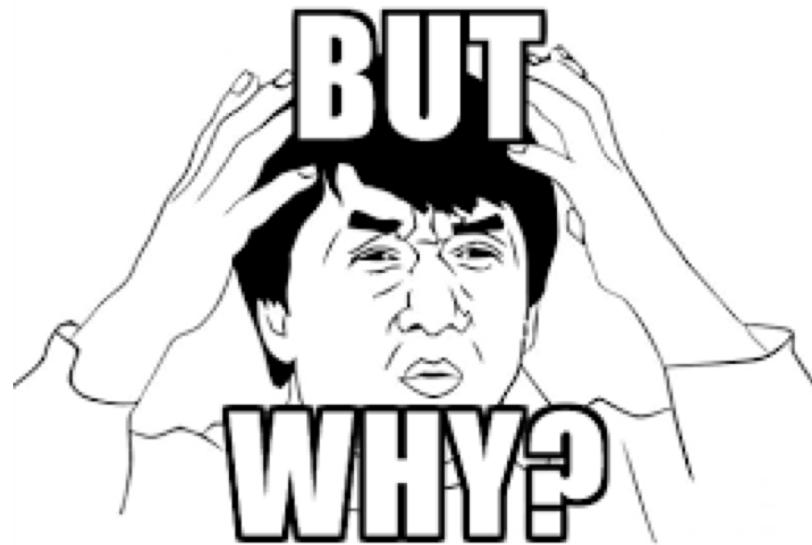
Can uniquely identify > 60% of the U.S. population [Sweeney '00, Golle '06, Sweeney '97]

Name	Sex	Blood	...	HIV?
XXXXX	M	B	...	N
XXXXX	M	O	...	Y
...
XXXXX	M	A	...	N
XXXXX	F	B	...	Y



Message

Releasing too many statistics with too much accuracy can lead to a reconstruction of the entire dataset or inference attacks



The story so far

- Motivations
 - Reidentification via Linkage Attacks
 - Reconstruction and Inference Attacks

Reconstruction attack: If we have dataset $x \in \{0, 1\}^n$ and person i has sensitive bit x_i and attacker/adversary gets $q_S(x) = \sum_{i \in S} x_i$ for any $S \subseteq [n]$.

The story so far

- Motivations
 - Reidentification via Linkage Attacks
 - Reconstruction and Inference Attacks

Reconstruction attack: If we have dataset $x \in \{0, 1\}^n$ and person i has sensitive bit x_i and attacker/adversary gets $q_S(x) = \sum_{i \in S} x_i$ for any $S \subseteq [n]$.

[Dinur-Nissim '03]: With high probability, adversary can reconstruct 0.99 fraction of the dataset $x \in \{0, 1\}^n$ if noise added to each query is less than $o(\sqrt{n})$ and #queries is n .

The story so far

- Motivations
 - Reidentification via Linkage Attacks
 - Reconstruction and Inference Attacks

Reconstruction attack: If we have dataset $x \in \{0, 1\}^n$ and person i has sensitive bit x_i and attacker/adversary gets $q_S(x) = \sum_{i \in S} x_i$ for any $S \subseteq [n]$.

[Dinur-Nissim '03]: With high probability, adversary can reconstruct 0.99 fraction of the dataset $x \in \{0, 1\}^n$ if noise added to each query is less than $o(\sqrt{n})$ and #queries is n .

Inference attack: Attacker gets n^2 answers and needs to know if someone is in dataset or not.

The story so far

Message

Releasing too many statistics with too much accuracy can lead to a reconstruction of the entire dataset or inference attacks

Some Approaches to Solve the Problem

So now what?

- Encryption doesn't work
- Anonymization doesn't work
- Even adding insufficient noise to an attacker's query is not good enough

Some Approaches to Solve the Problem

So now what?

- Encryption doesn't work
- Anonymization doesn't work
- Even adding insufficient noise to an attacker's query is not good enough

Possible Responses:

- Privacy is an illusion!

Some Approaches to Solve the Problem

So now what?

- Encryption doesn't work
- Anonymization doesn't work
- Even adding insufficient noise to an attacker's query is not good enough

Possible Responses:

- Privacy is an illusion!
- In the long run, it's better to use data for research!
Ignore privacy!



Some Approaches to Solve the Problem

So now what?

- Encryption doesn't work
- Anonymization doesn't work
- Even adding insufficient noise to an attacker's query is not good enough

Possible Responses:

- Privacy is an illusion!
- In the long run, it's better to use data for research!
Ignore privacy!
- Never release statistics about any dataset!



Some Approaches to Solve the Problem

So now what?

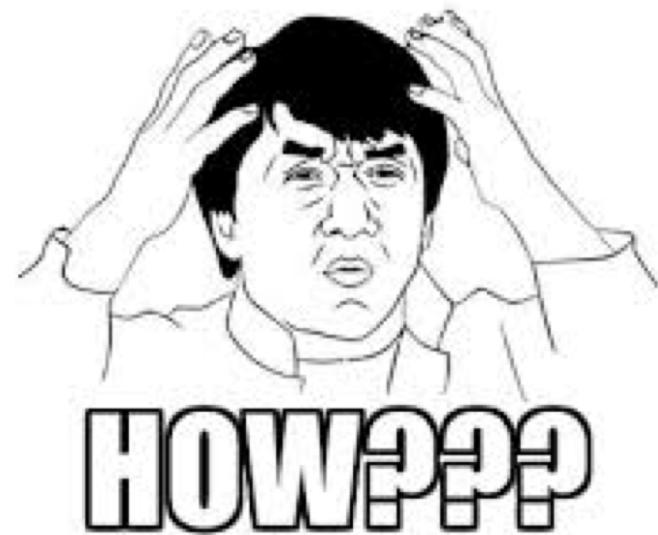
- Encryption doesn't work
- Anonymization doesn't work
- Even adding insufficient noise to an attacker's query is not good enough

Possible Responses:

- Privacy is an illusion!
- In the long run, it's better to use data for research! Ignore privacy!
- Never release statistics about any dataset!
- Is there a way to add enough noise to queries and still allow for usefulness?

Main Message of this Talk

Yes, there is a way to add enough noise to queries and
still allow for usefulness!



An approach: K-anonymity

[Sweeney '02]: A mechanism satisfies k -anonymity if for every dataset, the output of the mechanism has the property that every distinct row occurs at least k times.

An approach: K-anonymity

[Sweeney '02]: A mechanism satisfies k -anonymity if for every dataset, the output of the mechanism has the property that every distinct row occurs at least k times.

Intuition: Privacy ensured if I can't isolate you!

An approach: K-anonymity

[Sweeney '02]: A mechanism satisfies k -anonymity if for every dataset, the output of the mechanism has the property that every distinct row occurs at least k times.

3-anonymous dataset:

Zip code	Age	Nationality
021**	< 30	*
021**	< 30	*
021**	< 30	*
021**	> 40	*
021**	> 40	*
021**	> 40	*
021**	3*	*
021**	3*	*
021**	3*	*

An approach: K-anonymity

It's a nice approach but:

- Doesn't compose well (e.g. if you have two k -anonymous datasets)
- Utility not as quantifiable as other approaches

Zip code	Age	Nationality
021**	< 30	*
021**	< 30	*
021**	< 30	*
021**	> 40	*
021**	> 40	*
021**	> 40	*
021**	3*	*
021**	3*	*
021**	3*	*

Table of Contents

- Motivations
 - Reidentification via Linkage Attacks
 - Reconstruction and Inference Attacks
- Definitions
 - K-anonymity
 - Differential Privacy
- Mechanisms
 - Laplace Mechanism
- Code Demonstrations
 - Python Code

Differential Privacy

- Utility
- Privacy
- Definition

Differential Privacy

- Utility: enable “statistical analysis” on datasets
 - Can release (noisy) statistics such as means, sums, medians, etc.
 - Predictions from trained machine learning models

Differential Privacy

- Utility: enable “statistical analysis” on datasets
 - Can release (noisy) statistics such as means, sums, medians, etc.
 - Predictions from trained machine learning models
- Privacy: protect each individual in dataset against all possible attack strategies
 - Now and in the future!
 - Even with use of auxiliary information or datasets!
 - Group privacy also allowed!

Differential Privacy

- Utility: enable “statistical analysis” on datasets
 - Can release (noisy) statistics such as means, sums, medians, etc.
 - Predictions from trained machine learning models
- Privacy: protect each individual in dataset against all possible attack strategies
 - Now and in the future!
 - Even with use of auxiliary information or datasets!
 - Group privacy also allowed!
- Definition: pure and approximate

Differential Privacy

Definition: pure and approximate

[Dwork-McSherry-Nissim-Smith '06]

Other references:

Motivated from and based off of work in

[Dinur-Nissim '03, Dwork-Nissim '04, Blum-Dwork-McSherry-Nissim '05]

Differential Privacy

Definition: pure and approximate

[Dwork-McSherry-Nissim-Smith '06]

Intuition: for a statistic, the effect of each individual (whether in the dataset or not) should be close to nothing.

Differential Privacy

Definition: pure and approximate

[Dwork-McSherry-Nissim-Smith '06]

Intuition: for a statistic, the effect of each individual (whether in the dataset or not) should be close to nothing.

Worst-case notion: protects against all possible adversaries and any kind of individual.

Differential Privacy

Definition: pure and approximate

[Dwork-McSherry-Nissim-Smith '06]

For any algorithm \mathcal{A} , it satisfies ϵ differential privacy if

For all datasets D, D' differing in exactly one row all queries q

Distribution of $\mathcal{A}(D, q)$ is at most ϵ away from $\mathcal{A}(D', q)$

The smaller ϵ is, the more privacy is ensured!

Differential Privacy

Definition: pure and approximate

[Dwork-McSherry-Nissim-Smith '06]

For any algorithm \mathcal{A} , it satisfies ϵ differential privacy if

For all datasets D, D' differing in exactly one row all queries q

Distribution of $\mathcal{A}(D, q)$ is at most ϵ away from $\mathcal{A}(D', q)$

For all sets T ,

$$\Pr[\mathcal{A}(D, q) \in T] \leq (1 + \epsilon) \Pr[\mathcal{A}(D', q) \in T]$$

Differential Privacy

Definition: pure and approximate

[Dwork-McSherry-Nissim-Smith '06]

For any algorithm \mathcal{A} , it satisfies ϵ differential privacy if

For all datasets D, D' differing in exactly one row all queries q

Distribution of $\mathcal{A}(D, q)$ is at most ϵ away from $\mathcal{A}(D', q)$

The probability is only over the randomness of the algorithm \mathcal{A}

Table of Contents

- Motivations
 - Reidentification via Linkage Attacks
 - Reconstruction and Inference Attacks
- Definitions
 - K-anonymity
 - Differential Privacy
- Mechanisms
 - Laplace Mechanism
- Code Demonstrations
 - Python Code

Mechanisms for Differential Privacy

Examples:

1. Laplace Mechanism [we'll discuss and implement this one!]
2. Gaussian Mechanism
3. Exponential Mechanism
4. Geometric Mechanism

....

Laplace Mechanism

$\text{Lap}(s)$ is the Laplace Distribution with scale s .

Some properties:

- Has mean 0
- Has standard deviation $\sqrt{2} \cdot s$
- It's a “double-exponential” distribution

Laplace Mechanism for Sum and Average

$$1. \mathcal{A}(x) = \sum_{i=1} x_i + \text{Lap}\left(\frac{1}{\epsilon}\right)$$

where $x_i \in [0, 1]$ for all $i \in [n]$.

Laplace Mechanism for Sum and Average

$$1. \mathcal{A}(x) = \sum_{i=1} x_i + \text{Lap}\left(\frac{1}{\epsilon}\right)$$

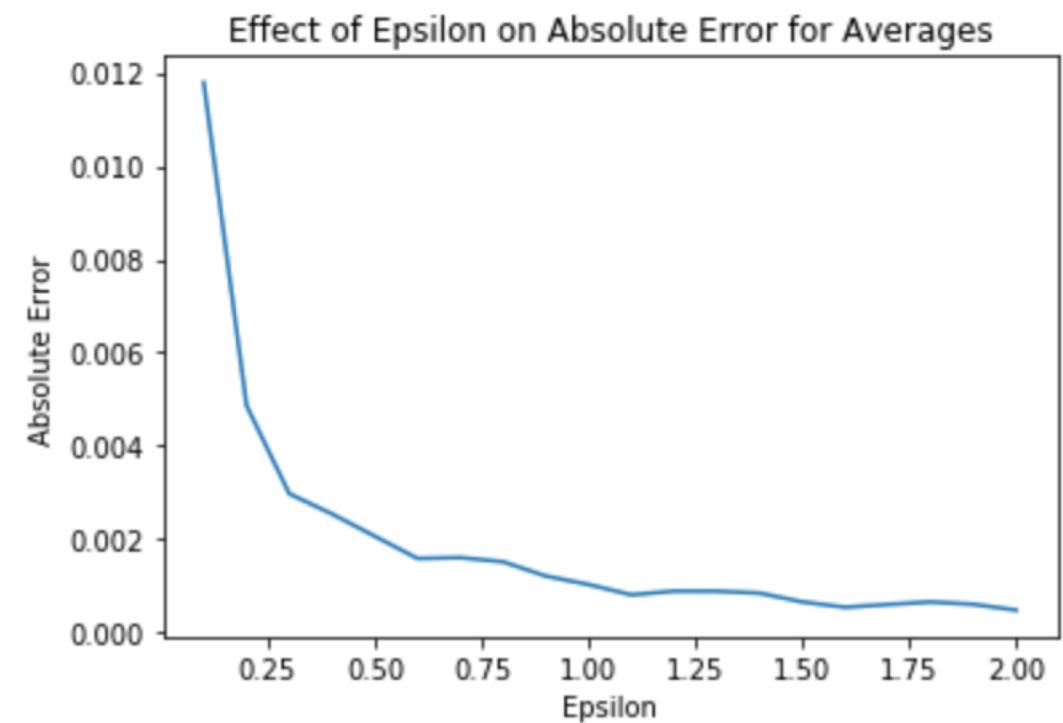
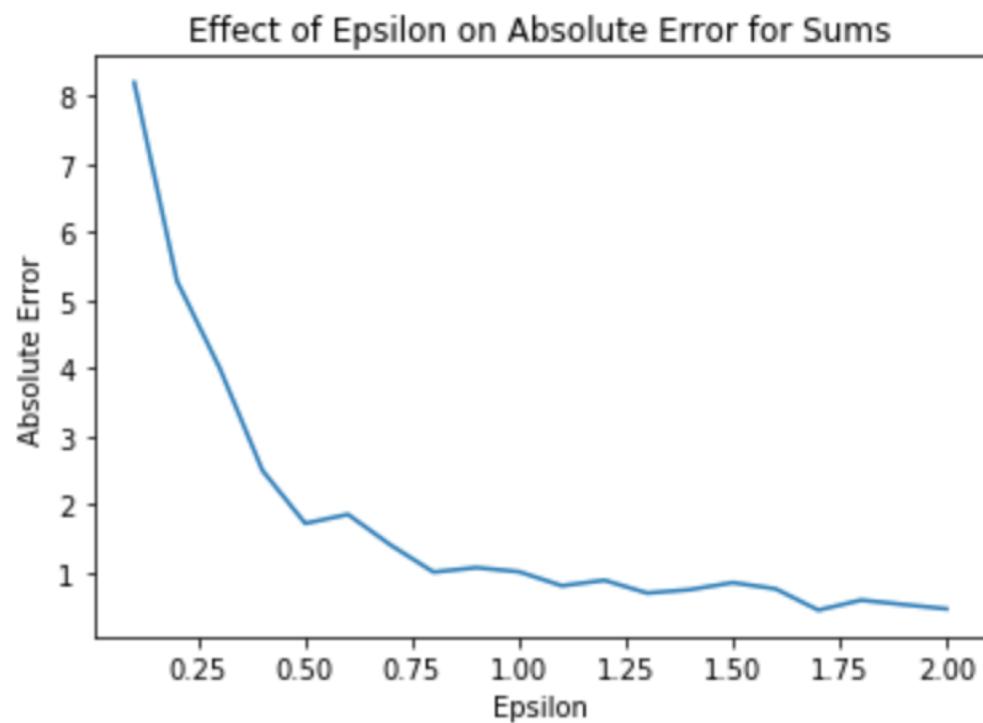
where $x_i \in [0, 1]$ for all $i \in [n]$.

$$2. \mathcal{A}(x) = \frac{1}{n} \cdot \sum_{i=1} x_i + \text{Lap}\left(\frac{1}{n \cdot \epsilon}\right)$$

where $x_i \in [0, 1]$ for all $i \in [n]$.

Code Demonstration

- <https://github.com/alabid/pre college 2019>



Conclusion

- Differential Privacy is a mathematically rigorous definition of individual data privacy.
- YOU can code it up. See GitHub page – clone it and play with the code there! https://github.com/alabid/pre_college_2019
- It's being used by the U.S. Census Bureau (for the 2020 Decennial Census), Google, Apple.