2550 Intro to cybersecurity

L15: Data Privacy
(Anonymous Data Isn’t!)

abhi shelat/Ran Cohen

The era of big data

Predict our preferences

Social networks

Medical & Genomic data

Contact tracing

Statistical data

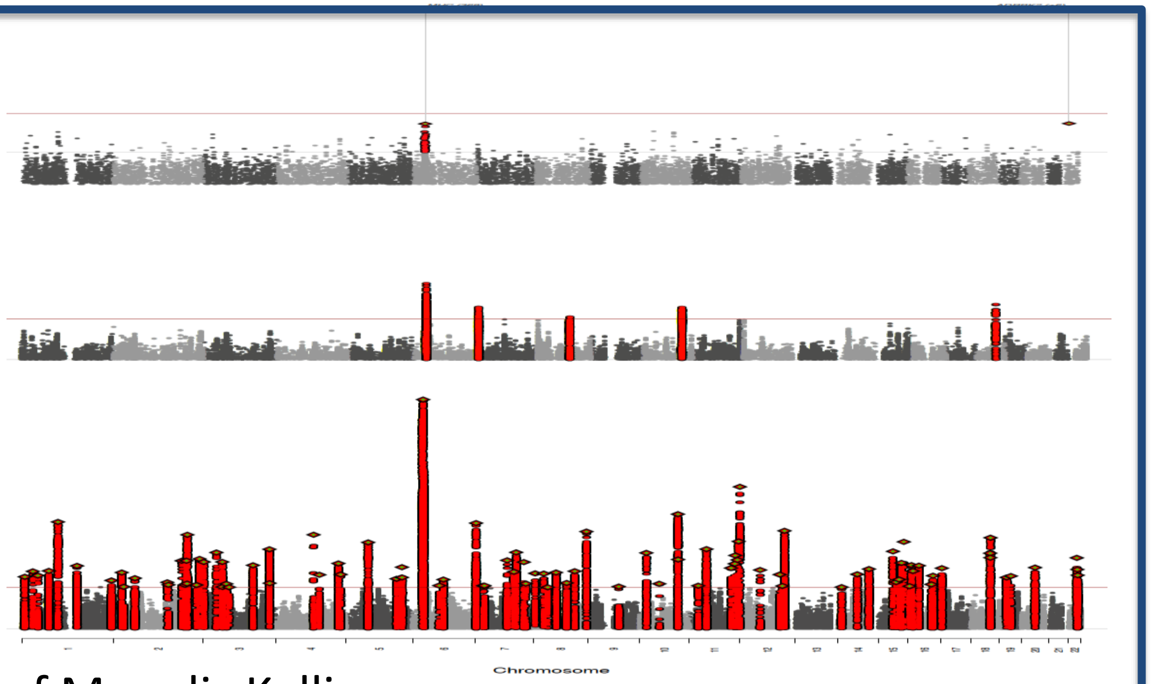
Big Data is Invaluable

Schizophrenia Genome-Wide Association Studies

3,500 cases
⇔ 0 loci

10,000 cases
⇔ 5 loci

35,000 cases
⇔ 62 loci!



Data courtesy of Manolis Kellis

Increasing sample sizes for schizophrenia association studies has led to increases in the number of risk genes discovered

new biological insights

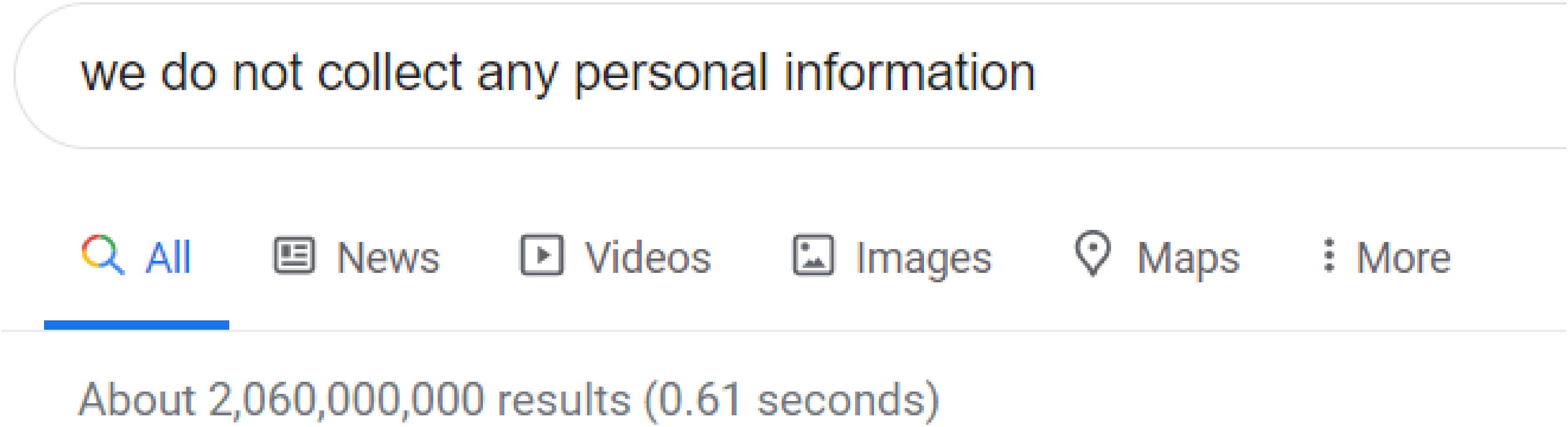
Outline

- Popular ideas that do not work
  + privacy horror stories

- An approach that works

Popular idea #1

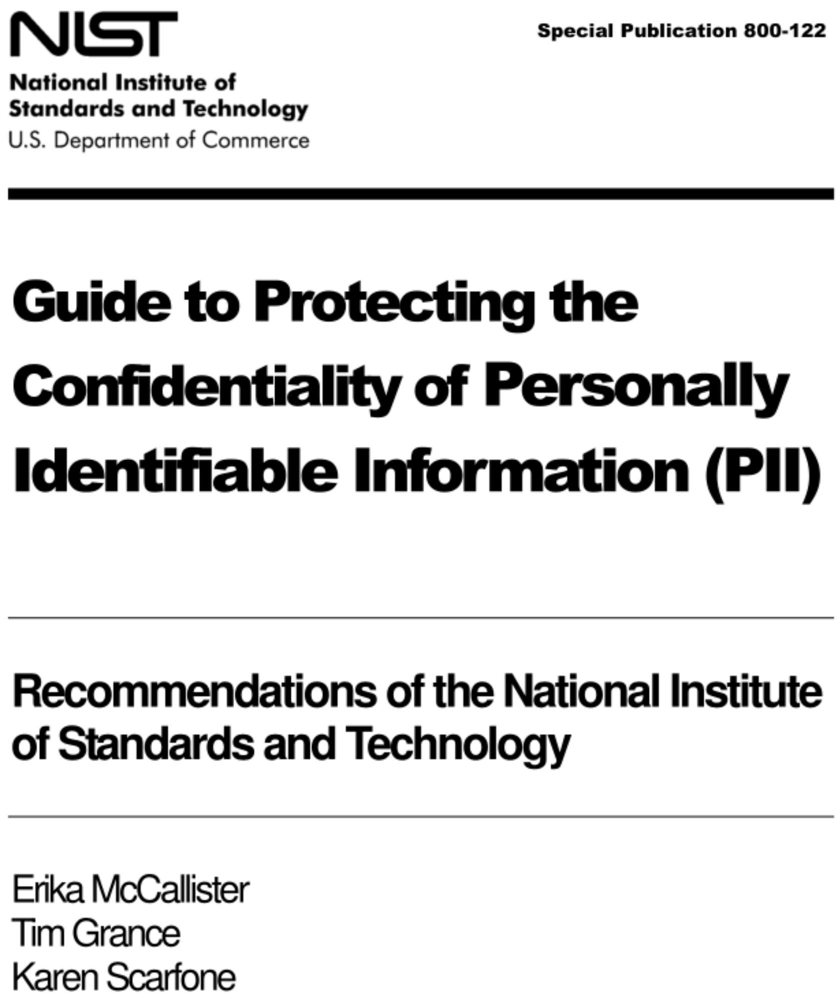
Remove Personally Identifiable Information (PII)



we do not collect any personal information

About 2,060,000,000 results (0.61 seconds)

Anonymizing data



NIST
National Institute of
Standards and Technology
U.S. Department of Commerce

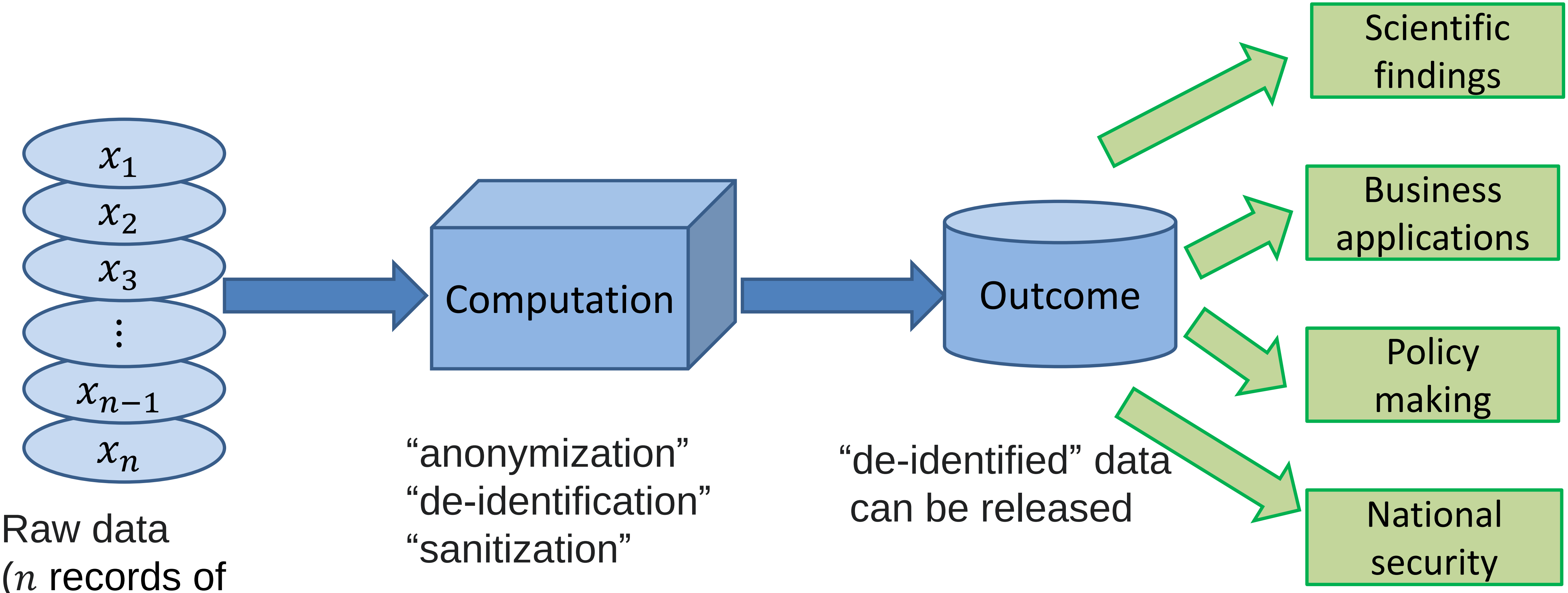
Special Publication 800-122

Guide to Protecting the Confidentiality of Personally Identifiable Information (PII)

Recommendations of the National Institute of Standards and Technology

Erika McCallister
Tim Grance
Karen Scarfone

“Privacy-preserving” data release



x_1

x_2

x_3

$\vdots$

x_{n-1}

x_n

Computation

Outcome

Scientific findings

Business applications

Policy making

National security

Raw data
(n records of
personal info)

“anonymization”
“de-identification”
“sanitization”

“de-identified” data
can be released

Linkage attack (Sweeney ‘97)

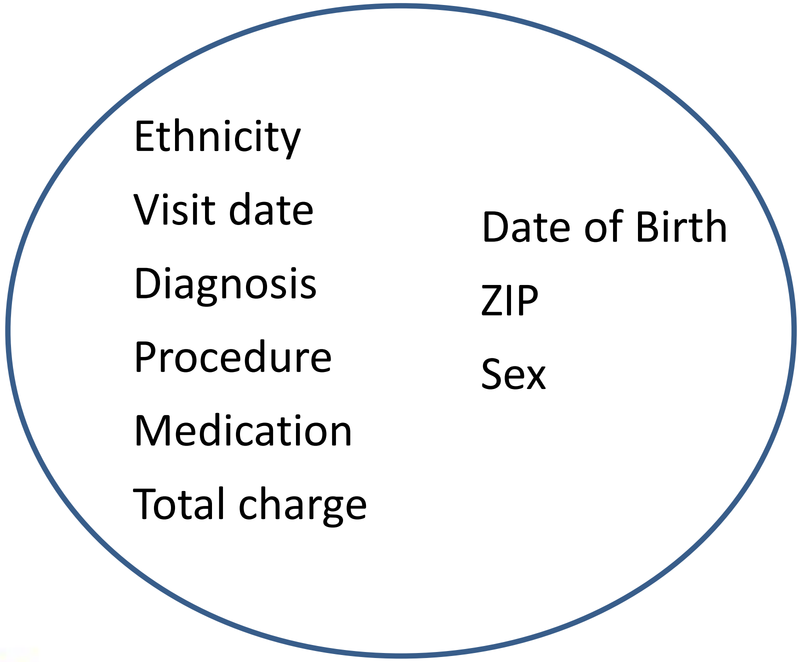
Massachusetts Group Insurance Commission (GIC)

- In mid-1990s GIC released “anonymized” data of state employees that showed every single hospital visit
- Goal: provide real data for researchers
- Privacy?
  Removed personally identifiable information (PII): Name, SSN, Address
- William Weld, then Governor of Massachusetts, assured the public that GIC had protected patient privacy by deleting identifiers

Linkage attack (Sweeney ‘97)

MA Group Insurance Commission

- Contained ~135,000 patients
- Anonymized: Name, SSN removed



Ethnicity
Visit date
Diagnosis
Procedure
Medication
Total charge

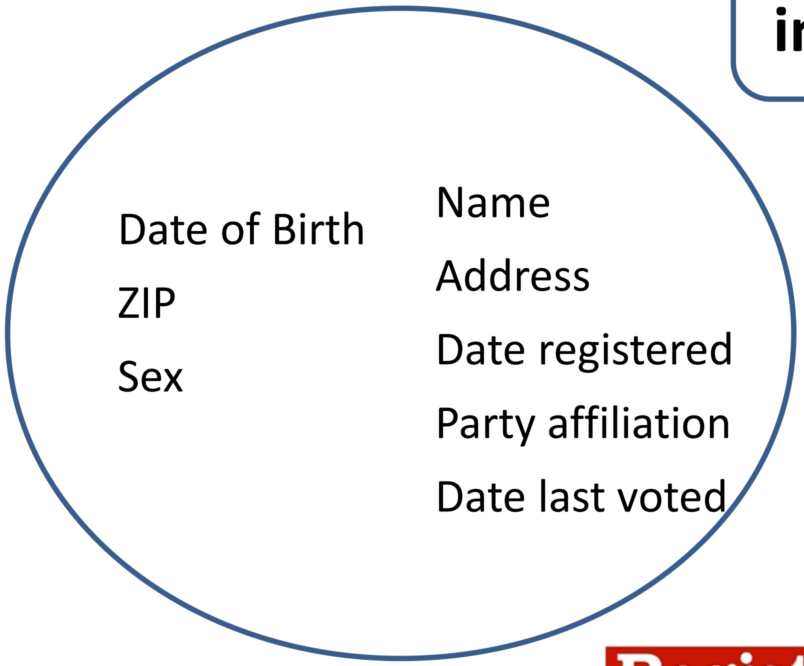
Date of Birth
ZIP
Sex

Commonwealth of Massachusetts
Group Insurance Commission

Voters registration of Cambridge MA

- Public information

Auxiliary information



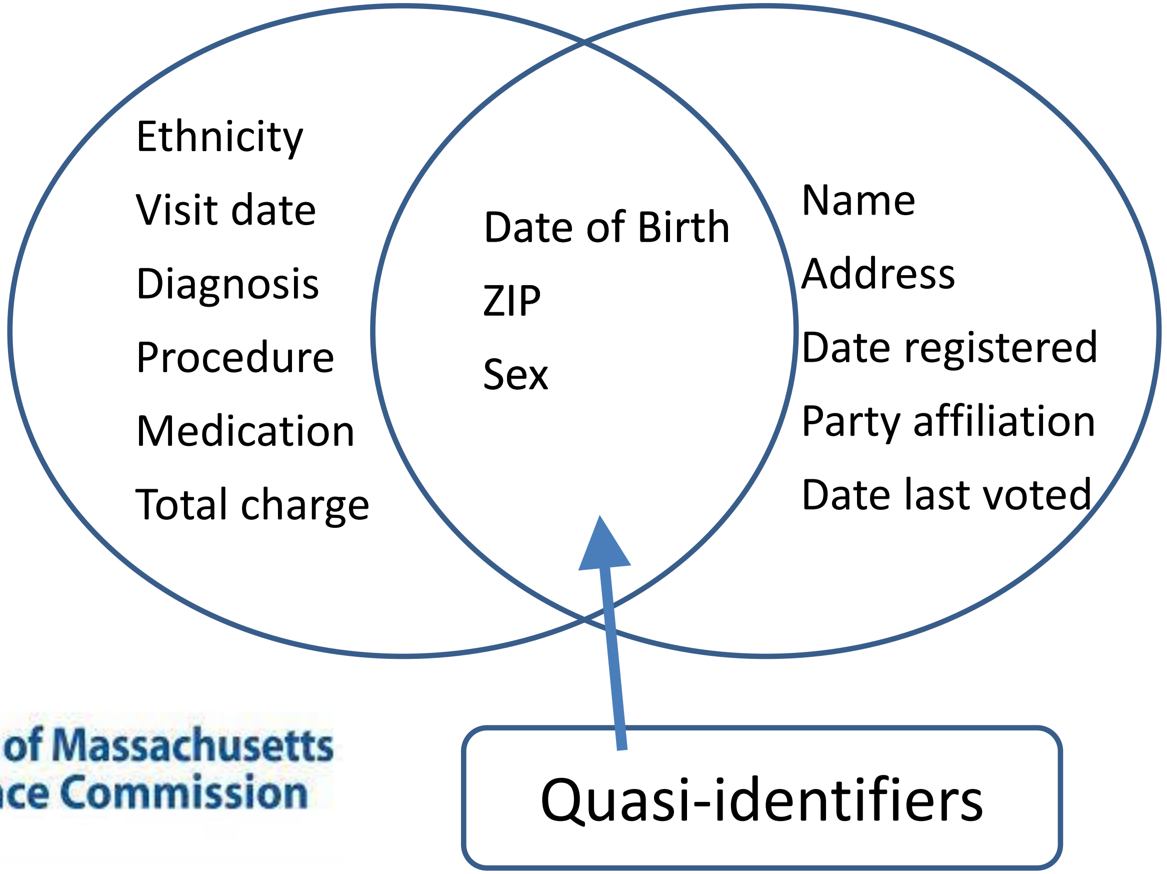
Date of Birth
ZIP
Sex

Name
Address
Date registered
Party affiliation
Date last voted

Register
★★★to★★★
VOTE

Linkage attack (Sweeney ‘97)

- A unique record fully de-anonymize the record
- (DoB, ZIP, Sex) uniquely identifies 87% of US population



Ethnicity

Visit date

Diagnosis

Procedure

Medication

Total charge

Date of Birth

ZIP

Sex

Name

Address

Date registered

Party affiliation

Date last voted

Quasi-identifiers

Commonwealth of Massachusetts
Group Insurance Commission

Register
to
VOTE

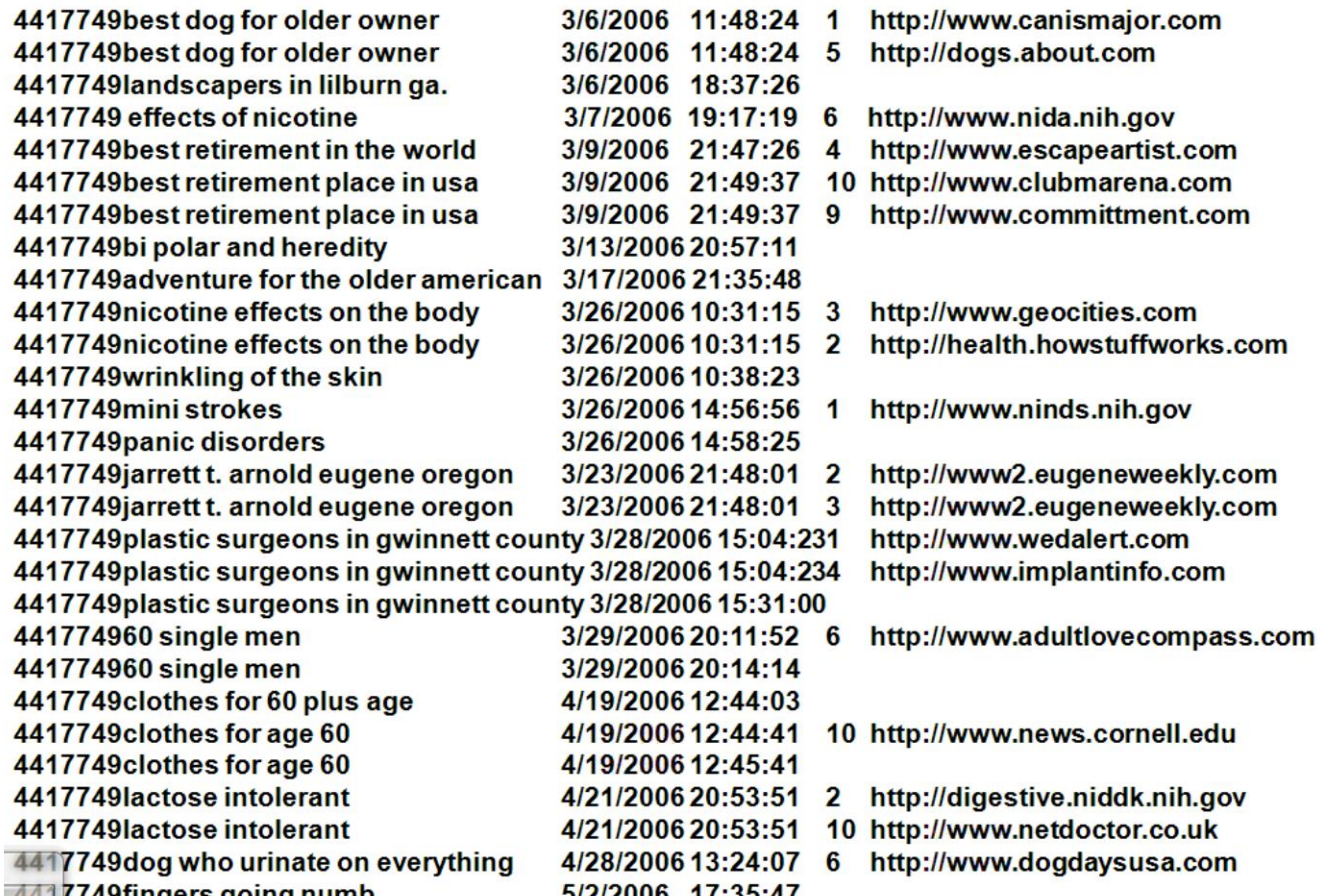
Linkage attack (Sweeney ‘97)

- A unique record fully de-anonymize the record
- (DoB, ZIP, Sex) uniquely identifies 87% of US population
- Re-identified medical records of William Weld (MA governor at the time)
- In Cambridge voters list
  - Six people shared his DoB
  - Three of which were men
  - He was the only one in his ZIP code
- Significant impact on privacy policymaking and the health privacy legislation HIPAA (Health Insurance Portability and Accountability Act)

AOL search history release (2006)

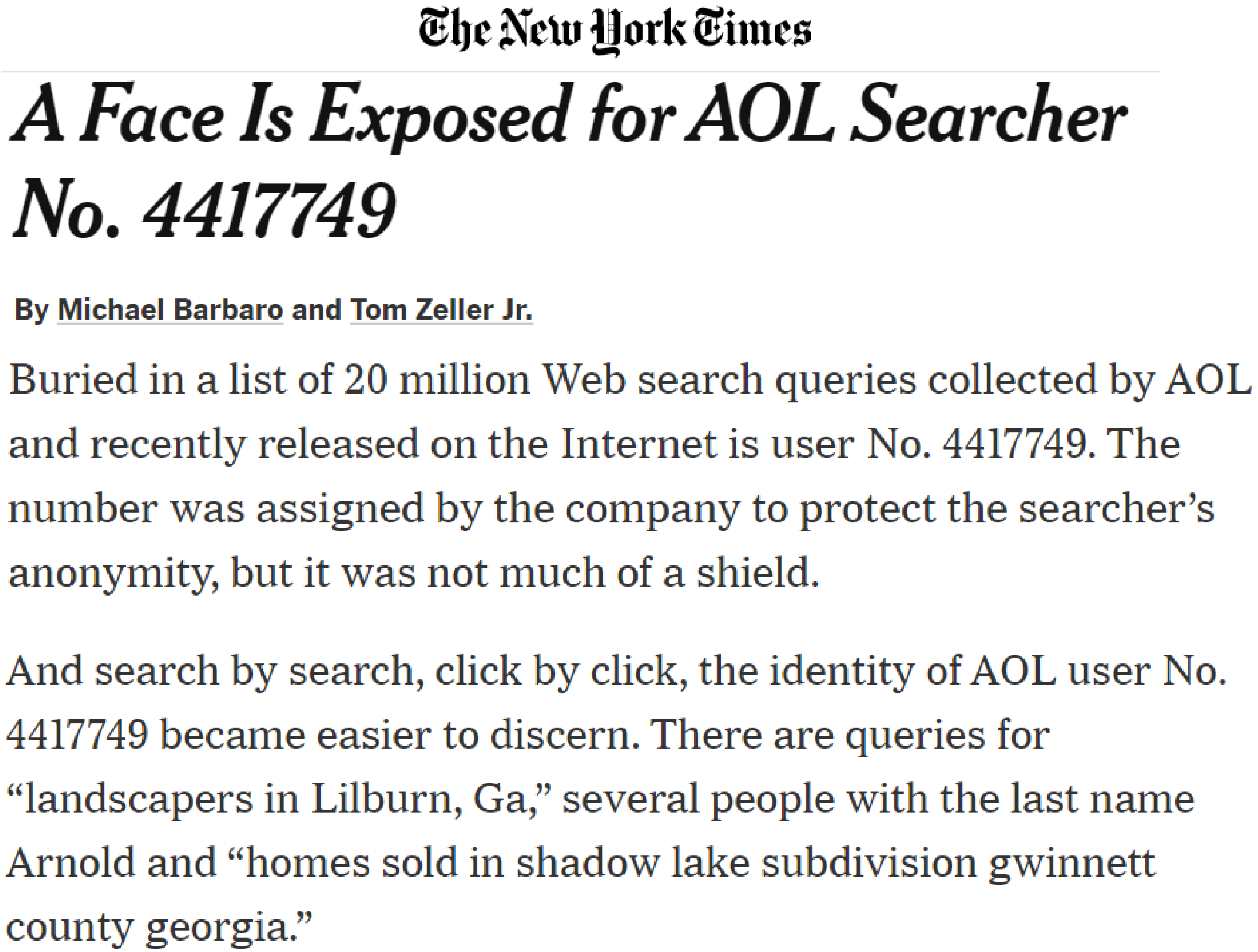
- In Aug 4th, 2006 AOL released users search requests to the public
- 20 million queries by 650,000 users over 3 months
- Goal: provide real query data by real users
- IP address replaced by random numbers
- In Aug 7th, 2006 AOL deleted the data

AOL search history release (2006)



4417749best dog for older owner	3/6/2006	11:48:24	1	http://www.canismajor.com
4417749best dog for older owner	3/6/2006	11:48:24	5	http://dogs.about.com
4417749landscapers in lilburn ga.	3/6/2006	18:37:26		
4417749 effects of nicotine	3/7/2006	19:17:19	6	http://www.nida.nih.gov
4417749best retirement in the world	3/9/2006	21:47:26	4	http://www.escapeartist.com
4417749best retirement place in usa	3/9/2006	21:49:37	10	http://www.clubmarena.com
4417749best retirement place in usa	3/9/2006	21:49:37	9	http://www.committment.com
4417749bi polar and heredity	3/13/2006	20:57:11		
4417749adventure for the older american	3/17/2006	21:35:48		
4417749nicotine effects on the body	3/26/2006	10:31:15	3	http://www.geocities.com
4417749nicotine effects on the body	3/26/2006	10:31:15	2	http://health.howstuffworks.com
4417749wrinkling of the skin	3/26/2006	10:38:23		
4417749mini strokes	3/26/2006	14:56:56	1	http://www.ninds.nih.gov
4417749panic disorders	3/26/2006	14:58:25		
4417749jarrett t. arnold eugene oregon	3/23/2006	21:48:01	2	http://www2.eugeneweekly.com
4417749jarrett t. arnold eugene oregon	3/23/2006	21:48:01	3	http://www2.eugeneweekly.com
4417749plastic surgeons in gwinnett county	3/28/2006	15:04:231		http://www.wedalert.com
4417749plastic surgeons in gwinnett county	3/28/2006	15:04:234		http://www.implantinfo.com
4417749plastic surgeons in gwinnett county	3/28/2006	15:31:00		
441774960 single men	3/29/2006	20:11:52	6	http://www.adultlovecompass.com
441774960 single men	3/29/2006	20:14:14		
4417749clothes for 60 plus age	4/19/2006	12:44:03		
4417749clothes for age 60	4/19/2006	12:44:41	10	http://www.news.cornell.edu
4417749clothes for age 60	4/19/2006	12:45:41		
4417749lactose intolerant	4/21/2006	20:53:51	2	http://digestive.niddk.nih.gov
4417749lactose intolerant	4/21/2006	20:53:51	10	http://www.netdoctor.co.uk
4417749dog who urinate on everything	4/28/2006	13:24:07	6	http://www.dogdaysusa.com
4417749fingers going numb	5/2/2006	17:35:47		

AOL search history release (2006)



The New York Times

A Face Is Exposed for AOL Searcher No. 4417749

By Michael Barbaro and Tom Zeller Jr.

Buried in a list of 20 million Web search queries collected by AOL and recently released on the Internet is user No. 4417749. The number was assigned by the company to protect the searcher's anonymity, but it was not much of a shield.

And search by search, click by click, the identity of AOL user No. 4417749 became easier to discern. There are queries for "landscapers in Lilburn, Ga," several people with the last name Arnold and "homes sold in shadow lake subdivision gwinnett county georgia."

Thelma Arnold, 62

Widow

Lives in Lilburn, GA

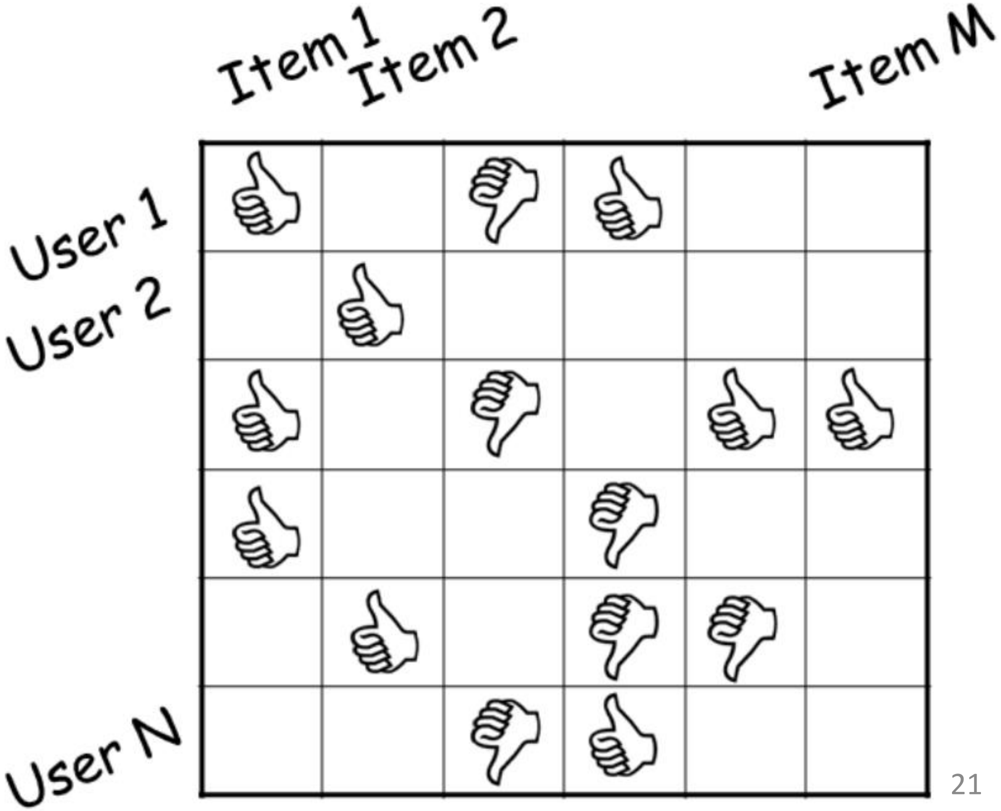
Data itself leaks PII

Netflix Prize (2006)

- Netflix recommends movies to its subscribers
- In 2006 offered $1,000,000 for 10% improvement in its algorithm
- Published training data:
  - More than 100 million ratings from over 480,000 randomly chosen anonymous users on nearly 18,000 movie titles
  - All PII have been removed, all customer id replaced by random numbers
- Prize won by Bellkore’s Pragmatic Chaos team, 2009

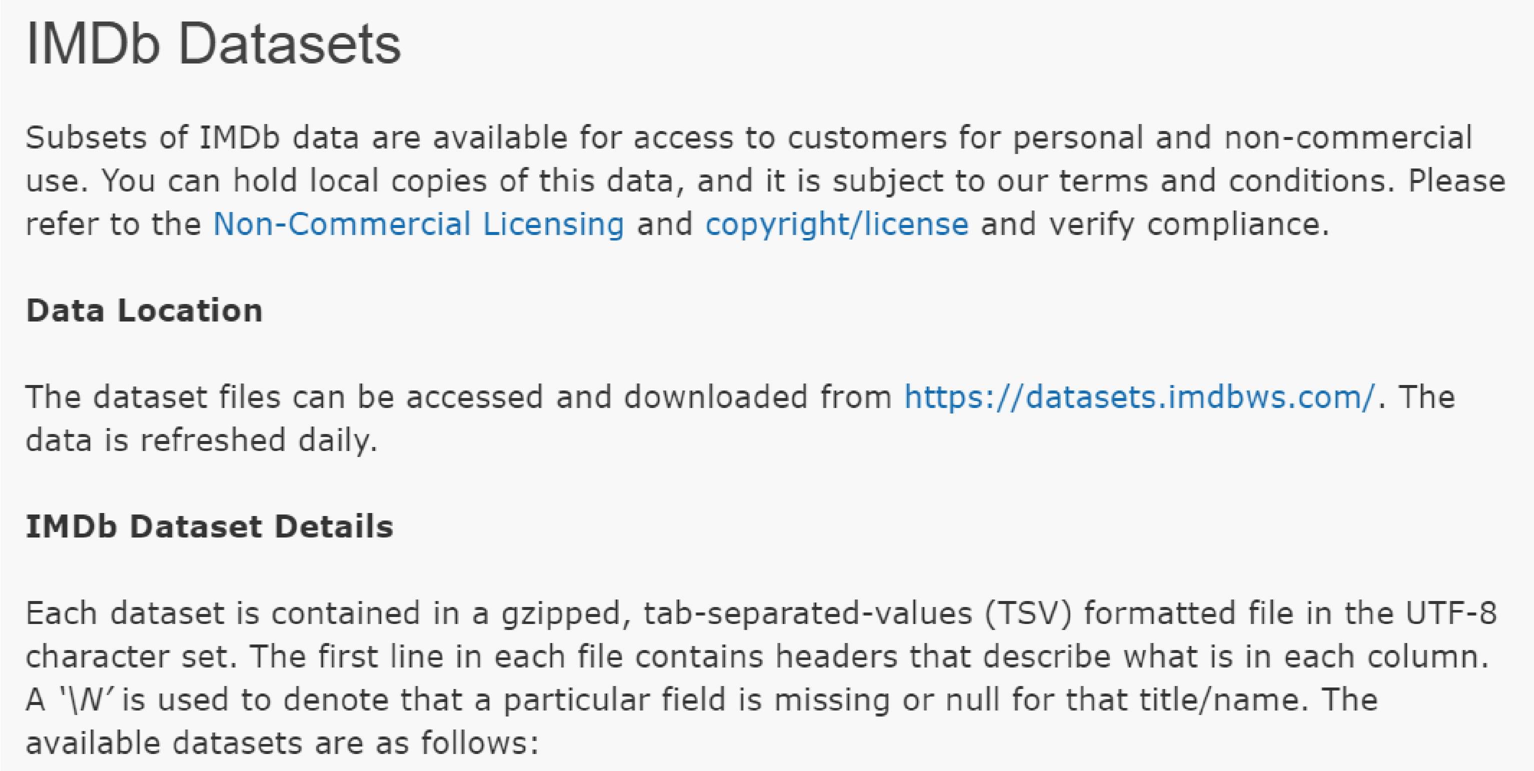
Netflix Prize (2006)

- Anonymized data included: rating (1-5 stars), date, watch/didn't watch
- 213 dated ratings per used, on average
- Narayanan and Shmatikov re-identified the data



Netflix Prize (2006)

- A source of auxiliary information:
  - Individuals may rate movies
  - Many use their real identify (not anonymous)
  - Visible data includes ratings, dates, comments



IMDb Datasets

Subsets of IMDb data are available for access to customers for personal and non-commercial use. You can hold local copies of this data, and it is subject to our terms and conditions. Please refer to the Non-Commercial Licensing and copyright/license and verify compliance.

Data Location

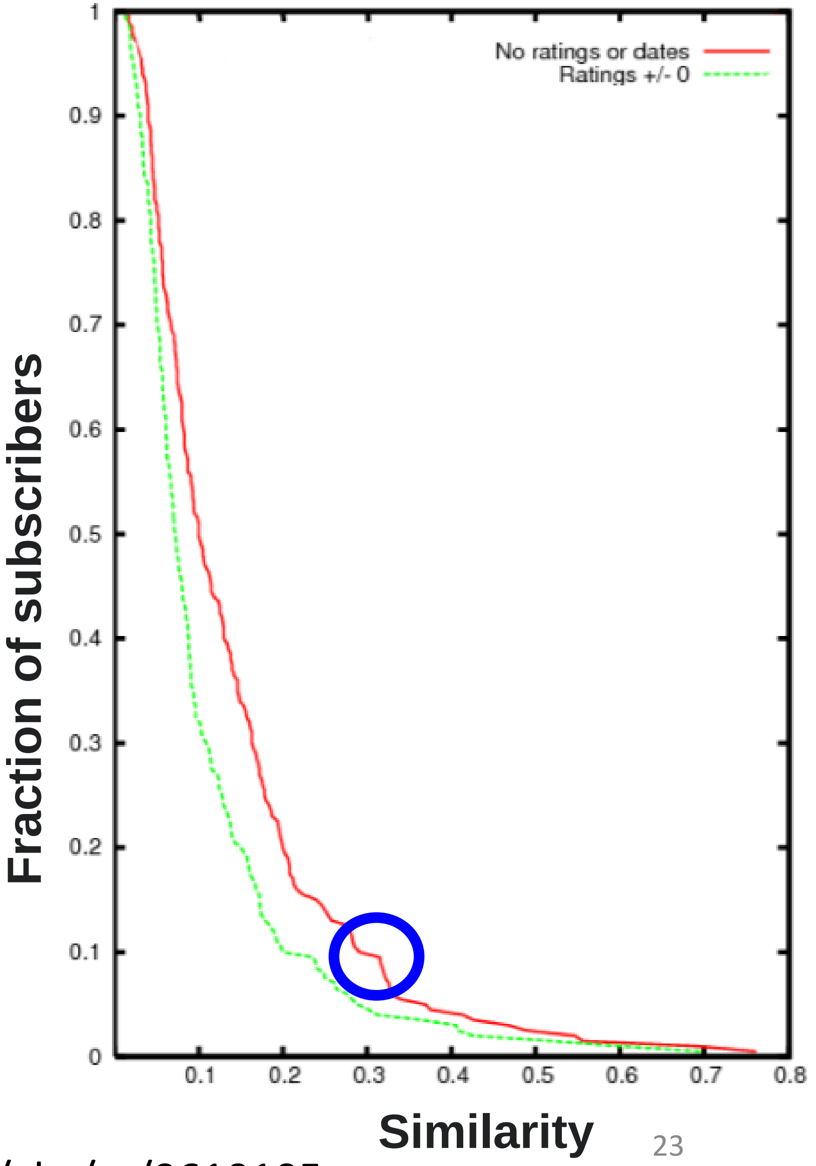
The dataset files can be accessed and downloaded from https://datasets.imdbws.com/. The data is refreshed daily.

IMDb Dataset Details

Each dataset is contained in a gzipped, tab-separated-values (TSV) formatted file in the UTF-8 character set. The first line in each file contains headers that describe what is in each column. A '\N' is used to denote that a particular field is missing or null for that title/name. The available datasets are as follows:

Netflix Prize (2006)

- **Sparse data cannot be anonymized!**
- Considering just watch/didn't watch for 90% of the records there isn't a **single** other record which is more than 30% similar
- Focus on movies that are not in top 10,000
- The whole point of privacy is that my record is similar to other records
- Here, to make two records "close" the data is destroyed



https://arxiv.org/abs/cs/0610105

Netflix Prize (2006)

Results of the attack

- With 8 movie ratings and dates that may have a 3-days error, 96% of Netflix clients whose data was released can be uniquely identified in the dataset
- For 89%, 2 ratings and dates are enough to reduce the set of plausible records to 8 out of almost 500,000

Consequences

- Learn about movies that IMDb users didn’t want to tell the world: sexual orientation, religious beliefs, political attitude, etc.
- In 2009 four Netflix users filled a lawsuit against Netflix
- In 2010 Netflix cancelled the second prize competition

Privacy is more than re-identification

Medical encounter data

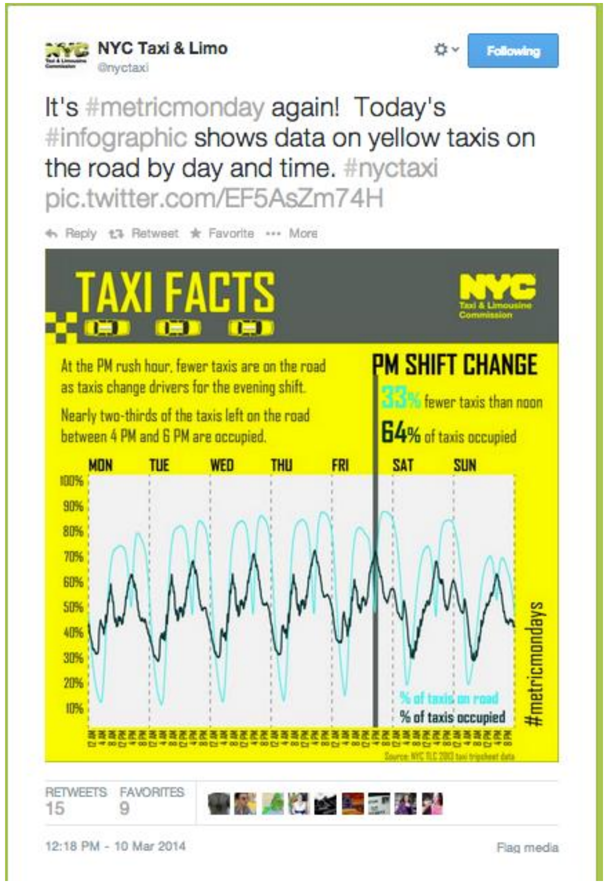
- Ambulance collects an elderly neighbor
- Daily medical encounter data shows that every elderly admitted patient was diagnosed with tachycardia, influenza, broken arm, panic attack
- Learn the neighbor suffers from one of these 4 complaints
- Next day, can rule out influenza, broken arm

- Re-identification fails to capture privacy risks!

NYC Taxi and Limo Commission (2014)

Taxi & Limousine Commission

- TLC is the regulator for establishing public transport policy setting and enforcing the fare rate in taxis, etc.
- Published statistics about taxi rides
- 2014 Whong filled a FOILed request (Freedom Of Information Law)
- Got 2 datasets (90 GB of data) trips and fares



NYC Taxi & Limo
@nyctaxi

It's #metricmonday again! Today's #infographic shows data on yellow taxis on the road by day and time. #nyctaxi pic.twitter.com/EF5AsZm74H

Following
Reply
Retweet
Favorite
More
TAXI FACTS
NYC
Taxi & Limousine Commission
At the PM rush hour, fewer taxis are on the road as taxis change drivers for the evening shift.
Nearly two-thirds of the taxis left on the road between 4 PM and 6 PM are occupied.
PM SHIFT CHANGE
33% fewer taxis than noon
64% of taxis occupied
MON
TUE
WED
THU
FRI
SAT
SUN
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
% of taxis on road
% of taxis occupied
#metricmondays
Source: NYC TLC 2013 taxi tripsheet data

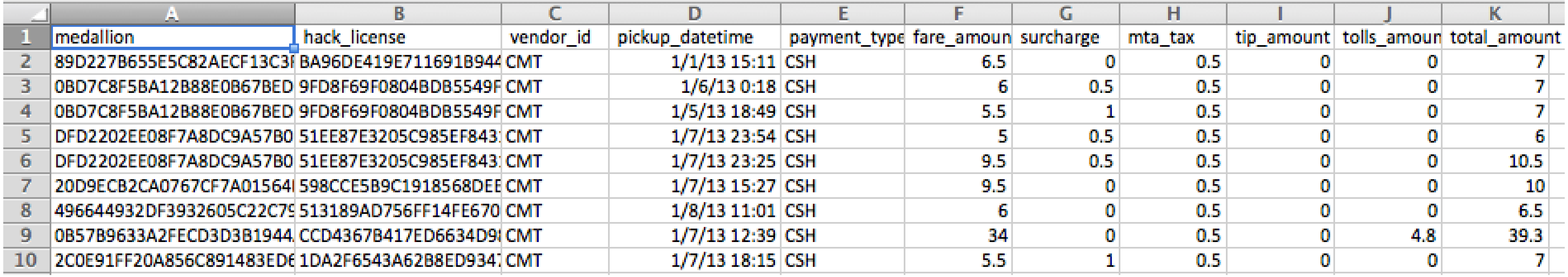
RETWEETS 15
FAVORITES 9

12:18 PM - 10 Mar 2014

Flag media

https://chriswhong.com/open-data/foil_nyc_taxi/

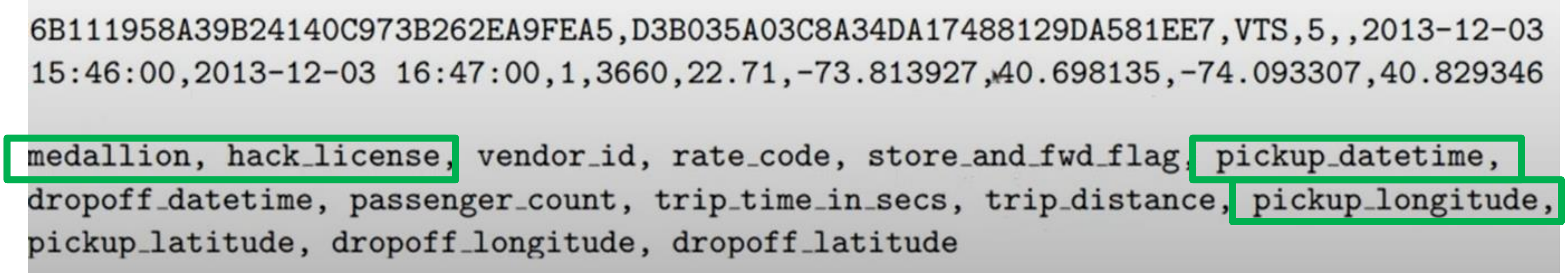
NYC Taxi and Limo Commission (2014)



	A	B	C	D	E	F	G	H	I	J	K
1	medallion	hack_license	vendor_id	pickup_datetime	payment_type	fare_amoun	surcharge	mta_tax	tip_amount	tolls_amoun	total_amount
2	89D227B655E5C82AECF13C3F	BA96DE419E711691B944	CMT	1/1/13 15:11	CSH	6.5	0	0.5	0	0	7
3	0BD7C8F5BA12B88E0B67BED	9FD8F69F0804BDB5549F	CMT	1/6/13 0:18	CSH	6	0.5	0.5	0	0	7
4	0BD7C8F5BA12B88E0B67BED	9FD8F69F0804BDB5549F	CMT	1/5/13 18:49	CSH	5.5	1	0.5	0	0	7
5	DFD2202EE08F7A8DC9A57B0	51EE87E3205C985EF843	CMT	1/7/13 23:54	CSH	5	0.5	0.5	0	0	6
6	DFD2202EE08F7A8DC9A57B0	51EE87E3205C985EF843	CMT	1/7/13 23:25	CSH	9.5	0.5	0.5	0	0	10.5
7	20D9ECB2CA0767CF7A01564	598CCE5B9C1918568DEE	CMT	1/7/13 15:27	CSH	9.5	0	0.5	0	0	10
8	496644932DF3932605C22C79	513189AD756FF14FE670	CMT	1/8/13 11:01	CSH	6	0	0.5	0	0	6.5
9	0B57B9633A2FECD3D3B1944	CCD4367B417ED6634D9	CMT	1/7/13 12:39	CSH	34	0	0.5	0	4.8	39.3
10	2C0E91FF20A856C891483ED6	1DA2F6543A62B8ED934	CMT	1/7/13 18:15	CSH	5.5	1	0.5	0	0	7

https://chriswhong.com/open-data/foil_nyc_taxi/

NYC Taxi and Limo Commission (2014)



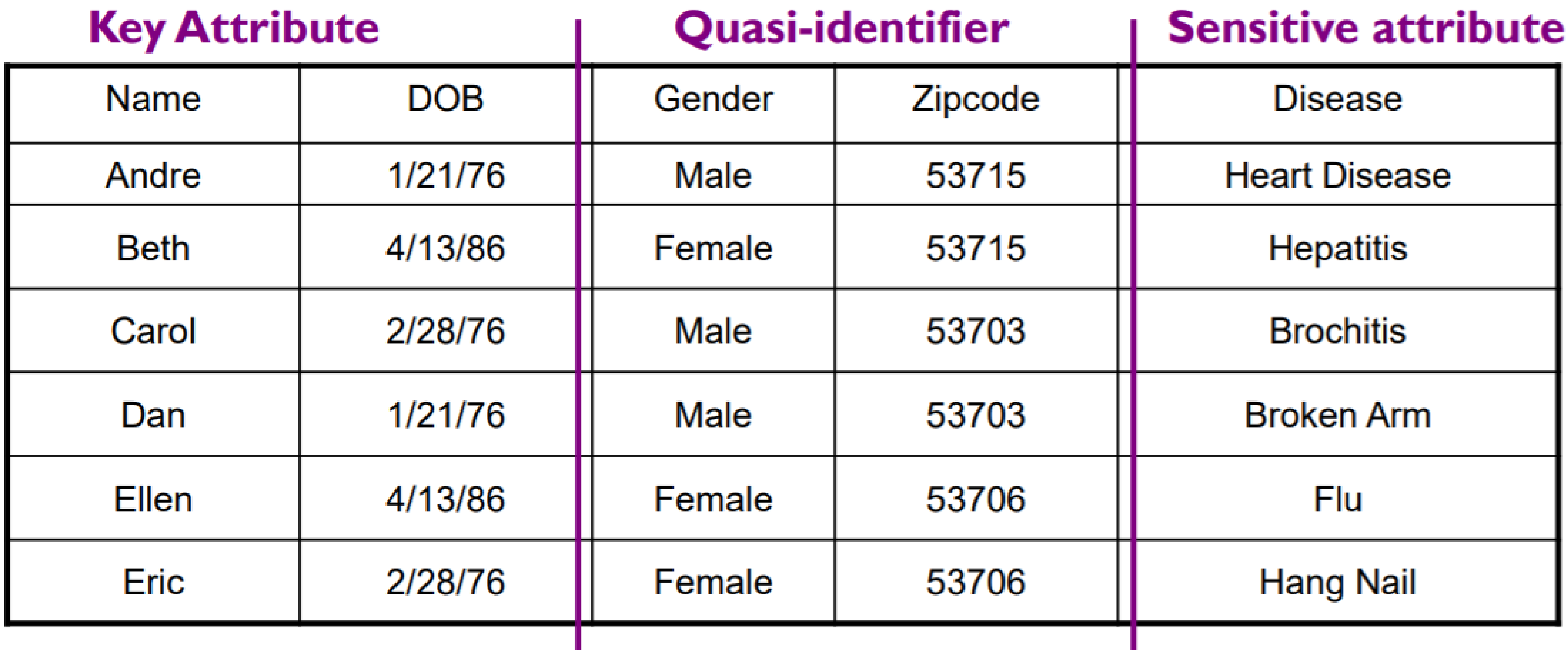
```
6B111958A39B24140C973B262EA9FEA5,D3B035A03C8A34DA17488129DA581EE7,VTS,5,,2013-12-03
15:46:00,2013-12-03 16:47:00,1,3660,22.71,-73.813927,40.698135,-74.093307,40.829346

medallion, hack_license, vendor_id, rate_code, store_and_fwd_flag, pickup_datetime,
dropoff_datetime, passenger_count, trip_time_in_secs, trip_distance, pickup_longitude,
pickup_latitude, dropoff_longitude, dropoff_latitude
```

- MD5 values of taxi number and driver license
- After a taxi ride one can learn information about the driver
- If someone is taking a taxi you can see where they’re going
- Are they good tippers

https://chriswhong.com/open-data/foil_nyc_taxi/

Identifiers vs. Sensitive attributes

- Key attributes: name, address, etc. (uniquely identifying)
- Quasi-identifiers: ZIP, DoB, etc.
- Sensitive attributes: medical records, etc.

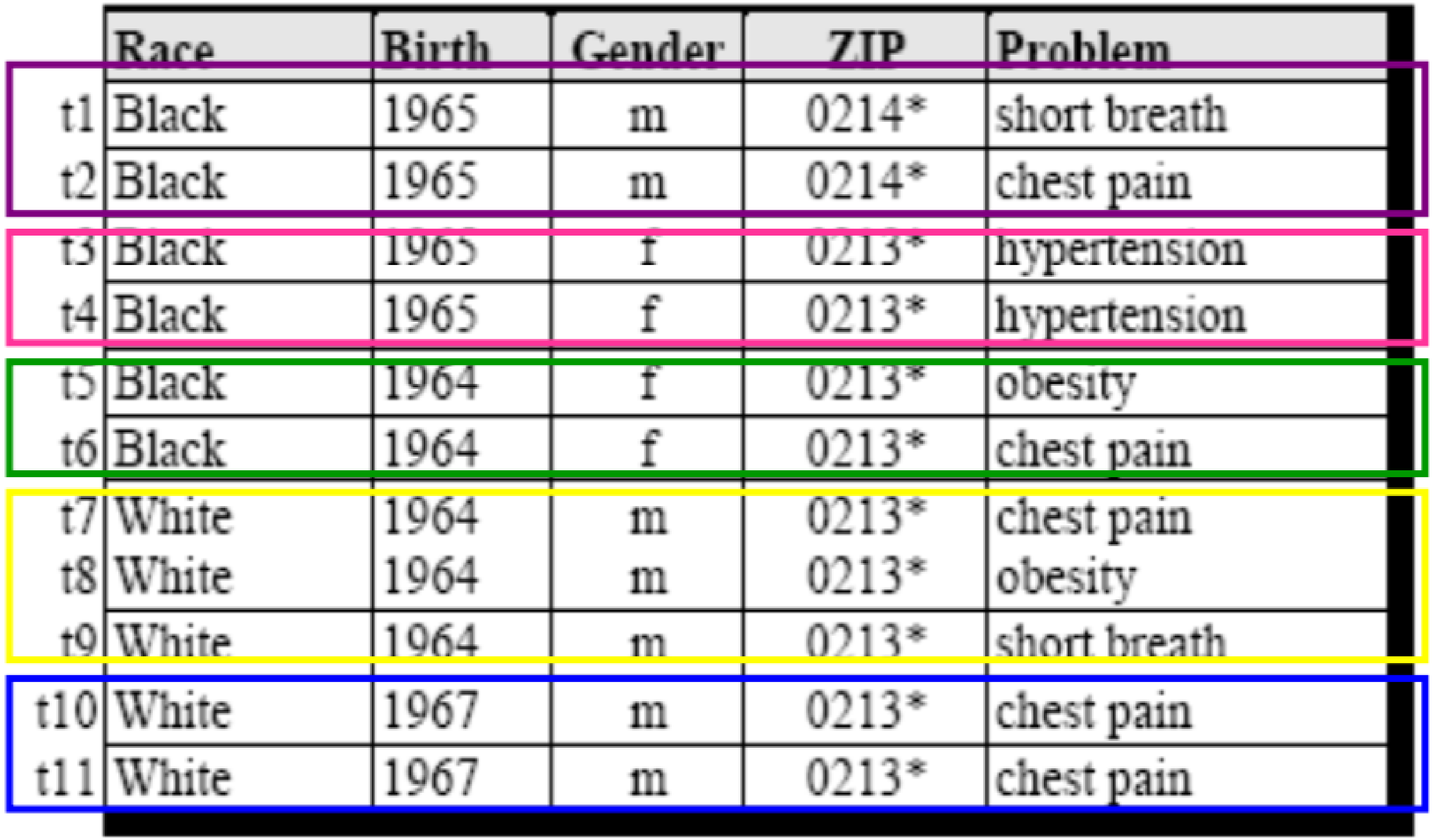


Key Attribute		Quasi-identifier		Sensitive attribute
Name	DOB	Gender	Zipcode	Disease
Andre	1/21/76	Male	53715	Heart Disease
Beth	4/13/86	Female	53715	Hepatitis
Carol	2/28/76	Male	53703	Brochitis
Dan	1/21/76	Male	53703	Broken Arm
Ellen	4/13/86	Female	53706	Flu
Eric	2/28/76	Female	53706	Hang Nail

k-Anonymity (Sweeney and Samarati 98)

- The information for each person contained in the released table cannot be distinguished from at least $k - 1$ individuals whose information also appears in the release
- Any quasi-identifier present in the released table must appear in at least k records
- Simple and syntactic property of the dataset
- Very popular technique

k-Anonymity (Sweeney and Samarati 98)



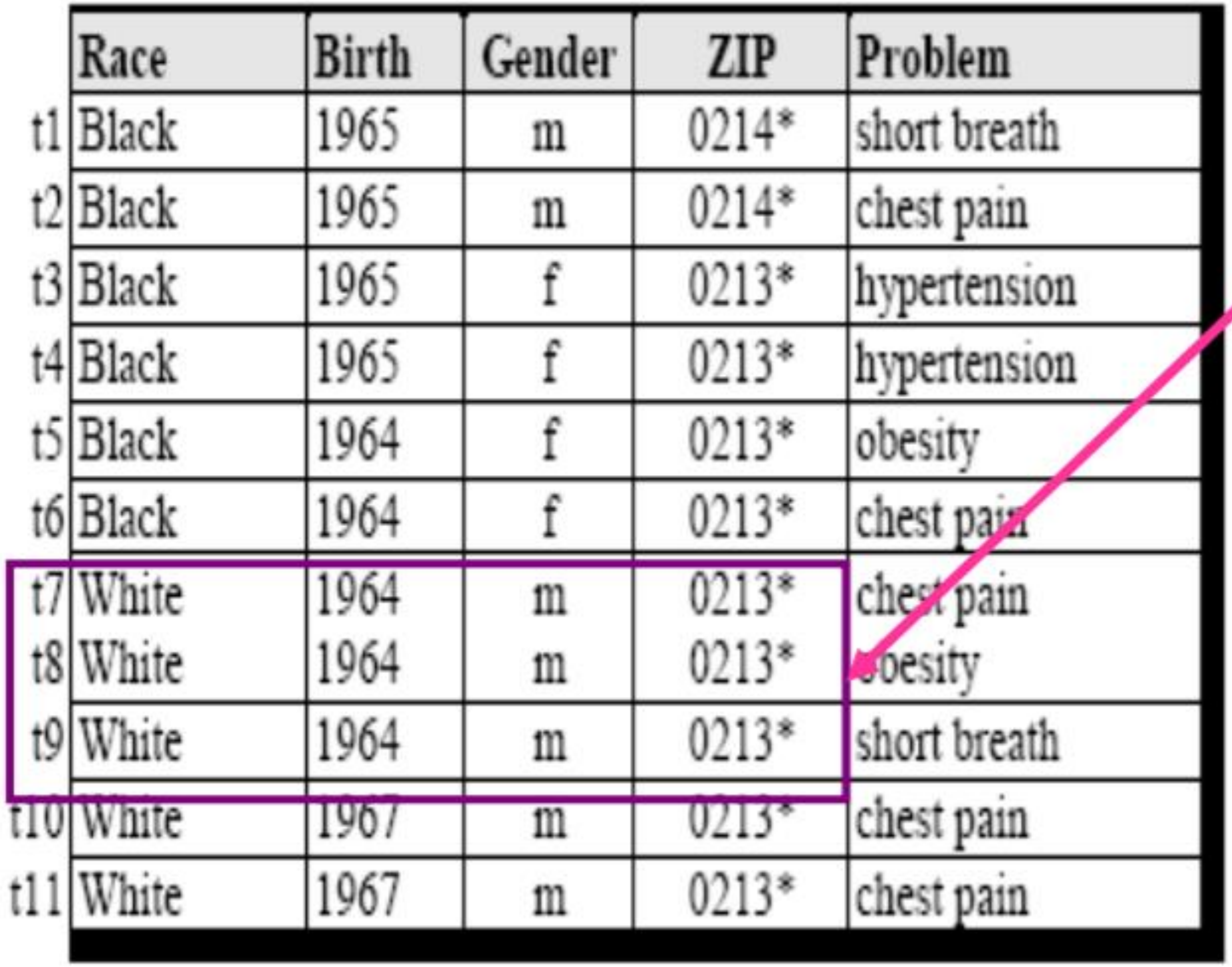
	Race	Birth	Gender	ZIP	Problem
t1	Black	1965	m	0214*	short breath
t2	Black	1965	m	0214*	chest pain
t3	Black	1965	f	0213*	hypertension
t4	Black	1965	f	0213*	hypertension
t5	Black	1964	f	0213*	obesity
t6	Black	1964	f	0213*	chest pain
t7	White	1964	m	0213*	chest pain
t8	White	1964	m	0213*	obesity
t9	White	1964	m	0213*	short breath
t10	White	1967	m	0213*	chest pain
t11	White	1967	m	0213*	chest pain

Figure 2 Example of *k*-anonymity, where *k*=2 and QI={*Race*, *Birth*, *Gender*, *ZIP*}

https://epic.org/privacy/reidentification/Sweeney_Article.pdf

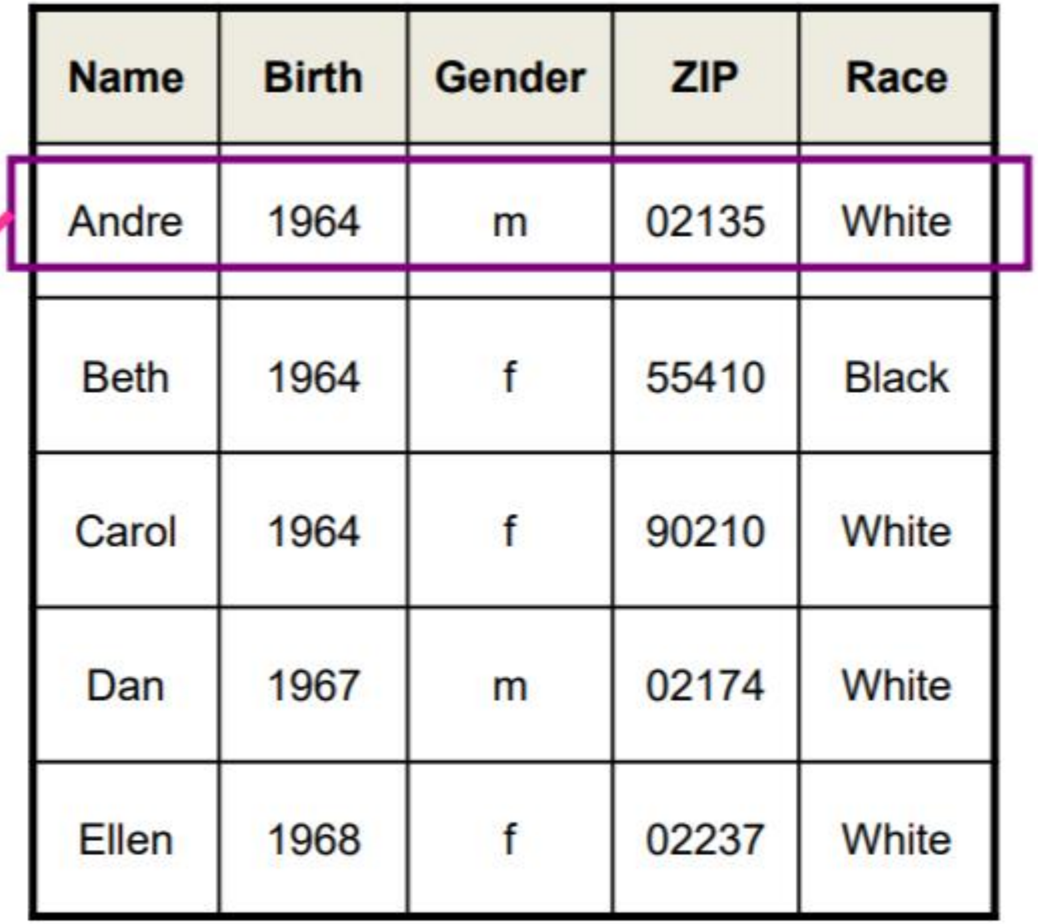
k-Anonymity (Sweeney and Samarati 98)

Released table



	Race	Birth	Gender	ZIP	Problem
t1	Black	1965	m	0214*	short breath
t2	Black	1965	m	0214*	chest pain
t3	Black	1965	f	0213*	hypertension
t4	Black	1965	f	0213*	hypertension
t5	Black	1964	f	0213*	obesity
t6	Black	1964	f	0213*	chest pain
t7	White	1964	m	0213*	chest pain
t8	White	1964	m	0213*	obesity
t9	White	1964	m	0213*	short breath
t10	White	1967	m	0213*	chest pain
t11	White	1967	m	0213*	chest pain

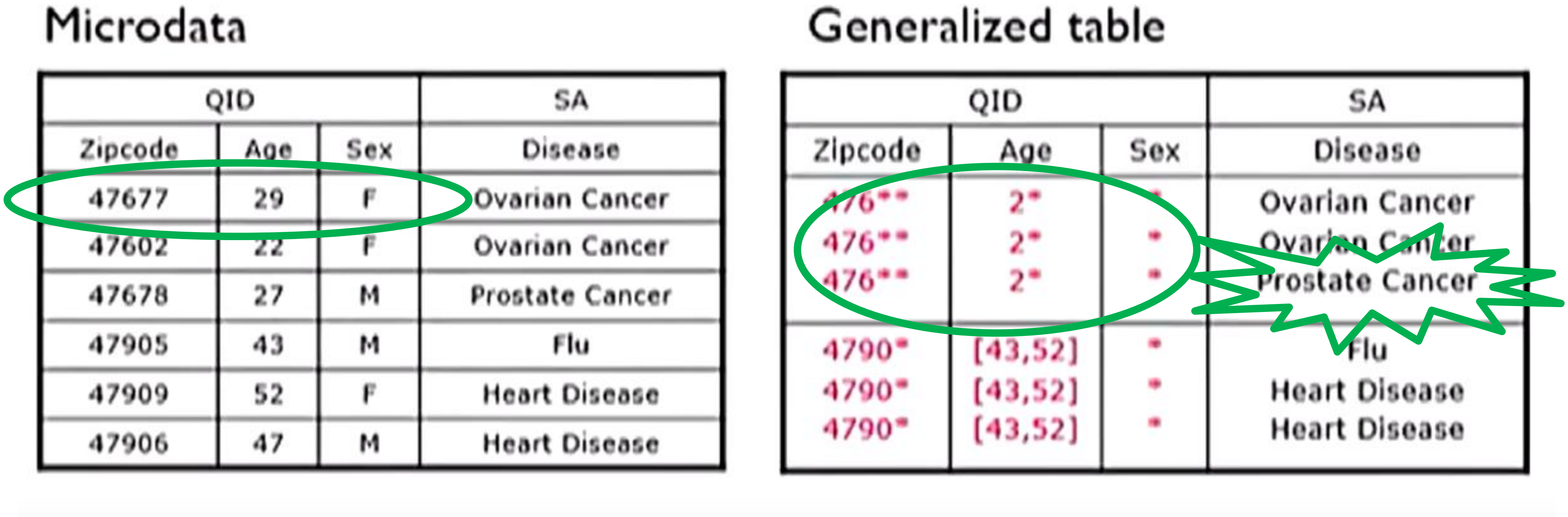
External data source



Name	Birth	Gender	ZIP	Race
Andre	1964	m	02135	White
Beth	1964	f	55410	Black
Carol	1964	f	90210	White
Dan	1967	m	02174	White
Ellen	1968	f	02237	White

https://epic.org/privacy/reidentification/Sweeney_Article.pdf

k-Anonymity (Sweeney and Samarati 98)



Microdata

QID			SA
Zipcode	Age	Sex	Disease
47677	29	F	Ovarian Cancer
47602	22	F	Ovarian Cancer
47678	27	M	Prostate Cancer
47905	43	M	Flu
47909	52	F	Heart Disease
47906	47	M	Heart Disease

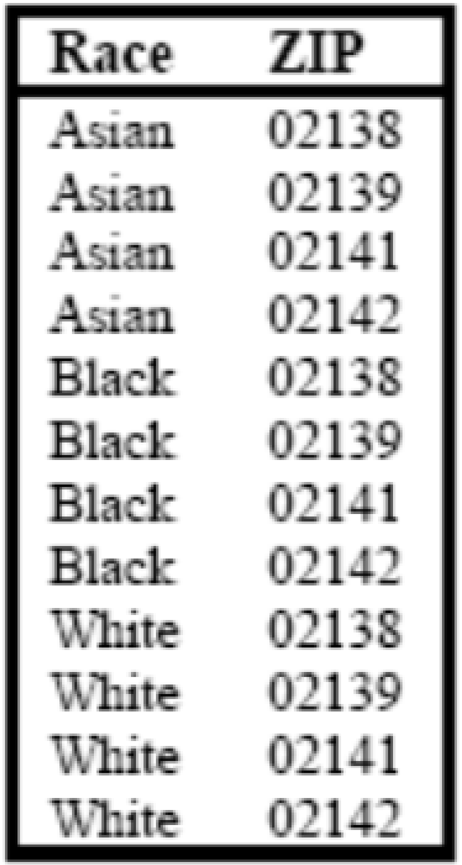
Generalized table

QID			SA
Zipcode	Age	Sex	Disease
476**	2*	*	Ovarian Cancer
476**	2*	*	Ovarian Cancer
476**	2*	*	Prostate Cancer
4790*	[43,52]	*	Flu
4790*	[43,52]	*	Heart Disease
4790*	[43,52]	*	Heart Disease

- Released table is 3-anonymous
- Alice’s quasi-identifier (47677, 29, F) does not reveal her disease

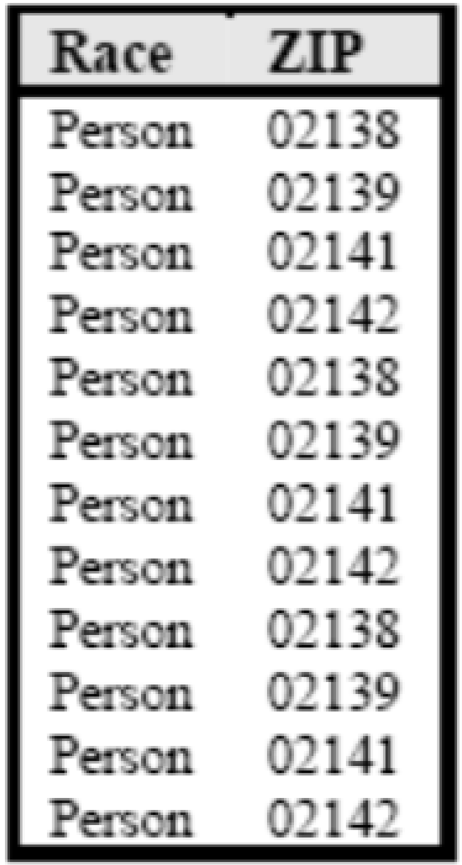
k-Anonymity (Sweeney and Samarati 98)

- Unsorted matching attack
- Records appear in the same order as in the original table
- Solution: randomize order before releasing



Race	ZIP
Asian	02138
Asian	02139
Asian	02141
Asian	02142
Black	02138
Black	02139
Black	02141
Black	02142
White	02138
White	02139
White	02141
White	02142

PT



Race	ZIP
Person	02138
Person	02139
Person	02141
Person	02142
Person	02138
Person	02139
Person	02141
Person	02142
Person	02138
Person	02139
Person	02141
Person	02142

GT1

https://epic.org/privacy/reidentification/Sweeney_Article.pdf

Quiz: what does k-Anonymity provide

- Membership discloser:
  attacker cannot tell that a given person is in the dataset
- Sensitive attribute discloser:
  attacker cannot tell that a given person has a certain sensitive attribute
- Identity discloser:
  attacker cannot tell which record corresponds to which person

Quiz: what does k-Anonymity provide

- Membership discloser:
  attacker cannot tell that a given person is in the dataset
- Sensitive attribute discloser:
  attacker cannot tell that a given person has a certain sensitive attribute
- Identity discloser:
  attacker cannot tell which record corresponds to which person

This interpretation is correct,
assuming the attacker does not know anything other than quasi-identifiers

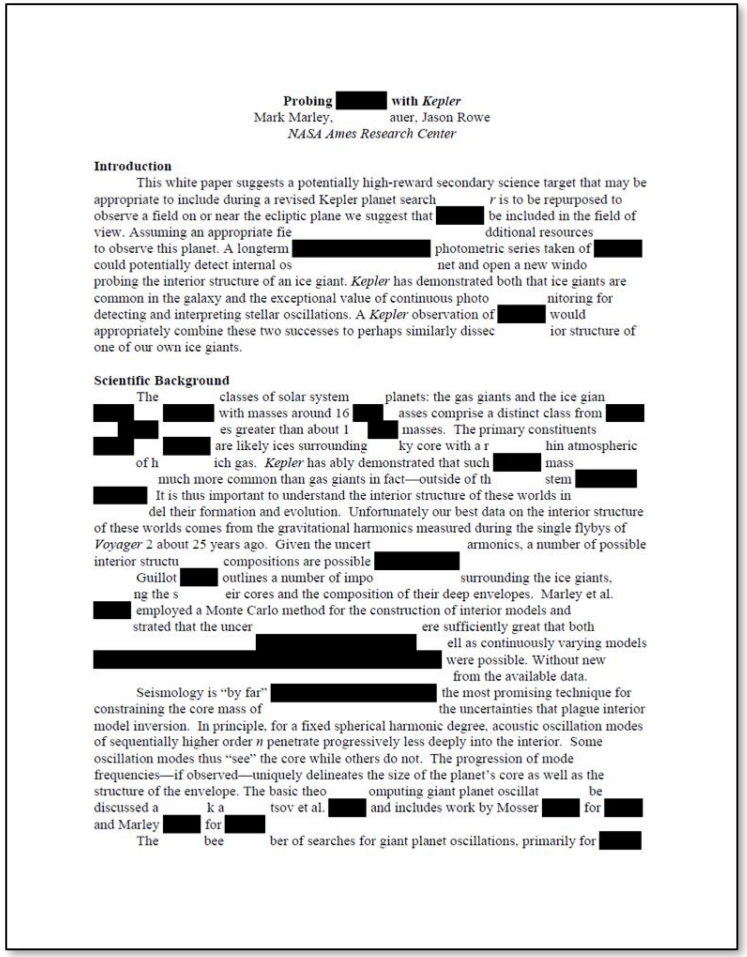
A chain of measures and counter measures

- k-anonymity [Sweeney and Samarati 98]
- Attacks against k-anonymity [Machanavajjhala et al. 06]
  Proposed L-diversity
- Attacks against L-diversity [Xiao and Tao 07]
  Proposed M-invariance
- Proposed T-closeness [Li et al. 07]

- Attacks against all the above [Ganta, Kasiviswanathan, Smith 08]

Popular idea #2

- Information not explicitly given cannot be harmful
- E.g., redaction



Probing [redacted] with *Kepler*
Mark Marley, auer, Jason Rowe
NASA Ames Research Center

Introduction

This white paper suggests a potentially high-reward secondary science target that may be
appropriate to include during a revised Kepler planet search *r* is to be repurposed to
observe a field on or near the ecliptic plane we suggest that [redacted] be included in the field of
view. Assuming an appropriate fie dditional resources
to observe this planet. A longterm [redacted] photometric series taken of [redacted]
could potentially detect internal os net and open a new windo
probing the interior structure of an ice giant. *Kepler* has demonstrated both that ice giants are
common in the galaxy and the exceptional value of continuous photo nitoring for
detecting and interpreting stellar oscillations. A *Kepler* observation of [redacted] would
appropriately combine these two successes to perhaps similarly dissec ior structure of
one of our own ice giants.

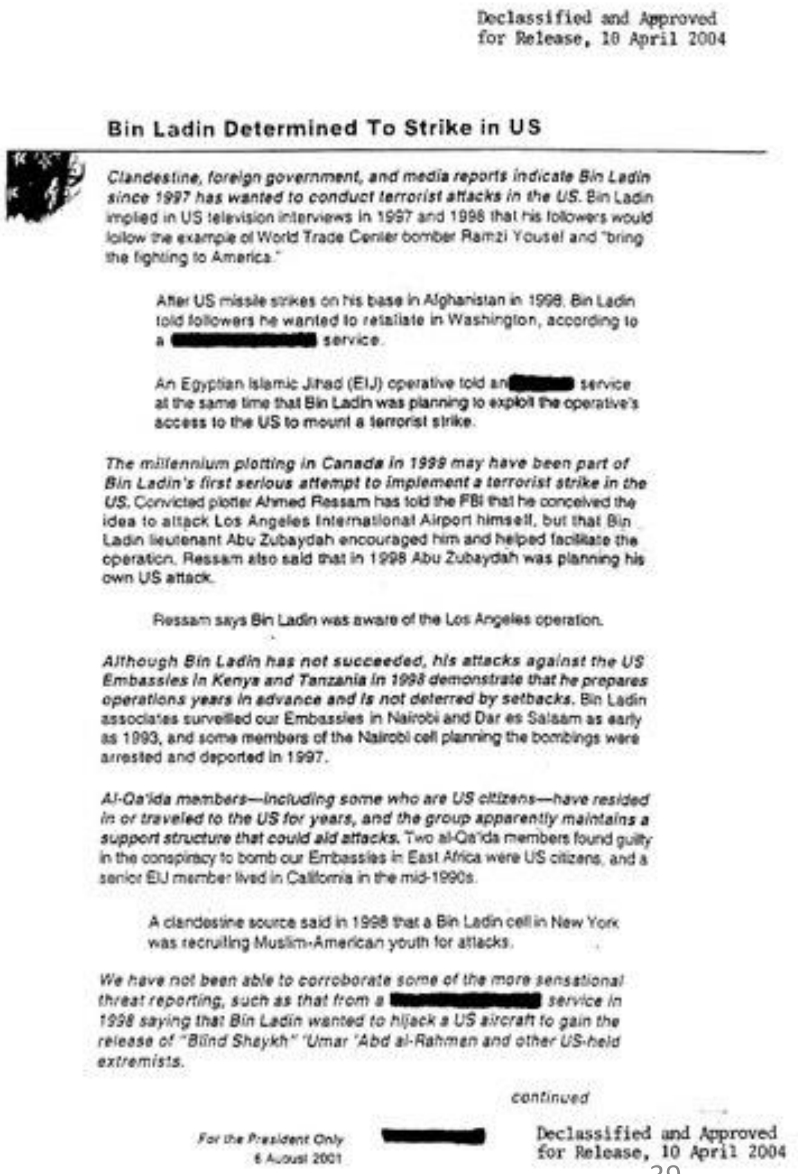
Scientific Background

The classes of solar system planets: the gas giants and the ice gian
[redacted] [redacted] with masses around 16 [redacted] asses comprise a distinct class from [redacted]
es greater than about 1 masses. The primary constituents
[redacted] are likely ices surrounding ky core with a r hin atmospheric
of h ich gas. *Kepler* has ably demonstrated that such [redacted] mass
much more common than gas giants in fact—outside of th stem [redacted]
[redacted] It is thus important to understand the interior structure of these worlds in
del their formation and evolution. Unfortunately our best data on the interior structure
of these worlds comes from the gravitational harmonics measured during the single flybys of
Voyager 2 about 25 years ago. Given the uncert armonics, a number of possible
interior structu compositions are possible [redacted]
Guillot [redacted] outlines a number of impo surrounding the ice giants,
ng the s eir cores and the composition of their deep envelopes. Marley et al.
[redacted] employed a Monte Carlo method for the construction of interior models and
strated that the uncer ere sufficiently great that both
[redacted] ell as continuously varying models
were possible. Without new
from the available data.

Seismology is "by far" [redacted] the most promising technique for
constraining the core mass of the uncertainties that plague interior
model inversion. In principle, for a fixed spherical harmonic degree, acoustic oscillation modes
of sequentially higher order *n* penetrate progressively less deeply into the interior. Some
oscillation modes thus "see" the core while others do not. The progression of mode
frequencies—if observed—uniquely delineates the size of the planet's core as well as the
structure of the envelope. The basic theo omputing giant planet oscillat be
discussed a k a tsov et al. [redacted] and includes work by Mosser [redacted] for [redacted]
and Marley [redacted] for [redacted]
The bee ber of searches for giant planet oscillations, primarily for [redacted]

Popular idea #2

- The President's Daily Brief (PDB) is a top-secret document given each morning to the US president
- August 6th, 2001 George W. Bush received a PDB Bin Laden and El Qaeda are planning to strike in the US
- Declassified and released to the 9/11 Commission in 2004



Declassified and Approved
for Release, 10 April 2004

Bin Ladin Determined To Strike in US

[redacted]

Clandestine, foreign government, and media reports indicate Bin Ladin since 1997 has wanted to conduct terrorist attacks in the US. Bin Ladin implied in US television interviews in 1997 and 1998 that his followers would follow the example of World Trade Center bomber Ramzi Yousef and "bring the fighting to America."

> After US missile strikes on his base in Afghanistan in 1998, Bin Ladin told followers he wanted to retaliate in Washington, according to a [redacted] service.
>
> An Egyptian Islamic Jihad (EIJ) operative told an [redacted] service at the same time that Bin Ladin was planning to exploit the operative's access to the US to mount a terrorist strike.

The millennium plotting in Canada in 1999 may have been part of Bin Ladin's first serious attempt to implement a terrorist strike in the US. Convicted plotter Ahmed Ressam has told the FBI that he conceived the idea to attack Los Angeles International Airport himself, but that Bin Ladin lieutenant Abu Zubaydah encouraged him and helped facilitate the operation. Ressam also said that in 1998 Abu Zubaydah was planning his own US attack.

> Ressam says Bin Ladin was aware of the Los Angeles operation.

Although Bin Ladin has not succeeded, his attacks against the US Embassies in Kenya and Tanzania in 1998 demonstrate that he prepares operations years in advance and is not deterred by setbacks. Bin Ladin associates surveilled our Embassies in Nairobi and Dar es Salaam as early as 1993, and some members of the Nairobi cell planning the bombings were arrested and deported in 1997.

Al-Qa'ida members—including some who are US citizens—have resided in or traveled to the US for years, and the group apparently maintains a support structure that could aid attacks. Two al-Qa'ida members found guilty in the conspiracy to bomb our Embassies in East Africa were US citizens, and a senior EIJ member lived in California in the mid-1990s.

> A clandestine source said in 1998 that a Bin Ladin cell in New York was recruiting Muslim-American youth for attacks.

We have not been able to corroborate some of the more sensational threat reporting, such as that from a [redacted] service in 1998 saying that Bin Ladin wanted to hijack a US aircraft to gain the release of "Blind Shaykh" 'Umar 'Abd al-Rahman and other US-held extremists.

continued

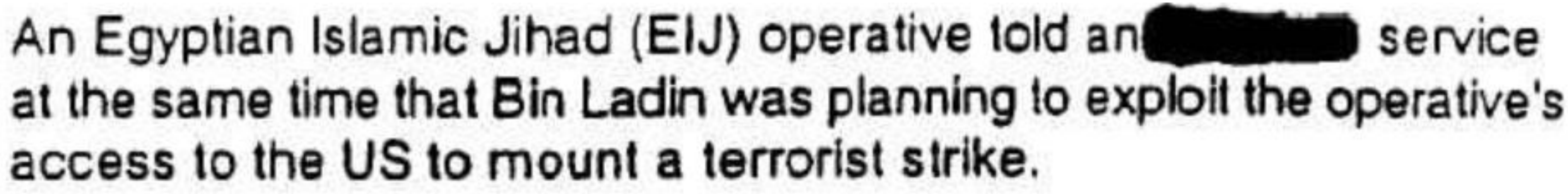
For the President Only
6 August 2001

[redacted]

Declassified and Approved
for Release, 10 April 2004

Popular idea #2

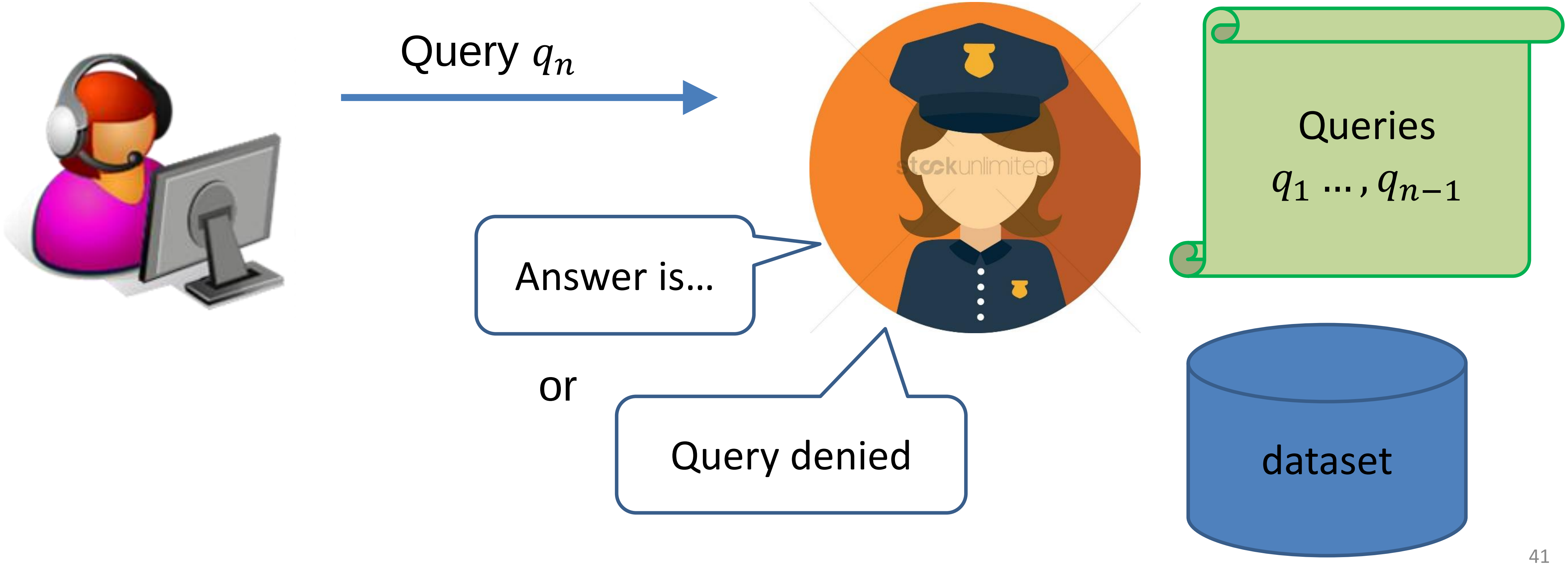
- Naccache and Whelan analyzed the geometry of the font
- 1530 plausible words
- The “an” reduced to 7 candidates: Ukrainian, uninvited, unofficial, incursive, Egyptian, indebted and Ugandan
- Egyptian is the only one who made sense in the context



An Egyptian Islamic Jihad (EIJ) operative told an [redacted] service at the same time that Bin Ladin was planning to exploit the operative's access to the US to mount a terrorist strike.

Query auditing

- Refuse to answer queries that would compromise privacy



Query q_n

Answer is…

or

Query denied

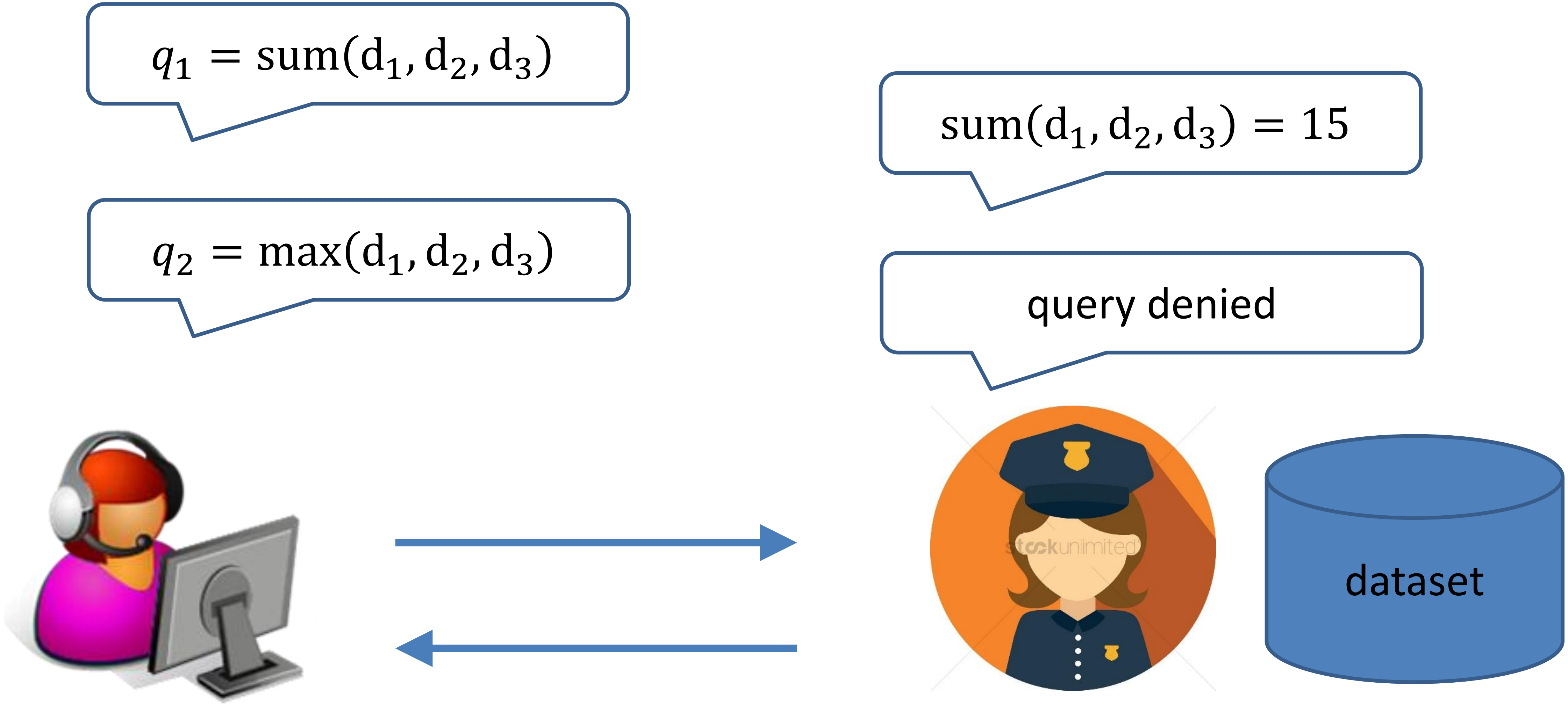
Queries

$q_1 \dots, q_{n-1}$

dataset

Example: sum/max auditing

- Sensitive info: d_i (real)



$q_1 = \mathrm{sum}(\mathrm{d}_1, \mathrm{d}_2, \mathrm{d}_3)$

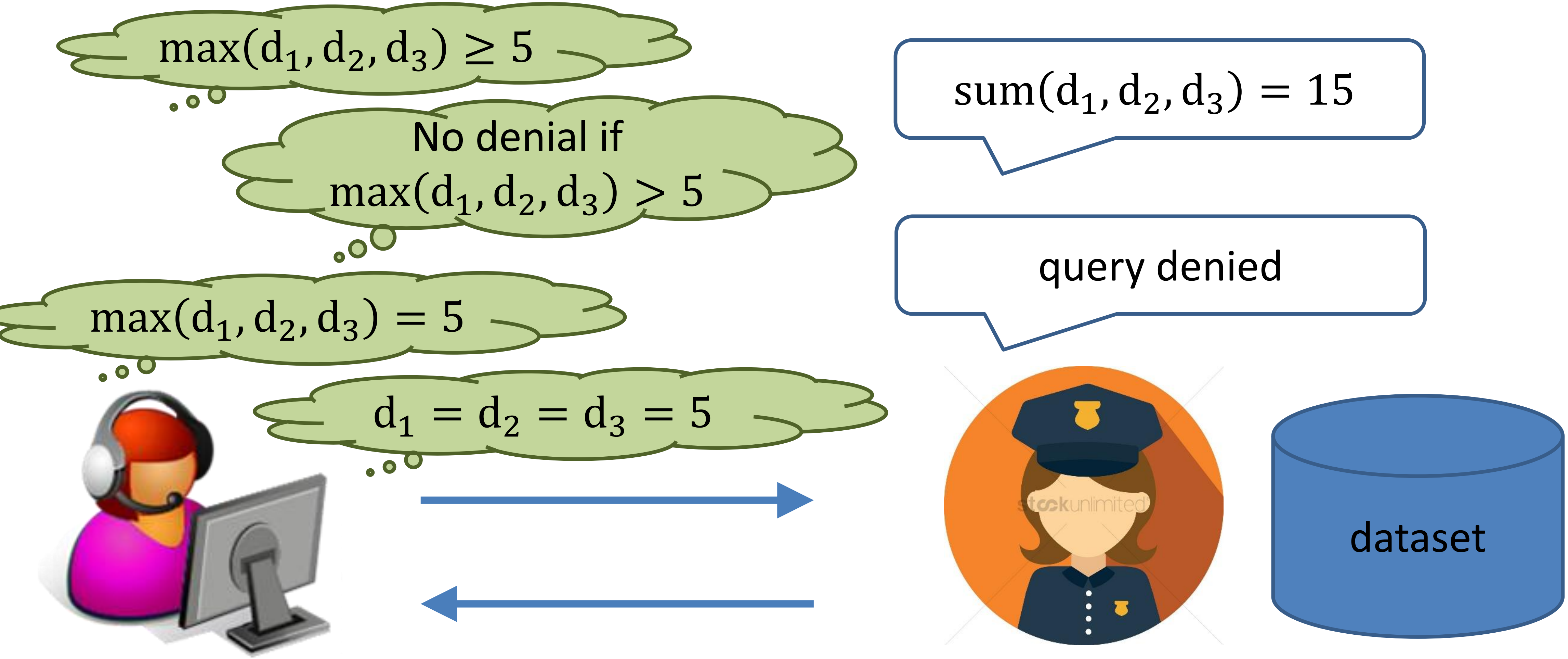
$q_2 = \max(\mathrm{d}_1, \mathrm{d}_2, \mathrm{d}_3)$

$\mathrm{sum}(\mathrm{d}_1, \mathrm{d}_2, \mathrm{d}_3) = 15$

query denied

Example: sum/max auditing

- Sensitive info: d_i (real)



$\max(\mathrm{d}_1, \mathrm{d}_2, \mathrm{d}_3) \geq 5$

No denial if $\max(\mathrm{d}_1, \mathrm{d}_2, \mathrm{d}_3) > 5$

$\max(\mathrm{d}_1, \mathrm{d}_2, \mathrm{d}_3) = 5$

$\mathrm{d}_1 = \mathrm{d}_2 = \mathrm{d}_3 = 5$

$\mathrm{sum}(\mathrm{d}_1, \mathrm{d}_2, \mathrm{d}_3) = 15$

query denied

dataset

Popular idea #3: add noise

- Mask numbers by adding a random number between $[-a, a]$
  - Privacy $2a@100\%$ confidence, Privacy $a@50\%$ confidence, …
- The larger the interval the better the privacy
- Example:
  - For each person mask the age by adding a random number between $[-100,100]$
  - Gives privacy 200@100% confidence
  - But, masked age -99 ⇒ a baby of age 0 or 1

So far

- Many ideas fall short of providing data privacy
- Auxiliary information
- Data itself may leak information
- Sparse dataset cannot be anonymized
- Privacy is more than re-identifying

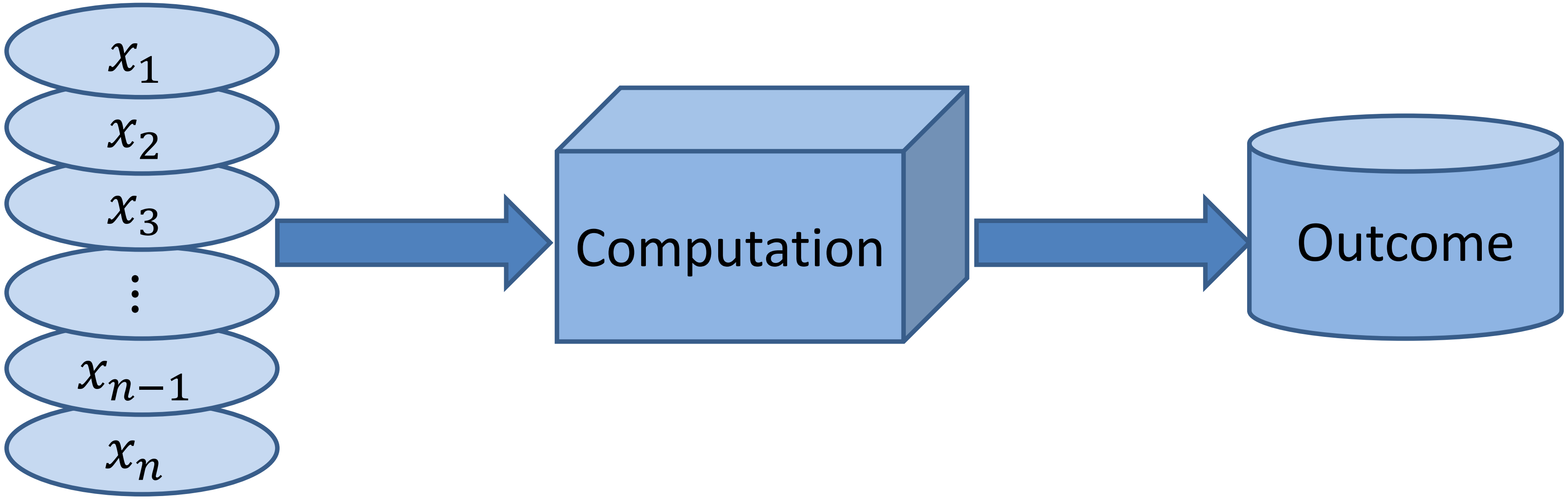
Outline

- Popular ideas that do not work
  + privacy horror stories

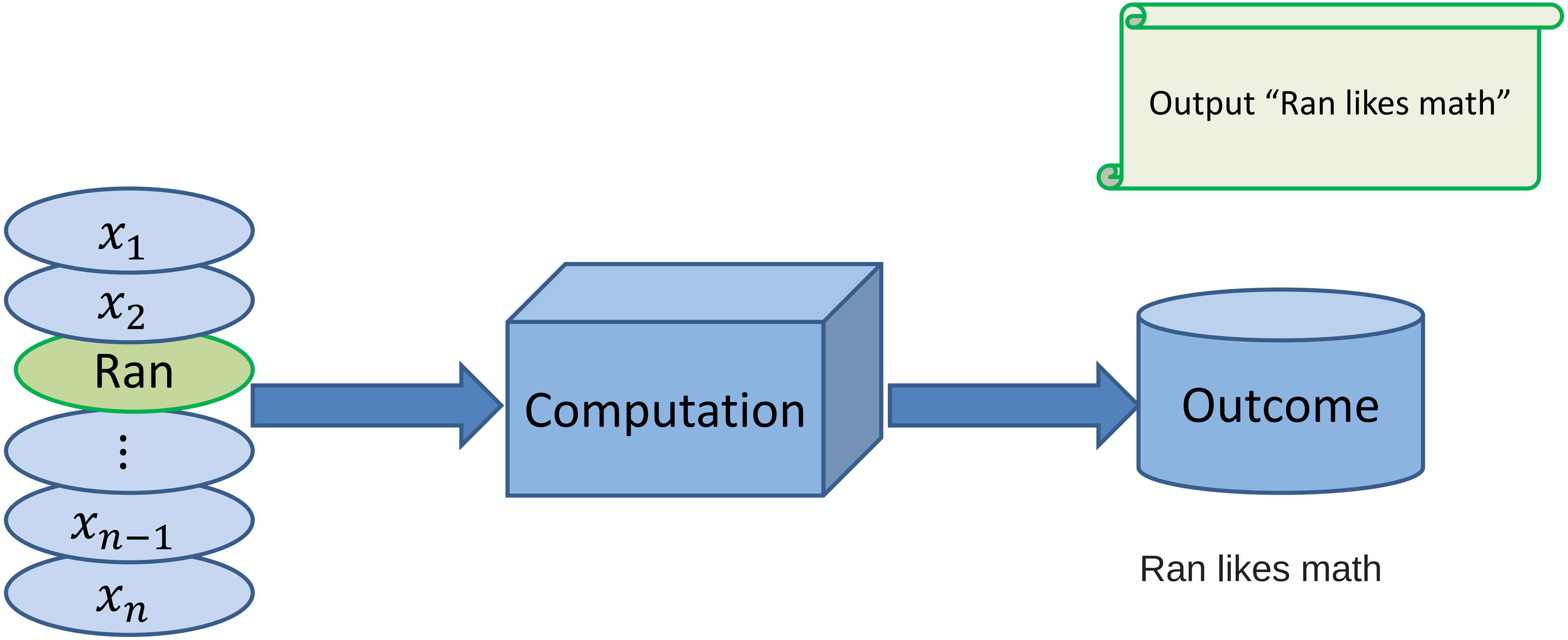
- An approach that works

What went wrong?

Privacy is NOT a property of the outcome but of the computation!!!



What went wrong?

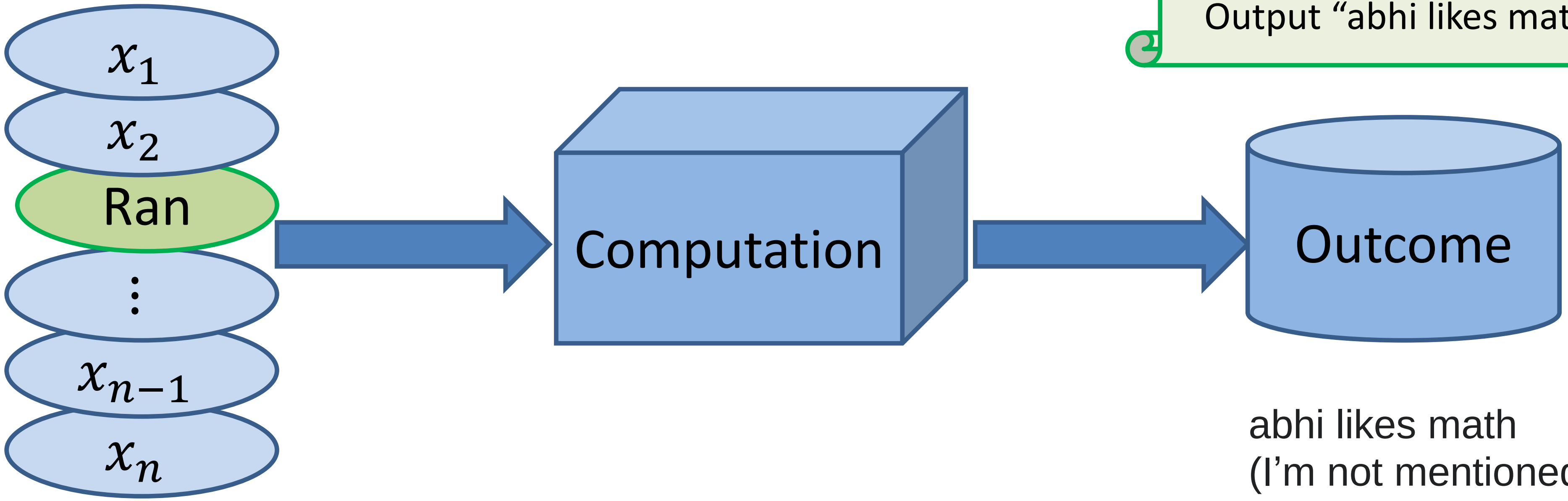


Ran likes math

Is my privacy breached? Yes / No / Cannot tell

What went wrong?

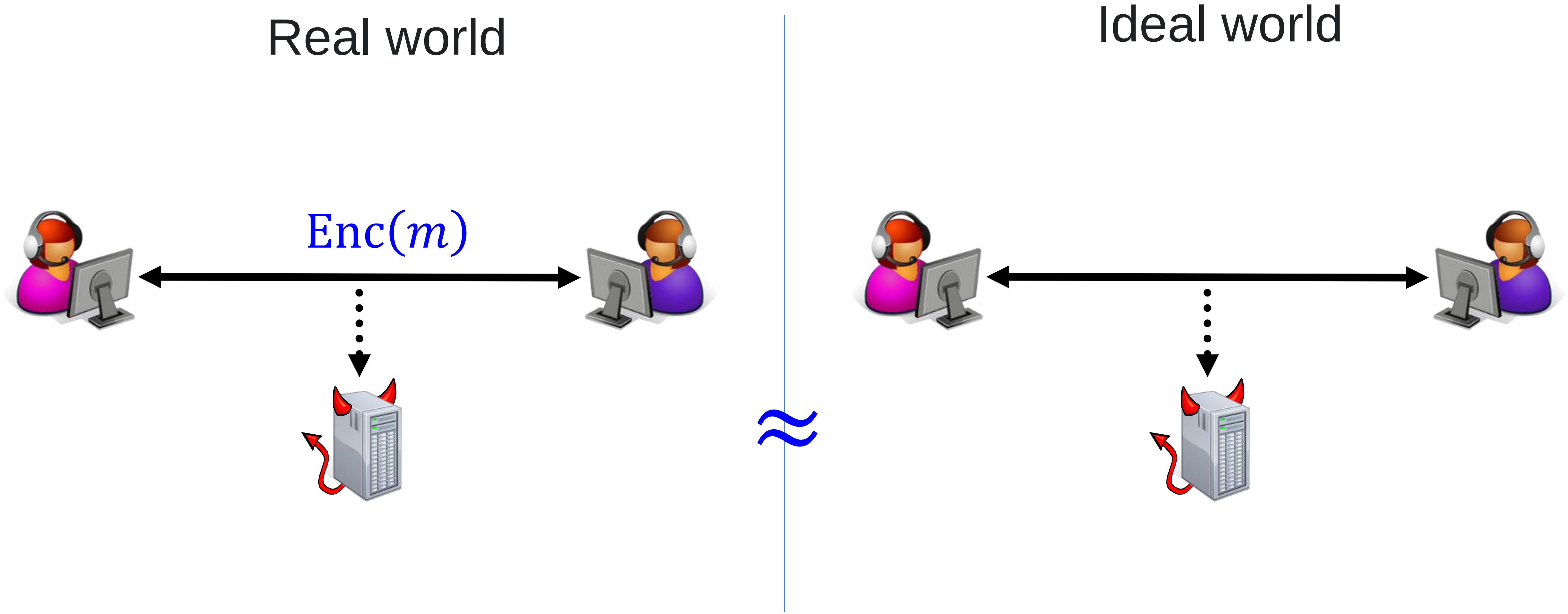
```
If likeMath(Ran)
  Output “Ran likes math”
Else
   Output “abhi likes math”
```



abhi likes math
(I’m not mentioned)

Is my privacy breached? Yes / No / Cannot tell

Recall sematic security



Real world

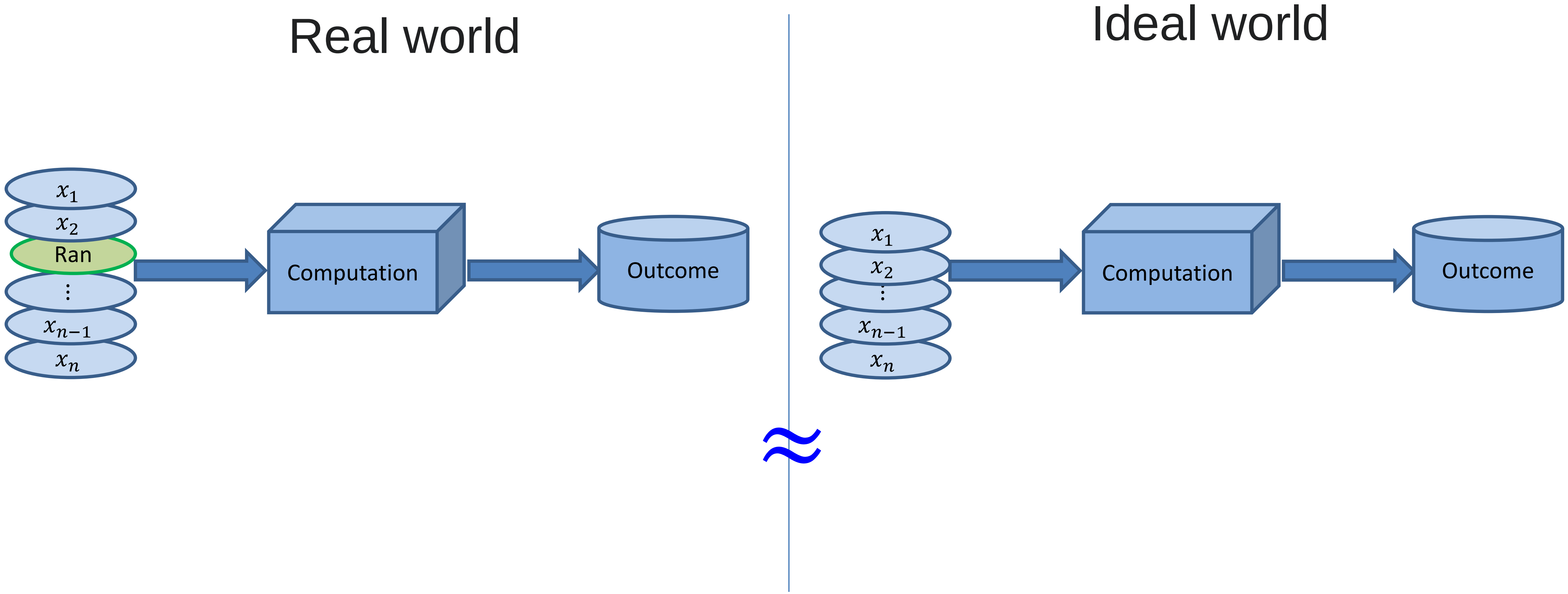
Ideal world

$\mathrm{Enc}(m)$

$\approx$

An encryption scheme is semantically secure if whatever can be learned given the ciphertext can be learned without the ciphertext

Privacy analogue



A computation is “private” if whatever can be learned with my record in the DB can be learned without my record

Differential Privacy
[Dwork, McSherry, Nissim, Smith 2006]

A mechanism / algorithm / computation M has **ε-differential privacy** if for any pair of neighboring databased D_1, D_2 (differing by 1 record) and for any $S \subseteq \mathrm{Range}(M)$

$$\Pr[M(D_1) \in S] \leq e^{\varepsilon} \cdot \Pr[M(D_2) \in S]$$

Differential Privacy

Adopted by:

- US census Bureau
- Google
- Apple
- YouTube
- Many more