Privacy-Enhancing Technologies

Module 1: General Background

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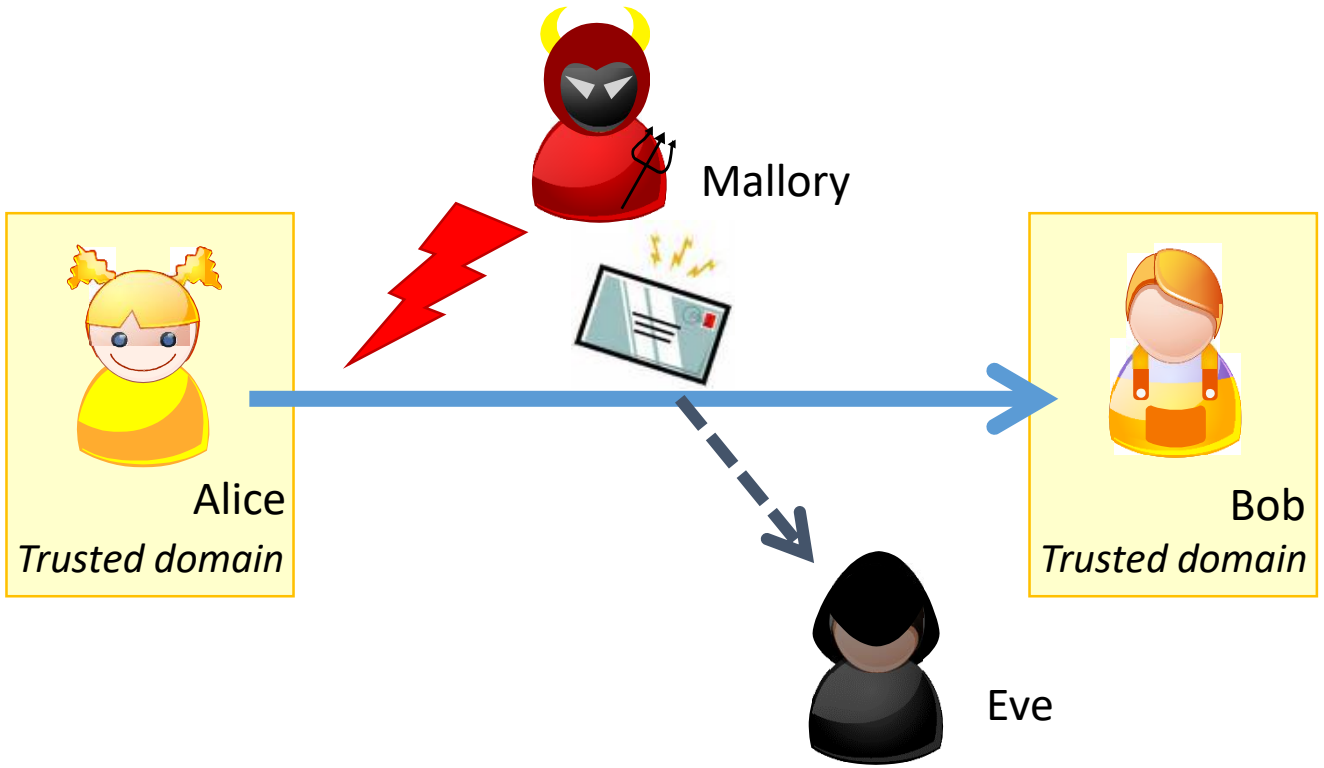
2.05.2022 – hybrid, KIT and TUD

Disclaimer: This lecture was prepared in cooperation with Patricia Arias-Cabarcos, Javier Parra-Arnau, and input from the people at the chair

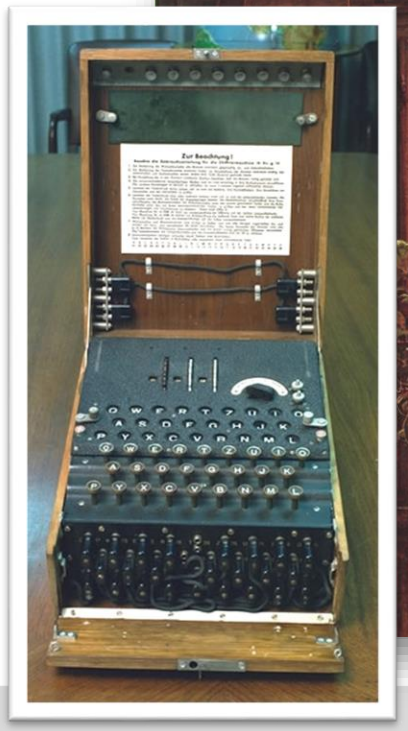
KASTEL Security Research Labs

The Classical Security View



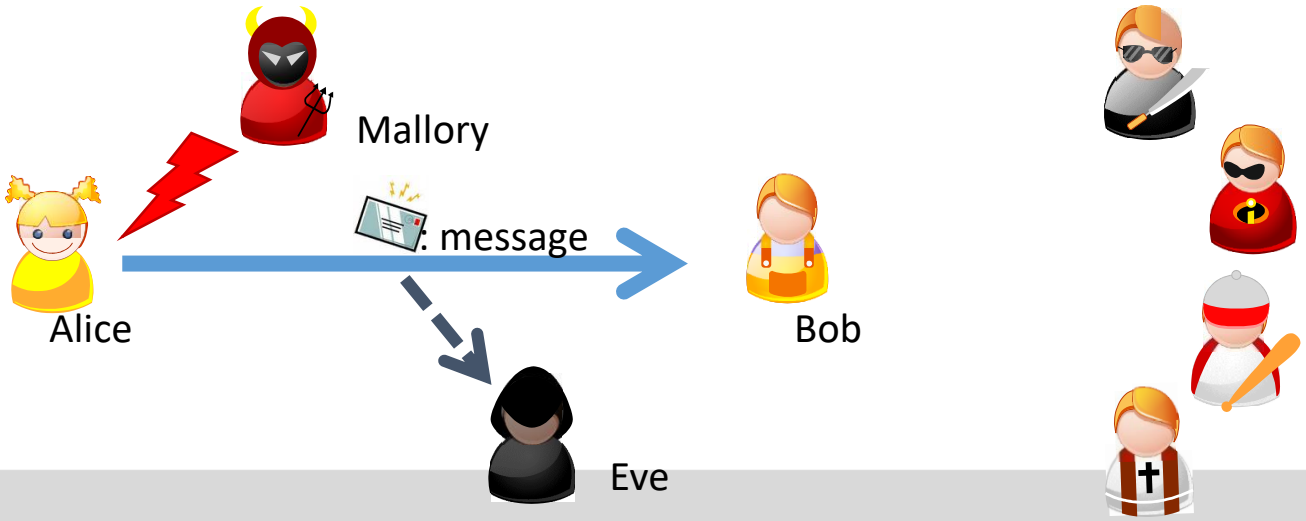
Threats!!

- Data loss
  - Data accessible to unintended parties
- Manipulation and forgery
  - Tampered, spoofed data



Classical *Security Goals* and *Adversaries*

- ***Confidentiality***
  - Data transmitted or stored should only be revealed to the intended audience
- ***Integrity***
  - Modification of data is detected (identify source, first!)
- ***Availability***
  - Services should function correctly upon request



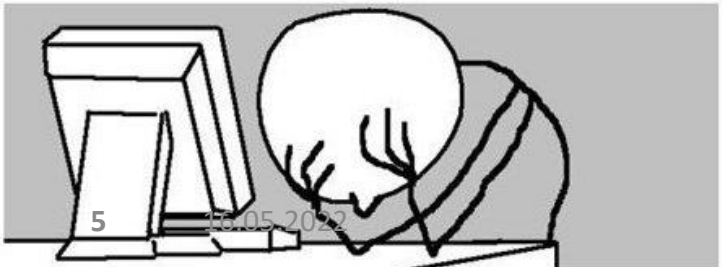
SUBSCRIBE

MIKE MCQUADE

ANDY GREENBERG SECURITY 08.22.2018 05:00 AM

The Untold Story of NotPetya, the Most Devastating Cyberattack in History

Crippled ports. Paralyzed corporations. Frozen government agencies. How a single piece of code crashed the world.



2014 - Mozilla Firefox

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Kickstarter

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Yahoo says all three billion accounts hacked in 2013 data theft - Mozilla Firefox

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Yahoo says all three billion accoun

https://www.reuters.com/article

Discover Thomson Reuters

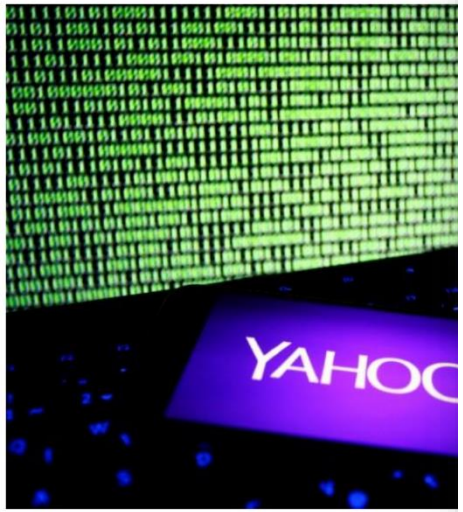
REUTERS

Yahoo says all three billi
in 2013 data theft

#BUSINESS NEWS OCTOBER 3, 2017 / 10:57 PM / UPDATED 14 HOURS AGO

Yahoo says all three billion hacked in 2013 data theft

Jonathan Stempel, Jim Finkle



A photo illustration shows a Yahoo logo on a smartphone in front of a display
code and keyboard on December 15, 2016. REUTERS/Dado Ruvic/Illustration

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Hacking

DDoS attack that disrupted internet was largest of its kind in history, experts say

Dyn, the victim of last week's denial of service attack, said it was orchestrated using a weapon called the Mirai botnet as the 'primary source of malicious attack'

- Major cyber attack disrupts internet service across Europe and US

Nicky Woolf *in San Fran*

@nickywoolf

Wed 26 Oct 2016 21.42 BST

The cyber-attack that b
caused by a new weapo
in history, experts said

The victim was the ser

So… Privacy?

Digital Dystopias

“With the development of television, and the technical advance which made it possible to receive and transmit simultaneously on the same instrument, private life came to an end.”

George Orwell, “1984”, 1948

Privacy – Dictionary Definition

pri·va·cy | \ ˈprī-və-sē , especially British ˈpri- \ plural privacies

Definition of privacy

1

a) a : the quality or state of being apart from company or observation : seclusion

b) freedom from unauthorized intrusion <one's right to privacy>

2

- archaic : a place of seclusion

3

a) Secrecy

b) a private matter : secret

From Merriam Webster Online Dictionary

- ***Social and legal aspect***
  - *a hard to define social concept:*
    - *social scientists, philosophers and lawyers*
- ***Privacy is somewhat subjective***
  - *Understanding is a cultural construct*
  - *Changes between different societies*
    - *no precise and universal definition*

Notions of Privacy: Right to be let alone

- Samuel Warren, Louis Brandeis: "**The Right to Privacy**", Harvard Law Review, Vol. IV, No. 5, 15th December **1890**

- **Reason:** "snapshot photography" (recent innovation at that time)
  - allowed newspapers to publish photographs of individuals without obtaining their consent.
  - private individuals were being continually injured
  - this practice weakened the "moral standards of society as a whole"

- **Consideration:**
  - basic principle of common law: individual shall have full protection in person and in property
  - "it has been found necessary from time to time to define anew the exact nature and extent of such protection"
  - "Political, social, and economic changes entail the recognition of new rights"

- **Conclusion:**
  - "**right to be let alone**"

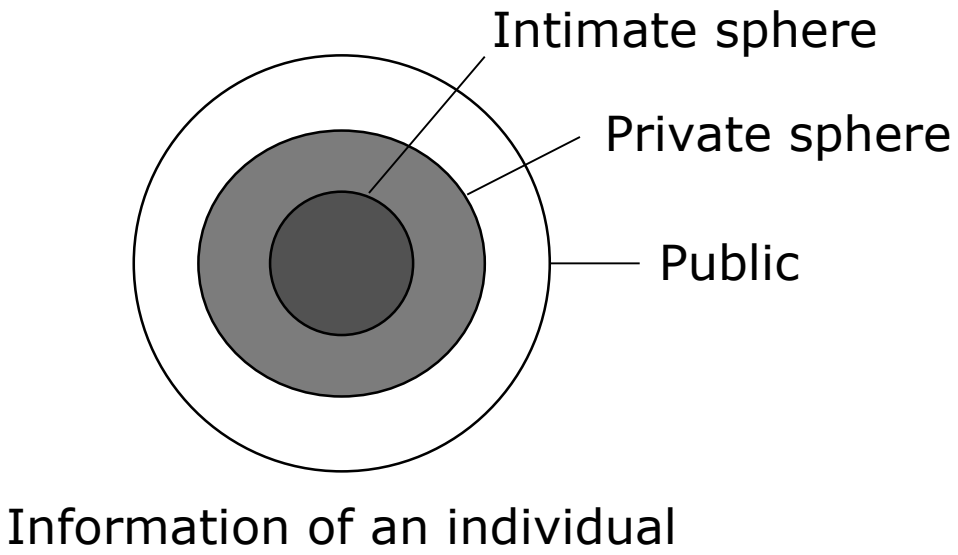
Privacy in CS and Engineering?

„the claim of individuals … to determine for themselves when, how, and what extent of information about them is communicated to others.“

-- Alan Westin (1967)

Modelling Privacy: Spheres

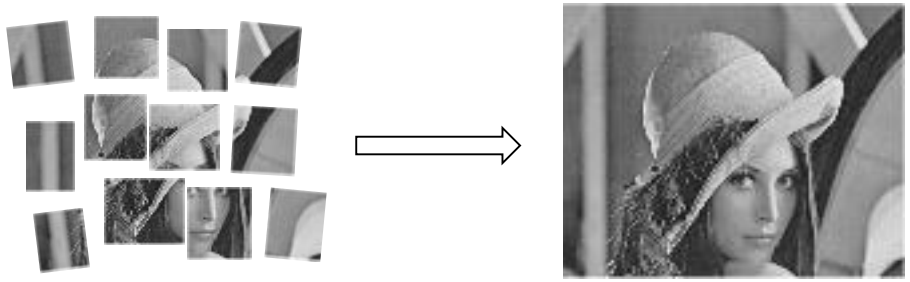
- Modelling protection requirements (expectations) of classes of information as concentric circles of decreasing need for protection



- Assign data to corresponding spheres
- Assignment may depend on context and situation…

Modelling Privacy: The Human Mosaic

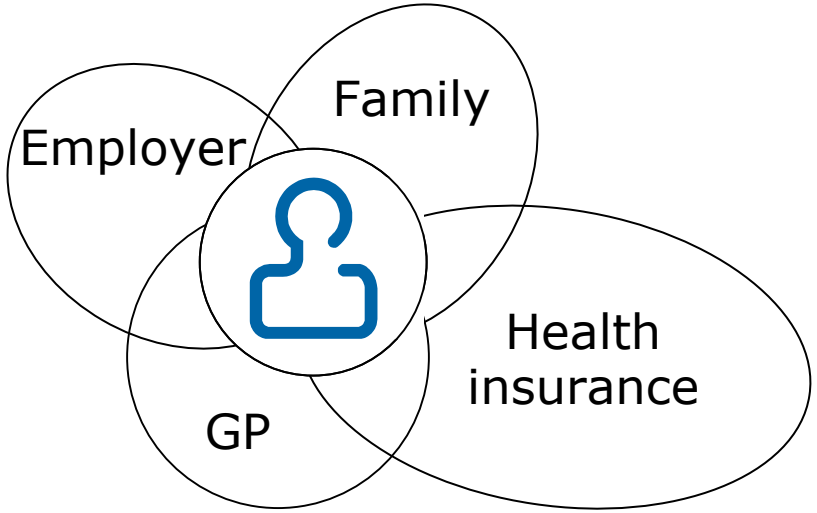
- Small snippets of information (probably) don‘t expose a human
- Loss (and aggregation) of several snippets lead to a mosaic of the individual
- Increasing aggregation of puzzle pieces increases detail of knowledge on the individual



- Management of pieces that initially are not considered „intimate“ possible
- Independence of the way data is lost (or: collected)
- Does not simplify determining criticality of pieces
- Considers data capture/collection, but also further data processing

Modelling Privacy: The Human in Roles

- Humans act in roles depending on their situation
- Usually specific information required to achieve certain task



- Group shared information according to context
- Personas, various levels of sensitivity

- Individual images to be restrained to context
- Transfer through 3rd parties may cause unknown leaks

Notions of Privacy: Contextual Integrity

- Helen Nissenbaum: *Privacy as Contextual Integrity*, 2004
- Idea that data is shared with specific mind set in specific context

- Two types of violation of expected privacy:
  - violation of **Appropriateness of Revelation**
    - the context „defines“ if revealing a given information is appropriate
    - **violation:** information disclosed in one context (even “public”) may not be appropriate in another (Asking a person participating in a gay pride vs. the same participating in a governmental press conference)
  - violation of **Distribution**
    - the context „defines“ which information flows are appropriate
    - **violation:** inappropriate information flows between spheres, or contexts; information disclosed in one context used in another (telling, even if first context was “public”)

Collateral Development: Ethics in Research

- Ahnenerbe Society, Head of Institute for Military Scientific Research (*Institut für Wehrwissenschaftliche Zweckforschung),* lead by Wolfram Sievers organizes human experiments

- Nuremberg Doctor‘s Trials
  - 20 Doctors, Sievers and 2 other Nazi officials
  - Led to 7 executions, 7 defendants acquitted

- Nuremberg Code (1947)
- Declaration of Helsinki (1964)
- Belmont Report (1978)

- Excerpt from ***Nuremberg code***:

1. Required is the ***voluntary, well-informed, understanding consent*** of the human subject in a full legal capacity.
2. The experiment should ***aim at positive results for society*** that cannot be procured in some other way.
3. It should be ***based on previous knowledge*** (like, an expectation derived from animal experiments) that justifies the experiment.
4. The experiment should be set up in a way that ***avoids unnecessary*** physical and mental ***suffering and injuries***.
5. It ***should not be conducted*** when there is any reason to believe that it implies a risk of death or disabling injury.
6. The ***risks of the experiment*** should be in proportion to (that is, not exceed) the expected ***humanitarian benefits***.

https://encyclopedia.ushmm.org/content/en/film/medical-case-us-prosecutor-details-illegal-experiments

Legal Foundations *(IANAL)*

- UDHR Art. 1: *„All human beings are born free and equal in dignity and rights. […]"*
  (Also: ECHR Art. 1, Art. 1 Grundgesetz)

- UDHR Art. 12: *„No one shall be subjected to arbitrary interference with his privacy, …"*
  (Also: ECHR Art. 8)

- Charter of Fundamental Rights (CFR) Art. 8:
  - *„1. Everyone has the right to the protection of personal data concerning him or her."*
  - *„2. Such data must be processed fairly for specified purposes and on the basis of the consent of the person concerned or some other legitimate basis laid down by law."*

- Important: ***Prohibition with reservation of authorization***
- Introduces concept of control through responsible institutions (data protection officer)
- Fundamental Law, historically protection from state, protection of minorities
- Regulation in Europe: General Data Protection Regulation (GDPR), US: per market, 4th Amdt.

Notions: Informational Self-Determination

- European Law based on ideas from the age of enlightenment:
  - freedom of choice and freedom to reinvent oneself
  - any citizen should be their own sovereign
- Service must not coerce disclosure
- Publishing/sharing free choice of citizen
- *Important underlying idea: the sovereign (self-determined) citizen **controls collection**, **use**, and can effectively **retract** even previously openly published data, upon change of mind*

- Based on principles of processing:
  - collect and process personal data **fairly and lawfully**
  - **purpose binding**
    - keep it only for one or more specified, explicit and lawful purposes
    - use and disclose it only in ways compatible with these purposes
  - **data minimization**
    - adequate, relevant and not excessive wrt. the purpose
    - retained no longer than necessary
  - **transparency**
    - inform who collects which data for which purposes
    - inform how the data is processed, stored, forwarded etc.
  - **user rights**
    - access to the data, correction, deletion
  - **keep the data safe and secure**

Informational self-determination in brief

"The claim of individuals, groups and institutions to
determine themselves,
when,
how and
to what extent
information about them
is communicated to others"

(GDPR: is processed)

EU Data Protection Directive (95/46/EC):

- "personal data" shall mean any information relating to an **identified or identifiable** natural person ('Data Subject');

*Privacy and Freedom: Westin 1967

Legalese: Personally Identifiable Information („PII“)

- ***US:*** *Name, address (Phone, Email), national identifiers (tax, passports), IP address, driving (vehicle registration, drivers licence), biometrics (face, fingerprints), credit card numbers, date/place of birth (age, login name(s), gender, "race", grades, salary, criminal records)*

- ***EU:*** *'personal data' means any information relating to an identified or identifiable natural person ('data subject'); an identifiable natural person is one who can be identified, directly or indirectly, in particular by reference to an identifier such as a name, an identification number, location data, an online identifier or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person;* [Art. 4, GDPR]

Which processing? „Anonymized“ (Pseudonyms)?

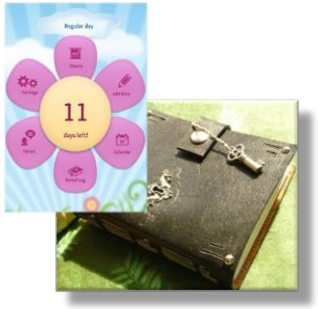
- *'processing' means **any operation** or set of operations which is performed on personal data or on sets of personal data, whether or not by automated means, such as **collection**, **recording**, organisation, structuring, storage, adaptation or alteration, retrieval, consultation, use, **disclosure by transmission**, dissemination or otherwise making available, alignment or combination, restriction, erasure or destruction;* [ebd]

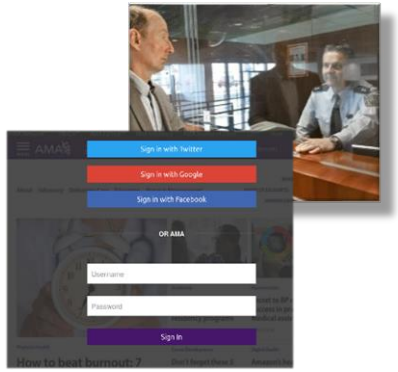
- GDPR’s take on ***pseudonymisation***:
- *'pseudonymisation' means the processing of personal data in such a manner that the personal data **can no longer be attributed to a specific data subject** without the use of **additional information**, provided that such additional information is kept separately and is subject to technical and organisational measures to ensure that the personal data are not attributed to an identified or identifiable natural person;* [ebd]

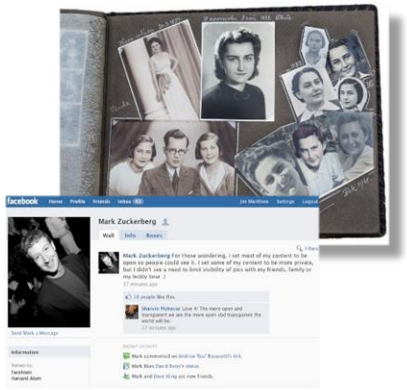
- ***Pseudonymous data can be linked back to individual, and it hence is considered PII!***

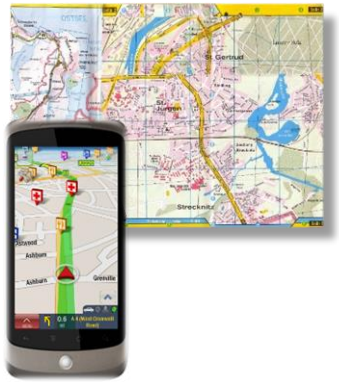
Why is this suddenly so relevant?

Humanity and Cultural Practices









#TactileInternet

ceti.one

Access: Type, Scope, and Trust

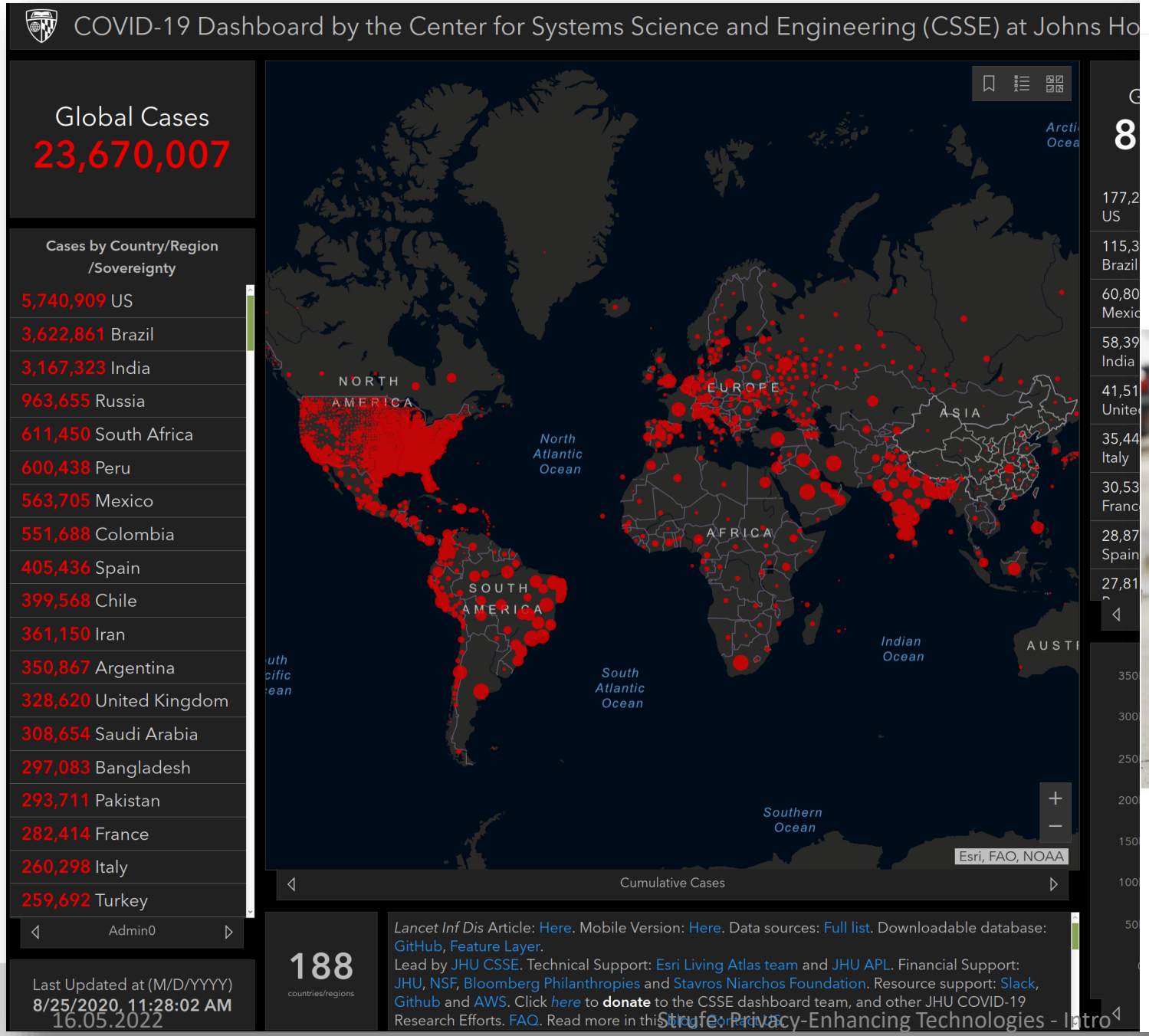
1: Personal, unidentified
2: Local, decentralized
3: Trust in direct peer (village)

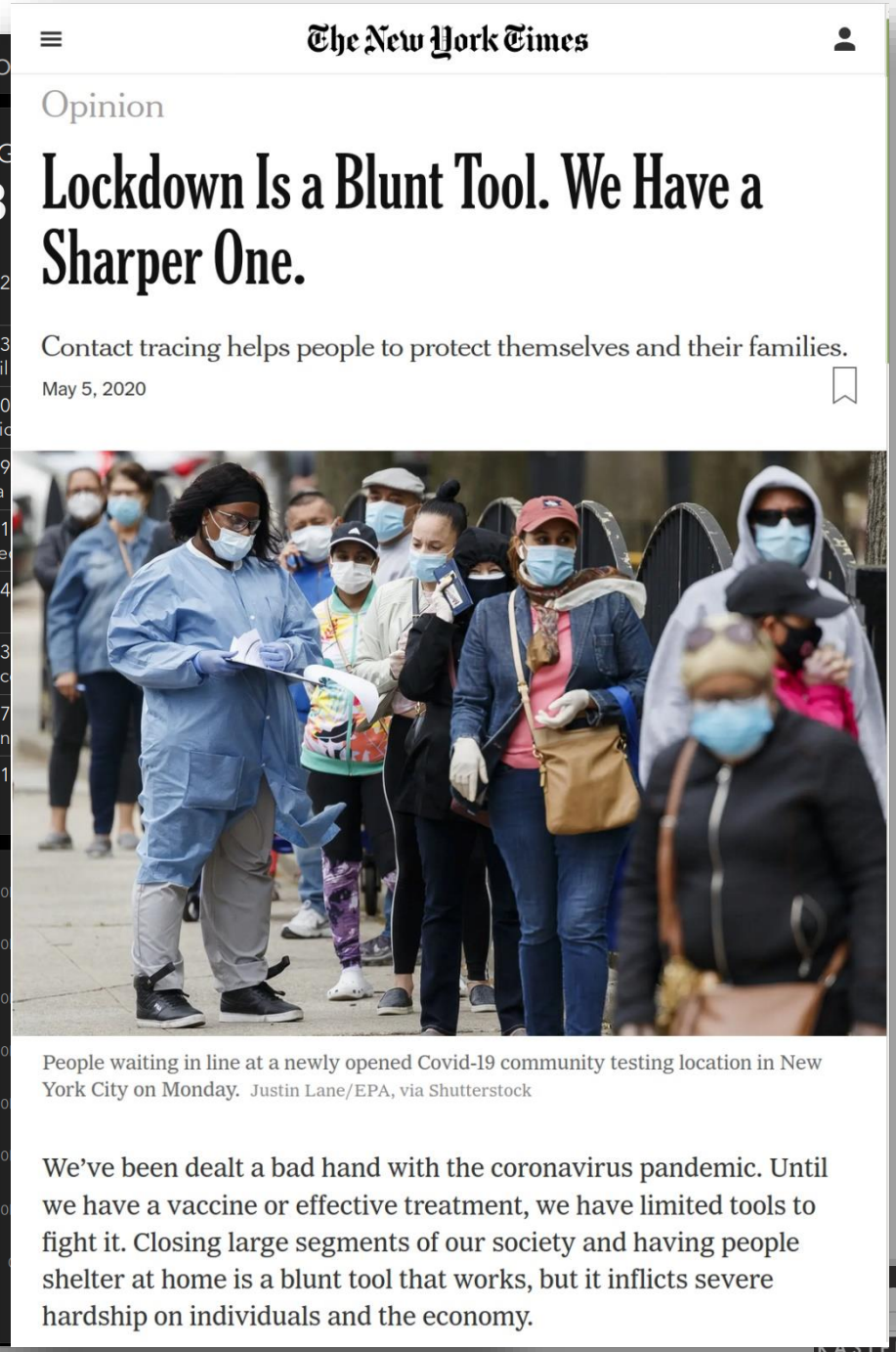
Access: Type, Scope, and Trust Today

1: Central, unique global login services
2: Global access over Internet
3: Trust in … (I)SP?

Recent Anecdotes from the Trenches…

Case Study: Corona Warn-Apps





The New York Times

Opinion

Lockdown Is a Blunt Tool. We Have a Sharper One.

Contact tracing helps people to protect themselves and their families.

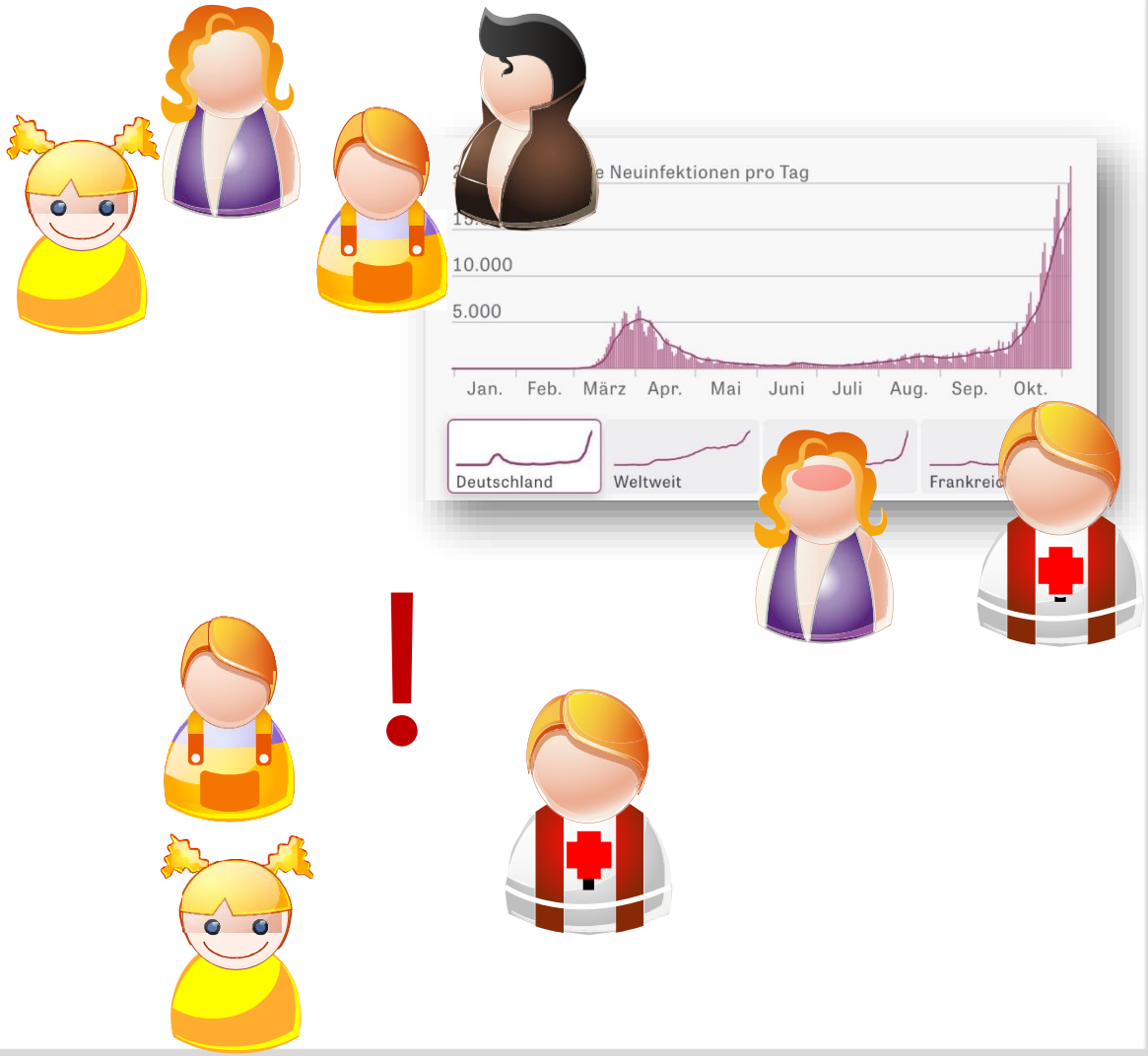
May 5, 2020

People waiting in line at a newly opened Covid-19 community testing location in New York City on Monday. Justin Lane/EPA, via Shutterstock

We've been dealt a bad hand with the coronavirus pandemic. Until we have a vaccine or effective treatment, we have limited tools to fight it. Closing large segments of our society and having people shelter at home is a blunt tool that works, but it inflicts severe hardship on individuals and the economy.

Surprisingly Difficult – Corona Warn Apps

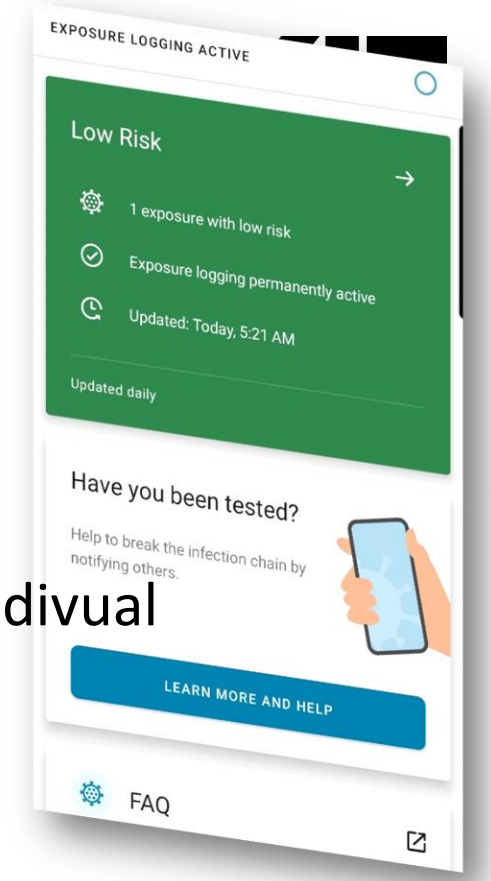
- Encounters of people at <2m distance leads to exposure risk
- Inform about risk in case of positive tests, to break infection chain



- Past: Ask who you met and call
- Now: Cell phones track encounters!

Corona Warn Apps – Overview

- Functionality:
  - Encounter logging
  - Infection reporting 1: Test positive report (verified)
  - *(implicit) match encounters with non-infected individuals*
  - Infection reporting 2 (risk notification): Inform potentially infected indivual

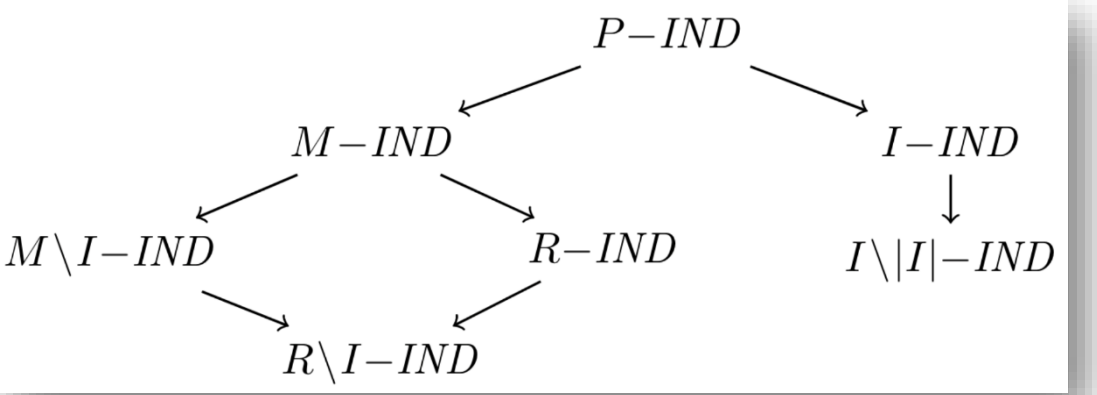


- Necessary data:
  - (Co-)locations
  - (infection risk factor)
  - Infection (verified)

Corona Warn Apps – Privacy Risks/Covid Notions

- ***Location*** (@time) of individuals (Beach, not the lecture)
  - Potentially linkable -> tracking
- ***Social network*** of individuals (Who meets and mingles)
- ***Stigmatization***
  - Infection of an individual
  - Frequencies/fractions of infections in populations

- Architectural Roles
  - Users (phones)
  - Servers (yes, there are always servers)
- Conclusions about
  - Colocated others/3rd parties?
  - Infected/non-infected individuals?
- *Model as Indistinguishability game*



Kuhn '20 Covid Notions (https://arxiv.org/pdf/2004.07723.pdf)

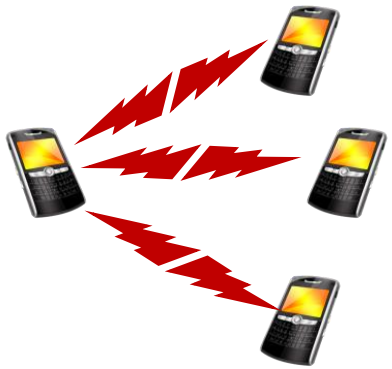
So where again is the Difference?

- Alternative narratives:
  - Trusted authorities, untrusted others
  - Trusted users, untrusted central party

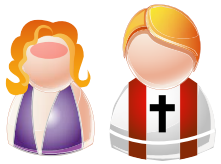
- Recall functions:
  1. Encounter logging
  2. Infection reporting 1 (positive test)
  3. Contact matching
  4. Infection reporting 2 (risk notification)

- In what follows: The European („Privacy Preserving“) perspective

1. BLE broadcast shortlived pseudonym



Infection Reporting („Centralized“/“Decentralized“)



„Centralized“

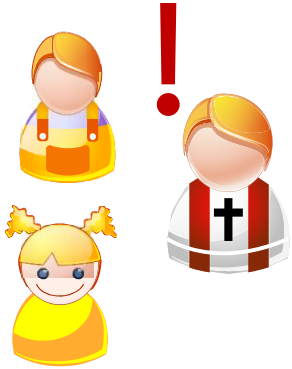
- Infection reporting 1:

„Pseudonyms that have been colocated with an infected individual are: RPI_a, RPI_b, RPI_c,…“

- Infection reporting 2:

„Has someone reported colocation with RPI,…?“

„yes|no“



„Decentralized“

- Infection reporting 1:

„I am infected, my pseudonyms are: RPI_a, RPI_b, RPI_c,…“

- Matching and infection reporting 2:

„Tell me who‘s infected“

„RPI_a, RPI_b, RPI_c,…“

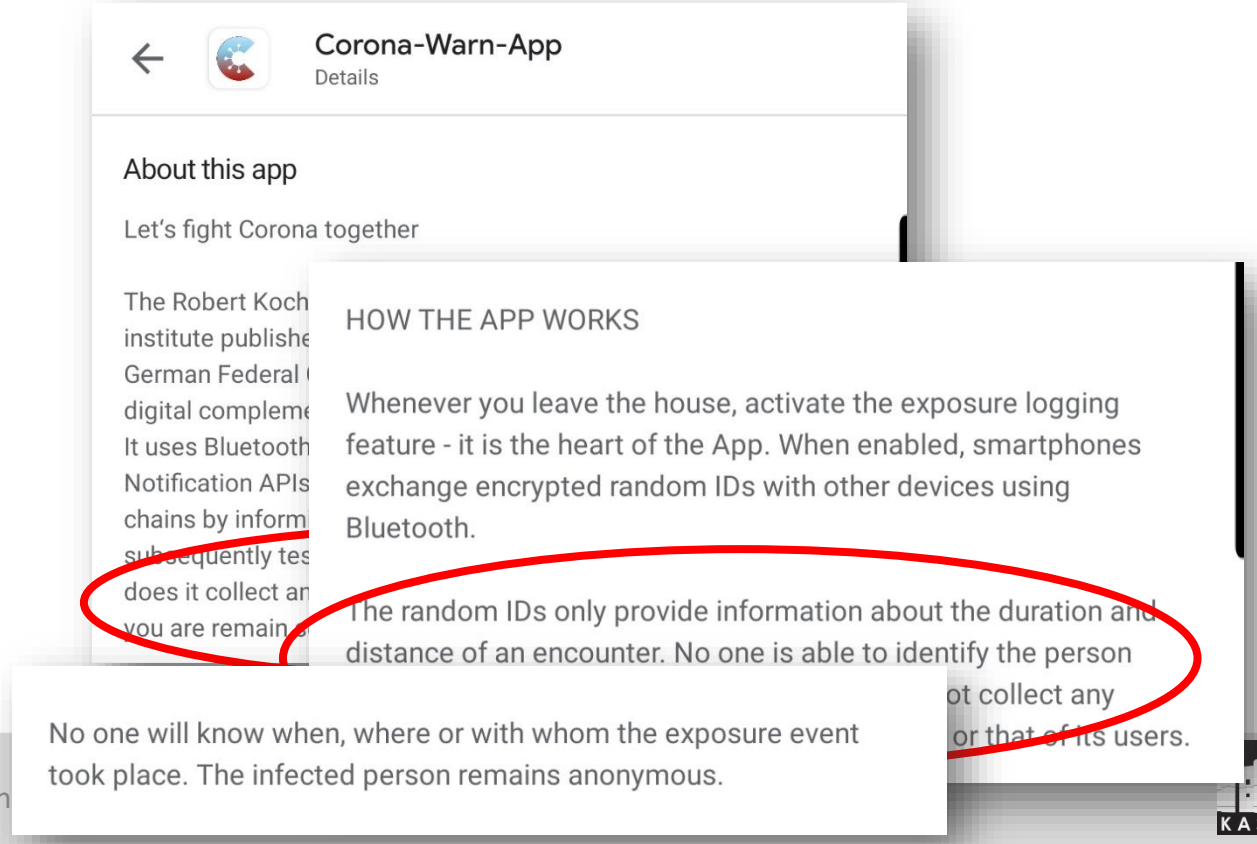
Secure hybrid approaches report colocated RPIs (1) and distribute the service provider

GAEN („decentralized“)

- *Exposure Notification API* in iOS/Android
  - Based on [CTA20]/DP3T-“simple“
  - **Encounter Logging**:
    - Phone creates daily pseudonym: tek_i
    - Derives „key“: $\mathrm{RPIK}_i = \mathrm{H}(\mathrm{tek}_i, <\mathrm{stuff}>)$
    - Derives/publishes linkable „transaction pseudonyms“ (with rolling MAC):

      $\mathrm{RPI}_{i,j} = \mathrm{AES}(\mathrm{RPIK}_i, <\mathrm{stuff}> | \mathrm{time\ slot})$
  - **Infection Reporting (1)**:
    - Rename „tek“ to „diagnosis keys“ and upload to servers (with times)

- **Infection Reporting (2)**:
  - Download all „diagnosis keys“
  - Derive all $\mathrm{RPI}_{i,j}$ and check for local coincidence, raise alarm



GAEN: Critical Assessment

- What data is collected and processed?
  - Personally identifiable, linkable, health-related information
- What is disclosed to whom?
  - Pseudonyms of infected individuals, linkable throughout 24h, to the public
- How difficult is re-identification?
  - Trivial, Apps, Web pages have existed before Telekom/SAP got contract:

README.md

BLE contact tracing sniffer PoC

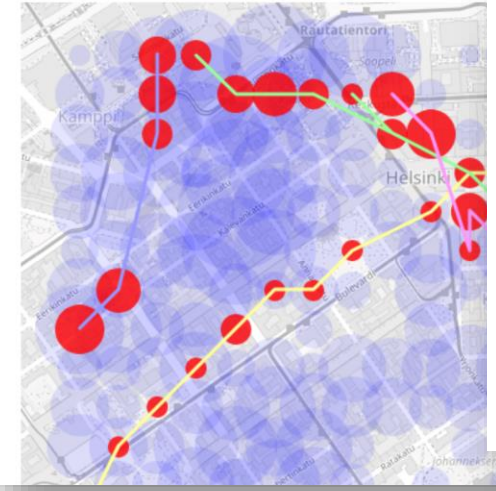
How "anonymous" is the semi-decentralized BLE contact tracing proposed by Apple & Google or DP-3T?

It is as anonymous as the simulated picture below - and this data is technically accessible to **any 3rd party who can install a large fleet of BLE-sniffing devices**. This is because all beacons signals broadcast by infected individuals are published to essentially all users of the system when an individual voluntarily uploads their positive infection status.

This repository contains a Proof-of-Concept implementation of a BLE-sniffing system that could uncover this data.

Simulation

The image shows the results of a simulation where 400 BLE-sniffing devices would have been deployed in a 20×20 grid over an area of 1500×1500 m². The movement of 300 people around the area have been (crudely) simulated as random walks.



COVID-LENS

List Exposu
Notification Se

Click this button to see a list of devic
contact tracing app install

List Nearby Device

3 Get notified when they get covid

CORONA DETECTIVE

Add people | Share | Settings | About

COVID19 amongst us

5:32 | 5:28 | You

-SAP commented on Jun 15 | Member

If yo
please read

Mit freundli
SW
Corona Warn

or if something is missing according to GDPR,
d Freedom of Information.

Mandatory DPIA (slightly paraphrased):
"If anybody were to deviate from the protocol that would be a crime. Can't do anything against crime, might as well ignore that problem."

GAEN: Critical Assessment

- What data is collected and processed?
  - Personally identifiable, linkable, health-related information
- What is disclosed to whom?
  - Pseudonyms of infected individuals, linkable throughout 24h, to the public
- How difficult is re-identification?
  - Trivial, Apps, Web pages have existed before Telekom/SAP got contract:
- Are these disclosures unavoidable?
  - *„Any proximity tracing system that notifies users that they are at risk enables a motivated attacker to identify the infected people“ [1]*
  - Not quite, and by far not that easily…
- For further vivid examples of corporate/academic campaigning, visit:
  https://en.wikipedia.org/wiki/Exposure_Notification

[1] DP3T - Privacy and Security Attacks on Digital Proximity Tracing Systems

Case Study: Ovulation Tracker App

Once upon a time last month…

- Case study: Ovulation tracker
  - Necessary functionality:
    - Record some regular observations on user's body
    - Extract some comp. simple cyclic regularities

May be…

Take photos of some supported products and check info online…

Uhm…

Allow for discussions on a forum

Upload data to the cloud (???)

  - Clearly
    - personally identifiable data
    - ***sensitive*** even sexual preferences and health related data..

Financials

AppsFlyer, the global attribution leader, empowers marketers to grow th
analytics solutions. Built around privacy by design, AppsFlyer takes a cu
partners make better business decisions every day.

https://www.appsflyer.com/services-

Search

2. **END USER DATA RECEIVED AND PROCESSED BY APPSFLYER**

When a Customer uses the Services, the following End User information may be received and processed by AppsFlyer (collectively, **"End User Data"**).

i. **"Technical Information"**: this refers to technical information related to an End User's mobile device or computer, such as: browser type, device type and model, CPU, system language, memory, OS version, Wi-Fi status, time stamp and zone, device motion parameters and carrier.

ii. **"Technical Identifiers"**: this refers to various unique identifiers that generally only identify a computer, device, browser or Application. For example, IP address (which may also provide general location information), User agent, IDFA (identifier for advertisers), Android ID (in Android devices); Google Advertiser ID, Customer issued user ID and other similar unique identifiers.

iii. **"Engagement Information"**: this refers to information relating to the

AppsFlyer uses artificial intelligence and machine learning for
big data analytics AppsFlyer, 04; VentureBeat, 01.

Google CrashLytics ➤

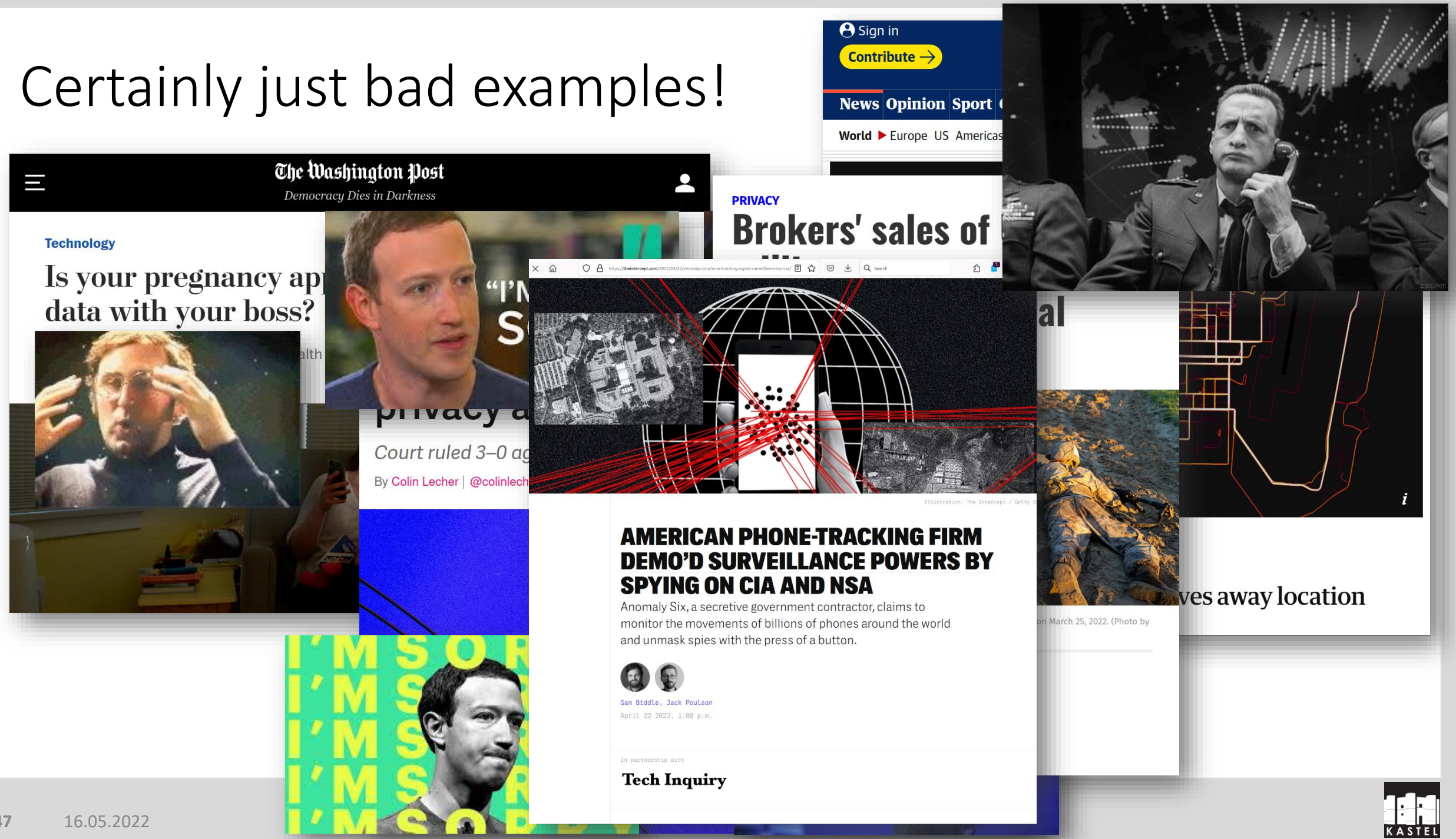
Google Firebase Analytics ➤

Google Tag Manager ➤

- Ok, ok, those won't be bad!?
  - Attribution, retargeting, immutable Ids?

But we're not sending anything to China, anymore!

Certainly just bad examples!



Data Processing and Threats

What‘s required to process PII?

- GDPR underlines
  - Legally: obtain *individual informed consent* or ***anonymize*** data
  - Honestly: Individual *informed* consent infeasible

- What does all that mean?
  - anonymos – without calling the name/unnamend
  - pseudonymos – with (any) pretense name (identifiable)

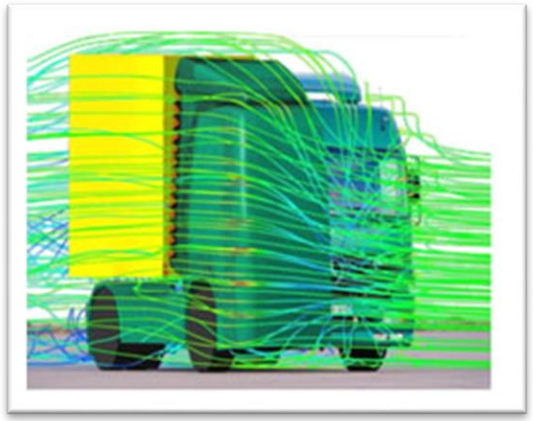
- Anonymity according to the GDPR 101:
  - Information is **anonymous** if it is **not pseudonymous**.
  - A ***pseudonym*** is any unique piece of **information** *corresponding to an* ***identity*** (***quasi id***)

- Process data in EU and/or of EU citizens: remove anything that makes data linkable to an (even seemingly unknown) individual

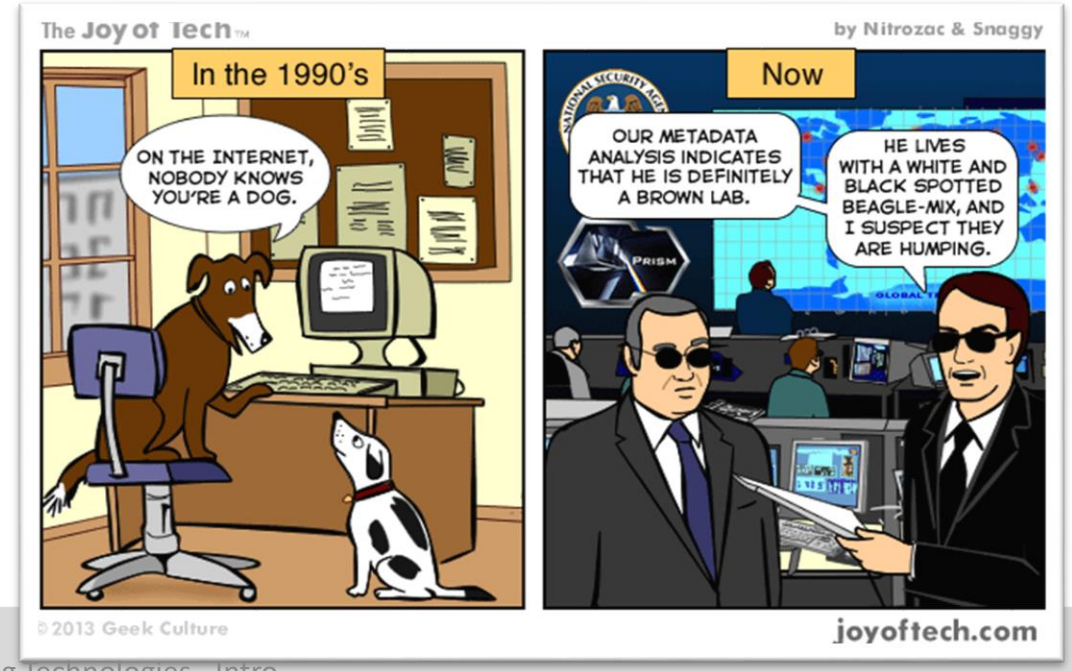
C Deußer, S Passmann, T Strufe. Browsing Unicity: On the limits of anonymizing web tracking data. Proceedings. IEEE Security and Privacy (S&P), 2020

Types of Data

- Data without any ***relation*** to ***individuals***
  - Simulation data
  - Measurements from experiments



- Data ***with relation to individuals***
  - Types
    - Content
    - Meta data
  - Revelation
    - Consciously
    - Unconsciously



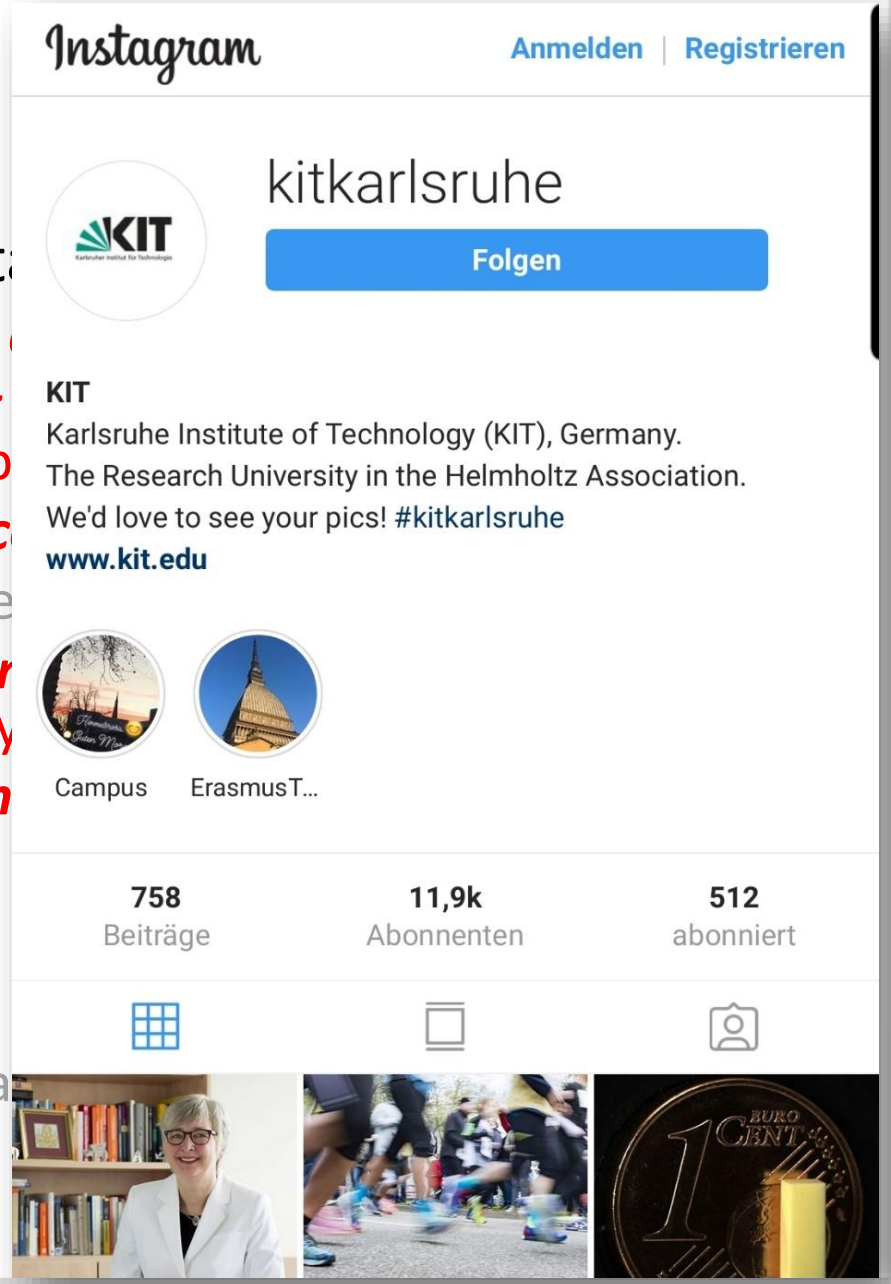
Case Study: Social Media

- Explicit
  - Created content
  - Comments
  - Structural interaction (contacts, likes)

- Inferred
  - Preference– and
  - Image recognition models
  - Personal details

- „Meta dat
  - ***Session***
  - ***interest*** in group
  - ***influenc***
  - Clickstre
  - ***commun*** intensity
  - ***location***

- Externally
  - Observa



Thomas Paul, Sonja Buchegger, and Thorsten Strufe. Decentralized social networking services. Trustworthy Internet, 187-199. 2011

Case Study: Social Media

- Explicit
  - Created content
  - Comments
  - Structural interaction (contacts, likes)

- Inferred
  - Preference– and
  - Image recognition models
  - Personal details

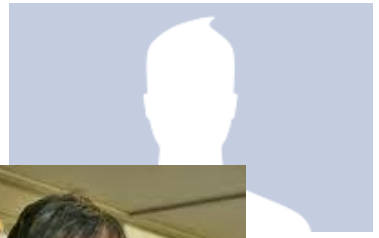
- „Meta data“
  - ***Session artifacts*** (time of actions)
  - ***interest*** (retrieved profiles; membership in groups/participation in discussions)
  - ***influence***
  - Clickstreams, ad preferences
  - ***communication*** (end points, type, intensity, frequency, extent)
  - ***location*** (IP; shared; gps coordinates)

- Externally correlated
  - Observation in ad networks

Thomas Paul, Sonja Buchegger, and Thorsten Strufe. Decentralized social networking services. Trustworthy Internet, 187-199. 2011

Perceived Adversaries

- *If you asked somebody on the road, they're worried about…*

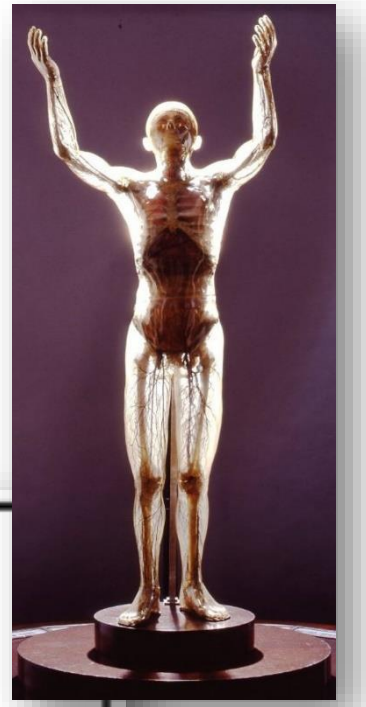


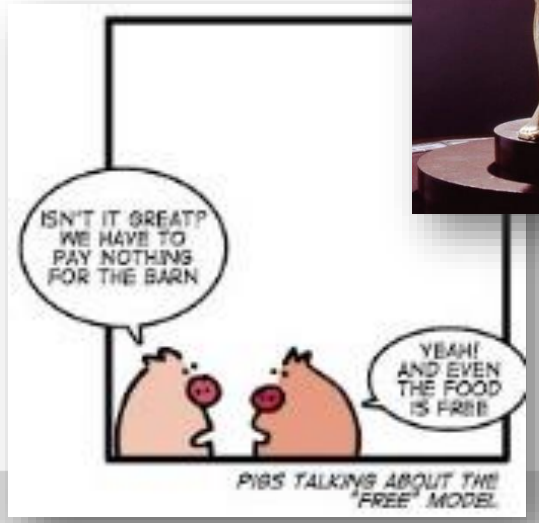
Types of Adversaries and Perceived Threat

- Social Circle:
  - Empirical studies *confirm*: privacy is absence of malware; colleagues **sigh**
  - (who cares about MAFIA – or: who fosters such empirical studies…)

- Interior "Security", aka "the state", "the government"
  - **Transparent citizen** was fear of Central Europeans (Cheka, Gestapo, Stasi)
  - State aims at maintenance of power and control
  - *(**so**: fundamental defensive rights against state („libertarians"))*

- Private Sector / corporate players
  - Prior belief in „the invisible hand of the market" fades
  - Corporations have the primate of profit
  - Network effects lead to monopolies that can dictate terms
  - *(Sometimes regulation of markets (US), also: GDPR)*





***M**icrosoft **A**lphabet **F**acebook **I**BM **A**pple*

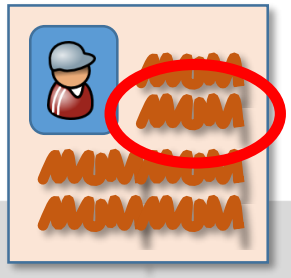
Linkability and the Risk of Disclosure

- Privacy threat: adversaries (*data loss incident: public*) can ***link* items of interest** with some probability

- Exemplary items of interest:
  - ***Individual,*** Identity of Sender, Receiver, Intermediate; pseudonyms (dossier aggregation)
  - ***Auxiliary Information***: Message, locations *(KIT, Wok Man (during lecture!?), Cheri Bar),* interest *(Web pages on diseases, religious beliefs, political – radical? – opinions, preferences (sexual), etc.)*

- *What types of disclosures?*
  - Disclosure of ***identity***
    - Identify an individual (in a dataset)
    - Link identity to an observation

  - Disclosure of ***attributes***
    - Infer a (hidden) attribute of an individual
    - Link additional information to identity



Nyms – Linking Identities to Data

- Let‘s define identifying information as symbols of an alphabet (name space)
  - Obvious:
    - $\{0,1\}^{7}$ -> ASCII: (A,B,C,…)
    - $\{0,1\}^{8x747}$ -> personal names: (Tamim, Thorsten,…)
    - $\{0,1\}^{51}$ -> service numbers: (010174-S-10512, …)
    - $\{0,1\}^{2^{17}}$ -> Portrait picture
    - $\{0,1\}^{3.2x10^{9}}$ -> DNA

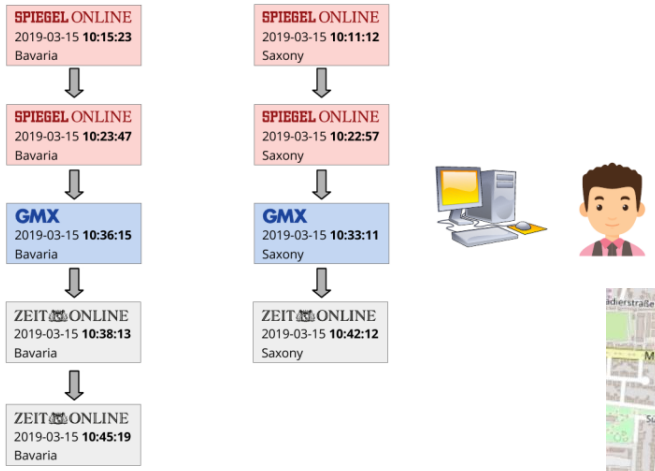
  - Less obvious: Technical pseudonyms
    - Cookies, IP addresses, handles (if7487@kit.edu)
    - `Referrer:[..]/login.php?un=thorsten%20strufe`
  - Again less obvious: Tuples
    - (DoB, gender, postal code)
    - Browser fingerprint
  - Again less obvious: Biometrics
    - $\{0,1\}^{25x(6x8)}$ -> Fingerprint minutiae
    - Iris, heartbeat, limb proportions, posture…

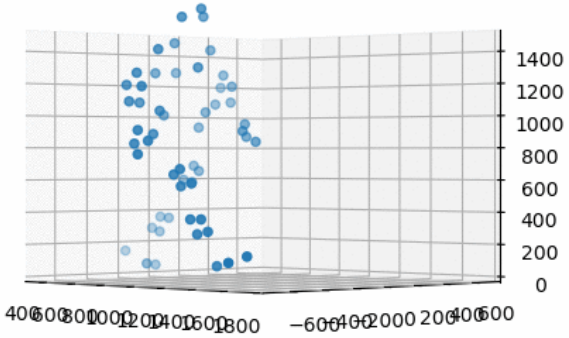
Observations:
- Name space (size of alphabet) vs entropy
- Sufficient entropy: ID any in 7BN individuals
- Low entropy record „quasi identifier“
- Also: „Soft biometrics“ (gender, age,..)
- Tuples of quasi identifiers can constitute ID

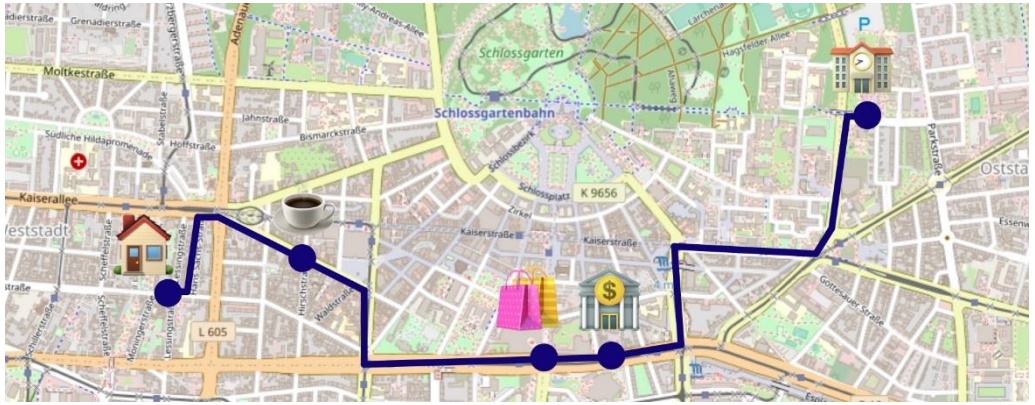
Extended (Pseudo)nyms: Sequences of Symbols

Karlsruhe Institute of Technology

- Patterns (behavioral, habitual)
  - *„Wenn Sie ... vom Hauptbahnhof in München ... mit zehn Minuten, ohne, dass Sie am Flughafen noch einchecken müssen, dann starten Sie im Grunde genommen am Flughafen ... am ... am Hauptbahnhof in München..“*
  - Sequences of actions
    - Web
    - Walking
    - Locations
      - GPS
      - Semantic
    - …







- Constraints
  - Potentially many, prior knowledge
  - $X_{t+1} = f(x_t)$ (locations, web pages?)
  - $P(x) > P(x')$ (you‘re the Flash? Driving through a lake? Broke your leg?)

So what could possibly go wrong?

- Data loss incidents
  - Member database of Ashley Madison et al. (id disclosure leaks sensitive information)
  - Web tracking database (attribute disclosure leaks your browser history)
- Legitimate purposes with unwanted side effects
  - Publish geo traces … of soldiers on secret bases (US army, Ukraine invasion)
  - Publish GPS of cars for traffic jam/parking analyses (speeding, religion, hobbies)
  - Publish „anonymized“ search history, medical records, Netflix preferences
  - Publish only *aggregates* (statistics about counties, patients in hospitals)
  - Train ML models for *queries* (membership inference on faces, user trajectories, …)
  - *Use* „free“ services (navigation, PoI recommendation, skill acquisition,…)

Expectation of Processing (and: Privacy)

Intended Actions

- Store some data
- Communicate with peer
- Retrieve some content
- Voice opinion/publish OC
- Prove identity
- Cast specific vote
- Buy/sell some item (at some price)
- (Participate in collaborative services)

Felix Günther, Mark Manulis, and Thorsten Strufe. Cryptographic treatment of private user profiles. Financial Cryptography and Data Security, 40-54. 2011

Intended Actions and Processed Data

- Store some data
- Communicate with peer
- Retrieve some content
- Voice opinion/publish OC
- Prove identity
- Cast specific vote
- Buy/sell some item (at some price)
- (Participate in collaborative services)

- Data (Items of Interest)
  - Identity
  - Primary physical characteristics
  - Properties and „immutable“ features
    - Health conditions
    - Ticks and habits
    - Taste
      - Political opinion
      - Sexual preferences
      - Religious beliefs…
  - Action of (and content of)
    - Communicating
    - Retrieving content
    - …

How is Data Collected *(== Processed!)*?

- Legitimate processing
  - Users want to
    - Communicate
    - Access content
    - Vote
    - Ride-Share
    - Navigate
    - …
- US Fourth Ammendment:
  - „Reasonable Expectation of Privacy“
  - What are your‘s?

- By purpose of service
  - Content of an unencrypted email
  - Content of a social media post
- Direct collateral of using service
  - Meta data of (sharing) action
  - Observations „necessary“ for the service (interest/location of navigation, movement for step counting, fitbit…)
- Indirect collateral of using service
  - Trackers on Web/phone applications
  - Trackers of services on secondary pages
  - Brokers buying and selling user data
- Collateral of existing
  - Google home, Amazon Echo
  - E-Call initiative, EU blackbox legislation
  - Public cameras (visual light, thermal, joint communication and sensing,…)
  - Google/Apple location services

Which Processing do Users want (accept)

- Legitimate processing
  - Users want to
    - Communicate
    - Access content
    - Vote
    - Ride-Share
    - Navigate
    - …

OnAudience.com

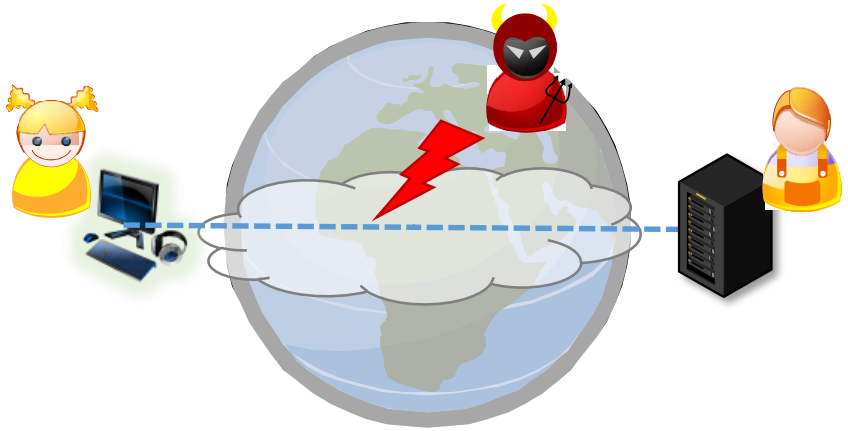
- Users agree to
  - Preference modeling (recommender)
  - Charitable studies (health)
  - Recognition for app functionality
  - Recognition for proof of identity
- Users probably accept
  - Recognition for advertising
- Users probably do not accept
  - User data exchanges
  - (Blanket surveillance)

Consequences.

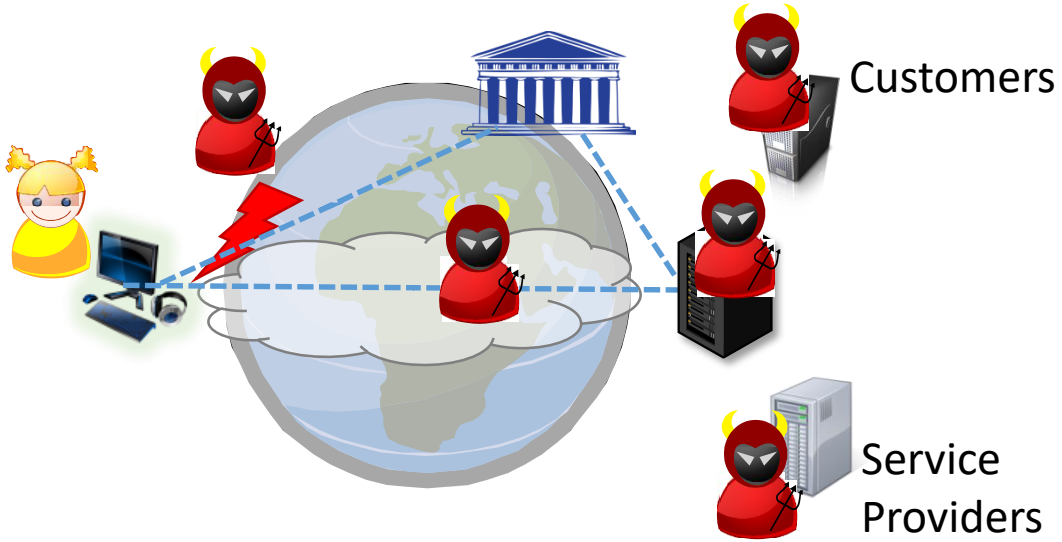
Updated Trust Assumptions and Defenses

Updating our Trust Assumptions…

- Trust assumption in crypto…



- Trust assumption for privacy



- Alice and Bob reside in trusted domains, Eve/Mallory attack on the channel
- Alice (or Bob) resides in a trusted domain. Other than that: Minimize trust assumption (choose wisely!)

Privacy Enhancing Technologies

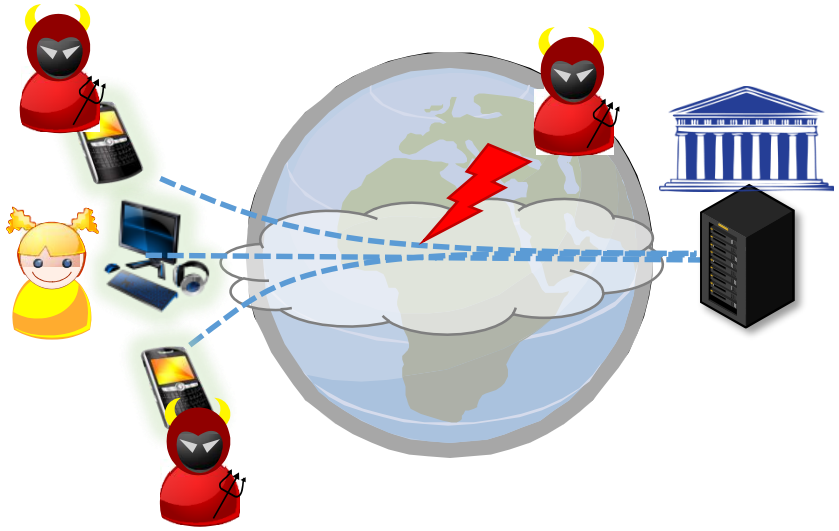
Privacy Enhancing Technologies

- *PET…*
  - *are coherent measures that protect privacy by*
    - *1) eliminating or reducing personal data or*
    - *2) by preventing unnecessary/undesired processing personal data*
    - *3) without losing the functionality of the system*
- Approaches and models
  - Transparency tools
  - Opacity mechanisms:
    - Generalization/Suppression
    - Perturbation
    - Concealment
- Semi-trusted entities provide functionality:
  - Message delivery (send/rcv)
  - Information access
  - Publication
  - Authentication/proof of attributes
  - Reference/Rating
  - Aggregation/learning/recommender
  - Voting

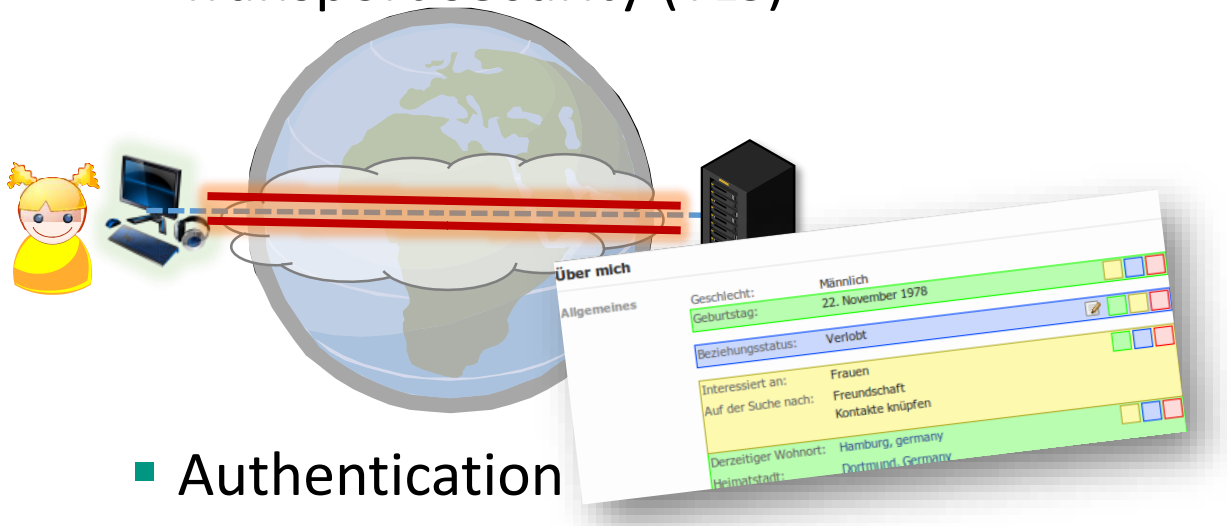
John Borking (1996)

Soft Privacy Technologies

- Trusted Service Provider
- Untrusted users, network



- Focus on consent, compliance and internal controls
  - Transport security (TLS)



  - Authentication
  - „Privacy settings“ (authorization and access control)
  - Trusted aggregation (tally polls…)

T Paul, M Stopczynski, D Puscher, M Volkamer, T Strufe. C4ps: colors for privacy settings. 21st International Conference on World Wide Web, 585-586. 2012

Hard Privacy Technologies

- Assumptions and Goals
  - No fully trusted entity
  - Minimize necessary trust into parties
  - No single entity may violate privacy
- Violation of privacy
  - Identity disclosure
  - Attribute (interest) disclosure
  - „Link items of interest“
    - Identities, attributes, actions, …
- Semi-trusted entities provide functionality:
  - Message delivery (se
  - Information access
  - Publication
  - Authentication/proof of attributes
  - Reference/Rating
  - Aggregation/learning/recommender
  - Voting

Anonymous comms

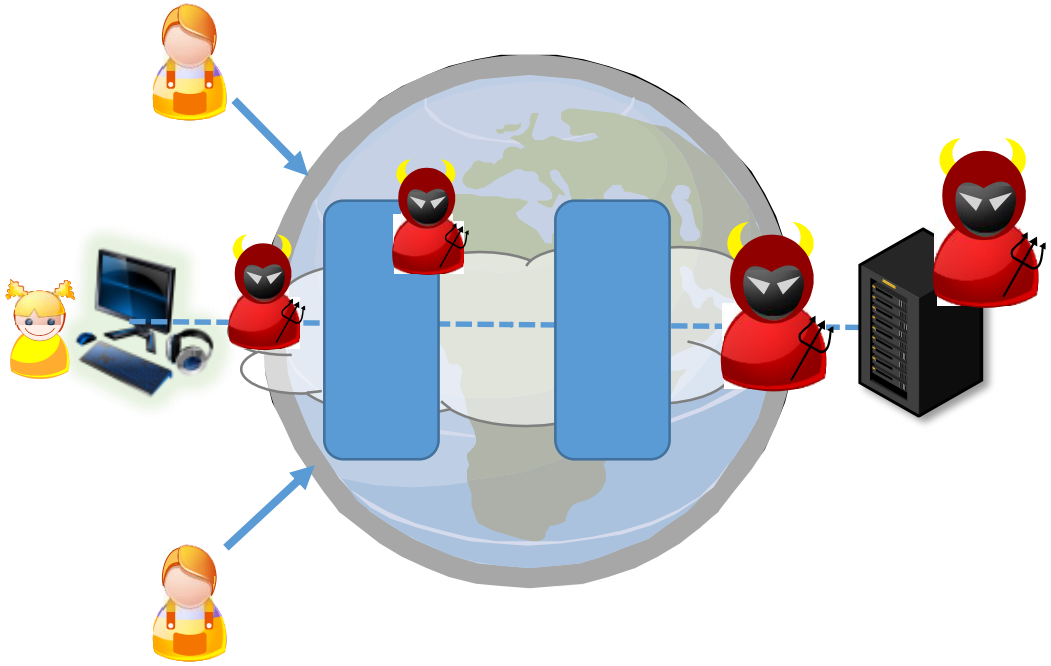
Dead drops/PIR

Zero-Knowledge

Secure Function Eval.
Private Data Release

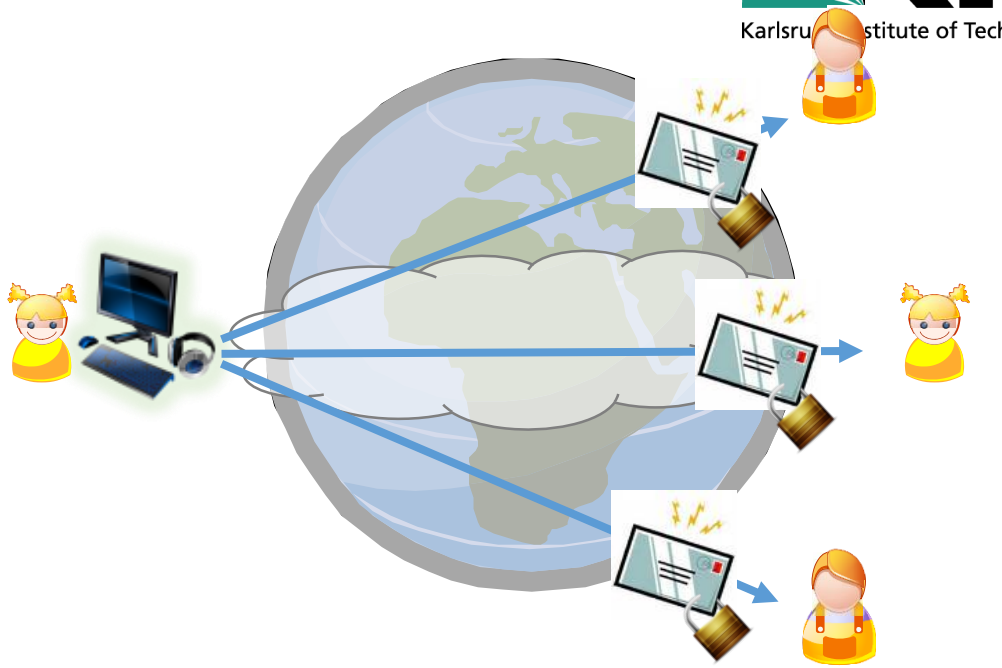
Hard PET – Anonymous Communication

- Function: *Communication*
- Threat: *sender-message linking*
  sender-receiver linking
- Untrusted
  - Network: *TLS*
  - Recipient: *Relay through intermediary*
  - Also ISP: *Cover traffic/mixing ham*
  - Relay: *Cascade*
- Variations:
  - Large ISP: Relay in various AS
  - Collusions…



Hard PET – Anonymous Communication

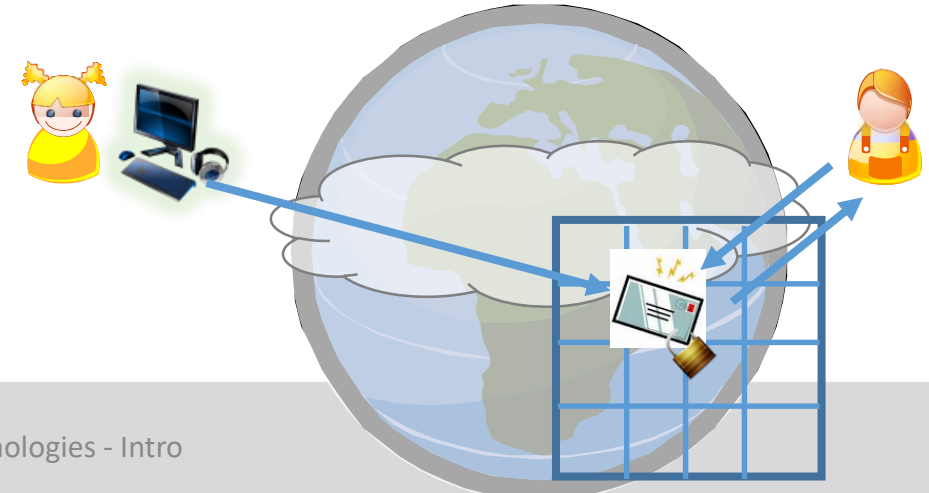
- Function: *Communication*
- Threat: *Receiver identification*



- Untrusted:
  - Sender: *Broadcast w/ implicit address*

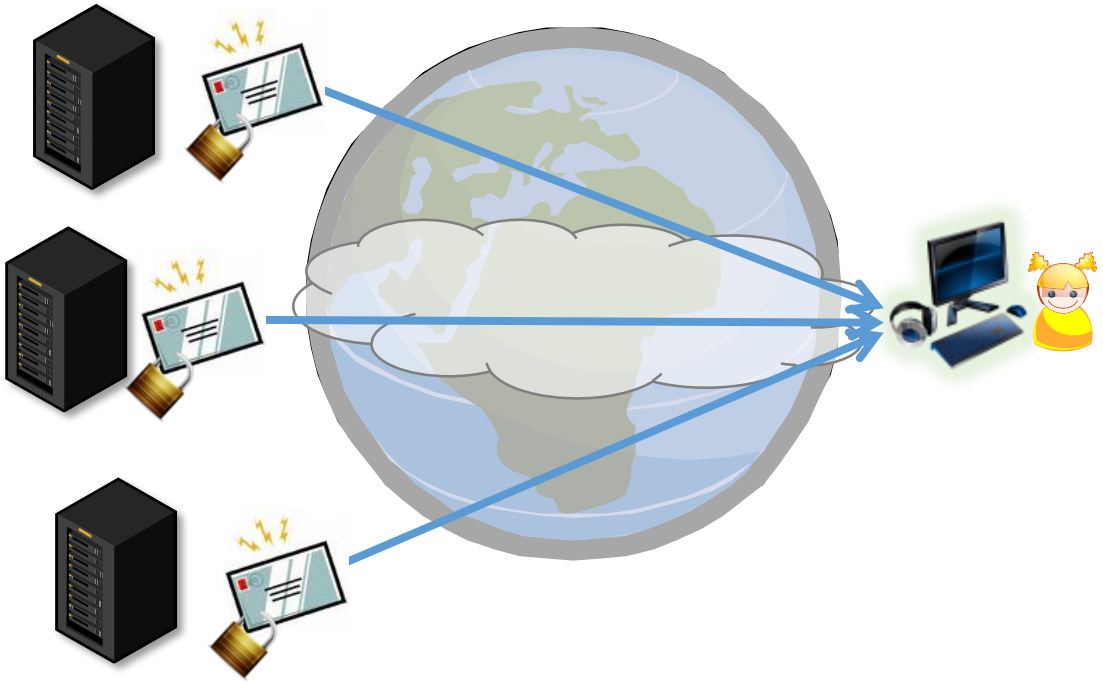
    Anonymous return address/dead drop

- How can we implement broadcast/dead drop on the web?
  - Hidden service, DC nets, or PIR…



Hard PET – Private Information Retrieval

- Function: *Writing/reading data*
- Untrusted: *Service providers*

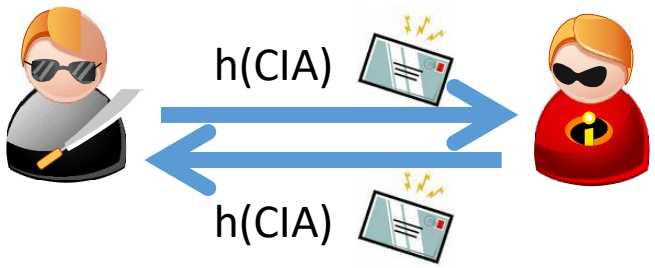


- Threat: Disclosed…
  - … interest: *Secret sharing*
  - … choice: *Transfer „everything“*
  - … additional data: *Oblivious transfer*
- Variation:
  - Writing to and reading from concealed storage cells: *ORAM*

Hard PET – Proving Attributes

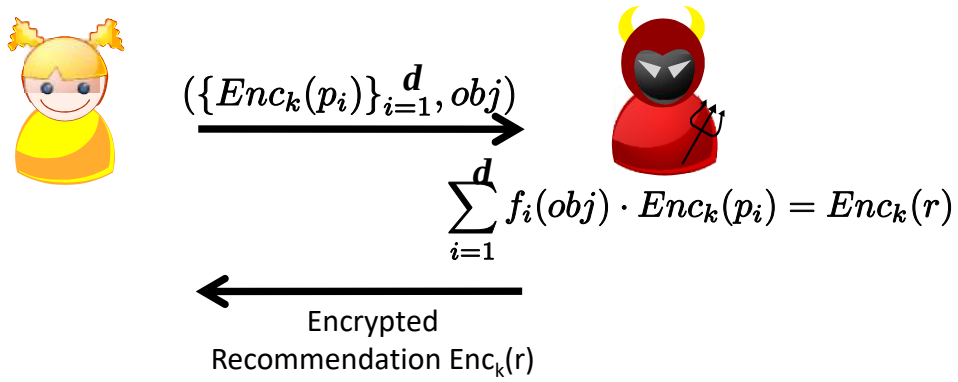
- Function: *Prove claimed attribute*
- Threat: *Disclosure of attribute*

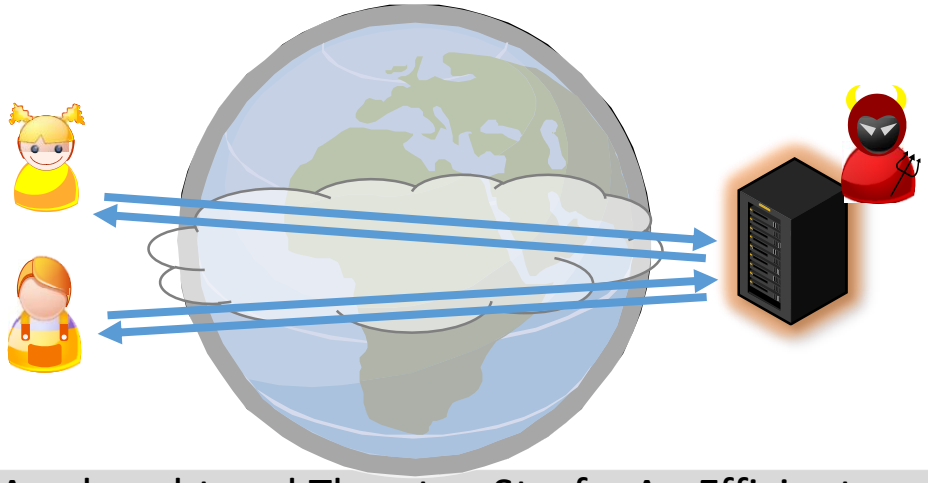
- Untrusted:
  - All parties: *Secret handshake*
  - Verifier: *Attribute credentials, Zero knowledge proofs*



Hard PET – Operations on Data

- General Secure Function Evaluation
- Threat: *Disclosure of Inputs*
- Untrusted: *Processors*
- Techniques:
  - *Homomorphic encryption*
  - *Secure Multiparty Computation*
- Examples:
  - Recommender
  - Benchmarking
  - Voting (count, proof of vote, audit…)





Frederik Armknecht and Thorsten Strufe. An Efficient Distributed Privacy-preserving Recommendation System.

Hard Privacy Technologies

- Semi-trusted entities provide functionality:
  - Message delivery (send/recv)

Anonymous comms

  - Information access
  - Publication

Dead drops/PIR

  - Authentication/proof of attributes

Zero-Knowledge

  - Reference/Rating
  - Aggregation/learning/recommender
  - Voting

Secure Function Eval.
Private Data Release

- *Note, that user information is hidden from others as much as possible.*

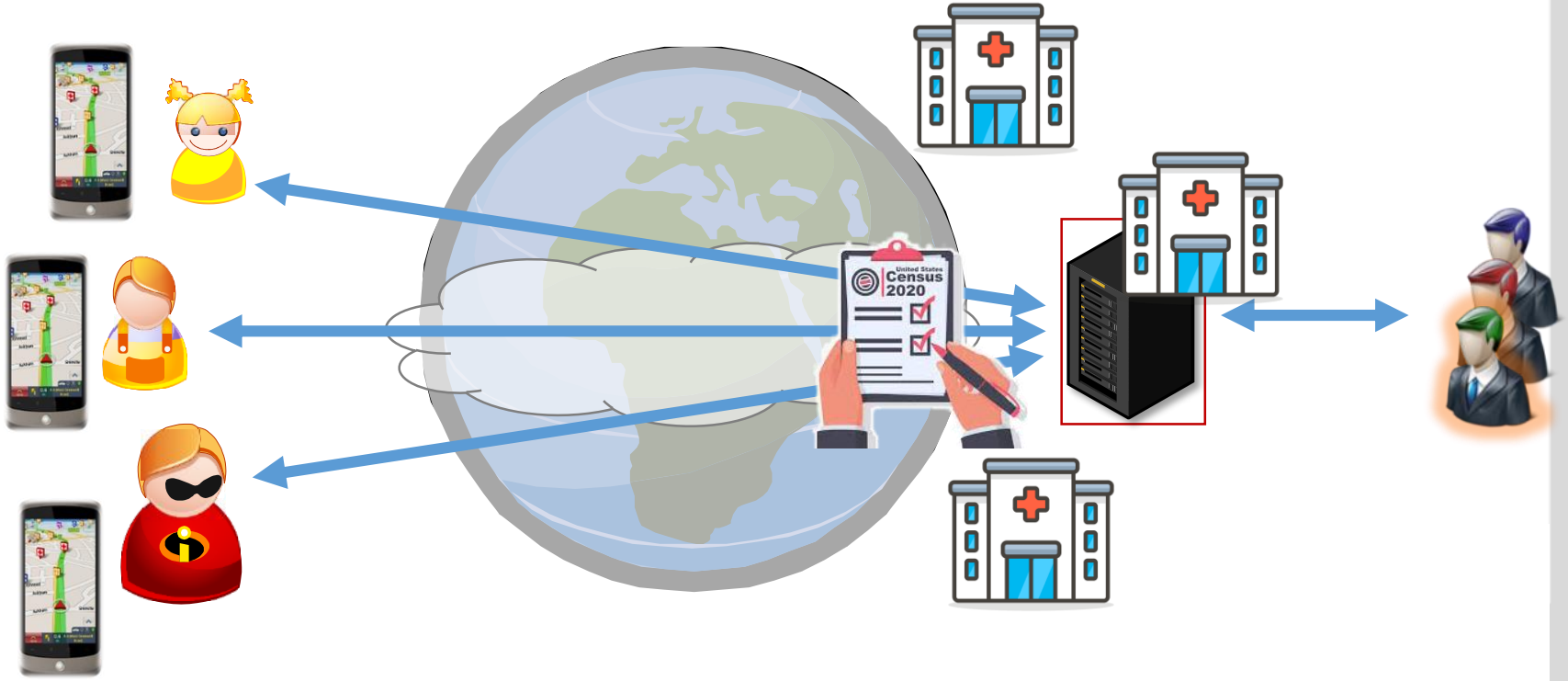
From Hard PETs to Statistical Disclosure Control

- Access/queries to data/models (Privacy-Preserving Data Mining/Publishing)
- Threat: *reconstruction/disclosure of inputs!*

- Untrusted: other participants/analysts

- Techniques
  - Syntactic SDC
  - Semantic SDC

- Examples:
  - US public census
  - Health data analysis
  - Mobile keyboards



Statistical Disclosure Control

What if someone (you) could sanitize observations about you…

Help: The (virtual) Curator

- Assumptions:
  - (Virtual) custodian has all data
  - governs access/processing
  - Provides
    - sanitized data or
    - sanitized aggregates or
    - sanitized response to analyst queries
  - (*Virtual*: real entity, semi-trusted distributed, or locally approximated)
- Threats
  - Identity disclosure
  - Attribute (interest) disclosure
- Privacy mechanisms
  - Non-perturbative
    - Concealment/Suppression
    - Generalization
  - Perturbation
    - Rounding
    - Noise addition
    - Permutation
  - Generation of synthetic data
- Goal:
  - Anonymized data set
  - Differentially private query response

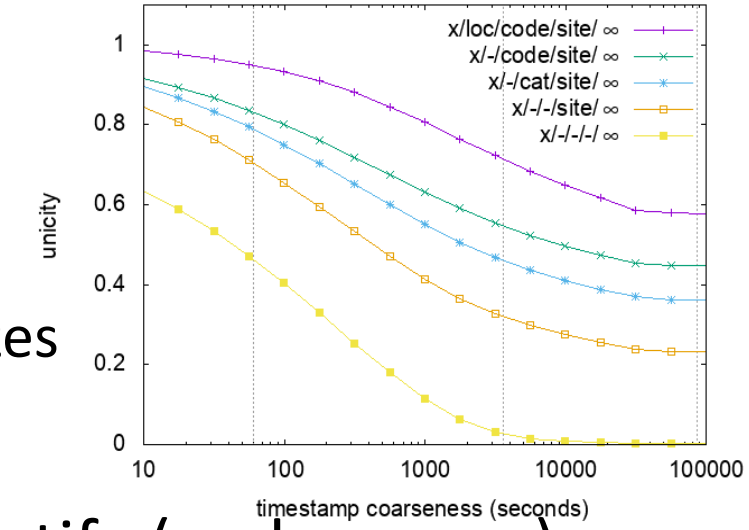
Data Publishing – Classification of Data

	Quasi ID			Sensitive		Non-sensitive	
	ZIP	Age	Sex	Disease	Salary	Q1	Q2
	47677	43	Male	Heart	3.000	a1	13
	47602	22	Female	Flu	5.000	a5	4
	47678	45	Female	Hepatitis	6.000	a4	22
	47905	31	Male	HIV	4.000	a1	12
	47909	36	Male	Flu	10.000	a2	8

- Explicit identifiers must be removed
- Link between Quasi-IDs and sensitive attributes needs to be obfuscated

* Bundesweites Identifikationsmerkmal, Foedselsnummer, Aadhar UID

Remaining Problems of Anonymization



- k-anonymity depends on knowledge of adversary:
  - Auxiliary datasets (phone book?) reduce anonymity-set sizes
- Quasi-identifiers (pseudonyms) are ***really*** hard to identify (and remove)
  - Any data directly linkable to individual (IP address? Cookie? Browser fingerprint?)
  - Any unique content parts in the data
  - Unique behavior…
- Proper anonymization destroys utility of the data (completely)

Clemens Deußer, Steffen Passmann, and Thorsten Strufe. Browsing Unicity: On the limits of anonymizing web tracking data Inproceedings. S&P '20

Publishing Differentially Private Aggregates

- Now Alice does not even want to help the medical sciences, anymore…
- Statistics to the rescue:
  - Curator adds noise to each entry
  - Calculates/outputs aggregate on data
- Aggregates:
  - Averages, Quantiles
  - ML models

	ZIP Code	Age	Disease
1	47677	29	Heart Disease
2	47602	22	Heart Disease
3	47678	27	Heart Disease
4	47905	43	Flu
5	47909	52	Heart Disease
6	47906	47	Cancer

	ZIP Code	Age	Disease
1	47677	29	Heart Disease
2	47602	22	Heart Disease
[redacted]			
4	47905	43	Flu
5	47909	52	Heart Disease
6	47906	47	Cancer

- ***Guarantee***: Even an adversary that knows all but Alice‘s entry cannot determine, if her entry was used for the calculation or not (let alone: what the entry may have been).
- ***Problems***:
  - Errors large, or most probably misunderstood
  - Doesn‘t mean what you think it does

Summary

- Society doesn‘t really manage digital transformation so well…
- Cherished practices now have unwanted ramifications (Extortion, Brexit)

- Privacy-Enhancing Technologies offer solutions
- Different functions, threat/trust models, guarantees
  - Communication, Publication/Retrieval, Proofs, Function evaluation
  - Soft PET (trusted service provider), Hard PET (minimized trust), Statistical Disclosure Control

- Very fast moving field of research
  - Investigation of pseudonymity, privacy – utility trade-offs
  - Formal analysis of privacy, efficient implementations/new protocols
  - DP for data with dependencies, distributed/local DP, attacks on DP ML

- ***Come see us after class, we‘ll be happy to discuss!***