Key Management in Distributed Online Social Networks

WoWMoM 2011 – D-SPAN, Lucca

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Users and the Web

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Modern Web is dominated by social interaction, networking, online communities.
Services are offered by users for users – Users are at the heart of the Web.

Social Networks as Global Players

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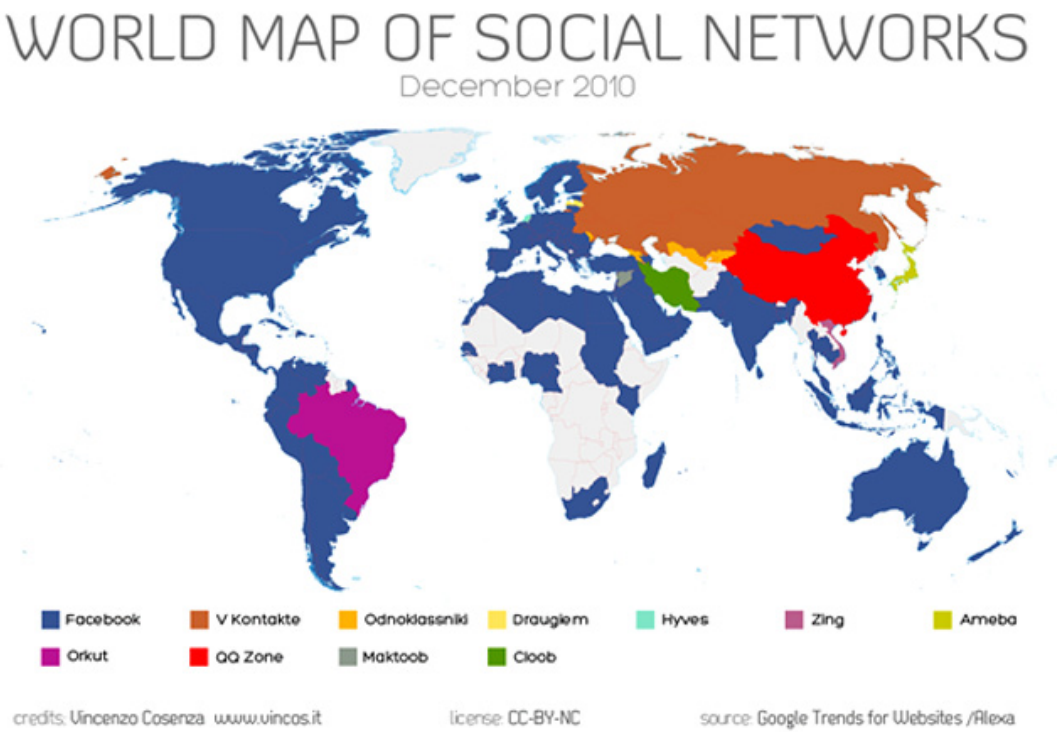
Social networking on the Web enjoys popularity all over the world.



Facebook alone has over 500 Mio. active users, 50% logging on every day.

Current Social Networks are Centralized

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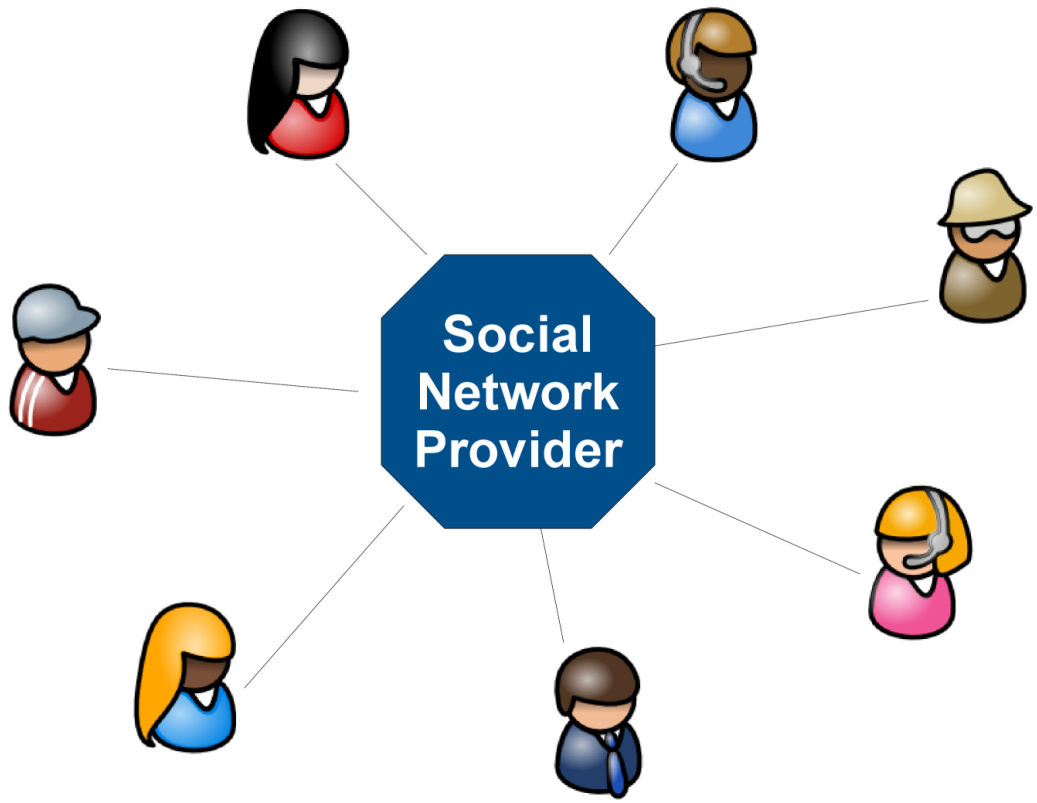
All big online social networks today are centralized.



Current Social Networks are Centralized

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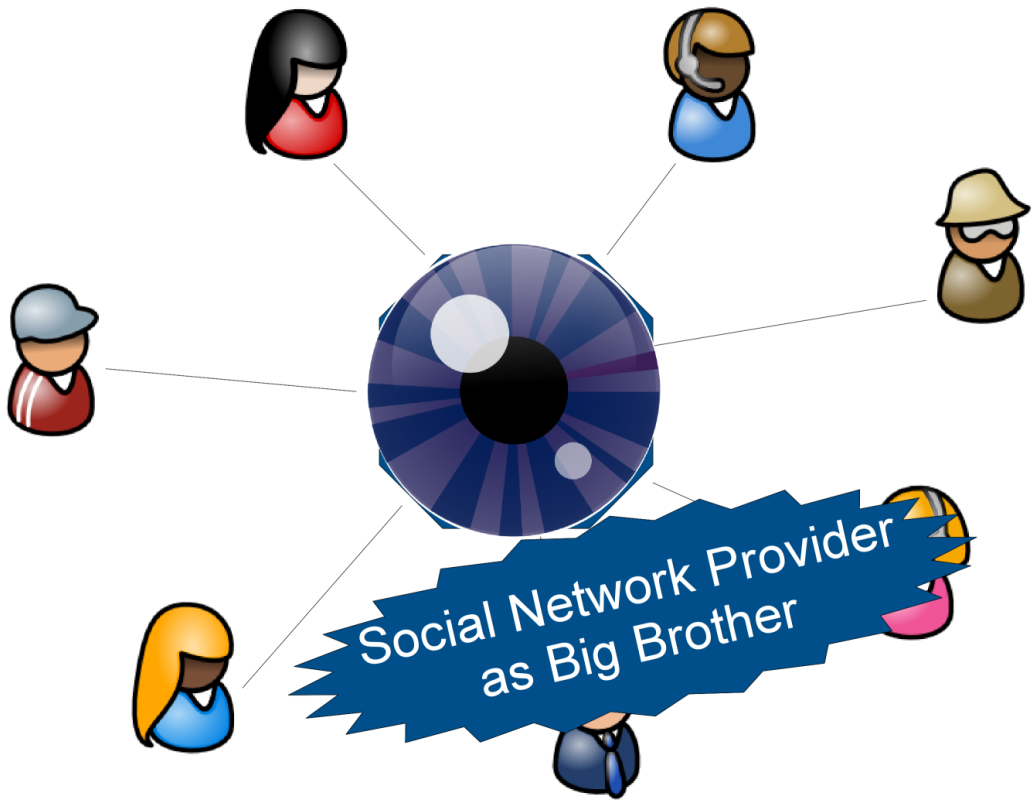
All big online social networks today are centralized.
Many trust has to be put into the Provider, which can act as a Big Brother.



Decentralized Approach and Requirements

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One approach to avoid a Big Brother is to decentralize storage and control. This however introduces some challenges:

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- availability of profiles

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Qualitative Requirements for Encryption Schemes

- confidentiality: hide data from unauthorized users
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Qualitative Requirements for Encryption Schemes

- confidentiality: hide data from unauthorized users
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Quantitative Requirements for Encryption Schemes

- low storage overhead
- little interaction with authorized users
- low ressources requirements for computations

Formal Model for User Profiles and Profile Management

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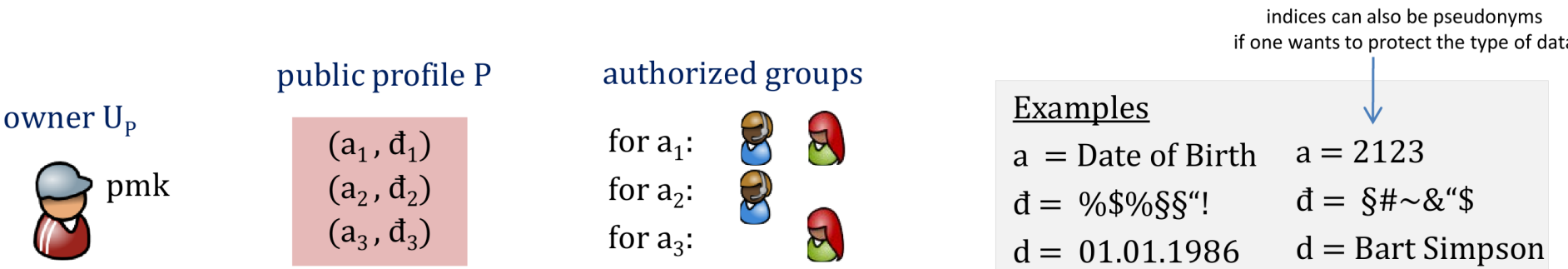
- A profile P is modeled as a set of pairs

$$P \stackrel{def}{=} \left\{(a, \bar{d}) | a \in \mathcal{I}, \bar{d} \in \{0,1\}^*\right\}$$

- $\mathcal{I}$ is set of unique attribute indices a; $\bar{d}$ is the corresponding value stored in P.
- P is public + authenticated by owner U_P, having profile management key pmk.
- U_P given $(a, \bar{d}) \in P$ knows attribute d and group G of authorized users.
- Profile Management Scheme offers:
  $\texttt{Init}(\kappa)$, $\texttt{Publish}(pmk, P, (a, d), G)$, $\texttt{Retrieve}(rk_U, P, a)$,
  $\texttt{Delete}(pmk, P, a)$, $\texttt{ModifyAccess}(pmk, P, a, U)$



Security Goal: Confidentiality

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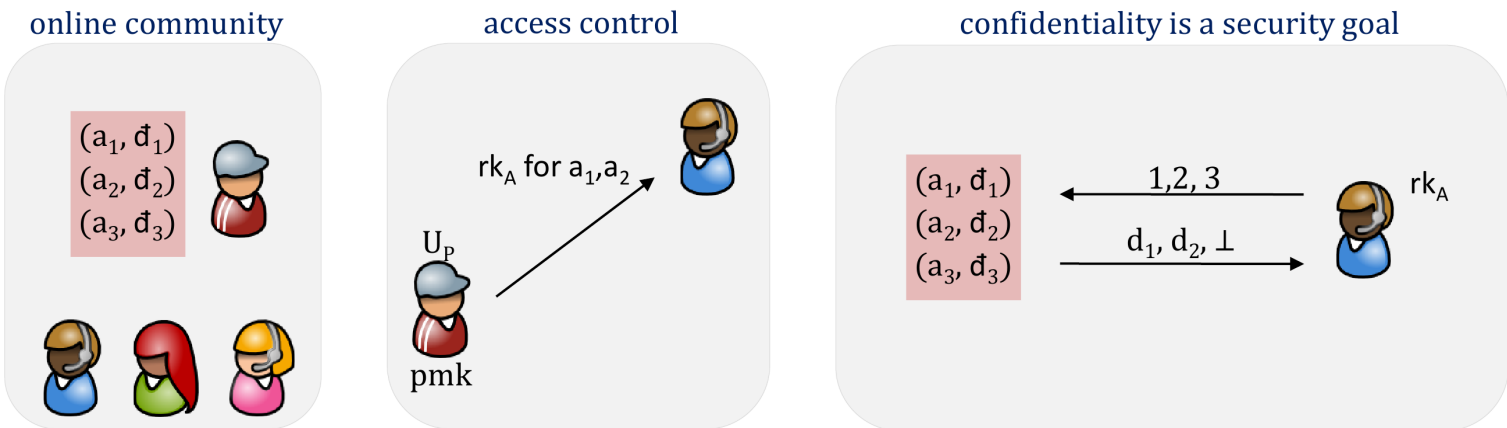
U_P publishes pairs $(a, \bar{d})$ in P and gives U retrieval key rk_U for some indices.
Confidentiality: Attributes d should remain hidden from unauthorized users.



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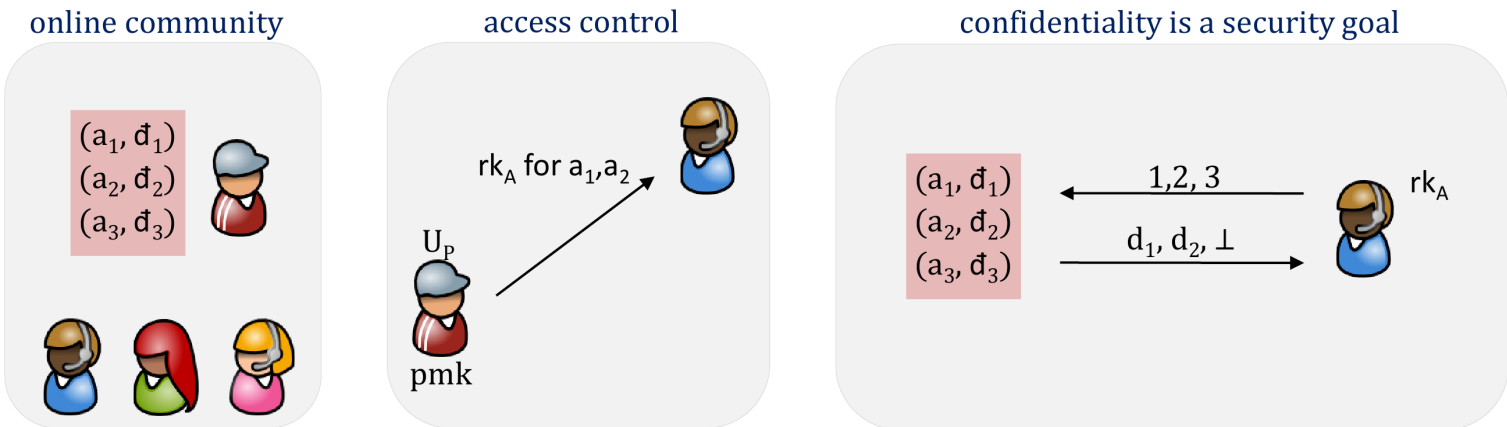

Indistinguishability approach:
$\mathcal{A}$ without access rights to $(a, \bar{d})$ should not be able to distinguish which attribute d is encrypted in $\bar{d}$.

. . . even if $\mathcal{A}$ can access other attributes in the same profile.

Privacy Goal: Unlinkability

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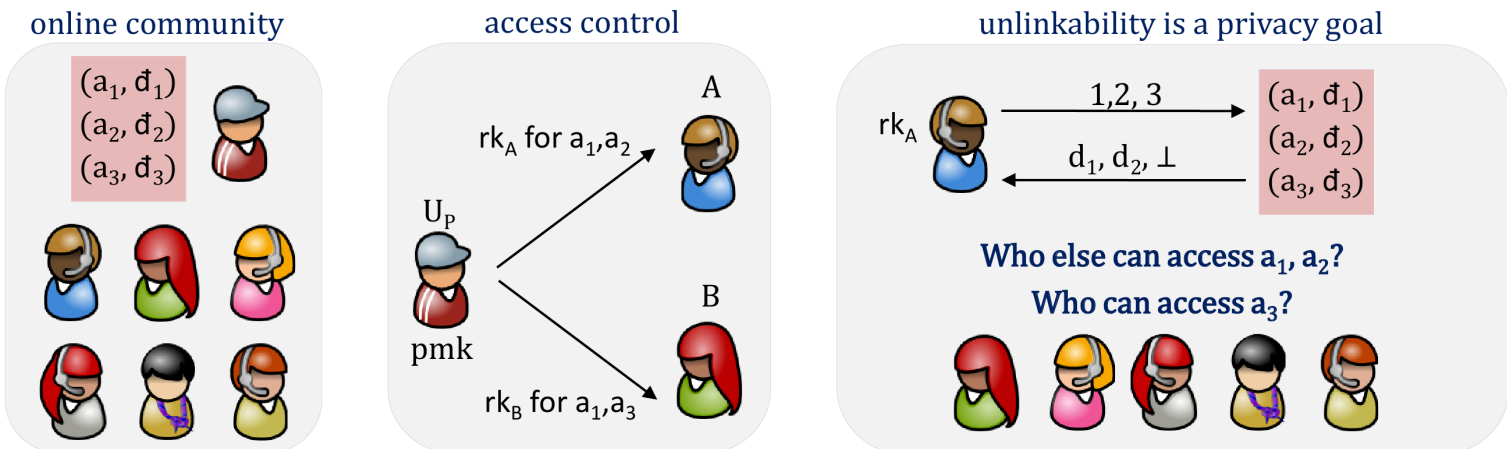
Owner U_P knows which users were granted access to which pairs (a, d) in P.
Unlinkability: Profiles should hide which users can access which attributes.



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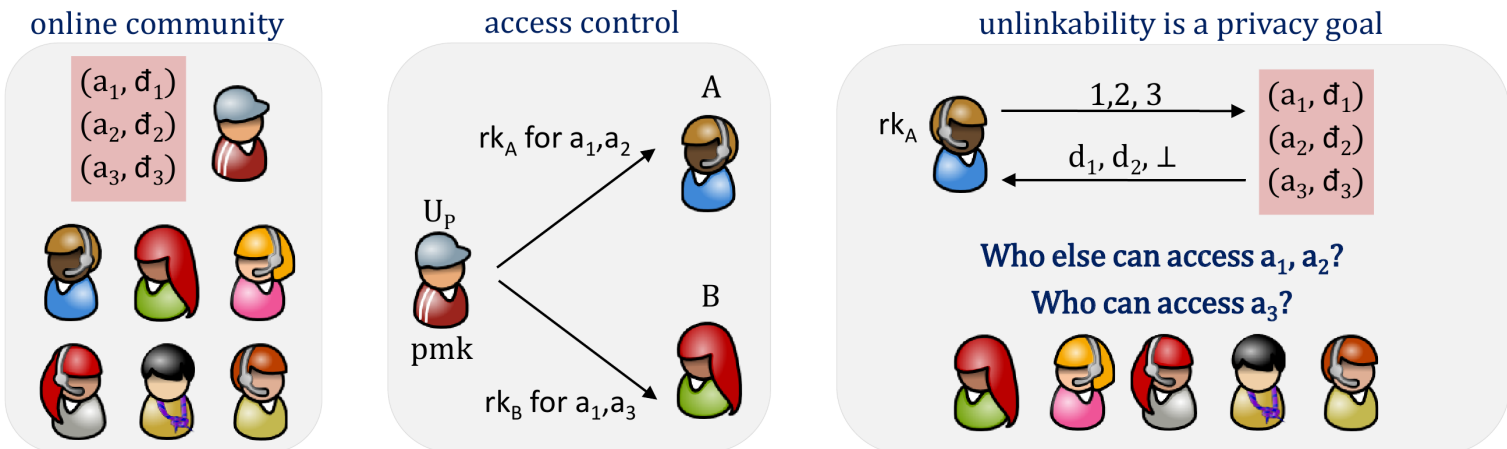

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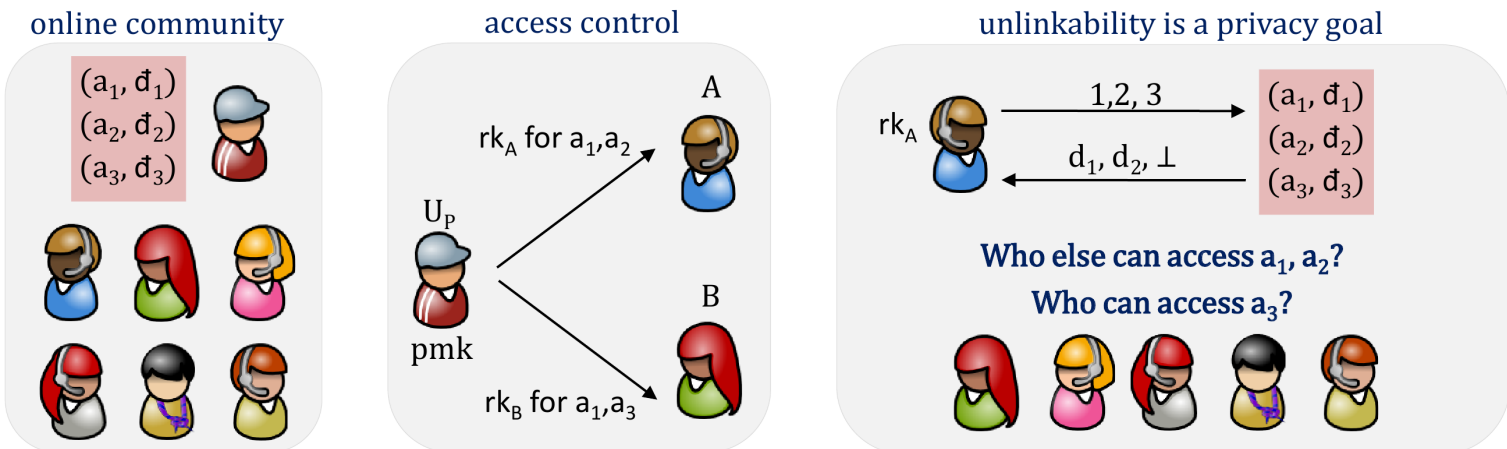

Indistinguishability approach:
$\mathcal{A}$ without access rights to $(a, \bar{d})$ should not be able to distinguish whether user A or user B was granted to access a.

- Formal model + Conf./Unlink. games in Günther et al. FC/RLCPS 2011.

Shared Key (SK) Approach

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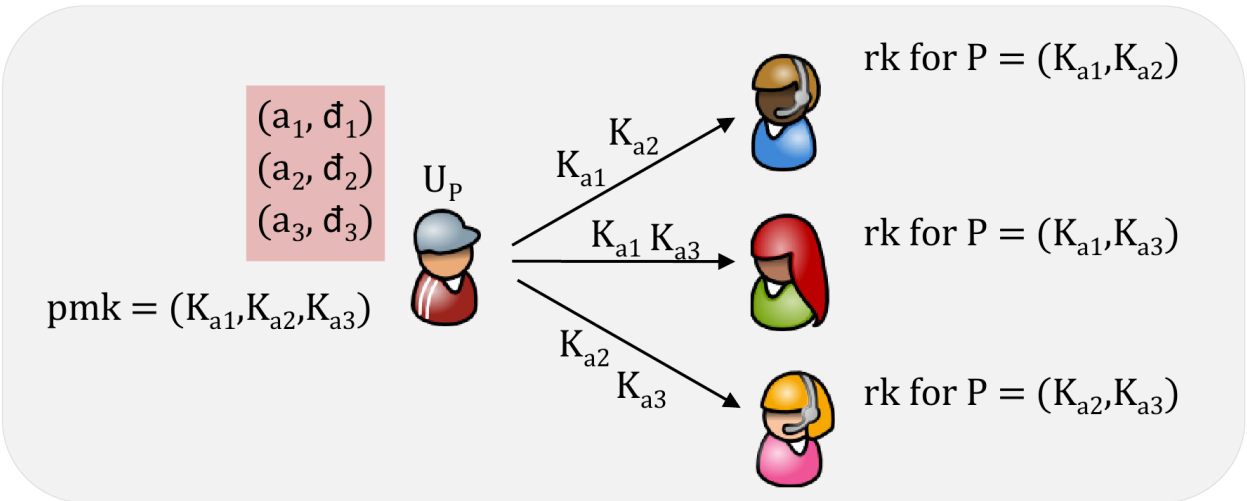
- intuitive approach: shared secret key for each attribute
- separate keys $K_a \leftarrow SE.KGen(\kappa)$ for each pair $(a, \bar{d})$: $\bar{d} = SE.Enc(K_a, d)$
- revocation: re-encryption with new K_a



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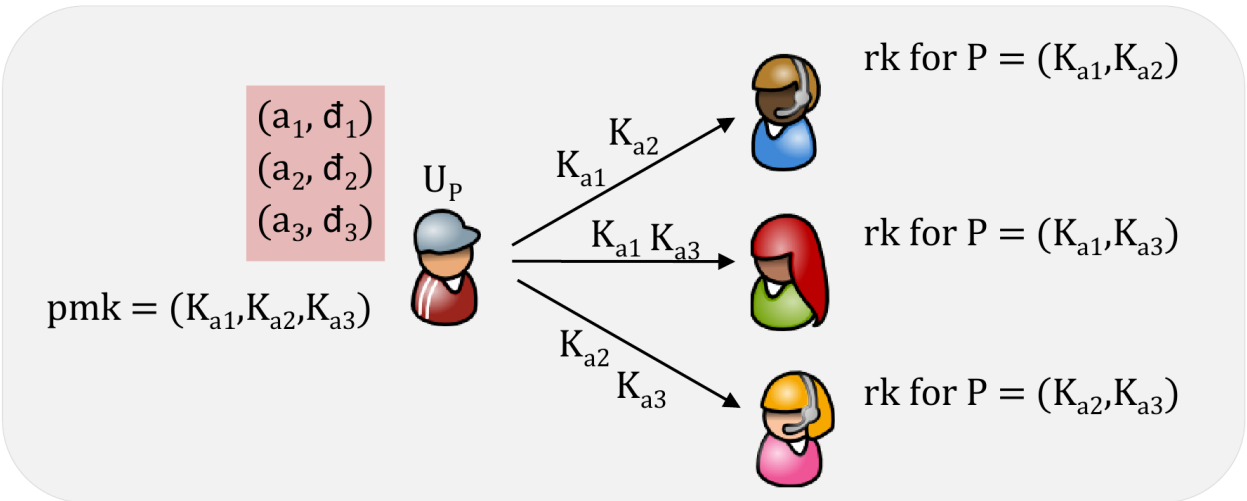

- provides confidentiality and perfect unlinkability
- each user has to store one key per attribute per profile
- two storage variants: at the users or (encrypted) in the profile
- key updates can be optimized with group key management for K_a (LKH, OFT)

Broadcast Encryption (BE) Approach

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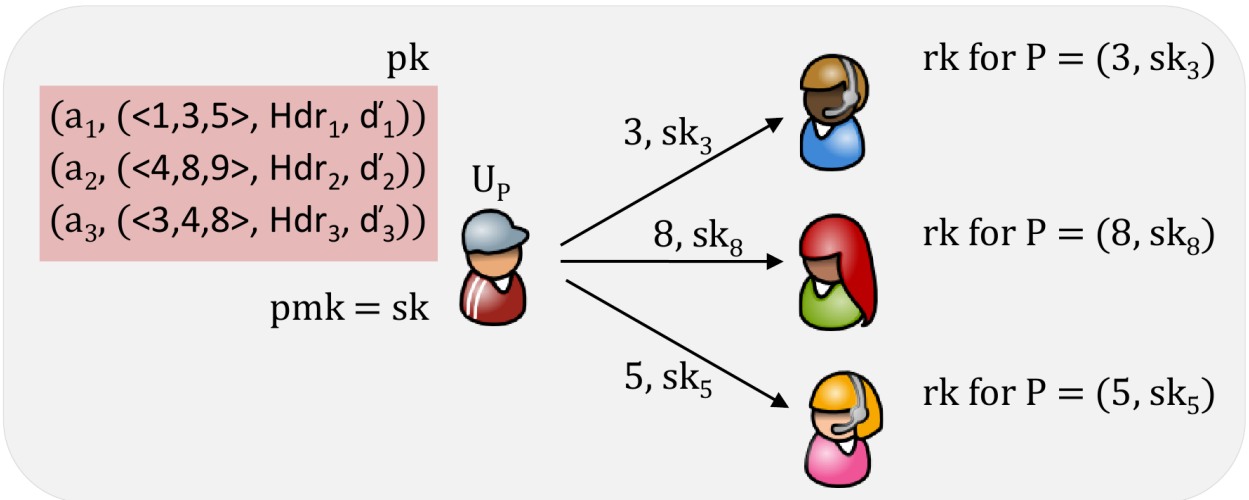
- each user manages own broadcast group using $(pk, sk) \leftarrow BE.Setup(\kappa, n)$
- each authorized user i receives a single key sk_i per profile
- for each $(a, d) : (Hdr, K_a) \leftarrow BE.Enc(S, pk)$, authorized users S, $\bar{d} = SE.Enc(K_a, d)$ and finally $\bar{d} = (Hdr, S, \bar{d})$.
- revocation: re-encryption with new (Hdr, K_a) for the modified set S



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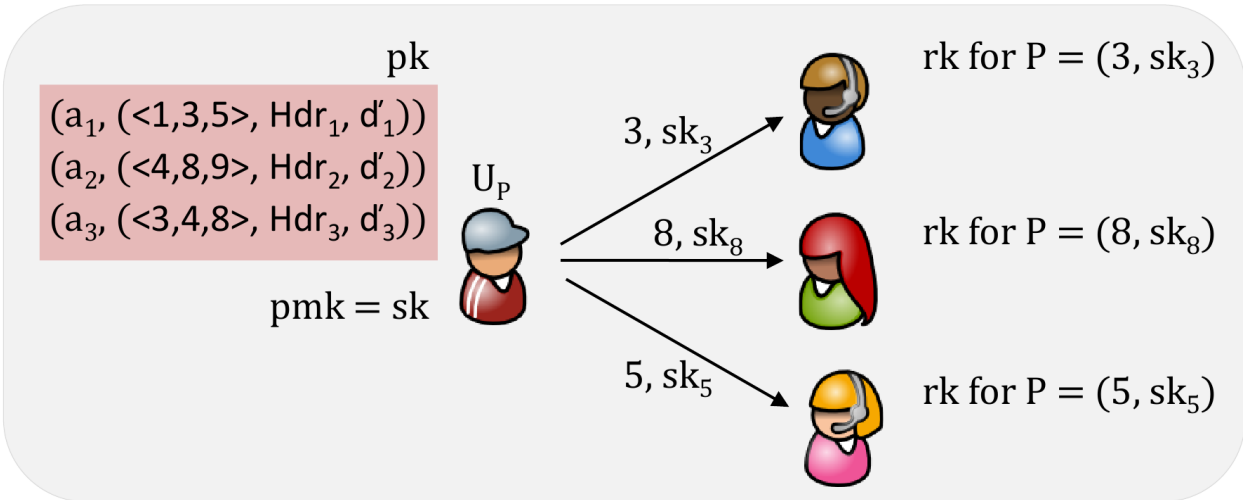

- confidentiality and perfect anonymity (strictly weaker than unlinkability)
- each user has to store one key per profile

Quantitative Evaluation

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Quantitative Evaluation was done regarding three properties:

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  - on initialization
  - on user addition
  - on user removal

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- number of encryptions
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- number of messages
  - on initialization
  - on user addition
  - on user removal

Quantitative Evaluation

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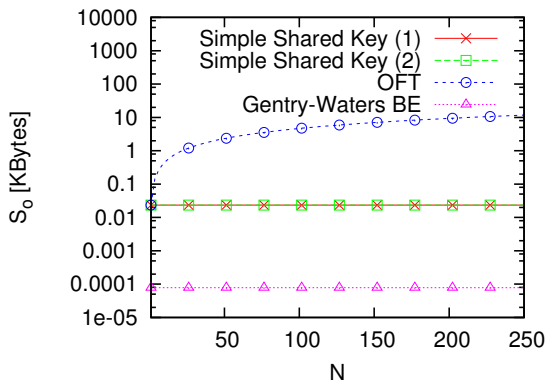
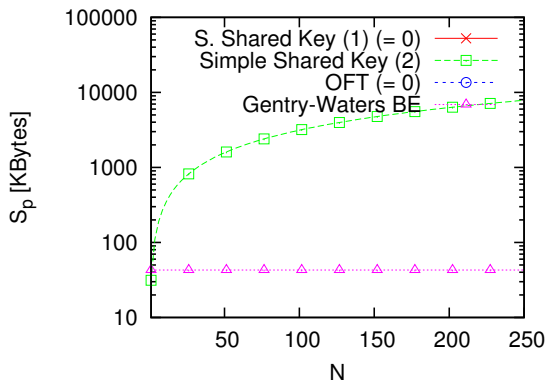
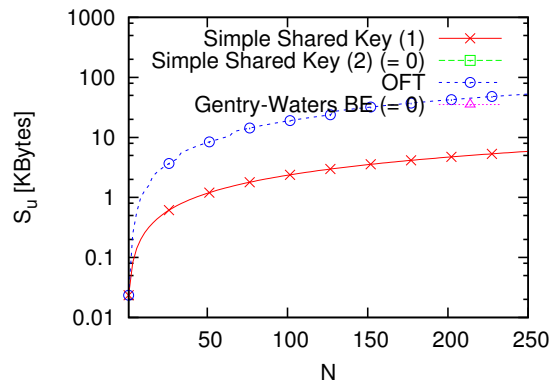
How much storage capacity is needed?



(a) at the owner



(b) in the profile



(c) at the users

- storage plots for a single attribute published for N users
- linear growth for some property for SK and OFT
- BE only needs constant storage

Quantitative Evaluation

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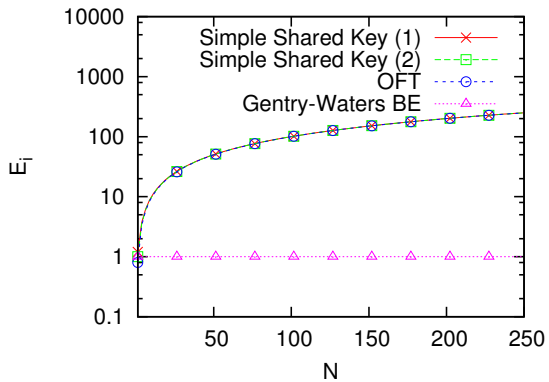
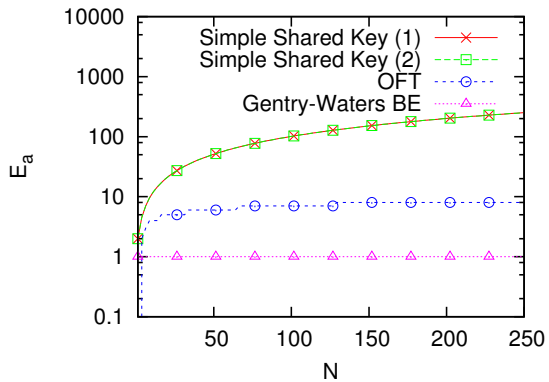
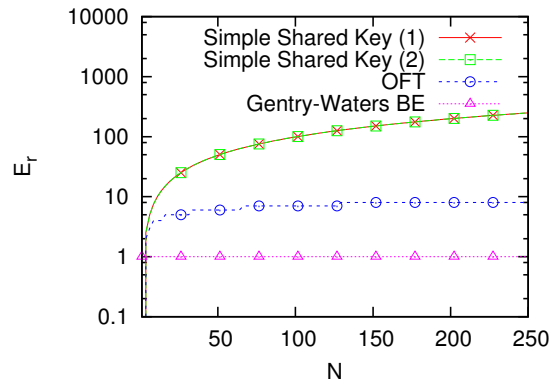
How many encryptions are needed?



(d) on initialization



(e) on user addition



(f) on user removal

- encryptions needed for a single attribute published for *N* users
- linear or logarithmic number of encryptions for Shared Key and OFT
- only a single encryption needed for BE, however more expensive

Quantitative Evaluation

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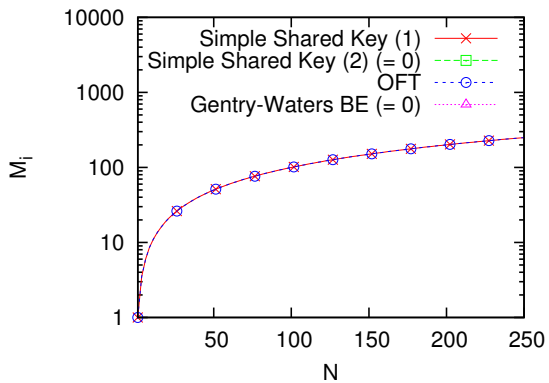
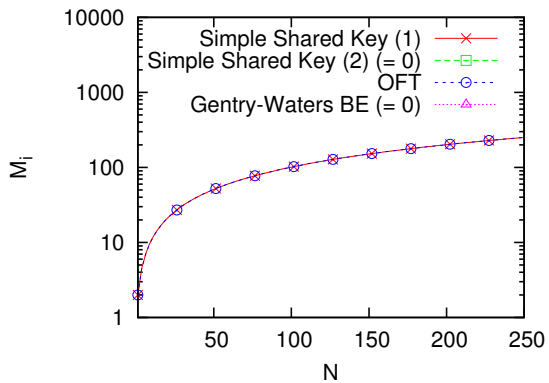
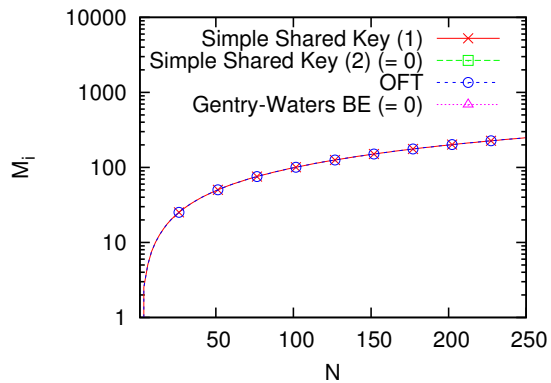
How many messages are sent?



(g) on initialization



(h) on user addition



(i) on user removal

- messages needed for a single attribute published for N users
- no messages needed for Shared Key with profile-side storage and BE
- client-side SK and OFT approaches need linear messaging

Impact on Real-Life Communities

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Analysis for Facebook, Twitter, XING, Flickr (based on their own statistics)

community	# contacts	# attributes	# keys		storage (KB)*	
			SK	BE	SK	BE
facebook	150	180	~27000	332	650	8
twitter	50	180	~9000	232	220	6
XING	168	~36	~8350	220	200	5
flickr	12	200	2000	214	62	5

* 192bit keys (SE and BE)

- SK and BE costs differ by a factor of 10 to 80
  - SK profile-side storage adds factor "#contacts" ($\rightarrow$ quadratic, difference 10^2–10^4)
- SK and BE overhead remains below 1 MB which could be acceptable

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- SK and BE overhead remains below 1 MB which could be acceptable
- generic approaches also applicable to secure established networks

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- practical trade-off between storage overhead and privacy

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- analysis in real-world settings shows low storage overhead
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- open question: possible to achieve unlinkability with sub-linear key overhead?
- implementation of plugin for existing OSN is ongoing

Security Goal: Confidentiality

Formal Definition

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Confidentiality Game (high level):

1. Execute $\texttt{Init}(\kappa)$ for each user U.
2. $\mathcal{A}$ interacts with users through queries (incl. Corrupt) until it outputs
   - $(a, d_0), (a, d_1)$ two index-attribute pairs
   - G_t group of users
   - U_P profile owner who is not in G_t
3. Bit $b \in_R \{0,1\}^*$. Execute $\texttt{Publish}(pmk, P, (a, d_b), G_t)$.
4. $\mathcal{A}$ interacts with users through queries until it outputs some bit b^*.

$\mathcal{A}$ is successful if:

- $b = b^*$
- $\mathcal{A}$ did not corrupt U_P or any user who was ever authorized to access a
- $\mathcal{A}$ did not retrieve d_b trivially via some suitable $\texttt{Retrieve}$ query

Profile Management Scheme is confidential if for all $\mathcal{A}$:

$$|Pr[\text{successfull attack}] - 1/2| \text{ is negligible in } \kappa.$$

Security Goal: Unlinkability

Formal Definition

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Unlinkability Game (high level):

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   - U_0, U_1 two users, (a, d) index-attribute pair, U_P profile owner
3. Bit $b \in_R \{0,1\}^*$.
   - If $(a, \cdot) \notin P$: execute $\texttt{Publish}(pmk, P, (a, d_b), \{U_b\})$.
   - If $(a, \cdot) \in P$: execute $\texttt{ModifyAccess}(pmk, P, a, U_b)$.
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- U_P, U_0, and U_1 are uncorrupted
- $\mathcal{A}$ did not query Retrieve(P, a, U_0) or Retrieve(P, a, U_1)

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Security Goal: Anonymity

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