Die wunderbare Welt kryptographischer Pseudonyme

Europäischer Datenschutztag 2026

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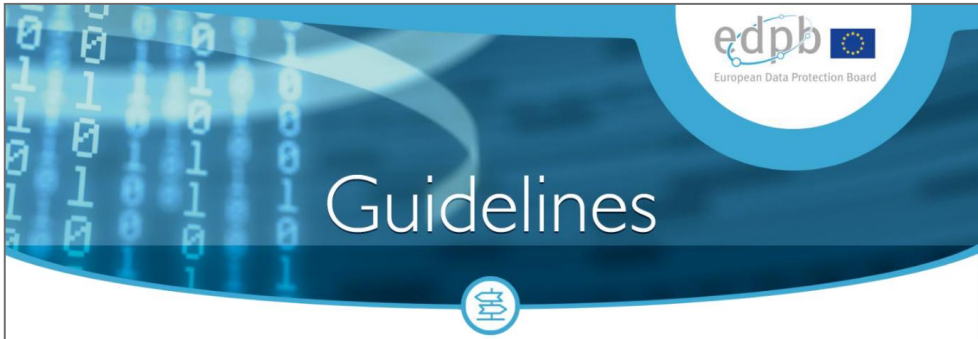
Pseudonymization

Pseudonymisation is defined in Art. 4(5) GDPR as "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."*

Disclaimer
This talks: pseudonymization from the perspective of cryptographic research



Pseudonymization

- Pseudonymization = replacing direct identifier with random-looking substitute

Name	Credit	IBAN
Alice Doe	52.650	CH56 0483 5084 1385 0100 0

Nym	Credit
xH2ban6	52.650

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- Requirements: pseudonymization must be
  - Secure, i.e., infeasible to determine **uid** from **nym**
  - Consistent, i.e., referential integrity must be preserved
  - Dynamic, i.e., data can be pseudonymized on the fly

UserID	Credit
Alice	€ 8.000
Bob	€ 3.500

UserID	Credit
Alice	€ 599

Nym	Credit
xH2ban6	€ 8.000
P3b0Ws	€ 3.500

Nym	Credit
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Pseudonymization | Current Solutions

87. Two classes of replacement procedures are commonly applied as pseudonymising transformations: cryptographic algorithms and lookup tables.[22]

UserID	Nym
Alice	xH2ban6
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Carol	912uj4V

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In theory: „Let K be a key“ In practice: Well, its not that easy ....

Challenge 1: Distributed Pseudonymization & Consistency

- Pseudonymization from multiple sources while preserving consistency

UserID	X-Ray
Alice	Picture-1
Bob	Picture-12

UserID	Doctor A
Alice	Measurement

UserID	Doctor B
Alice	Eval

Nym	X-Ray
xH2ban6	Picture-1
P3b0Ws	Picture-12

Nym	Doctor A
xH2ban6	Measurement

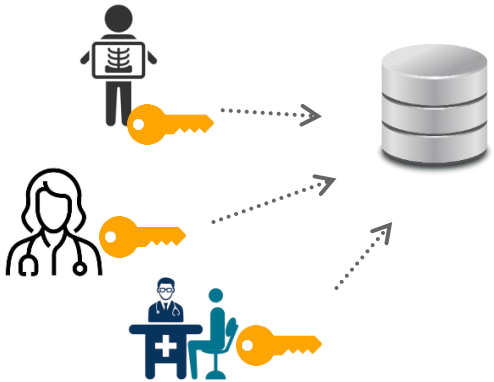
Nym	Doctor B
xH2ban6	Eval

How to ensure consistent and secure pseudonymization when data is pushed by many, distributed entities ?

Distributed Pseudonymization | Existing Solutions

- Secure pseudonymization requires strong cryptographic keys or secret lookup table

Key is shared with all entities



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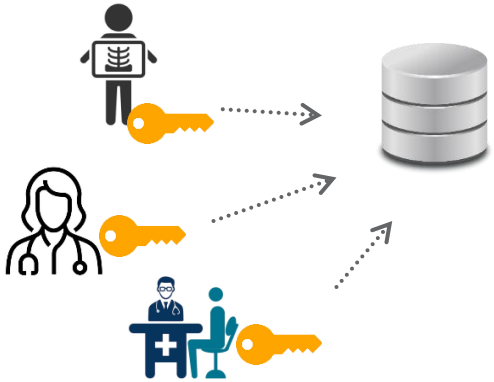

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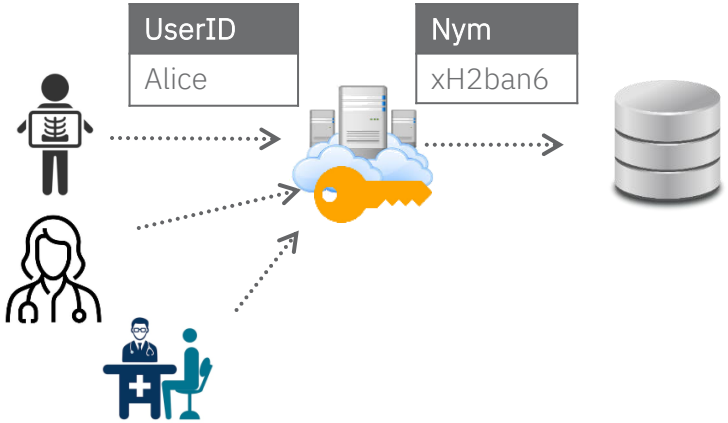
Central trusted service (TTP)



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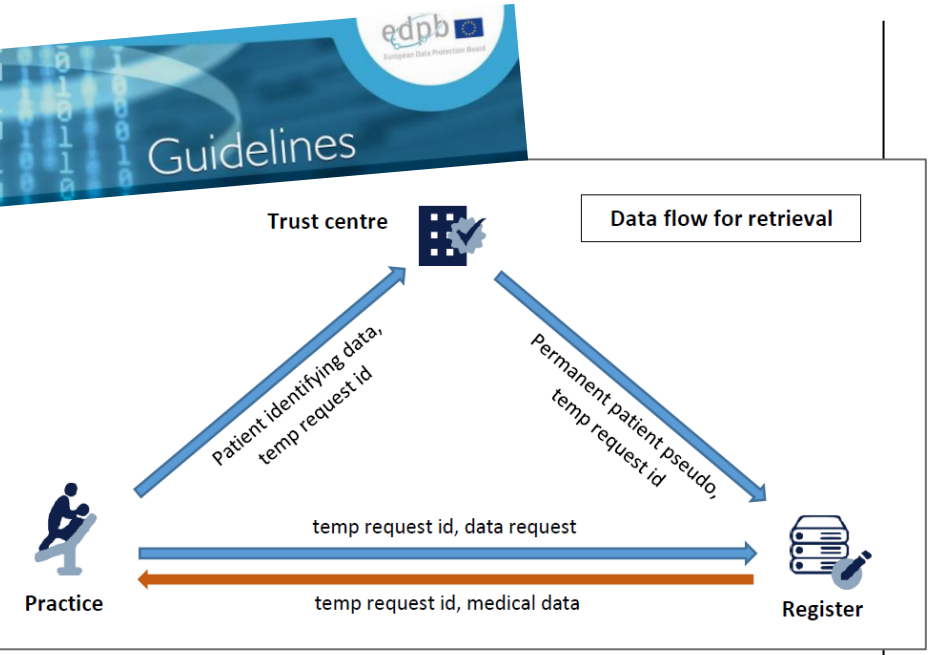

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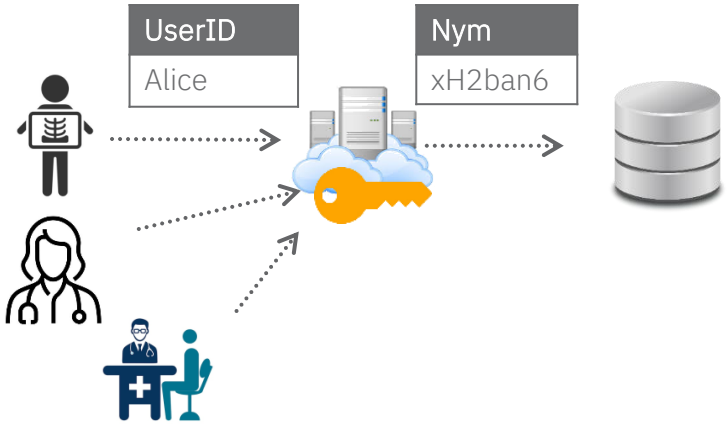

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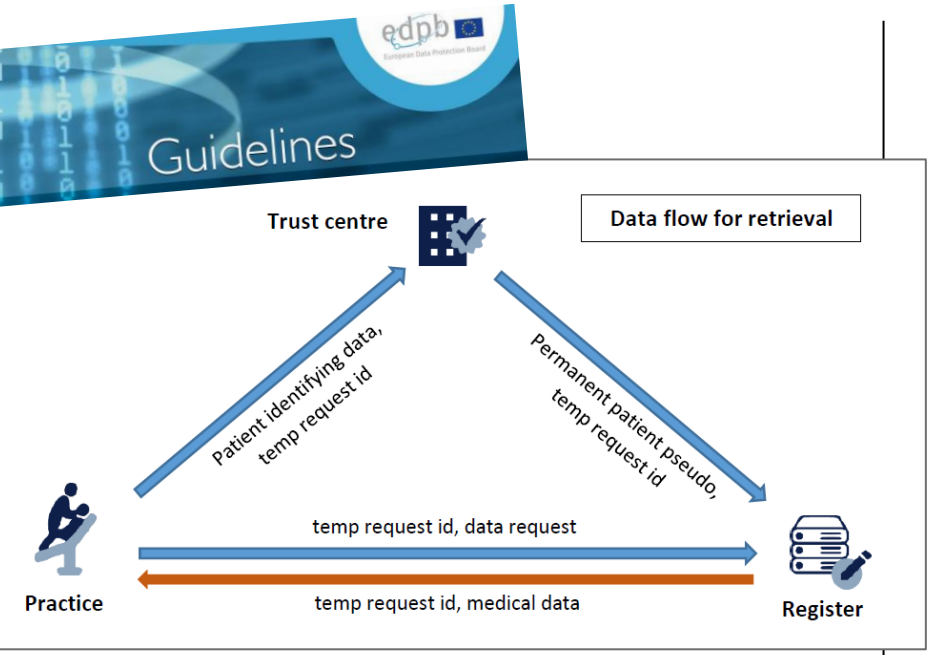

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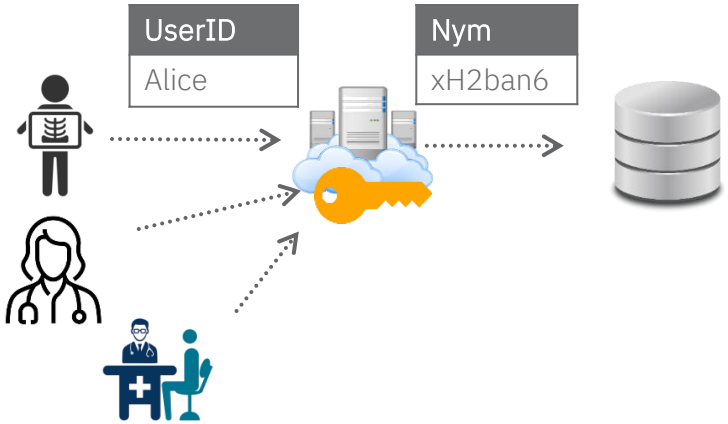

+ Simple and secure deployment
– TTP learns all metadata
– TTP must be fully trusted → privacy risk itself!

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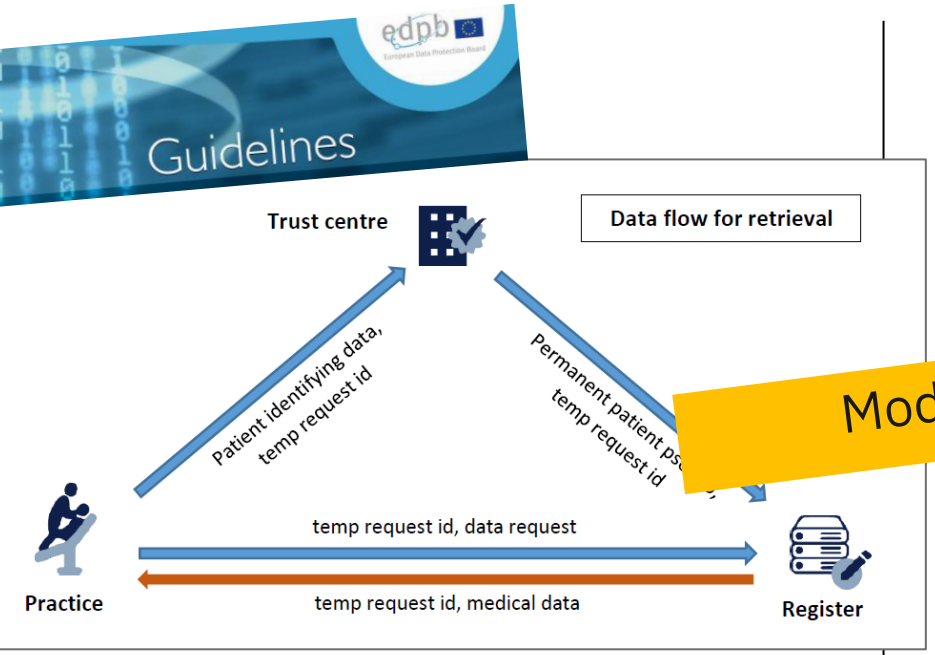

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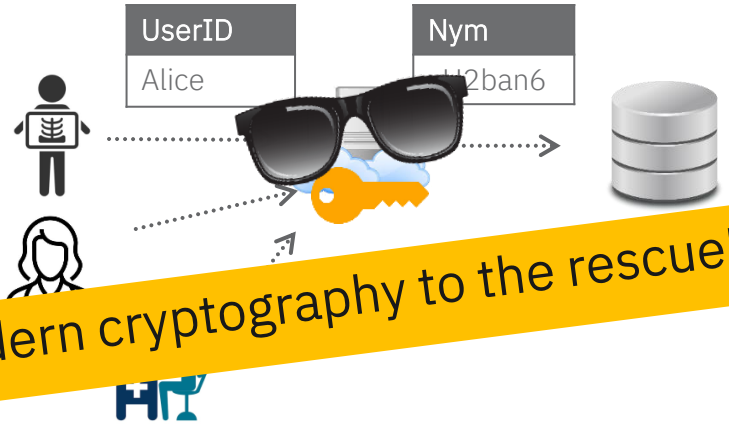


Modern cryptography to the rescue!

\+ Simple and secure deployment

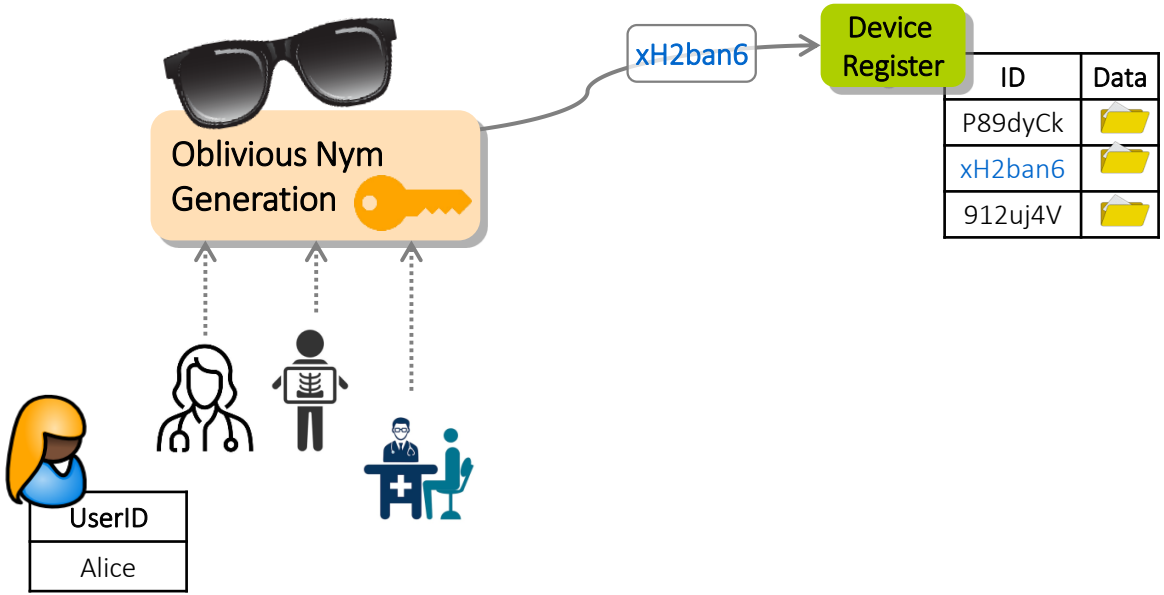
– ~~TTP learns all metadata~~

– ~~TTP must be fully trusted → privacy risk itself!~~

Distributed Pseudonymization | *Oblivious* Pseudonymization

- Central entity **blindly** computes consistent pseudonyms $nym = PRF(key, uid)$

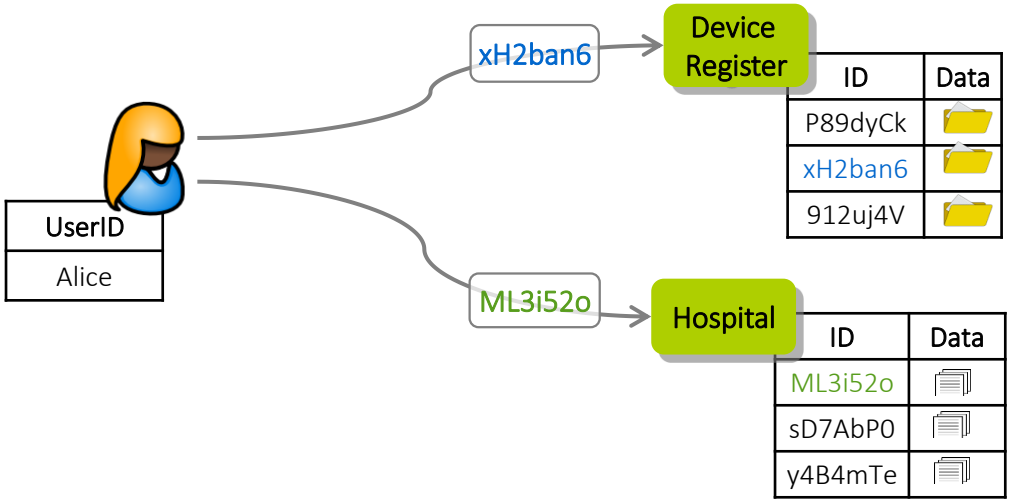
  → learns nothing about uid or nym!



[L19] *ScrambleDB: Oblivious (Chameleon) Pseudonymization-as-a-Service.* Lehmann. PETS 2019

Restrict Consistency to Domain Pseudonyms

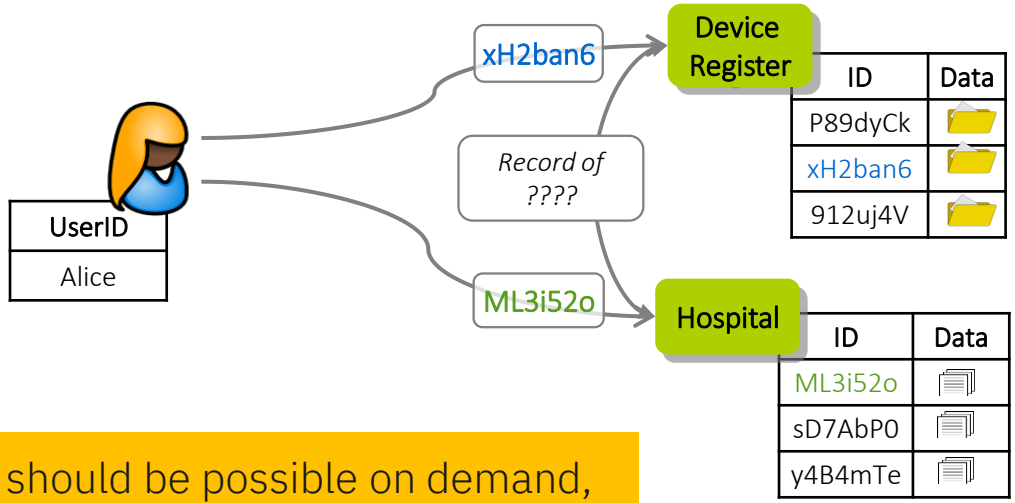
- Limit consistency of pseudonyms to minimally scoped domains
- User has domain-specific pseudonyms → unlinkable across domains



Challenge 2: Data Exchange with Unlinkable Pseudonyms

- How to exchange and correlate pseudonymous data ?

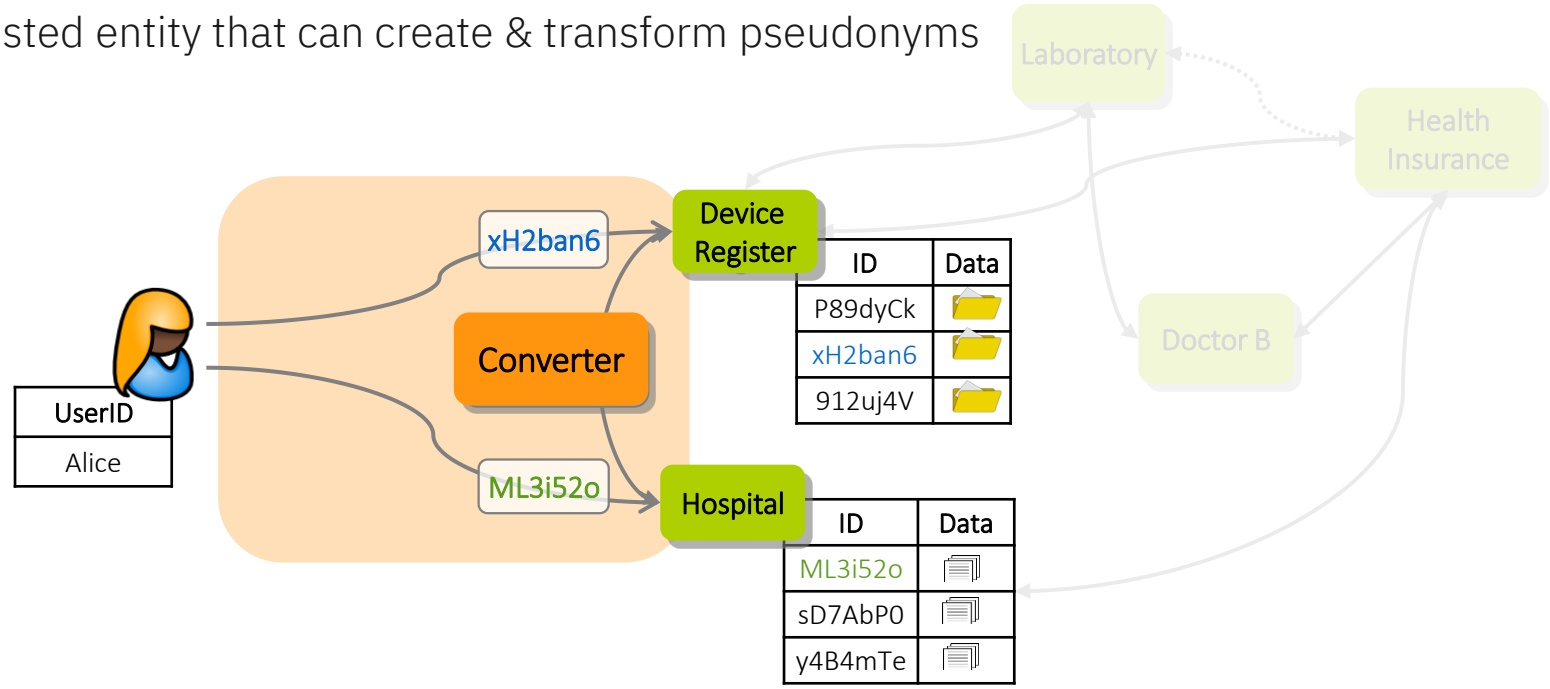
  E.g., eHealth records, social security system



Correlation should be possible on demand, but in a controlled way

Linkable Pseudonyms? *Trusted* Converter

- Central trusted entity that can create & transform pseudonyms



edpb European Data Protection Board

123. Several approaches to implementing pseudonymising transformations allow for the controlled linking of pseudonymised data held by different controllers: Sharing of pseudonymisation secrets among controllers, jointly using a trusted service provider for carrying out the pseudonymisation,

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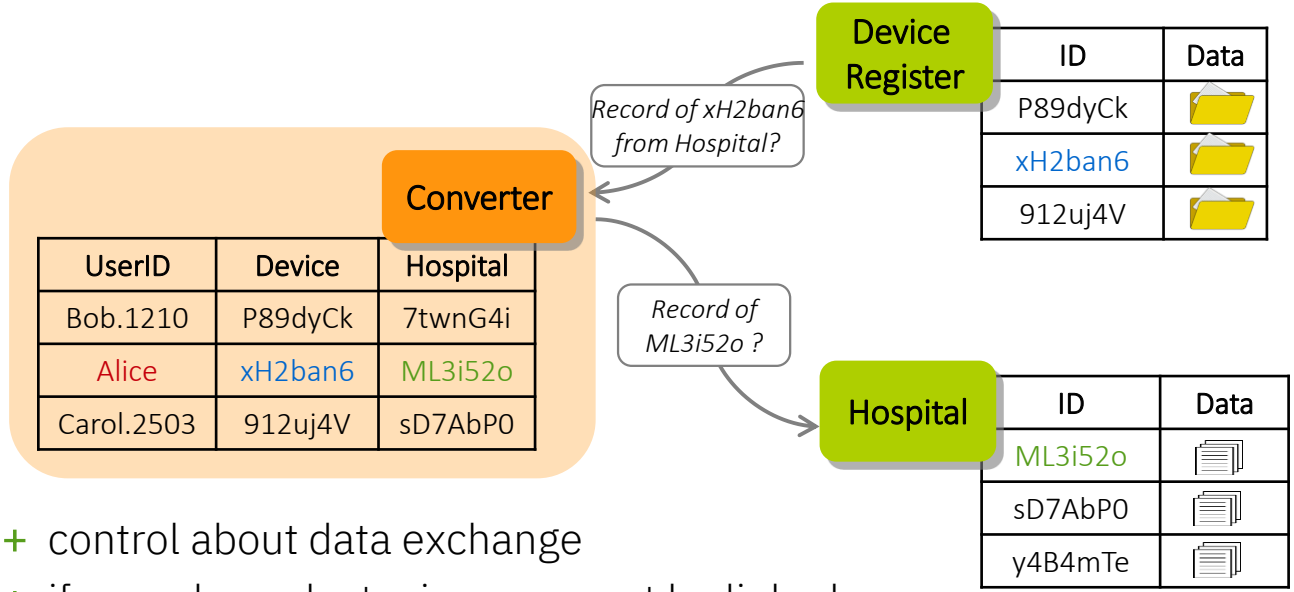

+ control about data exchange
+ if records are lost, pieces cannot be linked

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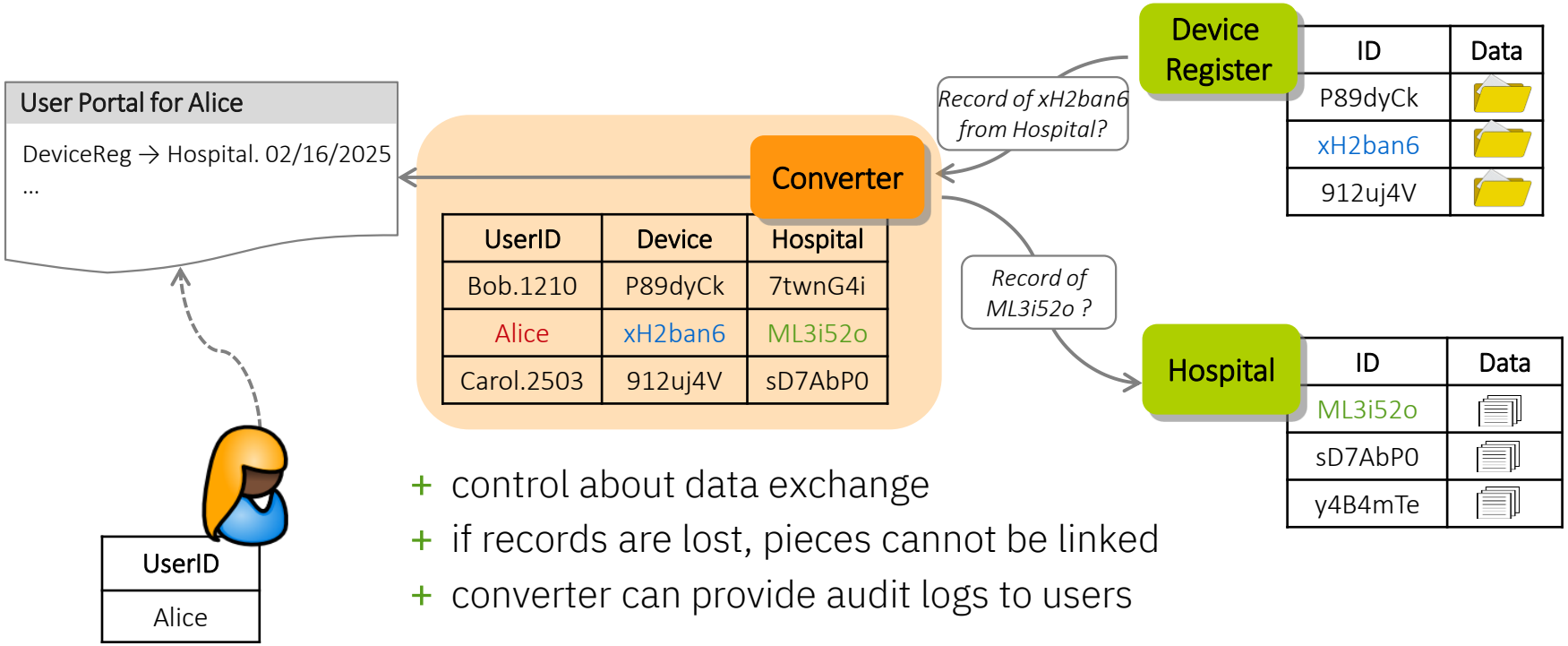

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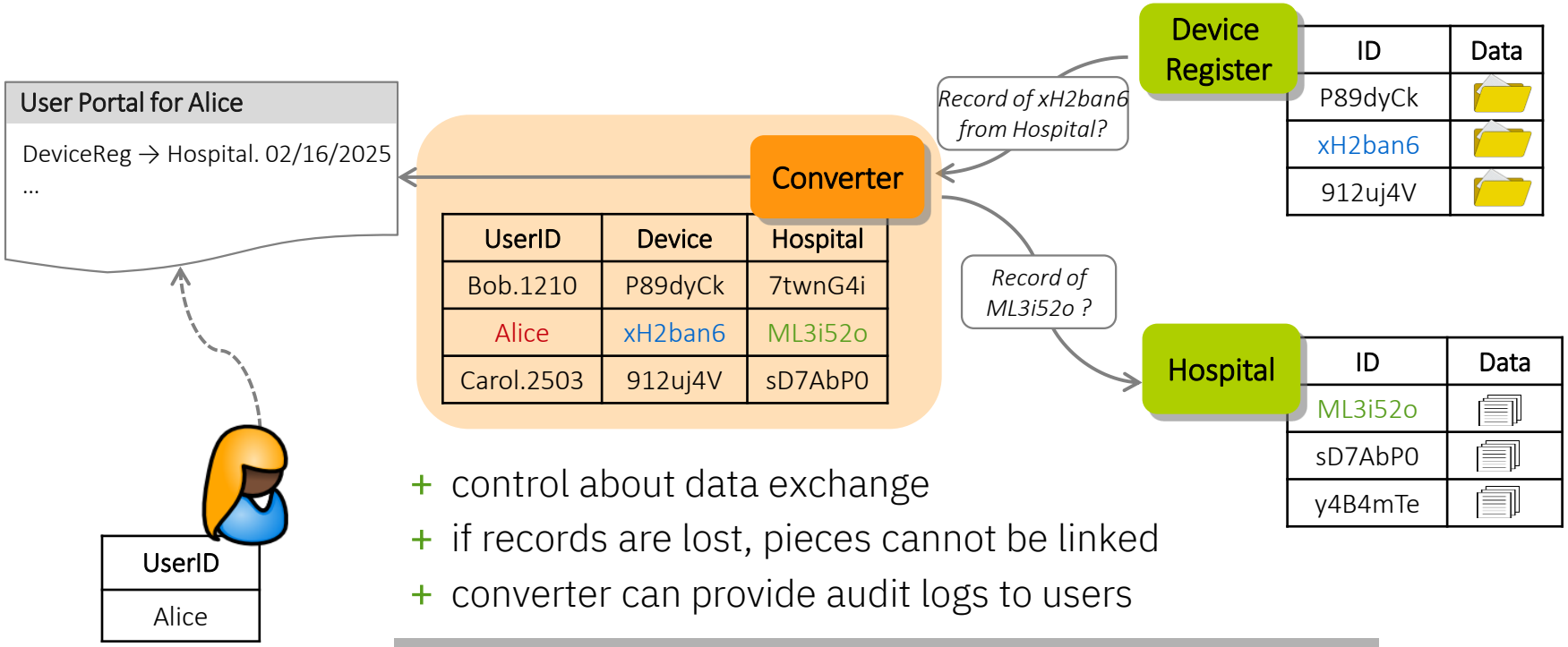

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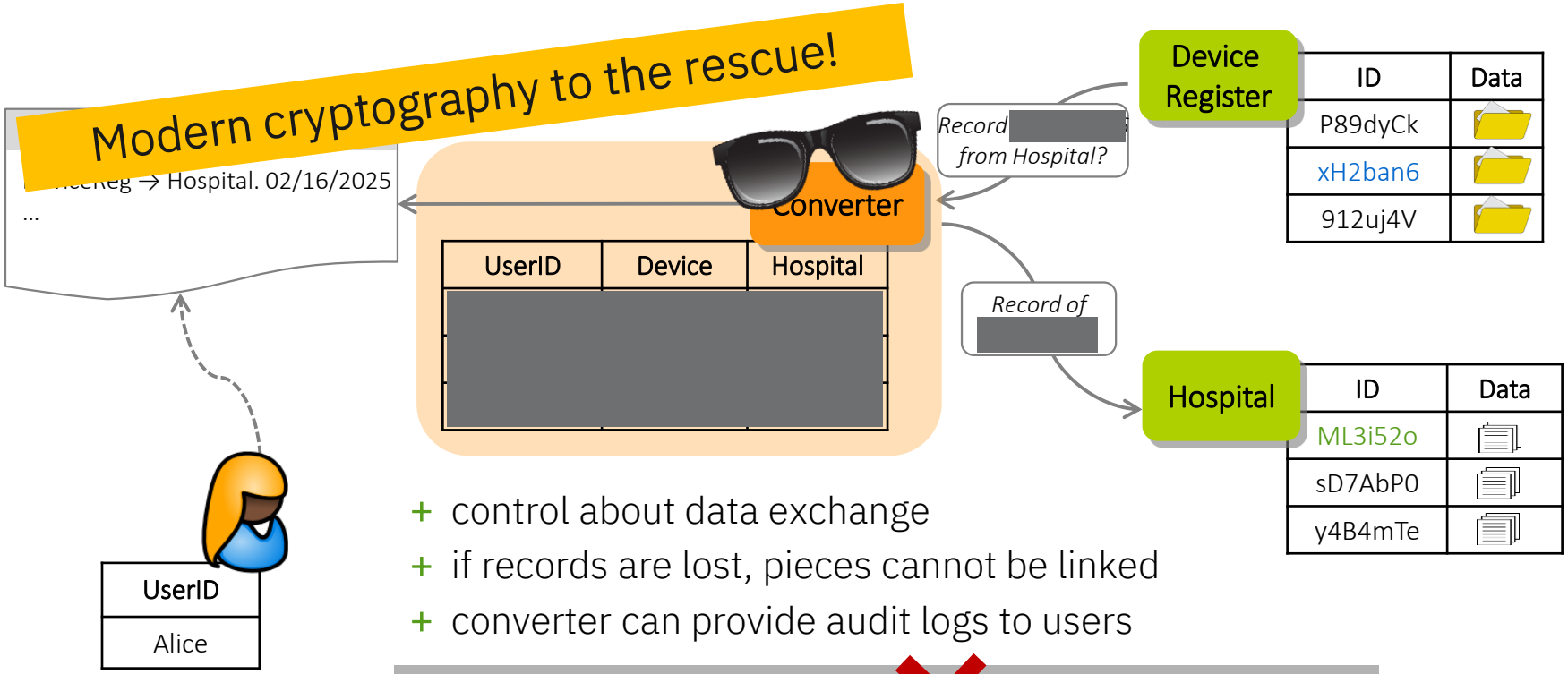
\+ converter can provide audit logs to users

– converter learns all requests & knows all correlations

Linkable Pseudonyms? *Oblivious* Converter

- Central trusted entity that can create & transform pseudonyms ***blindly***



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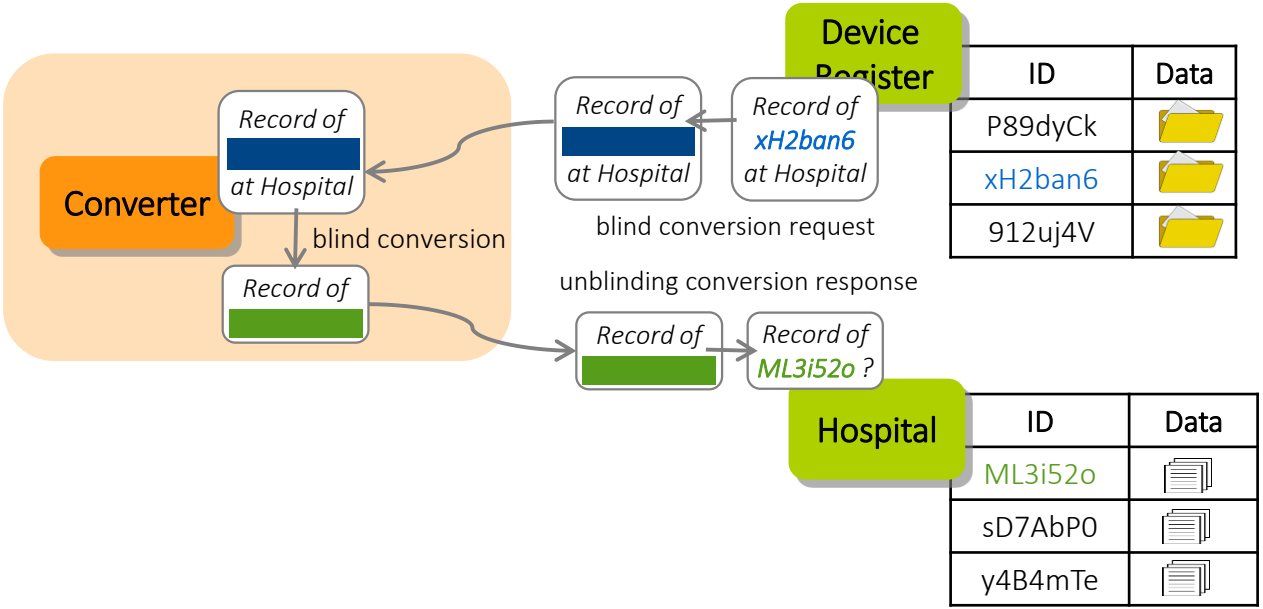
Blindly Convertible Pseudonyms | Pseudonym Conversion

- Only converter can link & transform pseudonyms, but does so in a blind way



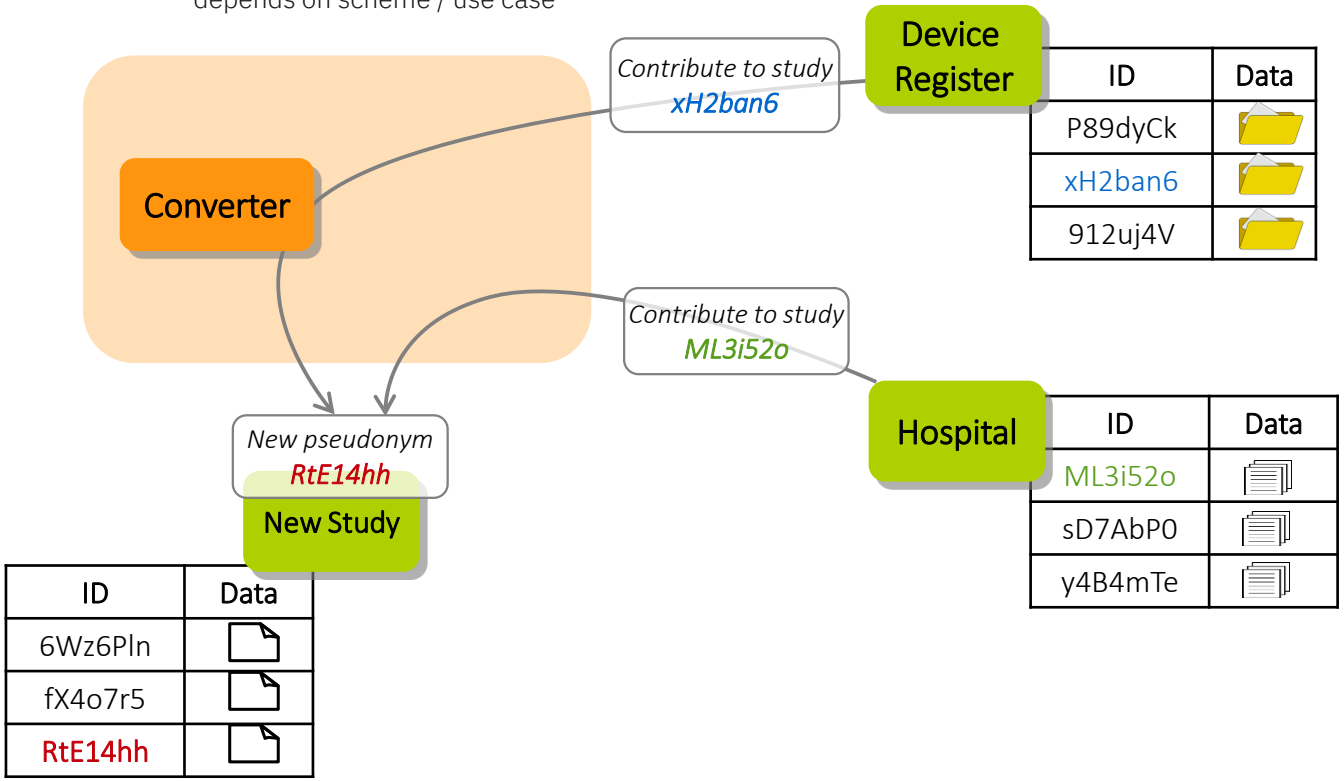
[CL15] *Privacy for Distributed Databases via (Un)linkable Pseudonyms*. Camenisch, Lehmann. ACM CCS 2015.

[VJM+16] *Polymorphic encryption and pseudonymisation for personalised healthcare.* Verheul et al., Technical Report 2016.

Blindly Convertible Pseudonyms | Consistent Joins

- Pseudonym conversions are transitive*, unlinkable data can be aggregated

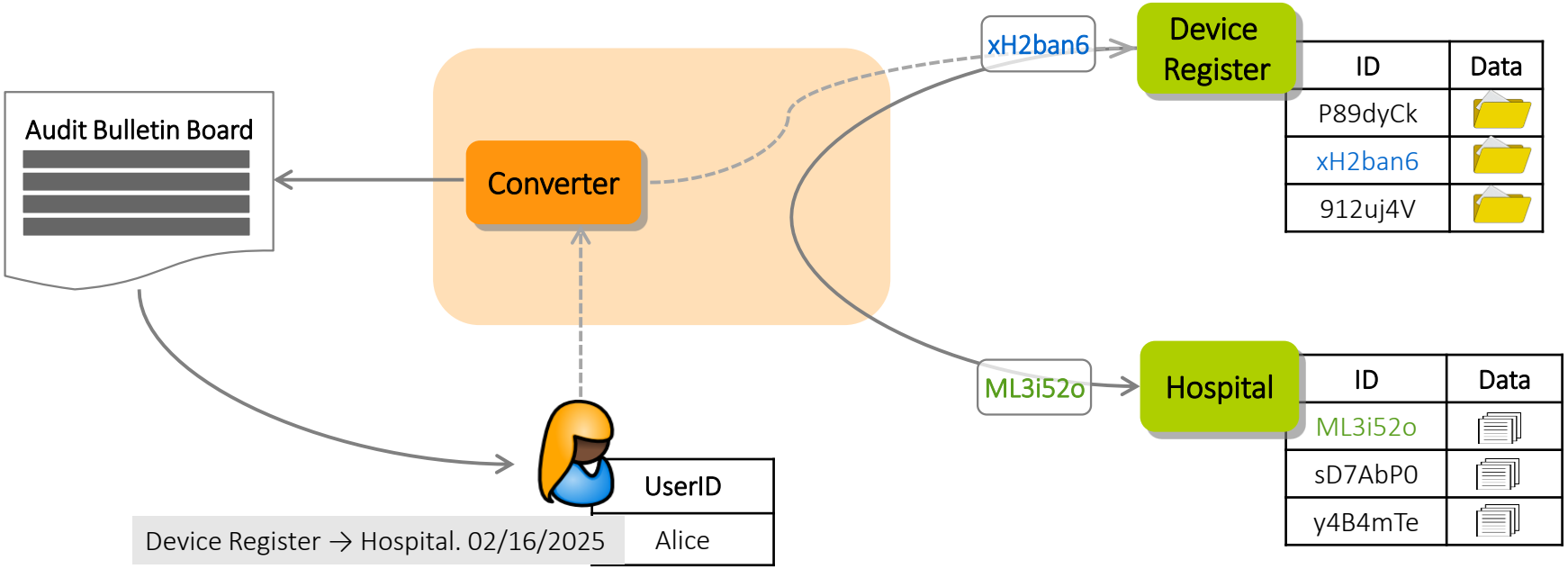
*depends on scheme / use case



[LMS26] *Multi-Party Private Join*. Lehmann, Mouchet, Sidorenko. PETS 2026

Blindly Convertible Pseudonyms | User Audits

- Every pseudonym conversion triggers blind generation of audit log entry



[CL17] *Privacy-Preserving User-Auditable Pseudonym Systems.* Camenisch, Lehmann. IEEE EuroS&P 2017

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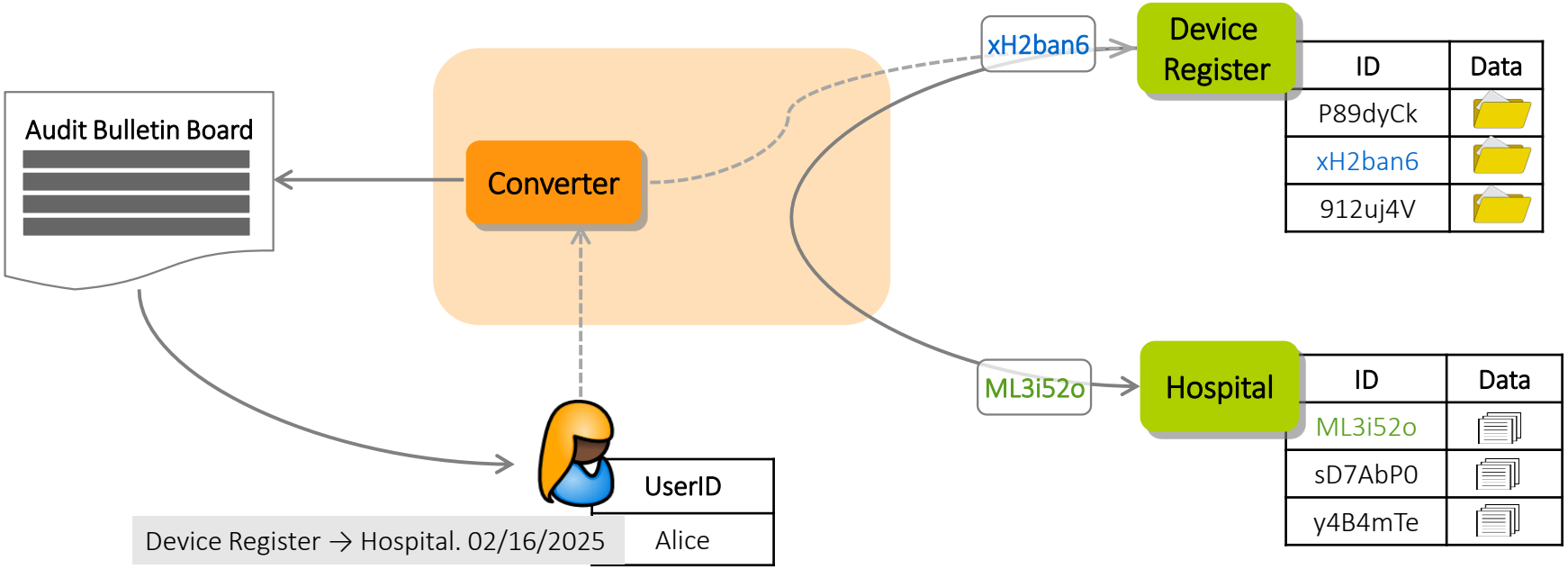

(Convertible) pseudonyms rely on disclosure of unique identifiers

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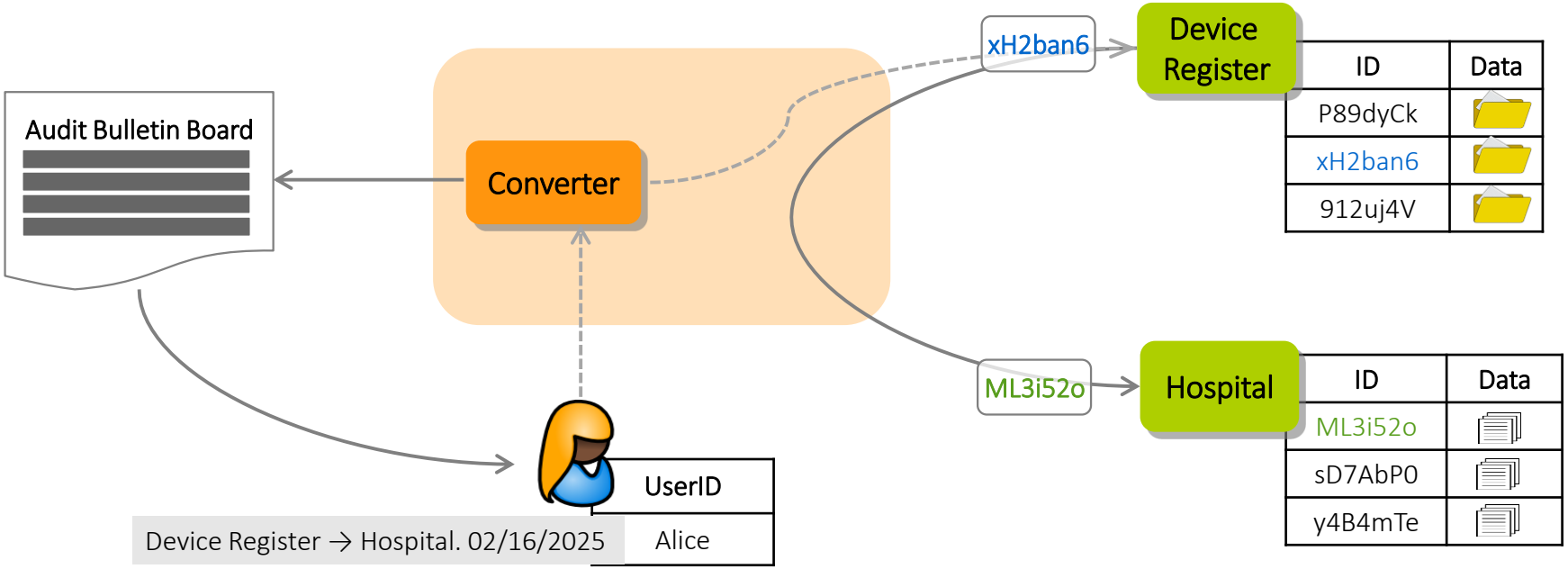
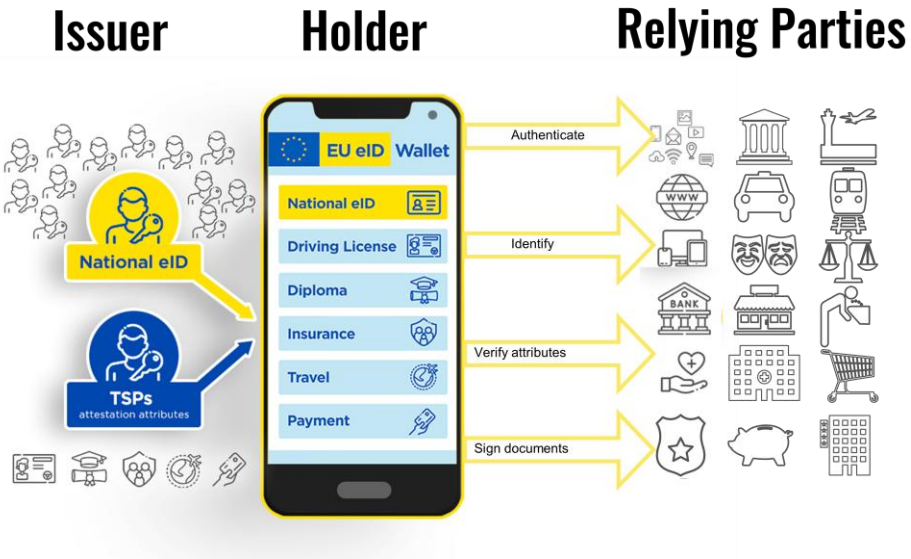


(Convertible) pseudonyms rely on disclosure of unique identifiers

… or on a *pseudonymous* digital identity → EUDI ?

European Digital Identity Wallet (EUDI)

- All EU member states must provide a EUDI Wallet by end of 2026



"fully mobile, secure and user-friendly"

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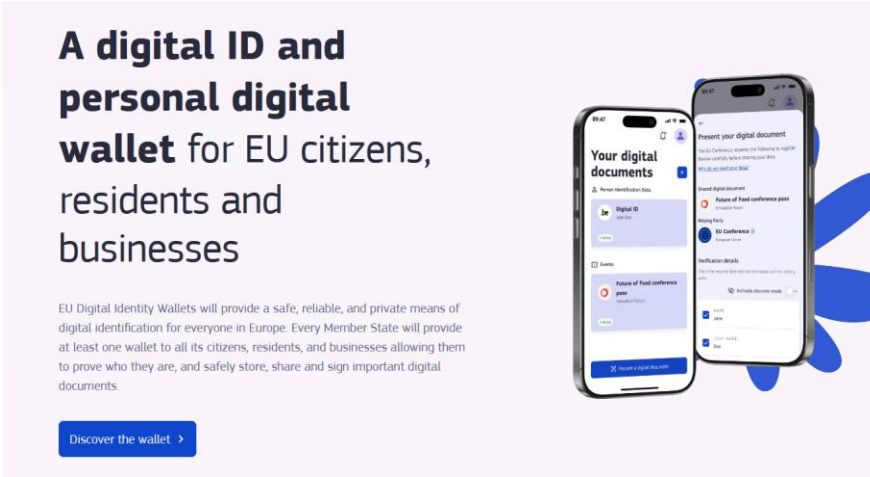

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EUDI | eIDAS Regulation → Wallet in 2026

- EU regulation eIDAS 2.0 entered into force in May 2024
- Regulation mandates strong privacy & security properties

https://eur-lex.europa.eu/eli/reg/2024/1183/oj

"securely [..] authenticate to relying parties [..] while ensuring **selective disclosure of data** [..]

enable privacy-preserving techniques which ensure **unlinkability** [..]

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Pseudonym = Donald Duck ??

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EUDI | Potential for Pseudonymous Authentication

Know-Your-Customer
open bank account

Age Proofs

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This is where **pseudonymous authentication** can have biggest impact

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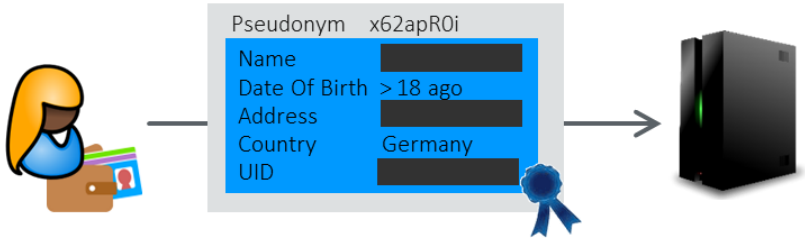

- Pseudonym derived from certified (but secret) UID: $nym = F(uid)$
  Establishes verifiable and unforgeable pseudonymous identity
  Pseudonymous authentication is unlinkable (with ZKPs)

[MLS25] *A Brief Note on Cryptographic Pseudonyms for Anonymous Credentials.* Mayrhofer, Lehmann, shelat

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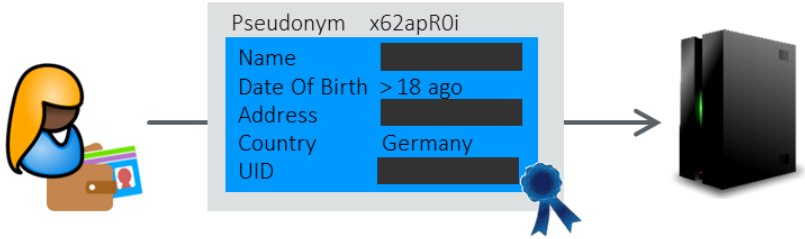

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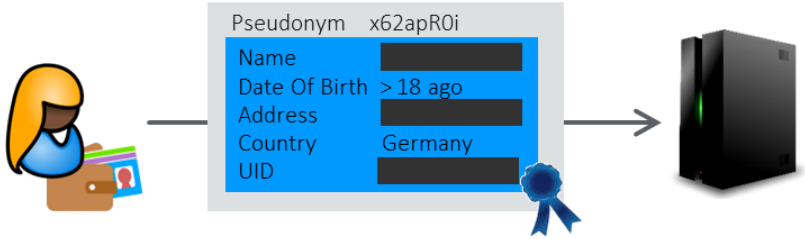

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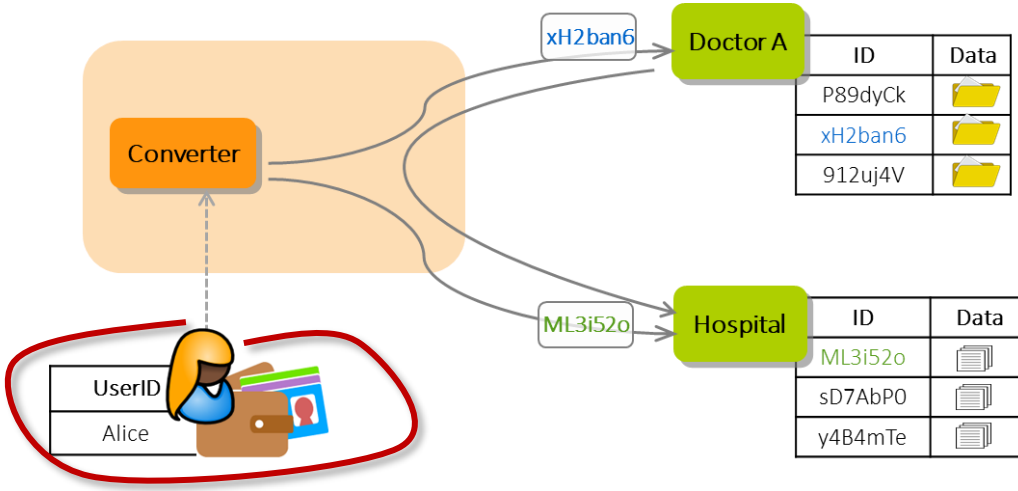
  Ensuring that users can only have single account
- Many properties associated with unique and full identification can be bootstrapped in pseudonymous manner

Cryptographic Pseudonyms | Summary & State of the Art

eID with proper pseudonyms would allow to bootstrap convertible pseudonym system

- Collect already pseudonymized data
- Unlinkable pseudonyms as default
- Controlled linkability only when needed



- Modern pseudonym systems enable *blind* computation & *blind* linkage of pseudonyms

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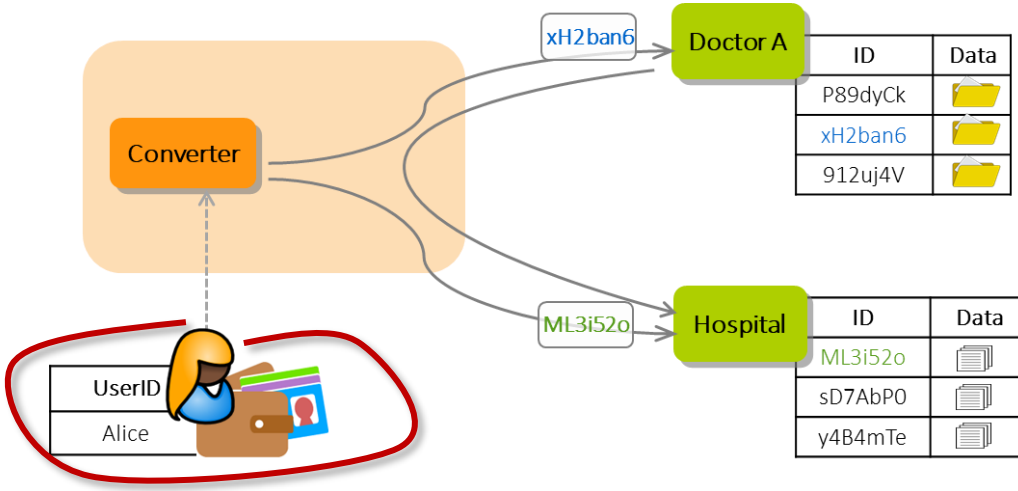
- Unlinkable pseudonyms as default
- Controlled linkability only when needed



- Modern pseudonym systems enable *blind* computation & *blind* linkage of pseudonyms

Note:

- Cryptographic pseudonyms focus on identification/linkage, not the associated data
  → Extra measures to ensure that associated data is not identifying (in particular when linked)

References

[CL15] *Privacy for Distributed Databases via (Un)linkable Pseudonyms*. Camenisch, Lehmann. ACM CCS 2015.

[VJM+16] *Polymorphic encryption and pseudonymisation for personalised healthcare (PEP).* Verheul, Jacobs, Meijer, Hildebrandt, Ruiter. Technical Report 2016.

[CL17] *Privacy-Preserving User-Auditable Pseudonym Systems.* Camenisch, Lehmann. IEEE EuroS&P 2017

[L19] *ScrambleDB: Oblivious (Chameleon) Pseudonymization-as-a-Service.* Lehmann. PETS 2019

[GL19] *Group Signatures with Selective Linkability.* Garms, Lehmann. PKC 2019

[MLS25] *A Brief Note on Cryptographic Pseudonyms for Anonymous Credentials.* Mayrhofer, Lehmann, shelat. https://arxiv.org/pdf/2510.05419 2025

[LMS26] *Multi-Party Private Join*. Lehmann, Mouchet, Sidorenko. PETS 2026