Balancing smartness and privacy

for the Ambient Intelligence

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Ambient Intelligence....

... is everywhere and has influence on many aspects of daily life

... is invisible

... renders fast technical developments in new, powerful, sensing capabilities

... has a memory

Why does the AmI have this 'memory'?

Storing of context data to facilitate 'smartness'

- Context histories make it possible to:
  - Infer, predict and learn
    - pattern recognition
    - inferring next location
    - predicting next events
    - ...*et cetera*
  - Share knowledge
    - profile matching
    - finding experts
    - interests sharing
    - ...*et cetera*

Smartness...

...depends on quality and quantity of context data

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Smartness...

...depends on quality and quantity of context data

This introduces a privacy problem!

- People will not always be aware of being monitored
- People do not know what happens or will happen with their data
- It will sometimes be hard to detect privacy violations
- Privacy sensitive ‘facts’ from the past will be kept forever in the system
  - Facts from the past can be used against you

Problem

We want to find a balance between smartness and privacy

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We want to find a balance between smartness and privacy

Why privacy protection?

- Data should not be retained excessively
  - Imposed by the law (U.N. regulations for example)
    - Reduces impact of hacking
    - Avoid tracing
  - Trusted organizations are pushed to respect the law

Related work

- *k*-Anonymization, l-diversity, et cetera
- Hippocratic databases, p3p policies
- Access control (encryption, micro-views, et cetera)
- ...

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Architecture

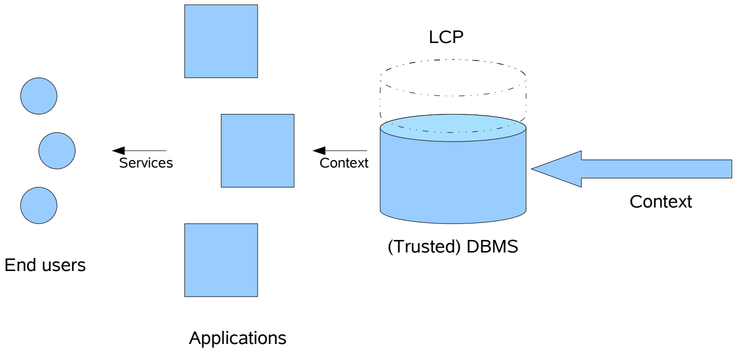

Figure: *Architecture*

Assumptions

- DBMS - Honest
  - DB and DB admin can be trusted *now* and in the near future, but might become untrusted in the future.
- Applications - Trusted
  - Applications have an interest to respect privacy (in order to keep their market segment).
  - Application code and data exchange communication cannot be attacked
- End users - Malicious
  - Only results or services given by applications are visible for end users.
  - Attacks because of (physical) spying between users are not addressed.

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Access control or limited retention?

Access control

- Policies define until when and to which data applications have access.
- Data is kept and protected within the system
- The DB (and administrator) should be trusted now and in the future

Limited retention

- Use policies to define until when and which data is kept in the system
- Physical removal of data
- DB can be trusted *now*, but might be not in the future

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Progressive degradation (as a retention model)

- Fill the gap between ‘all or nothing’
  - Destroy all data means no smartness for applications
  - Keeping all data means possible privacy violation for users

Example

- A supermarket uses accurate data to predict if new cash desks should be opened
- It uses per customer buying information to make personalized advertisements
- And uses general statistics to optimize its selection of goods.

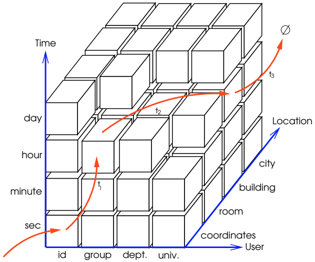
The Life-Cycle Policy model

Progressive value degradation of context histories

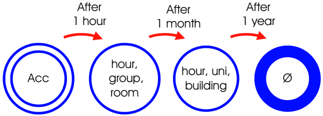
- Users specify when and how data should be degraded
- Goal is to protect context histories:
  - Degraded data is less privacy sensitive
- Current and recent accurate data is still available
  - Degraded data is still useful in terms of smartness
- There is room for negotiation about policies between application and users

The LCP model

- Data modeled as context triplets
- Triplets are elements in different states of accuracy
- Life-Cycle policies are transitions between states
- Users can specify their own LCP



(a) The Cube



(b) Example LCP

Functional degradation

- Data processing can be translated to SQL statements
- ‘Disable’ SQL operators by transforming the data
- Progressive degradation of the accuracy of those *abilities*

Example

- Keep the join ability without keeping real time values
- Degrade the ability from ‘join on minutes’ to ‘join on hour’

Functional degradation

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Value degradation and functional degradation

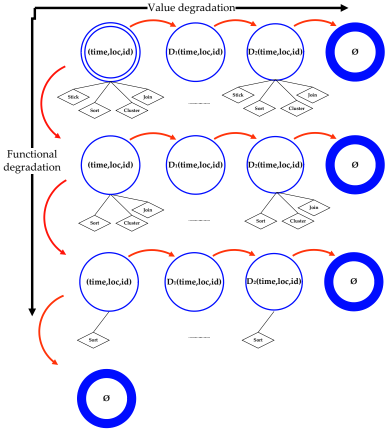

Figure: *(Natural) value degradation, and functional degradation of abilities*

Degradation in isolation for a known query set

Application oriented approach

Adequacy

Given a query Q on a dataset D, there is a degradation function V such that an alternative query Q' on $V(D)$ can be found which produces the same result as Q.

- Provide an adequate degradation function for a known set of queries
- Goal is to keep the least amount of information necessary to provide adequacy

Example: join on time

Query: $\pi_{door.event,window.event}\left(Door \bowtie_{hour(time)} Window\right)$

event	time	loc	id
e1	15.10	3090	1
e2	15.10	3090	2
e3	15.15	2045	2
e4	16.30	4180	1
e5	17.00	3090	3
e6	17.15	5360	3

(a) Door

event	time	loc	id
w1	15.10	3090	2
w2	16.05	1027	1
w3	17.02	2045	3
w4	18.05	2045	3
w5	18.15	2045	3
w6	18.16	2045	1

(b) Window

Result: $\{(e_1, w_1), (e_2, w_1), (e_3, w_1), (e_4, w_2), (e_5, w_3), (e_6, w_3)\}$

Example: join on time (cont'd)

Query: $\pi_{V(door).event', V(window).event'}(V(Door) \bowtie_{time'} V(Window))$

event'	time'	loc'	id'
e1	a	3090	1
e2	a	3090	2
e3	a	2045	2
e4	b	4180	1
e5	c	3090	3
e6	c	5360	3

(c) V(Door)

event'	time'	loc'	id'
w1	a	3090	2
w2	b	1027	1
w3	c	2045	3
w4	d	2045	3
w5	d	2045	3
w6	d	2045	1

(d) V(Window)

$18 \mapsto d$

Result: $\{(e_1, w_1), (e_2, w_1), (e_3, w_1), (e_4, w_2), (e_5, w_3), (e_6, w_3)\}$

Example: join on location

Query: $\pi_{door.event,window.event}\ (Door \bowtie_{loc} Window)$

event	time	loc	id
e1	15.10	3090	1
e2	15.10	3090	2
e3	15.15	2045	2
e4	16.30	4180	1
e5	17.00	3090	3
e6	17.15	5360	3

(e) Door

event	time	loc	id
w1	15.10	3090	2
w2	16.05	1027	1
w3	17.02	2045	3
w4	18.05	2045	3
w5	18.15	2045	3
w6	18.16	2045	1

(f) Window

Result: $\{(e_1, w_1), (e_2, w_1), (e_3, w_3), (e_3, w_4), (e_3, w_5), (e_3, w_6)\}$

Example: join on location (cont'd)

Query: $\pi_{V(door).event', V(window).event'}(V(Door) \bowtie_{loc'} V(Window))$

event	time	loc	id
e1	15.10	a	1
e2	15.10	a	2
e3	15.15	b	2
e4	16.30	d	1
e5	17.00	a	3
e6	17.15	e	3

(g) Door

event	time	loc	id
w1	15.10	a	2
w2	16.05	c	1
w3	17.02	b	3
w4	18.05	b	3
w5	18.15	b	3
w6	18.16	b	1

(h) Window

$3090 \mapsto a, 2045 \mapsto b, 1024 \mapsto c, 4180 \mapsto d, 5360 \mapsto e$

Result: $\{(e_1, w_1), (e_2, w_1), (e_3, w_3), (e_3, w_4), (e_3, w_5), (e_3, w_6)\}$

Problems

- Additional information is needed to keep the degraded data *adequate*
  - Possibly use secure hardware, access control, distributed keys, *et cetera*
  - At least the data itself can be stored in a non-secure database

Possible approach: one-way hash function

- But, domain is finit and sometimes small: easy to brake irreversability
- Use an additional key, and keep the key secret
  - Still requires access control, and disclosure of the key means disclosure of all data

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Conclusion

Ultimate goal is to balance privacy and smartness:

- Giving control to users limits asymmetric information
- Physical removal of data prevents unauthorized data disclosure
- Progressive degradation balances users wishes and application requirements

Questions?