Distributed data management with the rule-based language: ***Webdamlog***

Ph.D. defense

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Focus of this thesis

Allow the Web users to manage their personal data in place

Two main aspects:

- personal data are distributed
- Web users want to automate tasks and they are not programmers

Problem overview

We are interested in all kinds of data of a Web user

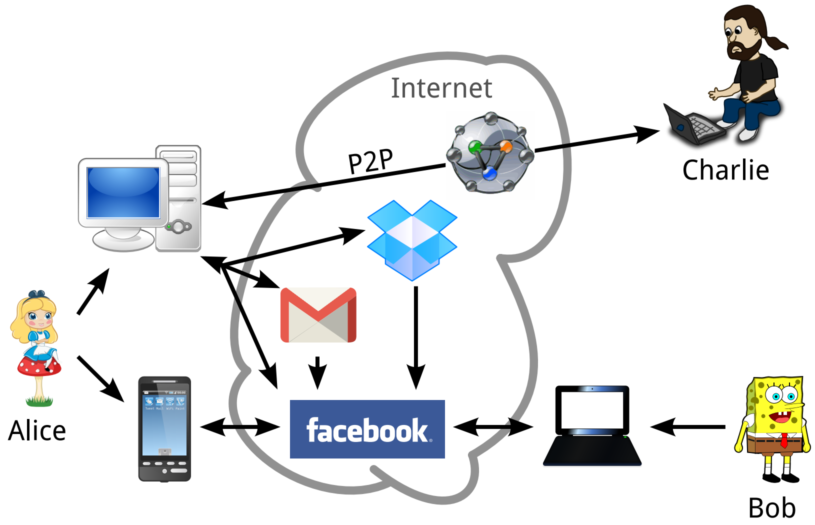
- **personal data** photos, movies, music, emails
- **social data** annotations, recommendations, social links
- **localization** bookmarks, phone numbers
- **privacy** logins/passwords, ssh keys

Data of users are heterogeneous by nature

Data are distributed on several

- **devices** laptops, smartphones, Internet boxes, cloud-storage, ...
- **systems** Facebook, Picasa, Gmail, ...

Typical distribution of knowledge



Example of distributed task on personal data

Alice has

- a blog on Wordpress.com to publish movie reviews
- a Facebook and Gmail account to talk to friends
- a Dropbox account to share files

she wishes to advertise friends about new reviews and share the movie

Cumbersome tasks for humans

- remember each login/password
- sign on each website
- use each GUI

Solutions

- hope that a system, e.g. Facebook, provides an appropriate wrapper
- try to specify it with a system such as `ifttt.com` "if this then that"
- if everything fails, write a script (only for hackers)

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The Web as a distributed knowledge base

Give to Alice a system that

- use the Web service to manage her knowledge
- allow her to specify tasks
- hide the network and protocol issues

Principles underlying the approach

- Knowledge and computation are distributed on several peers
- These peers are autonomous (P2P)
- They are willing to collaborate (delegation)
- Knowledge from heterogeneous systems is integrated using "wrappers" in a mediation style

Representing knowledge in datalog

Facts in relations:

Friend

user	friend with
Alice	Bob
Alice	Charlie
Bob	Charlie

Picture

id	tag
pic1	Alice
pic2	Bob
pic3	Charlie

Location

pic id	location
pic1	Grenoble
pic2	Nantes
pic3	Rennes

Rules:

$$\underbrace{\texttt{Where(\$someone,\$loc)}}_{\textit{head}} \;\texttt{:-}\; \underbrace{\underbrace{\texttt{Picture(\$pic,\$someone)}}_{\textit{atom}},\;\underbrace{\texttt{Location(\$pic,\$loc)}}_{\textit{atom}}}_{\textit{body}}$$

Representing knowledge in datalog

In datalog relations are either:

- extensional: `Friend,Picture,Location`
  - a list of facts stored in database
  - only in the body of datalog rules
- intensional: `Where`
  - a list of facts defined by rules ie. a *view*
  - appear at least once in the head of a rule

Datalog supports recursion

Recursion needed in graphs e.g. network path, social link

```
FoF($x,$y) :- Friend($x,$y)
FoF($x,$y) :- Friend($x,$z), FoF($z,$y)
```

Already exists in SQL but ugly

```
WITH RECURSIVE FoF(From, To) AS
(
SELECT From, To, FROM Friend
UNION
SELECT Friend.From, FoF.End
FROM Friend, FoF
WHERE Friend.To = FoF.From);
```

Some datalog extensions we use

update extensional relations in the head of rules:

```
Friend($y,$x) :- Friend($x,$y)
```

negation in the body of rules

```
Picture($x,Charlie) :- Picture($x,Alice), ¬Picture($x,Bob)
```

distributed relations are distributed over the network

```
Picture@Bob($x,Bob) :- Picture@Alice($x,Bob)
```

Webdamlog

Schema

(π, E, I, σ) where

- π is a possibly *infinite* set of peer names
- E is a set of extensional relations of the form `m@p` for $p \in \pi$
- I is a set of intensional relations of the form `m@p` for $p \in \pi$
- σ(`m@p`) typing function, arity and sorts of `m@p` fields

Webdamlog

Facts

`m@p(`$a_1, ..., a_n$`)`, where

- `m` is a relation name
- `p` is a peer name in π
- $n = \sigma(\texttt{m@p})$ and $a_1, \ldots, a_n$ are data values
  data values includes the relations and peer names

Extensional

```
Friend@Alice(Alice,Bob)
Friend@Alice(Alice,Charlie)
Friend@Alice(Bob,Charlie)
Picture@Alice(pic1,Alice)
...
```

Intensional

```
Where@Alice(Alice,Grenoble)
Where@Alice(Bob,Nantes)
Where@Alice(Charlie,Rennes)
```

Webdamlog

Rules

$\$R_{n+1}@\$P_{n+1}(\$\overline{U}_{n+1})$:- $(\neg)\$R_1@\$P_1(\$\overline{U}_1), \ldots, (\neg)\$R_n@\$P_n(\$\overline{U}_n)$

- $\$R_i$ are relation terms possibly variables
- $\$P_i$ are peer terms possibly variables
- $\$\overline{U}_i$ are tuples of terms
- read body from left to right

Safety condition

- $\$R_{n+1}$ $\$P_{n+1}$ must appear positively bound in the body
- $\$P_i$ must be previously bound
- each variables must appear in positive atom before being used

Rules reside at peers:

```
[at Alice]
Picture@Alice($x,$y) :- Friend@Alice(Alice, $friend ),
                                  Picture@ $friend ($x,$y)
```

Webdamlog

Rules

$\$R_{n+1}@\$P_{n+1}(\$\overline{U}_{n+1})$:- $(\neg)\$R_1@\$P_1(\$\overline{U}_1), \ldots, (\neg)\$R_n@\$P_n(\$\overline{U}_n)$

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[at Alice]
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```

Particularity of Webdamlog rules

[at p]

$r_0@p_0(\overline{x_o})$:- $r_1@p_1(\overline{x_1})$, $r_2@p_2(\overline{x_2})$, ..., $r_n@p_n(\overline{x_n})$

Semantic depending on 3 criteria

- $p_1, \ldots, p_n = p$, the rule is called *local*
- head $r_0@p_0(\overline{x_o})$ is intensional or extensional
- head $r_0@p_0(\overline{x_o})$ is local or not (p_0 = p or not)

Local rules with local intensional head

Extensional: Friend@Alice: (Alice,Bob),(Alice,Charlie),(Bob,Charlie)
Intensional: FoF@Alice

[at Alice]

```
FoF@Alice($x,$y):-Friend@Alice($x,$y)
FoF@Alice($x,$y):- Friend@Alice($x,$z), FoF@Alice($z,$y)
```

FoF will contain the transitive closure of Friend:
(Alice,Bob), (Alice,Charlie), (Bob,Charlie), (Alice,Charlie)

Intuition

This is standard datalog evaluation

Local rules with local extensional head

Extensional: Friend@Alice

Step 0: (Alice,Bob),(Alice,Charlie),(Bob,Charlie)

[at Alice]

```
Friend@Alice($y,$x):-Friend@Alice($x,$y)
```

- Step 1: (Bob,Alice),(Charlie,Alice),(Charlie,Bob)
- Step 2: (Alice,Bob),(Alice,Charlie),(Bob,Charlie)

Intuition

Database updates

Remarks:

- by default extensional facts are consumed
- unless we declare the relation as *persistent*

Local rules with non-local extensional head

Extensional: `Today@Alice(december 5)`
Extensional: `Event@Alice(birthday,december 5,SMS,Bob-phone)`

[at Alice]

```
$r@$p(Happy birthday):-Today@Alice($date),
                       Event@Alice(birthday,$date,$r,$p)
```

Produce `SMS@Bob-phone(Happy birthday)`

Intuition

Messaging between peers

Local rules with non-local intensional head

Extensional: Friend@Alice
Intensional: Contact@Bob

[at Alice]
```
Contact@Bob($x,$y):- Friend@Alice($x,$y)
```

Bob gets a view on Alice's friends

Intuition

External view definition

Non-local rules: *delegation*

The main novelty of Webdamlog

Extensional: `Friend@Alice`: (Alice,Bob),(Alice,Charlie),(Bob,Charlie)

[at Alice]

```
Picture@Alice($pic,Alice):-Friend@Alice(Alice,$f),
                           Picture@$f($pic,Alice)
```

This will install two rules:

[at Bob] `Picture@Alice($pic,Alice):-Picture@Bob($pic,Alice)`
[at Charlie] `Picture@Alice($pic,Alice):-Picture@Charlie($pic,Alice)`

Remark

If `Friend@Alice(Alice,Bob)` no longer holds the delegation is uninstalled

Non-local rules: *delegation* 2

The main novelty of Webdamlog

Intuition

- Possible to ask another peer to perform some tasks for you (distributed computation)
- Possible to exchange knowledge between peers

Webdamlog semantic

State

$(I, \Gamma, \widetilde{\Gamma})$

- $I(p)$ the local state of p is a finite set of extensional facts
- $\Gamma(p)$ is the finite set of rules at p
- $\widetilde{\Gamma}(p, q)$ $(p \neq q)$ is the set of rules that p delegated to q

State transition

Choose some peer p randomly – asynchronously
Compute the transition: $(I_0, \Gamma_0, \widetilde{\Gamma}_0) \rightarrow (I_1, \Gamma_1, \widetilde{\Gamma}_1) \rightarrow (I_2, \Gamma_2, \widetilde{\Gamma}_2) \rightarrow \ldots$

- the database updates at p
- the messages sent to the other peers
- the delegations of rules to other peers

Fair sequence: each peer is selected infinitely often

Webdamlog summary

Webdamlog is datalog with novel extensions

- variables in relation and peer names
- delegation

both imply installing rules at run-time

Results:

- formal definition of Webdamlog
- expressivity results:
  - the model with delegation is more general, unless all peers and programs are known in advance
- convergence is very hard to achieve because of asynchronicity

Implementation on top of *Bud*

Bud [UC Berkeley] is a distributed datalog engine with updates; it supports

- local rules with local extensional head (semi-naive)
- local rules with non-local extensional head (semi-naive)

Bud does not support

- negation
- intensional relation optimizations (query sub-query, magic sets)

Bud neither any other engine implements requirements for *Webdamlog*

- variables in relation and peer names
- delegation
- installing rules at run-time

Semi-naive

Naive evaluation leads to redundant computation

```
Edge:  (1,2),(2,3),(3,4),(4,5)
Path($x,$y):-Edge($x,$y)
Path($x,$y):-Edge($x,$z),Path($z,$y)
```

$$
\begin{aligned}
Path(I)^0 &= \emptyset \\
Path(I)^1 &= Path(I)^0 \cup \{Path(1,2), Path(2,3), Path(3,4), Path(4,5)\} \\
Path(I)^2 &= Path(I)^1 \cup \{Path(1,3), Path(2,4), Path(3,5)\} \\
Path(I)^3 &= Path(I)^2 \cup \{Path(1,4), Path(2,5)\} \\
Path(I)^4 &= Path(I)^3 \cup \{Path(1,5)\} \\
Path(I)^5 &= Path(I)^4
\end{aligned}
$$

$\underbrace{\qquad\qquad\qquad\qquad}_{\Delta \text{ new facts since previous step}}$

Semi-naive use delta of previous step to compute the current step

$\texttt{Path}^{\texttt{i}}\texttt{(\$x,\$y):-Edge(\$x,\$z),}\Delta Path^{i-1}\texttt{(\$z,\$y)}$

Webdamlog engine run

Run a Webdamlog stage $(I, \Gamma, \widetilde{\Gamma}) \rightarrow (I', \Gamma', \widetilde{\Gamma}')$ in three steps

1. inputs are collected and a new state is defined
   - insert/delete *Webdamlog* facts and rules
   - update deltas of relations
   - compile the *Webdamlog* program into a *Bud* program
2. semi-naive evaluation: monotonic *Bud* program with a fixed set of local rules run to fixpoint
3. output messages and delegations are collected and sent to other peers for next stage

Management of variables

[at p]

Fact: r_1@p(relname,peername)

Rule: $\underbrace{r_0@p(\overline{x_o})}_{head}$:- $\underbrace{r_1@p(\$x,\$y),}_{static}$ $\underbrace{\$x@p(\overline{x_1}),r_2@\$y(\overline{x_2}),\ldots}_{dynamic}$

Stage i:

step 1 install at p: i@p($x,$y) :- $\underbrace{r_1@p(\$x,\$y)}_{static}$

step 2 semi-naive evaluation evaluate i@p

step3 FOR EACH fact $F(v_x,v_y)$ IN i@p
send new rule: *head* :- *dynamic*
with variables bounded by $F(v_x,v_y)$
$\underbrace{r_0@p(\overline{x_0})}_{head}$:- $\underbrace{v_x@p(\overline{x_1}),r_2@v_y(\overline{x_2}),\ldots}_{dynamic}$

Stage i + 1, at step 1:

receive $r_0@p(\overline{x_o})$:- relname@p($\overline{x_1}$),r_2@peername($\overline{x_2}$),…

Management of variables

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Evaluation of deletion in datalog

```
Edge@Alice:  (1,2),(2,3),(3,4),(4,5)
Rule1:  Path@Alice($x,$y):-Edge@Alice($x,$y)
Rule2:  Path@Alice($x,$y):-Edge@Alice($x,$z),Path@Alice($z,$y)

Path@Bob:  (1,3),(1,5)
Rule3:  Path@Alice($x,$y):-Path@Bob($x,$y)

Path@Alice:
```

$$\underbrace{(1,2),(2,3),(3,4),(4,5),\overbrace{(1,3)}^{Rule3},(2,4),(3,5),(1,4),(2,5),\overbrace{(1,5)}^{\texttt{Rule 3}}}_{\texttt{Rule 1 and 2}}$$

Delete Path@Alice(2,3)

- semi-naive requires full recomputation
- we introduce a novel optimization based on provenance

Example for provenance in Webdamlog evaluation

Alice creates a gallery of pictures where she is tagged from her own pictures and the pictures of her friends

```
Picture@Alice(pic1,Alice)
Friend@Alice(Alice,Bob)
Picture@Bob(pic1,Alice)
```

- [Rule 1 at Alice]

  ```
  Gallery@Alice($pic,Alice):-Picture@Alice($pic,Alice)
  ```

- [Rule 2 at Alice]

  ```
  Gallery@Alice($pic,Alice):-Friend@Alice(Alice,$f),
                             Picture@$f($pic,Alice)
  ```

- [Rule 3 at Bob] delegation

  ```
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Example for provenance in Webdamlog evaluation

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```

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```
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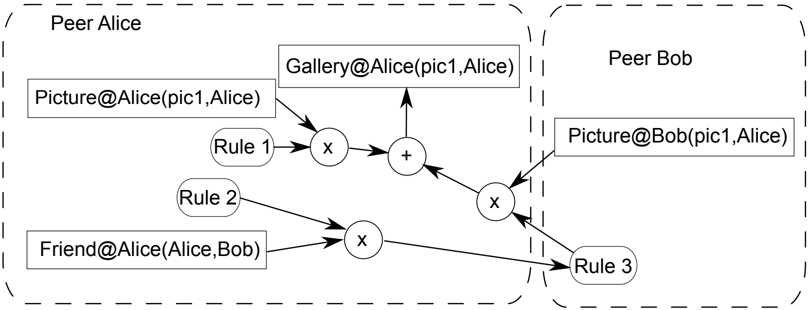
```

Optimization deletion using provenance

- Time nodes x are conjunction
- Plus nodes + are disjunction



- avoid to rederive the full relations
- keep trace of multiple proofs for the same fact

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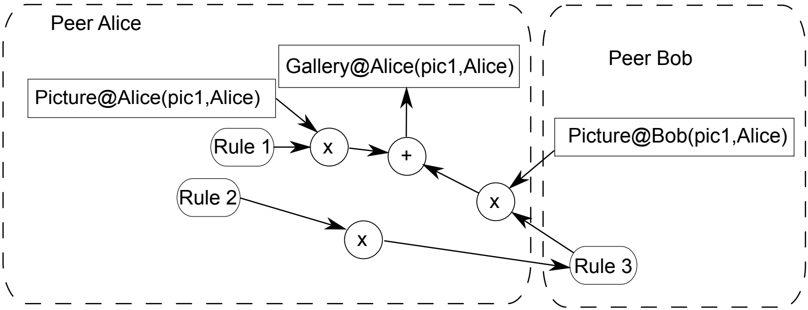

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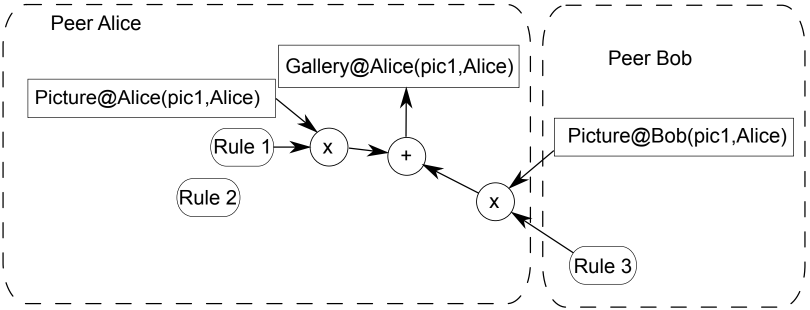

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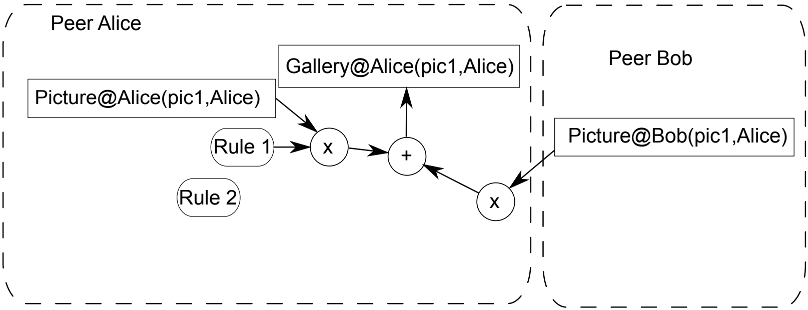

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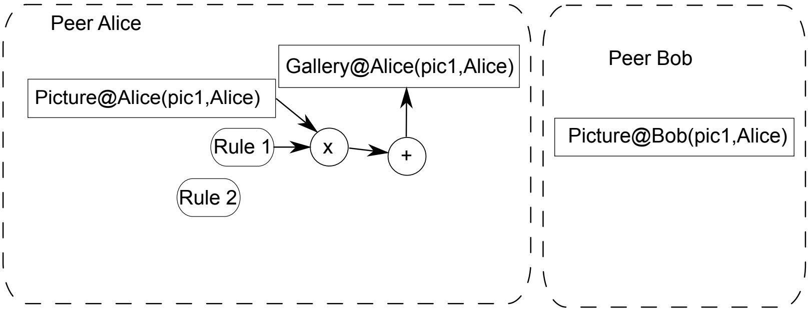

- avoid to rederive the full relations
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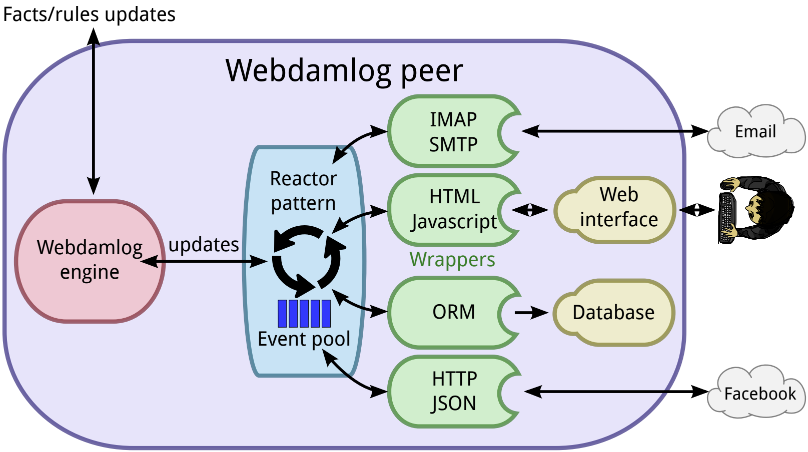
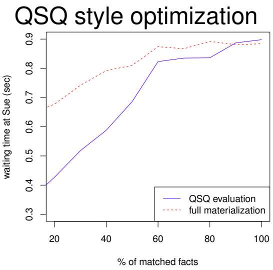
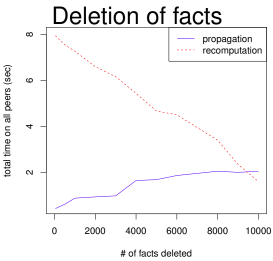
Architecture of a Webdamlog peer

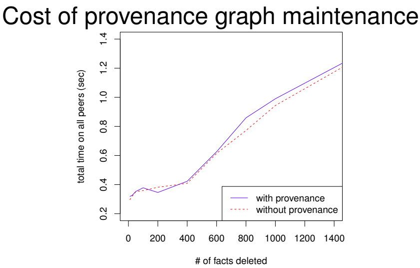


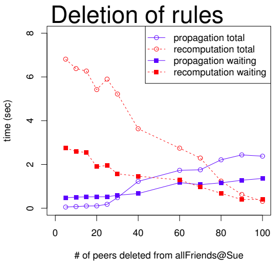
- Wrappers translate external commands into facts/rules updates
- Reactor pattern activates the Webdamlog engine if needed

Experiments









User study

To show that Webdamlog is declarative and user-friendly

Settings:

- pool of 27 participants with and without IT training
- a 20 minute lesson about the language
- an exam to test
  - understanding of Webdamlog programs
  - ability to write Webdamlog programs

Results:

- everyone but 2 participants perfectly understood the language
- a large majority wrote correct rules
- non technical participants took longer to answer

Demonstration

- A demonstration showed at SIGMOD 2013
- A social network to share pictures among the attendees of the conference
- This application “Wepic” run thanks to a Webdamlog engine and wrappers (web interface, database, . . .)
- Scenario
  - SIGMOD runs a “Wepic” peer with an empty program
  - attendees run their own peer with a basic program to exchange contact with SIGMOD
  - peer can be customized by adding rules

Play the video

Conclusion

We propose

- a formal language for data management
- an implementation of an engine for this language (with optimizations)
- a system for application development (with wrappers)

Future work

- on access control (on-going work)
- a better graphical interface
- a more in-depth user study
- an API for the development of applications and wrappers
- the enhancement Webdamlog with ontology technology
- optimization techniques, e.g. dQSQ