Viewing the Web as a Distributed Knowledge Base

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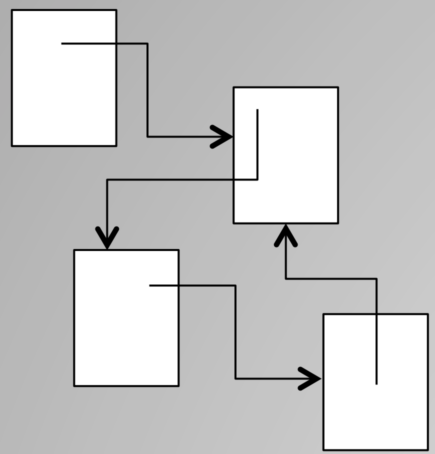
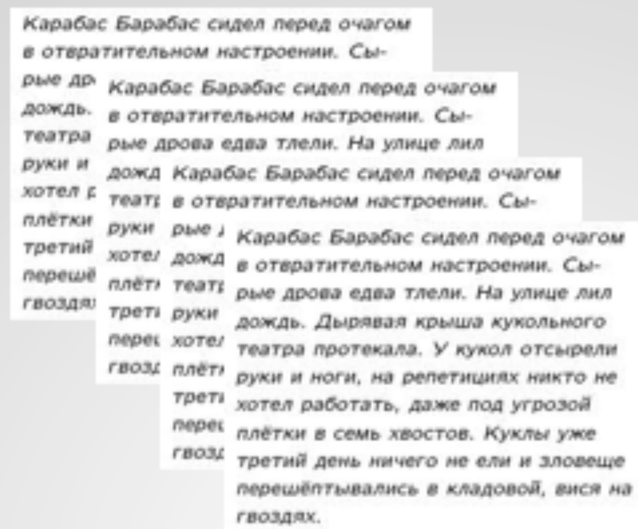
- The Web as a distributed knowledge base
- WebdamLog: a rule-based language for the Web
- The WebdamLog system
- Inconsistencies and uncertainty
- Conclusion

The Web



hypertext



Карабас Барабас сидел перед очагом
в отвратительном настроении. Сы-
рые дрова едва тлели. На улице лил
дождь. Дырявая крыша кукольного
театра протекала. У кукол отсырели
руки и ноги, на репетициях никто не
хотел работать, даже под угрозой
плётки в семь хвостов. Куклы уже
третий день ничего не ели и зловеще
перешёптывались в кладовой, вися на
гвоздях.

universal library of text

and multimedia

personal/private data

social data

A typical Web user's data

- What kinds of data? *all kinds*

  - *data*: photos, music, movies, reports, email
  - *metadata*: photo taken by Alice in Paris on ...
  - *ontologies*: Alice's ontology and mapping with other ontologies
  - *localization*: Alice's pictures are on Picasa, back-ups are at INRIA
  - *security*: Facebook credentials (Alice, 123456)
  - *annotations*: Alice likes Elvis' website
  - *beliefs*: Alice believes Elvis is alive
  - *external knowledge*: Bob keeps copies of Alice's pictures
  - *time*, *provenance*, ...

Social data

A typical Web user's data

- What kinds of data? *all kinds*
- Where is the data? *everywhere*
  - laptop, desktop, smartphone, tablet, car computer
  - mail, address book, agenda
  - Facebook, LinkedIn, Picasa, YouTube, Tweeter
  - svn, Google docs
  - also access to data / information of family, friends, companies associations

A typical Web user's data

- What kinds of data? *all kinds*
- Where is the data? *everywhere*
- What kind of organization? *heterogeneous*
  - terminology: different ontologies
  - systems: personal machines, social networks
  - distribution: different localization
  - security: different protocols
  - quality: incomplete / inconsistent information

Example of processing

Alice and *Bob* are getting engaged. Their friends want to offer them an album of photos where they are together

To make such a photo album

- Find friends of *Alice* & *Bob* (say with *Facebook*)
- for each friend, find where she keeps her photos (say, *Picassa*)
  - find the means to access her photos possibly via friends
  - find the photos that feature *Bob* and *Alice* together, e.g., using tags or face recognition software
- possibly ask someone to verify the results

Some reasoning is needed to execute these tasks (automatically)!

A typical Web user

- Overwhelmed by the mass of information
- Cannot find the information needed
- Is not aware of important events
- Cannot manage/control how others access and use his/her own data

How can systems help?

- We need to move from a Web of text to a Web of knowledge
  - In the spirit of semantic Web
- To better support user needs,
  - Systems need to analyze what is happening and construct knowledge
  - Systems should exchange knowledge
  - Systems should reason and infer knowledge

YOU need help!

Thesis

All this forms a distributed knowledge base

with processing based on automated reasoning

Issues

- Distributed reasoning
- Exchanging facts and rules

WebdamLog

- Contradictions
- Missing and noisy data

Ignore for now

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WebdamLog: a datalog-style language

Why datalog? A prehistoric language by Web time...

- \+ nice and compact syntax
- \+ well-studied with many extensions
- \+ recursion essential in a distributed setting: cycles in the network

Extensional facts

friend(“peter”,”paul”) friend(“paul”, “mary”) friend(“mary”,”sue”)

Datalog program

fof(x,y) :- friend(x,y)
fof(x,y) :- friend(x,z), fof(z,y)

Intentional facts

fof(“peter”,”paul”) fof(“peter”,”mary”) fof(“peter”, “sue”)
fof(“paul”, “mary”) fof(“paul”, “sur”)
fof(“mary”,”sue”)

WebdamLog

Extends datalog

- negation, updates, distribution, delegation, time

For a world that is

- distributed: autonomous and asynchronous peers
- dynamic: knowledge evolves; peers come and go

Influenced by

- Active XML (INRIA) - for distribution & intentional data
- Dedalus (UC Berkeley) - for time & implementation

Warning

Not as simple

Not as beautiful

More procedural

But this is needed for
real Web applications!

WebdamLog is not datalog

Schema

(π, E, I, σ)

π possibly infinite set of peer IDs

E set of extensional relations of the form m@p

I set of intentional relations of the form m@p

σ sorting function

for each m@p, σ(m@p) is an integer (its sort)

Facts

Facts are of the form $m@p(a_1, ..., a_n)$, where

m is a *relation* name & p is a *peer* name

$a_1, ..., a_n$ are *data* values (n is the arity of $m@p$)

the set of data values includes the relations and peer names

Examples

friend@my-iphone(“peter”, “paul”) extensional

fof@my-iphone(“adam”, “paul”) intentional

Examples of facts

data & metadata: pictures@alice-iphone(1771.jpg, “Paris”, 11/11/2011)

ontology: isA@yago.com("Elvis”, theKing)

annotations: tags@delicious.com(“wikipedia.org”, encyclopedia)

localization: where@alice(pictures, picasa/alice)

access rights: right@picasa(pictures, friends, read)

security: secret@picasa/alice; public@picasa/alice

Rules

A ***term*** is a variable or a constant

Rules are of the form

$R@$P($U) :- (not) $R1@$P1($U1), ..., (not) $Rn@$Pn($Un)

where

$R, $Ri are *relation* terms

$P, $Pi are *peer* terms

$U, $Ui are *tuples* of terms

Safety condition

$R and $P must appear positively bound in the body

each variable in a negative literal must appear positively bound in the body

Examples coming up, stay tuned

Semantics

A state (I, Γ, Γ^*) : each peer p has

extensional facts $I(p)$, defining the local state of p

local rules $\Gamma(p)$, defining the program of p

rules $\Gamma^*(p,q)$ that have been delegated to p by some peer q

State transition

Choose some peer p randomly – asynchronously

Compute the transition of p

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

Keep going forever

$(I_0, \Gamma_0, \varnothing) \rightarrow (I_1, \Gamma_1, \Gamma_1^*) \rightarrow \ldots \rightarrow (I_n, \Gamma_n, \Gamma_n^*) \rightarrow \ldots$

Fair sequence: each peer is selected infinitely often

The semantics of rules

Classification based on locality and nature of head predicates (intentional or extensional)

- Local rule at my-laptop: all predicates in the body of the rules are from my-laptop

Local with local intentional head	classic datalog
Local with local extensional head	database update
Local with non-local extensional head	messaging between peers
Local with non-local intentional head	view delegation
Non-local	general delegation

Local rules with local intentional head

Example: Rule at peer my-laptop

friend is extensional, fof is intentional

fof@my-iphone($x, $y) :- friend@my-iphone($x,$y)

fof@my-iphone($x,$y) :- friend@my-iphone($x,$z), fof@my-iphone($z,$y)

fof is the transitive closure of friend

Datalog = WebdamLog with only local rules and local intentional head

Local rules with local extensional head

A new fact is inserted into the local database

```
believe@my-iphone("Alice", $loc) :-
        tell@my-iphone($p,"Alice", $loc),
        friend@my-iphone($p)
```

Local rules with non-local extensional head

A new fact is sent to an external peer via a message

$message@$peer($name, “Happy birthday!”) :-

today@my-iphone($date),

birthday@my-iphone($name, $message, $peer, $date)

Extensional facts:

today@my-iphone(March 6)

birthday@my-iphone("Manon”, “sendmail”, “gmail.com”, March 6)

sendmail@gmail.com("Manon”, “Happy birthday”)

Local rules with non-local intentional head

View delegation!

boyMeetsGirl@gossip-site($girl, $boy) :-

girls@my-iphone($girl, $loc),

boys@my-iphone($boy, $loc)

Semantics of boyMeetGirl@gossip-site is a join of relations girls and boys from my-iphone

Formally, my-iphone delegates a rule boyMeetGirl@gossip-site(g,b) for each g, b, l, girls@my-iphone(g,l), boys@my-iphone(b,l)

Non-local rules: general delegation

(at my-iphone): boyMeetsGirl@gossip-site($girl, $boy) :-

girls@my-iphone($girl, $loc),

boys@alice-iphone($boy, $loc)

Suppose that girls@my-iphone("Alice", "Julia's birthday") holds.

Then my-iphone installs the following rule at alice-iphone

(at alice-iphone): boyMeetsGirl@gossip-site("Alice", $boy) :-

boys@alice-iphone($boy, "Julia's birthday")

When girls@my-iphone("Alice", "Julia's birthday") no longer holds, my-iphone uninstalls the rule

Non-local rules: general delegation

(at my-iphone): boyMeetsGirl@gossip-site($girl, $boy) :-

girls@my-iphone($girl, $loc),

boys@alice-iphone($boy, $loc)

An alternative, more database-ish, way of looking at this:

at my-iphone : seed@alice-iphone($girl, $loc):- *view*

girls@my-iphone($girl, $loc) *delegation*

at alice-iphone : boyMeetsGirl@gossip-site($girl, $boy) :-

seed@alice-iphone($girl, $loc),

boys@alice-iphone($boy, $loc) *delegation*

Complexity of delegation: illustration

fof(x,y) :- friend(x,y)

(at p) fof@p(x,y) :- peers@p($q), friend@$q(x,y)

If peers@p(q_1) holds, this rule installs

(at q_1) fof@p(x,y) :- friend@q_1(x,y)

If peers@p contains 100 000 tuples

peers@p(q_1), ..., peers@p($q_{100\,000}$)

This rule will install 100 000 rules!

for i=1 to 100 000 (at q_i) fof@p(x,y) :- friend@q_i(x,y)

Data complexity transformed into program complexity

Summary of results [PODS 2011]

- Formal definition of the semantics of WebdamLog
- Results on expressivity
  - the model with delegation is more general, unless all peers and programs are known in advance
- Convergence is very hard to achieve
  - positive WebdamLog
  - strongly stratified programs with negation

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WebdamLog peers

[demo ICDE 2011, WebDB 2011]

Support communication with other peers

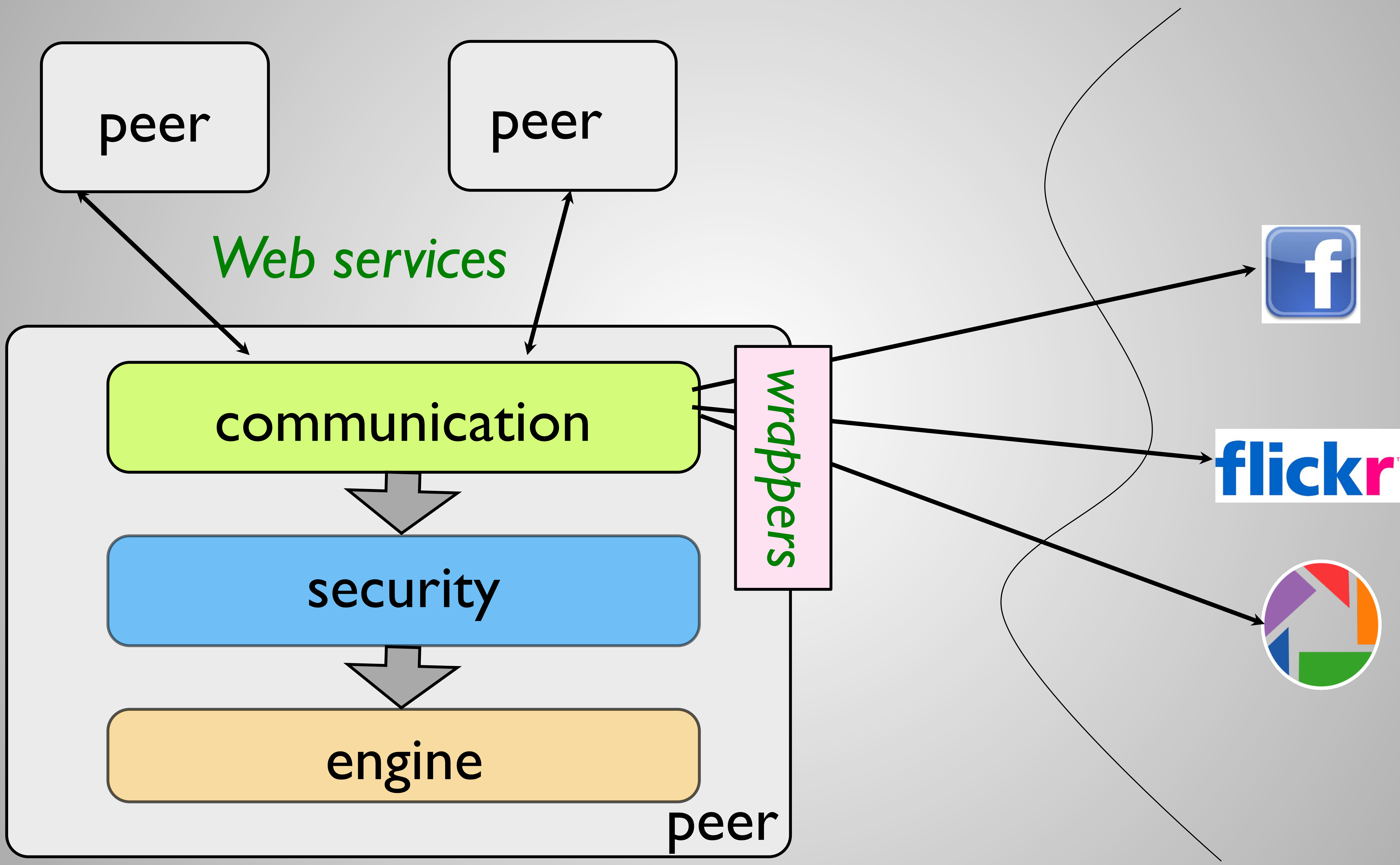
Support common security protocols

Support wrappers to external systems such as Facebook

Manage knowledge

- store knowledge (facts and rules)
- exchange knowledge with other peers
- perform reasoning

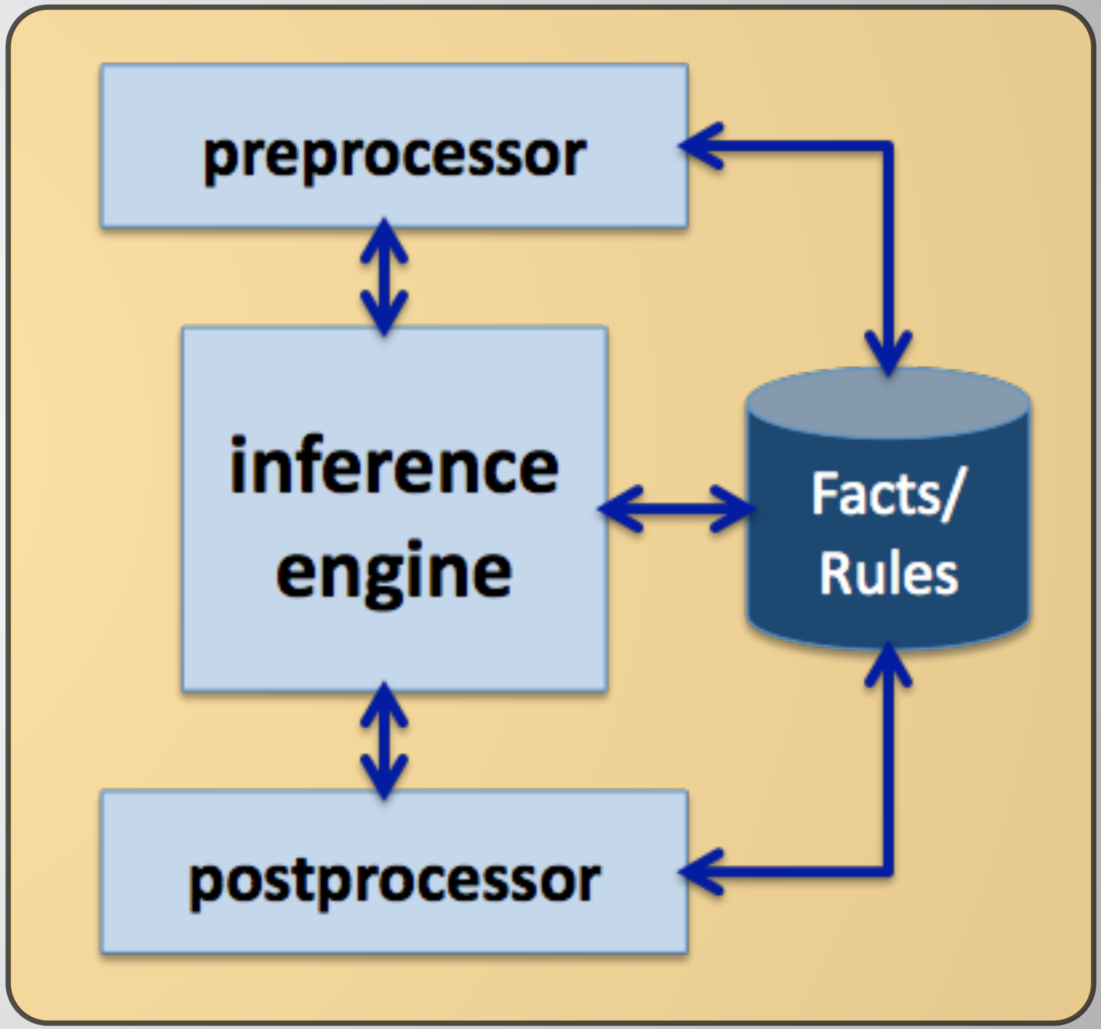
WebdamLog peers



WebdamLog engine [ongoing work]

Based on Bud

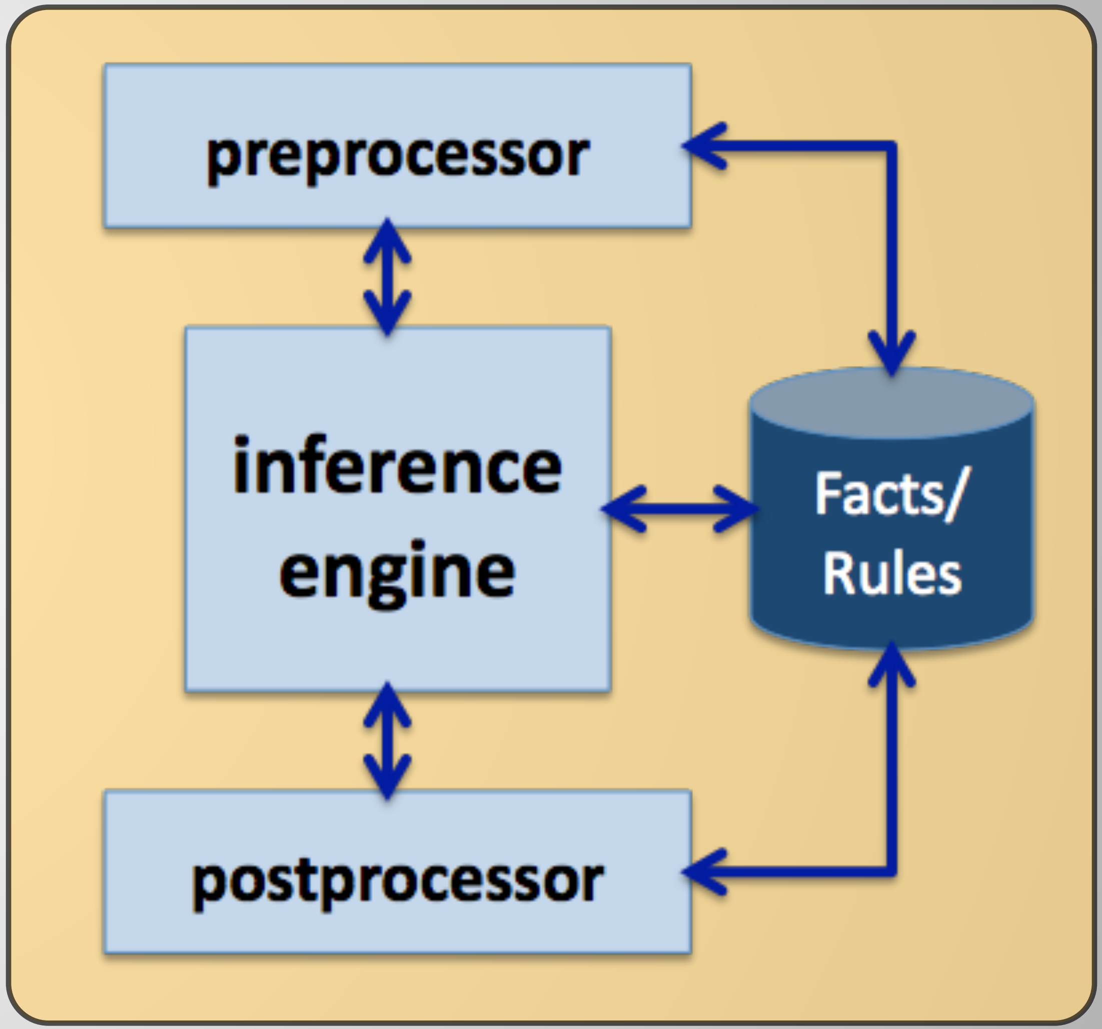
- developed at UC Berkeley, implemented in Ruby, open-source
- supports Bloom - an extension of datalog
- implements communication between peers
- serious experiments



WebdamLog inference: beyond Bud

- Translation of WebdamLog to Bloom (Bud's language)
- Features of WebdamLog not supported in Bud

1. Variable relation and peer names
2. Delegation: non-local rules, non-local relations in the body
3. Adding and removing rules at runtime: needed because of delegation



Example of runtime inference

(rule$_1$ at p) boyMeetsGirl@p($girl, $boy) :-

girls@p($girl, $loc),

boys@p($boy, $loc)

direct knowledge

(rule$_2$ at q) gossip@$peer($girl, $boy) :-

boyMeetsGirl@q($girl, $boy),

allPeers($peer)

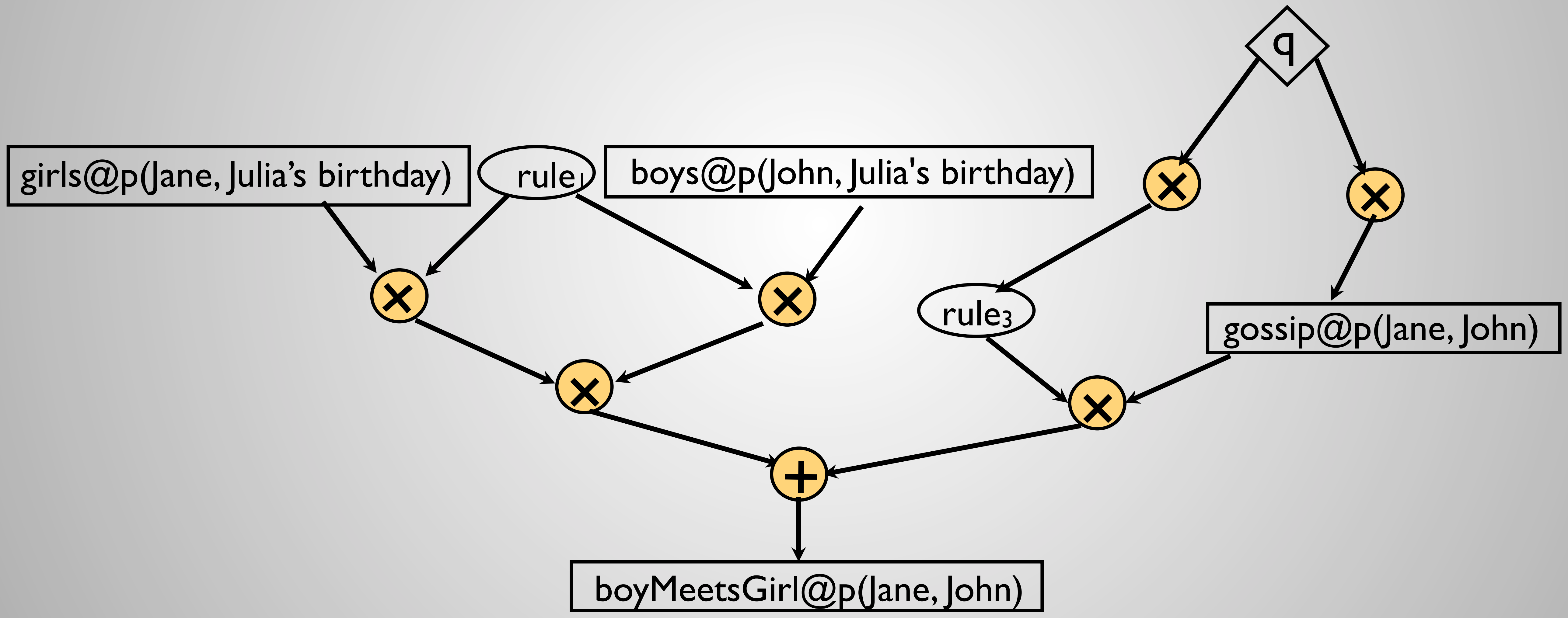
hearsay

(rule$_3$ at q) boyMeetsGirl@p($girl, $boy) :-

gossip@p($girl, $boy)

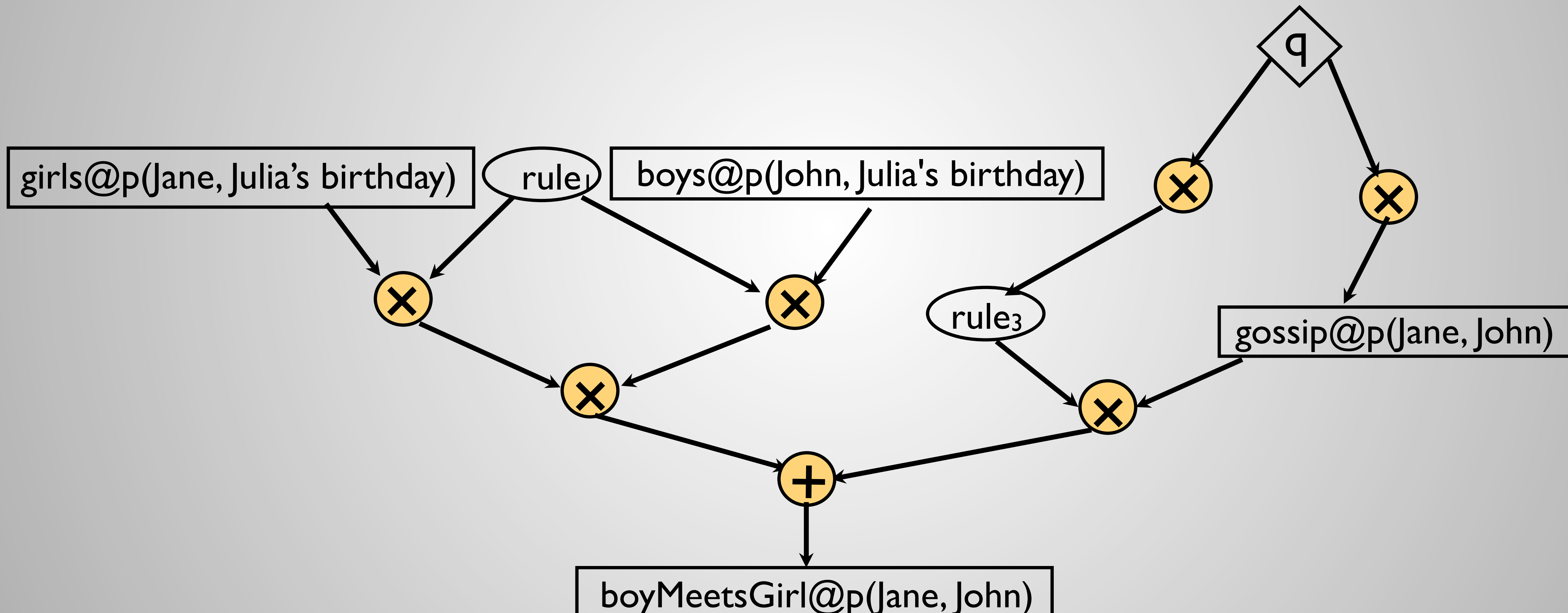
Adding facts at runtime

Maintain a provenance graph for update management



Removing facts at runtime

Avoid recomputation at each update using provenance



Provenance graphs

- Records the history of derivation
- Provenance semiring semantics [Green et al. 07]
  - alternative or joint use of data
  - facts, rules, peers are nodes
- Useful for performance optimization
- Other uses
  - explain results to users
  - specify and verify access rights

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Motivation

- Contradictions (in intentional or extensional data) come from
  - errors, lies, rumors, updates
  - FD violations: some think Alice was born in Paris, others that she was born in London
  - opinions: some think Brahms is great; others don't
- Uncertainty comes from
  - lack of information
  - contradictions
- Probabilities may be used to measure uncertainty
  - 80% think Alice was born in Paris, 20% in London
  - sources: we observed that Peter is wrong 20% of the time

Roadmap

We consider

reasoning in an uncertain and inconsistent world

We do this

- first for the centralized setting
- then with distribution
- finally with probabilities

Datalog + FDs

WebdamLog

and sampling

Datalog example

- Where is Alice?
- A relation IsIn(*person*, *city*, *peer*)

  with the FD (*person*, *peer*) → *city*

  peer believes *person* to be in *city*
- Consider a datalog rule

IsIn($per, $city, $p') :- IsIn($per, city, $p), friend($p', $p)

IsIn(Alice, London, Bob) IsIn(Alice, Paris, Sue)

friend(my-iphone, Bob) friend(my-iphone, Sue)

Datalog with nondeterministic fact-at-a-time semantics

Immediate consequence operator: a single fact is derived only if it does not contradict known facts

A possible world is a maximal consequence. Example:

IsIn($per, $city, $p') :- IsIn($per, city, $p), friend($p', $p)

IsIn(Alice, London, Bob)

friend(my-iphone, Bob)

IsIn(Alice, Paris, Sue)

friend(my-iphone, Sue)

Infer: IsIn(Alice, Paris, my-iphone)

In practice set-at-a-time semantics is more efficient

Discussion

Inflationary non-deterministic semantic ("stubborn" choices)

Related to 2-stable models

Proof theory

- Possible facts NP-complete
- Sure facts coNP-complete

Many possible alternative semantics

Distributed setting: use WebdamLog

To simplify, we focus only on local and deductive rules

The semantics is inflationary and non-deterministic

A subtlety: Each peer has to recall the choices made to always make the same choice in the future (when talking to other peers): stubborn

The causes of uncertainty

- Uncertainty in base facts
- Uncertainty in the order of peer activations
- Uncertainty in choosing immediate consequences

Probabilities

Probabilistic interpretation to measure uncertainty

- For base facts, use independent probabilistic events
- Uniform distribution for the next peer to activate
- Uniform distribution in choosing the next immediate consequence
  - Can be done efficiently if there is a single FD & more complicated otherwise

Example: captures voting

Bob's rules

IsIn@$p($x,$y) :- Follower@bob($p), IsIn@bob($x,$y)

IsIn@bob($x,$y) :- baseIsIn@bob($x,$y)

Suppose each peer has similar rules

Claim: For acyclic networks, the probability of a peer inferring a fact is exactly its relative support at his friends

Note: this also give semantics for more complicated cases such as networks with cycles

Query answering

Resulting tuples of a query q have associated probabilities

Exact evaluation using c-tables

- Too costly in practice

Sampling technique

- Each peer makes probabilistic choices along the way
- Converges to the probability of q when the number of samples grows

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Thesis

Let us turn the Web into a distributed knowledge base

with billions of users

supported by billions of systems

analyzing information

extracting knowledge

exchanging knowledge

inferring knowledge

Contribution

WebdamLog

- A language for distributed data management [PODS 2011]
- Datalog with distribution, updates, messaging
- Main novelty: delegation

System implementation

- Handles heterogeneity, localization and access control [WebDB 2011]
- WebdamlExchange peer In Java [demo ICDE 2011]
- WebdamLog engine based on Bud

On-going work

The implementation

- More optimization strategies such as Magic Set

Probabilistic WebdamLog

- Query processing
- Explaining results to users: top-k proofs

Collaboration between peers to answer queries

Lots of fun & many open questions

Issues

- Access control based on provenance
- Concurrency control
  - Difficulty: right revocation
- Optimization
  - Links with optimization in Active XML
- Verification of applications
  - Links with business artifacts

Joint work with Emilien Antoine, Meghyn Bienvenu, Daniel Deutch, Alban Galland, Kristian Lyndbaek, Julia Stoyanovich, Jules Testard

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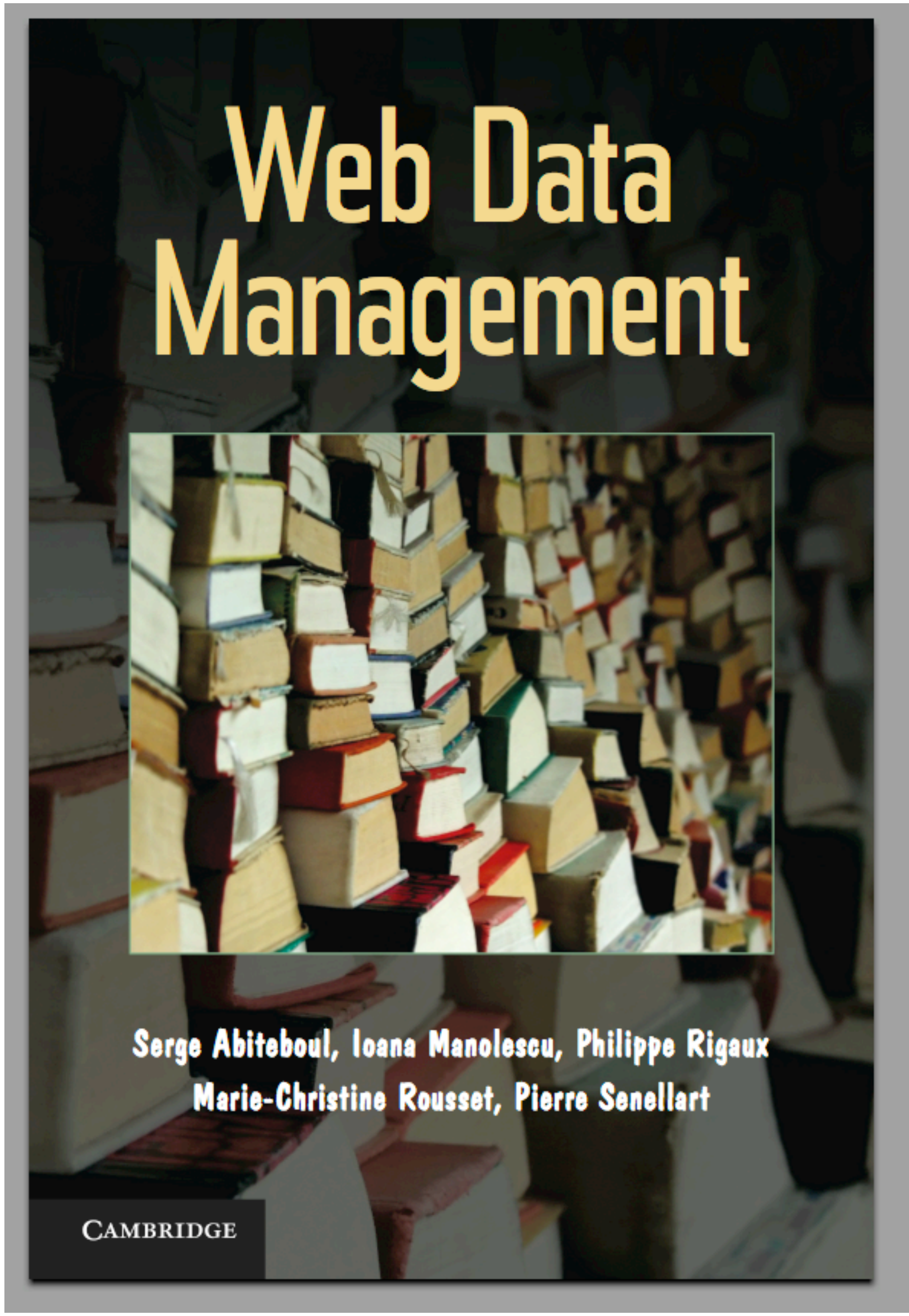
After a short break

- Two authors of the Web Data Management Book (aka Jorge)
- Two friends



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Reasoning in the Semantic Web

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