Towards a theory of search queries on dataspaces

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Outline

1. Theory of database queries
2. Relational algebra
3. Semijoin algebra
4. Search queries
5. Dataspaces
6. Structured querying versus searching
7. Research problems

Computational problems

- Classically, any computational problems is a function (mapping) from inputs to outputs

- E.g., route planning:
  - Input: a map (graph), source, target
  - Output: shortest route in graph from source to target

Database queries

- A query is a function from databases to databases
- E.g., Employee query
  - Input: history of employee hirings
  - Output: list of all employees who have been hired at least twice
- Also route planning!

Relational Algebra

- Language in which queries over relational databases can be expressed
- Every expression denotes a query
  - compare arithmetic: $\mathtt{avg}(x, y)$ expresses the function $\frac{(x+y)}{2}$
- Expression is a combination of operators
  - union, intersection, difference
  - cartesian product (join)
  - selection
  - projection
  - renaming

Employee query

relation **History**(emp_id, hire_date)

$$\Pi_{\mathbf{H}_1.\mathtt{emp\_id}}\sigma_{\mathbf{H}_1.\mathtt{emp\_id}=\mathbf{H}_2.\mathtt{emp\_id}\ \mathtt{AND}\ \mathbf{H}_1.\mathtt{hire\_date}\neq\mathbf{H}_2.\mathtt{hire\_date}} (\rho_{\mathbf{H}_1}(\mathbf{History}) \times \rho_{\mathbf{H}_2}(\mathbf{History}))$$

equivalently:

$$\Pi_{\mathbf{H}_1.\mathtt{emp\_id}}(\rho_{\mathbf{H}_1}(\mathbf{History}) \underset{\substack{\mathbf{H}_1.\mathtt{emp\_id} = \mathbf{H}_2.\mathtt{emp\_id} \\ \mathbf{H}_1.\mathtt{hire\_date} \neq \mathbf{H}_2.\mathtt{hire\_date}}}{\bowtie} \rho_{\mathbf{H}_2}(\mathbf{History}))$$

Expressibility

- Not all queries are expressible in relational algebra
- E.g., route planning
- Not surprising
  - Ackermann function is not expressible as a primitive recursive formula

The first-order queries

- Relational algebra forms an important **core query language**
  - SQL select-statements = relational algebra + aggregates
  - XPATH 2.0 = relational algebra
  - SPARQL = relational algebra

- Queries expressible in relational algebra are called first-order queries (relational calculus)

Semijoin

- Recall Employee query:

$$\Pi_{\mathbf{H}_1.\texttt{emp\_id}}(\rho_{\mathbf{H}_1}(\textbf{History}) \underset{\substack{\mathbf{H}_1.\texttt{emp\_id} = \mathbf{H}_2.\texttt{emp\_id} \\ \mathbf{H}_1.\texttt{hire\_date} \neq \mathbf{H}_2.\texttt{hire\_date}}}{\bowtie} \rho_{\mathbf{H}_2}(\textbf{History}))$$

- We don't need attributes of $\mathbf{H}_2$ after join
- Semijoin:

$$\Pi_{\mathbf{H}_1.\texttt{emp\_id}}(\rho_{\mathbf{H}_1}(\textbf{History}) \underset{\substack{\mathbf{H}_1.\texttt{emp\_id} = \mathbf{H}_2.\texttt{emp\_id} \\ \mathbf{H}_1.\texttt{hire\_date} \neq \mathbf{H}_2.\texttt{hire\_date}}}{\ltimes} \rho_{\mathbf{H}_2}(\textbf{History}))$$

The semijoin algebra (SA)

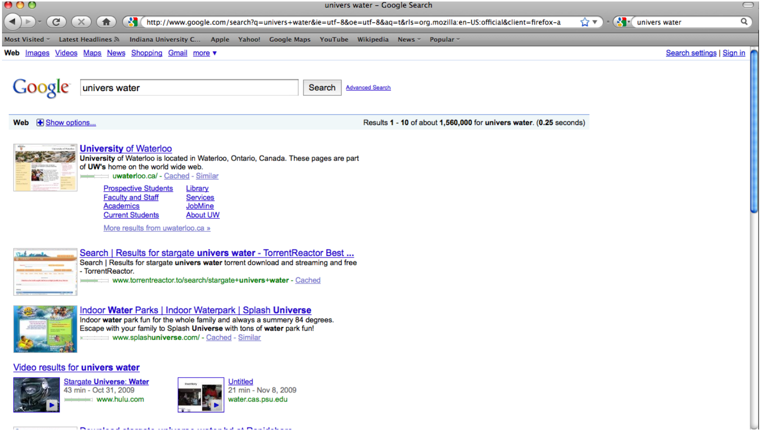
- Same as relational algebra, except: $\times$ and $\bowtie$ are replaced by $\ltimes$
- SA queries ...
  - always return subset of the relations (modulo Π)
  - can be efficiently processed
    - sorting
    - one-pass query processing
    - linear
- SA with only equalities in join conditions

  $=$ the linear fragment of relational algebra.

Searching versus (Structured) Querying

- Users of information systems do not use (full) SQL
  - Library catalog
  - Text search
  - Google, Yahoo, Bing etc
  - Amazon EC2 (searching data in the cloud)
  - mapreduce (key-value pairs)

- They can search:
  - `title` = **OED** `AND` `author` = **Tompa**
  - **Brussel** `AND NOT` **Bruxelles**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water.cas.psu.edu

Amazon Web Services Developer Community : Migrating to Amazon SimpleDB API Version 2009-04-15

http://developer.amazonwebservices.com/connect/entry.jspa?externalID=2542&categoryID=152

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QueryWithAttributes API returns a set of item names and corresponding attributes that match the query expression and the attribute names requested. This cans we easily re-written using Select API. For example, a QueryWithAttributes API call with parameters:

```
me.2=Size&DomainName=MyStore&QueryExpression=['Size'  = 'Medium' or 'Size' = 'Small']
```

can be re-written using Select API with parameter

```
SelectExpression= SELECT  Color, Size FROM MyStore WHERE Size = 'Medium' or Size = 'S
```

QueryExpression can be easily converted to SelectExpression. In most cases the operators will be the same. The following table lists various operators supported by Query and Select expression. Select API provides more powerful operators such as count, every, in, etc.

	Query /QueryWithAttributes	Select
Comparison operators	=,!=, >, <, >=, <=, starts-with, does-notstart-with	=, !=, >, <, >=, <=, like, not like, between, in, is null, is not null, every
Set operators	intersection, union, not	intersect, (*or* can be used for union see example below),not
Logical operators	and, or, not	and, or, not
Sort operators	sort asc, sort desc	Order by asc, order by desc
Limiting result sets	*MaxNumberOfItems* parameter	limit
Counting	n/a	count

Abstract Dataspaces

- An abstract dataspace is a set of objects
- Each object is a set of items
- E.g., set of webpages
  - each webpage = set of strings
- E.g., classical relation is a set of tuples
  - each tuple = set of attribute-value pairs

Attribute-value pairs

- Tuple

epm_imp	hire_date	job
1234	20091021	programmer

- Set of attribute-value pairs

att	value
emp_id	1234
hire_date	20091021
job	programmer

Attribute-value dataspaces

- Objects are arbitrary sets of AV-pairs

name	Anne
paper	p1
location	Brussels
phone	022222785

name	John
paper	p1
paper	p2
location	Namur
likes	voetbal

naam	Ellen
artikel	p2
artikel	p3
plaats	Brussel
plaats	Namen
houdtvan	rugby

drink_type	beer
name	Orval
kind	Trappist

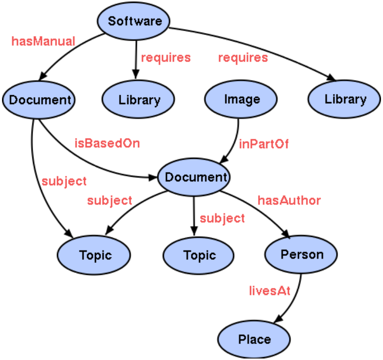
paper_id	p1
title	SQL
proceedings	VLDB

paper_id	p3
title	OED
author	Tompa
journal	unknown

"Database of everything"

- Alon Halevy (University of Washington, Google)

- Very similar to Semantic Web
  - RDF
  - Linked Data


Software
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subject
Topic
Topic
Person
livesAt
Place

A-V dataspace as RDF store

- RDF store: set of triples
  - (subject, predicate, object)
- view A-V dataspace D as set of triples:
  - $\{(\mathtt{oid}, \mathtt{att}, \mathtt{val}) : \mathtt{oid} \in D \;\&\; (\mathtt{att}, \mathtt{val}) \in \mathtt{oid}\}$

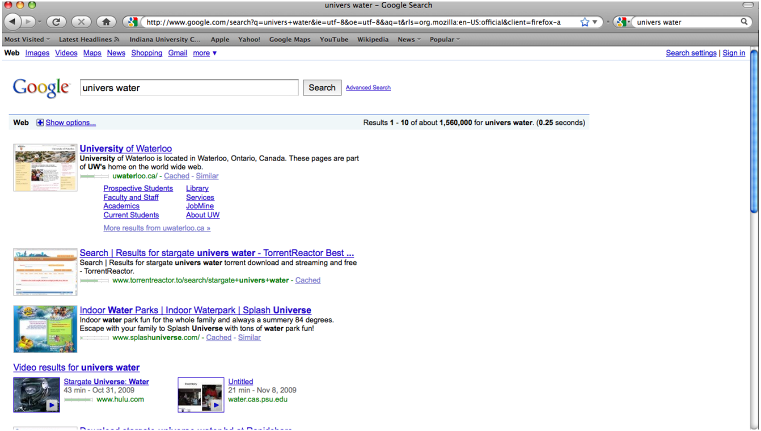
oid	**att**	**val**
1	name	Anne
1	paper	p1
1	location	Brussels
1	phone	022222785
...	...	...
...	...	...
6	paper_id	p3
6	title	OED
6	author	Tompa
6	journal	unknown

RDF triple store as A-V dataspace

- Use 3 special attributes
  - subject
  - predicate
  - object
- RDF triple store is just a relation over the scheme $\{\texttt{subj}, \texttt{pred}, \texttt{obj}\}$
- Already know that a relation is a dataspace!
- No RDFS

Searching Dataspaces

- Abstract Dataspace
  - set of objects
  - object: set of items
- Abstract keywords
  - predicate on items
- E.g., when items are strings:
  - string contains “Water”
  - string contains “Univers”
  - strings following “Waterloo” in OED
  - synonyms of “data”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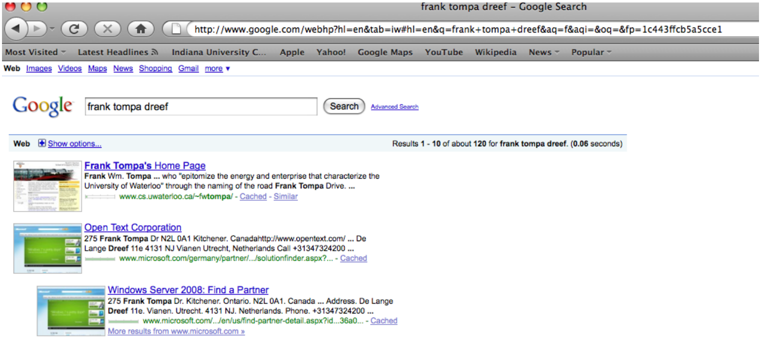
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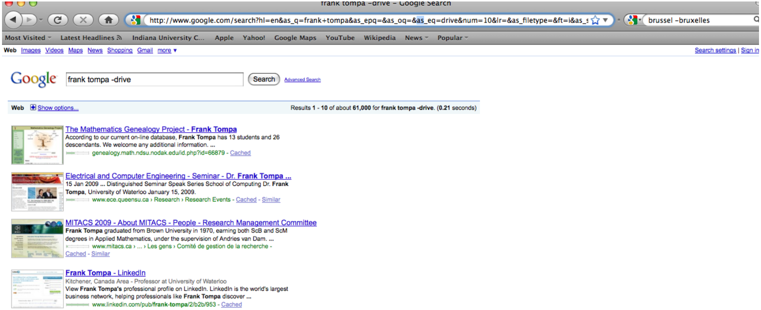
Boolean Search Language (BSL)

- Every keyword k is an expression
- Meaning:
  - Retrieve all objects containing some item satisfying k
- If e_1 and e_2 are expressions then so are:
  - e_1 `AND` e_2
  - e_1 `OR` e_2
  - e_1 `AND NOT` e_2
- Meaning: union, intersection, set difference

Waterloo AND NOT(Toronto OR Vancouver)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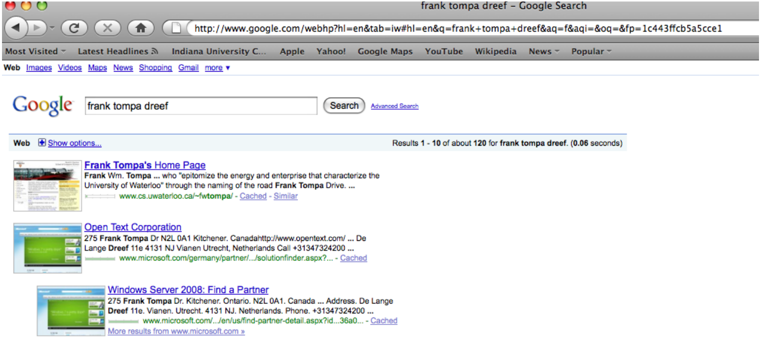
Dataspace search queries

- Database query:
  - mapping from databases to databases
- Dataspace query:
  - mapping q from dataspaces to dataspaces
- Dataspace search query:
  - such that $q(D) \subset D$ for each D
- Bit like semijoin queries ...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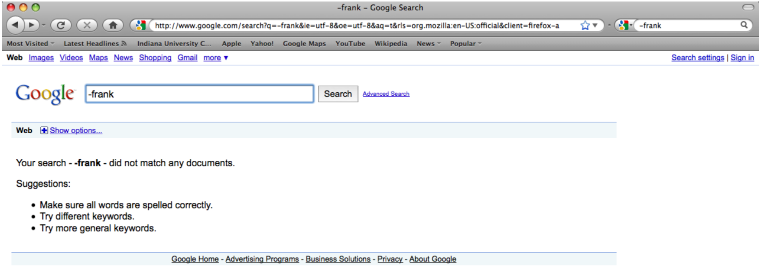
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Try different keywords.
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FRANK TOMPA DR

What dataspace search queries are expressible in BSL?

- BSL queries are safe
  - Only return objects containing some item satisfying (matching) some keyword that we used

- BSL queries are additive

$$q(D) = \text{union of all } q(\{o\}) \text{ for all } \in D$$

BSL queries are finitely distinguishing

- Only distinguish objects using some finite set K of keywords
- o_1 and o_2 are K-equivalent of for each $k \in K$,

$$o_1 \texttt{ matches } k \Leftrightarrow o_2 \texttt{ matches } k$$

- when o_1 and o_2 from D are K-equivalent then

$$o_1 \in q(D) \Leftrightarrow o_2 \in q(D)$$

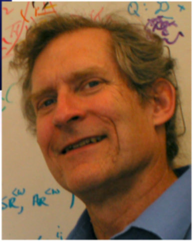
Characterization of BSL

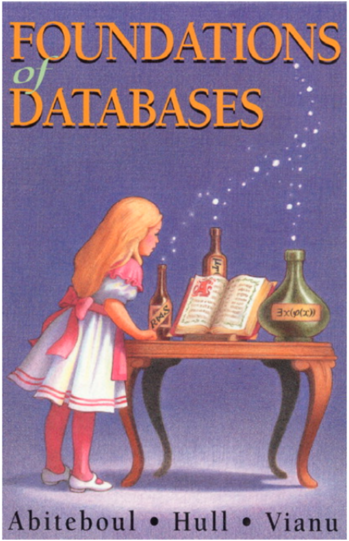
- A dataspace query q is expressible in BSL if (and only if) q is additive, and for some finite set K of keywords,
  - q is K-safe and
  - q is K-distinguishing

Application to relational selection queries

- Recall: relation = set of tuples = set of objects
- Object = set of attribute-value pairs
- Keywords: `A = c`
  - `A`: attribute from the given relation scheme
  - `c`: arbitrary constant
- Also wildcard keyword: `*`
- Example BSL query:

  `* AND NOT(job=programmer OR emp_id = 1234)`
- Same as relational algebra using only $\cup$, $-$, $\sigma_{\mathtt{A}=\mathtt{c}}$

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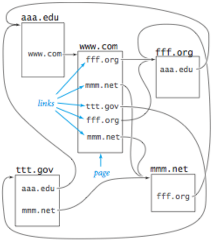
Not expressible in BSL

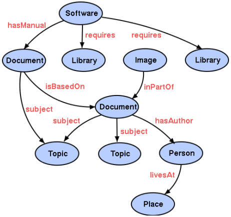
- Negated keywords (if you don't have them)
  - retrieve all objects containing an item **not** matching "Waterloo"
  - not finitely distinguishing over positive keywords
- Normally will use boolean-closed repertoire of keywords

Neither expressible in BSL

- Retrieve all objects sharing an item with an object matching "Waterloo"
- Retrieve all co-authors of "Frank Tompa"
- Not additive
- We cannot do joins or even semijoins
- Want to do such "associate search"



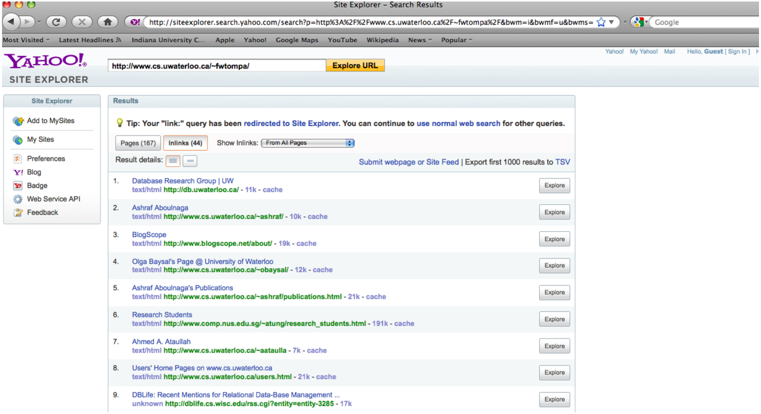
Pages and links



Similarity relations (simrels)

- How to link (associate) two objects?
  - hard wire links between objects in the dataspace
  - not necessary
  - not flexible

- Better: use simrels between items
  - a simrel is a binary predicate on items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Pages (187)
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Show Inlinks:
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1. Database Research Group | UW
text/html http://db.uwaterloo.ca/ - 11k - cache
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3. BlogScope
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6. Research Students
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7. Ahmed A. Ataullah
text/html http://www.cs.uwaterloo.ca/~aataulla - 7k - cache
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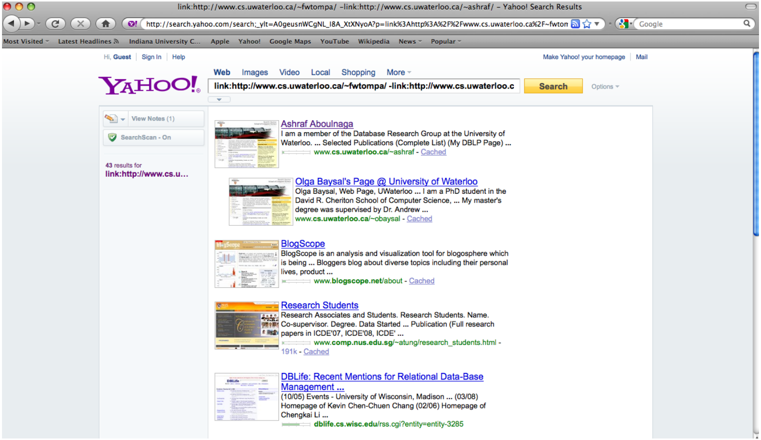
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Examples of simrels

- Equality
- Translation on city names:
  - Namur trans Namen
  - Bruxelles trans Brussel
  - Anvers trans Antwerpen
- Equal-value on A-V pairs:
  - (likes, Tompa) eqval (name, Tompa)
- Equal-attribute on A-V pairs:
  - (name, Tompa) eqval (name, Gonnet)

Simlinks

- If k and k' are keywords, and $\approx$ is a simrel, then $k \approx k'$ is a simlink
- Meaning: binary predicate on items
  - will be used to link (associate) objects
- $i_1[k \approx k']i_2$ if
  - i_1 matches k
  - i_2 matches k'
  - $i_1 \approx i_2$
- Example on string items, with sub-string and wildcard keywords and translation simrel:

"Citadelle de Namur" [Namur trans *] "Citadel van Namen"

Linking objects using simlinks

- For objects o_1 and o_2, $o_1[k \approx k']o_2$ if
  - o_1 contains some item i_1
  - o_2 contains some item i_2
  - $i_1[k \approx k']i_2$ if

- New associative search operator on dataspaces:

$$\textbf{LINK}\ [k \approx k'](S)$$

- retrieve all objects in the dataspace that are linked by $[k \approx k']$ to some objects in S

LINK [Namur trans *] (Citadel)

Associate Search Language (ASL)

- BSL extended with link operator
- Parametrized by choice of:
  - keywords (already as BSL)
  - simrels (for link operator)
- What is the expressiveness of ASL?
- Link operators is like semijoin ...

$$e_1 \texttt{ AND } \texttt{LINK}[\theta](e_2)$$

$$e_1 \ltimes_\theta e_2$$

ASL on A-V dataspaces

- Keywords:
  - literals & wildcards
    (name: Frank) (name: *) (*: Frank)
  - negation on values
    (likes: ¬(Heineken,Budweiser))
  - negation on attributes
    (¬(paper_id, title):Kriek)
  - negation on both values and attributes
    (¬(paper_id, title): ¬(Heineken,Budweiser))
- Simrels:
  - eq, eq_val, eq_att

Example query

- Retrieve all people located in Waterloo who have published a paper in CACM:

  (location: Waterloo) AND
  LINK[(paper: *) `eq_val` (paper_id: *)](journal: CACM)

- Which queries can we express?

A-V dataspace as relation

- We saw this already: set of (oid, att, val)

oid	**att**	**val**
1	name	Anne
1	paper	p1
1	location	Brussels
1	phone	022222785
...	...	...
...	...	...
6	paper_id	p3
6	title	OED
6	author	Tompa
6	journal	unknown

- How does ASL compare to querying this relation using relational algebra?

ASL translated into semijoin algebra

(location: Waterloo) AND
LINK[(paper: *) eq_val (paper_id: *)] (journal: CACM)

$$\Pi_{\texttt{oid}}\sigma_{\texttt{att=location\&val=Waterloo}}(T) \ltimes \Pi_{\texttt{oid}}\sigma_{\texttt{att=}\text{paper}}(T) \ltimes \Pi_{\texttt{oid}}\sigma_{\texttt{att=paper\_id}}(T \ltimes \Pi_{\texttt{oid}}\sigma_{\texttt{att=journal\&val=CACM}}(T))$$

- Only natural semijoins are used

SA queries not expressible in ASL

- Retrieve all people who have the same value for a boss and a friend attribute
- Retrieve all people who like some professor that nobody else likes
- Can prove that these are not expressible using invariance under bisimulations

Bisimilarity of Dataspace

- Dataspace D and object o, also D' and o'
- Natural number n
- We say that $(D, o) \leftrightarrows_n (D', o')$ if
  - o and o' match precisely the same keywords
  - moreover for $n > 0$:
    - for each simrel $\approx$ and for each object $p \in D$ such that $o \approx p$, there exists $p' \in D'$ such that $o' \approx p'$ and $(D, p) \leftrightarrows_{n-1} (D', p')$
    - vice versa (from D' to D)

Invariance under bisimilarity

- Let q be an ASL query using at most n nested link operators
- Let $(D, o) \leftrightarrows_n (D', o')$
- Then $o \in q(D)$ if and only if $o' \in q(D')$

SA queries not expressible in ASL (repeated)

- Retrieve all people who have the same value for a boss and a friend attribute
- Retrieve all people who like some beer that nobody else likes
- Can prove that these are not expressible using invariance under bisimulations

The "search" fragment of SA (semi-join algebra)

$$
\begin{array}{rcl}
E & ::= & T \\
  & | & \sigma_{\mathtt{att}=\mathtt{c}}(E) \\
  & | & \sigma_{\mathtt{val}=\mathtt{c}}(E) \\
  & | & E \cup E \\
  & | & E - E \\
  & | & \Pi_{\alpha}(E) \\
  & | & E \ltimes \Pi_{\mathtt{oid}}(E) \\
  & | & \Pi_{\mathtt{oid}}(E \ltimes \Pi_{\beta}(E))
\end{array}
$$

- c: constant
- α : $\{\mathtt{oid}\}$, $\{\mathtt{oid}, \mathtt{att}\}$, or $\{\mathtt{oid}, \mathtt{val}\}$
- β : $\{\mathtt{att}\}$, $\{\mathtt{val}\}$, or $\{\mathtt{att}, \mathtt{val}\}$

What have we learned?

- Searching unstructured information motivates to investigate new query languages
  - but the classical theory is still very useful:
    - relational databases
    - relational algebra
    - genericity
    - semijoin algebra
    - bisimilarity
- Querying RDF triple stores

Open research problems

- Algorithms, data structures for query processing
- Are BSL and ASL sufficient? Other primitives?
- User interface: search should be easier than full querying in SQL
- How to represent relational databases as dataspaces (or RDF) such that querying can be done by searching?