Towards a Decision Query Language

Jan Chomicki

University at Buffalo

http://www.cse.buffalo.edu/~chomicki

Decisions, decisions,...

- decision scope: Possible vacation destinations? For how long? For how much?
- desirability: I prefer a beach to a large city.
- uncertainty: Enough parking space? Too crowded?
- resources: Where to book?

Some requirements are hard, others are soft.

What is required

Languages in which possible choices and decision criteria of agents can be formulated.

Essential features:

- data and queries
- constraints
- preferences
- *uncertainty, risk,...*

Preferences

Ordering the choices in terms of:

- desirability, coolness, ...
- reliability
- cost, convenience
- timeliness...

Two options:

- binary preference relations: what's better
- numeric utility functions: scores.

Many different preference relations

Between two hawks, which flies the higher pitch;
Between two dogs, which hath the deeper mouth;
Between two blades, which bears the better temper;
Between two horses, which doth bear him best;
Between two girls, which hath the merriest eye.

W. Shakespeare, King Henry VI.

Decision querying

Find the best answers to a query, instead of all the answers.

“Find the lowest price for this book on the Web...

... but also keep in mind my preference for `amazon.com`.”

What to do with the obtained information is not addressed:
“We report, you decide.”

Preferences as first-order formulas

[Chomicki, EDBT'02].

Relation *Book(Title,Vendor,Price)*.

Preference:

$$(i, v, p) \succ_{C_1} (i', v', p') \equiv i = i' \land p < p'.$$

Indifference:

$$(i, v, p) \sim_{C_1} (i', v', p') \equiv i \neq i' \lor p = p'.$$

Utility functions?

Relational algebra embedding

[Chomicki, EDBT'02; Kiessling, VLDB'02]:

New winnow operator returning the tuples in the given instance that are not dominated by any other tuple in the instance.

Book	*Title*	*Vendor*	*Price*
t_1	The Flanders Panel	`amazon.com`	$14.75
t_2	The Flanders Panel	`fatbrain.com`	$13.50
t_3	The Flanders Panel	`bn.com`	$18.80
t_4	Green Guide: Greece	`bn.com`	$17.30

Application scenarios

E-commerce:

- B2C: comparison shopping
- B2B: e-procurement (Cosima [Kiessling, CEC'04])
- E-services

Personalization:

- personalized query results [Koutrika et al. ICDE'04]
- personalized interaction

Configuration:

- "soft" constraints

Plan of the talk

1. Preference relations vs. utility functions.
2. Query languages.
3. Applications: skylines, linear optimization.
4. Preference query evaluation.
5. Preference query optimization.
6. Extensions.
7. Related work.
8. Future work.

Definitions

Preference relation: a binary relation $\succ$ between the tuples of a given relation.

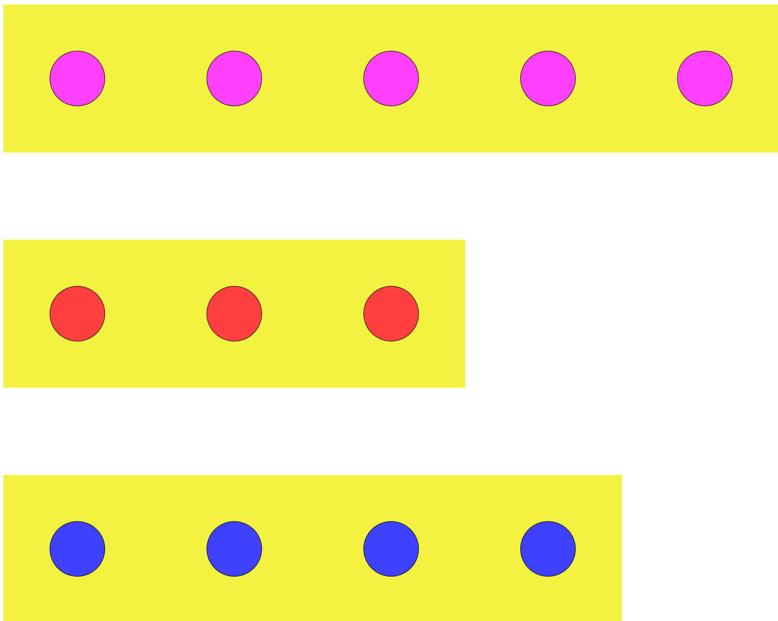
Preference formula: a first-order formula defining a preference relation.

Intrinsic preference formula: the definition uses only built-in predicates.

Typical properties of preference relations: irreflexivity, and transitivity ($\Rightarrow$ strict partial orders), can be effectively checked for intrinsic preference formulas with $=, \neq, <, >, \leq, \geq$.

Weak orders

Weak order: a strict partial order with transitive indifference.



Preference constructors [Kiessling, VLDB'02]

Atomic:

- `LOWEST`, `HIGHEST`
- `POS`, `NEG`, and combinations
- `AROUND`, `BETWEEN`, `SCORE`

Composite:

- unidimensional: intersection, disjoint union
- multidimensional: Pareto and lexicographic composition

Strict partial orders, definable using first-order formulas.

Utility (scoring) functions

An approach grounded in utility theory:

1. construct a real-valued function u such that:

$$t_1 \succ t_2 \equiv u(t_1) > u(t_2)$$

2. return the answers that maximize u in the given instance.

Typically, top K answers are requested.

Properties of scoring functions

+ can be implemented using SQL3 user-defined functions [Agrawal et al, SIGMOD'00] [Hristidis et al., SIGMOD'01]

+ provide an ordering of all the answers

+ capture preference intensity

+ can be numerically aggregated

– need to be hand-crafted for every input

– hard to logically aggregate

– not expressive enough: only weak order pref. relations.

Non-existence of utility functions

	Title	*Vendor*	*Price*
t_1	The Flanders Panel	`amazon.com`	\$14.75
t_2	The Flanders Panel	`fatbrain.com`	\$13.50
t_3	The Flanders Panel	`bn.com`	\$18.80
t_4	Green Guide: Greece	`bn.com`	\$17.30

The set of constraints

$$\{u(t_2) > u(t_1) > u(t_3), u(t_4) = u(t_1), u(t_4) = u(t_2)\}$$

is unsatisfiable.

Winnow

Given a preference relation $\succ$ defined using a preference formula C:

$$\omega_C(r) = \{t \in r | \neg \exists t' \in r.\ t' \succ t\}.$$

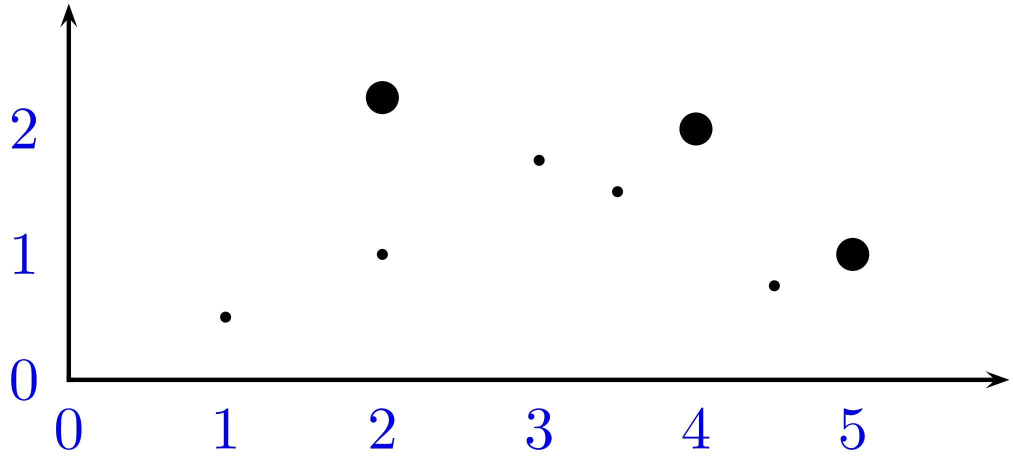
Example (*"preference for* `amazon.com`*"*):

$$\begin{aligned}(i, v, p) \succ_2 (i', v', p') \quad &\equiv \quad i = i' \\ &\wedge\ v = '\texttt{amazon.com}' \wedge v' \neq '\texttt{amazon.com}'\end{aligned}$$

	Title	*Vendor*	*Price*
t_1	The Flanders Panel	`amazon.com`	$14.75
t_2	The Flanders Panel	`fatbrain.com`	$13.50
t_3	The Flanders Panel	`bn.com`	$18.80
t_4	Green Guide: Greece	`bn.com`	$17.30

Skyline queries

Find all the tuples that are not dominated by any other tuple in every dimension [Börzsönyi et al, ICDE'01] (Pareto set).



Skylines contain maxima of monotone scoring functions.

Skyline in SQL

```
SELECT ... FROM ... WHERE ...
  GROUP BY ... HAVING ...
  SKYLINE OF A1[MIN|MAX|DIFF],..., An[MIN|MAX|DIFF]
```

Skyline:

```
SKYLINE OF A DIFF, B MAX, C MIN
```

maps to the preference formula:

$$(x, y, z) \succ (x', y', z') \equiv x = x' \wedge y \geq y' \wedge z \leq z' \wedge (y > y' \vee z < z').$$

Linear optimization queries

Query formulation:

Find the input tuples that maximize $\sum_{i=1}^{n} a_i x_i$.

The preference relation:

$$\bar{x} \succ \bar{y} \equiv \sum_{i=1}^{n} a_i x_i > \sum_{i=1}^{n} a_i y_i.$$

Convex hulls contain maxima of positive linear scoring functions.

Winnow evaluation

General methods:

- translation to relational algebra/SQL (Preference SQL [Kiessling et al, VLDB'02])
- BNL: Block-Nested-Loops [Börzsönyi et al, ICDE'01]
- β-tree [Torlone, Ciaccia, SEBD'03]

Special methods:

- skyline queries:
  - SFS: Sort-Filter-Skyline [Chomicki et al, ICDE'03]
  - nearest-neighbor search [Kossmann et al., VLDB'02], [Papadias et al, SIGMOD'03].
- linear optimization queries (*top K* answers):
  - convex hull [Chang et al.,SIGMOD'00]
  - ranked views [Hristidis et al.,SIGMOD'01]
  - ...

BNL

1. initialize the window W and the temporary file F to empty;
2. repeat the following until the input is empty:
3. for every tuple t in the input:
   - t is dominated by a tuple in $W \Rightarrow$ ignore t,
   - t dominates some tuples in $W \Rightarrow$ eliminate them and insert t into W,
   - t is incomparable with all tuples in $W \Rightarrow$ insert t into W (if there is room), otherwise add t to F;
4. output the tuples from W that were added there when F was empty,
5. make F the input, clear F.

SFS

1. sort the input w.r.t. any monotone scoring function;
2. initialize the window W and the temporary file F to empty;
3. repeat the following until the input is empty:
4. for every tuple t in the input:
   - t is dominated by a tuple in $W \Rightarrow$ ignore t,
   - t is incomparable with all tuples in $W \Rightarrow$ insert t into W (if there is room), otherwise add t to F;
5. output the tuples from W.
6. make F the input, clear F.

Optimization of preference queries

Algebraic query optimization.

Semantic query optimization.

Cost-based query optimization.

Algebraic laws [Chomicki, TODS'03]

Commutativity with selection:

If the formula

$$(\alpha(t_2) \wedge \gamma(t_1, t_2)) \Rightarrow \alpha(t_1)$$

is valid, then for every r

$$\sigma_\alpha(\omega_\gamma(r)) = \omega_\gamma(\sigma_\alpha(r)).$$

Under the preference relation

$$(i, v, p) \succ_{C_1} (i', v', p') \equiv i = i' \wedge p < p'$$

the selection $\sigma_{Price<20}$ commutes with ω_{C_1} but $\sigma_{Price>20}$ does not.

Distributivity over Cartesian product: For every r_1 and r_2

$$\omega_C(r_1 \times r_2) = \omega_C(r_1) \times r_2.$$

Commutativity of winnow: If $C_1(t_1, t_2) \Rightarrow C_2(t_1, t_2)$ and $\succ_{C_1}$ and $\succ_{C_2}$ are strict partial orders, then for all finite instances r:

$$\omega_{C_1}(\omega_{C_2}(r)) = \omega_{C_2}(\omega_{C_1}(r)) = \omega_{C_2}(r).$$

Also commutativity with projection.

Semantic query optimization

[Chomicki, CDB'04].

Using information about integrity constraints to:

- eliminate redundant occurrences of winnow.
- make more efficient computation of winnow possible.

Eliminating redundancy: Given a set of integrity constraints F, ω_C is redundant w.r.t. F iff F entails the formula

$$\forall t_1, t_2.\ R(t_1) \wedge R(t_2) \Rightarrow t_1 \sim_C t_2.$$

Integrity constraints

Constraint-generating dependencies (CGDs) [Baudinet et al, ICDT'95]:

$$\forall t_1. \ldots . \forall t_n. \, [R(t_1) \wedge \cdots \wedge R(t_n) \wedge \gamma(t_1, \ldots t_n)] \Rightarrow \gamma'(t_1, \ldots t_n).$$

Entailment is decidable for CGDs by reduction to the validity of $\forall$-formulas in the constraint theory.

Cost-based optimization

For skylines [Buchta, 1989; Godfrey, FOIKS'04]:

> The expected cardinality of a d-dimensional skyline of n tuples is equal to $H_{d-1,n}$, the $d-1$-order harmonic of n (under attribute independence).

Asymptotically: $H_{d,n} \in \Theta((\ln n)^d / d!)$.

Some values:

$$\begin{aligned} H_{2,10^6} &= 104 \\ H_{6,10^6} &= 14,087 \end{aligned}$$

Extension: extrinsic preference

Extrinsic preference relation: depends not only on the components of the tuples being compared but also on other factors:

- the presence or absence of other tuples in the database
- computed or aggregate values.

Solution: winnow + SQL.

Preference for a lower total cost of a book (including shipping and handling).

Vendor	*SH*
`amazon.com`	$6.99
`fatbrain.com`	$3.99
`bn.com`	$5.99

Apply winnow to the following view:

```
CREATE VIEW TotalCost(Title, Vendor, Cost) AS
SELECT Book.Title, Book.Vendor, Book.Price + SHCosts.SH
FROM Book, SHCosts WHERE Book.Vendor = SHCosts.Vendor
```

Problem: computing Cartesian products.

Extension: preferences between sets

A best set does not necessarily consist of the best individuals:

- bundling [Chang et al, EC'03]
- complementarity
- diversity $\Rightarrow$ College Admissions Problem

Design query language extensions in which:

- sets are first-class citizens: powerset? nondeterminism?
- solutions can be constrained
- set winnow is available.

Other related work

Preference queries [Lacroix, Lavency, VLDB'87]:

Pick the tuples of R satisfying $Q \wedge P_1 \wedge P_2$; if none, pick the tuples satisfying $Q \wedge P_1 \wedge \neg P_2$; if none, pick the tuples satisfying $Q \wedge \neg P_1 \wedge P_2$.

This can be expressed as

$$\omega_{C_2}(\omega_{C_1}(\sigma_Q(R)))$$

where $C_1(t_1, t_2) \equiv P_1(t_1) \wedge \neg P_1(t_2)$ and $C_2(t_1, t_2) \equiv P_2(t_1) \wedge \neg P_2(t_2)$.

Datalog with preferences [Kiessling et al, 1994], [Govindarajan et al, 2000]:

- clausally-defined preference relations
- extension of Datalog, requires a special evaluation method.

Other areas:

- AI: inference of propositional preferences, “soft” constraints
- philosophy: axiomatizations of preference
- economics: modelling economic behavior.

Future work

Preference modelling and management:

- elicitation: how to construct preference formulas?
- aggregation
- modelling risk and uncertainty

Decision components:

- preferences between actions and plans: workflows, ECA systems
- preferences between E-services

Preferences for XML?