The skyline operator

recent research directions and applications

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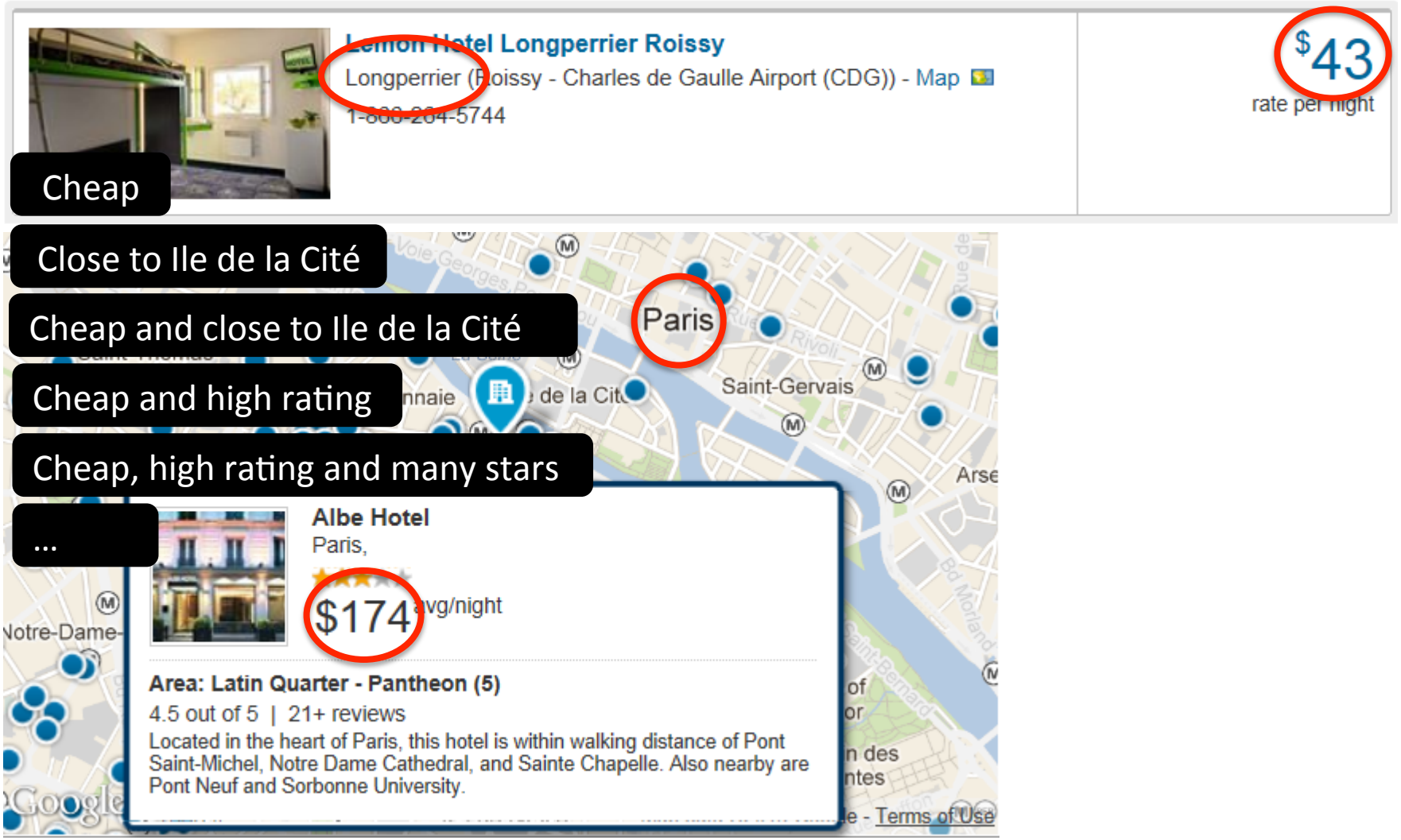
A very basic operation in data management

Extract the best elements from a set of options

According to **multiple criteria**.

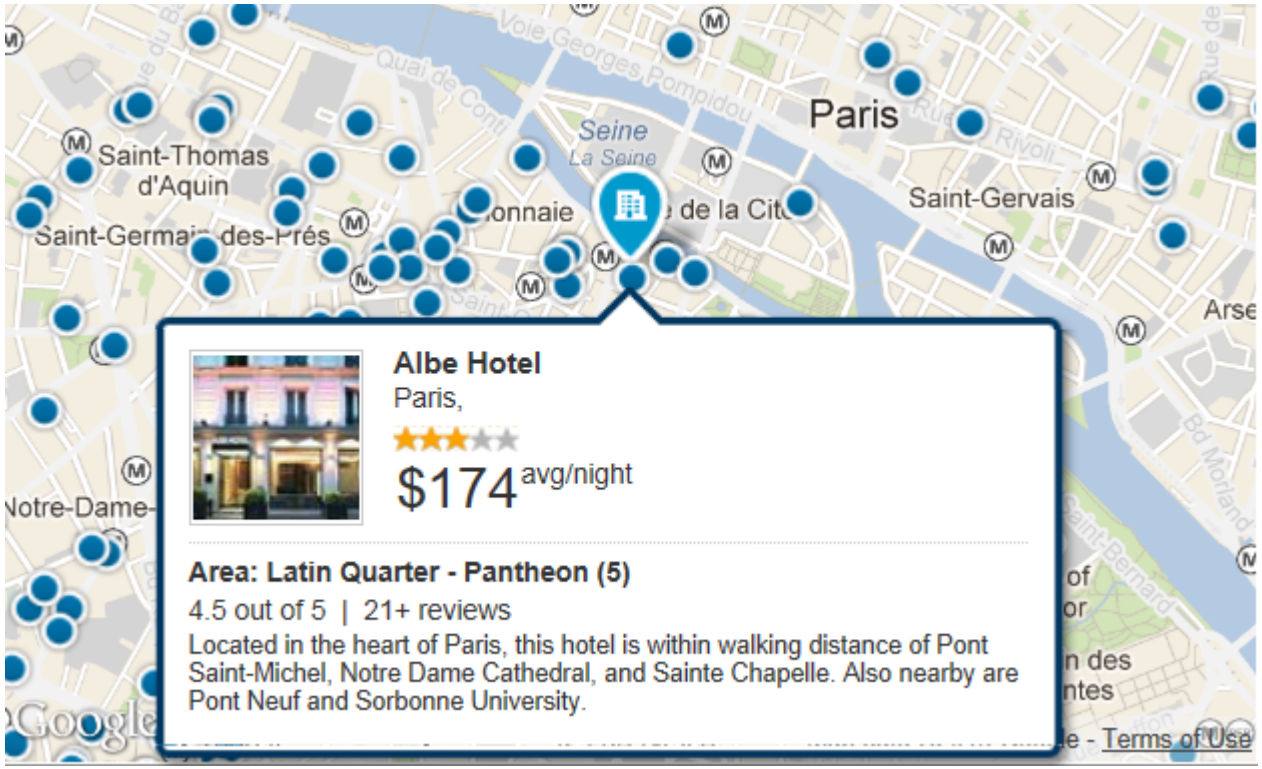
Motivation (hotel booking)



Motivation (hotel booking)

Lemon Hotel Longperrier Roissy
Longperrier (Roissy - Charles de Gaulle Airport (CDG)) - Map
1-866-264-5744

$43
rate per night



Every Km is worth 10$

1) Albe Hotel
2) L'orangerie
3) Lemmon Hotel
4) …

Outline

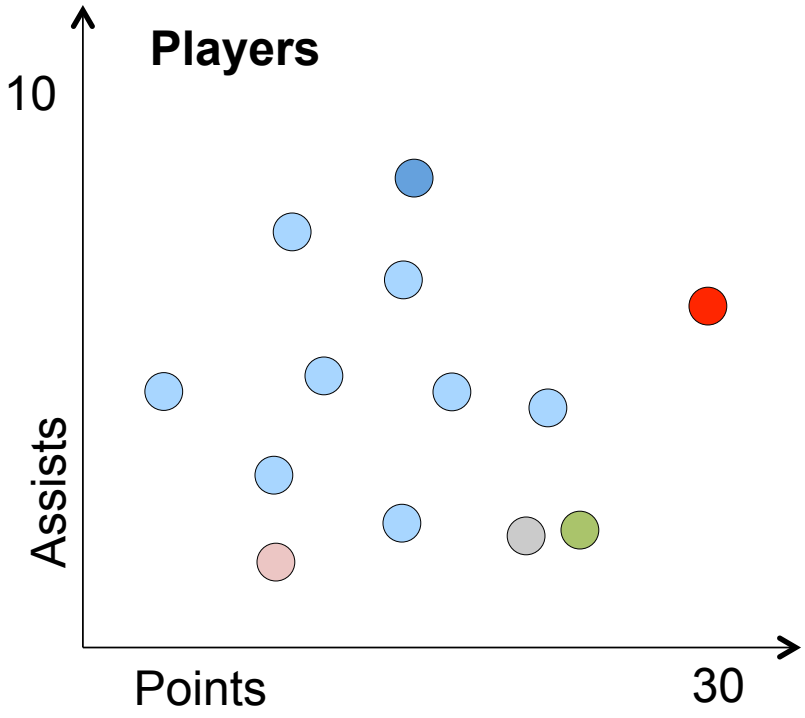
- The skyline (Pareto front) operator.
- Practical issues.
- Current research directions.

THE SKYLINE OPERATOR

Skyline

```
SELECT *
FROM PLAYERS
SKYLINE OF Assists MAX, Points MAX
```

Player	Assists	Points
Yao Ming	1.6	19
Steve Nash	8.5	14.6
Michael Jordan	5.3	30
Dirk Novitzki	1.8	22
Marco Belinelli	1.3	8



Skyline

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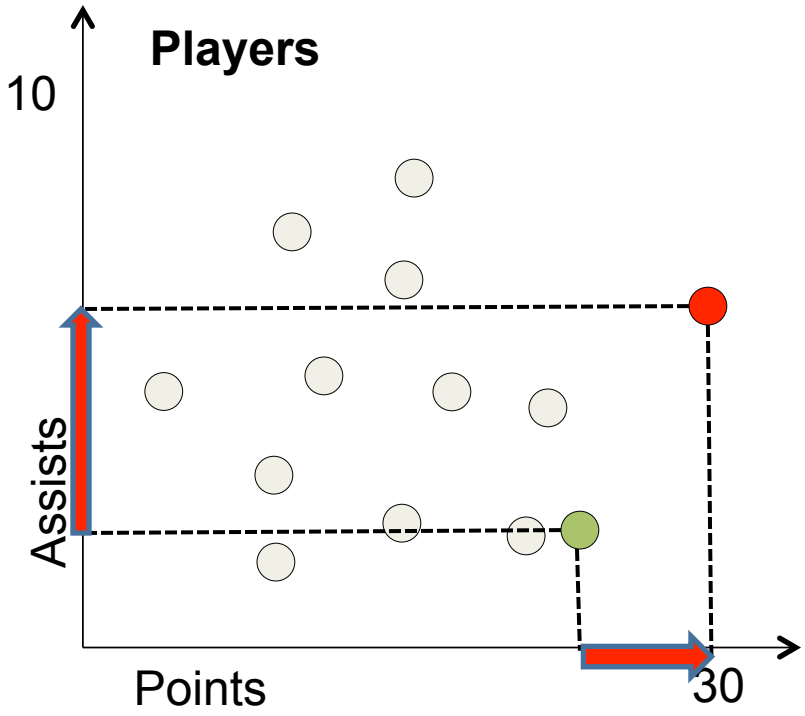

DEFINITION 1 (DOMINANCE). *Let r and s be two records in d dimensions. r dominates s iff* $\forall i \in [1,d]\ r_i \geq s_i \wedge \exists i\ r_i > s_i$

Skyline

Player	Assists	Points
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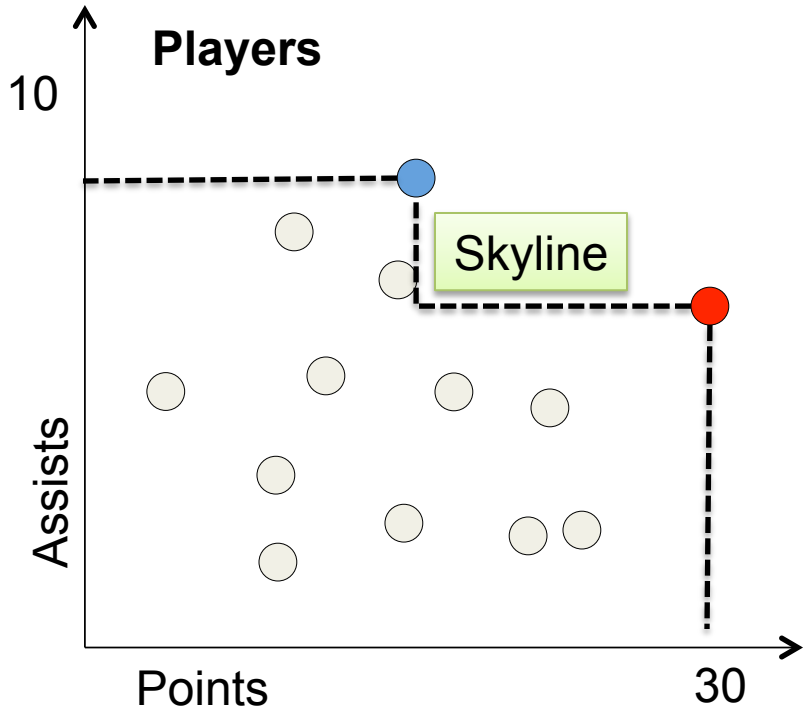


Properties of the skyline

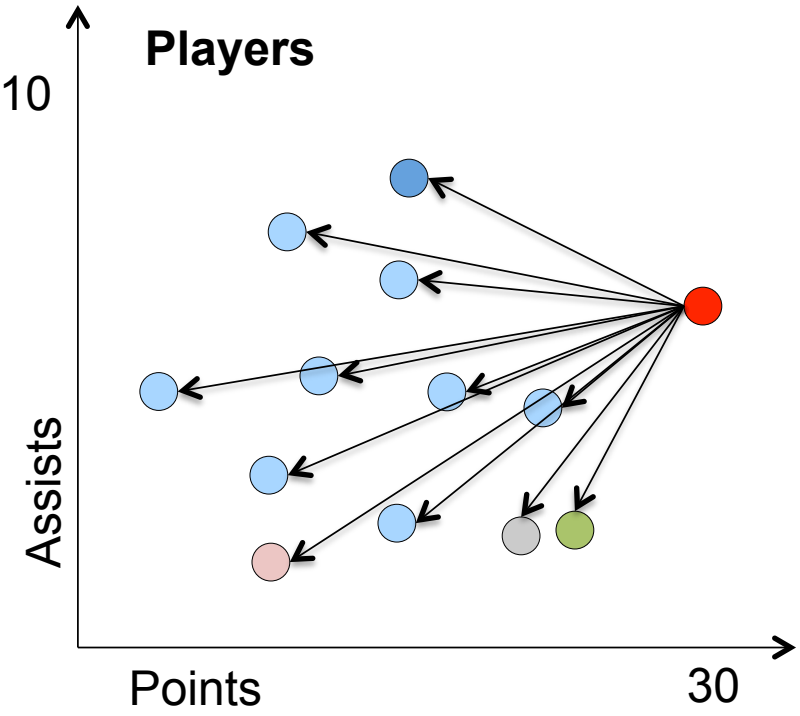
- Selects the best option for all reasonable users.
- It is the tightest result with this property.
- Requires nearly no parameters.
  - Differently from ranking.

PRACTICAL ISSUES

Practical issues

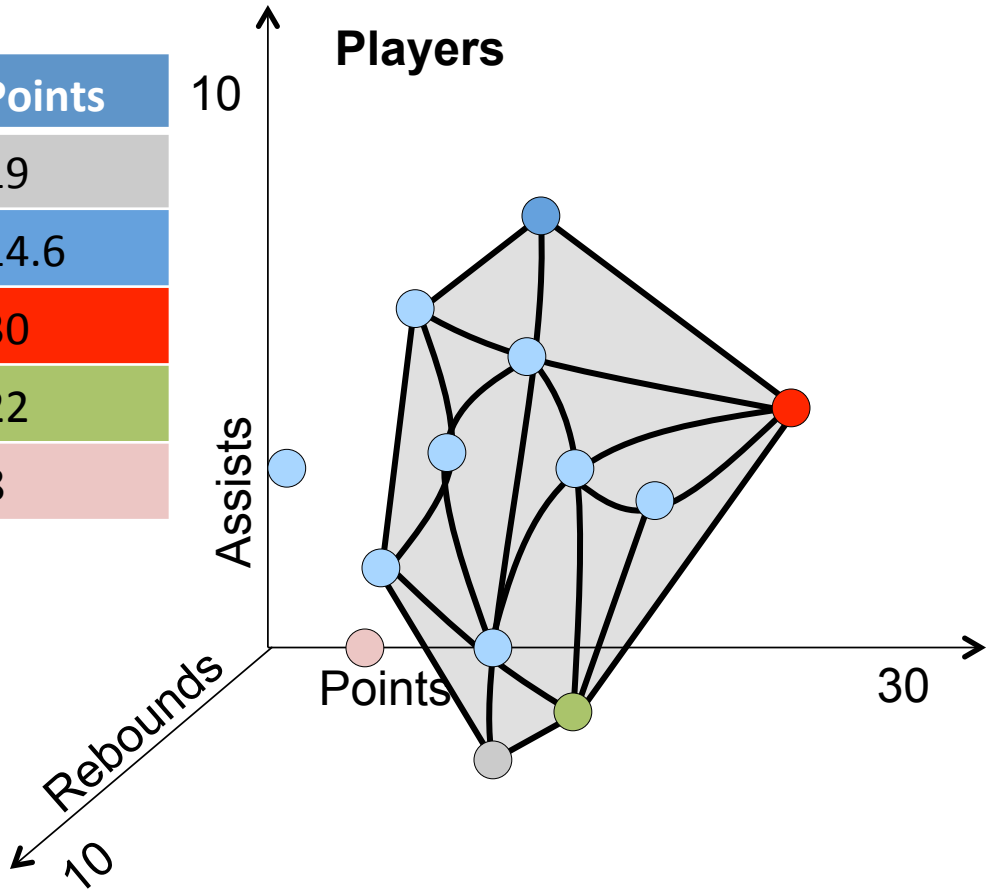
Player	Assists	Points
Yao Ming	1.6	19
Steve Nash	8.5	14.6
Michael Jordan	5.3	30
Dirk Novitzki	1.8	22
Marco Belinelli	1.3	8

To decide if a record is in the skyline, it may be necessary to **compare it with all other records**.



Practical issues

Player	Assists	Rebounds	Points
Yao Ming	1.6	9.2	19
Steve Nash	8.5	3	14.6
Michael Jordan	5.3	6.2	30
Dirk Novitzki	1.8	7.1	22
Marco Belinelli	1.3	1.5	8



Computational complexity.

The **size** of a skyline can be very large depending on the number of attributes and the data distribution

Practical issues

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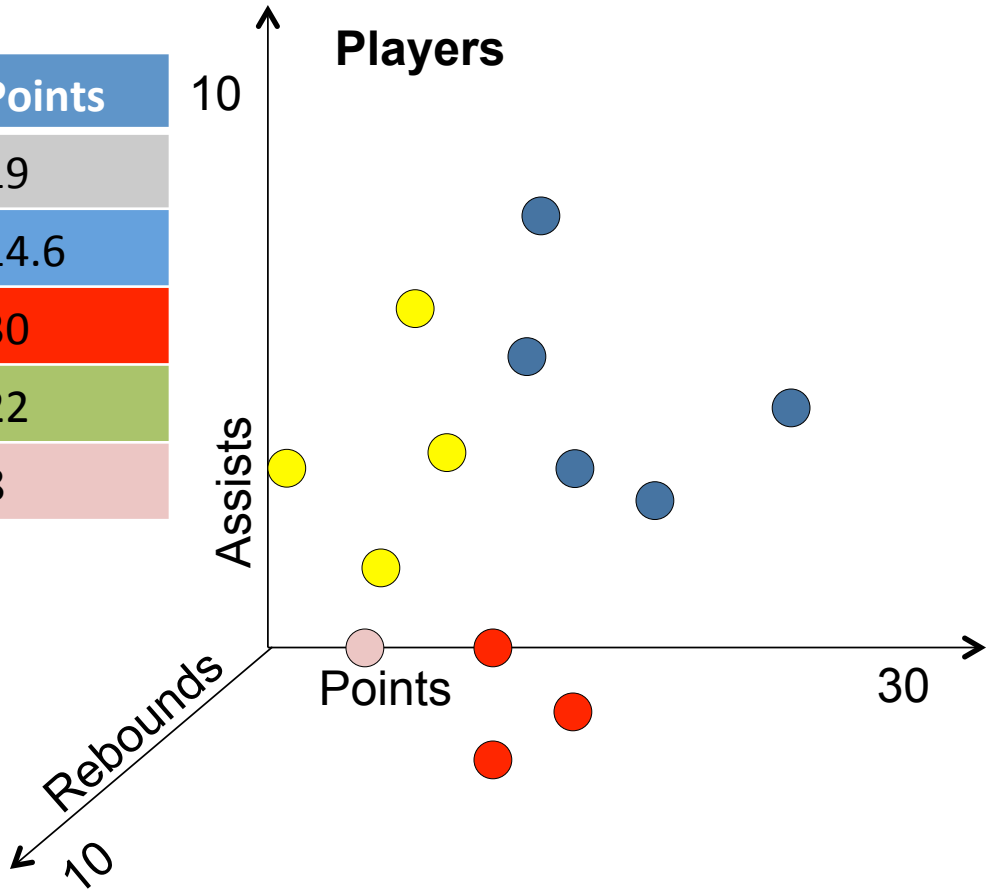
Computational complexity.

Size of the result.

Not used in **isolation.**



Practical issues

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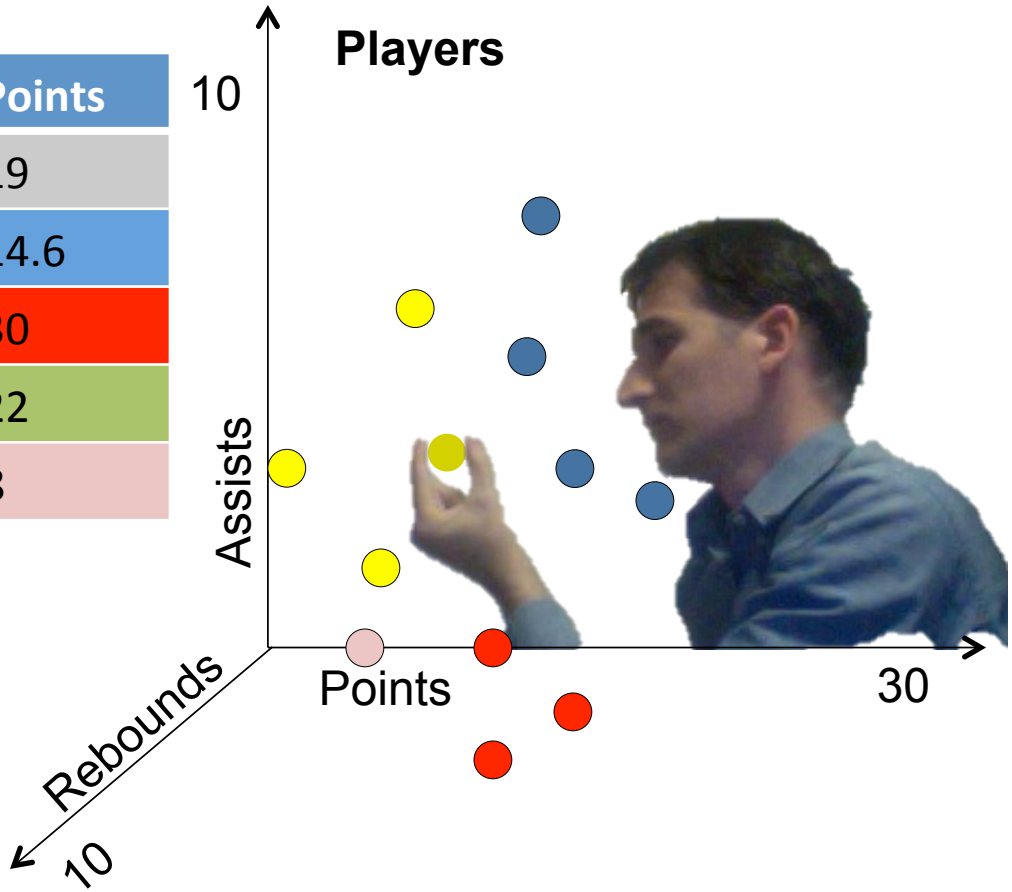
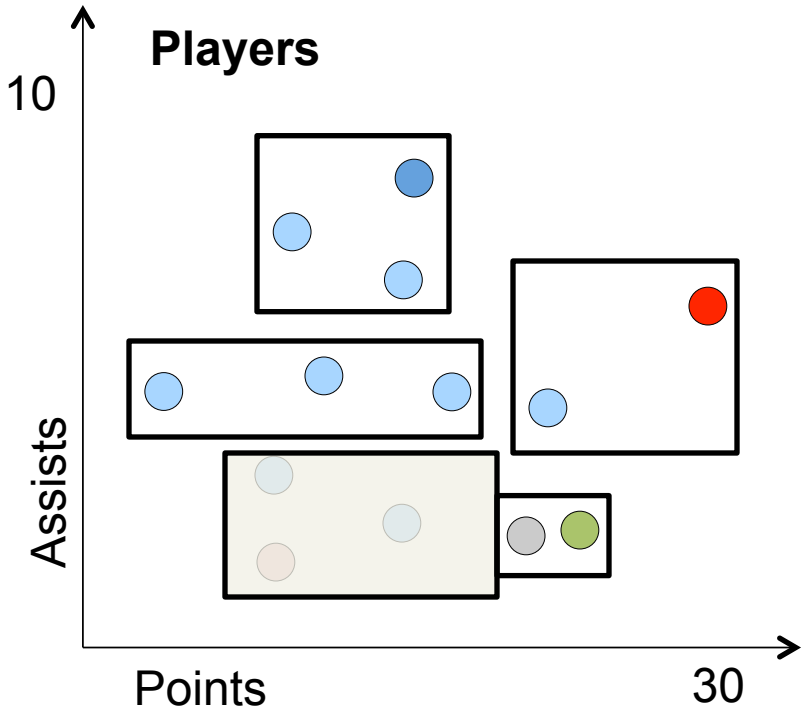


- **Computational complexity**.
- **Size** of the result.
- Not used in **isolation.**
- Which interface to the **users?**

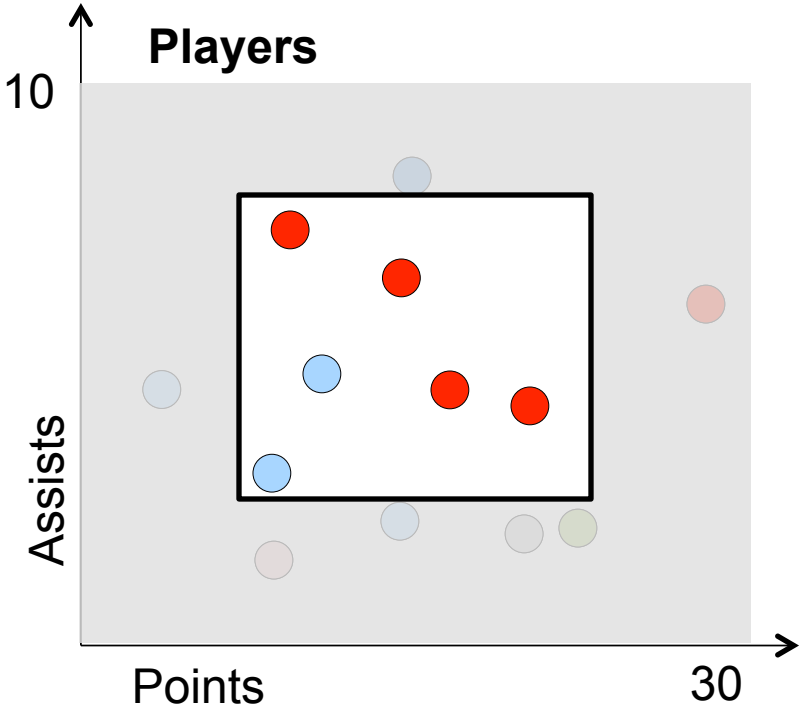
Issue 1: Computational Complexity

- Traditional approach: multidimensional index.
- Very efficient with limited number of parameters.
- May not be fast enough for interactive systems.



Instant skyline computation

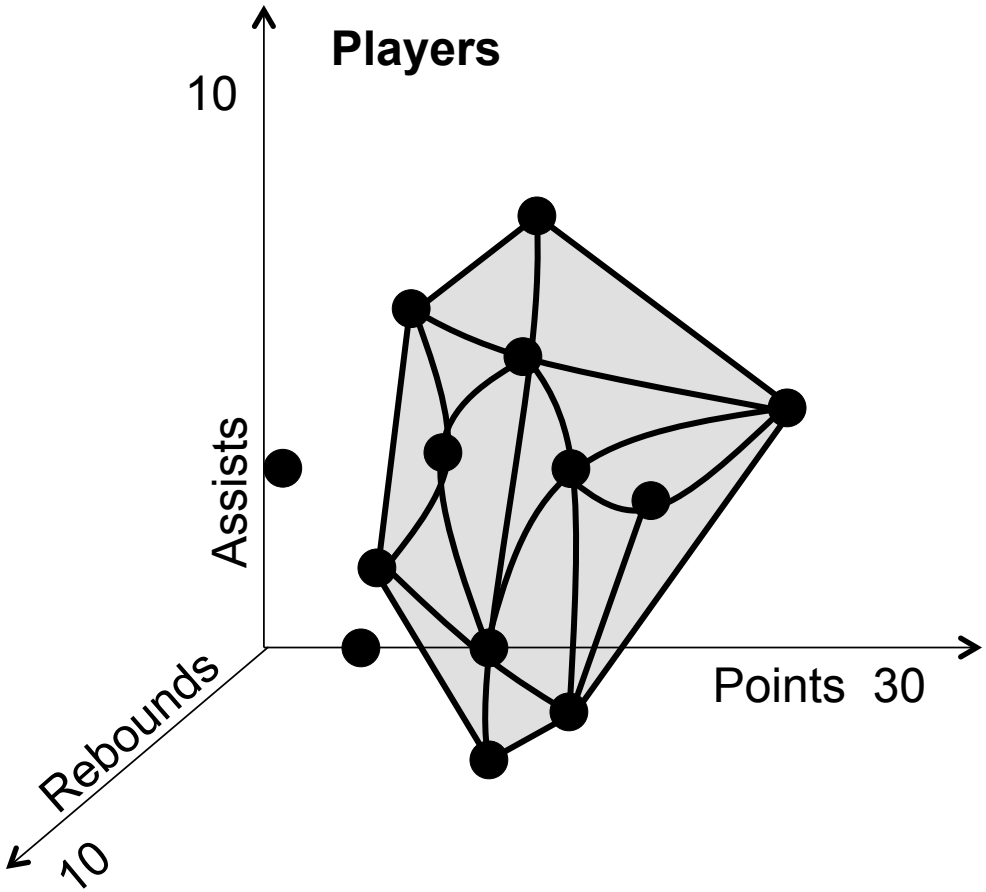
- GP-GPU computing.
- Anytime skylines.



Kenneth S. Bøgh, Ira Assent, Matteo Magnani. **Efficient GPU-based skyline computation.** SIGMOD Workshops (DaMoN), 2013

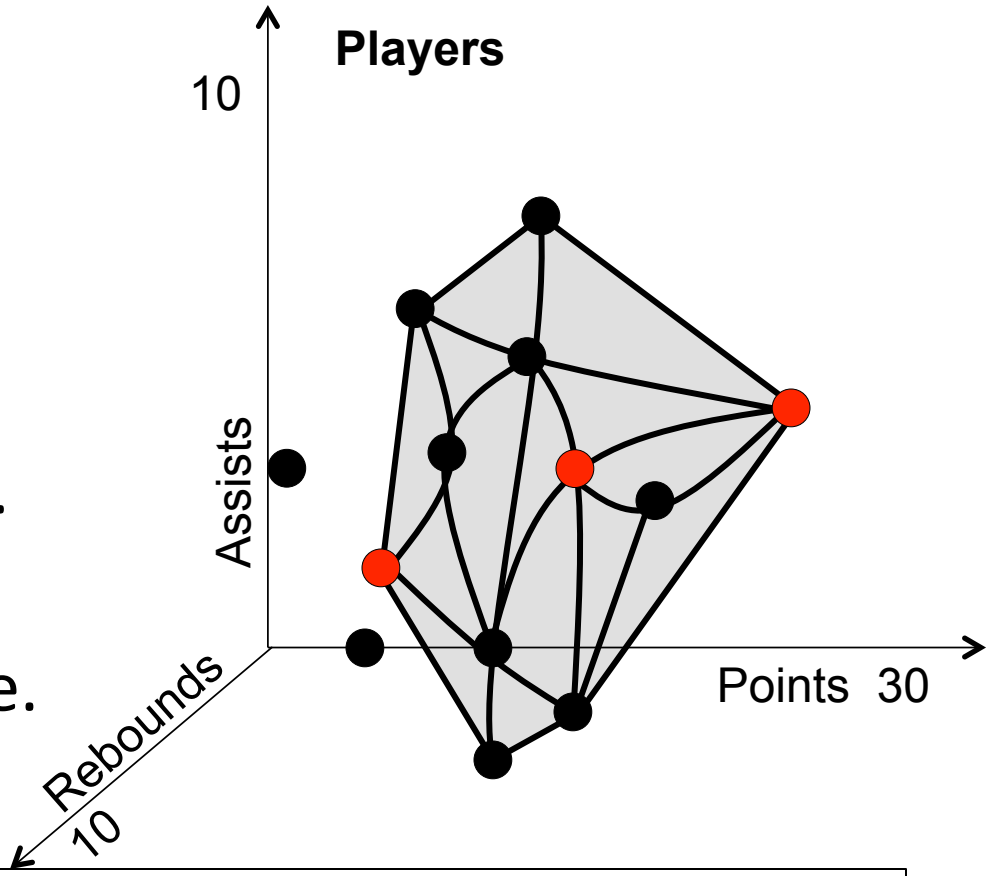
Matteo Magnani, Ira Assent, Michael L. Mortensen. **Anytime skyline query processing for interactive systems.** VLDB Workshops (DBRank), 2012.

Issue 2: skyline size



Representative skyline

- Computation of the skyline.
- Followed by the selection of a set of representative options.
- Based on notions of coverage and relevance.



M. Magnani, I. Assent, M. L. Mortensen.
Taking the Big Picture: representative skylines based on relevance and diversity.
Under submission at VLDB Journal.

Issue 3: combination with other operators

Title	Year	Director	Pop	Qual
Avatar	2009	Cameron	404	8.0
Batman Begins	2005	Nolan	371	8.3
Kill Bill	2003	Tarantino	313	8.2
Pulp Fiction	1994	Tarantino	557	9.0
Star Wars (V)	1980	Kershner	362	8.8
Terminator (II)	1991	Cameron	326	8.6
The Godfather	1972	Coppola	531	9.2
The Lord of the Rings	2001	Jackson	518	8.7
The Room	2003	Wiseau	10	3.2
Dracula	1992	Coppola	76	7.3

Find the best directors according to the movies they have directed

Title	Year	Director	Pop	Qual
Avatar	2009	Cameron	404	8.0
Batman Begins	2005	Nolan	371	8.3
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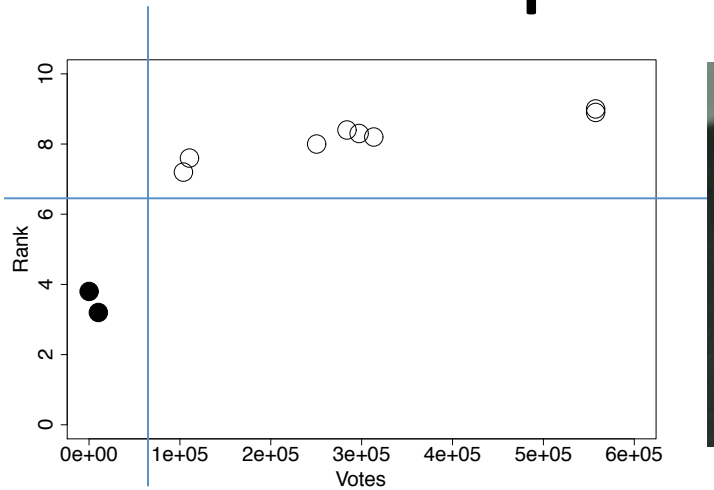
The Room	2003	Wiseau	10	3.2
Dracula	1992	Coppola	76	7.3

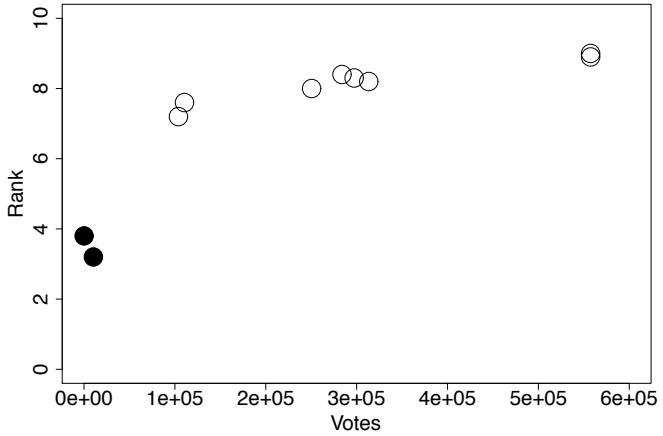
```
SELECT director
FROM movies
GROUP BY Director
SKYLINE OF Pop MAX, Qual MAX
```

Group dominance

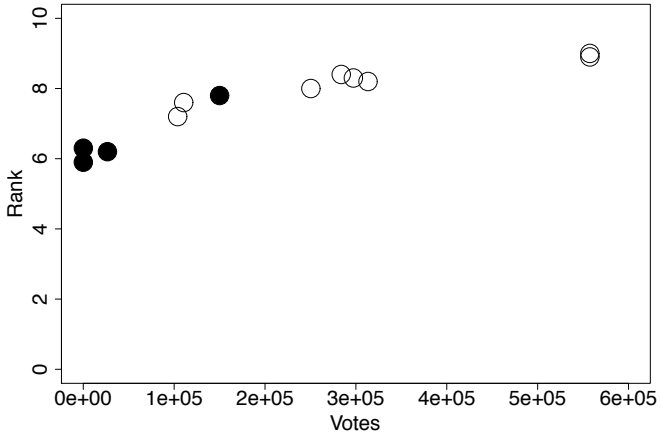


(a) Tarantino vs Wiseau

Group dominance

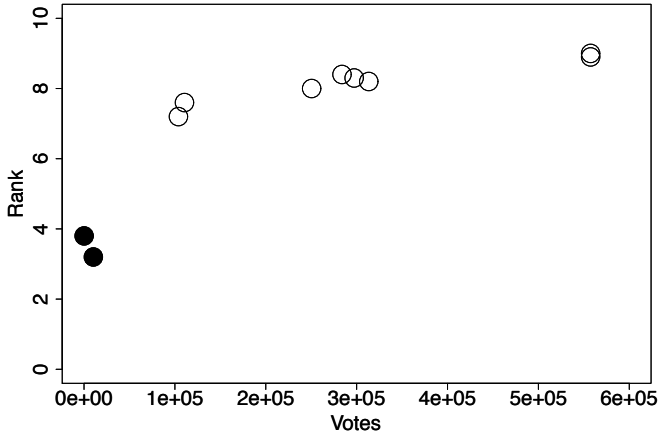


(a) Tarantino vs Wiseau

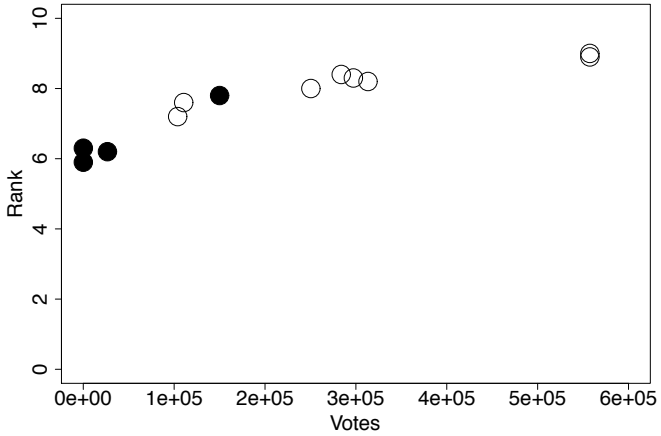


(b) Tarantino vs Fleischer

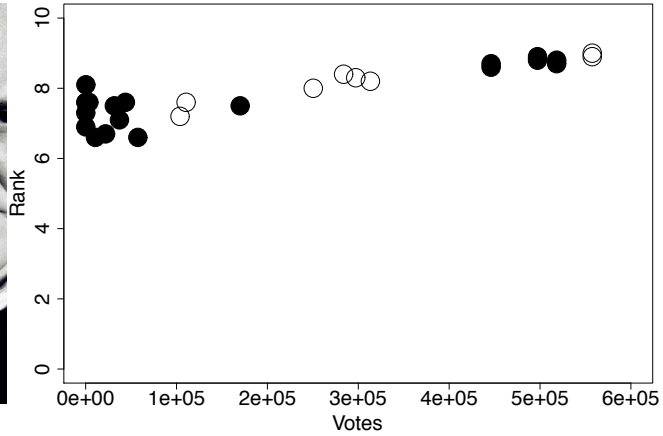
Group dominance

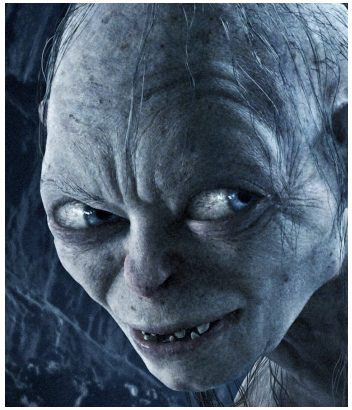


(a) Tarantino vs Wiseau



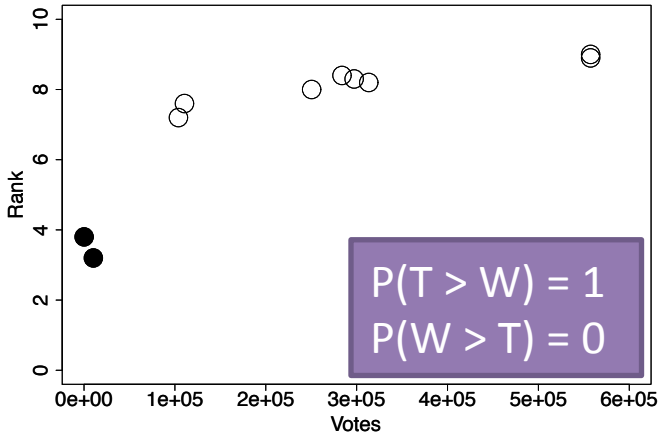
(b) Tarantino vs Fleischer



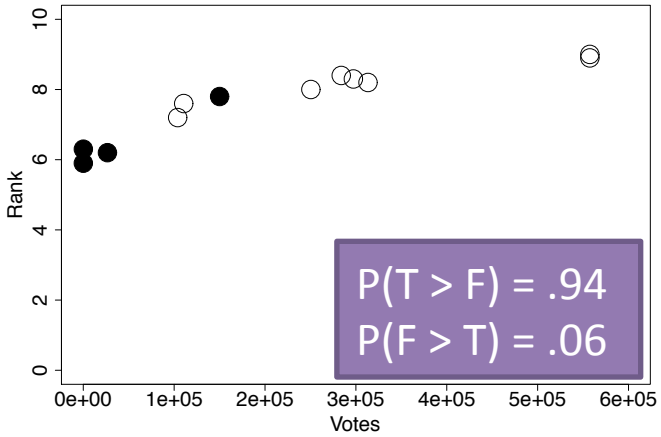


(c) Tarantino vs Jackson

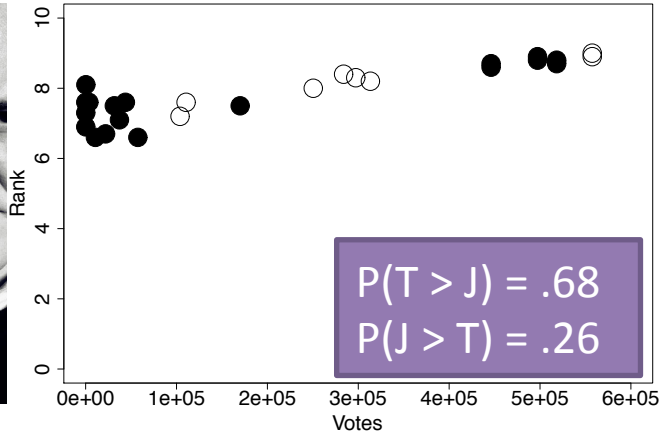
DEFINITION 3 (γ-DOMINATION). *Let $p(S \succ R)$ be the probability that, given a random pair of records $(r, s) \in R \times S$, $s \succ r$. We say that $S \succ_\gamma R$ iff $p(S \succ R) = 1 \vee p(S \succ R) > \gamma$.*

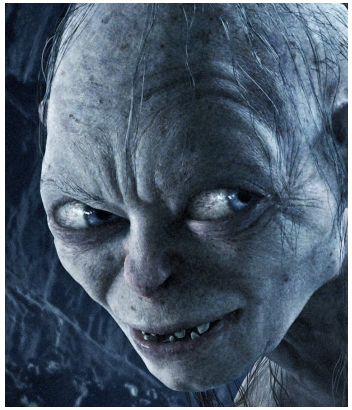


(a) Tarantino vs Wiseau



(b) Tarantino vs Fleischer

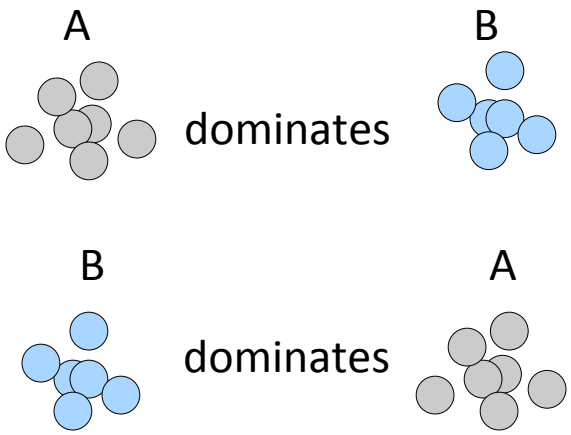




(c) Tarantino vs Jackson

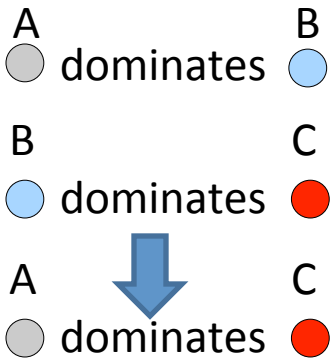
Thresholds and asymmetry

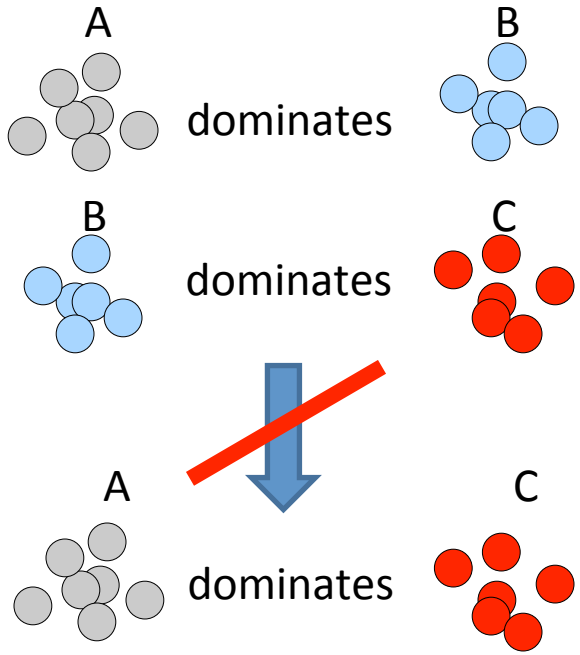
- Above which probability should we filter out a group of records?
- Relevant threshold: probability > .5
- Otherwise, no asymmetry.

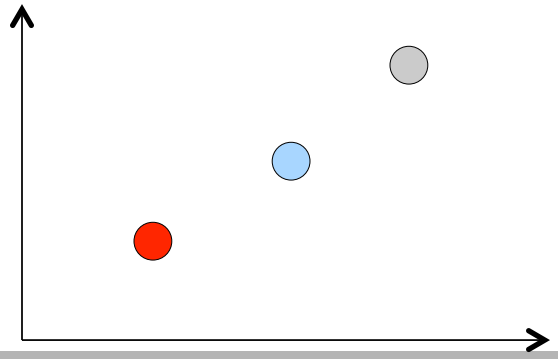


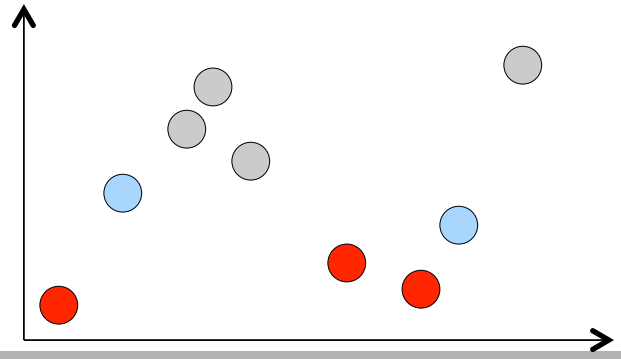
Transitivity

- In general transitivity does not hold.



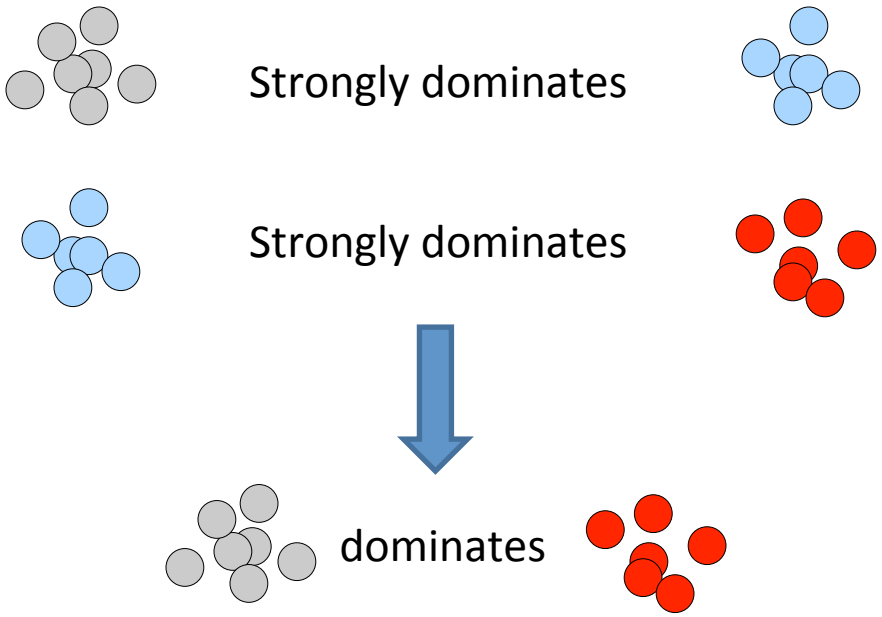




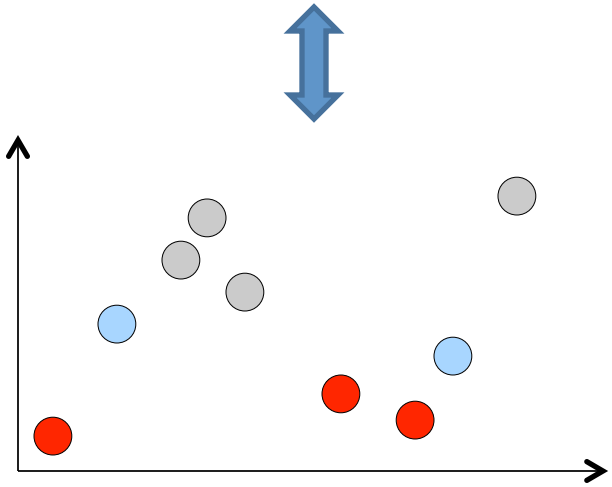


Weak transitivity

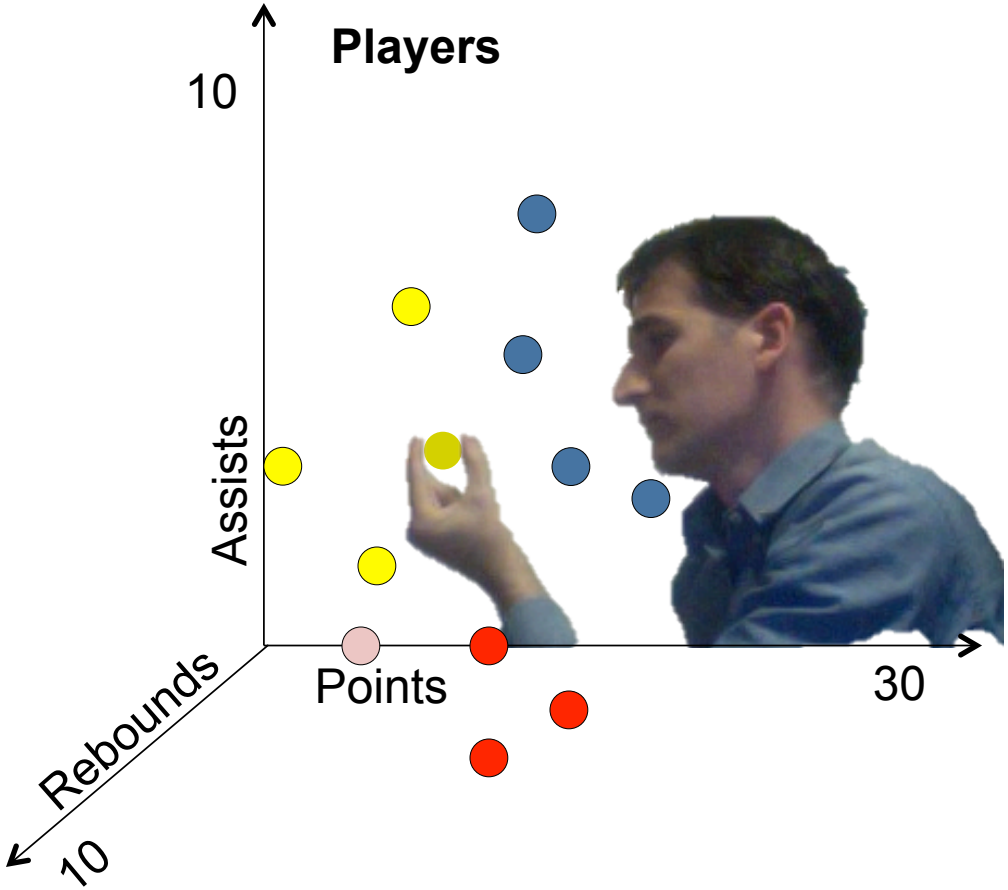
PROPOSITION 5 (WEAK TRANSITIVITY). *If* $R \succ_{\overline{\gamma}} S$ *and* $S \succ_{\overline{\gamma}} T$ *then* $R \succ_{\gamma} T$, *where* $\overline{\gamma} = 1 - \frac{\sqrt{1-\gamma}}{2}$.



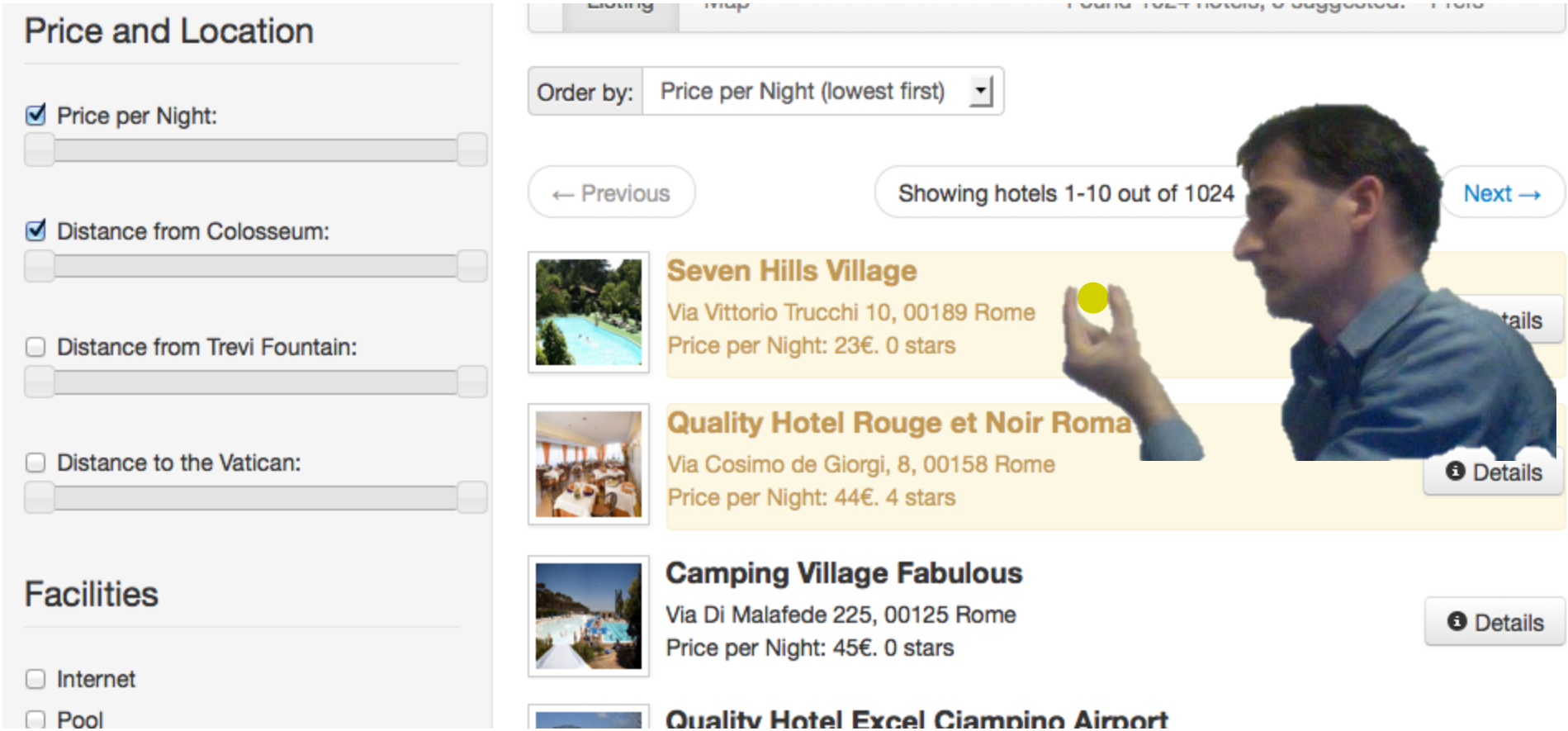
$$\begin{pmatrix} 1 & 0 \\ 1 & 1 \\ 1 & 0 \\ 1 & 0 \end{pmatrix} \times \begin{pmatrix} 1 & 0 & 0 \\ 1 & 1 & 1 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 2 & 1 & 1 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix}$$



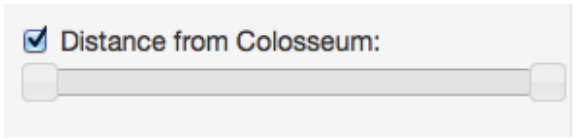
Issue 4: user interface?



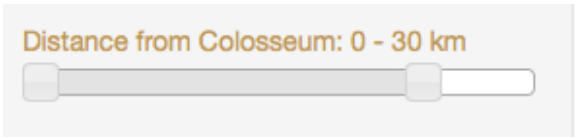
User evaluation of a skyline-enhanced hotel booking interface



Multiple options, think-aloud study

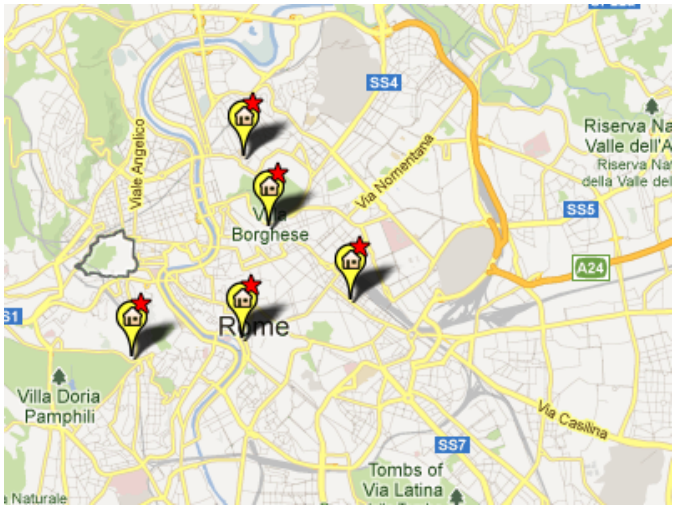


(a)

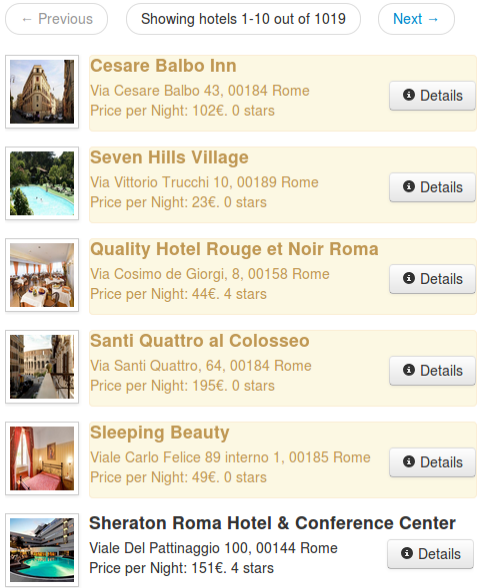


(b)

(c)



(d)



(e)

Result highlights (1)

- No complete understanding of the result.
  - "Probably based on prices, and distance to the Colosseum, and what do I know" (after having set only the number of stars).
  - Setting max price while skylining on lower prices.
- Some algorithmic features confusing.
  - E.g., non deterministic behavior (toggle/untoggle).
  - E.g., non-monotone result generation.

Result highlights (2)

- Confusing interaction of skyline and ranking.
  - Representative skyline on stars, sorting on price.
  - After a selection of 5-star hotels, 1-star options coming before other 5-star hotels.
- Difficult to operate explicit skyline selections.
  - Implicit selection works better, but not possible to decouple skyline and filtering.
- Highlighting hotels in the map-view works well.
  - Not necessarily in the list-view.

Summary

- Skyline operator.
  - Low-parameter selection of best options.
- Practical issues.
  - Complexity, size, embedding and user interfaces.
- Recent advances.
  - Anytime skyline queries.
  - Representative skylines.
  - Aggregate skyline queries.
- Need to test data management operators *in vivo*.

References

- S. Börzsöny, D. Kossmann, and K. Stocker. **The Skyline operator**, ICDE Conference, 2001.
- M. Magnani, I. Assent, M. L. Mortensen. **Taking the Big Picture: representative skylines based on relevance and diversity.** Under submission, VLDB Journal.
- M. Magnani, I. Assent, M.L. Mortensen. **Anytime skyline processing for interactive systems.** VLDB Workshops (DBRank), 2012.
- Kenneth S. Bøgh, Ira Assent, Matteo Magnani. **Efficient GPU-based skyline computation.** SIGMOD Workshops (DaMoN), 2013.
- M. Magnani, I. Assent. **From stars to galaxies: skyline queries on aggregate data.** EDBT, 2013.
- Magnani, M., Assent, I., Hornbæk, K., Jakobsen, M., Larsen, K. **SkyView: a user evaluation of the skyline operator.** CIKM, 2013.

The skyline operator

recent research directions and applications

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