# FDB: A Query Engine for Factorised Relational Databases

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## Factorised Relational Databases

### Compact representations that reduce data redundancy and boost query performance

- Algebraic factorisations of relational data using distributivity of product over union
- Can be exponentially more succinct than the relations they encode
- Allow for constant-delay enumeration of tuples, unlike join decompositions and trivial representation (Q,D)

PlaysFor

| player | team |
|---|---|
| Messi | Barcelona |
| Villa | Barcelona |
| Cech | Chelsea |
| Torres | Chelsea |
| van Persie | Arsenal |

CompetesIn

| team | league |
|---|---|
| Barcelona | Primera |
| Barcelona | Champions |
| Chelsea | Premier |
| Chelsea | Champions |
| Arsenal | Premier |

LeagueStadium

| league | stadium |
|---|---|
| Primera | CampNou |
| Champions | CampNou |
| Champions | Wembley |
| Premier | Stamford |
| Premier | Wembley |

$Q_1$ = PlaysFor $\bowtie_{\text{team}}$ CompetesIn $\bowtie_{\text{league}}$ LeagueStadium

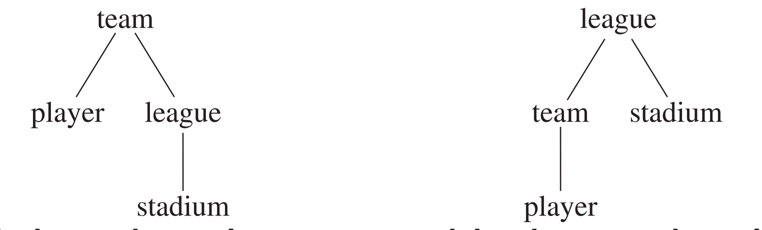
| player | team | league | stadium |
|---|---|---|---|
| Messi | Barcelona | Primera | CampNou |
| Messi | Barcelona | Champions | CampNou |
| Messi | Barcelona | Champions | Wembley |
| Villa | Barcelona | Primera | CampNou |
| Villa | Barcelona | Champions | CampNou |
| | | … | |

Two examples of **factorised representations** of the above query result:

$$\begin{aligned}&\langle\text{Barcelona}\rangle \times (\langle\text{Messi}\rangle \cup \langle\text{Villa}\rangle)\times\\ &\quad\times (\langle\text{Primera}\rangle \times \langle\text{CampNou}\rangle\cup\\ &\qquad\langle\text{Champions}\rangle \times (\langle\text{CampNou}\rangle \cup \langle\text{Wembley}\rangle))\cup\\ &\langle\text{Chelsea}\rangle \times (\langle\text{Cech}\rangle \cup \langle\text{Torres}\rangle)\times\\ &\quad\times ((\langle\text{Premier}\rangle \times (\langle\text{Stamford}\rangle \cup \langle\text{Wembley}\rangle))\cup\\ &\qquad\langle\text{Champions}\rangle \times (\langle\text{CampNou}\rangle \cup \langle\text{Wembley}\rangle))\cup\\ &\langle\text{Arsenal}\rangle \times \langle\text{van Persie}\rangle\times\\ &\quad\times ((\langle\text{Premier}\rangle \times (\langle\text{Stamford}\rangle \cup \langle\text{Wembley}\rangle)).\end{aligned}$$

$$\begin{aligned}&\langle\text{Primera}\rangle \times \langle\text{Barcelona}\rangle \times (\langle\text{Messi}\rangle \cup \langle\text{Villa}\rangle) \times \langle\text{CampNou}\rangle\cup\\ &\langle\text{Champions}\rangle \times (\langle\text{Barcelona}\rangle \times (\langle\text{Messi}\rangle \cup \langle\text{Villa}\rangle)\cup\\ &\qquad\langle\text{Chelsea}\rangle \times (\langle\text{Cech}\rangle \cup \langle\text{Torres}\rangle))\times\\ &\qquad\times (\langle\text{CampNou}\rangle \cup \langle\text{Wembley}\rangle)\cup\\ &\langle\text{Premier}\rangle \times (\langle\text{Chelsea}\rangle \times (\langle\text{Cech}\rangle \cup \langle\text{Torres}\rangle)\cup\\ &\qquad\langle\text{Arsenal}\rangle \times \langle\text{van Persie}\rangle)\times\\ &\qquad\times (\langle\text{Stamford}\rangle \cup \langle\text{Wembley}\rangle).\end{aligned}$$

**Factorisation trees** (f-trees) describe the nesting structure of the above factorisations:




Left: First group by team and then by players and independently by leagues with stadiums.
Right: First group by league and then by teams with players and independently by stadiums.

## Size of Factorised Representations of Query Results

For any conjunctive (aka select-project-join) query $Q$, there is a number $s(Q)$ such that

For any database **D**, there is a factorised representation of $Q(D)$ with size $O(|\mathbf{D}|^{s(Q)})$.

This is the **best possible bound** for factorisations inferred from $Q$, without looking at **D**.
How to compute the parameter $s(Q)$?

- Iterate over all f-trees inferred from $Q$
- For each f-tree $\mathcal{T}$, for each root-to-leaf path $p$ in $\mathcal{T}$, compute:
  - the **fractional edge cover number** of the hypergraph of the sub-query defined by $p$,
  - the maximum such number $s(\mathcal{T})$ over all paths in $\mathcal{T}$
- Take $s(Q)$ as the minimum $s(\mathcal{T})$ over all f-trees $\mathcal{T}$ of $Q$

## Publications


- **On Factorisation of Provenance Polynomials** D. Olteanu, J. Závodný. In *TaPP*, 2011.
- **Factorised Representations of Query Results.** D. Olteanu, J. Závodný. In *ICDT*, 2012.
- **FDB: A Query Engine for Factorised Relational Databases** N. Bakibayev, D. Olteanu, J. Závodný. In *PVLDB* 5(11):1232-1243, 2012.
- **Demonstration of the FDB Query Engine for Factorised Databases** N. Bakibayev, D. Olteanu, J. Závodný. In *PVLDB* 5(12), 2012.


## Query Evaluation

Any query can be evaluated by a sequential composition of operations called **factorisation plan** $f = \omega_1, \dots, \omega_k$ that performs the following sequence of transformations:

$$\mathcal{T}_{\text{initial}} = \mathcal{T}_0 \overset{\omega_1}{\mapsto} \mathcal{T}_1 \overset{\omega_2}{\mapsto} \dots \overset{\omega_k}{\mapsto} \mathcal{T}_k = \mathcal{T}_{\text{final}}$$

and is defined by the following operators on f-trees.

**Restructuring: Normalisation Operator**
- factors out expressions common to all terms of a union.
- all our operators preserve normalisation.

**Restructuring: Swap Operator** $\chi_{\mathcal{A},\mathcal{B}}$
- exchanges a node $\mathcal{B}$ with its parent node $\mathcal{A}$ in the input f-tree $\mathcal{T}$ while preserving normalisation of $\mathcal{T}$.

**Cartesian Product** $\times$
- simply concatenates the input representations.

**Merge (Absorb) Join Operator** $\mu_{\mathcal{A},\mathcal{B}}$ ($\alpha_{\mathcal{A},\mathcal{B}}$)
- executes selection condition $\mathcal{A} = \mathcal{B}$ if $\mathcal{A}$ and $\mathcal{B}$ are sibling nodes (respectively, $\mathcal{A}$ is an ancestor of $\mathcal{B}$) in $\mathcal{T}$.

**Projection Operator** $\pi_{-A}$
- projects away the attribute $A$, if $A$ is a leaf in $\mathcal{T}$.

The operators need **quasilinear time in the data input and output sizes**. The evaluation time for $f$ is $O(|\mathbf{D}|^{s(f)} \cdot \log|\mathbf{D}|)$, where $s(f) = \max(s(\mathcal{T}_0), s(\mathcal{T}_1), \dots, s(\mathcal{T}_k))$.

## Query Optimisation

Two optimisation objectives (in this order):

1. find a **factorisation plan with minimal cost**, and
2. find a **small factorisation of the query result**.

Cost based on asymptotic bounds (i.e., $s(f)$) or estimates.
Search space defined by the order of join, swap, and projection operators. Two optimisers:

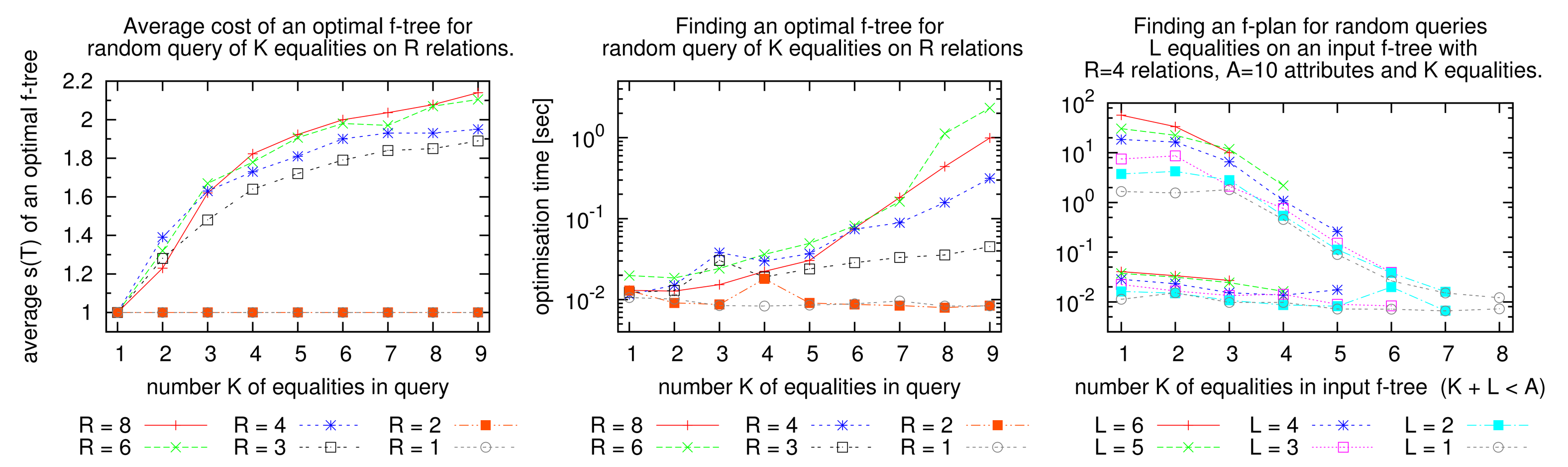
1. Exhaustive/full search
2. Greedy search: always choose the cheapest operator.

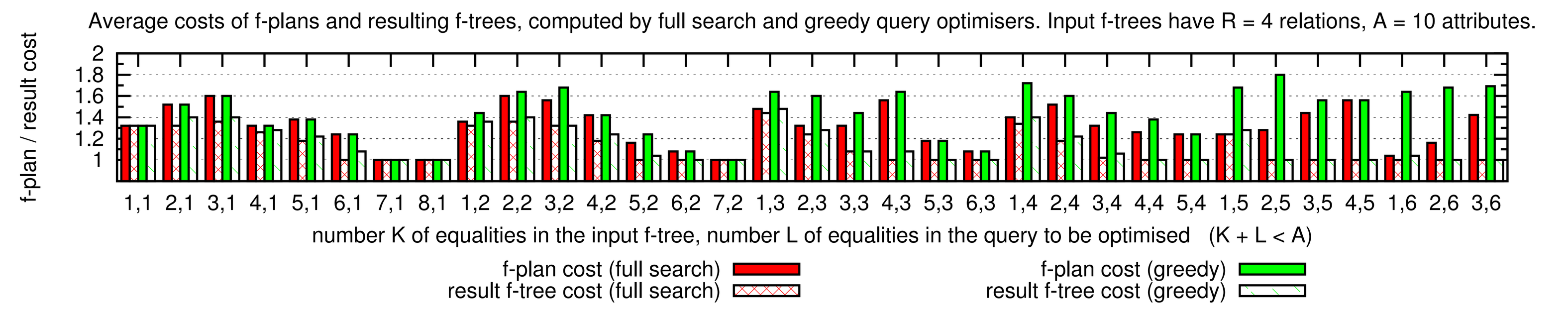
## Applications

- **Succinct representation of large query results**
- **Knowledge compilation in relational databases**
  - Compile data into compact factorised form
  - Speed up processing of many subsequent queries
- **Natural fit for large search spaces**
  - AND/OR trees used in design specification
  - World-set decompositions for incomplete data
  - Configuration problems in constraint satisfaction
- **Factorised provenance polynomials**
  - Compact encoding for provenance information
  - Efficient query evaluation in probabilistic databases

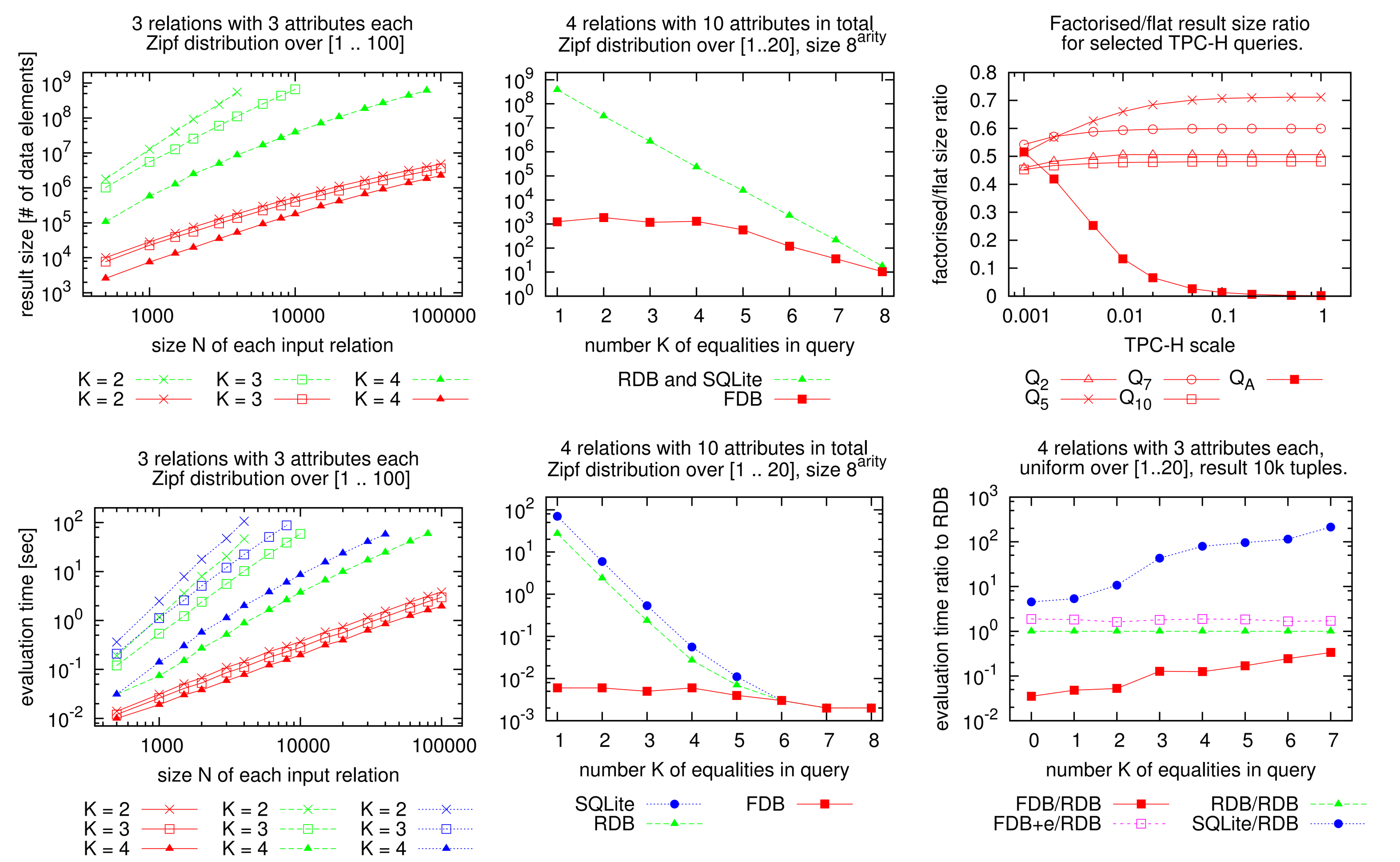
## Experiments: Query Optimisation

**Full search** (slower, top series) vs **greedy** (faster, bottom series):

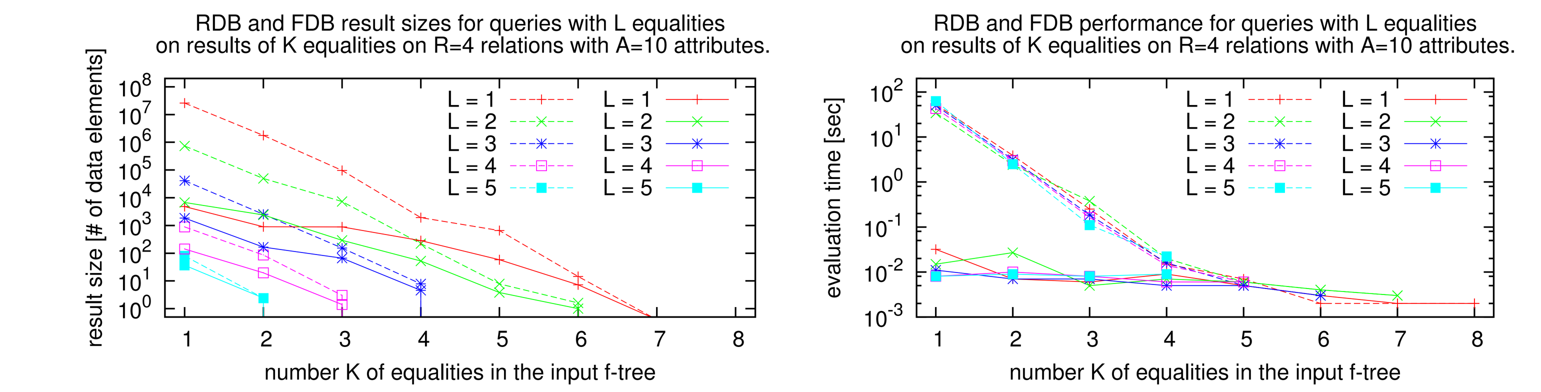



## Experiments: Query Evaluation on Flat Relational Data




## Experiments: Query Evaluation on Factorised Data




FDB/RDB: solid/dashed lines, bottom/top series in the right plot
RDB (lightweight purpose-built relational engine):

- is three times faster than SQLite.
- works on flat data equivalent to the input factorised data.
- needs one scan over the input, while FDB needs restructuring.