Do Programming Languages need Query Languages?

Jelle Hellings

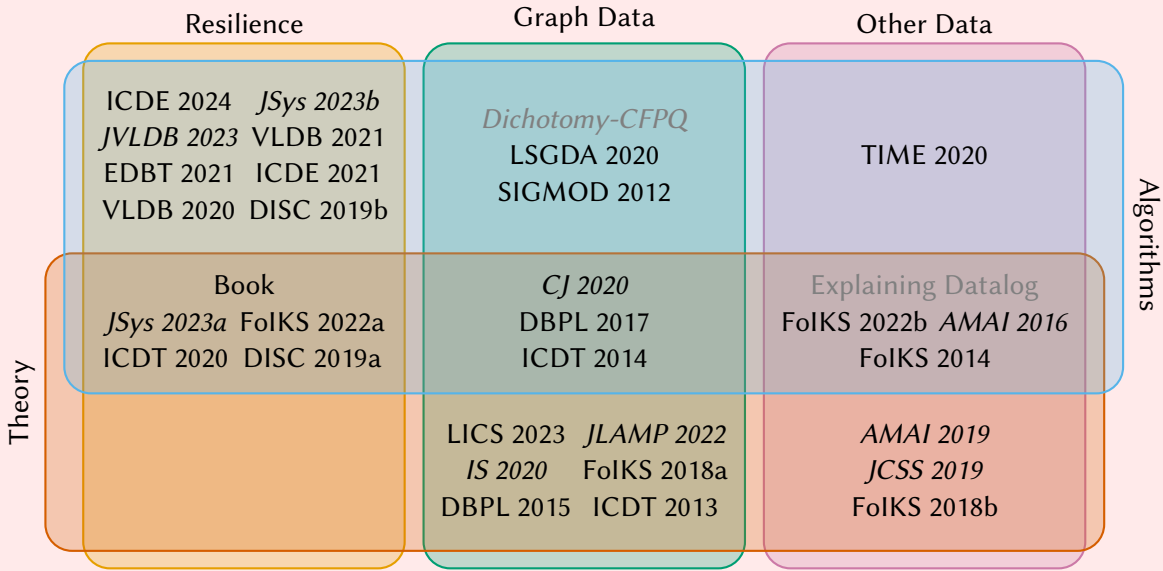
Department of Computing and Software
McMaster University
1280 Main St. W., Hamilton, ON L8S 4L7, Canada

Do Programming Languages need Query Languages?

(spoiler alert)

Yes they do!

About my reasearch: Data and data management!



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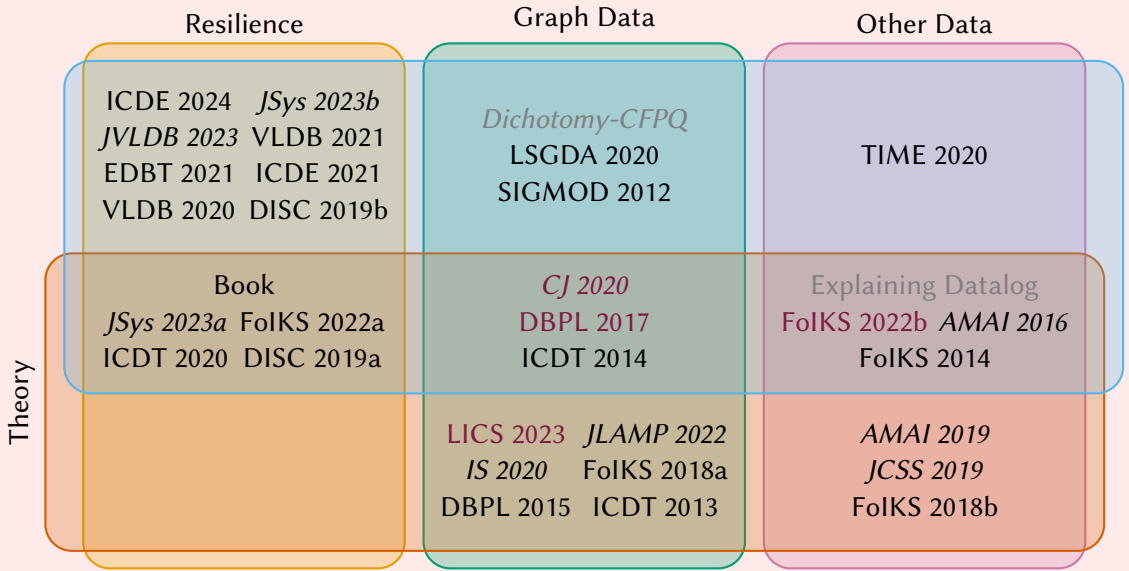

Programming and data processing

Claims

1. Data processing plays a central role in programming.

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Examples: standard support libraries

1. *Collections* to store data
   binary search trees, hash tables, tuples, dynamic arrays, ...
2. *Algorithms* to operate on data
   sorting, filtering, transforming, set operations, ...

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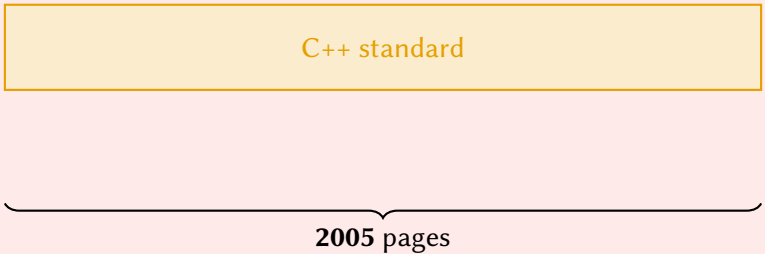
Working Draft of the C++ standard

(Document Number: N4964, Date 2023-10-15.)



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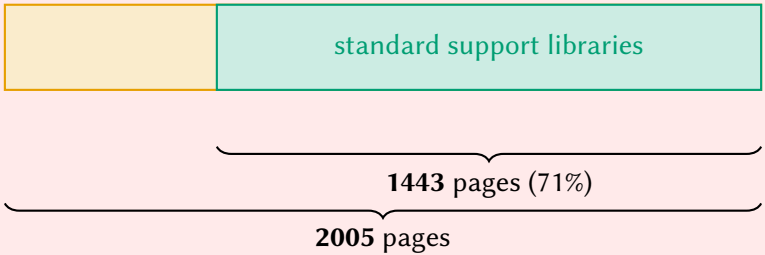

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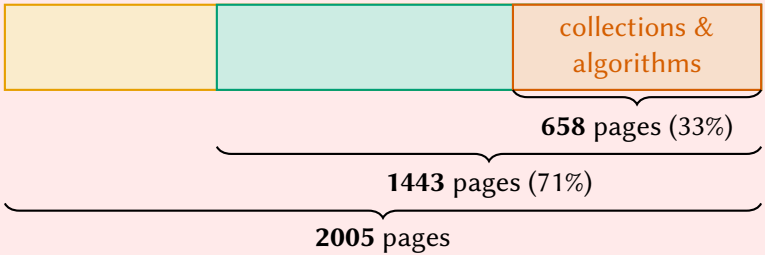

Not counting: numeric, time, formatting, IO, threads, ...

An example: How to *program* relational algebra in C++

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- **Projection** (π_{columns}): `std::transform`.
- **Selection** ($\sigma_{\text{conditions}}$): `std::copy_if`, `std::views::filter`.
- **Joins** ($\times$, $\bowtie$): loops, `std::views::cartesian_product`.
- **Set operations** ($\cap$, $\cup$, $\setminus$): `std::set_union`, ...

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- **Deduplication**: `std::unique_copy`.
- **Aggregation**: `std::accumulate` and `std::reduce`, `std::ranges::fold_left`.

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- **Aggregation**: `std::accumulate` and `std::reduce`, `std::ranges::fold_left`.

- **Parallelization**: execution policies (algorithms), `std::async` (evaluation), ...
- **Pipelined execution**: `std::ranges`, coroutines using `std::generator`, ...

An example: How to *program* relational algebra in C++

$$\pi_{R.\text{parent}}(\sigma_{R.\text{child}=S.\text{name}}(\rho_R(\text{parentOf}) \times \sigma_{S.\text{place}=\text{“Hamilton”}}(\rho_S(\text{person}))))$$

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$$\pi_{R.\text{parent}}(\sigma_{R.\text{child}=S.\text{name}}(\rho_R(\text{parentOf}) \times \sigma_{S.\text{place}=\text{“Hamilton”}}(\rho_S(\text{person}))))$$

```
using namespace std::views;

auto where_pred = [](auto l) { return l.place == "Hamilton"; };

auto product_pred = [](auto t) {
  auto [po, p] = t; return po.child == p.name; };

auto join = cartesian_product(parents, persons | filter(where_pred));
for (auto [po, p] : join | filter(product_pred)) {
    std::cout << po.parent << std::endl;
}
```

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Efficient data processing

"*Complex*" data processing algorithms even for *simple* data processing tasks.
E.g., join algorithms, join ordering, index usage, selection push down, ...

This complexity is delegated to the programmer.

An example: A *more-efficient* query in C++

```
/* parents is a set, ordered on (parent, child).
 * persons is a set, ordered on (name, place). */

auto where_pred = [](auto l) { return l.place == "Hamilton"; };
auto filtered = persons | filter(where_pred)
                        | std::ranges::to<std::vector>();

for (auto& [pname, cname] : parents) {
  person_t p{cname, "Hamilton"};
  bool has_child = std::binary_search(filtered.begin(),
                                      filtered.end(), p);
  if (has_child) {
    std::cout << pname << std::endl;
  }
}
```

An example: A *more-efficient* query in C++

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for (auto& [pname, cname] : parents) {
  person_t p{cname, "Hamilton"};
  bool has_child = persons.contains(p);
  if (has_child) {
    std::cout << pname << std::endl;
  }
}
```

An example: A *more-efficient* query in C++

	Runtime complexity	Memory usage
Original	$\Theta(\lvert\text{parents}\rvert \cdot \lvert\text{persons}\rvert)$	$\Theta(1)$
First variant	$\Theta(\lvert\text{parents}\rvert \log \lvert\text{filtered}\rvert + \lvert\text{persons}\rvert)$	$\Theta(\lvert\text{filtered}\rvert)$
Second variant	$\Theta(\lvert\text{parents}\rvert \log \lvert\text{persons}\rvert)$	$\Theta(1)$

Both “improved” versions can be significantly improved to reduce overheads!

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What if we want *unique* parents?

An example: A *more-efficient* query in SQL

```
SELECT pname
FROM parents R, persons S
WHERE R.child = S.name AND S.place = "Hamilton";
```

An example: A *more-efficient* query in SQL

```
SELECT DISTINCT pname
FROM parents R, persons S
WHERE R.child = S.name AND S.place = "Hamilton";
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SELECT DISTINCT pname
FROM parents R, persons S
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```

Some database systems need a helping hand…

```
SELECT DISTINCT pname
FROM parents
WHERE child IN (SELECT name
                FROM persons
                WHERE place = "Hamilton");
```

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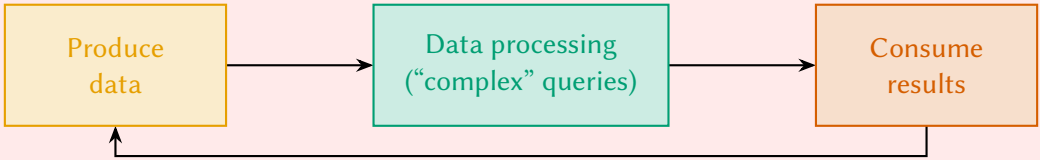
1. Data processing plays a central role in programming.
2. Programming languages are *bad* at data processing.
3. We need database technology in our programming languages.

Potential solution?



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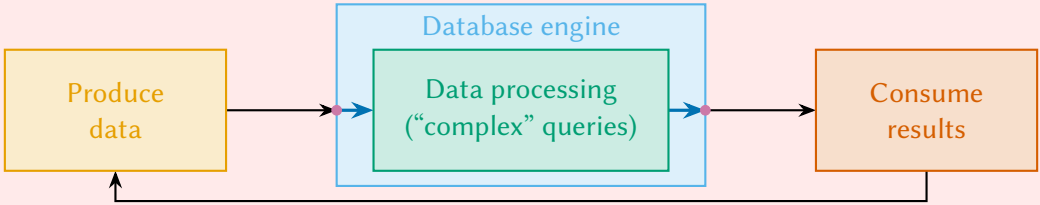
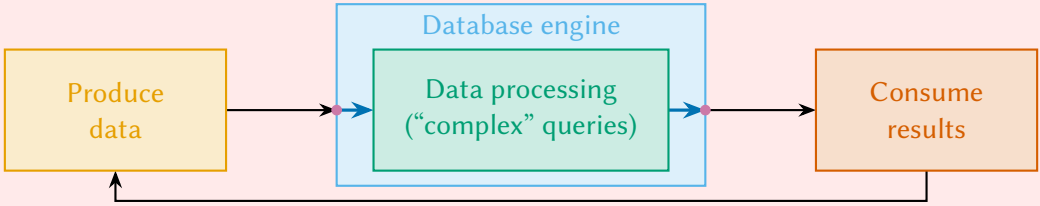


Database systems are *not* the solution



What if we use a database system

For example, PostgreSQL (is free!)

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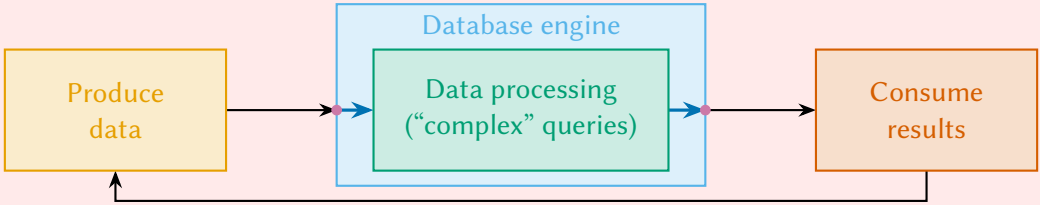

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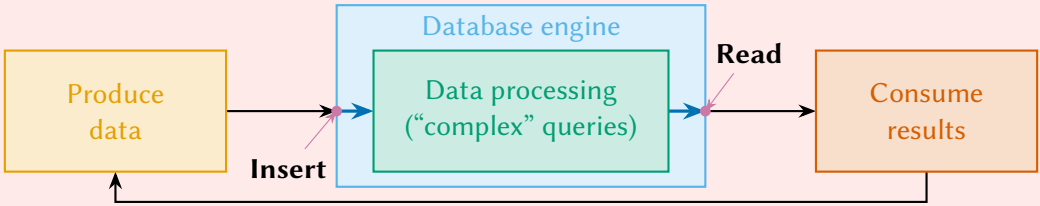

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  Data transfers, necessary code to "translate" between types, ...

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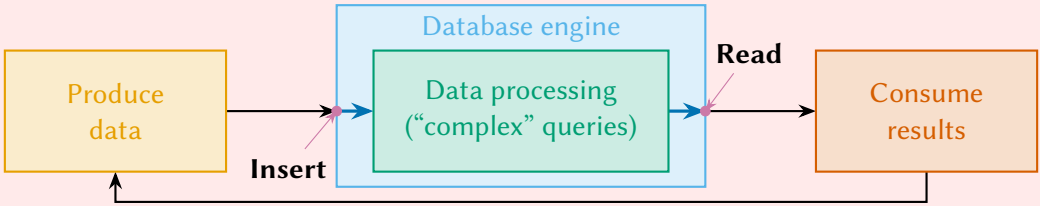

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  For example, type safety (program) versus "no" type safety (query results).

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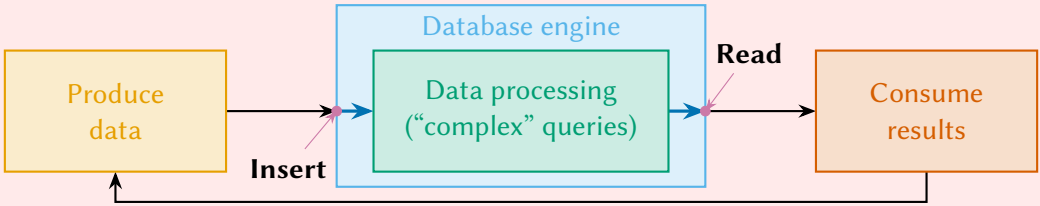

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Proposed solution

What if…

```
#include "my_fancy_library.hpp"
          ⋮
query<"%(parent) :- parents(parent, c),"
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```

is valid C++ code in which **query** generates an *optimized* C++ algorithm (at compile time).

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How to do so

Create a C++ library that

- Provides a *domain specific query language* for C++.
- At C++ compile time, the library *compiles these queries* into C++ algorithms: derive result types, derive query evaluation strategy, ….
- At runtime: these query algorithms are *normal C++ functions*.

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   With zero overhead: the *query plan representation is* the algorithm.

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   Result: the Datalog program in some *internal representation*.

3. A compile-time *query optimizer* and *query plan* compiler:
   Goal: turn the *internal representation* into an efficient query plan.

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C++ compile-time support for *domain specific languages*

Almost feature complete (optimistic: publication in 2024?).

C++ compile-time support for *domain specific languages*

What we have

- A high-level grammar language based on *parsing expression grammars*:
  that controls scanning, parsing, and syntax tree generation.
- A C++ compile-time parser generator that turns grammars into compile-time parsers.
- Utilities to transform syntax trees into complex types
  (as part of new compile-time compilers).
- Runtime parser generator support and debugging utilities.

C++ compile-time support for *domain specific languages*

What is still being worked on

- Full integration of optimizations in the generated parsers.
- Memorization support for the runtime parser generator.
- Evaluation.

A compile-time *query optimizer* and *query plan* compiler

We can use a database-style query planner and query optimizer.
A compile time environment is different, however.

Zero-cost principle

Our *abstraction* of a domain specific query language should not introduce costs (when compared to a handwritten algorithm).

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A compile time environment is different, however.

Zero-cost principle

Our *abstraction* of a domain specific query language should not introduce costs (when compared to a handwritten algorithm).

- *Only-once* query optimization (one compile time, many executions).
- Query optimization *without* access to the data.
- At runtime: algorithms can make choices (e.g., `if-else`),
  But there is only limited information: C++ containers do not have heuristics.

A compile-time *query optimizer* and *query plan* compiler

A blank-slate design

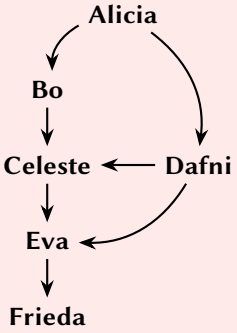
Only-once query optimization: we can use *costly yet effective* optimization techniques!

Inspiration: Automated semi-join rewritings

- In [DBPL 2017, CJ 2020], we showed that
  - almost all node queries expressed in terms of graph navigation can be expressed *without joins* and *without transitive closure*;
  - provided an algorithm to apply such optimizations on (parts) of graph queries.
- In [FoIKS 2022b], we showed that
  - these results *generalize to SQL*: weak-equivalent rewrite rules.
- In [LICS 2023], we showed that
  - *all first-order node queries on trees* are expressible in semi-join-based languages.

Inspiration: Graph query evaluation and SQL [FoIKS 2022b]

edges	
nfrom	nto



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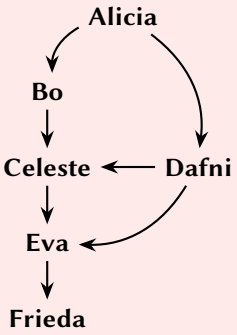

$$\pi_1[Edges \circ Edges \circ Edges \circ Edges].$$

```
SELECT DISTINCT S.nfrom
FROM edges S, edges R, edges T, edges U
WHERE S.nto = R.nfrom AND
      R.nto = T.nfrom AND
      T.nto = U.nfrom;
```

Inspiration: Graph query evaluation and SQL [FoIKS 2022b]

edges	
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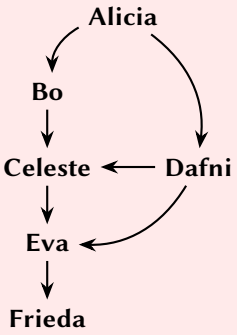

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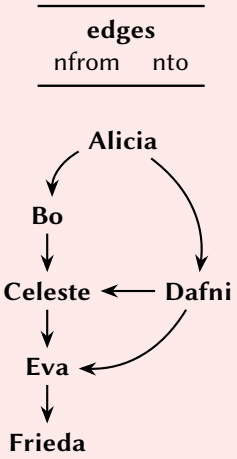
FROM edges S, edges R, edges T, edges U
WHERE S.nto = R.nfrom AND
      R.nto = T.nfrom AND
      T.nto = U.nfrom;
```

Cost of query plan

Depending on system $\pm\mathcal{O}(|\text{edges}|^3)$–$\mathcal{O}(|\text{edges}|^4)$:
Queries do not complete.

Inspiration: Graph query evaluation and SQL [FoIKS 2022b]



$$\pi_1[Edges \ltimes (Edges \ltimes (Edges \ltimes Edges))].$$

```
SELECT DISTINCT nfrom FROM edges
WHERE nto IN (
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```

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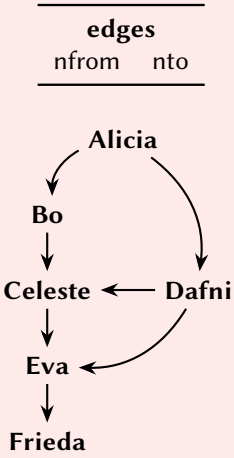

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Cost of query plan

$\pm\mathcal{O}(|\text{edges}|)$: 90 ms with 75,000 edges.

Inspiration: An SQL-based example [FoIKS 2022b]

Original query

```
SELECT DISTINCT C.cname, P.type
FROM customer C, bought B, product P
WHERE C.cname = B.cname AND B.pname = P.pname AND
        P.type = 'food';
```

Inspiration: An SQL-based example [FoIKS 2022b]

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Rewritten query

```
SELECT cname, 'food' AS type
FROM customer WHERE cname IN (
    SELECT cname FROM bought WHERE pname IN (
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Rewrite result

Performance gain of at-least 15%.

(Instance with 500 customers, 24 077 products, and 100 000 records in *Bought*).

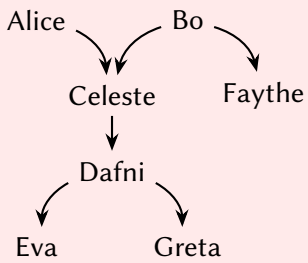
At runtime: *Execute* query plans using *efficient query algorithms*

Central idea

Represent the query plan by a complex type:
use standard *C++ template meta-programming* to generate data structures and algorithms.

Demo

- *person*(id, name) assigns names to nodes.
- *parentOf*(parent, child) relates persons.



Proposed solution: Challenges

Ease-of-use: Writing code

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Integration with existing code-bases

```
std::set<my_fancy_type, my_fancy_ordering> my_fancy_dataset;
```

- Which fields does `my_fancy_type` define?
- What ordering does `my_fancy_ordering` provide? Keys? Index?

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Reflection (potential future C++ standards) might partly help.

Proposed solution: Challenges

Source: https://xkcd.com/303/ by Randall Munroe.

Evaluation: Two perspectives

First perspective: How do we compare with existing database products.

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Second perspective: How do we compare with (C++) *programmers*?

- Performance?
- Readability?
- Ease-of-use?

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Second perspective: How do we compare with (C++) *programmers*?

- Performance?
- Readability?
- Ease-of-use?

Central question

Should we switch to *declarative languages* even in traditional *procedural* source code?

Research volunteers needed

To evaluate our research, we will compare with data processing programs written in C++.

You can provide these C++ programs via an online questionnaire.

- Letter of Information https://jhellings.nl/q/loi.pdf.
- Questionnaire at https://jhellings.nl/q/.

The questionnaire takes 30min–120min and participation is entirely voluntarily.

This study has been reviewed by and received ethics clearance from the *McMaster Research Ethics Board* (#6885).

Conclusion

Programming Languages do need Query Languages!

References at https://jhellings.nl/.

Questionnaire at https://jhellings.nl/q/.