Do Programming Languages need Query Languages?

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Do Programming Languages need Query Languages?

(spoiler alert)

Yes they do!

(and vice versa)

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, ...

Data processing

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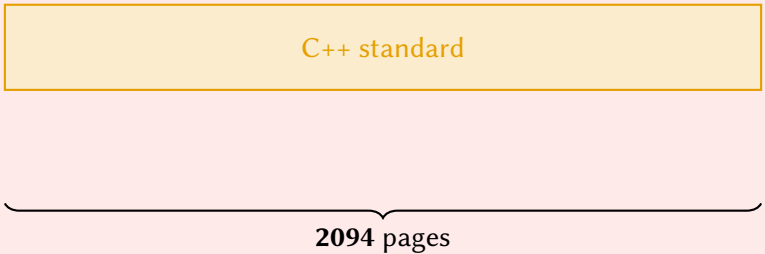
Working Draft of the C++ standard

(Document N4981, Date 2024-04-16.)



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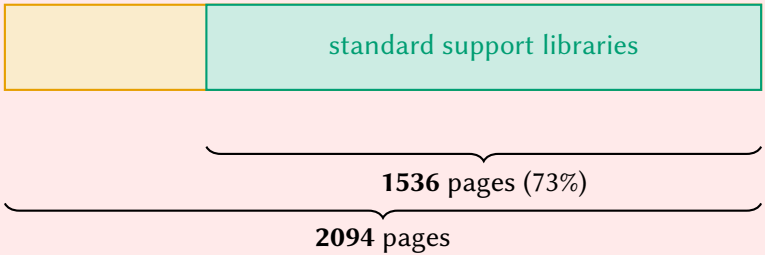

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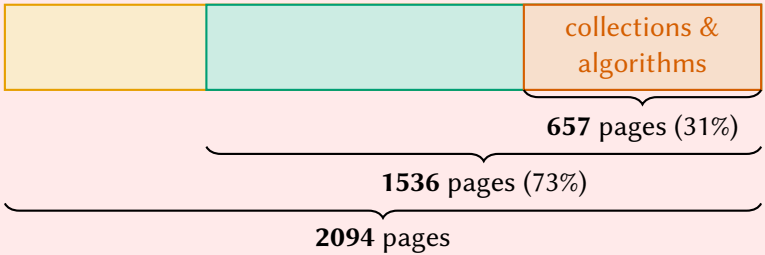

Not counting: numeric, time, formatting, IO, threads, ...

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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```
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;
}
```

Programming and data processing

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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;
}
```

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  bool has_child = std::binary_search(filtered.begin(),
                                      filtered.end(), p);

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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";
```

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";
```

Some database systems need a helping hand…

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

Programming and data processing

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1. Data processing plays a central role in programming.
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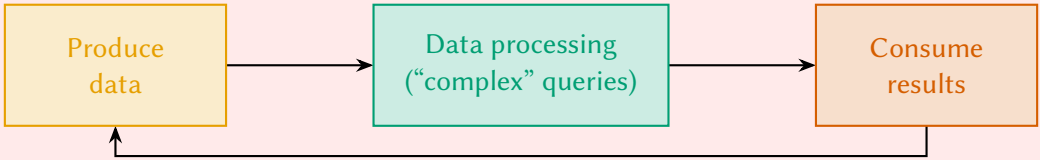
3. We need database technology in our programming languages.

Potential solution?



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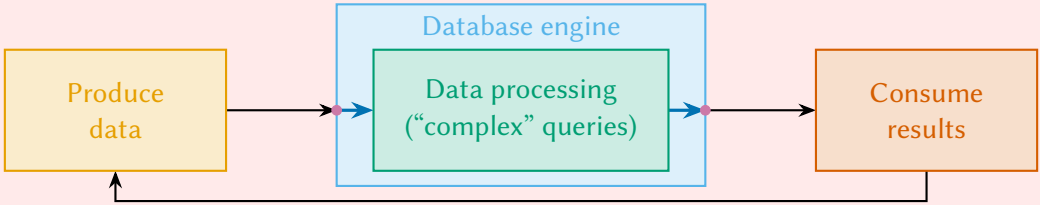

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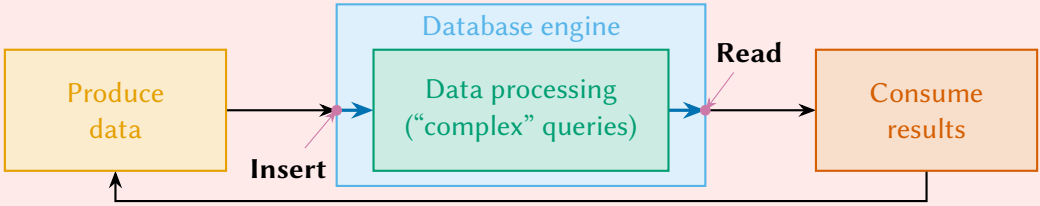

Proposed solution

What if…

```
#include "my_fancy_library.hpp"
          ⋮
query<"%(parent) :- parents(parent, c),"
      "             persons(c, 'Hamilton')">(dataset);
```

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 compile time: use database technologies to turn *queries* into C++ algorithms.
- At runtime: these algorithms are *normal C++ functions* that answer queries efficiently.

Proposed solution: Detailed plans

1. Design the *domain specific query language*:
   Target: multiset aware Datalog with stratified negation and aggregation.

2. A *compile-time parser* for the query language:
   Result: the Datalog program in some internal representation.

3. Use database technology to find an *optimal query plan*:
   Goal: turn the internal representation into an efficient query algorithm.

4. At runtime: *execute* the optimal query plan.
   With zero overhead: the query plan representation *is* the algorithm &
   a programmer should not be able to do significantly better.

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

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

What we already have

- A *high-level grammar language* that controls parsing and syntax tree generation.
- A C++ compile-time parser generator that turns grammars into *compile-time parsers*.
- Utilities to transform syntax trees into *C++ functionality* (e.g., algorithms).
- Runtime parser generator support and debugging utilities.

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

Challenges

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

Database technology and finding *optimal query plans*

Idea

Look at existing database systems and use their approach to query optimization.
A compile-time environment is different, however: e.g., no access to data.

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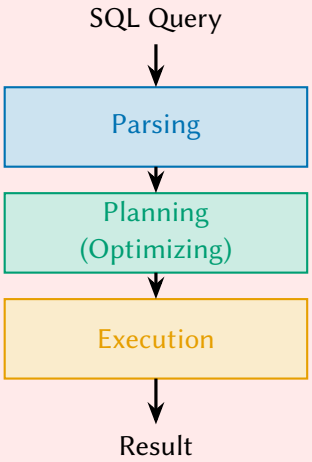
Claims

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.
4. Typical database technology is *not good* at finding optimal query plans.

Typical query evaluation



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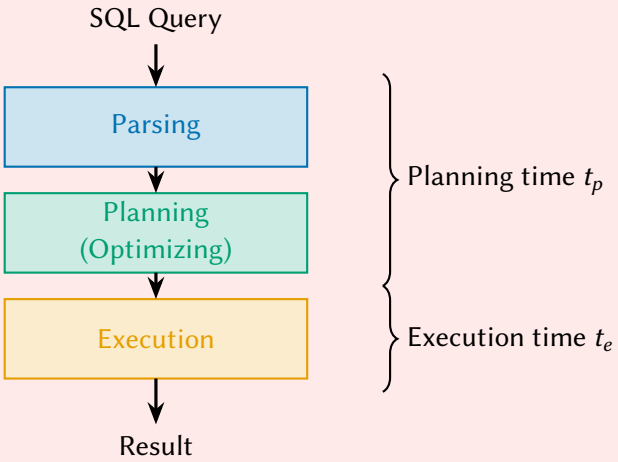

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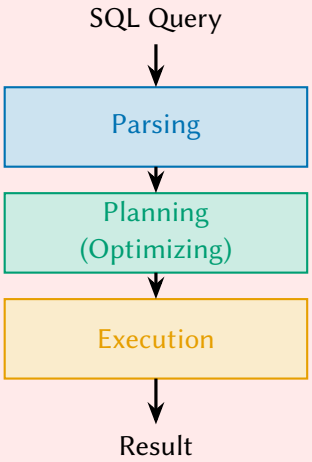

Planning time t_p

Execution time t_e

Database systems:
Attempt to minimize $t_p + t_e$.

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

```
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';
```

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Manual optimizations

```
SELECT cname, 'food' AS type
FROM customer WHERE cname IN (
    SELECT cname FROM bought
    WHERE pname IN (
        SELECT pname FROM product
        WHERE type = 'food'));
```

Planning time: 8.700 ms
Execution time: 75.195 ms

Issue: A graph-inspired example [FoIKS 2022b]

```
SELECT DISTINCT S.nfrom
FROM edges S, edges R, edges T, edges U
WHERE S.nto = R.nfrom AND
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$\pm\mathcal{O}(|\text{edges}|^3)$–$\mathcal{O}(|\text{edges}|^4)$:
Evaluation will not complete.

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Manual optimizations

```
SELECT DISTINCT nfrom FROM edges
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  WHERE nto IN (
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Should we focus on finding optimal query plans?

Do we need optimal query plans?

Database technology with some tweaking is good-enough for practical situations???

Should we focus on finding optimal query plans?

A typical *query pattern P* in a website

```
SELECT a.name, art.id, art.title, art.content, art.tcreate
FROM author a, article art
WHERE a.id = art.author_id AND art.id = ?;
```

- Pattern *P* is used every time a user visits an article on the website.
- Pattern *P* only changes when the source code of the website changes.

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Say our website can force the database system to fully optimize *P once*

- The system takes 10 min to optimize *P*.
- The system makes evaluating *P only* 10 ms faster on average.
- The website is not very busy: only 1 visitors/s.

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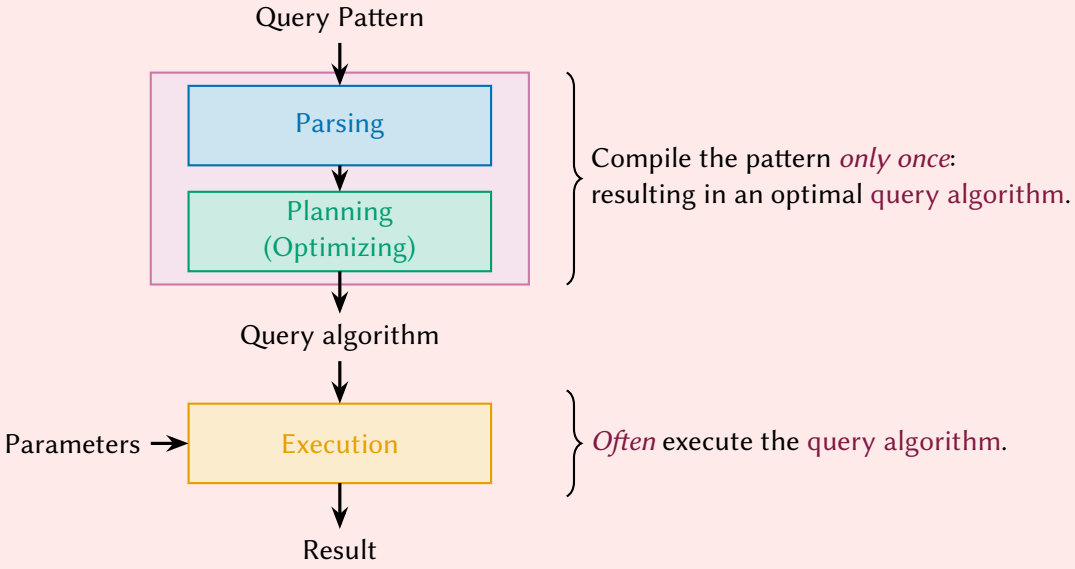
Overall benefit within 17 h.

Research focus: Fully-optimized query evaluation



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*?

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- 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/.