Do Programming Languages need Query Languages?

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Do Programming Languages need Query Languages?

(spoiler alert)

Yes they do!

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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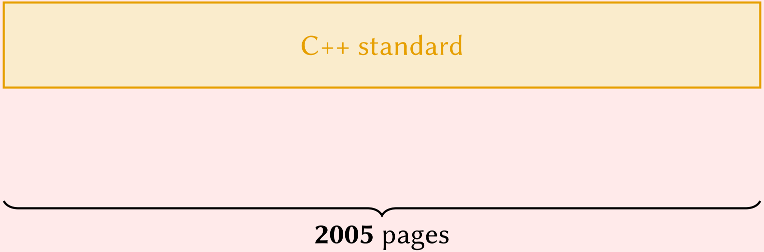
Working Draft of the C++ standard

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



C++ standard

2005 pages

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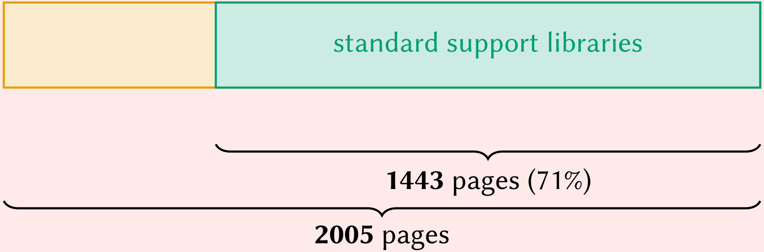

standard support libraries

1443 pages (71%)

2005 pages

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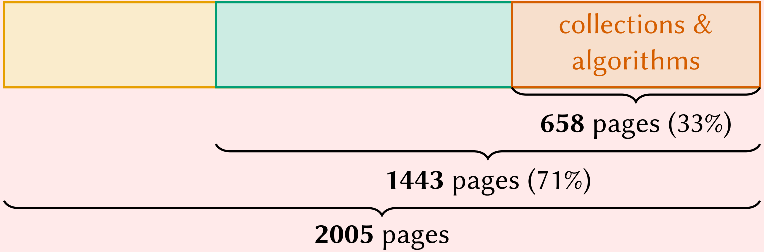

collections & algorithms

658 pages (33%)

1443 pages (71%)

2005 pages

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`.
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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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```
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 pcname, "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++

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

for (auto& [pname, cname] : parents) {
  person_t pcname, "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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Both “improved” versions can be significantly improved to reduce overheads!

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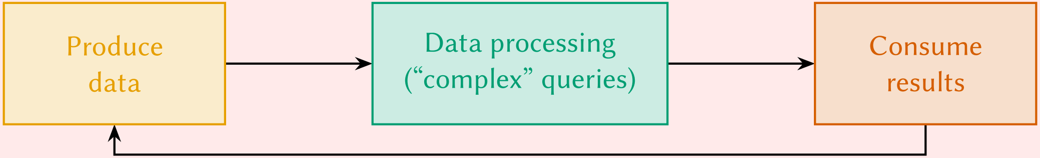
1. Data processing plays a central role in programming.
2. Programming languages are *bad* at data processing.
3. We need database technology in our programming languages.

Potential solution?


Produce data

Data processing (“complex” queries)

Consume results

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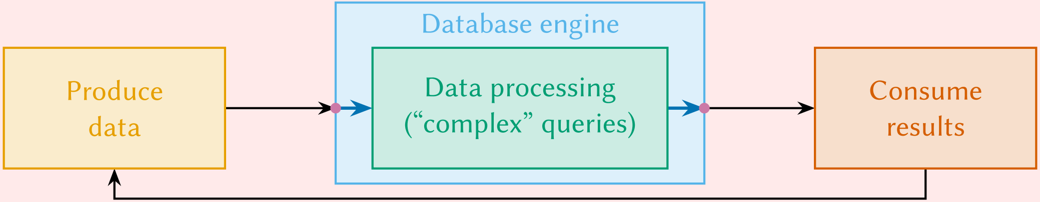
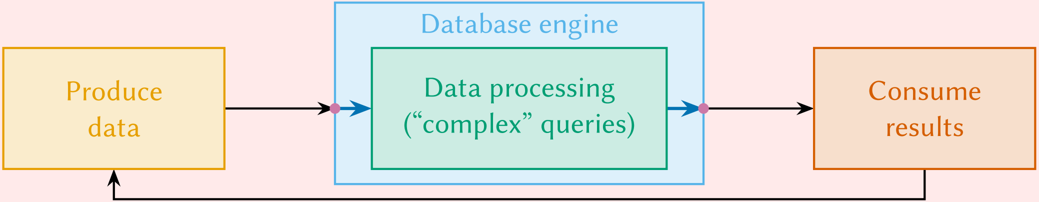


Database systems are *not* the solution



What if we use a database system

For example, PostgreSQL (is free!)

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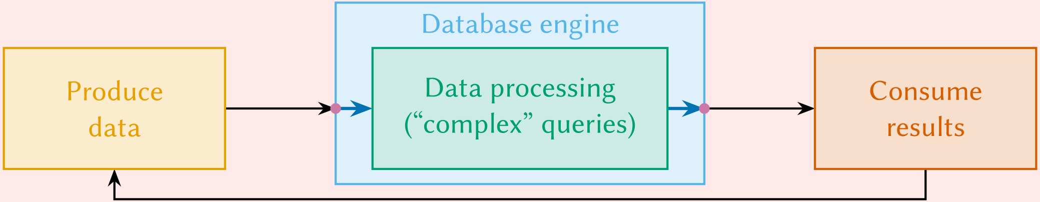

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- There might not be a database system.

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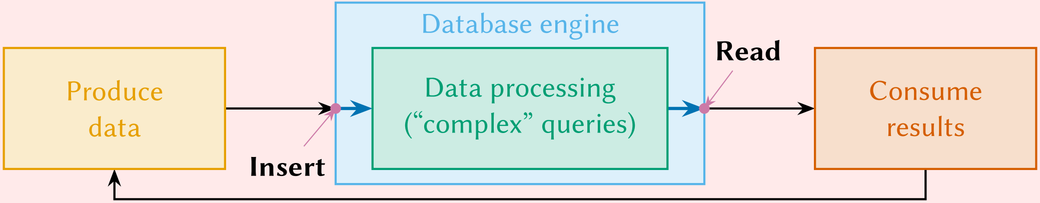

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  Data transfers, necessary code to "translate" between types, ...

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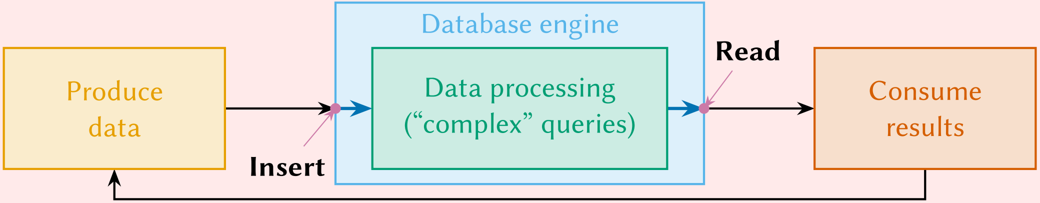

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  For example, type safety (program) versus no type safety (query results).

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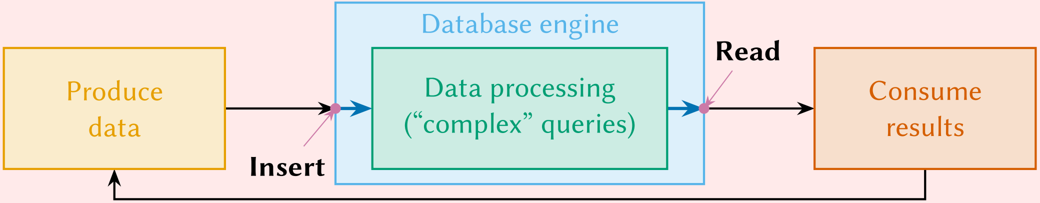

What if we use a database system

For example, ~~PostgreSQL~~ SQLLite (is free!)

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Proposed solution

What if…

```
query<"%(parent) :- parents(parent, c),"
      "              persons(c, 'Hamilton')">(dataset);
```

is valid C++ code in which **`query`** implements an *optimized* C++ algorithm.

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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 queries are *normal C++ functions*.

Proposed solution: Feasibility and status

- C++ compile-time support for *domain specific languages*:
  Almost feature complete (optimistic: publication in 2024?).
- C++ compile-time query compiler:
  Proof-of-concept complete → we can turn high-level Datalog into algorithms.
- Compile-time query planner and query optimizer: *more work needed*.

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Challenges

```
std::set<my_fancy_type, my_fancy_ordering> my_fancy_dataset;
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- 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: Feasibility and status

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

Query compilation and evaluation

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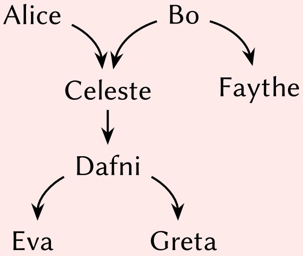
- *Only-once* query optimization (one compile time, many executions).
- Query optimization *without* access to the data.
- At runtime: algorithms can make choices (e.g., `if-else`),
  But there is only limited information: C++ containers do not have heuristics.

Demonstration—If time allows

Base relations

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

Example dataset


Alice
Bo
Celeste
Faythe
Dafni
Eva
Greta

Demonstration—If time allows

Example queries

```
grandparentOf(0, 1) :- parentOf(0, 2), parentOf(2, 1);

grandparentOnly(0) :-  parentOf(0, 1), parentOf(1, 2);

ancestorOf(0, 1) :- parentOf(0, 1);
ancestorOf(0, 1) :- parentOf(0, 2), ancestorOf(2, 1);

ancestorNamed(0, 1) :- ancestorOf(2, 3), person(2, 0), person(3, 1);

siblingOf(0, 1) :- parentOf(2, 0), parentOf(2, 1);
```

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!

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