Query Combinators for Medical Research and Decision Support

an algebraic theory of database queries applied to medicine

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Outline of Talk

Introduction: A Shared Language

Clinical Research Workflow

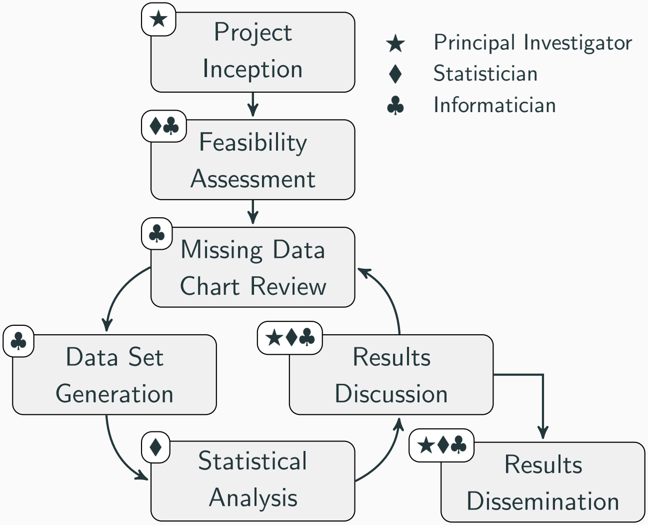

Figure 1: Clinical Research Workflow as inspired from Hruby's observations at Columbia University [**?**]

Example: Complex Query

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Consider the inquiry, "Which anti-hypertensive medications are effective in improving blood pressure?". This inquiry could be operationalized as:

> *Within 6 months of a hypertension diagnosis, when an anti-hypertensive medication was added or intensified, was there a blood pressure decrease of 5 mmHg or more within 5 days after the medication adjustment?*

What are the combinators?

The first thing to do is convert specialized vocabulary in this query into combinator definitions in a *query mediation* session.

Combinator	Query Mediation Notes
hypertension_diagnosis	exclude pregnancy & kidney failure
antihypertensive_medication	a product list is provided
added_or_intensified	new therapy or larger dose
blood_pressure_decrease	of both systolic & diastolic
medication_adjustment	change of daily medication
normalized_active_ingredient	normalize dosage records across compound products

Table 1: Anti-hypertensive Query Combinators

Anti-Hypertensive Query

```
patient
    .medication_adjustment(
        normalized_active_ingredient(
            antihypertensive_medication))
:filter(added_or_intensified  &
    during(previous(6months), patient.hypertension_diagnosis)
:define(is_effective :=
    during(subsequent(5days),
      patient.blood_pressure_decrease(5mmHg)))
:group(normalized_active_ingredient)
:select(normalized_active_ingredient,
  count(medication_adjustment:filter(is_effective)),
  count(medication_adjustment:filter(not(is_effective))))
```

Query Elements and Operations

- combinator query algebra and implementation
- built-in combinators, such as filter, define, group, select, count, etc.
- data source queries, including patient and medication.
- domain specific combinators, such as medication_adjustment, normalized_active_ingredient, and blood_pressure_decrease.

The domain specific combinators, in particular, are then independently defined, constructed, documented, and tested. They can be reused across questions and reflect the shared vocabulary for the research team.

Thinking in Query Combinators

Tabular Model of Clinical Research Data Repository

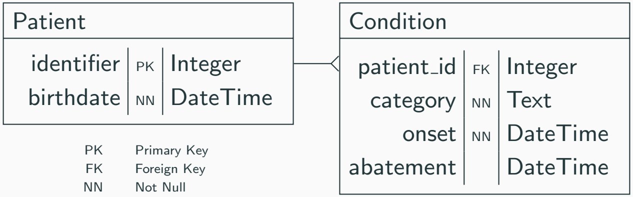


Figure 2: Tabular Model for CRDR

Hierarchical Model of Clinical Research Data Repository

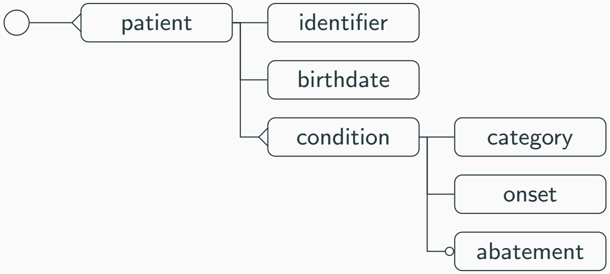
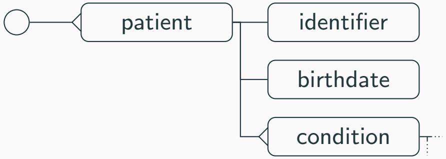


Figure 3: Hierarchical Model for CRDR

Example Queries



- patient
- count(patient)
- patient.condition
- patient.count(condition)
- mean(patient.count(condition))

Query Combinator Algebra

Query Combinators are an algebra of query functions.

- This algebra's elements, or *queries*, represent relationships among class entities and datatypes.
- This algebra's operations, or *combinators*, are applied to construct query expressions.

Query expressions, such as count(condition) are constructed by applying combinators, such as count to queries, such as condition.

Functional Model

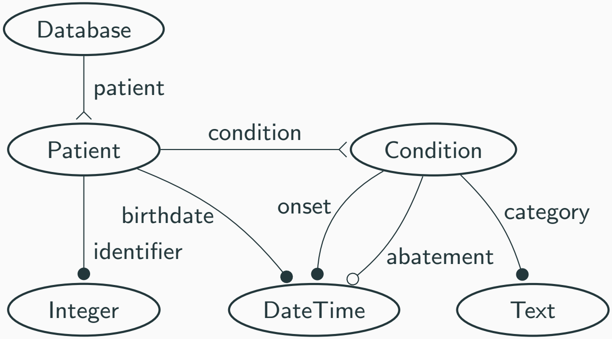


Figure 4: Functional Model for CRDR

Query Primitives

Primitive	Signature
patient	Database $\rightarrow$ Patient*
identifier	Patient $\rightarrow$ Integer
birthdate	Patient $\rightarrow$ DateTime
condition	Patient $\rightarrow$ Condition*
category	Condition $\rightarrow$ Text
onset	Condition $\rightarrow$ DateTime
abatement	Condition $\rightarrow$ DateTime$^?$

Table 2: Query Primitives for CRDR

The Count Combinator

$$\frac{f \qquad A \rightarrow B^*}{\text{count}(f) \qquad A \rightarrow \text{Integer}}$$

$$\frac{\text{patient} \qquad \text{Database} \rightarrow \text{Patient}^*}{\text{count(patient)} \qquad \text{Database} \rightarrow \text{Integer}}$$

$$\frac{\text{condition} \qquad \text{Patient} \rightarrow \text{Condition}^*}{\text{count(condition)} \qquad \text{Patient} \rightarrow \text{Integer}}$$

The Composition Combinator

$$\frac{\begin{array}{rl} f & A \to B^* \\ g & B \to C^* \end{array}}{\begin{array}{rl} f.g & A \to C^* \end{array}}$$

$$\frac{\begin{array}{rl} \text{patient} & \text{Database} \to \text{Patient}^* \\ \text{condition} & \text{Patient} \to \text{Condition}^* \end{array}}{\begin{array}{rl} \text{patient.condition} & \text{Database} \to \text{Condition}^* \end{array}}$$

$$\frac{\begin{array}{rl} \text{condition} & \text{Patient} \to \text{Condition}^* \\ \text{category} & \text{Condition} \to \text{Text}^* \end{array}}{\begin{array}{rl} \text{condition.category} & \text{Patient} \to \text{Text}^* \end{array}}$$

Example: Feasibility Assessment

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Suppose that an informatician would like to conduct a feasibility assessment to see if the CRDR database has at least some candidate patients relevant to this hypertension effectiveness inquiry.

> *How many patients, ages 18 or older, have an active diagnosis of Essential Hypertension?*

Combinators for Feasibility Assessment

How many patients, ages 18 or older, have an active diagnosis of *Essential Hypertension*?

Combinator	Definition
essential_hypertension	`'59621000'`
age	years(now() − birthdate)
has_active_diagnosis(x)	exists(condition.filter(category = x & is_null(abatement)))

Table 3: Combinator Definitions for Feasibility Assessment

Adults /w Hypertension

How many patients, ages 18 or older, have an active diagnosis of Essential Hypertension?

```
patient
:filter (age >= 18
        & has_active_diagnosis(
            essential_hypertension))
:count
```

Conclusion: DataKnots.jl Lives!

DataKnots.jl a working prototype

There is an implementation of Query Combinators for the Julia Language, called DataKnots.jl.

- this implementation is MIT/Apache licensed
- it includes an in-memory, column-oriented database
- it has adapters to XML, CSV, JSON
- essential query operators are implemented
- any Julia code can be *lifted* to a combinator
- an adapter to SQL datasources is possible

References i

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G. Hruby, J. McKiernan, S. Bakken, and C. Weng.
A centralized research data repository enhances retrospective outcomes research capacity: A case report.
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