Types and Patterns for Querying XML

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Language Primitives

Working on XML data requires at least two kinds of primitives:

1. **deconstruction/extraction primitives**: pinpoint and capture subparts of the XML data

2. **iteration primitives**: iterate over XML trees the process of extraction and transformation of data.

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   No emerging solution: FLWR (XQuery), select-from-where ($C\omega$, CQL), select-where (Lorel, loto-ql), `filter` (XDuce), `xtransform` (CDuce), in the language semantics (XSLT), . . .

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In running query/programming languages:

- **Paths:** "vertical" exploration of data, capture elements that may be at different depths (unary queries)
  Usually XPath paths, but also the "dot" navigations (Cω, Lorel, TQL) or caterpillar expressions.
- **Regular expression patterns:** "horizontal" exploration of data, perform finer grained decomposition on sequences of elements.
  Proposed by Hosoya&Pierce for XDuce and then adopted by CDuce/CQL, Xtatic, Scala, XHaskell, ...

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It seems natural to integrate both of them into a query/programming language for XML.

Mixing horizontal and vertical selectors

Several theoretical works from *different areas* about integrating vertical and horizontal exploration:

1. *Unranked tree logics*: e.g. Neven&Schwentick's ETL.
2. *Spatial modal logics*: e.g. Cardelli&Ghelli's TQL.
3. *Query languages*: e.g. Papakonstantinou&Vianu's Loto-ql

But in running languages I am aware of just two examples:

1. CQL (i.e. CDuce Query Language)
2. Xtatic (an extension of C#)

Paths and Regexp Patterns "coexist" but they are not integrated.

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Opportunity of collaboration between the database and the programming languages communities

Outline of the talk

1. **An overview of regexp types/patterns**
   - Patterns in functional languages
   - Patterns as types with variables
   - Regexp Patterns and types for XML
2. **Eight reasons to consider regexp types/patterns**
   - Classic usages of type systems (1 2 3)
   - Efficient and type precise main memory execution (4 5 6)
   - Secondary memory optimization (7 8)
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Regular expression Types and Patterns for XML

Types & patterns: the functional languages perspective

- **Types** are sets of **values**
- Values are decomposed by **patterns**
- Patterns are roughly values with **capture variables**

Instead of

```
let x = fst(e) in
let y = snd(e) in (y,x)
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with pattern one can write

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let (x,y) = e in (y,x)
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"`match`" is more interesting than "`let`", since it can test several "|"-separated patterns.

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type List = (Any,List) | ‘nil
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fun length (x:(List,Int)) : Int =
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   | (‘nil , n) -> n
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So patterns are values with

But if we:

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Define types: patterns come for free.

Which types should we start from?

Patterns are tightly connected to boolean type constructors, that is unions (|), intersections (&) and differences (\):

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Let us type the function.

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```

The first branch is executed only for values and are both in `(List,Int)` **and** in $\wr$`(`nil,n)`$\int$

```
(List,Int) & (`nil,Any)
```

Which types should we start from?

$t = \{v \mid v$ value of type $t\}$ **and** $\wr p \int = \{v \mid v$ matches pattern $p\}$

(this is a type)

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type List = (Any,List) | `nil

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`((List,Int)\(‘nil,Any))&((Any,Any),Any)`

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The match expression has type the union of the possible results

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```
Int | Int
```

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The match expression has type the union of the possible results

$$\texttt{Int} \mid \texttt{Int} = \texttt{Int}$$

Which types should we start from?

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The match expression has type the union of the possible results

`Int | Int` $=$ `Int`

The function is well-typed

Unions, intersections, differences

- **Boolean operators are needed to type pattern matching:**

  `match` e `with` p_1 `->` e_1 `|` p_2 `->` e_2

  - To infer the type t_1 of e_1 we need $t \& \llparenthesis p_1 \rrparenthesis$ (where $e : t$);
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- **Boolean type constructors are useful for programming:**

```
map catalogue with
    x :: (Car & (Guaranteed|(Any\Used)) -> x
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Select in *catalogue* all cars that if used then are guaranteed.

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Roadmap to extend it to XML:

1. Define types for XML documents,
2. Add boolean type constructors,
3. Define patterns as types with capture variables

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Roadmap to extend it to XML:

1. **Define types for XML documents,**
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XML Types Example: A bibliography

```
type Bib = <bib>[Book*]
type Book = <book year=String>[
                    Title
                    (Author+ | Editor+ )
                    Price?
                    Publisher]
type Author = <author>[Last First]
type Editor = <editor>[Last First]
type Title = <title>[PCDATA]
type Last = <last>[PCDATA]
type First = <first>[PCDATA]
type Publisher = String
type Price = <price>[PCDATA]
```

This and: singletons, intersections, differences, `Empty`, and An

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XML Types Example: A bibliography

```
type Bib = <bib>[Book*]
type Book = <book year=String>[
                    Title
                    (Author+ | Editor+ )
                    Price?
                    Publisher]           mixed content
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type Title = <title>[PCDATA]
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This and: singletons, intersections, differences, `Empty`**, and** `Any`**.**

Patterns

Patterns = Types + Capture variables

TYPES

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```
type Bib = <bib>[Book*]
```

Patterns

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```
type Bib = <bib>[Book*]
```

PATTERNS

```
<bib>[x::Book*]
```

Patterns

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TYPES

```
type Bib = <bib>[Book*]
```

PATTERNS

```
<bib>[x::Book*]
```

The pattern binds x to the *sequence* of all books in the bibliography

Patterns

Patterns = Types + Capture variables

TYPES

```
type Bib = <bib>[Book*]
```

PATTERNS

```
match bibs with
    <bib>[x::Book*] -> x
```

Patterns

Patterns = Types + Capture variables

TYPES

```
type Bib = <bib>[Book*]
```

PATTERNS

```
match bibs with
    <bib>[x::Book*] -> x
```

Returns the content of `bibs`.

Patterns

Patterns = Types + Capture variables

TYPES

```
type Bib = <bib>[Book*]
```

PATTERNS

```
<bib>[( x::<book year="2005">_ | y::_ )*]
```

Patterns

Patterns = Types + Capture variables

TYPES

```
type Bib = <bib>[Book*]
```

PATTERNS

```
<bib>[( x::<book year="2005">_ | y::_ )*]
```

Binds `x` to the sequence of all this year's books, and `y` to all the other books.

Patterns

Patterns = Types + Capture variables

TYPES

```
type Bib = <bib>[Book*]
```

PATTERNS

```
match bibs with
    <bib>[( x::<book year="2005">_ | y::_ )*] -> x@y
```

Patterns

Patterns = Types + Capture variables

TYPES

```
type Bib = <bib>[Book*]
```

PATTERNS

```
match bibs with
    <bib>[( x::<book year="2005">_ | y::_ )*] -> x@y
```

Returns the concatenation (i.e., "@") of the two captured sequences

Patterns

Patterns = Types + Capture variables

TYPES

```
type Bib = <bib>[Book*]
type Book = <book year=String>[Title Author+ Publisher]
```

PATTERNS

```
<bib>[(x::<book year="1990">[ _* Publisher\"ACM"] | _)*]
```

Patterns

Patterns = Types + Capture variables

TYPES

```
type Bib = <bib>[Book*]
type Book = <book year=String>[Title Author+ Publisher]
```

PATTERNS

```
<bib>[(x::<book year="1990">[ _* Publisher\"ACM"] | _)*]
```

Binds x to the *sequence* of books published in 1990 from publishers others than “ACM” and discards all the others.

Patterns

Patterns = Types + Capture variables

TYPES

```
type Bib = <bib>[Book*]
type Book = <book year=String>[Title Author+ Publisher]
```

PATTERNS

```
match bibs with
  <bib>[(x::<book year="1990">[ _* Publisher\"ACM"] | _)*] -> x
```

Patterns

Patterns = Types + Capture variables

TYPES

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type Bib = <bib>[Book*]
type Book = <book year=String>[Title Author+ Publisher]
```

PATTERNS

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match bibs with
  <bib>[(x::<book year="1990">[ _* Publisher\"ACM"] | _)*] -> x
```

Returns all the captured books

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Patterns = Types + Capture variables

TYPES

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type Bib = <bib>[Book*]
type Book = <book year=String>[Title Author+ Publisher]
```

PATTERNS

```
match bibs with
  <bib>[(x::<book year="1990">[ _* Publisher\"ACM"] | _)*] -> x
```

Returns all the captured books

Exact type inference:

E.g.: if we match the pattern `[(x::Int|_)*]` against an expression of type `[Int* String Int]` the type deduced for x is `[Int+]`

Patterns

Patterns = Types + Capture variables

TYPES

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type Bib = <bib>[Book*]
type Book = <book year=String>[Title Author+ Publisher]
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PATTERNS

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match bibs with
  <bib>[(x::<book year="1990">[ _* Publisher\"ACM"] | _)*] -> x
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Exact type inference:

E.g.: if we match the pattern `[(x::Int|_)*]` against an expression of type `[Int* String Int]` the type deduced for x is `[Int+]`

Select-from-where

Instead of just variables

```
select e from
    x1 in e1
        ⋮
    xn in en
where c
```

```
Biblio = <bib>[Book*]
Book = <book year=String>[Title (Author+|Editor+) Price?]
```

Select-from-where

Instead of just variables use patterns

$$
\begin{array}{l}
\texttt{select e from} \\
\quad p_1 \ \texttt{in} \ e_1 \\
\qquad \vdots \\
\quad p_n \ \texttt{in} \ e_n \\
\texttt{where c}
\end{array}
$$

```
Biblio = <bib>[Book*]
Book = <book year=String>[Title (Author+|Editor+) Price?]
```

Select-from-where

Instead of just variables use patterns

```
select e from
    p1 in e1
       ⋮
    pn in en
where c
```

```
<bib>[b::Book*]
<book year="1990">[ t::Title _+ <price>"69.99" ]
```

(1) captures in b all the books of a bibliography

(2) captures in t the title of a book if it is of 1990 and costs 69.99

```
Biblio = <bib>[Book*]
Book = <book year=String>[Title (Author+|Editor+) Price?]
```

Select-from-where

Instead of just variables use patterns

select e from
  p_1 in e_1
  ⋮
  p_n in e_n
where c

```
select <book>t from
  <bib>[b::Book*] in bibs,
  <book year="1990">[ t::Title _+ <price>"69.99" ] in b
```

```
Biblio = <bib>[Book*]
Book = <book year=String>[Title (Author+|Editor+) Price?]
```

Select-from-where

Instead of just variables use patterns

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select e from
    p1 in e1
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    pn in en
where c
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```
select <book>t from
  <bib>[b::Book*] in bibs,
  <book year="1990">[ t::Title _+ <price>"69.99" ] in b
```

Selects from bibs the titles of all books of 1990 and of price 69.99

```
Biblio = <bib>[Book*]
Book = <book year=String>[Title (Author+|Editor+) Price?]
```

Select-from-where

Instead of just variables use patterns

```
select e from
    p1 in e1
       ⋮
    pn in en
where c
```

```
fun getTitles(bibs : Biblio) : [(<book>[Title])*]
  select <book>t from
    <bib>[b::Book*] in bibs,
    <book year="1990">[ t::Title _+ <price>"69.99" ] in b
```

Selects from bibs the titles of all books of 1990 and of price 69.99 and has type `Biblio -> [(<book>[Title])*]`

```
Biblio = <bib>[Book*]
Book = <book year=String>[Title (Author+|Editor+) Price?]
```

XPath encoding

For instance in $\mathbb{C}$QL (...but see Xtatic for a very different encoding):

- All children of *e* with tag *tag* (*e*/*tag*)

  ```
  select x from <_ ..>[( x::(<tag ..>_)|_ )*] in e
  ```

- All attributes labelled by *id* (*e*/@*id*)

  ```
  select x from <_ id=x ..> in e
  ```

- Notice that regexp patterns can define non-unary queries.

XPath encoding

For instance in $\mathbb{CQL}$ (...but see Xtatic for a very different encoding):

- All children of e with tag *tag* (e/*tag*)

  `select x from <_ ..>[( x::(<tag ..>_)|_ )*] in e`

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For instance in ℂQL (...but see Xtatic for a very different encoding):

- All children of e with tag *tag* (e/*tag*)

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select x from <_ ..>[( x::(<tag ..>_)|_ )*] in e
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$\mathbb{C}$QL, Xtatic, add syntactic sugar for XPath ... but we need more

. . . it is all syntactic sugar!

Types

$$t \ ::= \ \texttt{Int} \ \mid \ v \ \mid \ (t,t) \ \mid \ t \vee t \ \mid \ t \wedge t \ \mid \ \neg t \ \mid \ \texttt{Any}$$

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Example:

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$$\begin{aligned} Book &= (\text{`}book, (Title, X \vee Y)) \\ X &= (Author, X \vee (Price, \text{`}nil) \vee \text{`}nil) \\ Y &= (Editor, Y \vee (Price, \text{`}nil) \vee \text{`}nil) \end{aligned}$$

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Some reasons to consider regular expression types and patterns

Some good reasons to consider regexp patterns/types

- **Theoretical reason: very compact**
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  2. Informative error messages
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1. Classic usages of types

Use these types as usual: static detection of errors, partial correctness, schema specification

Not much to say here, just notice that:

Singletons, unions, intersections, and differences have set-theoretic semantics on "types as set of values": they are easy to understand.

A natural and powerful specification and constraint language:

- It is possible to specify constraints such as:
- Types can be composed:

then <bib>[((BiblioThisYear)\WithPrice)*] defines a view containing only this year's books that do not have price element.

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Not very innovative but useful properties

2. Informative error messages

In case of error return a sample value in the difference of the inferred type and the expected one

List of books of a given year, stripped of the Editors and Price

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fun onlyAuthors (year:Int,books:[Book*]):[Book*] =
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type Book = <book year=String>[Title (Author+|Editor+) Price?]
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Spot subtle errors that elude current type checking technology

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fun extract(x:[Book*]) =
  select (z,y) from
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```

- Despite the typo the function is well-typed:
  - no typing rule is violated
  - the pattern is not useless, it can match authors
- They are not regexp-patterns specific.
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Can be formally characterised and statically detected by the types/patterns presented here and integrated in current regexp type-checkers with no overhead

4. Efficient execution

Use static type information to perform an optimal set of tests

Idea: if types tell you that something cannot happen, don't test it.

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type A = <a>[A*]
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Computing the optimal solution requires to fully exploit intersections and differences of types

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Transform the `from` clauses so as to capture in a single pattern as much information as possible

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These optimisations are orthogonal to the classical optimisations: they sum up and bring a further gain of performance

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Build regexp of "pattern matches" for user-defined iterators

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How to define new iterators?

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`select` e `from` p `in` e' $=$ `filter[(`p`->`e`|_->[])*](`e'`)`

`map` e `with` p_1`->`e_1`|`...`|`p_n`->`e_n

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match e with p1->e1|...|pn->en
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Type precision obtained by specific typing, as for patterns.

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Use type analysis to determine which parts of an XML data need not to be loaded in main memory

Given a query q execute it on documents in which parts not necessary to evaluate q are pruned. Recently adopted in main memory XML query engines, e.g. [Marian-Siméon], [Bressan et al]

We can start from the optimal compilation of patterns. Compile patterns in order to have as many "_" wildcards as possible.

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Data matched by wildcards "_" not in the scope of a capture variable are not necessary to the evaluation. Use boolean type constructors to determine the program data-need.

8. Type-based query optimisation

Use the precision of the type system in query optimisation

- **Data description is more precise:**
  E.g. in IMDB there are constraints such as:
  If a `show`*-element contains* `season`*-elements, then its* `type`*-attribute is* `"TV Series"`.
- **Transformation description is more precise:**
- DTD/Schema already used to optimise access to XML data on disk. It should be possible to use also the precision of regexp types to optimise secondary memory queries.

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for         bibs/book/(title|author|editor)
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  - Use the same constructors for types and value
  - Define patterns as types with capture variables
- **Tightly connected with boolean combinators, make several aspects programmer-friendly:**
  - Semantic types are set of values, and unions, intersections and differences behave set theoretically
  - Concepts are easier for the programmer (e.g. subtyping)
  - Informative error messages
  - Precise and powerful specification language
- **Several benefits:**
  - Types yield highly efficient runtime: in main memory it outperforms efficiency oriented XQuery processors such as Qizx and Qexo
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... but that's not enough

- Regexp are good for horizontal exploration but not for vertical one. Should be integrated with path-like primitives, extended to iterators, endowed with more friendly QBE-like interfaces, ...
- I tried to give an idea about the kind of research that is pursued on XML in the programming language community but much other research goes on (security, distribution, integration in mainstream languages, streaming, ...)
- I hope that this talk convinced some of you that it may be worth to have a look to this kind of research.
- A good place to start from is PLAN-X, *ACM SIGPLAN Workshop on Programming Languages Technologies for XML*

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- I tried to give an idea about the kind of research that is pursued on XML in the programming language community but much other research goes on (security, distribution, integration in mainstream languages, streaming, . . .)
- I hope that this talk convinced some of you that it may be worth to have a look to this kind of research.
- A good place to start from is PLAN-X, *ACM SIGPLAN Workshop on Programming Languages Technologies for XML*

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