Types and Patterns for Querying XML

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

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

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

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Two solutions stem from *practice*:

- Path expressions
- Regular expression patterns
- iteration primitives: iterate over XML trees the process of extraction and transformation of data.

No emerging solution: FLWR (XQuery), select-from-where (Cw, EQE), select-where (Lorel, loto-ql), filter (XDuce), xtransform (EDuce), 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&Pience for XDuce and then
 - adopted by CDuce/CQL, Xtatic, Scala, XHaskell,....
- The two primitives are not antagonist: they are orthogonal and complementary.

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The two primitives are not antagonist: they are orthogonal and complementary.

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

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.
- Query languages: e.g. Papakonstantinou&Vianu's Loto-ql

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

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

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

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

Opportunity of collaboration between the database and the programming languages communities

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Duce

Outline of the talk

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
- Efficient and type precise main memory execution
- Secondary memory optimization

3 Conclusion.

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3 Conclusion.

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Regular expression Types and Patterns for XML

- 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)

with pattern one can write

let (x,y) = e in (y,x)

which syntactic sugar for

match e with $(x,y) \rightarrow (y,x)$

"match" is more interesting than "let", since it can test several "|"-separated patterns.



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```
type List = (Any,List) | 'nil
```

So patterns are values with

But if we:

- Quuse for types the same constructors as for values
- O use values to denote singleton types

9 consider the wildcard "-" as synonym of Asyn

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So patterns are values with capture variables, wildcards,

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So patterns are values with capture variables, wildcards, constants.

But if we:

- use for types the same constructors as for values (e.g. (s,t) instead of s < t)
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- use for types the same constructors as for values (e.g. (s,t) instead of s × t)
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 (e.g. (nil) in the list type):
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- use for types the same constructors as for values (e.g. (s,t) instead of s × t)
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 - (e.g. 'nil in the list type);
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```
type List = (Any,List) | 'nil
fun length (x:(List,Int)) : Int =
```

```
match x with
  | ('nil , n) -> n
  | ((_,t), n) -> length(t,n+1)
```

So patterns are values with capture variables, wildcards, constants.

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- use for types the same constructors as for values (e.g. (s,t) instead of s × t)
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So patterns are values with capture variables, wildcards, constants.

Key idea behind regular patterns

Patterns are types with capture variables

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Juce

So patterns are values with capture variables, wildcards, constants.

Key idea behind regular patterns Patterns are types with capture variables

So patterns are values with capture variables, wildcards, constants.

Key idea behind regular patterns

Patterns are types with capture variables

Define types: patterns come for free.

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

```
type List = (Any,List) | 'nil
fun length (x :(List,Int)):Int =
    match x with
    | ('nil , n) -> n
    | ((_,t), n) -> length(t,n+1)
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Patterns are tightly connected to boolean type constructors, that is unions (|), intersections (&) and differences (\backslash):

To type this function we need basic types products, singletons,...

t ::= Int \mid v \mid (t,t) \mid

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

To type this function we need basic types products, singletons,...

t ::=Int | v | (t,t) | t | t | t & t t | Empty | Any

but also boolean type constructors.

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t ::=Int | v | (t,t) | t | t | t & t t | Empty | Any

but also boolean type constructors. Let us type the function.

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```
t = \{v \mid v \text{ value of type } t\}
```

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```
| ((_,t), n) -> length(t,n+1)
```

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The first branch is executed only for values and are both in (List,Int) and in ((inl,n))

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The first branch is executed only for values and are both in (List,Int) and in (('nil,n)) = ('nil,Any)

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The first branch is executed only for values and are both in (List,Int) and in ((inl,n))

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

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The first branch is executed only for values and are both in (List,Int) and in ((nil,n))

(List,Int) & ('nil,Any) = ('nil,Int)

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The first branch is executed only for values and are both in (List,Int) and in ((nil,n))

(List,Int) & ('nil,Any) = ('nil,Int)

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The second branch is executed for values that are in (List,Int) not in $(('nil,n) \int$ and in $(((_,t),n) \int$

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```
t = \{v \mid v \text{ value of type } t\} and \{p\} = \{v \mid v \text{ matches pattern } p\}
                                               (this is a type)
 type List = (Any,List) | 'nil
   fun length (x :(List,Int)):Int =
     match x with
       | ('nil , n) -> n
                                                 Int
      | ((\_,t), n) \rightarrow length(t,n+1)
The second branch is executed for values that are in
(List, Int) not in ((nil,n)) and in ((_,t),n)
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((List,Int)\('nil,Any))&((Any,Any),Any)

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 $((List,Int) \setminus ((nil,Any)) \& ((Any,Any),Any) = ((Any,List),Int)$

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((List,Int)\('nil,Any))&((Any,Any),Any) = ((Any,List),Int)

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The match expression has type the union of the possible results

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The function is well-typed

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- Boolean operators are needed to type pattern matching: match e with p_1 -> e_1 \mid p_2 -> e_2
 - To infer the type t_1 of e_1 we need $t \& [p_1]$ (where e: t);
 - To infer the type t_2 of e_2 we need $(t \setminus p_1) \& p_2$;
 - The type of the match is $t_1 \mid t_2$.
- Boolean type constructors are useful for programming: map catalogue with x :: (Car & (Guaranteed|(Any\Used)) -> x
 - Select in *catalogue* all cars that if used then are guaranteed.

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- Boolean operators are needed to type pattern matching: match e with p_1 -> e_1 \mid p_2 -> e_2
 - To infer the type t_1 of e_1 we need $t \And (p_1)$ (where e: t); - To infer the type t_2 of e_2 we need $(t \land p_1) \And (p_2)$:
 - The type of the match is $t_1 | t_2$.
- Boolean type constructors are useful for programming: map catalogue with x :: (Car & (Guaranteed|(Any\Used)) -> x
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 - To infer the type t_2 of e_2 we need $(t \setminus p_1) \& p_2$;
 - The type of the match is $t_1 \mid t_2$.

Boolean type constructors are useful for programming:

map catalogue with
 x :: (Car & (Guaranteed|(Any\Used)) -> x

Select in *catalogue* all cars that if used then are guaranteed.

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- Boolean operators are needed to type pattern matching: match e with p₁ -> e₁ | p₂ -> e₂
 - To infer the type t_1 of e_1 we need $t \ge \frac{p_1}{p_1}$ (where e: t);
 - To infer the type t_2 of e_2 we need $(t \setminus p_1) \& p_2$;
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- Add boolean type constructors,
- Define patterns as types with capture variables

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Select in *catalogue* all cars that if used then are guaranteed.

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- **O** Define patterns as types with capture variables

```
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 A Spuce

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type Bib = <bib>[Book*]
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This and: singletons, intersections, differences, Empty, and A Spuce



```
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type Book = <book year=String>[
                                       attribute types
                     Title
                     (Author+ | Editor+ )
                     Price?
                     Publisher]
type Author = <author>[Last First]
type Editor = <editor>[Last First]
type Title = <title>[PCDATA]
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                                                 unions
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                     (Author+ | Editor+ )
                     Price?
                                        optional elems
                     Publisher
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type Last = <last>[PCDATA]
type First = <first>[PCDATA]
type Publisher = String
type Price = <price>[PCDATA]
```

This and: singletons, intersections, differences, Empty, and A Spuce

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

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This and: singletons, intersections, differences, Empty, and AnyDuce

Patterns = Types + Capture variables



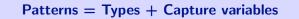
Patterns = Types + Capture variables

type Bib = <bib>[Book*]

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CDuce

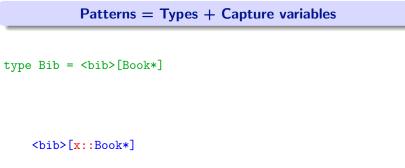


<bib>[x::Book*]

type Bib = <bib>[Book*]

TYPES

ATTERNS



The pattern binds \mathbf{x} to the sequence of all books in the bibliography



```
TYPES
    type Bib = <bib>[Book*]
PATTERNS
    match bibs with
```

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

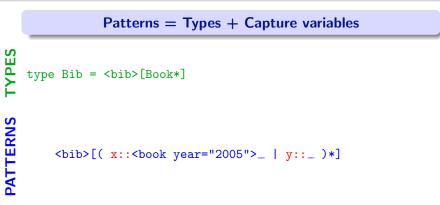
TYPES

Patterns = Types + Capture variables

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

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

Returns the content of bibs.



TYPES

PATTERNS

```
Patterns = Types + Capture variables
type Bib = <bib>[Book*]
<bib>[( x::<book year="2005">_ | y::_ )*]
```

Binds \mathbf{x} to the sequence of all this year's books, and \mathbf{y} to all the other books.

Duce

TYPES

PATTERNS

```
Patterns = Types + Capture variables
type Bib = <bib>[Book*]
match bibs with
    <bib>[( x::<book year="2005">_ | y::_ )*] -> x@y
```

TYPES

ATTERNS

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

Duce

PATTERNS

```
Patterns = Types + Capture variables
```

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

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

PATTERNS

```
Patterns = Types + Capture variables
```

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


<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 = Types + Capture variables
```

Duce

```
Patterns = Types + Capture variables
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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+]

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Select-from-where

Instead of just variables select e from x1 in e1 : xn in en where c



Select-from-where

Instead of just variables use patterns

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



Select-from-where

Instead of just variables use patterns

```
select e from
     p_1 in e_1
     p_n in e_n
 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*]
                                                                      Duce
Book = <book year=String>[Title (Author+|Editor+) Price?]
                                                                      13/28
```

Select-from-where

Instead of just variables use patterns

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

```
Biblio = <bib>[Book*]
Book = <book year=String>[Title (Author+|Editor+) Price?]
G. Castagna Types and Patterns for Querying XML 13/28
```

Select-from-where

Instead of just variables use patterns

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

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?]
G. Castagna Types and Patterns for Querying XML 13/28
```

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 $\mathbb{C}\mathrm{QL}$ (... 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.

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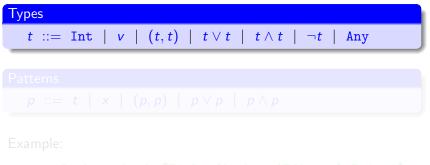
Rationale CQL, Xtatic, add syntactic sugar for XPath ...

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... it is all syntactic sugar!



```
type Book = <book>[Title (Author+|Editor+) Price?]
encoded as
```

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



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Example:

```
type Book = \langle book \rangle [Title (Author+|Editor+) Price?]
encoded as
Book = ('book, (Title, X \lor Y))
X = (Author, X \lor (Price, 'nil) \lor 'nil)
```

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Some reasons to consider regular expression types and patterns



• Theoretical reason: very compact

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- Classic usage
- Informative error messages
- Error mining
- Efficient execution
- Logical optimisation of pattern-based queries
- Pattern matches as building blocks for iterators
- Type/pattern-based data pruning for memory usage optimisation
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• Eight practical reasons:

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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:
 - type Mitthing a second life Price
 - type://lil.e?ee.r==<...yee.r=?2005?>...
 - then (bib) [((Bib)) of This Tear) (MithPrice) a) defines a view
 - containing only this year's books that do not have price elementtread



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- Types can be composed:
 - type Michieles C. . . . Michieles Michieles
 - type 11.1.1 Tear 4... year-2005*>...
 - then <bib>[((Biblio&ThisTear)\WithPrice)*] defines a view
 - containing only this year's books that do not have price element

CDuce

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 - type WitthPrice (....) (.... Brite
 - type 11.1.2 fear = 4... year=12005*5...
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type WithPrice = <_ ..>[_* Price _*]
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```

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```

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Not very innovative but useful properties

Duce

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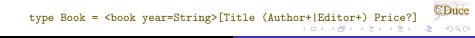
In case of error return a sample value in the difference of the inferred type and the expected one

List of books of a given year, stripped of the Editors and Price
fun onlyAuthors (year:Int,books:[Book*]):[Book*] =



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

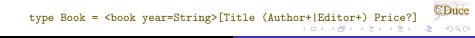
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In case of error return a sample value in the difference of the inferred type and the expected one

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

fun onlyAuthors (year:Int,books:[Book*]):[Book*] =
 select <book year=y>(t@a) from
 <book year=y>[(t::Title | a::Author | _)+] in books
 where int_of(y) = year



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

Returns the following error message:

```
Error at chars 81-83:
    select <book year=y>(t@a) from
This expression should have type:
[ Title (Editor+|Author+) Price? ]
but its inferred type is:
[ Title Author+ | Title ]
which is not a subtype, as shown by the sample:
[ <title>[ ] ]
```



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```
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This expression should have type:
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but its inferred type is:
[ Title Author+ | Title ]
which is not a subtype, as shown by the sample:
[ <title>[ ]
```



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

fun onlyAuthors (year:Int,books:[Book*]):[Book*] =
 select <book year=y>(t@a) from
 <book year=y>[(t::Title | a::Author | _)+] in books
 where int_of(y) = year

Returns the following error message:

```
Error at chars 81-83:
    select <book year=y>(t@a) from
This expression should have type:
[ Title (Editor+|Author+) Price? ]
but its inferred type is:
[ Title Author+ | Title ]
which is not a subtype, as shown by the sample:
[ <title>[ ]]
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Spot subtle errors that elude current type checking technology

```
fun extract(x:[Book*]) =
  select (z,y) from
  <book >[ z:Title v::(<author> |<edtor> )
```

- 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: (agreed) all (10) (clood) ad to
- Such errors are not always typos: they can be conceptual errors.

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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

Juce

Use static type information to perform an optimal set of tests

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

type A = <a>[A*] type B = [B*]

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No backtracking.

Whole parts of the matched data are not checked

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Computing the optimal solution requires to fully exploit intersections and differences of types

Duce

- I merge distinct patterns that work on a common sequence,
- Itransform where clauses into patterns,
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Transform the from clauses so as to capture in a single pattern as much information as possible

```
select <book year=y>[t] from
b in bibs/book,
p in b/price,
t in b/title,
y in b/@year
where p = <price>"69.99"
```

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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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In XML processing it is important to allow the programmer to define her/his own iterators.

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Hosoya's smart idea: Define regular expression over patternmatches " $p \rightarrow e$ " (rather than over patterns).

- In-depth iterators are obtained by recursive filters
- If instead of regexp we use the core-algebra, then it is possible to define more powerful iterators.

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select e from p in e'

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select e from p in e' = filter[($p \rightarrow e \mid _ \rightarrow []$)*](e')

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Type precision obtained by specific typing, as for patterns.

Duce

7. Type/pattern-based pruning to optimise memory usage

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 "..." "gradular as possible of each of the compile of the scatter of the constant of the cons

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 $0 < \dots > 0$ is $< \dots < 0$ if $x < \dots < 0$ if x < x (0) is x < 0 if x < x (0) is x < 0.

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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.

)uce

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-element then its type-attribute is "ITV Service".
- Transformation description is more precise:



Use the precision of the type system in query optimisation

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E.g. in IMDB there are constraints such as: If a show-element contains season-elements, then its type-attribute is "TV Series".

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Finer type inference for queries:

infer type [(Title (Author+[Editor+))*] ather than [(Title)Author=[Editor]*]

DTD/Scheme already used to optimise access to XML data on disk. It should be possible to use also the precision of regen types to optimise secondary memory queries.

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bibs : <bib>[(<book year=String>[Title (Author+|Editor+) Price?])*]CDuce

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• 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. CDuce

1. Introduction 2. XML regexp types/patterns 3. Properties of regexp types/patterns 4. Conclusion MPRI: Cours de sous-typage

Conclusion

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• Regexp patterns start from two simple ideas:

- 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 asser Qizz and Qizzo
 - High precision in typing queries, iterators, complex transformations.
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