Greedy regular expression matching

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ICALP

The matching problem

The problem

Project the structure of a regular expression on a flat sequence.

- $R = (a * | b)*$
- $w = a_1 a_2 b_1 b_2 a_3$
- $\Rightarrow v = [1 : [a_1; a_2];\ \ 2 : b_1;\ \ 2 : b_2;\ \ 1 : [a_3]]$

- The result retains the structure of the regexp and the content of the sequence.
- Result driven by the syntax of regexps $\neq$ automata.
- Issues: efficiency, disambiguation.

Main motivation

- Type-directed native representation of values in XDuce-like languages: E.g.:
  `[ int ]` $\rightsquigarrow$ `int`
  `[ int int* ]` $\rightsquigarrow$ `struct {int fst; int[] snd;}`
- Advantages over uniform representation:
  - More compact representation, less boxing
  - Fast random access
  - Easier to interface/integrate with other language
- Requires coercion between subtypes.
  - Flatten sequences.
  - Project the structure of the new regexp = matching.

Other applications

- Regexp packages with structured matching semantics.
- Lexer-parser generators.
- Operation/representation defined by induction on the structure of regexps (e.g.: Hosoya's filters).

Proof of concept

- A regexp iterator extension for C#

```
object[] a = new object[] {1,2,3,4,"abc",4,5,"xyz",6,7,false};
applyregexp(a) (
  (
    ( int  , int                    )*,
    string

  )
  |
   (
    ( int                  )*,
    bool

   )
)*;
```

Proof of concept

- A regexp iterator extension for C#

```
object[] a = new object[] {1,2,3,4,"abc",4,5,"xyz",6,7,false};
applyregexp(a) (
  ( { int sum = 0; },
    ( int x, int y, { sum += x*y; } )*,
    string s,
    { System.Console.WriteLine(s + ":" + sum); }
  )
  |
  ( { int sum = 0; },
    ( int x, { sum += x; } )*,
    bool b,
    { System.Console.WriteLine(b + ":" + sum); }
  )
)*;
↪
abc:14
xyz:20
False:13
```

Key issue: avoiding backtracking

- Consider the regexp:

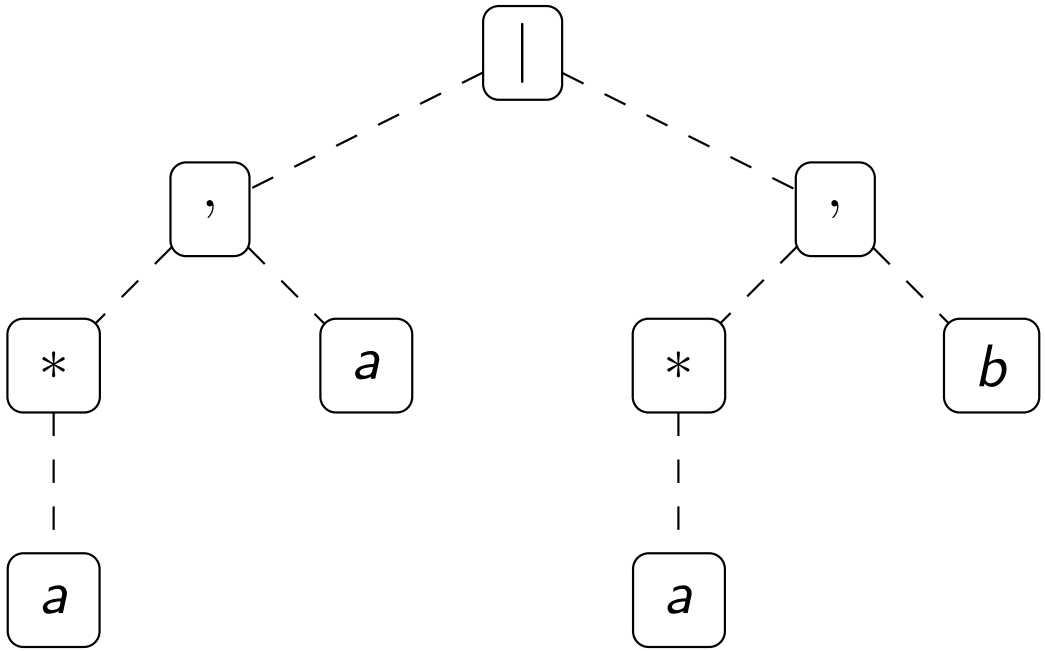
$$R = a* \mid (a*, b, a*)$$

- To avoid backtracking, and still proceed by induction on the regexp, we need to decide first which branch to take (left or right?)
- Unbounded look-ahead!

An example

- Abstract syntax tree of the regexp.

$R = (a*, a)|(a*, b)$
$w = \quad a \;\; b$



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- Abstract syntax tree of the regexp.
- Build an automaton on top of it.

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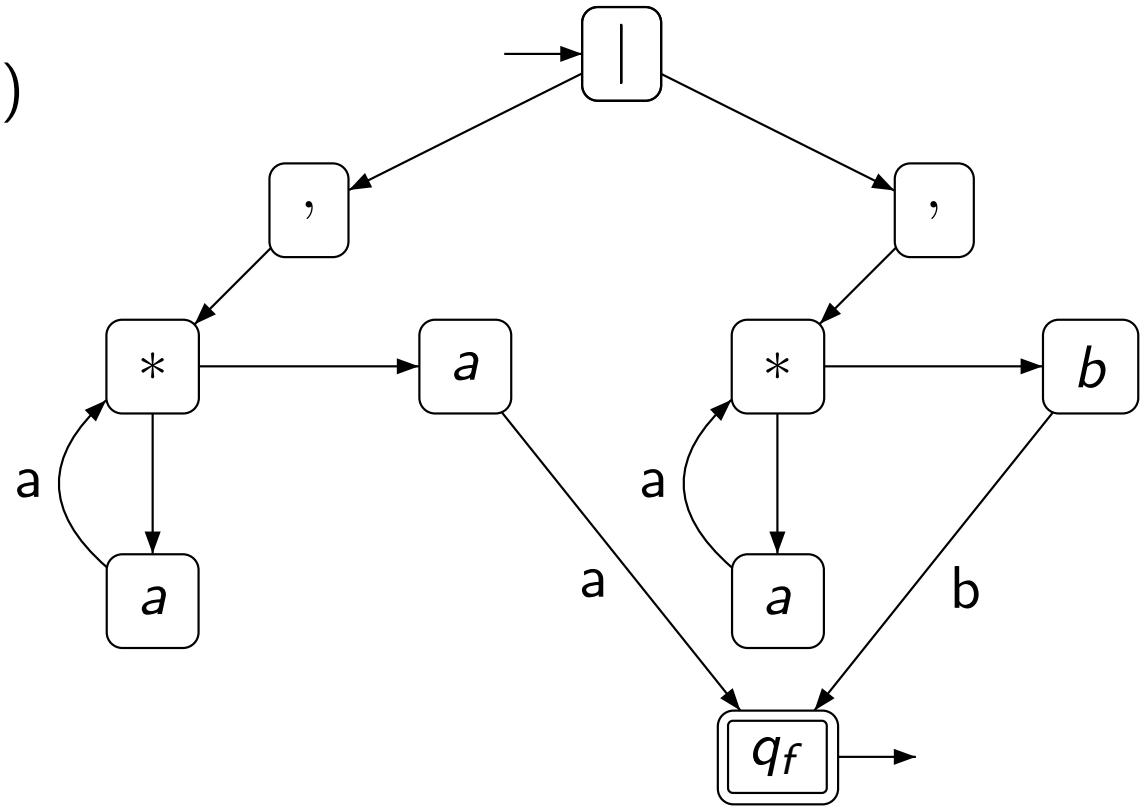

An example

- Abstract syntax tree of the regexp.
- Build an automaton on top of it.
- Scan the input backwards ("subset construction").

$R = (a*, a)|(a*, b)$

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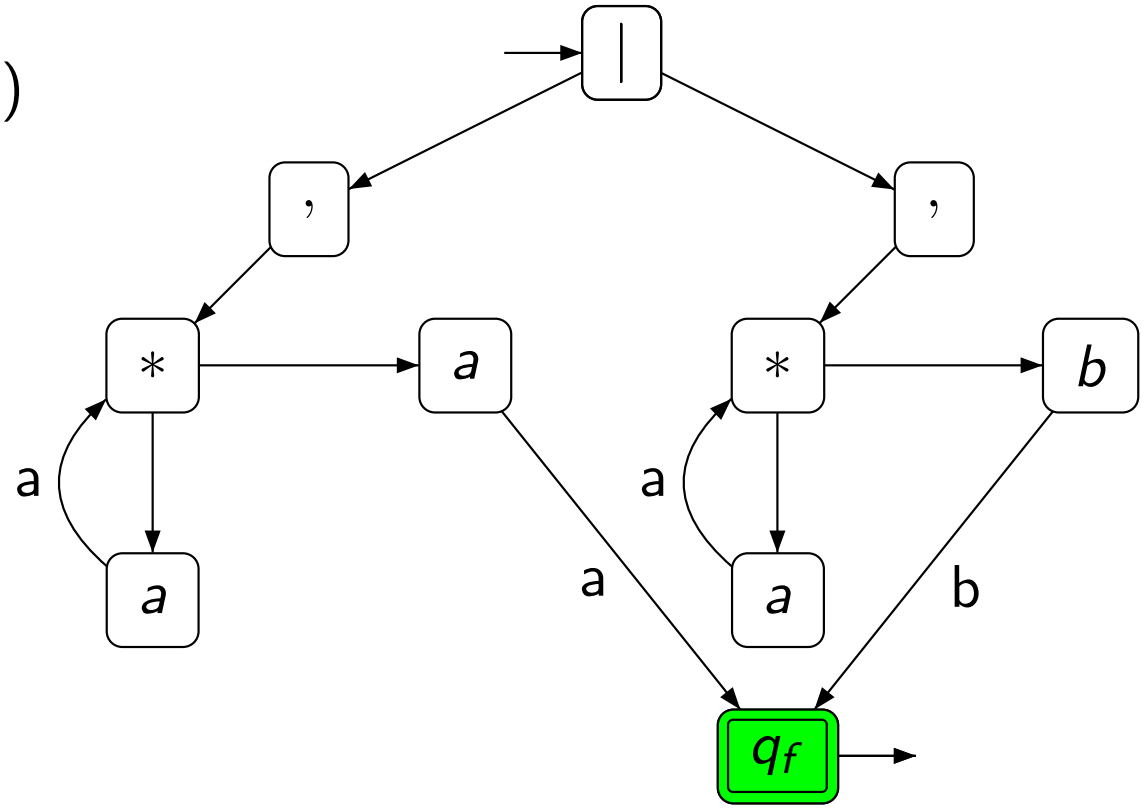

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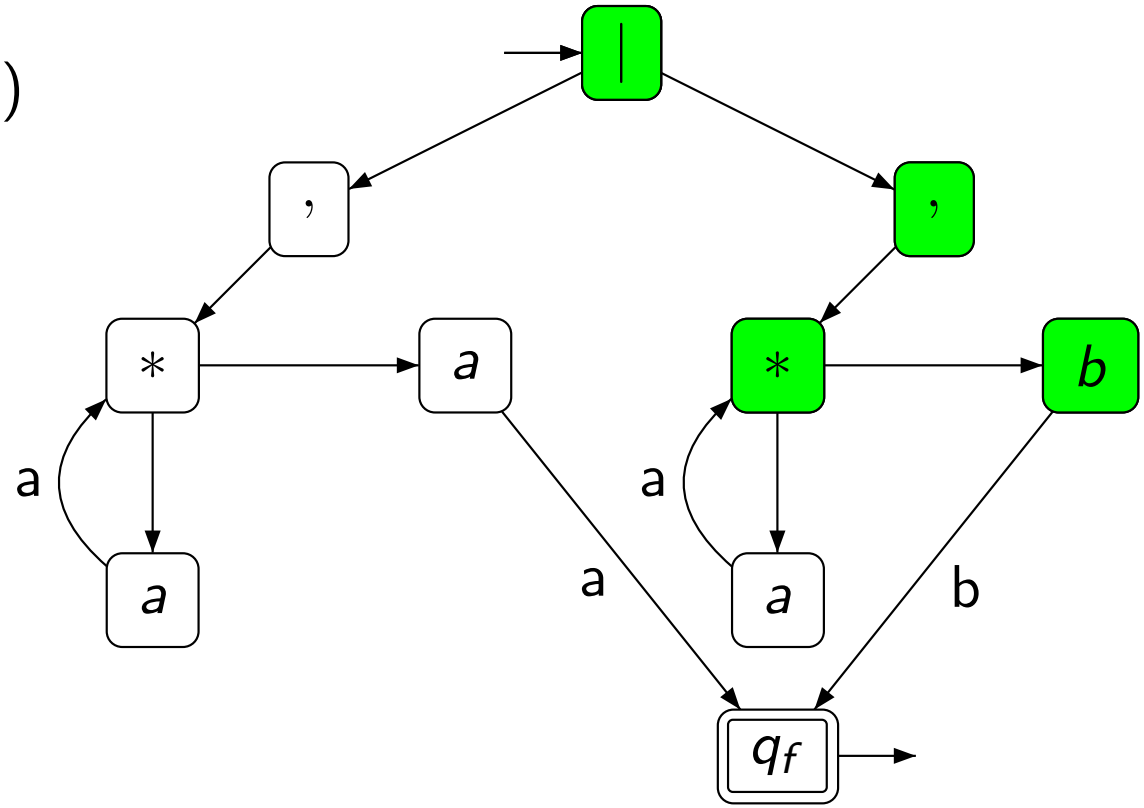

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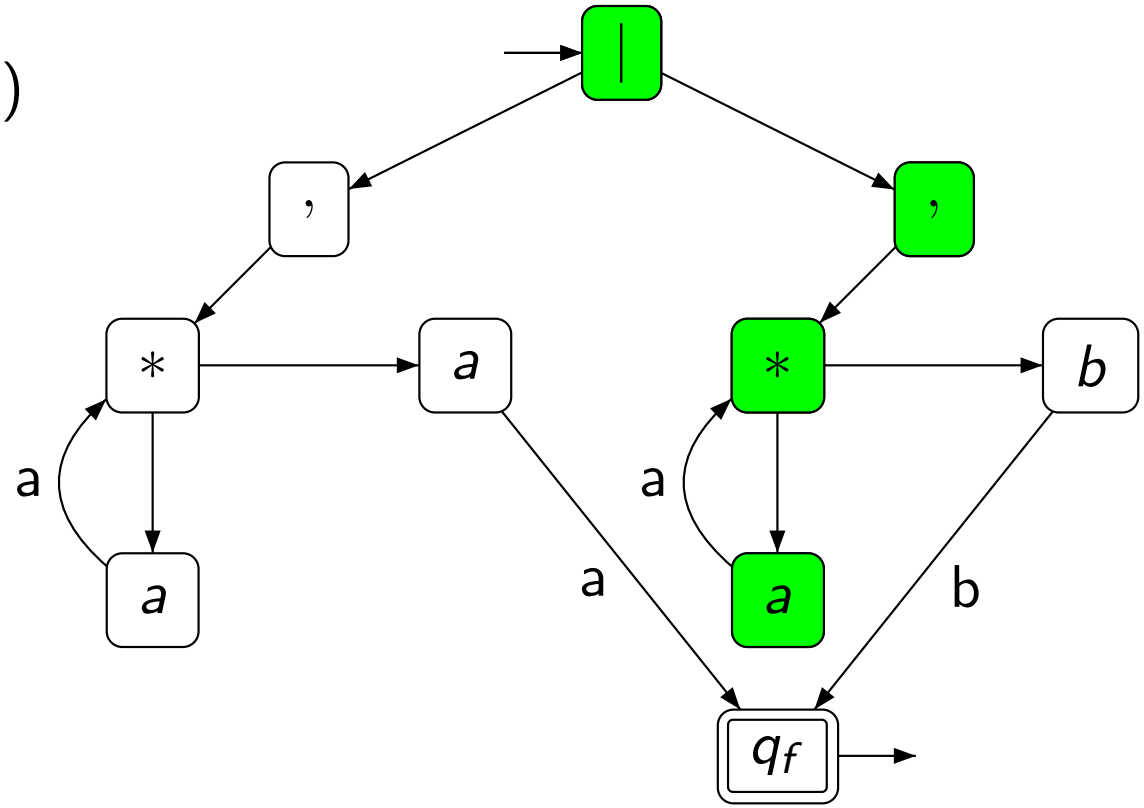


Second pass: the matcher

```
let rec loop = function
  | ε -> ()
  | r1 , r2 -> (loop r1, loop r2)
  | r1 | r2 -> if  ... then (1,loop r1) else (2,loop r2)
  | r* -> if  ... then (loop r)::(loop r*) else []
  | c -> (*  Consume the token *)
```

- What are the ... ?
- Given by the first pass.
- Disambiguation:
  - first-match for |
  - greedy semantics for $*$

Non-termination problem

The algorithm always terminates except with a subregexp $R*$ where R is "nullable".

Examples: $(a*, b*)*$ $(a* \mid b*)*$

Same problem in the folklore syntax-directed recognizer:

```
let rec loop r k w = match r with
  | ε -> k w
  | r1 , r2 -> loop r1 (loop r2 k) w
  | r1 | r2 -> (loop r1 k w) || (loop r2 k w)
  | r* -> (loop r (loop r* k) w) || (k w)
  | c -> (w <> []) && (hd w = c) && (k (tl w))

let accept r = loop r ( (=) [] )
```

r : regexp
k : continuation
w : input sequence

loop r k w = true $\iff$ w = w1 @ w2 s.t. (r matches w1) && (k w2 = true)

Non-termination problem: solutions

Rewrite regexps to avoid the problematic situation

- E.g.: $(a*, b*)* \rightsquigarrow ((a*, b+)|a+)*$
- The structure of the regexp is lost: not suitable for the matching problem.
- Interaction with the disambiguation policy ?

Prevent iterations in stars from accepting empty sequences

- In the functional recognizer, replace

```
(loop r (loop r* k) w) || (k w)
```

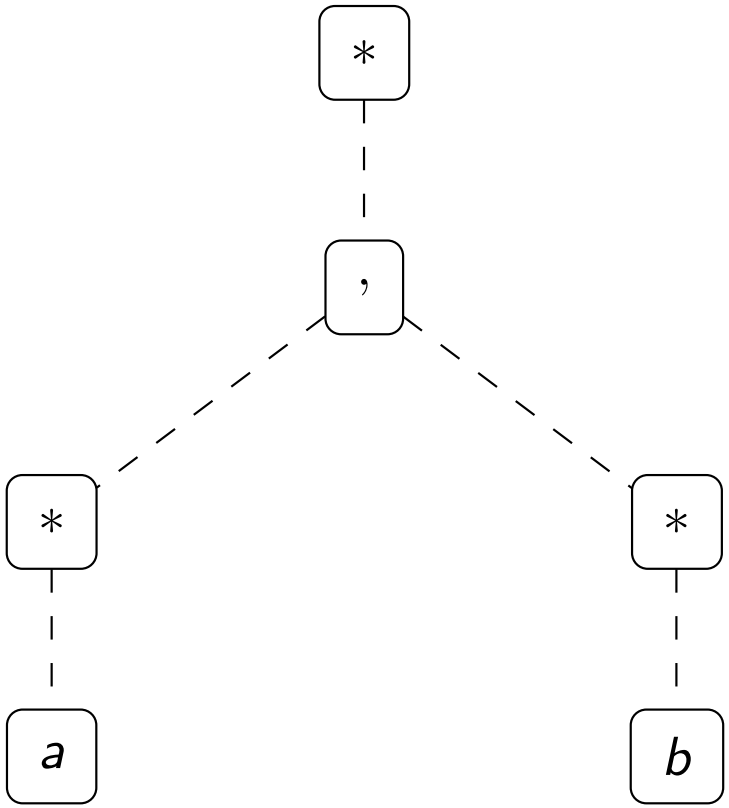
  with:

```
(loop r (fun w' -> (w <> w') && (loop r* k w')) w)) || (k w)
```

- How to adapt our algorithm ?

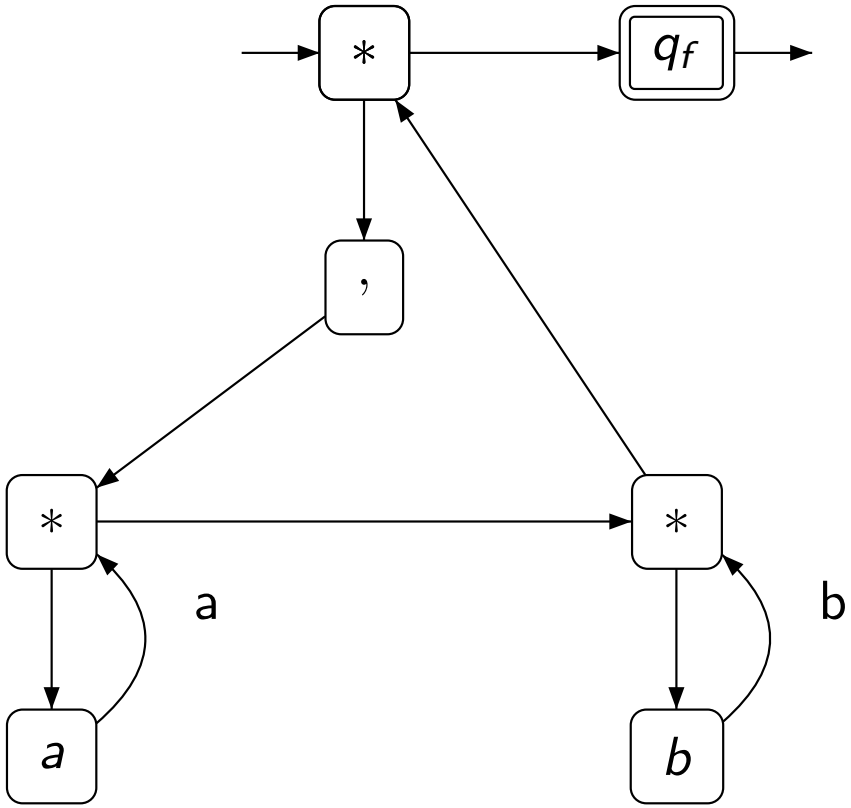
An example

- $R = (a*, b*)*$



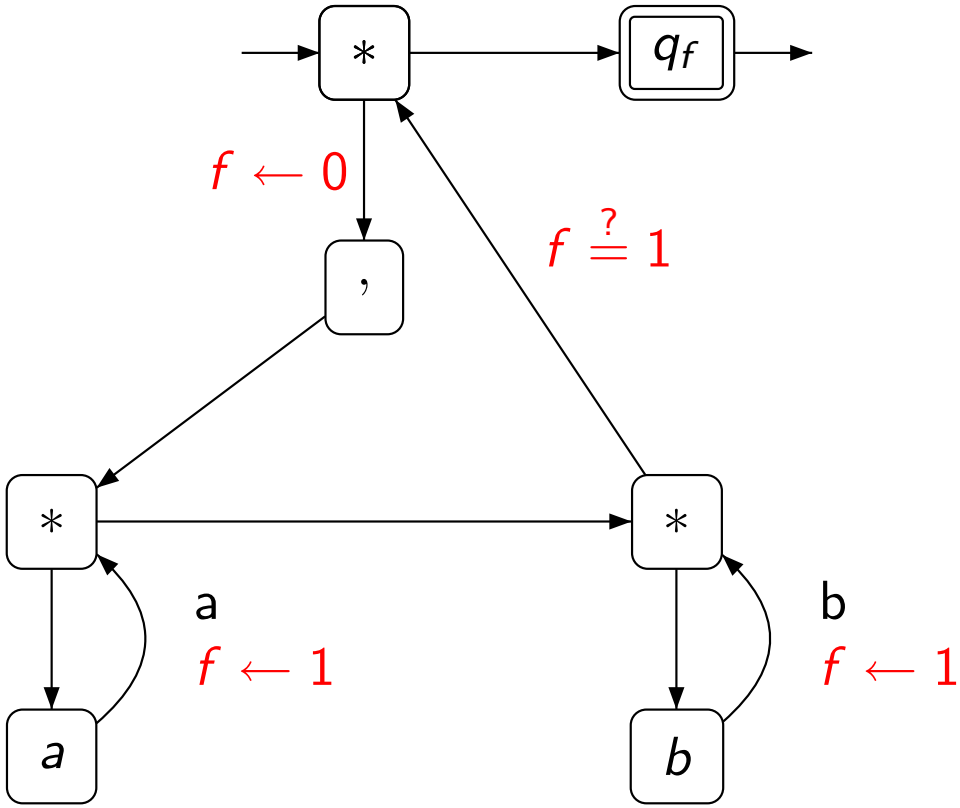
An example

- $R = (a*, b*)*$
- Loop of ε-transitions



An example

- $R = (a*, b*)*$
- Loop of ε-transitions . . . now broken.
- Still a finite state automaton (states (q, f)).



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  | r* -> if  ... then ( f := 0; (loop r)::(loop r*)) else []
  | c ->  f := 1;  (* Consume the token *)
```

The ... are given by the first pass.

Conclusion

- Keep a tight connection between regexps and automata.
  - Direct construction of the automaton
- Accept problematic regexps, reject problematic matchings.
- Result: linear time (two-passes) matching algorithm, which can be efficiently implemented.
- Abstract specification of the disambiguation policy as an optimization problem (not presented).
- Characterization and study of problematic cases (not presented).

Future work

- Evaluate the alternative implementation technique for XML languages.
- Optimizations: the first pass is not always necessary. Use (bounded) look-ahead as long as possible, or a lazy first pass.
- Non-local disambiguation policy, e.g.: longest match semantics.
- Non-regular languages.

Questions ?