CS 421 Lecture 6: Regular expressions

- Announcements
- Lecture outline
  - Regular expressions
  - Ocamllex

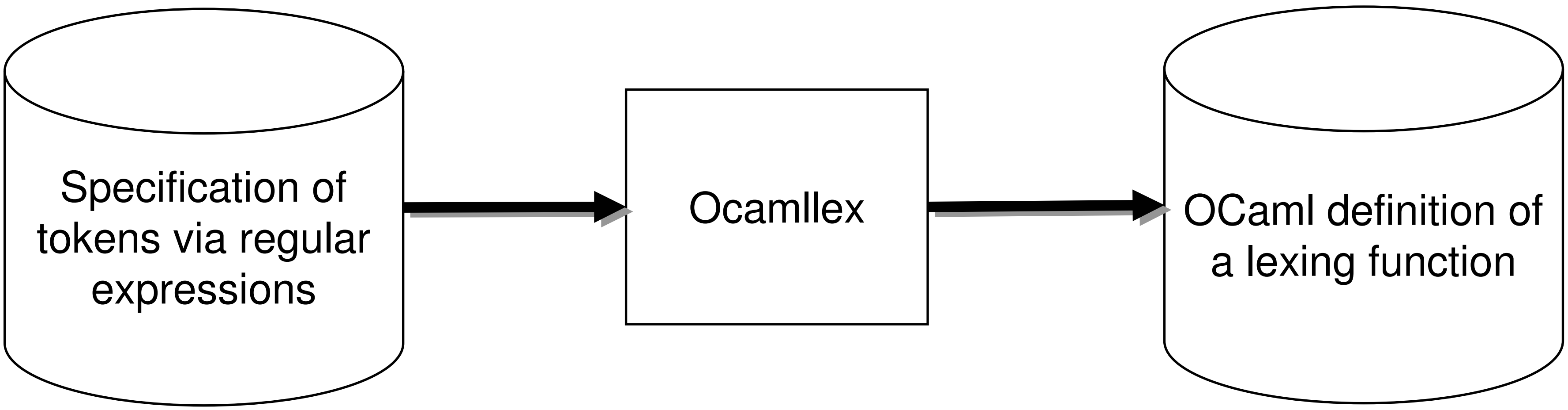
Announcements

- MP2 extension and update
  - New due date 1:00pm Friday, June 12
  - Problem 10 has been updated
  - “Valid” old solutions will get full credit

- MP3 has been posted
  - Due 1:00pm Wed, June 17
  - Warning: more work than the first MPs
  - Collaboration is allowed in two-person teams

Overview of Ocamllex

- Automatic OCaml lexer generator



Regular expressions

- A regular expression is one of
  - *ε*, a.k.a. ""
  - '*a*' for any character *a*
  - r_1r_2, where r_1 and r_2 are regular expr's
  - $r_1|r_2$, where r_1 and r_2 are regular expr's
  - r*, where r is a regualr expr
  - Ø
- Every regular expr r represents a set of strings, denoted L(r)
  - *Language* of r

Regular expression examples

- L(‘a’ ’b’ ’c’) = {“abc”}
- L((‘a’ | ’b’) ‘c’) = {“ac”, “bc”}
- L((‘a’ | ‘b’)* ‘c’) =
  {“c”, “ac”, “bc”, “aac”, “abc”, ...}

Regular expression examples

- Keywords:
  - ‘c’ ‘a’ ‘s’ ‘e’ | ‘c’ ‘ ‘l’ ‘a’ ‘s’ ‘s’ | …
- Operators
  - ‘<‘ | ‘<‘ ‘<‘ | ‘<‘ ‘=‘ | …
- Identifiers
  - (‘a’ | ‘b’ | … | ‘z’ | ‘A’ | … | ‘Z’)
    (‘a’ | ‘b’ | … | ‘z’ | ‘A’ | … | ‘Z’ | ‘0’ | ‘1’ | … | ‘9’)*
- Int literals
  - ??

Abbreviations

- "$c_1c_2 \ldots c_n$" => 'c_1' 'c_2' … 'c_n'
- ['a' – 'z' '#'] => 'a' | 'b' | … | 'z' | '#'
- ['a' 'w' '#'] => 'a' | 'w' | '#'
- r+ => r(r*)
- r? => r | ""
- [^ 'a' – 'z'] => all chars except 'a' – 'z' (complement of 'a' – 'z')
- _ => any single char

Regular expressions examples

- Floating-point literal

  [‘0’-’9’]+ . [‘0’-’9’]+ ([‘e”E’] [‘+”-’]? [‘0’-’9’]+)?

  - Note: r* = (r+)?

Regular expression examples

- C++ style comments (// …)
  “//” [^ ‘\n’]* ‘\n’

- C style comments (/* … */)
  “/*” ([^ ‘*’] | ‘*’+ [^ ‘*”/’])* “*/”

Implementing regular expressions

- Translate REs to NFAs
- Translate NFAs to DFAs

Lexing with regular expressions

- Create one large RE:

```
  RE for case        {action for case}
| RE for class       {action for class}
| …
| RE for idents      {action for idents}
| RE for FP lits     {action for FP lits}
| RE for Int lits    {action for int lits}
```

- Then add some actions

Lexing with regular expressions (cont.)

- Ambiguous cases:

- Two tokens found, one longer
  - Choose the longer one

- Two tokens found, the same length
  - Choose the earlier reg. expr.

Ocamllex mechanics

- Put table of regular expressions and corresponding actions (written in Ocaml) into a file

  <filename>.mll
- Call

  ocamllex <filename.mll>
- Produces Ocaml code for a lexical analyzer in

  <filename>.ml

Ocamllex input

```
{header}
let ident = regexp …
rule entrypoint[arg1 … argn] =
   parse regexp {action}
and entrypoint[arg1 … argn] =
   parse … and …
{trailer}
```

Ocamllex input

```
{header}
let ident = regexp …
rule entrypoint[arg1 … argn] =
   parse regexp {action}
and entrypoint[arg1 … argn] =
   parse … and …
{trailer}
```

header – ocaml defns

Entrypoint – name of gen'd function with args arg1, …, argn, lexbuf

trailer – ocaml defns

Ocamllex input

- *header* and *trailer* contain arbitrary Ocaml code put at top and bottom of <filename>.ml
- let *ident* = *regexp* ... introduces *ident* for use in later regular expressions

Sample input

```
rule main = parse
  ['0'-'9']+                   { print_string "Int\n" }
| ['0'-'9']+'.'['0'-'9']       { print_string "Float\n" }
| ['a'-'z']+                   { print_string "String\n" }
| _                            { main lexbuf }
{
let newlexbuf = (Lexing.from_channel stdin) in
  print_string "Ready to lex.\n";
  main newlexbuf
}
```

Ocamllex output

- <filename>.ml contains one lexing function per *entrypoint*
  - Name of function is name given for *entrypoint*
  - Each entry point becomes an Ocaml function that takes *n*+1 arguments
    - The extra implicit argument being of type Lexing.lexbuf
  - *arg1* ... *argn* are for use in *action*

Ocamllex regular expressions

- ‘a’ : single quoted characters for letters
- _ : matches any character
- eof : special end_of_file marker
- e_1e_2 : concatenation
- “string” : concatenation of a sequence of characters
- $e_1|e_2$: choice

Ocamllex regular expressions

- $[c_1 - c_2]$: choice of any character between first and second, inclusive, as determined by character codes
- $[\hat{}c_1 - c_2]$: choice of any character NOT in the set
- e* : same as before
- e+ : same as e e*
- e? : option – was $e_1|\varepsilon$

Ocamllex regular expression

- $e_1 \# e_2$: the characters in e_1 but not in e_2; e_1 and e_2 must describe just sets of characters
- *ident* : abbreviation for earlier reg exp in let *ident* = *regexp*
- e_1 as *id* : binds the result of e_1 to *id*, to be used in the associated action
  - Example

```
(['0'-'9']+ as decpart '.' (['0'-'9']+ as fracpart …
```

Ocamllex manual

- More details can be found at
  - http://caml.inria.fr/pub/docs/manual-ocaml/manual026.html

Example: test.mll

```
{ type result = Int of int | Float of float | String
  of string }
let digit = [‘0’-’9’]
let digits = digit+
let lower_case = [‘a’-’z’]
let upper_case = [‘A’-’Z’]
let letter = lower_case | upper_case
let letters = letter+
...
```

Example: test.mll

```
rule main = parse
  digits'.'digits as f  { Float (float_of_string f) }
| digits as n           { Int (int_of_string n) }
| letters as s          { String s }
| _                     { main lexbuf }
{let newlexbuf = (Lexing.from_channel stdin) in
  print_string "Ready to lex.\n";
  main newlexbuf }
```

Example

```
> ocamllex test.mll
> ocaml
# #use "test.ml"
...
val main : Lexing.lexbuf -> result = <fun>
Ready to lex.
hi there 234 5.6
- : result = String "hi"
#
```

- What happened to the rest?

Example

```
# let b = Lexing.from_channel stdin;;
# main b;;
hi 789 there
- : result = String “hi”
# main b;;
- : result = Int 789
# main b;;
- : result = String “there”
```

Problem

- How to get the lexer to look at more than the first token?
- Answer 1: repeatedly call lexing function
- Answer 2: *action* has to tell it to – recursive calls. Value of action is token list instead of token.
- Note: already used this with the _ case

Example

```
rule main = parse
  digits'.'digits as f  { Float (float_of_string f)
                              :: main lexbuf }
| digits as n           { Int (int_of_string n)
                              :: main lexbuf }
| letters as s          { String s :: main lexbuf }
| eof                   { [] }
| _                     { main lexbuf }
```

Example results

```
Ready to lex.
hi there 234 5.6
- : result list = [String “hi”; String “there”; Int
  243; Float 5.6]
#
```

- Use Ctrl-D to send the end_of_file character

Example: dealing with comments

- First attempt

```
let open_comment = "(*"
let close_comment = "*)"
rule main = parse
    ...
  | open_comment                { comment lexbuf }
  | eof                         { [] }
  | _                           { main lexbuf }
and comment = parse
    close_comment               { main lexbuf }
  | _                           { comment lexbuf }
```

Example: dealing with comments

- Second attempt – nested comments

```
rule main = parse ...
   | open_comment          { comment 1 lexbuf }
   | eof                   { [] }
   | _                     { main lexbuf }
and comment depth = parse
     open_comment          { comment (depth+1) lexbuf }
   | close_comment         { if depth = 1
                             then main lexbuf
                             else comment (depth-1) lexbuf}
   | _                     { comment depth lexbuf }
```