CMSC 330: Organization of Programming Languages

OCaml Regular Expressions

String Processing in OCaml

- String module provides many useful functions for manipulating strings
  - Concatenate two strings
  - Extract substrings
  - Search for a substring and Replace with something else

String Operations in OCaml

- What if we want to find more complicated patterns? E.g.,
  - Either Steve, Stephen, Steven, Stefan, or Esteve
  - All words that have even number vowels

We need Regular Expressions

Regular Expressions

- A regular expression is a pattern that describes a set of strings. It is useful for
  - Searching and matching
  - Formally describing strings
    - The symbols (lexemes or tokens) that make up a language
- Common to lots of languages and tools
  - Syntax for them in sed, grep, awk, Perl, Python, Ruby, …
    - Popularized (and made fast) as a language feature in Perl
- Based on some elegant theory
  - Future lecture

OCaml Regular Expressions

Multiple Regexp libraries exist:

- RE: a pure OCaml regular expressions library that supports several formats (glob, posix, str…)
  - In this lecture, we will use the posix format of the RE library

- Str: OCaml comes with the Str module.
  - This module is **not** recommended because it is not particularly fast
  - It does not support Unicode

Example

```
#require "re" (* only needed in Utop *)
# let str2re t = Re.Posix.compile (Re.Posix.re t);;

#let r = str2re "[a-z][0-9]+";;
   val r : re = <abstr>

# Re.matches r "a12#b22abcd";;
- : string list = ["a12"; "b22"]
```

A letter followed by one or more digits

Basic Concepts

A regular expression is a pattern that the regular expression engine attempts to match in input text.

A pattern consists of one or more character literals, operators, or constructs.

- “OCaml”: Strings are matched exactly
- “a|b”: A vertical bar separates alternatives. (Boolean Or)
- “ab*”: A quantifier (?, *, +, {n}) after an element (such as a character, or group) specifies how many times the element is allowed to repeat.
- The wildcard . matches any character.

Repetition in Regular Expressions

The following are suffixes on a regular expression *e*

*e**	*zero or more occurrences of e*
e+	*one or more occurrences of e*

so *e*+ is the same as *ee**

a*	“”, “a”, “aa”, “aaa”, …
a+	“a”, “aa”, “aaa”, …
bc*	“b”, “bc”, “bcc”, …
a+b*	“a”, “ab”, “aa”, “aab”, “aabb”, “aabbb”, “aaa”, …

Repetition in Regular Expressions

The following are suffixes on a regular expression *e*

*e**	*zero or more occurrences of e*
e+	*one or more occurrences of e*
	so *e*+ is the same as *ee**
e?	*exactly zero or one e*
e{*x*}	*exactly x occurrences of e*
e{*x*,}	*at least x occurrences of e*
e{*x*,*y*}	*at least x and at most y occurrences of e*

Watch Out for Precedence

- (OCaml)* means {"", ”OCaml", ”OCamlOCaml", ...}
- OCaml* means {”OCam", ”OCaml", ”OCamlllll", ...}
- Best to use parentheses to disambiguate
  - Note that parentheses have another use, to extract matches, as we’ll see later

Character Classes

- [abcd]
  - {"a", "b", "c", "d"} (Can you write this another way?)
- [a-zA-Z0-9]
  - Any upper- or lower-case letter or digit
- [^0-9]
  - Any character except 0-9 (the ^ means *not,* and must come first)
- [\t\n]
  - Tab, newline or space
- [a-zA-Z_\$][a-zA-Z_\$0-9]*
  - Java identifiers ($ escaped...see next slide)

Special Characters

^	beginning of line
$	end of line
\$	just a $

Using **^pattern$** ensures entire string/line must match pattern

Languages like Ruby and Python provide more special characters

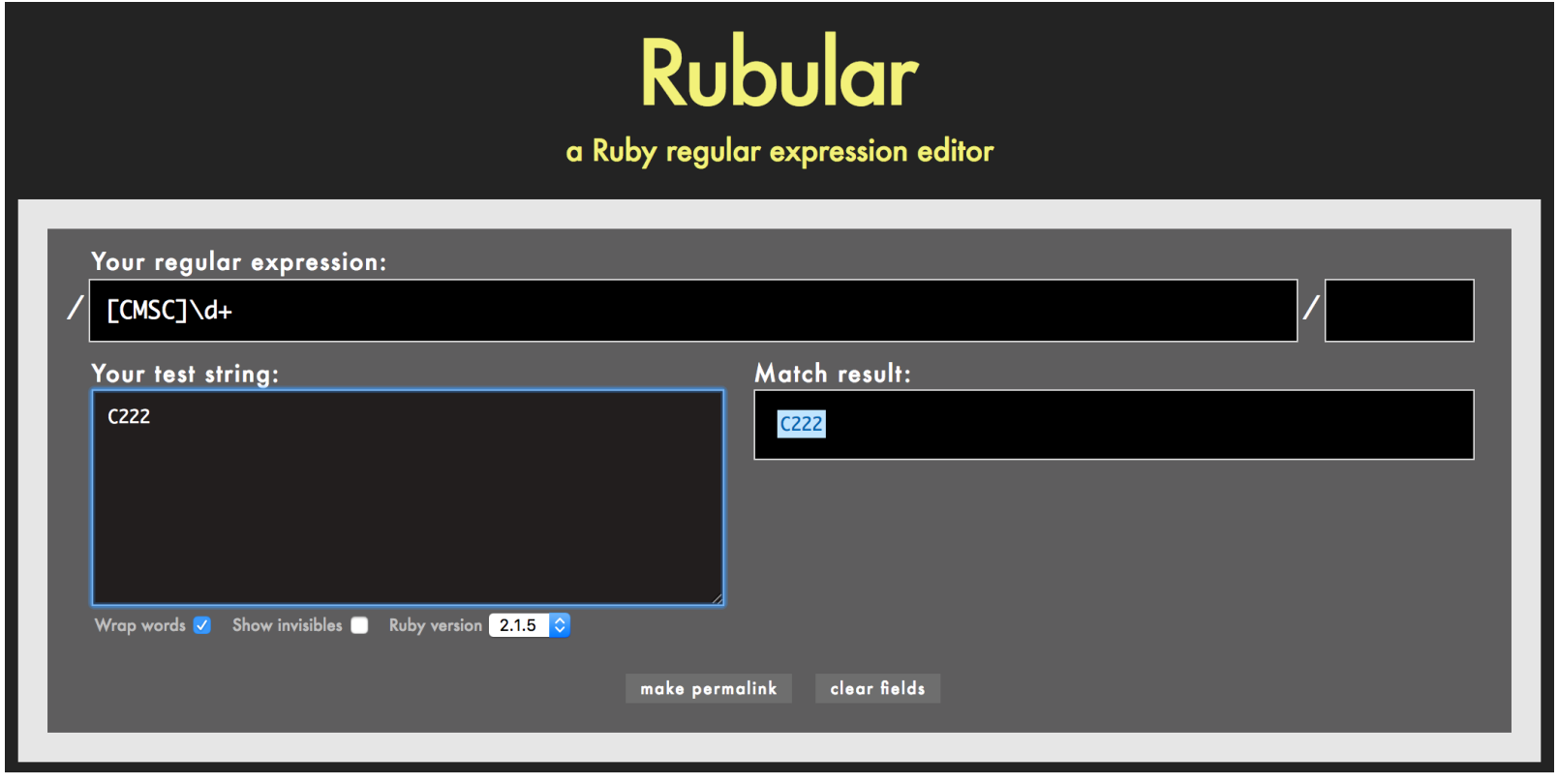
Potential Syntax Confusions

- ^
  - Inside regex character class: *not*
  - Outside regex character class: beginning of line
- ( )
  - Inside character classes: literal characters ( )
    - Note /(0..2)/ does not mean 012
  - Outside character classes in regex: used for grouping
- –
  - Inside regex character classes: range (e.g., a to z given by [a-z])
  - Outside regular expressions: subtraction

Summary

- Let *re* represents an arbitrary pattern; then:
  - *re* – matches regexp *re*
  - (re_1|re_2) – match either re_1 or re_2
  - (*re*)* – match 0 or more occurrences of *re*
  - (*re*)+ – match 1 or more occurrences of *re*
  - (*re*)? – match 0 or 1 occurrences of *re*
  - (*re*){2} – match exactly two occurrences of *re*
  - [a-z] – same as (a|b|c|...|z)
  - [^0-9] – match any character that is not 0, 1, etc.
  - ^, $ – match start or end of string

Try out regexps at rubular.com



Regular Expression Practice

- Any string containing two consecutive ab

- Any string containing a or two consecutive b

Regular Expression Practice

- Any string containing two consecutive ab

(ab){2}

- Any string containing a or two consecutive b

a|bb

Regular Expression Practice

Contains sss or ccc

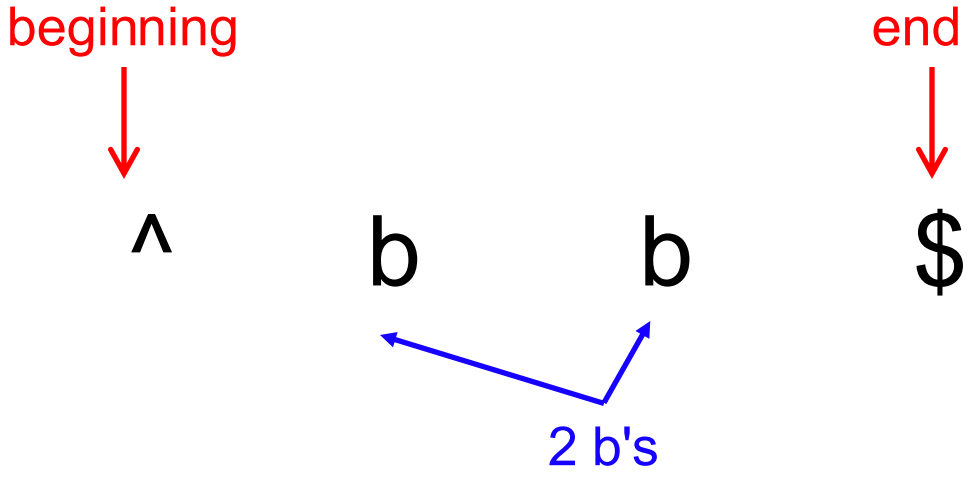
Regular Expression Practice

Contains sss or ccc

s{3}|c{3}

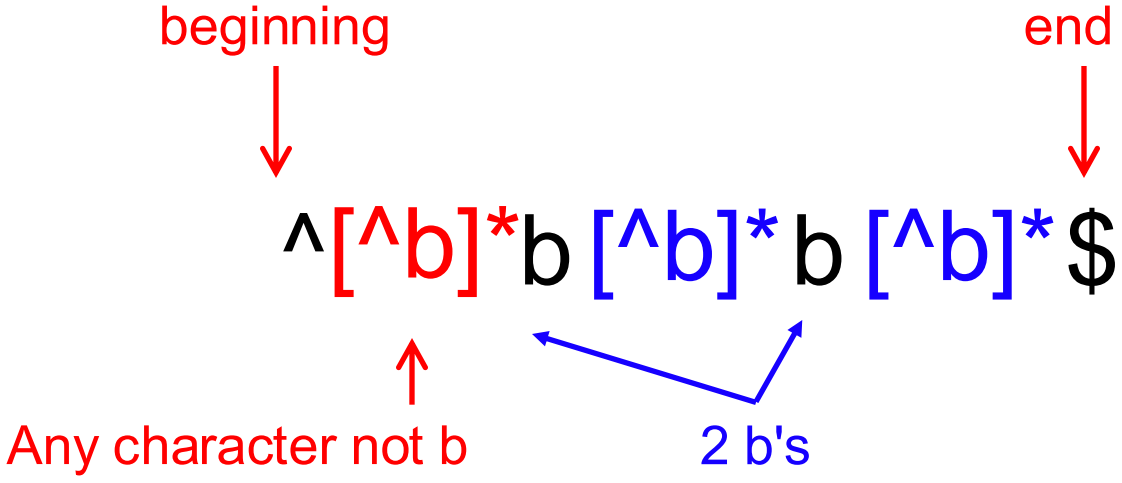
Regular Expression Practice

Contains exactly 2 b's, not necessarily consecutive.



Regular Expression Practice

Contains exactly 2 b's, not necessarily consecutive.



Regular Expression Practice

- Starts with c, followed by one lowercase vowel, and ends with any number of lowercase letters

^c[aeiou][a-z]*$

Regular Expression Practice

- Starts with c, followed by one lowercase vowel, and ends with any number of lowercase letters

^c [aouei] [a-z]* $

one vowel

any number of letters

Regular Expression Practice

- Starts with a and has exactly 0 or 1 letter after that

Regular Expression Practice

- Starts with a and has exactly 0 or 1 letter after that

^a[A-Za-z]?$

Regular Expression Practice

- Only lowercase letters, in any amount, in alphabetic order

Regular Expression Practice

- Only lowercase letters, in any amount, in alphabetic order

^a*b*c*d*e*f*g*h*i*j*k*l*m*n*o*p*r*t*u*v*w*x*y*z*$

Regular Expression Practice

- Contains one or more ab or ba

Regular Expression Practice

- Contains one or more ab or ba

(ab|ba)+

Regular Expression Practice

- Precisely steve, steven, or stephen

Regular Expression Practice

- Precisely steve, steven, or stephen

^ste(ve|phen|ven)$

Regular Expression Practice

- Even length string

Regular Expression Practice

- Even length string

^(..)*$

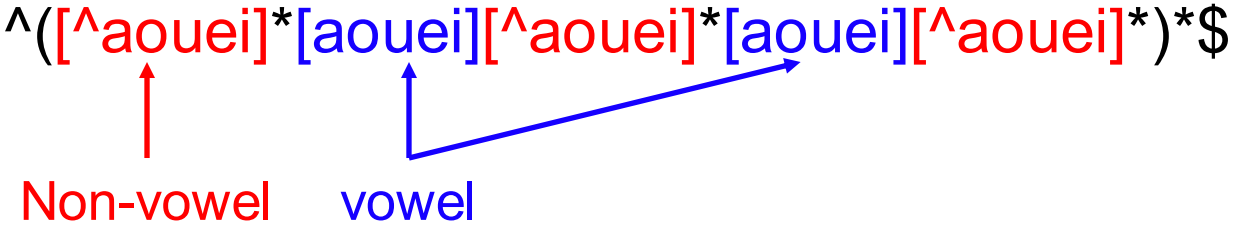
any two characters

Regular Expression Practice

- Even number of lowercase vowels

Regular Expression Practice

- Even number of lowercase vowels



Regular Expression Practice

- Starts with anything but b, followed by one or more a's and then no other characters

Regular Expression Practice

- Starts with anything but b, followed by one or more a's and then no other characters

^[^b]+a+$

Quiz 1

How many different strings could this regex match?

```
^Hello, Anyone awake?$
```

A. 1
B. 2
C. 4
D. More than 4

Quiz 1

How many different strings could this regex match?

∈ or nothing

```
^Hello, Anyone awake?$
```

A. 1
B. 2
C. 4
D. More than 4

Quiz 2

Which regex is not equivalent to the others?

A. `^[cmsc]$`

B. `^c?m?s?c?$`

C. `^(c|m|s|c)$`

D. `^([cm]|[sc])$`

Quiz 2

Which regex is not equivalent to the others?

A. `^[cmsc]$`

B. `^c?m?s?c?$`

C. `^(c|m|s|c)$`

D. `^([cm]|[sc])$`

Quiz 3

Which string does not match the regex?

```
[a-z]{4}[0-9]{3}
```

A. `"cmsc\d\d\d"`
B. `"cmsc330"`
C. `"hellocmsc330"`
D. `"cmsc330world"`

Quiz 3

Which string does not match the regex?

*Recall that without ^ and $, a regex will match any **sub**string*

```
[a-z]{4}[0-9]{3}
```

A. `"cmsc\d\d\d"`
B. `"cmsc330"`
C. `"hellocmsc330"`
D. `"cmsc330world"`

RE Library

- Modules
  - Emacs, Glob, Perl, Pcre, Posix, Str
- Basic Functions
  - matches:extracts the matched substring
  - compile: Compile a regular expression into an executable version that can be used to match strings
  - exec:matches str against the compiled expression re, and returns the matched groups if any
  - split: splits s into chunks separated by the regular expression

Example (again)

```
#require "re" (* only needed in Utop *)
# let str2re t = Re.Posix.compile (Re.Posix.re t);;

#let r = str2re "[a-z][0-9]+";;
   val r : re = <abstr>

# Re.matches r "a12#b22abcd";;
- : string list = ["a12"; "b22"]
```

A letter followed by one or more digits

Extracting Substrings based on Regexps

- **Capturing Groups**
  - Re remembers which strings matched the parenthesized parts of a Regexp
  - These parts can be referred as Groups

Example: Capturing Groups

```
let r = str2re "^Min:([0-9]+) Max:([0-9]+)$";;
let t = Re.exec r "Min:50 Max:99";;
let min = Re.Group.get t 1;;     (* 50 *)
let max = Re.Group.get t 2;;     (* 99 *)
```

- Input

```
Min:1 Max:27
Min:10 Max:30
Min:  11 Max: 30
Min: a Max: 24
```

- Output

```
min=1 max=27
min=10 max=30
```

Extra space messes up match

Not a digit; messes up match

Quiz 4

What is the output of the following code?

```
let r = str2re "([A-Z]+)"
let t = Re.exec r "HELP! I'm stuck"
Re.Group.get t 1
```

A. H
B. HELP
C. I
D. I'm stuck

Quiz 4

What is the output of the following code?

```
let r = str2re "([A-Z]+)"
Let t = Re.exec r "HELP! I'm stuck"
Re.Group.get t 1
```

A. H
B. HELP
C. I
D. I'm stuck

Quiz 5

What is the output of the following code?

```
let r = str2re "[0-9] ([A-Za-z]+).*([0-9])";;
let t = Re.exec r "Why was 6 afraid of 7?";;
Re.Group.get t 2
```

A. afraid
B. 7
C. 6
D. *(empty string)*

Quiz 5

What is the output of the following code?

```
let r = str2re "[0-9] ([A-Za-z]+).*([0-9])";;
let t = Re.exec r "Why was 6 afraid of 7?";;
Re.Group.get t 2
```

A. afraid
B. 7
C. 6
D. *(empty string)*

Re.matches

- extracts all matched substrings as a list

```
let r = str2re "[A-Za-z]+ [0-9]+";;
Re.matches r "CMSC 330 Spring 2021";;
# ["CMSC 330", ”Spring 2021"]
```

```
let r = str2re “[A-Za-z0-9]{2}”
Re.matches r "CMSC 330 Spring 2021";;
["CM", "SC", "33", "Sp", "ri", "ng", "20", "21"]
```

Quiz 6

What is the output of the following code?

```
let r = str2re "[A-Za-z]{2}";;
Re.matches r "Hello World";;
```

A. ["Hello"; "World"]
B. ["Hello World"]
C. ["He"; "ll"; "Wo"; "rl"]
D. ["He"; "ll"; "o " "Wo"; "rl"; "d"]

Quiz 6

What is the output of the following code?

```
let r = str2re "[A-Za-z]{2}";;
Re.matches r "Hello World";;
```

A. ["Hello"; "World"]
B. ["Hello World"]
C. ["He"; "ll"; "Wo"; "rl"]
D. ["He"; "ll"; "o " "Wo"; "rl"; "d"]

Quiz 7

What is the output of the following code?

```
let r = str2re "[A-Za-z]+";;
Re.matches r "To be, or not to be!";;
```

A. `["To","be,","or","not","to","be!"]`
B. `["To","be","or","not","to","be"]`
C. `[["To","be,"],["or","not"],["to","be!"]]`
D. `["to","be!"]`

Quiz 7

What is the output of the following code?

```
let r = str2re "[A-Za-z]+";;
Re.matches r "To be, or not to be!";;
```

A. ["To","be,","or","not","to","be!"]
B. ["To","be","or","not","to","be"]
C. [["To","be,"],["or","not"],["to","be!"]]
D. ["to","be!"]