Regular Expressions

Lecture 10

Language

- Definition: a set of strings
- Examples
  - $\mathcal{L}_1 = \{ \text{"cat"}, \text{"dog"}, \text{"fish"} \}$
  - $\mathcal{L}_2 = \{ \alpha\beta \mid \alpha \text{ and } \beta \text{ are hex digits} \}$
  - $\mathcal{L}_3 = \left\{ \alpha_1\alpha_2\alpha_3 \ldots \alpha_n \,\middle|\, n > 0 \wedge \left(\forall_{i=1}^{n-1} \alpha_i = \alpha_{i+1}\right) \right\}$
- Activity: For each $\mathcal{L}$ above, find
  - $|\mathcal{L}|$ (the cardinality of the set)
  - $\max_{\sigma \in \mathcal{L}} |\sigma|$

Programming Languages

- Q: Are C, Java, Ruby, Python, … languages in this formal sense?

Programming Languages

- Q: Are C, Java, Ruby, Python, … languages in this formal sense?
- A: Yes!
  - $\mathcal{L}_{Ruby}$ is the set of well-formed Ruby programs
  - What the interpreter (compiler) accepts
  - The syntax of the language
- But what does *one* such string mean?
  - The semantics of the language
  - Not part of formal definition of "language"
  - But necessary to know to claim "I know Ruby"

Regular Expression (RE)

- A *formal* mechanism for defining a language
  - Precise, unambiguous, well-defined
- In math, a clear distinction between:
  - Characters in string (the "alphabet")
  - Metacharacters used to write a RE

$$(a \cup b)^{*}a(a \cup b)(a \cup b)(a \cup b)$$

- In computer applications, there isn't
  - Is '*' a Kleene star or an asterisk?

```
(a|b)*a(a|b)(a|b)(a|b)
```

Literals

- A *literal* represents a character from the alphabet
- Some are easy:
  - `f`, `i`, `s`, `h`, …
- Whitespace is hard (invisible!)
  - `\t` is a tab (ascii 0x09)
  - `\n` is a newline (ascii 0x0A)
  - `\r` is a carriage return (ascii 0x0D)
- So the character '\' needs to be escaped!
  - \\ is a \ (ascii 0x5c)

Basic Operators

- ( ) for grouping, | for choice
- Examples
  - `cat|dog|fish`
  - `(h|H)ello`
  - `R(uby|ails)`
  - `(G|g)r(a|e)y`
- These operators are meta-characters too
  - To represent the literal: `\(  \)  \|`
  - `\(61(3|4)\)`
- Activity: For each RE above, write out the corresponding language explicitly (ie, as a set of strings)

Character Class

- Set of possible characters
  - `(0|1|2|3|4|5|6|7|8|9)` is annoying!
- Syntax: `[ ]`
  - Explicit list as `[0123456789]`
  - Range as `[0-9]`
- Negate with `^` at the beginning
  - `[^A-Z]` a character that is not a capital letter
- Activity: Write the language defined by
  - `Gr[ae]y`
  - `0[xX][0-9a-fA-F]`
  - `[Qq][^u]`

Character Class Shorthands

- Common
  - `\d` for digit, ie `[0-9]`
  - `\s` for whitespace, ie `[ \t\r\n]`
  - `\w` for word *character*, ie `[0-9a-zA-Z_]`
- And negations too
  - `\D`, `\S`, `\W` (ie `[^\d]`, `[^\s]`, `[^\w]`)
  - Warning: `[^\d\s]` ≠ `[\D\S]`
- POSIX standard (& Ruby) includes
  - `[[:alpha:]]` alphabetic character
  - `[[:lower:]]` lowercase alphabetic character
  - `[[:digit:]]` decimal digit (in any script)
  - `[[:xdigit:]]` hexadecimal digit
  - `[[:space:]]` whitespace including newlines

Wildcards

- A `.` matches any character (almost)
  - Includes space, tab, punctuation, etc
  - But does *not* include newline
- So add `.` to list of metacharacters
  - Use `\.` for a literal period
- Examples
  - **`Gr.y`**
  - **`buckeye\.\d`**
- Problem: What is RE for OSU email address for everyone named Smith?
  - Answer is *not*: **`smith\.\d@osu\.edu`**

Repetition

- Applies to preceding thing (character, character class, or `( )` group)
  - `?` means 0 or 1 time
  - `*` means 0 or more times (unbounded)
  - `+` means 1 or more times (unbounded)
  - `{`***k***`}` means exactly *k* times
  - `{`***a***`,`***b***`}` means *k* times, for $a \leq k \leq b$
- More meta-characters to escape!
  - `\? \* \+ \{ \}`

Examples

- `colou?r`
- `smith\.[1-9]\d*@osu\.edu`
- `0[xX](0|[1-9a-fA-F][0-9a-fA-F]*)`
- `.*\.jpe?g`

Your Turn

- (Language consisting of) strings that:
  - Contain only letters, numbers, and _
  - Start with a letter
  - Do not contain 2 consecutive _'s
  - Do not end with _
- Exemplars and counter-exemplars:
  - `EOF`, `4Temp`, `Test_Case3`, `_class`, `a4_Sap_X`, `S__T_2`
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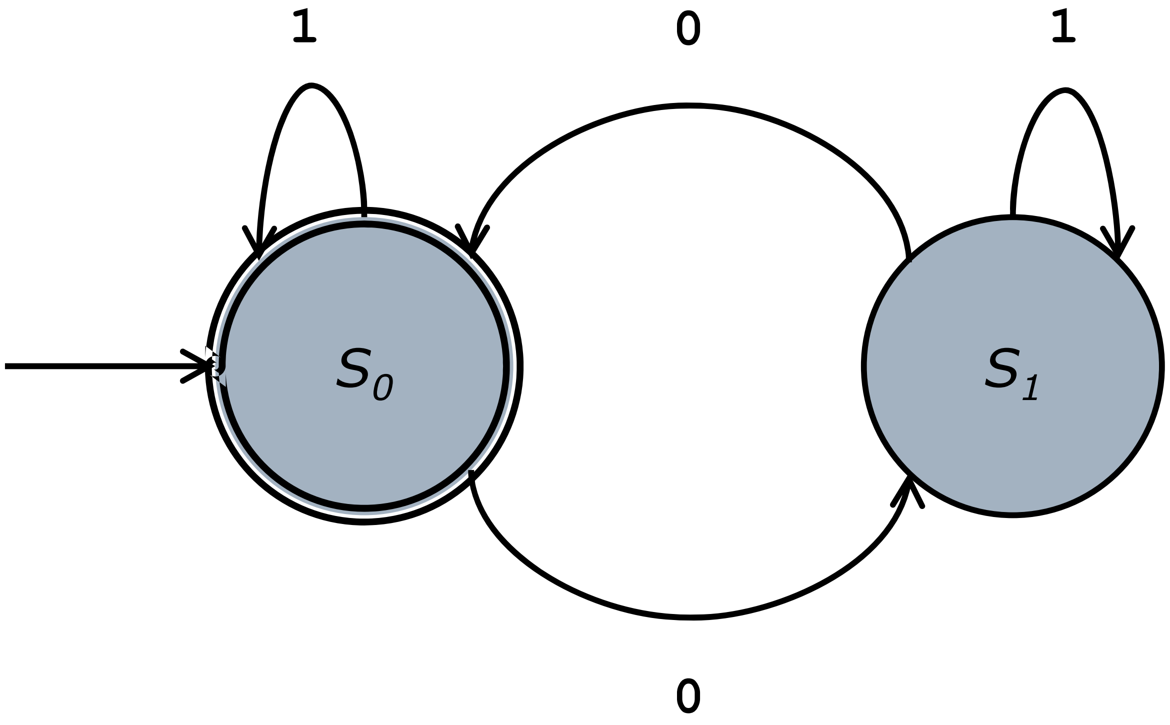
Finite State Automota (FSA)

- An FSA is an *accepting machine*
  - Finite set of states
  - Transition function (relation) between states based on next character in string
    - DFA vs NFA
  - Start state (s_0)
  - Set of accepting states
- An FSA *accepts* a string if you can start in s_0 and end up in an accepting state, consuming 1 character per step

Example

- What language is defined by this FSA?



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- Write the corresponding *FSA*

Solution

Fundamental Results

- Expressive power of RE is the same as FSA
- Expressive power of RE is limited
  - Write a RE for "strings of balanced parens"
    - ()(()()), ()(), (((()))), …
    - (((, ())(()), …
  - Can not be done! (impossibility result)
- Take CSE 3321…

REs in Practice

- REs often used to find a “match”
  - A substring s *within a longer string* such that s is in the language defined by the RE

```
(CSE|cse) ?3901
```

- Possible uses:
  - Report matching substrings and locations
  - Replace match with something else
- Practical aspects of using REs this way
  - Anchors
  - Greedy vs lazy matching

Anchors

- Used to specify where matching string should be with respect to a line of text
- Newlines are natural breaking points
  - `^` anchors to the *beginning* of a line
  - `$` anchors to the *end* of a line
  - Ruby: `\A` `\z` for beginning/end of *string*
- Examples

```
^Hello World$
\A[Tt]he
^[^\d].\.jpe?g
end\.\z
```

Greedy vs Lazy

- Repetition (**+** and *****) means multiple matches might begin at same place
  - Example: **<.*>**

```
<h1>Title</h1>
<h1>Title</h1>
```

- The match selected depends on whether the repetition matching is
  - *greedy*, ie matches as much as possible
  - *lazy*, ie matches as little as possible
- Default is typically greedy
- For lazy matching, use ***?** or **+?**

Regular Expressions in Ruby

- Instance of a class (Regexp)

```
pattern = Regexp.new('^Rub.')
```

- But literal notation is common: */pattern/*

```
/[aeiou]*/
%r{hello+} # no need to escape /
```

- Match operator =~ (negated as !~)
  - Operands: String and Regexp (in either order)
  - Returns index of *first* match (or nil if not present)

```
'hello world' =~ /o/ #=> 4
/or/ =~ 'hello' #=> nil
```

- Case equality, Regexp === String, → Boolean
- Options post-pended: */pattern/options*
  - i ignore case
  - x ignore whitespace & comments ("free spacing")

Strings and Regular Expressions

- Find all matches as an array

```
s.scan /[[:alpha:]]/
```

- Delimeter for spliting string into array

```
s.split /[aeiou]/
```

- Substitution: sub and gsub (+/- !)
  - Replace first match vs all (“globally”)

```
s = 'the quick brown fox'
s.sub /[aeiou]/, '@'
           #=> "th@ quick brown fox"
s.gsub /[aeiou]/, '@'
           #=> "th@ q@@ck br@wn f@x"
```

Your Turn: REs in Ruby

- Check if phone number in valid format

```
phone = '614-292-2900'   # bad
phone = '(614) 292-2900' # good

format = ? # replace ? with a RE
if phone ? format # replace ? with op
    # phone is well-formatted string
 ...
```

Summary

- Language: A set of strings
- RE: Defines a language
  - Recipe for making elements of language
- Literals
  - Distinguish characters and metacharacters
- Character classes
  - Represent 1 character in RE
- Repetition
- FSA
  - Expressive power same as RE