Regular Language Applications

Friday, October 21, 2011
Reading: Stoughton 3.14, Kozen Chs. 7-8

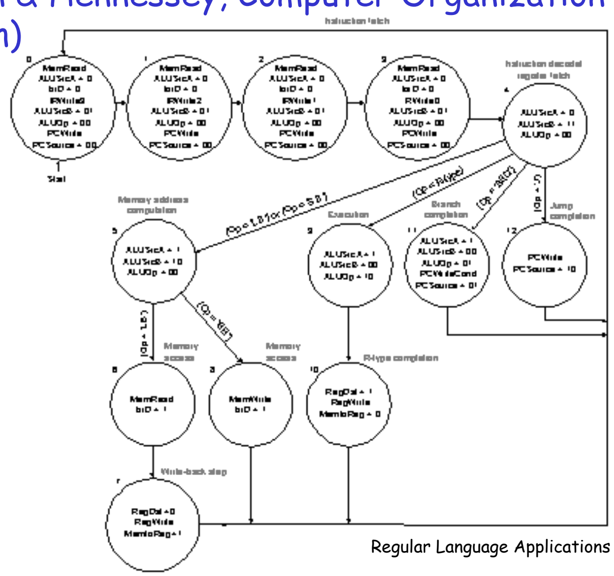
CS235 Languages and Automata

Department of Computer Science
Wellesley College

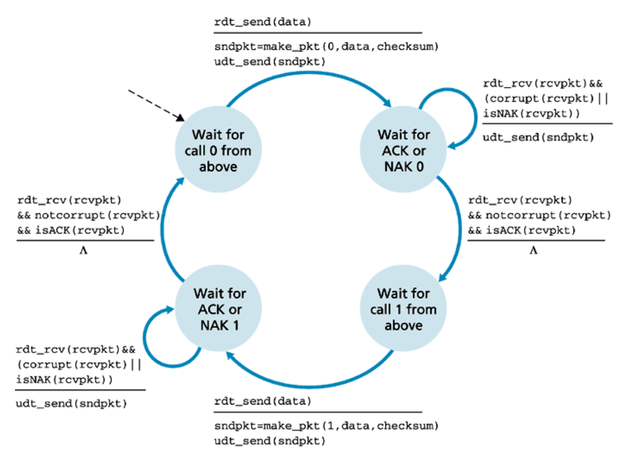
Some Applications of Regular Languages

- Automata = finite state machines (or extensions thereof) used in many disciplines
- Efficient string searching
- Pattern matching with regular expressions (example: Unix grep utility)
- Lexical analysis (a.k.a. scanning, tokenizing) in a compiler (the topic of a lecture later in the course)

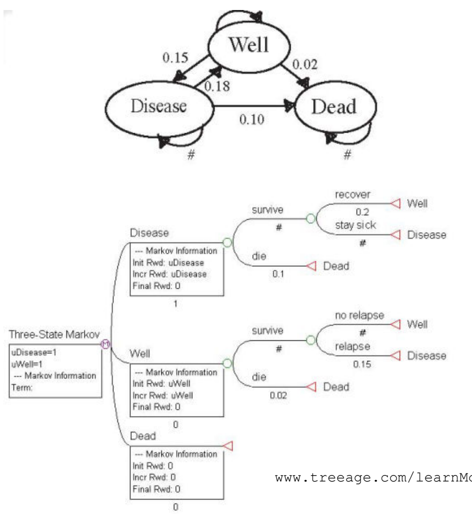
CS240: FSM for Instruction Execution (Patterson & Hennessey, Computer Organization and Design)



CS242: Reliable Data Transmission (sender) (Kurose & Ross, Computer Networking)



Markov Models



www.treeage.com/learnMore/MarkovModels.html

DFAs in User Interfaces

Example:

Black Diamond *Storm* headlamp provides access to all features via a single button. Can construct a DFA to explain the interface.

www.treeage.com/learnMore/MarkovModels.html

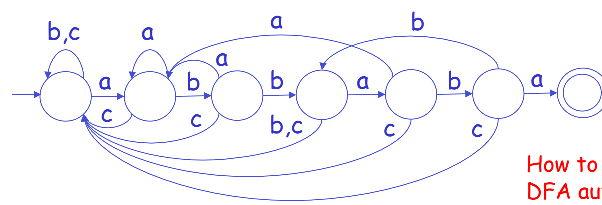
Naïve String Searching

How to search for abbaba in abbabcabbabbaba?

a	b	b	a	b	c	a	b	b	a	b	b	a	b	a
a	b	b	a	b	a									
	a	b	b	a	b	a								
		a	b	b	a	b	a							
			a	b	b	a	b	a						
				a	b	b	a	b	a					
					a	b	b	a	b	a				
						a	b	b	a	b	a			
							a	b	b	a	b	a		
								a	b	b	a	b	a	
									a	b	b	a	b	a

More Efficient String Searching

Knuth-Morris-Pratt algorithm: construct a DFA for searched-for string, and use it to do searching.



How to construct this DFA automatically?

a	b	b	a	b	c	a	b	b	a	b	b	a	b	a
a	b	b	a	b	a									
						a	b	b	a	b	a			
									a	b	b	a	b	a

Pattern Matching with Regular Expressions

Can turn any regular expression (possibly extended with complement, intersection, and difference) into a DFA and use it for string searching.

This idea is used in many systems/languages:

- **grep**: Unix utility that searches for lines in files matching a pattern. ("grep" comes from g/re/p command in the ed editor.)
- **sed**: Unix stream editor
- **awk**: text-manipulation language
- **Perl**: general-purpose programming language with built-in pattern matching
- **JavaScript**: can use regular expressions for form validation.
- **Java, Python, etc.**: have support for regular expressions.
- **Emacs**: supports regular expression search

Some grep Patterns

Pattern	Matches
c	the character 'c'
.	any character except newline
[a-zA-Z0-9]	any alphanumeric character
[^d-g]	any character except lowercase d,e,f,g
\w	synonym for [a-zA-Z0-9]
\W	synonym for [^a-zA-Z0-9]
[[:space:]]	all whitespace characters
^	beginning of line
$	end of line
\<	beginning of word
\>	end of word
$r_1 r_2$	r_1 followed by r_2, where r_1, r_2 are reg. exps.
$r_1 \mid r_2$	r_1 or r_2
*r**	zero or more *r*s, where *r* a reg. exp.
r+	one or more *r*s
r?	zero or one *r*s
r{*n*}	exactly *n* *r*s
r{*n*,}	*n* or more *r*s
r{*n*,*m*}	between *n* and *m* *r*s
(*r*)	*r* (parens for grouping)
n	the substring previously matched by the *n*th parenthesized subexpression of the regular expression (**not regular in general!**)

Some grep Examples

As a rule, grep patterns should be double-quoted to prevent Linux from interpreting certain characters specially. (But \ is still a problem, as we'll soon see.)

cd ~cs235/public_html
grep "a.*b.*c.*d" words.txt

grep "^a.*b.*c.*d" words.txt

grep "a.*b.*c.*d$" words.txt

grep "^a.*b.*c.*d$" words.txt

grep "^a.*b.*c.*d$" wordlists/*words* *(in Scowl final database)*

cd ~cs230/archive/cs230_fall04/download/collections
grep "delete[[:space:]]*(Object" *.java

grep "//.*sorted" *.java

A Powerful Combination: find With grep

Unix's `find` command enumerates all files in a directory. E.g

cd ~cs230/archive/cs230_fall04/download/
find .

In combination with `grep`, it can search all these files!

find . | xargs grep "delete[[:space:]]*(Object"

find -exec grep –H "delete[[:space:]]*(Object" {} \;

Escapes in Grep Patterns

grep patterns use special metacharacters that (at least in some contexts) do not stand for themselves:

? + | ( ) { } . * ^ $ \ [ ]

In order to reference the blue characters as themselves, it is necessary to escape them with a backslash. E.g.,

$ is a pattern that matches the end of line
\$ is a pattern that matches the dollar sign character
\\ is a pattern that matches the backslash character
\\\\ is a pattern that matches two backslash characters in a row

But the backslash character is also an escape character in Linux! To safely pass backslashes from Linux to grep, you should* type *two* backslashes for every backslash you wish to send to grep. E.g.

grep "\\$" searches for the dollar sign character
grep "\\\\" searches for a single backslash
grep "\\\\\\\\" searches for two backslash characters in a row

*In some, but not all cases, a single backslash will suffice.

What About the Red Metacharacters?

The red metacharacters are handled in a rather confusing way:

? + | ( ) {

In the **basic regular expressions** used by **grep**, these characters stand for themselves and must be escaped to have the metacharacter meaning. E.g.

grep "(ab)+" searches for the substring "(ab)+"
grep "(ab){2}" searches for the substring "(ab){2}"
grep "\\(ab\\)\\+" searches for any nonempty sequence of abs.
grep "\\(ab\\)\\{2\\}" searches two abs in a row.
grep "\\(.\\)\\1" searches for two consecutive occurrences of the same character

In the **extended regular expressions** used by **grep -E** and **egrep**, these characters are metacharacters and must be escaped to stand for themselves.

egrep "(ab)+" searches for any nonempty sequence of abs.
egrep "(ab){2}" searches two abs in a row.
egrep "\\(ab\\)\\+" searches for the substring "(ab)+"
grep "\\(ab\\)\\{2\\}" searches for the substring "(ab){2}"
egrep "(.)\\1" searches for two consecutive occurrences of the same character

Moral of the story: use egrep instead of grep!

egrep Examples

cd ~cs235/public_html /wordlists

egrep "(ab){2}" *words*

egrep "(a.*b){2}" *words*

egrep "(a.*b.*){2}" *words*

egrep "(a.*b)\\1" *words*

egrep "(a.*b).*\\1" *words*

egrep "(a.+b).*\\1" *words*

egrep "(a.+a).*\\1" *words*

egrep "(....)\\1" *words*

egrep "(....).*\\1" *words*

egrep "(..).*(..).*\\2.*\\1" *words*

egrep "^(.)(.)(.).*\\3\\2\\1$" *words*

More Practical Examples

1. Write an egrep regular expression that matches only well-formed short FirstClass usernames (e.g., fturbak, gdome, etc.)

   Such usernames consist of at least 2 and at most 8 characters and are sequences of lowercase letters followed by at most 2 digits.

2. Write an egrep regular expression that matches only well-formed email address of the form *username@server.domain*, where
   - username is any sequence of letters, numbers, underscores, and dots that begins with a letter;
   - Server is any sequence of letters and numbers that begins with a letter;
   - Domain is one of `com`, `edu`, or `gov`.

Regexp Support in Programming Languages

Many popular programming languages (Java, JavaScript, Python, Perl, etc.) have built-in or library support for regular expressions.

E.g. *Dive Into Python* chapter on regular expressions:

http://diveintopython.nfshost.com/regular_expressions

Javascript example (Tanner'10 photo upload site):

```
function validRegistration() {
  var emailPattern = /(^[a-zA-Z]{2,8}$)|(^[a-zA-Z]{2,7}[0-9]$)|(^[a-zA-Z]{2,6}[0-9]{2}$)/;
  var emailAddress = document.registrationForm.email.value;
  ...
  if (emailAddress.search(emailPattern) == -1) {
    document.getElementById("registration_status").innerHTML =
      "<span style='color:red;'>You must use a legal Wellesley email address.</span>";
    return false;
  } ...
}
```

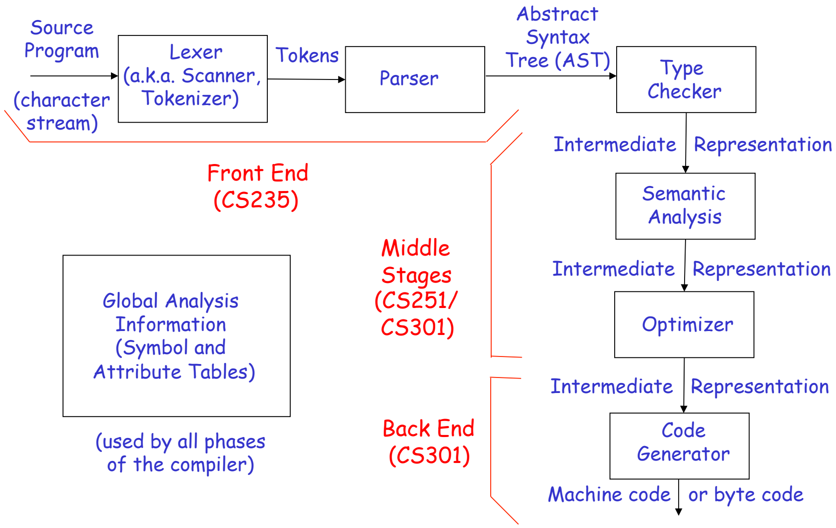
Jamie Zawinski's warning:

Some people, when confronted with a problem, think "I know, I'll use regular expressions." Now they have two problems.
(quoted at end of Sec. 7.7, *Dive Into Python*)

Applications of Search/Pattern Matching

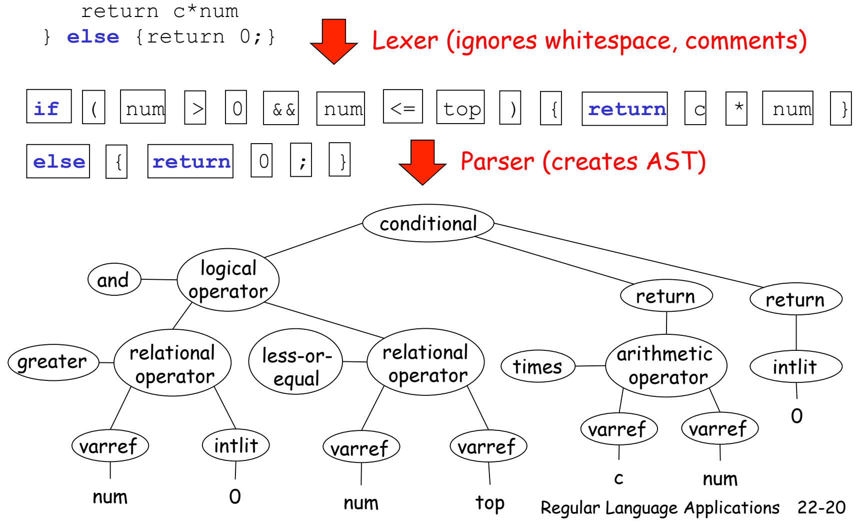
- Document/file search
- Antivirus software
  - many viruses have a characteristic signature = sequence of bytes
  - virus-writers can create polymorphic viruses that thwart signature-based attacks.
- DNA/protein analysis
  - DNA is a 4-character alphabet; proteins a 20-character alphabet
  - in practice, don't look for exact matches but want "close" ones; this uses **dynamic programming** technology (see CS231).

Compiler Structure



Front End Example

```
if (num > 0 && num <= top) { // Is num in range?
   return c*num
} else {return 0;}
```



Lexical Analysis

Lexical analysis = breaking programs into tokens, the first stage of a compiler.

The structure of tokens can be specified by regular expressions.

Example: the ML-Lex tool can automatically derive a lexical analyzer from a .lex file --- a description of tokens specified by regular expressions.

We will spend an entire lecture on lexing later this semester.

Slip.lex Definitions and Rules

```
alpha=[a-zA-Z];
alphaNumUnd=[a-zA-Z0-9_];
digit=[0-9];
whitespace=[\ \t\n];
any= [^];
%%
"print" => (PRINT);
{alpha}{alphaNumUnd}*  => (ID(yytext));
{digit}+  => (INT(pluck(Int.fromString(yytext))));
"+" => (OP(Add));
"-" => (OP(Sub));
"*" => (OP(Mul));
"/" => (OP(Div));
"(" => (LPAREN);
")" => (RPAREN);
"," => (COMMA);
";" => (SEMI);
":=" => (GETS);
{whitespace} => (lex());
{any} => ((* Signal a failure exception when encounter unexpected character.
              A more flexible implementation might raise a more refined
              exception that could be handled. *)
           raise Fail("Slip scanner: unexpected character \"" ^ yytext ^ "\""))
```

Definitions

String matched by regular expression

Remove SOME from option type.

Discard current token and continue lexing

Rules