COS 333:
Advanced Programming Techniques

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- **Today**
  - course overview
  - administrative stuff
  - regular expressions and grep
- **Check out the course web page (CS, not Blackboard!)**
  - notes, readings and assignments will be posted there
  - Assignment 1 is posted
  - project information is posted
- **Do the survey if you haven't already**

Themes

- **languages**
  - C, Java, AWK, Perl, C++, Visual Basic, C#, ...
  - programmable tools, application-specific languages
- **tools**
  - where did they come from and why
    how they have evolved, mutated, decayed
  - how to use them
  - how they work
  - how to build your own
- **programming**
  - design, interfaces, patterns
  - reuse, theft, prototyping, components
  - programs that write programs
  - portability, standards, style
  - debugging, testing
  - performance assessment and improvement
  - tricks of the trade
  - tradeoffs, compromises, engineering
- **history and culture of programming**

(Very) Tentative Outline

Feb 1	**regular expressions; grep**
Feb 8	**scripting languages: Awk & Perl**
Feb 15	**more scripting: Perl, PHP(?), *CGI***
Feb 22	**Java; object-oriented programming**
Mar 1	**networking; MySQL; project**
Mar 8	**user interfaces, Swing**
Mar 15	**(spring break)**
Mar 22	***C++***
Mar 29	***C++*, Standard Template Library**
Apr 5	**Visual Basic; *COM*, components**
Apr 12	**XML, web services; .net, *C#***
Apr 19	**Tcl/Tk?, language tools?**
Apr 26	**?**
May 4-5	**project presentations**

Some Mechanics

- **prerequisites**
  - *C*, Unix (*COS* 217)
- **5 programming assignments in first half**
  - posted on course web page
  - deadlines matter
- **group project in second half**
  - groups of 3-4; start identifying potential teammates
  - details in a few weeks
  - deadlines matter
- **monitor the web page**
  - readings for most weeks
  - notes generally posted ahead of time
- **class attendance and participation**

  <=> no midterm or final
  - sporadic unannounced short quizzes are possible

Regular expressions and grep

- **regular expressions**
  - notation
  - mechanization
  - pervasive in Unix tools
  - not in most general-purpose languages
    though common in scripting languages and (some) editors
  - basic implementation is remarkably simple
  - efficient implementation requires theory and practice

- **grep is the prototypical tool**
  - people used to write programs for searching
    (or did it by hand)
  - tools became important
  - tools are not as much in fashion today

Grep regular expressions

c **any character matches itself, except for**
***metacharacters* . [ ] ^ $ * + **

$r_1 r_2$ **matches r_1 followed by r_2**

. **matches any single character**

[...] **matches one of the characters in set ...**
a set like a-z or 0-9 includes any character in the range

[^...] **matches one of the characters not in set**
a set like a-z or 0-9 includes any char in the range

^ **matches beginning of line when ^ begins pattern**
no special meaning elsewhere in pattern

$ **matches end of line when $ ends pattern**
no special meaning elsewhere in pattern

***** **any regular expression followed by * matches zero or more instances**

\c **matches c unless c is ( ) or digit**

\\(...\\) **tagged regular expression that matches ...**
the matched strings are available as \1, \2, etc.

Examples of matching

thing	*thing* anywhere in string
^thing	*thing* at beginning of string
thing$	*thing* at end of string
^thing$	string that contains only *thing*
^$	empty string
.	non-empty, i.e., at least 1 char
^	matches any string, even empty
thing.$	*thing* plus any char at end of string
thing\.$	*thing.* at end of string
\\thing\\	*thing*\\ anywhere in string
[tT]hing	*thing* or *Thing* anywhere in string
thing[0-9]	*thing* followed by one digit
thing[^0-9]	*thing* followed by a non-digit
thing[0-9][^0-9]	*thing* followed by digit, then non-digit
thing1.*thing2	*thing1* then any text then *thing2*
^thing1.*thing2$	*thing1* at beginning and *thing2* at end

egrep: fancier regular expressions

r+	one or more occurrences of r
r?	zero or one occurrences of r
$r_1 \| r_2$	r_1 or r_2
(r)	r (grouping)

```
([0-9]+\.?[0-9]*|\.[0-9]+)([Ee][-+]?[0-9]+)?
```

Grammar for egrep regular exprs

r: ***c*** **.** **^** **$** **[*ccc*]** **[^*ccc*]**

r* **r+** **r?**

$\mathbf{r_1\ r_2}$

$\mathbf{r_1 | r_2}$

(r)

Precedence:

*** + ? are higher than concatenation**
which is higher than |

```
([0-9]+\.?[0-9]*|\.[0-9]+)([Ee][-+]?[0-9]+)?
```

The grep family

- **grep**
  - basic matching
- **egrep**
  - fancier regular expressions
  - trades compile time and space for run time
- **fgrep**
  - parallel search for many fixed strings
- **agrep**
  - "approximate" grep: search with errors permitted

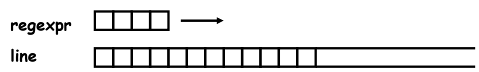
- **relatives that use similar regular expressions**
  - ed original unix editor
  - sed stream editor
  - vi, emacs, sam, ... editors
  - lex lexical analyzer generator
  - awk, perl, tcl, python, … scripting languages
  - Java, C# ... libraries in mainstream languages

- **simpler variants**
  - filename "wild cards" in Unix and other shells
  - "LIKE" operator in Visual Basic, SQL, etc.

Basic grep algorithm

```
while (get a line)
    if match(regexpr, line)
        print line
```

- (perhaps) compile regexpr into an internal representation suitable for efficient matching
- match() slides the regexpr along the input line, looking for a match at each point



Grep (TPOP, p 226)

```
/* grep: search for regexp in file */
int grep(char *regexp, FILE *f, char *name)
{
	int n, nmatch;
	char buf[BUFSIZ];

	nmatch = 0;
	while (fgets(buf, sizeof buf, f) != NULL) {
		n = strlen(buf);
		if (n > 0 && buf[n-1] == '\n')
			buf[n-1] = '\0';
		if (match(regexp, buf)) {
			nmatch++;
			if (name != NULL)
				printf("%s:", name);
			printf("%s\n", buf);
		}
	}
	return nmatch;
}
```

Match anywhere on a line

- **look for match at each position of text in turn**

```
/* match: search for regexp anywhere in text */
int match(char *regexp, char *text)
{
	if (regexp[0] == '^')
		return matchhere(regexp+1, text);
	do {	/* must look even if string is empty */
		if (matchhere(regexp, text))
			return 1;
	} while (*text++ != '\0');
	return 0;
}
```

Match starting at current position

```
/* matchhere: search for regexp at beginning of text */
int matchhere(char *regexp, char *text)
{
	if (regexp[0] == '\0')
		return 1;
	if (regexp[1] == '*')
		return matchstar(regexp[0], regexp+2, text);
	if (regexp[0] == '$' && regexp[1] == '\0')
		return *text == '\0';
	if (*text!='\0' && (regexp[0]=='.' || regexp[0]==*text))
		return matchhere(regexp+1, text+1);
	return 0;
}
```

- **follow the easy case first: no metacharacters**
- **note that this is recursive**
  - maximum depth: one level for each regexpr character that matches

Matching * (repetitions)

- **matchstar() called to match c*...**
- **matches if rest of regexpr matches rest of input**
  - null matches require test at the bottom

```
/* matchstar: search for c*regexp at beginning of text */
int matchstar(int c, char *regexp, char *text)
{
	do {	/* a * matches zero or more instances */
		if (matchhere(regexp, text))
			return 1;
	} while (*text != '\0' && (*text++ == c || c == '.'));
	return 0;
}
```

- **finds the leftmost shortest match**
  - just right for pattern matching in grep
  - NOT usually what we want in a text editor
    - null matches are surprising and rarely desired

Profiling: where does the time go

- **count number of times each line is executed**
  - measure how long each function takes
  - plus lots of other information

```
$ lcc -p grep.c
$ a.out x ../bib >foo
$ prof
 %Time Seconds Cumsecs  #Calls   msec/call  Name
  52.1    0.37    0.37 4360969      0.0001  matchhere
  16.9    0.12    0.49 4528173      0.0000  _mcount
  11.3    0.08    0.57   31102      0.0026  match
   8.5    0.06    0.63     546      0.11    _read
   7.0    0.05    0.68   31642      0.0016  _memccpy
   1.4    0.01    0.69     546      0.02    __filbuf
   1.4    0.01    0.70   31103      0.0003  fgets
   1.4    0.01    0.71   32429      0.0003  strlen
   0.0    0.00    0.71       1      0.      main
   0.0    0.00    0.71       1      0.      grep
   0.0    0.00    0.71       1      0.      setprognam
   0.0    0.00    0.71    1326      0.000   printf
   ...
$ wc ../bib
  31102  851820 4460056 ../bib
$ a.out x ../bib | wc
 1326   39057  207477
```

- **_mcount is profiling overhead**
- **note consistent counts**

Statement frequency counts

$ gcc -fprofile-arcs -ftest-coverage grep.c; a.out x ../bib
$ gcov grep.c; cat grep.c.gcov

```
        /* matchhere: search for regexp at beginning of
        int matchhere(char *regexp, char *text)
4360969 {
4360969     if (regexp[0] == '\0')
   1326         return 1;
4359643     if (regexp[1] == '*')
 ######         return matchstar(regexp[0], regexp+2, te
4359643     if (regexp[0] == '$' && regexp[1] == '\0')
 ######         return *text == '\0';
4359643     if (*text!='\0' && (regexp[0]=='.' || regexp
   1326         return matchhere(regexp+1, text+1);
4358317     return 0;
        }
        /* match: search for regexp anywhere in text */
        int match(char *regexp, char *text)
  31102 {
  31102     if (regexp[0] == '^')
 ######         return matchhere(regexp+1, text);
4359643     do {    /* must look even if string is empty
4359643         if (matchhere(regexp, text))
   1326                 return 1;
4358317     } while (*text++ != '\0');
  29776     return 0;
        }
```

- **note conservation laws**

How to make grep faster

- **use optimization (cc -O)**
- **change compilers (lcc, gcc, vc++)**
- **code tuning**
  - e.g., match calls matchhere many times
  - even though most of them must necessarily fail
  - because the target string doesn't contain the first character of the pattern
- **algorithm changes**

Code tuning variant

- **checks whether target contains first character of pattern before calling matchhere**
  - unless it is x*

```
/* match: search for regexp anywhere in text */
int match(char *regexp, char *text)
{
    char *p;
    if (regexp[0] == '^')
        return matchhere(regexp+1, text);
    if (regexp[0] != '\0' && regexp[0] != '.'
                                  && regexp[1] != '*')
        if ((p=strchr(text, regexp[0])) == NULL)
            return 0;
    do {    /* must look even if string is empty */
        if (matchhere(regexp, p))
            return 1;
    } while (*p++ != '\0');
    return 0;
}
```

- **is this faster?**

Statement frequencies after change

```
        /* matchhere: search for regexp at beginning of
        int matchhere(char *regexp, char *text)
  2652  {
  2652      if (regexp[0] == '\0')
  1326          return 1;
  1326      if (regexp[1] == '*')
######          return matchstar(regexp[0], regexp+2, te
  1326      if (regexp[0] == '$' && regexp[1] == '\0')
######          return *text == '\0';
  1326      if (*text!='\0' && (regexp[0]=='.' || regexp
  1326          return matchhere(regexp+1, text+1);
######      return 0;
        }

        /* match: search for regexp anywhere in text */
        int match(char *regexp, char *text)
 31102  {
 31102      char *p = text;

 31102      if (regexp[0] == '^')
######          return matchhere(regexp+1, text);
 31102      if (regexp[0] != '\0' && regexp[0] != '.' &&
 31102          if ((p=strchr(text, regexp[0])) == NULL)
 29776              return 0;
  1326      do {    /* must look even if string is empty
  1326          if (matchhere(regexp, p))
  1326              return 1;
######      } while (*p++ != '\0');
######      return 0;
        }
```

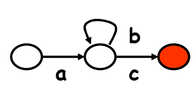
Simple grep algorithm

- **best for short simple patterns**
  - e.g., grep foo *.[ch]
  - most use is like this
  - reflects use in text editor for a small machine
- **limitations**
  - tries the pattern at each possible starting point
    e.g., look for aaaaab in aaaa....aaaab
    potentially O(mn) for pattern of length m
  - complicated patterns (.* .* .*) require backup
    potentially exponential
  - can't do some things, like alternation (OR)

- **this leads to extensions and new algorithms**
  - egrep complicated patterns, alternation
  - fgrep lots of simple patterns in parallel
  - boyer-moore long simple patterns
  - agrep approximate matches

Finite state machines/finite automata

- **finite state machine**
  - a set of states
  - an alphabet (e.g., ascii)
  - transition rules: current state & input char -> new state
  - a start state
  - a set of final "accepting" states
- **regular expressions are equivalent to finite state machines**
  - can go from one to the other mechanically
- **ab*c**



- **a^nb^n, if n < 4**

  - can't count: can't handle arbitrary n in a fixed number of states
  - can't do palindromes: no memory

Non-deterministic finite automata (NDFA)

RE: .*ab.*abab

FSM: 0 1 2 3 4 5 6

input: x x a b a b a a b a b

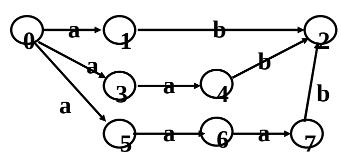
state after: 0 0 1 2 3 4 5 ?

diff seq: 0 0 1 2 2 2 2 3 4 5 6

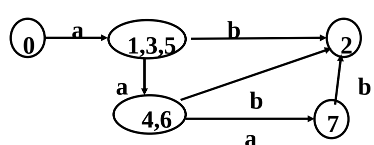
- **if the machine could guess right every time, it would match properly**
  - avoids "backing up", decides about each character the first time it's seen
- **a NDFA matches an input if there is any possible path from start state to a final state.**
- **it rejects/does not match if there is no path from the start state to a final state.**
- **how do we make a machine that's always lucky?**
  - make a deterministic finite automaton that simulates the NDFA

Egrep: regexpr -> NDFA -> DFA

- **Example: (a|aa|aaa)b**
- **NDFA:**



- **Convert to DFA by inventing states that represent *sets of states* of the NDFA:**



- **Recognition time is O(n)**
- **Construction time could be O(2^m)**
  - because there are 2^m subsets of the states
  - newer versions construct states as needed: lazy evaluation

Important ideas from regexprs & grep

- **tools: let the machine do the work**
  - good packaging matters
- **notation: makes it easy to say what to do**
  - may organize or define implementation
- **hacking can make a program faster, sometimes, usually at the price of more complexity**

- **a better algorithm can make a program go a lot faster**

- **don't worry about performance if it doesn't matter (and it often doesn't)**

- **when it does,**
  - use the right algorithm
  - use the compiler's optimization
  - code tune, as a last resort