COS 333: Advanced Programming Techniques

- **How to find me**
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- **TA's:**
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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 posted (only) there
    - monitor the web page every day
  - Assignment 1 is posted
  - initial project information is posted
- **Do the survey if you haven't already**

Themes

- **languages and tools**
  - mainstream: C, C++, Java, C#, (Objective-C?), ...
  - scripting: AWK, (Perl?), Python, (PHP?), Javascript, ...
  - programmable tools, application-specific languages
  - frameworks, toolkits, development environments, interface builders
  - debuggers (gdb), source code control (SVN), ...
- **programming**
  - design, prototyping, reuse, components, interfaces, patterns
  - debugging, testing, performance, mechanization
  - portability, standards, style
  - tricks of the trade
- **reality**
  - tradeoffs, compromises, engineering
- **history and culture of programming**
- **etc.**

Very Tentative Outline

Feb 2	**regular expressions; grep, shell**
Feb 9	**AWK; testing; project stuff**
Feb 16	**Perl, Python, PHP**
Feb 23	**Javascript, Ajax, CGI**
Mar 2	**frameworks, databases**
Mar 9	**networks, user interfaces**
Mar 15	**(spring break)**
Mar 23	**C++, STL, objects**
Mar 30	**Java, collections**
Apr 6	**components: COM, .NET, C#**
Apr 13	**XML, REST/Atom, JSON**
Apr 20	**?**
Apr 27	**?**
May 5-7	**demo days: project presentations**

Some Mechanics

- **prerequisites**
  - C, Unix (COS 217); Java (COS 126, 226)
- **5 programming assignments in first half**
  - posted on course web page Tuesday, due Friday evening 10 days later
  - deadlines matter
- **project in second half (starts earlier!)**
  - groups of 3-5; start identifying potential teammates
  - start thinking about topic
  - deadlines matter
- **monitor the web page**
  - readings for most weeks
  - notes generally posted ahead of time
  - newsgroup for discussion, finding partners, ...
- **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) text editors
  - basic implementation is remarkably simple
  - efficient implementation requires good theory and good 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_1r_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 0 or more**
`\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*
`^`	matches any string, even empty
`^$`	empty string
`.`	non-empty, i.e., at least 1 char
`thing.$`	*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

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egrep: fancier regular expressions

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

grammar:

r: *c* . ^ $ [*ccc*] [^*ccc*]
r* r+ r?
$r_1 r_2$
$r_1 | r_2$
(r)

precedence:

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

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

The grep family

- **grep**
- **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**

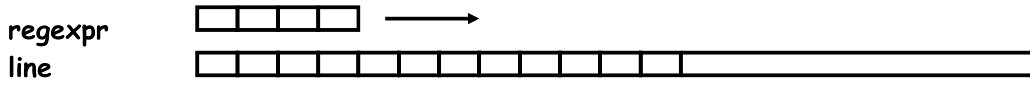
ed	original Unix editor
sed	stream editor
vi, emacs, sam, ...	editors
lex	lexical analyzer generator
awk, perl, python, …	all scripting languages
Java, C# ...	libraries in mainstream languages

- **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

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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

- **measure how long each function takes:**

```
gcc -pg x.c
a.out
gprof
```

  - display is very flaky

- **count number of times each line is executed:**

```
gcc -fprofile-arcs -ftest-coverage x.c
a.out
gcov x.c
cat x.c.gcov
```

Statement frequency counts

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

```
        /* matchhere: search for regexp at beginning of text */
        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, text);
4359643     if (regexp[0] == '$' && regexp[1] == '\0')
 ######         return *text == '\0';
4359643     if (*text!='\0' && (regexp[0]=='.' || regexp[0]==*text))
   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;
        }
```

How to make grep faster

- **use optimization (cc -O)**
- **change compilers**
- **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

```
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, text);
  1326      if (regexp[0] == '$' && regexp[1] == '\0')
######          return *text == '\0';
  1326      if (*text!='\0' && (regexp[0]=='.' || regexp[0]==*text))
  1326          return matchhere(regexp+1, text+1);
######      return 0;
        }
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] != '.' && regexp[1]!='*')
 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

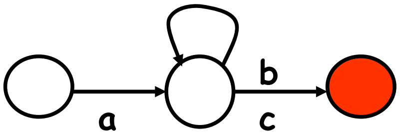
    potentially exponential
  - can't do some things, like alternation (OR)

- **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

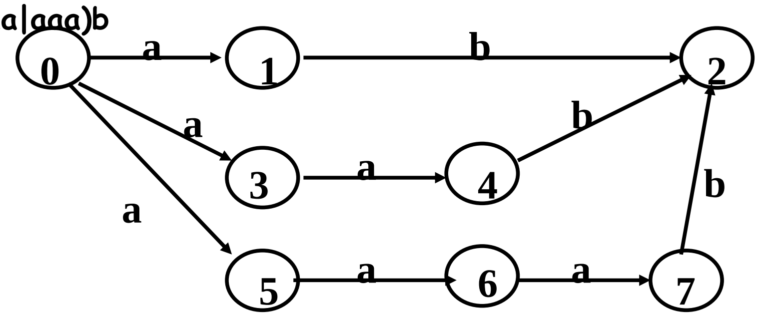
state after: 0 0 1 2 3 4 5 ?

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

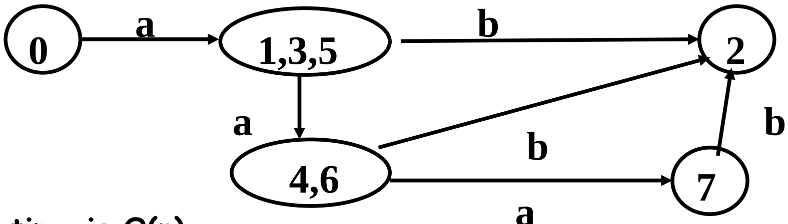
- **if the machine could guess right every time, it would match properly**
  - avoids "backing up", decides about each character the first time it's seen
- **a NDFA matches an input if there is any possible path from start state to a final state.**
- **it rejects/does not match if there is no path from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

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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