MA/CSSE 473 Day 26

String Search

Horspool

Boyer-Moore

MA/CSSE 473 Day 26

Assignment	Old due date	New due date
10	Tuesday, Oct 19	Wednesday, Oct 20
Convex Hull	Thursday, Oct 21	Friday, Oct 22
11	Saturday, Oct 23	Tuesday, Oct 26
12	Tuesday, Oct 26	Thursday, Oct 28
13	Thursday, Oct 28	Wednesday, Nov 3

Tomorrow!

- **Take-home exam** available by Oct 29 (Friday) at 9:55 AM, due Nov 1 (Monday) at 8 AM.
- **Student Questions**
- Horspool string search algorithm
- Boyer-Moore

Brute Force String Search Example

What makes brute force so slow?
When we find a mismatch, we can shift the pattern by only one character position in the text.

```
Text:    abracadabtabradabracadabcadaxbrabbracadabraxxxxxxabracadabracadabra
Pattern: abracadabra
          abracadabra
           abracadabra
            abracadabra
             abracadabra
              abracadabra
```

Recap: Horspool's Algorithm ideas

- It is a simplified version of the Boyer-Moore algorithm
- A good bridge to understanding Boyer-Moore
- Like Boyer-Moore, Horspool does the comparisons in a counter-intuitive order (moves right-to-left through the pattern)
- If there is a character mismatch, how far can we shift the pattern, with no possibility of missing the first match within the text?
- What if the last character in the pattern is compared with a character in the text that does not occur in the pattern at all?

```
Text:     ... ABCDEFG ...
Pattern:      BOUTELL
```

Q1-2

How Far to Shift?

- Look at first (rightmost) character in the part of the text that is compared to the pattern:
- The character is not in the pattern

```
.....C..........   { C not in pattern)
BAOBAB
```

- The character is in the pattern (but not the rightmost)

```
.....O..........(O occurs once in pattern)
BAOBAB
.....A..........(A occurs twice in pattern)
BAOBAB
```

- The rightmost characters do match

```
.....B.....................
BAOBAB
```

Harpool Shift Table

- We precompute shift amounts by scanning the pattern before the search begins, and storing the results in a table.
- Use the formula

$$t(c) = \begin{cases} \text{distance } \textit{from } c\text{'s rightmost occurrence among the first } m\text{-1 characters in the pattern } \textit{to} \text{ the pattern's right end} \\ \text{pattern's entire length } m\text{, otherwise} \end{cases}$$

Q3

Shift Table Example

- Shift table is indexed by text and pattern alphabet
  E.g., for BAOBAB:

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1	2	6	6	6	6	6	6	6	6	6	6	6	6	3	6	6	6	6	6	6	6	6	6	6	6

Q4

Example of Horspool's Algorithm

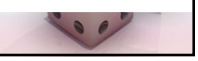
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	_
1	2	6	6	6	6	6	6	6	6	6	6	6	6	3	6	6	6	6	6	6	6	6	6	6	6	6

```
BARD LOVED BANANAS
BAOBAB
      BAOBAB
        BAOBAB
              BAOBAB  (unsuccessful search)
```

Horspool Code

```
def populateShiftTable(table, pattern, mMinusOne):
    for i in range(mMinusOne):
        table[ord(pattern[i])] = mMinusOne - i
```

```
def search(pattern, text):
    """ return index of first occurrence of pattern in text;
        return -1 if no match """
    n, m = len(text), len(pattern)
    shiftTable = [m]*128 # if char not in pattern, shift by full amount
    populateShiftTable(shiftTable, pattern, m-1)

    i = m - 1 # i is position in text that corresponds to end of pattern

    while i < n:  # while not past end of text
        k = 0 # k is number of pattern characters compared so far

        while k < m and pattern[m-1-k]==text[i-k]:
            k += 1;  # loop stops if mismatch or complete match

        if k==m:  # found a match
            return i - m + 1

        i = i + shiftTable[ord(text[i])] # ready to begin next comparison
    return -1
```



Horspool Example

```
pattern = abracadabra
text =
abracadabtabradabracadabcadaxbrabbracadabraxxxxxxabracadabracadabra
shiftTable:  a3 b2 r1 a3 c6 a3 d4 a3 b2 r1 a3 x11
abracadabtabradabracadabcadaxbrabbracadabraxxxxxxabracadabracadabra
abracadabra
abracadabtabradabracadabcadaxbrabbracadabraxxxxxxabracadabracadabra
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               abracadabra
abracadabtabradabracadabcadaxbrabbracadabraxxxxxxabracadabracadabra
                  abracadabra
```

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Horspool Example Continued

```
pattern = abracadabra
text =
abracadabtabradabracadabcadaxbrabbracadabraxxxxxxabracadabracadabra
shiftTable:  a3 b2 r1 a3 c6 a3 d4 a3 b2 r1 a3 x11
```

```
abracadabtabradabracadabcadaxbrabbracadabraxxxxxxabracadabracadabra
                  abracadabra
abracadabtabradabracadabcadaxbrabbracadabraxxxxxxabracadabracadabra
                             abracadabra
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                                   abracadabra
abracadabtabradabracadabcadaxbrabbracadabraxxxxxxabracadabracadabra
                                                abracadabra
abracadabtabradabracadabcadaxbrabbracadabraxxxxxxabracadabracadabra
                                                   abracadabra
49
```

Using brute force, we would have to compare the pattern to 50 different positions in the text before we find it; with Horspool, only 13 positions are tried.

Boyer Moore Intro

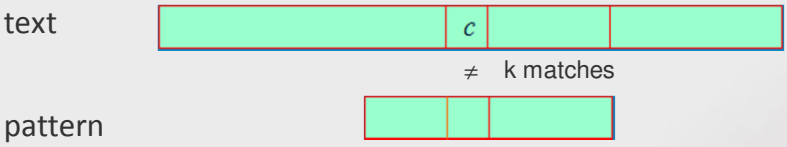
- When determining how far to shift after a mismatch, Horspool only uses the text character corresponding to the rightmost pattern character
- Often there is a partial match (from the right) before a mismatch occurs
- Boyer-Moore takes into account k, the number of matched characters (from the right) before a mismatch occurs.
- If k=0, we do the same shift as Horspool's algorithm.

Boyer-Moore Algorithm

- Based on two main ideas:
- compare pattern characters to text characters from right to left
- precompute the shift amounts in two tables
  - **bad-symbol table** indicates how much to shift based on the text's character that causes a mismatch
  - **good-suffix table** indicates how much to shift based on matched part (suffix) of the pattern

Bad-symbol shift in Boyer-Moore

- If the rightmost character of the pattern does not match, Boyer-Moore algorithm acts much like Horspool's
- If the rightmost character of the pattern does match, BM compares preceding characters right to left until either
  - all pattern's characters match, or
  - a mismatch on text's character c is encountered after $k > 0$ matches



bad-symbol shift: How much should we shift by?

$d_1 = \max\{t_1(c) - k, 1\}$,
where $t_1(c)$ is the value form the Horspool shift table.

Q5

Boyer-Moore Algorithm

After successfully matching $0 < k < m$ characters, the algorithm shifts the pattern right by

$$d = \max \{d_1, d_2\}$$

where $d_1 = \max\{t_1(c) - k, 1\}$ is the bad-symbol shift

$d_2(k)$ is the good-suffix shift

Remaining question:
How to compute good-suffix shift table?

Good-suffix Shift in Boyer-Moore

- Good-suffix shift d_2 is applied after the k last characters of the pattern are successfully matched
  - $0 < k < m$
- How can we take advantage of this?
- As in the bad suffix table, we want to pre-compute some information based on the characters in the suffix.
- We create a **good suffix table** whose indices are k = 1...m-1, and whose values are how far we can shift after matching a k-character suffix (from the right).
- Spend some time talking with one or two other students. Try to come up with criteria for how far we can shift.
- Example patterns: CABABA AWOWWOW
  WOWWOW ABRACADABRA

Q6-8

Boyer-Moore Example

- On Moore's home page
- http://www.cs.utexas.edu/users/moore/best-ideas/string-searching/fstrpos-example.html