Week 14 - Friday

COMP 2100

Last time

- What did we talk about last time?
- Tries

Questions?

Assignment 7

Project 4

Substring Search

Substring search

- Finding a string within another string is a fundamental task
- Applications:
  - Finding text on a web page
  - Find/replace while word processing
  - Looking for DNA subsequences within a larger sequence
  - Countless others …

Brute-force substring search

Write a method to find **needle** in **haystack**, returning the starting index of **needle** in **haystack** or **-1** if not found.

```
public static int find(String needle,
  String haystack)
```

Running time

- How long does the brute-force substring search take if the length of **`haystack`** is n and the length of **`needle`** is m?
- There are $n - m + 1$ positions to start looking in haystack, and you have to check m characters for each position
- $m(n - m + 1)$ is $\Theta(nm)$
  - Note that m is usually much smaller than n

Knuth-Morris-Pratt

- A cleverer approach to substring search uses the observation that the act of matching tells us what to do when we reach a mismatch:
- Needle: BARBED
- Haystack: BARBARBED

B	A	R	B	A	R	B	E	D
B	A	R	B	E				

- On mismatch, skip ahead to:

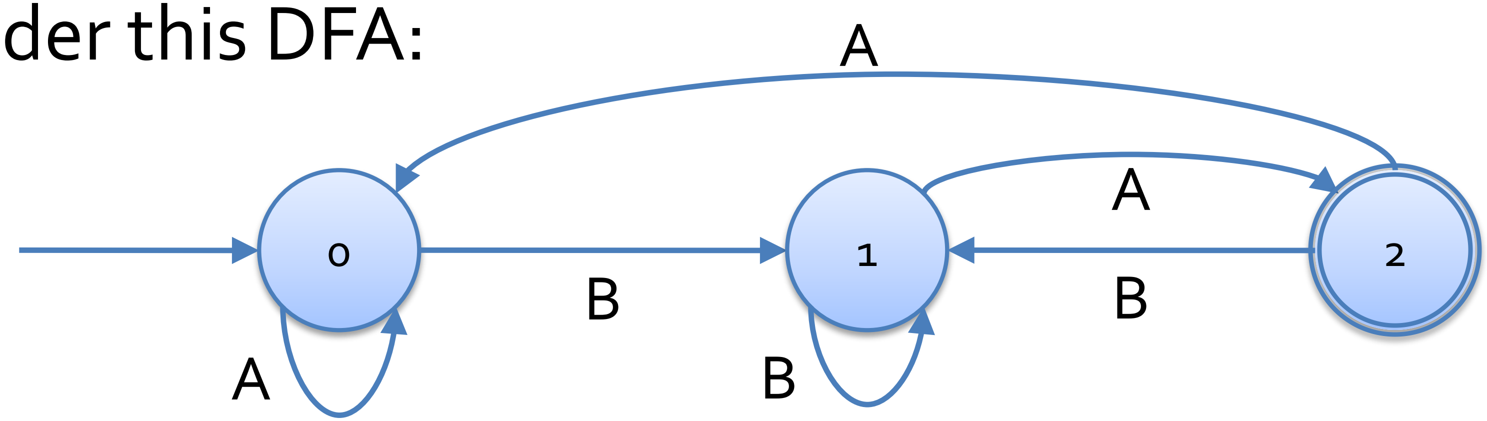
			B	A				

How do we know where to skip to?

- It depends on the structure of needle
- Some strings will have repetitive substrings that will "rematch" part of the substring
- Some strings will need to jump back to the beginning
- We could map these transitions out with a **deterministic finite automaton (DFA)**

DFA example

- Consider this DFA:



- State 0 is the initial state
- The circled state (2) is an accepting state
- Is the string AAAAABBA accepted?
- What about the string BBBBBBAB?
- What's a verbal description for the strings accepted?

DFA practice

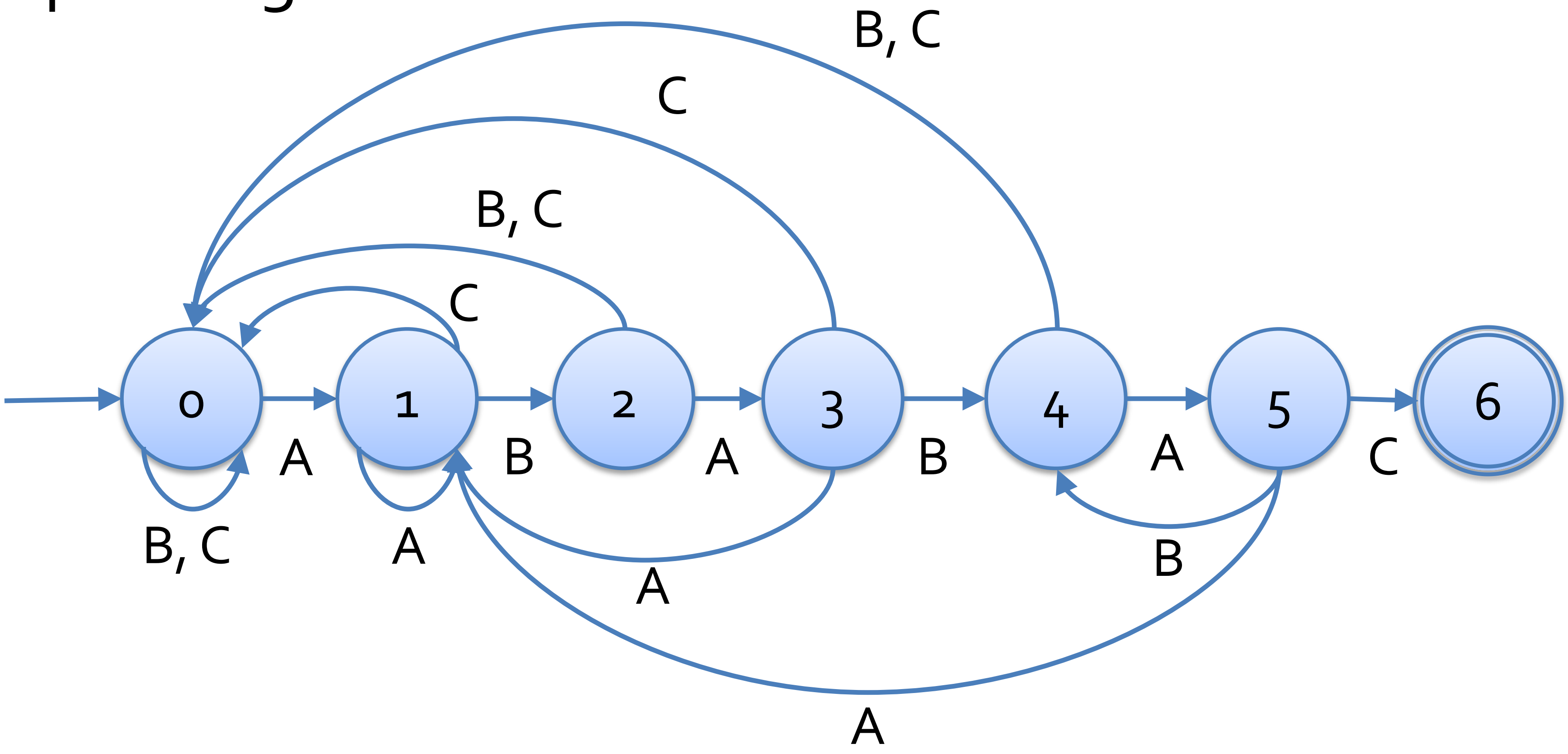
- Make a DFA that accepts all strings that have an even number of A's and an odd number of B's

Using DFAs

- DFAs can be created to accept many different patterns of strings
- They are equivalent to regular expressions
- Fortunately the DFAs needed for the Knuth-Morris-Pratt algorithm are easy to construct

KMP DFA example

- Needle string: ABABAC
- Corresponding DFA:



Making the DFA

- The algorithm for constructing the DFA is not obvious, but the code isn't very complex

```
public static int[][] makeDFA(String pattern) {
      final int M = pattern.length();
      int[][] DFA = new int[128][M];
      // for all ASCII characters
      DFA[pattern.charAt(0)][0] = 1;
      for (int x = 0, i = 1; i < M; ++i) {
            for(char c = 0; c < 128; ++c)
                  DFA[c][i] = DFA[c][x];
            DFA[pattern.charAt(i)][i] = i + 1;
            x = DFA[pattern.charAt(i)][x];
      }
      return DFA;
}
```

Using the DFA

- Once you have the DFA, you can use it to search

```
public static int find(String text, int[][] DFA) {
        final int M = DFA[0].length;
        int i, j;
        for (i = 0, j = 0; i < text.length() && j < M; ++i) {
                j = DFA[text.charAt(i)][j];
        }

        if (j == M) {
                return i - M;
        } else {
                return -1;
        }
}
```

Running time

- If the length of the pattern is ***m***, it takes ***m*** time to make the DFA
  - Actually, it's like 128***m*** or |***Alphabet***|***m***, but the size of the alphabet will always be constant
- If the length of the text is ***n***, it takes at most ***n*** time to do the search (often better if we make a match)
- Total running time is thus Θ(***n*** + ***m***)
- This improvement over brute force can be significant when ***n*** is large (as it often is)

Other approaches

- The KMP algorithm can process the text as a stream (without backing up or looking at more than one character at a time)
- You can't do better than KMP in the worse case
- However, Boyer-Moore substring looks for mismatched characters and can perform better in practice (but relies on analysis of random strings)
- Rabin-Karp constructs a fingerprint (a hash) of a sliding window of ***m*** characters
    - But there's always a chance that you match a substring that just happens to have the same hash

Upcoming

Next time…

- Review up to Exam 1

Reminders

- **Finish Assignment 7**
  - **Due tonight!**
- Work on Project 4
- Review all material