Multiple Pattern Matching with the Aho-Corasick Algorithm

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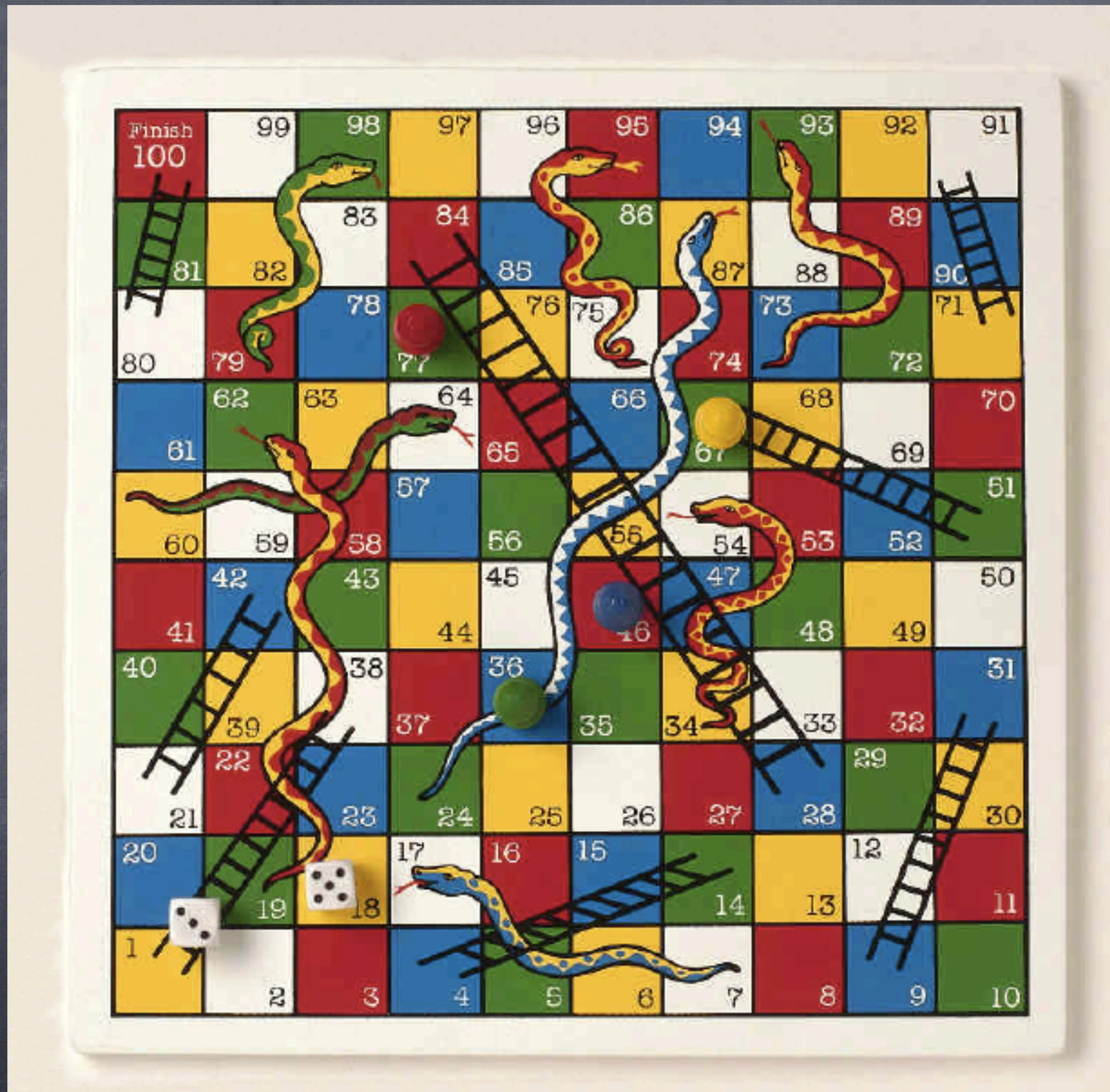
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99 98 97 96 95 94 93 92 91
81 82 83 84 85 86 87 88 89 90
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61 62 63 64 65 66 67 68 69 70
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41 42 43 44 45 46 47 48 49 50
40 39 38 37 36 35 34 33 32 31
21 22 23 24 25 26 27 28 29 30
20 19 18 17 16 15 14 13 12 11
1 2 3 4 5 6 7 8 9 10

Intro: A Few Definitions

- TEXT: a (usually large) set of characters that we wish to search through (the "haystack")
- PATTERN: a smaller set of characters that we are looking for in the text (the "needle")
- DICTIONARY: a set of (distinct) patterns that we are looking for (a "handful of different needles")

Motivation

- There are many real-world cases whereby we need to search for instances of not one, but many different patterns in a given text (exact-set matching)
- Problem: large sets, long patterns and huge texts result in unacceptable (s-l-o-w-w-w-w) performance using naive methods

Motivation

- Example 1: DNA Contamination
- The Question: “Did we find Dinosaur DNA?”
- TEXT: a candidate DNA sample from a paleontological dig site
- DICTIONARY: several small snippets of human mitochondrial DNA
- http://www.dinosauria.com/jdp/misc/dna.htm

Motivation

- Example 2: Computer Virus Detection
- Question: “Is my program infected?”
- TEXT: the complete code of a suspect program (eg. Microsoft Word)
- DICTIONARY: the set of all known computer viruses which could infect the given system

Implementation

- Clearly, multiple pattern matching is important
- How do we do FAST multiple pattern searches?


CONFUSION
You're not making any sense at all.
DIY.DESPAIR.COM

Aho-Corasick Algorithm

- due to Alfred V. Aho and Margaret J. Corasick (Bell Labs)
- first published in June 1975

Aho-Corasick Algorithm

- MAIN IDEA: go through the text just ONCE, searching for all of the patterns in the dictionary at once

Aho-Corasick Algorithm

- Question: How do we examine a given text for instances of an entire dictionary, ALL AT ONCE?
- Answer: Smart pre-processing!

Aho-Corasick Algorithm

- STEP 1: Build a KEYWORD TREE **K** from the dictionary elements
- Label certain nodes of the keyword tree **K** with the index of that particular pattern in the dictionary **P** (starting at 1). These will be the NUMBERED NODES.

Aho-Corasick Algorithm

- STEP 2: Create FAILURE LINKS within the keyword tree **K**
- FAILURE LINK: a link from the longest suffix of the current pattern that also exists as a prefix in the keyword tree, to that prefix in the tree.
- THEOREM: Failure links are unique

Aho-Corasick Algorithm

- STEP 3: Using the A-C Algorithm, search the text **T** using the pre-constructed keyword tree for the dictionary **P**

Algorithm **full_AC_search**

```
l := 1;         // l : starting pos of current search in the text
c := 1;         // c : current character position in the text
w := root; // w : the node we are currently at in the tree
repeat
  while there is an edge (w, w') labeled T(c)
    begin          // w' : some child of w that fits the description
      IF (w' is a numbered node), OR
        (there is a directed path of failure links
             from w' to a numbered node)
      THEN
        report occurrence of P_i, ending at position c;
      w = w', and c = c + 1;
    end;
  w := n_w and l := c - lp(w);   // ask us about lp(w)! :-)
until c > n;
```

Running Time

- Preprocessing: O(n) time to create prefix tree and failure links, where n is the total length of the dictionary **P**
- Searching: we proceed through the text **T** exactly once, possibly reporting occurrences of **P** in **T**
- Thus, the total running time is $O(n) + O(m+k)$, where $m = |T|$ and $k = \#$ occurrences

Running Time

- **Theorem:** If **P** is a set of patterns with total length n, and **T** is a text of total length m, then one can find all occurrences of **T** in patterns from **P** in O(n) preprocessing time plus O(m+k) search time, where k is the number of occurrences found.

Aho-Corasick Algorithm

- One last real-world application:
- `grep -F` (UNIX and derivatives; search a document for a list of fixed strings) makes use of the Aho-Corasick algorithm
- if you run Mac OS X or any other -nix system, you have Aho-Corasick!

Primary Reference:

- Gusfield, Dan. Algorithms on Strings, Trees, and Sequences: Computer Science and Computational Biology. Cambridge, England: Cambridge University Press, 2005.

Questions?