# More on Strings

Hsuan-Tien Lin

Dept. of CSIE, NTU

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# What We Have Done

- Various Implementations of 2D Array
- Row Major vs. Col Major Access
- Adding Sparse Polynomials
- Sparse Matrix by Ordered Triples
- Fast Transpose of Sparse Matrix
- Fast Multiplication of Sparse Matrix
- Reading Assignment:
  Structures and Unions, Abstract Polynomials et al.,
  Multi-Dim Arrays, String (ADT/C)

# Homework 2

- Asympototic Complexity:
  "proof" from only the known definitions/theorems
- Structure:
  simple, do after reading assignment
- Sparse Matrix:
  explore another implementation that uses (dense-bit-array + elements) instead of (paired-indices + elements)
- Special Matrix:
  much like method 1 of 2D Array, but on a band matrix
- Sparse Matrix Processing:
  coding for huge data set

# Some Hints on Sparse Matrix Processing

row = 18000, col = 480000, element = 100000000

- on your computer:
  - read in the file by your special program
    —better than Notepad/VIM/etc.
  - no need to open the whole file before you can start
    —check README, check first few lines, etc.
- on CSIE R217 workstation:
  - access the file /tmp2/DSA2011/data_2_5.txt
    —better than a file in your home dir
    - no quota vs. quota
    - local copy vs. network file system
  - can use `head` or `tail`
- design before implement:
  - large data set: hard to "trial-and-error"
  - express your design on paper is important

# More Hints on Sparse Matrix Processing

discuss with TAs/classmates/instructor and be creative

- do you need a 4-byte integer per element $\in \{1, 2, 3, 4, 5\}$?
- storing both $R$ and $R^T$ (some redundancy) so both $users(m, n)$ and $movies(u, v)$ would be fast?
- don't be afraid to try; don't settle for naive solutions

# Strings: Pattern Matching (Subsec. 2.7.3)

find the position that *pat* (first) shows up in *string*

**for** $i \leftarrow 0$ to $len(string) - 1$ **do**
  **if** *pat* matches $strings[i, i + len(pat) - 1]$
    matching found
  **end if**
**end for**
matching not found

- the IF takes $O(m)$ for $m = len(pat)$
  —can use heuristic on comparing *begin* and *end* first, but still $O(m)$ in the worst case
- so total $O(n * m)$ for $n = len(string)$

# Slow (Naive) Pattern Matching

$i, j \leftarrow 0$
**while** $i < len(string)$ and $j < len(pat)$ **do**
  **if** $pat[j] == string[i]$
    $i \leftarrow i + 1, j \leftarrow j + 1$ (continue matching)
  **else**
    $i \leftarrow i - j + 1$
    $j \leftarrow 0$
    (fail and totally go back)
  **end if**
**end while**
check matching status

see demo

# "Jump" Pattern Matching

$i, j \leftarrow 0$
**while** $i < len(string)$ and $j < len(pat)$ **do**
  **if** $pat[j] == string[i]$
    $i \leftarrow i + 1, j \leftarrow j + 1$ (continue matching)
  **else**
    $i \leftarrow i - \min(jump, j) + 1$
    $j \leftarrow 0$
    (fail and go to next possible starting point)
  **end if**
**end while**
check matching status

see demo

# Fast (Knuth-Morris-Pratt) Pattern Matching

$i, j \leftarrow 0$
**while** $i < len(string)$ and $j < len(pat)$ **do**
  **if** $pat[j] == string[i]$
    $i \leftarrow i + 1, j \leftarrow j + 1$ (continue matching)
  **else**
    $i \leftarrow i$
    decrease $j$ such that $pat[0, j-1]$ matches $string[i-j, i-1]$
    (fail but continue partially)
  **end if**
**end while**
check matching status

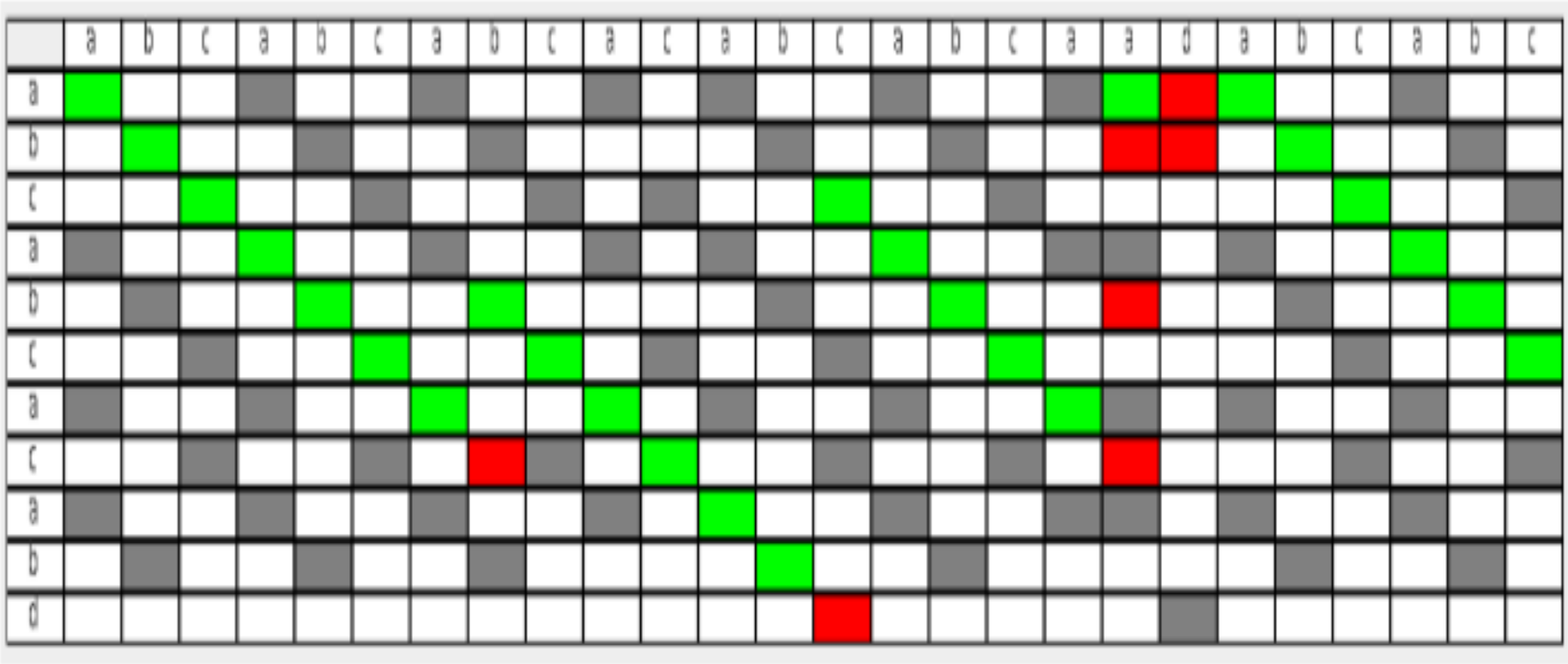
see demo

# Donald Knuth 高德納

- Ph.D., Caltech Math
- Professor Emeritus, Stanford
- 1974 ACM A. M. Turing Award
  (who is Turing and what is Turing Award?)
- 1995 IEEE John von Neumann Medal
  (who is von Neumann?)

*For his major contributions to the analysis of algorithms and the design of programming languages, and in particular for his contributions to "The Art of Computer Programming" through his well-known books in a continuous series by this title*

# KMP Pattern Matching




- number of increase $i$ = $O(len(string))$ = number of increase $j$
- number of decrease $j$ = $O($ number of increase $j)$ because $j \geq 0$
- total: $O(len(string))$ IF the decrease step is $O(1)$

# How To Make the Decrease Step $O(1)$

- main tool: pre-compute how you decrease $j$
- how to decrease $j$ to $t+1$ such that $pat[0,t]$ matches $string[i-t-1, i-1]$
  - originally, $pat[0, j-1] == string[i-j, i-1]$
  - want, $pat[0,t] == string[i-t-1, i-1]$
  - note, $pat[j-t-1, j-1] == string[i-t-1, i-1]$
  - so, $pat[0,t] == pat[j-t-1, j-1]$

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An $O(1)$ decrease step:

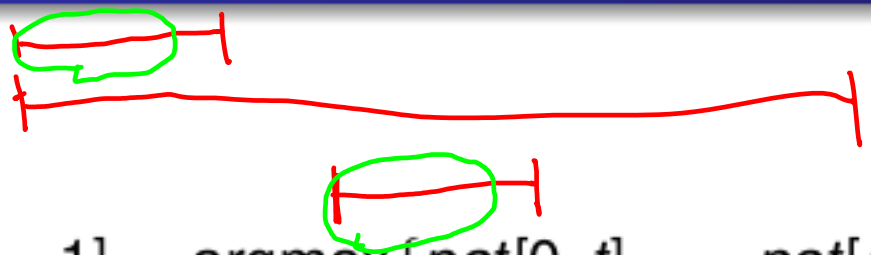
$$j \leftarrow f[j-1]+1$$

where $f[j-1] = \underset{t}{\text{argmax}}\{pat[0,t] == pat[j-t-1, j-1]\}$

or $f[j-1] = -1 (\text{otherwise})$

- a trivial algorithm of $O(len(pat)^2)$ for pre-computing $f$: double for loops on $j$ and $t$

# Even Faster Algorithm for Pre-Computing $f$



$$f[j-1] = \operatorname*{argmax}_t \{pat[0,t] == pat[j-t-1, j-1]\}$$

or $f[j-1] = -1$(otherwise)

- see textbook for something not so easy to understand
- a vernacular explanation: to get $f[j] = res$,
  - candidate 1: $res = f[j-1] + 1$, check if $pat[res] == pat[t]$
  - candidate 2: $res = f[f[j-1]] + 1$, check if $pat[res] == pat[t]$
  - candidate 3: $res = f[f[f[j-1]]] + 1$, check if $pat[res] == pat[t]$
  - $\cdots$
  - otherwise: $res = -1$

read the textbook for why it's faster!