acm International Collegiate Programming Contest

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CS3233
Competitive Programming

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Week 02 – Data Structures & Libraries

Focus on Bit Manipulation & Binary Indexed Tree

Outline

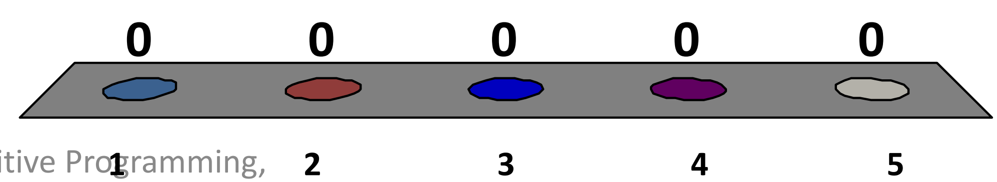
- Mini Contest 1 + Break (discussion of A/B)
- Some Admins
- Data Structures With Built-in Libraries
  - Just a quick walkthrough
    - Read/experiment with the details on your own
  - Linear Data Structures (CS1010/1st half of CS2020)
  - Non Linear Data Structures (CS2010/2nd half of CS2020)
    - Focus on the **red highlights**
- "Top Coder" Coding Style (overview) + Break
- Data Structures With Our-Own Libraries
  - Focus on Binary Indexed (Fenwick) Tree

Basic knowledge that all ICPC/IOI-ers must have!

LINEAR DATA STRUCTURES WITH BUILT-IN LIBRARIES

I am…

1. A pure C coder
2. A pure C++ coder
3. A mix between C/C++ coder
4. A pure Java coder
5. A multilingual coder: C/C++/Java



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Linear DS + Built-In Libraries (1)

1. Static Array, built-in support in C/C++/Java
2. Resize-able: C++ STL **vector**, Java **Vector**
   - Both are very useful in ICPCs/IOIs

- There are 2 very common operations on Array:
  - Sorting
  - Searching
  - Let's take a look at efficient ways to do them

Two “fundamental” CS problems

SORTING + SEARCHING INVOLVING ARRAY

Sorting (1)

- Definition:
  – Given unsorted stuffs, sort them… *
- Popular Sorting Algorithms
  – $O(n^2)$ algorithms: Bubble/Selection/Insertion Sort
  – O(n log n) algorithms: Merge/Quick^/Heap Sort
  – Special purpose: Counting/Radix/Bucket Sort
- Reference:
  – http://en.wikipedia.org/wiki/Sorting_algorithm

Sorting (2)

- In ICPC, you can “forget” all these…
  - In general, if you need to sort something…, just use the O(n log n) sorting library:
    - C++ STL **algorithm:: sort**
    - Java **Collections.sort**
- In ICPC, sorting is either used as *preliminary step* for more complex algorithm or to *beautify output*
  - Familiarity with sorting libraries is a must!

Sorting (3)

- Sorting routines in C++ STL **algorithm**
  - sort – a bug-free implementation of *introsort**
    - Fast, it runs in O(n log n)
    - Can sort basic data types (ints, doubles, chars), **Abstract Data Types (C++ class), multi-field sorting (≥ 2 criteria)**
  - partial_sort – implementation of *heapsort*
    - Can do O(k log n) sorting, if we just need top-k sorted!
  - stable_sort
    - If you need to have the sorting 'stable', keys with same values appear in the same order as in input

Searching in Array

- Two variants:
  - When the array is sorted versus not sorted
- Must do O(n) linear scan if not sorted - trivial
- Can use O(log n) binary search when sorted
  - PS: must run an O(n log n) sorting algorithm once
- Binary search is ‘tricky’ to code!
  - Instead, use C++ STL **algorithm::lower_bound**

Linear DS + Built-In Libraries (2)

3. Array of Boolean: C++ STL **bitset**
   – Faster than **array of bools** or **vector<bool>**!
   – No specific API in Java that is similar to this
4. **Bitmask**
   – **a.k.a. lightweight set of Boolean or bit string**
   – **Explanation via:**
     http://www.comp.nus.edu.sg/~stevenha/visualization/bitmask.html

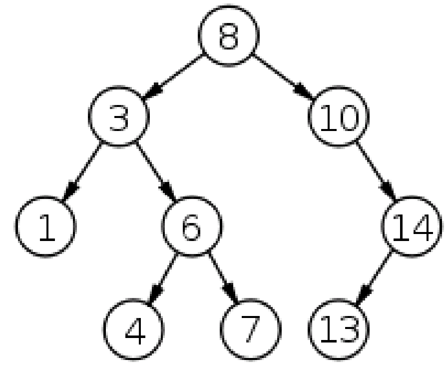
Linear DS + Built-In Libraries (3)

5. Linked List, C++ STL **list**, Java **LinkedList**
   – Usually not used in ICPCs/IOIs
   – If you need a resizeable "list", just use **vector**!
6. Stack, C++ STL **stack**, Java **Stack**
   – Used by default in Recursion, Postfix Calculation, Bracket Matching, etc
7. Queue, C++ STL **queue**, Java **Queue**
   – Used in Breadth First Search, Topological Sort, etc
   – **PS: Deque, used in 'Sliding Window' algorithm**

More efficient data structures

NON-LINEAR DATA STRUCTURES WITH BUILT-IN LIBRARIES

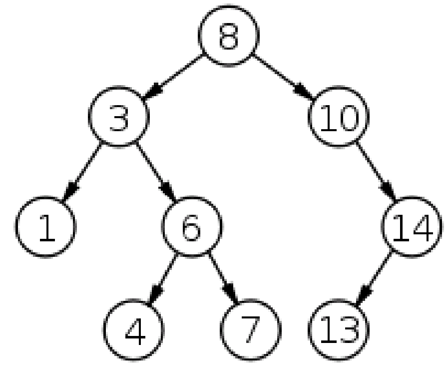
Binary Search Tree (1)



A binary search tree of size 9 and depth 3, with root 8 and leaves 1, 4, 7 and 13

- ADT Table (key → data)
- Binary Search Tree (BST)
  - Advertised O(log n) for insert, search, and delete
  - Requirement: the BST must be **balanced**!
    - AVL tree, Red-Black Tree, etc… *argh*
- Fret not, just use: C++ STL **map** (Java **TreeMap**)
  - UVa 10226 (Hardwood Species)*

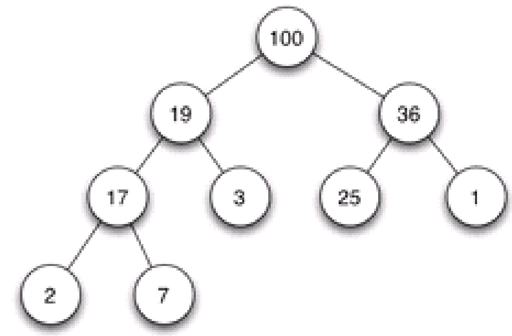
Binary Search Tree (2)



A binary search tree of size 9 and depth 3, with root 8 and leaves 1, 4, 7 and 13

- ADT Table (key exists or not)
- Set (Single Set)
  - C++ STL **set**, similar to C++ STL **map**
    - map stores a **(key, data)** pair
    - set stores just the **key**
  - In Java: **TreeSet**
- Example:
  - UVa 11849 – CD

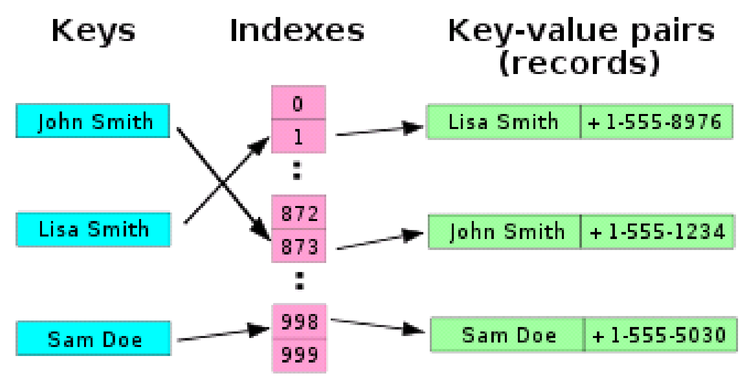
Heap



Example of a full binary max heap

- Heap
  - C++ STL **algorithm** has some heap algorithms
    - partial_sort uses heapsort
  - C++ STL **priority_queue** (Java **PriorityQueue**) is heap
    - Prim's and Dijkstra's algorithms use priority queue
- But, we rarely see pure heap problems in ICPC

Hash Table



A small phone book as a hash table.

- Hash Table
  - Advertised O(1) for insert, search, and delete, but:
    - The hash function must be good!
    - There is no Hash Table in C++ STL (∃ in Java API)
  - Nevertheless, O(log n) using **map** is usually ok
- Direct Addressing Table (DAT)
  - Rather than hashing, we more frequently use DAT
  - UVa 11340 (Newspaper)

Top Coder Coding Style

SUPPLEMENTARY

Top Coder Coding Style (1)

- You may want to follow this coding style (C++)

1. Include **important** headers ☺
   - #include <algorithm>
   - #include <cmath>
   - #include <cstdio>
   - #include <cstring>
   - #include <iostream>
   - #include <map>
   - #include <queue>
   - #include <set>
   - #include <string>
   - #include <vector>
   - using namespace std;

Want More?

Add libraries that you frequently use into this template, e.g.:

ctype.h
bitset

etc

Top Coder Coding Style (2)

2. Use shortcuts for common data types

```
– typedef long long          ll;
– typedef vector<int>        vi;
– typedef pair<int, int>     ii;
– typedef vector<ii>         vii;
```

3. Simplify Repetitions/Loops!

```
– #define REP(i, a, b)       for (int i = int(a); i <= int(b); i++)
– #define REPN(i, n)         REP (i, 1, int(n))
– #define REPD(i, a, b)      for (int i = int(a); i >= int(b); i--)
– #define TRvi(c, it) \
  for (vi::iterator it = (c).begin(); it != (c).end(); it++)
– #define TRvii(c, it) \
  for (vii::iterator it = (c).begin(); it != (c).end(); it++)
```

Define your own loops style and stick with it!

Top Coder Coding Style (3)

4. More shortcuts
   - `for (i = ans = 0; i < n; i++)… // do variable assignment in for loop`
   - `while (scanf("%d", n), n) { … // read input + do value test together`
   - `while (scanf("%d", n) != EOF) { … // read input and do EOF test`
5. STL/Libraries all the way!
   - `isalpha (ctype.h)`
     - `inline bool isletter(char c) {`
       `return (c>='A'&&c<='Z')||(c>='a'&&c<='z'); }`
   - `abs (math.h)`
     - `inline int abs(int a) { return a >= 0 ? a : -a; }`
   - `pow (math.h)`
     - `int power(int a, int b) {`
       `int res=1; for (; b>=1; b--) res*=a; return res; }`
   - Use STL data structures: vector, stack, queue, priority_queue, map, set, etc
   - Use STL algorithms: sort, lower_bound, max, min, max_element, next_permutation, etc

Top Coder Coding Style (4)

6. Use I/O Redirection

```
– int main() {
–   // freopen("input.txt", "r", stdin); // don't retype test cases!
–   // freopen("output.txt", "w", stdout);
–   scanf and printf as per normal; // I prefer scanf/printf than
    // cin/cout, C style is much easier
```

7. Use memset/assign/constructor effectively!

```
– memset(dist, 127, sizeof(dist));
  // useful to initialize shortest path distances, set INF to 127!
– memset(dp_memo, -1, sizeof(dp_memo));
  // useful to initialize DP memoization table
– memset(arr, 0, sizeof(arr)); // useful to clear array of integers
– vector<int> dist(v, 2000000000);
– dist.assign(v, -1);
```

Top Coder Coding Style (5)

8. Declare (large) static DS as global variable
   - All input size is known, declare data structure size LARGER than needed to avoid silly bugs
   - Avoid dynamic data structures that involve pointers, etc
   - Use global variable to reduce "stack size" issue

- Now our coding tasks are much simpler ☺
- Typing less code = shorter coding time
  = better rank in programming contests ☺

Quick Check

1. I can cope with this pace…
2. I am lost with so many new information in the past few slides

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5 Minutes Break

- One data structures *without* built-in libraries will be discussed in the last part…
  - Binary Indexed (Fenwick) Tree
  - Graph, Union-Find Disjoint Sets, and Segment Tree are not discussed in this year's CS3233 Week02
    - Graph DS is covered in details in CS2010/CS2020
    - UFDS is covered briefly in CS2010/CS2020
    - Please study Segment Tree on your own
      - We try not set any contest problem involving Segment Tree

Time Check:
8.30pm

Graph (not discussed today, revisited in Week05/08)

Union-Find Disjoint Sets (not discussed today, read Ch2 on your own)

Segment Tree (not discussed today, read Ch2 on your own)

Fenwick Tree (discussed today)

DATA STRUCTURES WITHOUT BUILT-IN LIBRARIES

Fenwick Tree (1)

- Cumulative Frequency Table
  - Example, s = {2,4,5,5,6,6,6,7,7,8} (already sorted)

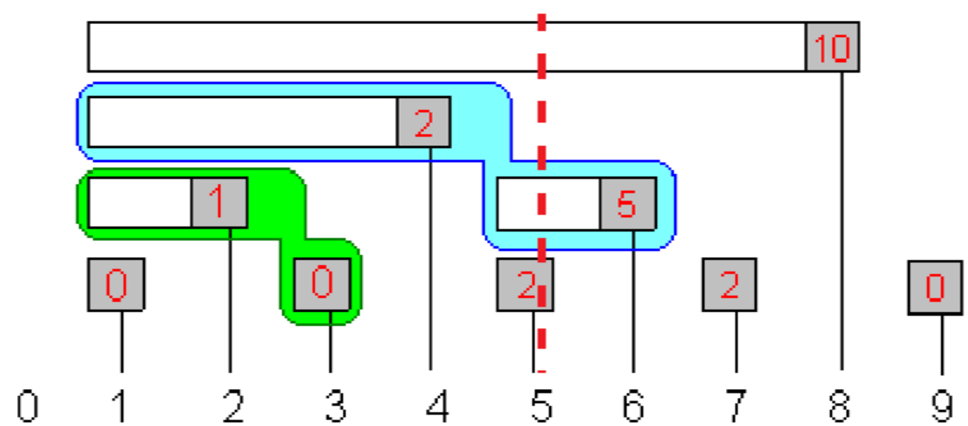
Index/Score/Symbol	Frequency	Cumulative Frequency
0	0	0
1	0	0
2	1	1
3	0	1
4	1	2
5	2	
6	3	
7	2	
8	1	

Fenwick Tree (2)

- Fenwick Tree (inventor = Peter M. Fenwick)
  - Also known as "**Binary Indexed** Tree", very *aptly* named
  - Implemented as an **array**, let call the array name as **ft**
    - Each **index** of **ft** is responsible for certain **range** (see diagram)

Key/Index	Binary	Range	F	CF	FT
0	**0000**	**N/A**	**N/A**	**N/A**	**N/A**
1	0001	1	0	0	0
2	0010	1..2	1	1	1
3	0011	3	0	1	0
4	0100	1..4	1	2	2
5	0101	5	2	4	2
6	0110	5..6	3	7	5
7	0111	7	2	9	2
8	1000	1..8	1	10	10
9	1001	9	0	10	0

Do you notice
any particular **pattern**?

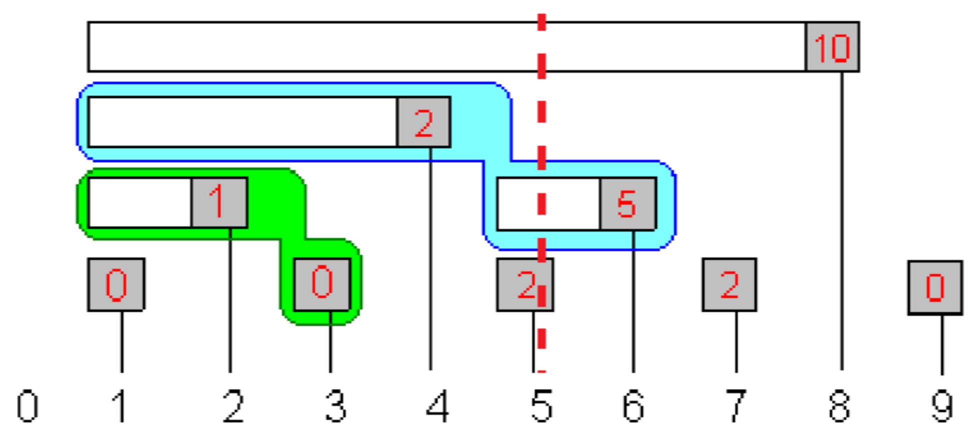


Fenwick Tree (3)

- To get the cumulative frequency from index **1** to b, use `ft_rsq(ft, b)`
  - The answer is the sum of sub-frequencies stored in array `ft` with indices related to b via this formula `b' = b - LSOne(b)`
    - Recall that `LSOne(b) = b & (-b)`
      - » That is, strip **the least significant bit** of b
  - Apply this formula iteratively until b is `0`
    - Example: `ft_rsq(ft, 6)`
      - » b = 6 = 0110, b' = b - LSOne(b) = 0110 - 0010, b' = 4 = 0100
      - » b' = 4 = 0100, b'' = b' - LSOne(b') = 0100 - 0100, b'' = 0, **stop**
    - Sum **ft[6] + ft[4] = 5 + 2 = 7 (see the blue area that covers range [1..4] + [5..6] = [1..6])**

Analysis:
This is
O(log n)

Why?

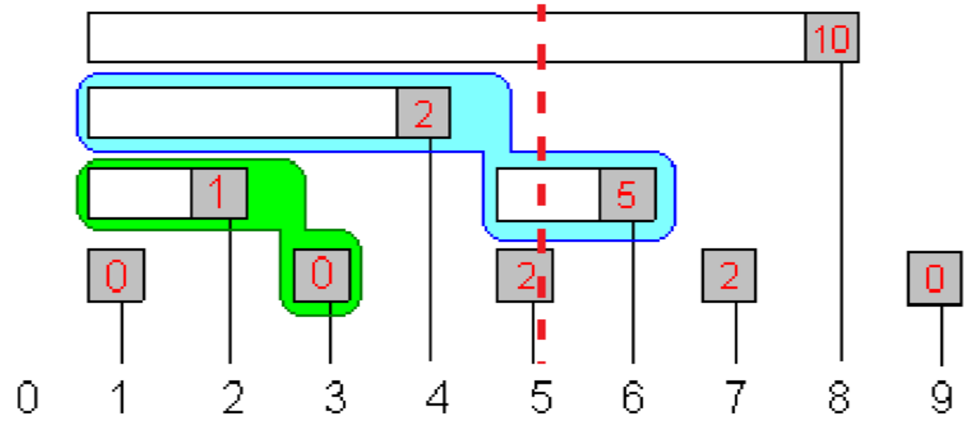


Fenwick Tree (4)

– To get the cumulative frequency from index **a** to b, use `ft_rsq(ft, a, b)`
  - If a is not one, we can use: `ft_rsq(ft, b) – ft_rsq(ft, a - 1)` to get the answer
    – Example: `ft_rsq(ft, 3, 6) =`
    `ft_rsq(ft, 6) – ft_rsq(ft, 3 – 1) =`
    `ft_rsq(ft, 6) – ft_rsq(ft, 2) =`
    blue area minus **green area** =
    (5 + 2) - **(0 + 1)** =
    7 - **1** = 6

Analysis:
This is
O(2 log n) =
O(log n)

Why?

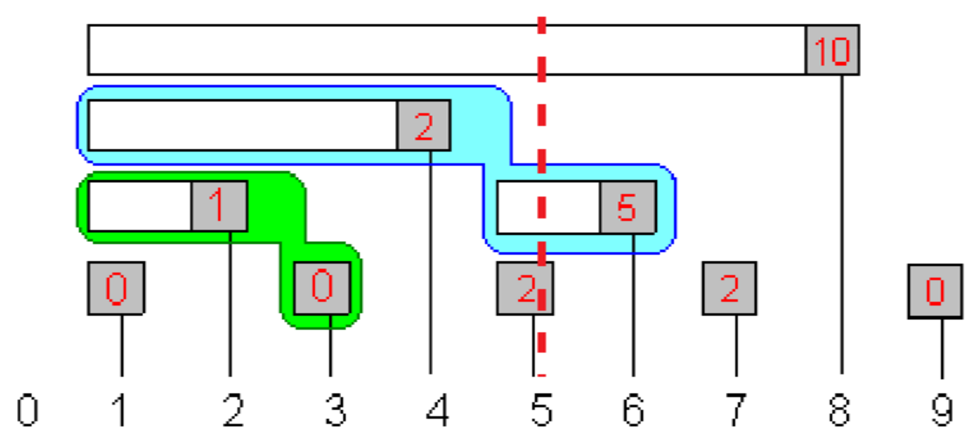


Fenwick Tree (5)

- To update the frequency of an key/index k, by v (either positive or negative), use `ft_adjust(ft, k, v)`
  - Indices that are related to k via `k' = k + LSOne(k)` will be updated by v when `k < ft.size()`
    - Example: `ft_adjust(ft, 5, 2)`
      - » k = 5 = 0101, k' = k + LSOne(k) = 0101 + 0001, k' = 6 = 0110
      - » k' = 6 = 0110, k'' = k' + LSOne(k') = 0110 + 0010, k'' = 8 = 1000
      - » And so on while k < ft.size()
  - Observe that the **dotted red line** in the figure below **stabs through** the ranges that are under the responsibility of indices 5, 6, and 8
    - ft[5], 2 updated to 4
    - ft[6], 5 updated to 7
    - ft[8], 10 updated to 12

Analysis:
This is also
O(log n)

Why?



Fenwick Tree (6) – Library

```
typedef vector<int> vi;
#define LSOne(S) (S & (-S))

void ft_create(vi &ft, int n) { ft.assign(n + 1, 0); }  // init: n+1 zeroes

int ft_rsq(const vi &ft, int b) {                      // returns RSQ(1, b)
  int sum = 0; for (; b; b -= LSOne(b)) sum += ft[b];
  return sum; }

int ft_rsq(const vi &t, int a, int b) {                // returns RSQ(a, b)
  return ft_rsq(t, b) - (a == 1 ? 0 : ft_rsq(t, a - 1)); }

// adjusts value of the k-th element by v (v can be +ve/inc or -ve/dec)
void ft_adjust(vi &ft, int k, int v) {
  for (; k < (int)ft.size(); k += LSOne(k)) ft[k] += v; }
```

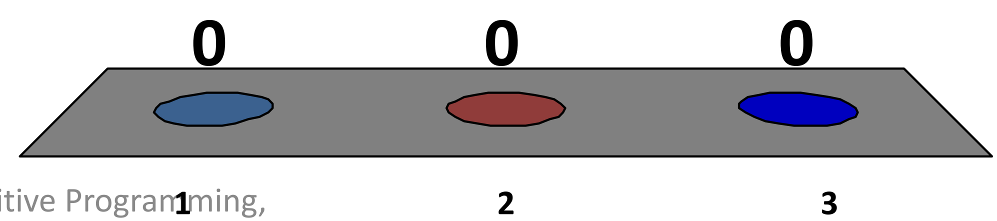

FT/BIT is in IOI syllabus!

Fenwick Tree (7) – Application

- Fenwick Tree is very suitable for *dynamic* RSQs (cumulative frequency table) where each update occurs on a certain index only
- Now, think of potential real-life applications!
  - http://uhunt.felix-halim.net/id/32900
  - Consider code running time of [0.000 - 9.999] for a particular UVa problem
    - There are up to 9+ million submissions/codes
      - About thousands submissions per problem
    - If your code runs in 0.342 secs, what is your rank?
- How to use Fenwick Tree to deal with this problem?

Quick Check

1. I am lost with Fenwick Tree
2. I understand the basics of Fenwick Tree, but since this is new for me, I may/may not be able to recognize problems solvable with FT
3. I have solved several FT-related problems before



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Summary

- There are a lot of great Data Structures out there
  - We need the most efficient one for our problem
    - Different DS suits different problem!
- Many of them have **built-in libraries**
  - For some others, we have to build **our own (focus on FT)**
    - Study these libraries! Do not rebuild them during contests!
- From Week03 onwards and future ICPCs/IOIs,
  use C++ STL and/or Java API and our built-in libraries!
  - Now, your team should be in rank 30-45 (from 60)
    (still solving ~1-2 problems out of 10, but faster)