



Chulalongkorn University

What Name ?

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template from KACTL

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1 Template

2 Mathematics

3 Combinatorial

4 Data Structures

5 Various

6 Competitive Programming Topics

Template (1)

template.cpp

31 lines

```
#pragma once
#include <bits/stdc++.h>
#define sz(x) (int)(x).size()
#define all(x) (x).begin(), (x).end()

using namespace std;

typedef long long ll;
typedef double db;
typedef long double ld;
typedef pair<int, int> pii;
typedef pair<ll, ll> pll;

template<typename T> bool ckmin(T &a, const T &b) { return b < a ? a = b, 1 : 0; }
template<typename T> bool ckmax(T &a, const T &b) { return a < b ? a = b, 1 : 0; }

mt19937 rng(chrono::steady_clock::now().time_since_epoch().
    count());
const char nl = '\n';
const int INF = 0x3fffffff;
const int MOD=1000000007;
// const int MOD = 998244353;
const ll LINF = 0xffffffffffffffff;
const db DINF = numeric_limits<db>::infinity();
const db EPS = 1e-9;
const db PI = acos(db(-1));

signed main(){
    ios_base::sync_with_stdio(0); cin.tie(NULL);
    return 0;
}
```

c.sh

2 lines

Mathematics (2)

2.1 Goldbach's Conjecture

- Even number can be written in sum of two primes (Up to $1e12$)

- 1 • Range of N^{th} prime and $N + 1^{th}$ prime will be less than or equal to 300 (Up to $1e12$)

2.2 Divisibility

1 Number of divisors of N is given by $\prod_{i=1}^k (a_i + 1)$ where $N = \prod_{i=1}^k p_i^{a_i}$ and p_i are prime factors of N .

2 Combinatorial (3)

3.1 Permutations

3.1.1 Factorial

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|------|-------|-------|-------|--------|--------|--------|--------|----------|--------|---------|
| $n!$ | 1 | 2 | 6 | 24 | 120 | 720 | 5040 | 40320 | 362880 | 3628800 |
| n | 11 | 12 | 13 | 14 | 15 | 16 | 17 | | | |
| $n!$ | 4.0e7 | 4.8e8 | 6.2e9 | 8.7e10 | 1.3e12 | 2.1e13 | 3.6e14 | | | |
| n | 20 | 25 | 30 | 40 | 50 | 100 | 150 | 171 | | |
| $n!$ | 2e18 | 2e25 | 3e32 | 8e47 | 3e64 | 9e157 | 6e262 | >DBL_MAX | | |

IntPerm.h

3.1.2 Cycles

Let $g_S(n)$ be the number of n -permutations whose cycle lengths all belong to the set S . Then

$$\sum_{n=0}^{\infty} g_S(n) \frac{x^n}{n!} = \exp\left(\sum_{n \in S} \frac{x^n}{n}\right)$$

3.1.3 Derangements

Permutations of a set such that none of the elements appear in their original position.

$$D(n) = (n-1)(D(n-1) + D(n-2)) = nD(n-1) + (-1)^n = \left\lfloor \frac{n!}{e} \right\rfloor$$

3.1.4 Burnside's lemma

Given a group G of symmetries and a set X , the number of elements of X up to symmetry equals

$$\frac{1}{|G|} \sum_{g \in G} |X^g|,$$

where X^g are the elements fixed by g ($g \cdot x = x$).

If $f(n)$ counts “configurations” (of some sort) of length n , we can ignore rotational symmetry using $G = \mathbb{Z}_n$ to get

$$g(n) = \frac{1}{n} \sum_{k=0}^{n-1} f(\gcd(n, k)) = \frac{1}{n} \sum_{k|n} f(k) \phi(n/k).$$

3.2 Partitions and subsets

3.2.1 Partition function

Number of ways of writing n as a sum of positive integers, disregarding the order of the summands.

$$p(0) = 1, \quad p(n) = \sum_{k \in \mathbb{Z} \setminus \{0\}} (-1)^{k+1} p(n - k(3k - 1)/2)$$

$$p(n) \sim 0.145/n \cdot \exp(2.56\sqrt{n})$$

| n | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 20 | 50 | 100 |
|--------|---|---|---|---|---|---|----|----|----|----|-----|------------|------------|
| $p(n)$ | 1 | 1 | 2 | 3 | 5 | 7 | 11 | 15 | 22 | 30 | 627 | $\sim 2e5$ | $\sim 2e8$ |

3.2.2 Lucas' Theorem

Let n, m be non-negative integers and p a prime. Write $n = n_k p^k + \dots + n_1 p + n_0$ and $m = m_k p^k + \dots + m_1 p + m_0$. Then $\binom{n}{m} \equiv \prod_{i=0}^k \binom{n_i}{m_i} \pmod{p}$.

3.2.3 Binomials

multinomial.h

3.3 General purpose numbers

3.3.1 Bernoulli numbers

EGF of Bernoulli numbers is $B(t) = \frac{t}{e^t - 1}$ (FFT-able).

$$B[0, \dots] = [1, -\frac{1}{2}, \frac{1}{6}, 0, -\frac{1}{30}, 0, \frac{1}{42}, \dots]$$

Sums of powers:

$$\sum_{i=1}^n m^i = \frac{1}{m+1} \sum_{k=0}^m \binom{m+1}{k} B_k \cdot (n+1)^{m+1-k}$$

Euler-Maclaurin formula for infinite sums:

$$\sum_{i=m}^{\infty} f(i) = \int_m^{\infty} f(x) dx - \sum_{k=1}^{\infty} \frac{B_k}{k!} f^{(k-1)}(m) \approx \int_m^{\infty} f(x) dx + \frac{f(m)}{2} - \frac{f'(m)}{12} + \frac{f''(m)}{720} + O(f^{(5)}(m))$$

3.3.2 Stirling numbers of the first kind

Number of permutations on n items with k cycles.

$$c(n, k) = c(n-1, k-1) + (n-1)c(n-1, k), \quad c(0, 0) = 1$$

$$\sum_{k=0}^n c(n, k) x^k = x(x+1) \dots (x+n-1)$$

$$c(8, k) = 8, 0, 5040, 13068, 13132, 6769, 1960, 322, 28, 1$$

$$c(n, 2) = 0, 0, 1, 3, 11, 50, 274, 1764, 13068, 109584, \dots$$

3.3.3 Eulerian numbers

Number of permutations $\pi \in S_n$ in which exactly k elements are greater than the previous element. k :s s.t. $\pi(j) > \pi(j+1)$, $k+1$:s s.t. $\pi(j) \geq j$, k :s s.t. $\pi(j) > j$.

$$E(n, k) = (n-k)E(n-1, k-1) + (k+1)E(n-1, k)$$

$$E(n, 0) = E(n, n-1) = 1$$

$$E(n, k) = \sum_{j=0}^k (-1)^j \binom{n+1}{j} (k+1-j)^n$$

3.3.4 Stirling numbers of the second kind

Partitions of n distinct elements into exactly k groups.

$$S(n, k) = S(n - 1, k - 1) + kS(n - 1, k)$$

$$S(n, 1) = S(n, n) = 1$$

$$S(n, k) = \frac{1}{k!} \sum_{j=0}^k (-1)^{k-j} \binom{k}{j} j^n$$

3.3.5 Bell numbers

Total number of partitions of n distinct elements. $B(n) = 1, 1, 2, 5, 15, 52, 203, 877, 4140, 21147, \dots$. For p prime,

$$B(p^m + n) \equiv mB(n) + B(n + 1) \pmod{p}$$

3.3.6 Labeled unrooted trees

on n vertices: n^{n-2}

on k existing trees of size n_i : $n_1 n_2 \cdots n_k n^{k-2}$

with degrees d_i : $(n - 2)! / ((d_1 - 1)! \cdots (d_n - 1)!)$

3.3.7 Catalan numbers

$$C_n = \frac{1}{n+1} \binom{2n}{n} = \binom{2n}{n} - \binom{2n}{n+1} = \frac{(2n)!}{(n+1)!n!}$$

$$C_0 = 1, C_{n+1} = \frac{2(2n+1)}{n+2} C_n, C_{n+1} = \sum C_i C_{n-i}$$

$C_n = 1, 1, 2, 5, 14, 42, 132, 429, 1430, 4862, 16796, 58786, \dots$

- sub-diagonal monotone paths in an $n \times n$ grid.
- strings with n pairs of parenthesis, correctly nested.
- binary trees with $n + 1$ leaves (0 or 2 children).
- ordered trees with $n + 1$ vertices.
- ways a convex polygon with $n + 2$ sides can be cut into triangles by connecting vertices with straight lines.
- permutations of $[n]$ with no 3-term increasing subseq.

Data Structures (4)

OrderedSet.hpp

SparseTable.hpp

FenwickTree.hpp

2DFenwickTree.hpp

PersistentSegmentTree.hpp

LiChaoTree.hpp

BinaryTrie.hpp

StaticTopTree.hpp

template c topics

Treap.hpp

Various (5)

GaussianElimination.hpp

XORBasis.hpp

RangeXor.hpp

5.1 Optimization tricks

`_builtin_ia32_ldmxcsr(40896);` disables denormals (which make floats 20x slower near their minimum value).

5.1.1 Bit hacks

- $x \& -x$ is the least bit in x .
- `for (int x = m; x;) { --x &= m; ... }` loops over all subset masks of m (except m itself).
- $c = x \& -x$, $r = x + c$; $((r^x) >> 2) / c$ | r is the next number after x with the same number of bits set.
- `rep(b, 0, K) rep(i, 0, (1 << K)) if (i & 1 << b) D[i] += D[i^(1 << b)];` computes all sums of subsets.

5.1.2 Pragmas

- `#pragma GCC optimize ("Ofast")` will make GCC auto-vectorize loops and optimizes floating points better.
- `#pragma GCC target ("avx2")` can double performance of vectorized code, but causes crashes on old machines.
- `#pragma GCC optimize ("trapv")` kills the program on integer overflows (but is really slow).

Competitive Programming Topics

(6)

topics.txt

159 lines

Recursion
Divide and conquer
 Finding interesting points in $N \log N$
Algorithm analysis
 Master theorem
 Amortized time complexity
Greedy algorithm
 Scheduling
 Max contiguous subvector sum
Invariants
 Huffman encoding
Graph theory
 Dynamic graphs (extra book-keeping)
 Breadth first search
 Depth first search
 Normal trees / DFS trees
 Dijkstra's algorithm
 MST: Prim's algorithm

Bellman-Ford
König's theorem and vertex cover
Min-cost max flow
Lovasz toggle
Matrix tree theorem
Maximal matching, general graphs
Hopcroft-Karp
Hall's marriage theorem
Graphical sequences
Floyd-Warshall
Euler cycles
Flow networks
 * Augmenting paths
 * Edmonds-Karp
Bipartite matching
Min. path cover
Topological sorting
Strongly connected components
2-SAT
Cut vertices, cut-edges and biconnected components
Edge coloring
 * Trees
Vertex coloring
 * Bipartite graphs (\Rightarrow trees)
 * 3^n (special case of set cover)
Diameter and centroid
K'th shortest path
Shortest cycle
Dynamic programming
 Knapsack
 Coin change
 Longest common subsequence
 Longest increasing subsequence
 Number of paths in a dag
 Shortest path in a dag
 Dynprog over intervals
 Dynprog over subsets
 Dynprog over probabilities
 Dynprog over trees
 3^n set cover
 Divide and conquer
 Knuth optimization
 Convex hull optimizations
 RMQ (sparse table a.k.a 2^k -jumps)
 Bitonic cycle
 Log partitioning (loop over most restricted)
Combinatorics
 Computation of binomial coefficients
 Pigeon-hole principle
 Inclusion/exclusion
 Catalan number
 Pick's theorem
Number theory
 Integer parts
 Divisibility
 Euclidean algorithm
 Modular arithmetic
 * Modular multiplication
 * Modular inverses
 * Modular exponentiation by squaring
 Chinese remainder theorem
 Fermat's little theorem
 Euler's theorem
 Phi function
 Frobenius number
 Quadratic reciprocity
 Pollard-Rho
 Miller-Rabin
 Hensel lifting

Chula[What Name ?]

- Vieta root jumping
- Game theory
- Combinatorial games
- Game trees
- Mini-max
- Nim
- Games on graphs
- Games on graphs with loops
- Grundy numbers
- Bipartite games without repetition
- General games without repetition
- Alpha-beta pruning
- Probability theory
- Optimization
 - Binary search
 - Ternary search
 - Unimodality and convex functions
 - Binary search on derivative
- Numerical methods
 - Numeric integration
 - Newton's method
 - Root-finding with binary/ternary search
 - Golden section search
- Matrices
 - Gaussian elimination
 - Exponentiation by squaring
- Sorting
 - Radix sort
- Geometry
 - Coordinates and vectors
 - * Cross product
 - * Scalar product
 - Convex hull
 - Polygon cut
 - Closest pair
 - Coordinate-compression
 - Quadtreees
 - KD-trees
 - All segment-segment intersection
- Sweeping
 - Discretization (convert to events and sweep)
 - Angle sweeping
 - Line sweeping
 - Discrete second derivatives
- Strings
 - Longest common substring
 - Palindrome subsequences
 - Knuth-Morris-Pratt
 - Tries
 - Rolling polynomial hashes
 - Suffix array
 - Suffix tree
 - Aho-Corasick
 - Manacher's algorithm
 - Letter position lists
- Combinatorial search
 - Meet in the middle
 - Brute-force with pruning
 - Best-first (A*)
 - Bidirectional search
 - Iterative deepening DFS / A*
- Data structures
 - LCA (2^k -jumps in trees in general)
 - Pull/push-technique on trees
 - Heavy-light decomposition
 - Centroid decomposition
 - Lazy propagation
 - Self-balancing trees
 - Convex hull trick (wcipeg.com/wiki/Convex_hull_trick)

troubleshooting

Monotone queues / monotone stacks / sliding queues
 Sliding queue using 2 stacks
 Persistent segment tree

troubleshooting.txt

52 lines

Pre-submit:

Write a few simple test cases if sample is not enough.
 Are time limits close? If so, generate max cases.
 Is the memory usage fine?
 Could anything overflow?
 Make sure to submit the right file.

Wrong answer:

Print your solution! Print debug output, as well.
 Are you clearing all data structures between test cases?
 Can your algorithm handle the whole range of input?
 Read the full problem statement again.
 Do you handle all corner cases correctly?
 Have you understood the problem correctly?
 Any uninitialized variables?
 Any overflows?
 Confusing N and M, i and j, etc.?
 Are you sure your algorithm works?
 What special cases have you not thought of?
 Are you sure the STL functions you use work as you think?
 Add some assertions, maybe resubmit.
 Create some testcases to run your algorithm on.
 Go through the algorithm for a simple case.
 Go through this list again.

Explain your algorithm to a teammate.
 Ask the teammate to look at your code.
 Go for a small walk, e.g. to the toilet.
 Is your output format correct? (including whitespace)
 Rewrite your solution from the start or let a teammate do it.

Runtime error:

Have you tested all corner cases locally?
 Any uninitialized variables?
 Are you reading or writing outside the range of any vector?
 Any assertions that might fail?
 Any possible division by 0? (mod 0 for example)
 Any possible infinite recursion?
 Invalidated pointers or iterators?
 Are you using too much memory?
 Debug with resubmits (e.g. remapped signals, see Various).

Time limit exceeded:

Do you have any possible infinite loops?
 What is the complexity of your algorithm?
 Are you copying a lot of unnecessary data? (References)
 How big is the input and output? (consider scanf)
 Avoid vector, map. (use arrays/unordered_map)
 What do your teammates think about your algorithm?

Memory limit exceeded:

What is the max amount of memory your algorithm should need?
 Are you clearing all data structures between test cases?