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template from KACTL

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1 Template**2 Mathematics****3 Combinatorial****4 Data Structures****5 Number Theory****6 Graph****7 Tree****8 Polynomials****9 Strings****10 Geometry****11 Dynamic Programming****12 Convolutions****13 Various****14 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();
```

template c

```
1 const db EPS = 1e-9;
const db PI = acos(db(-1));

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

2 c.sh
2 g++ -std=gnu++2a -Wall $1 -o a.out
2 ./a.out
```

2 lines

2 Mathematics (2)**2.1 Goldbach's Conjecture**

- Even number can be written in sum of two primes (Up to 1e12)
- Range of N^{th} prime and $N + 1^{th}$ prime will be less than or equal to 300 (Up to 1e12)

2.2 Divisibility

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 .

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

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

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 ($g.x = x$).

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:

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

Euler-Maclaurin formula for infinite sums:

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

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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 j :s s.t. $\pi(j) > \pi(j+1)$, $k+1$ j :s s.t. $\pi(j) \geq j$, k j :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 : $n_1 n_2 \dots n_k n^{k-2}$

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

3.3.7 Catalan numbers

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

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

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

- 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
Treap.hpp

Number Theory (5)

ExtendedEuclid.hpp
euclid.h
CRT.hpp
phiFunction.hpp
FloorSum.hpp

5.1 Prime Numbers

MillerRabin.hpp
LinearSieve.hpp
FastEratosthenes.hpp
GolbachConjecture.hpp

Graph (6)

6.1 Matching
HopcroftKarp.hpp
Kuhn.hpp
WeightedMatching.hpp

6.2 Network Flow

Dinic.hpp

MinCostFlow.hpp

BinaryOptimization.hpp

KaryOptimization.hpp

6.3 Connectivity

SCC.hpp
LowLink.hpp

Tree (7)

HLD.hpp
CentroidDecom.hpp

Polynomials (8)

8.1 Newton's Method

if $F(Q) = 0$, then $Q_{2n} \equiv Q_n - \frac{F(Q_n)}{F'(Q_n)}$ (mod x^{2n})

$$Q = P^{-1} : Q_{2n} \equiv Q_n \cdot (2 - P \cdot Q_n^2) \pmod{x^{2n}}$$

$$Q = \ln P = \int \frac{P'}{P} dx$$

$$Q = e^P : Q_{2n} \equiv Q_n(1 + P - \ln Q_n) \pmod{x^{2n}}$$

$$Q = \sqrt{P} : Q_{2n} \equiv \frac{1}{2}(Q_n + P \cdot Q_n^{-1}) \pmod{x^{2n}}$$

$$Q = P^k = \alpha^k x^{kt} e^{k \ln T}; P = \alpha \cdot x^t \cdot T, T(0) = 1$$

FormalPowerSeries.hpp

FFT.hpp

NTT.hpp

Strings (9)

KMP.hpp
ZAlgo.hpp
AhoCorasick.hpp
Ukkonen.hpp
SuffixArray.hpp
PrefixFunction.hpp
SuffixAutomaton.hpp

Geometry (10)

10.1 Geometric primitives

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Point.h

lineDistance.h

SegmentDistance.h

SegmentIntersection.h

lineIntersection.h

sideOf.h

OnSegment.h

linearTransformation.h

LineProjectionReflection.h

Angle.h

10.2 Circles

CircleIntersection.h

CircleTangents.h

CircleLine.h

CirclePolygonIntersection.h

circumcircle.h

MinimumEnclosingCircle.h

10.3 Polygons

InsidePolygon.h

PolygonArea.h

PolygonCenter.h

PolygonCut.h

ConvexHull.h

HullDiameter.h

PointInsideHull.h

LineHullIntersection.h

10.4 Misc. Point Set Problems

ClosestPair.h

ManhattanMST.h

kdTree.h

DelaunayTriangulation.h

FastDelaunay.h

10.5 3D

PolyhedronVolume.h

Point3D.h

3dHull.h

sphericalDistance.h

ComplexGeometry.hpp

DefiniteIntegral.hpp

Dynamic Programming (11)

DVC.hpp

SlopeTrick.hpp

Convolutions (12)

AndConvolution.hpp

GCDConvolution.hpp

LCMConvolution.hpp

ORConvolution.hpp

XORConvolution.hpp

MaxPlusConvolution.hpp

Various (13)

GaussianElimination.hpp

XORBasis.hpp

RangeXor.hpp

13.1 Optimization tricks

`__builtin_ia32_ldmxcsr(40896);` disables denormals
(which make floats 20x slower near their minimum value).

13.1.1 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.

13.1.2 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).

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Competitive Programming Topics (14)

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
 Konig'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

topics troubleshooting

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
 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
 Quadtrees
 KD-trees
 All segment-segment intersection
 Sweeping
 Discretization (convert to events and sweep)
 Angle sweeping
 Line sweeping
 Discrete second derivatives
 Strings

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?

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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?