University of Tartu ICPC Team Notebook (2017-2018) September 29, 2018

Contents

1 Setup

```
set smartindent cindent
set ts=4 sw=4 expandtab
syntax enable
set clipboard=unnamedplus
"colorscheme elflord
"setxkbmap -option caps:escape
"setxkbmap -option
"valgrind --vgdb-error=0 ./a <inp &
"gdb a
"target remote | vgdb
```

2 crc.sh

```
#!/bin/envbash
starts=($(sed '/^\s*$/d' $1 | grep -n "//\!start" | cut -f1 -d:))
finishes=($(sed '/^\s*$/d' $1 | grep -n "//\!finish" | cut -f1 -d:))
for ((i=0;i<${#starts[@]};i++)); do
  for j in `seq 10 10 $((finishes[$i]-starts[$i]+8))`; do
    sed '/^\s*$/d' $1 | head -$((finishes[$i]-1)) | tail
    ↪  -$((finishes[$i]-starts[$i]-1)) | \
      head -$j | tr -d '[[:space:]]' | cksum | cut -f1 -d ' ' | tail -c
      ↪  4
  done #whistespaces don't matter
  echo #there shouldn't be any comments in the checked range
done #check last number in each block
```

3 gcc ordered set

```
#include <bits/stdc++.h>
typedef long long   ll;
using namespace std;
#include <ext/pb_ds/assoc_container.hpp>
#include <ext/pb_ds/tree_policy.hpp>
using namespace __gnu_pbds;
template <typename T>
using ordered_set = tree<T, null_type, less<T>, rb_tree_tag,
↪  tree_order_statistics_node_update>;
int main(){
  ordered_set<int>  cur;                                          #221
  cur.insert(1);
  cur.insert(3);
  cout << cur.order_of_key(2) << endl; // the number of elements in the
  ↪  set less than 2
  cout << *cur.find_by_order(0) << endl; // the 0-th smallest number in
  ↪  the set(0-based)
  cout << *cur.find_by_order(1) << endl; // the 1-th smallest number in
  ↪  the set(0-based)
}                                                                 %574
```

4 Numerical integration with Simpson's rule

```
//computing power = how many times function integrate gets called
template<typename T>
double simps(T f, double a, double b) {
  return (f(a) + 4*f((a+b)/2) + f(b))*(b-a)/6;
}
template<typename T>
double integrate(T f, double a, double b, double computing_power){
  double m = (a+b)/2;
  double l = simps(f,a,m), r = simps(f,m,b), tot=simps(f,a,b);
  if (computing_power < 1) return tot;
  return integrate(f, a, m, computing_power/2) + integrate(f, m, b,
  ↪  computing_power/2);                                          #430
}                                                                 %360
```

5 Triangle centers

```
const double min_delta = 1e-13;
const double coord_max = 1e6;
typedef complex < double > point;
point A, B, C; // vertixes of the triangle
bool collinear(){
  double min_diff = min(abs(A - B), min(abs(A - C), abs(B - C)));
  if(min_diff < coord_max * min_delta)
    return true;
  point sp = (B - A) / (C - A);
  double ang = M_PI/2-abs(abs(arg(sp))-M_PI/2); //positive angle with
  ↪  the real line                                                 #623
  return ang < min_delta;
}                                                                 %446
point circum_center(){
  if(collinear())
    return point(NAN,NAN);
  //squared lengths of sides
  double a2, b2, c2;
  a2 = norm(B - C);
  b2 = norm(A - C);
  c2 = norm(A - B);
  //barycentric coordinates of the circumcenter
  double c_A, c_B, c_C;
  c_A = a2 * (b2 + c2 - a2);//sin(2 * alpha) may be used as well
  c_B = b2 * (a2 + c2 - b2);                                      #385
  c_C = c2 * (a2 + b2 - c2);
  double sum = c_A + c_B + c_C;
  c_A /= sum;
  c_B /= sum;
  c_C /= sum;
  // cartesian coordinates of the circumcenter
  return c_A * A + c_B * B + c_C * C;
}                                                                 %742
point centroid(){ //center of mass
  return (A + B + C) / 3.0;
}
point ortho_center(){ //euler line
  point O = circum_center();
  return O + 3.0 * (centroid() - O);
};
point nine_point_circle_center(){ //euler line
  point O = circum_center();
  return O + 1.5 * (centroid() - O);                              #193
};                                                                %031
point in_center(){
  if(collinear())
    return point(NAN,NAN);
  double a, b, c; //side lengths
  a = abs(B - C);
  b = abs(A - C);
  c = abs(A - B);
  //trilinear coordinates are (1,1,1)
  //barycentric coordinates
  double c_A = a, c_B = b, c_C = c;
  double sum = c_A + c_B + c_C;
  c_A /= sum;                                                     #157
  c_B /= sum;
  c_C /= sum;
  // cartesian coordinates of the incenter
  return c_A * A + c_B * B + c_C * C;
}                                                                 %980
```

6 2D line segment

```
const long double PI = acos(-1.0L);
struct Vec {
  long double x, y;
  Vec& operator-=(Vec r) {
    x -= r.x, y -= r.y;
    return *this;
  }
  Vec operator-(Vec r) {return Vec(*this) -= r;}
  Vec& operator+=(Vec r) {
    x += r.x, y += r.y;                                           #054
    return *this;
  }
  Vec operator+(Vec r) {return Vec(*this) += r;}
  Vec operator-() {return {-x, -y};}
  Vec& operator*=(long double r) {
    x *= r, y *= r;
    return *this;
  }
  Vec operator*(long double r) {return Vec(*this) *= r;}
  Vec& operator/=(long double r) {                                #673
    x /= r, y /= r;
    return *this;
  }
  Vec operator/(long double r) {return Vec(*this) /= r;}
  long double operator*(Vec r) {
    return x * r.x + y * r.y;
  }
};
```

```cpp
ostream& operator<<(ostream& l, Vec r) {
  return l << '(' << r.x << ", " << r.y << ')';                  #724
}
long double len(Vec a) {
  return hypot(a.x, a.y);
}
long double cross(Vec l, Vec r) {
  return l.x * r.y - l.y * r.x;
}
long double angle(Vec a) {
  return fmod(atan2(a.y, a.x)+2*PI, 2*PI);
}                                                                 #872
Vec normal(Vec a) {
  return Vec({-a.y, a.x}) / len(a);
}                                                                 %654
```

```cpp
struct Segment {
  Vec a, b;
  Vec d() {
    return b-a;
  }
};
ostream& operator<<(ostream& l, Segment r) {
  return l << r.a << '-' << r.b;
}
Vec intersection(Segment l, Segment r) {                          #355
  Vec dl = l.d(), dr = r.d();
  if(cross(dl, dr) == 0)
    return {nanl(""), nanl("")};
  long double h = cross(dr, l.a-r.a) / len(dr);
  long double dh = cross(dr, dl) / len(dr);
  return l.a + dl * (h / -dh);
}
//Returns the area bounded by halfplanes
long double getArea(vector<Segment> lines) {
  long double lowerbound = -HUGE_VALL, upperbound = HUGE_VALL;
  vector<Segment> linesBySide[2];                                 #658
  for(auto line : lines) {
    if(line.b.y == line.a.y) {
      if(line.a.x < line.b.x) {
        lowerbound = max(lowerbound, line.a.y);
      } else {
        upperbound = min(upperbound, line.a.y);
      }
    } else if(line.a.y < line.b.y) {
      linesBySide[1].push_back(line);
    } else {                                                      #049
      linesBySide[0].push_back({line.b, line.a});
    }
  }
  sort(linesBySide[0].begin(), linesBySide[0].end(), [](Segment l, Segment r) {
    if(cross(l.d(), r.d()) == 0) return normal(l.d())*l.a > normal(r.d())*r.a;
    return cross(l.d(), r.d()) < 0;
  });
  sort(linesBySide[1].begin(), linesBySide[1].end(), [](Segment l, Segment r) {
    if(cross(l.d(), r.d()) == 0) return normal(l.d())*l.a < normal(r.d())*r.a;
    return cross(l.d(), r.d()) > 0;                               #434
  });
  //Now find the application area of the lines and clean up redundant ones
  vector<long double> applyStart[2];
  for(int side = 0; side < 2; side++) {
    vector<long double> &apply = applyStart[side];
    vector<Segment> curLines;
    for(auto line : linesBySide[side]) {
      while(curLines.size() > 0) {
        Segment other = curLines.back();
        if(cross(line.d(), other.d()) != 0) {
          long double start = intersection(line, other).y;        #501
          if(start > apply.back()) break;
        }
        curLines.pop_back();
        apply.pop_back();
      }
      if(curLines.size() == 0) {
        apply.push_back(-HUGE_VALL);
      } else {
        apply.push_back(intersection(line, curLines.back()).y);
      }                                                           #060
      curLines.push_back(line);
    }
    linesBySide[side] = curLines;
  }
  applyStart[0].push_back(HUGE_VALL);
  applyStart[1].push_back(HUGE_VALL);
  long double result = 0;
  {
    long double lb = -HUGE_VALL, ub;
    for(int i=0, j=0; i < (int)linesBySide[0].size() && j < (int)linesBySide[1].size();lb = ub) {   #349
      ub = min(applyStart[0][i+1], applyStart[1][j+1]);
      long double alb = lb, aub = ub;
      Segment l0 = linesBySide[0][i], l1 = linesBySide[1][j];
      if(cross(l1.d(), l0.d()) > 0) {
        alb = max(alb, intersection(l0, l1).y);
      } else if(cross(l1.d(), l0.d()) < 0) {
        aub = min(aub, intersection(l0, l1).y);
      }
      alb = max(alb, lowerbound);
      aub = min(aub, upperbound);                                 #419
      aub = max(aub, alb);
      {
        long double x1 = l0.a.x + (alb - l0.a.y) / l0.d().y * l0.d().x;
      long double x2 = l0.a.x + (aub - l0.a.y) / l0.d().y * l0.d().x;
      result -= (aub - alb) * (x1 + x2) / 2;
    }
    {
      long double x1 = l1.a.x + (alb - l1.a.y) / l1.d().y * l1.d().x;
      long double x2 = l1.a.x + (aub - l1.a.y) / l1.d().y * l1.d().x;
      result += (aub - alb) * (x1 + x2) / 2;                    #228
    }
    if(applyStart[0][i+1] < applyStart[1][j+1]) {
      i++;
    } else {
      j++;
    }
   }
  }
  return result;
}                                                               %011
```

7 Convex polygon algorithms

```
ll dot(const pair< int, int > &v1, const pair< int, int > &v2) {
  return (ll)v1.first * v2.first + (ll)v1.second * v2.second;
}
ll cross(const pair< int, int > &v1, const pair< int, int > &v2) {
  return (ll)v1.first * v2.second - (ll)v2.first * v1.second;
}
ll dist_sq(const pair< int, int > &p1, const pair< int, int > &p2) {
  return (ll)(p2.first - p1.first) * (p2.first - p1.first) +
         (ll)(p2.second - p1.second) * (p2.second - p1.second);
}                                                               %025
struct Hull {
  vector< pair< pair< int, int >, pair< int, int > > > hull;
  vector< pair< pair< int, int >, pair< int, int > > >::iterator
 ↪  upper_begin;
  template < typename Iterator >
  void extend_hull(Iterator begin, Iterator end) {  // O(n)
    vector< pair< int, int > > res;
    for (auto it = begin; it != end; ++it) {
      if (res.empty() || *it != res.back()) {
        while (res.size() >= 2) {
          auto v1 = make_pair(res[res.size() - 1].first -
           ↪  res[res.size() - 2].first,                        #048
                              res[res.size() - 1].second -
                               ↪  res[res.size() - 2].second);
          auto v2 = make_pair(it->first - res[res.size() - 2].first,
                              it->second - res[res.size() - 2].second);
          if (cross(v1, v2) > 0)
            break;
          res.pop_back();
        }
        res.push_back(*it);
      }
    }                                                           #901
    for (int i = 0; i < res.size() - 1; ++i)
      hull.emplace_back(res[i], res[i + 1]);
  }
  Hull(vector< pair< int, int > > &vert) {  // atleast 2 distinct
 ↪  points
    sort(vert.begin(), vert.end());          // O(n log(n))
    extend_hull(vert.begin(), vert.end());
    int diff = hull.size();
    extend_hull(vert.rbegin(), vert.rend());
    upper_begin = hull.begin() + diff;
  }                                                             %873
  bool contains(pair< int, int > p) {  // O(log(n))
    if (p < hull.front().first || p > upper_begin->first) return false;
    {
      auto it_low = lower_bound(hull.begin(), upper_begin,
                                make_pair(make_pair(p.first,
                                 ↪  (int)-2e9), make_pair(0, 0)));
      if (it_low != hull.begin())
        --it_low;
      auto v1 = make_pair(it_low->second.first - it_low->first.first,
                          it_low->second.second -
                           ↪  it_low->first.second);
      auto v2 = make_pair(p.first - it_low->first.first, p.second -
       ↪  it_low->first.second);                                #094
      if (cross(v1, v2) < 0)  // < 0 is inclusive, <=0 is exclusive
        return false;
    }
    {
      auto it_up = lower_bound(hull.rbegin(), hull.rbegin() +
       ↪  (hull.end() - upper_begin),
                               make_pair(make_pair(p.first, (int)2e9),
                                ↪  make_pair(0, 0)));
      if (it_up - hull.rbegin() == hull.end() - upper_begin)
        --it_up;
      auto v1 = make_pair(it_up->first.first - it_up->second.first,
                          it_up->first.second - it_up->second.second);
                           ↪  #900
      auto v2 = make_pair(p.first - it_up->second.first, p.second -
       ↪  it_up->second.second);
      if (cross(v1, v2) > 0)  // > 0 is inclusive, >=0 is exclusive
        return false;
    }
    return true;
  }                                                             %092
  template < typename T >  // The function can have only one local min
 ↪  and max and may be constant
                           // only at min and max.
  vector< pair< pair< int, int >, pair< int, int > > >::iterator max(
      function< T(const pair< pair< int, int >, pair< int, int > > &) >
       ↪  f) {  // O(log(n))
    auto l = hull.begin();
    auto r = hull.end();
    vector< pair< pair< int, int >, pair< int, int > > >::iterator best
     ↪  = hull.end();
    T best_val;
  while (r - l > 2) {
    auto mid = l + (r - l) / 2;
    T l_val = f(*l);                                              #242
    T l_nxt_val = f(*(l + 1));
    T mid_val = f(*mid);
    T mid_nxt_val = f(*(mid + 1));
    if (best == hull.end() ||
        l_val > best_val) {  // If max is at l we may remove it from
          ↪  the range.
      best = l;
      best_val = l_val;
    }
    if (l_nxt_val > l_val) {
      if (mid_val < l_val) {                                      #012
        r = mid;
      } else {
        if (mid_nxt_val > mid_val) {
          l = mid + 1;
        } else {
          r = mid + 1;
        }
      }
    } else {
      if (mid_val < l_val) {                                      #373
        l = mid + 1;
      } else {
        if (mid_nxt_val > mid_val) {
          l = mid + 1;
        } else {
          r = mid + 1;
        }
      }
    }
  }                                                               #332
  T l_val = f(*l);
  if (best == hull.end() || l_val > best_val) {
    best = l;
    best_val = l_val;
  }
  if (r - l > 1) {
    T l_nxt_val = f(*(l + 1));
    if (best == hull.end() || l_nxt_val > best_val) {
      best = l + 1;
      best_val = l_nxt_val;                                       #930
    }
  }
  return best;
}                                                                 %331
vector< pair< pair< int, int >, pair< int, int > > >::iterator
↪  closest(
    pair< int, int >
        p) {  // p can't be internal(can be on border), hull must
          ↪  have atleast 3 points
  const pair< pair< int, int >, pair< int, int > > &ref_p =
  ↪  hull.front();  // O(log(n))
  return max(function< double(const pair< pair< int, int >, pair<
  ↪  int, int > > &) >(
      [&p, &ref_p](const pair< pair< int, int >, pair< int, int > >
                      &seg) {  // accuracy of used type should be
                          coord^2
        if (p == seg.first) return 10 - M_PI;
        auto v1 =
            make_pair(seg.second.first - seg.first.first,
            ↪  seg.second.second - seg.first.second);            #685
        auto v2 = make_pair(p.first - seg.first.first, p.second -
        ↪  seg.first.second);
        ll cross_prod = cross(v1, v2);
        if (cross_prod > 0) {  // order the backside by angle
          auto v1 = make_pair(ref_p.first.first - p.first,
          ↪  ref_p.first.second - p.second);
          auto v2 = make_pair(seg.first.first - p.first,
          ↪  seg.first.second - p.second);
          ll dot_prod = dot(v1, v2);
          ll cross_prod = cross(v2, v1);
          return atan2(cross_prod, dot_prod) / 2;
        }
        ll dot_prod = dot(v1, v2);                                 #395
        double res = atan2(dot_prod, cross_prod);
        if (dot_prod <= 0 && res > 0) res = -M_PI;
        if (res > 0) {
          res += 20;
        } else {
          res = 10 - res;
        }
        return res;
      }));
}                                                                  %483
pair< int, int > forw_tan(pair< int, int > p) {  // can't be internal
↪  or on border
  const pair< pair< int, int >, pair< int, int > > &ref_p =
  ↪  hull.front();  // O(log(n))
  auto best_seg = max(function< double(const pair< pair< int, int >,
  ↪  pair< int, int > > &) >(
      [&p, &ref_p](const pair< pair< int, int >, pair< int, int > >
                      &seg) {  // accuracy of used type should be
                          coord^2
        auto v1 = make_pair(ref_p.first.first - p.first,
        ↪  ref_p.first.second - p.second);
        auto v2 = make_pair(seg.first.first - p.first,
        ↪  seg.first.second - p.second);
        ll dot_prod = dot(v1, v2);
        ll cross_prod = cross(v2, v1);       // cross(v1, v2) for
            back_tan!!!
        return atan2(cross_prod, dot_prod);  // order by signed
        ↪  angle                                                   #291
      }));
  return best_seg->first;
}                                                               %850
vector< pair< pair< int, int >, pair< int, int > > >::iterator
↪ max_in_dir(
    pair< int, int > v) {  // first is the ans. O(log(n))
  return max(function< ll(const pair< pair< int, int >, pair< int,
  ↪ int > > &) >(
      [&v](const pair< pair< int, int >, pair< int, int > > &seg) {
      ↪ return dot(v, seg.first); }));
}
pair< vector< pair< pair< int, int >, pair< int, int > > >::iterator,
      vector< pair< pair< int, int >, pair< int, int > > >::iterator
      ↪ >                                                       %013
intersections(pair< pair< int, int >, pair< int, int > > line) {  //
↪ O(log(n))
  int x = line.second.first - line.first.first;
  int y = line.second.second - line.first.second;
  auto dir = make_pair(-y, x);
  auto it_max = max_in_dir(dir);
  auto it_min = max_in_dir(make_pair(y, -x));
  ll opt_val = dot(dir, line.first);
  if (dot(dir, it_max->first) < opt_val || dot(dir, it_min->first) >
  ↪ opt_val)
    return make_pair(hull.end(), hull.end());
  vector< pair< pair< int, int >, pair< int, int > > >::iterator
  ↪ it_r1, it_r2;                                               #785
  function< bool(const pair< pair< int, int >, pair< int, int > > &,
                 const pair< pair< int, int >, pair< int, int > > &)
                 ↪ >
      inc_comp([&dir](const pair< pair< int, int >, pair< int, int >
      ↪ > &lft,
                      const pair< pair< int, int >, pair< int, int >
                      ↪ > &rgt) {
        return dot(dir, lft.first) < dot(dir, rgt.first);
      });
  function< bool(const pair< pair< int, int >, pair< int, int > > &,
                 const pair< pair< int, int >, pair< int, int > > &)
                 ↪ >
      dec_comp([&dir](const pair< pair< int, int >, pair< int, int >
      ↪ > &lft,
                      const pair< pair< int, int >, pair< int, int >
                      ↪ > &rgt) {                               #979
        return dot(dir, lft.first) > dot(dir, rgt.first);
      });
  if (it_min <= it_max) {
    it_r1 = upper_bound(it_min, it_max + 1, line, inc_comp) - 1;
    if (dot(dir, hull.front().first) >= opt_val) {
      it_r2 = upper_bound(hull.begin(), it_min + 1, line, dec_comp) -
      ↪ 1;
    } else {
      it_r2 = upper_bound(it_max, hull.end(), line, dec_comp) - 1;
    }
  } else {                                                      #684
    it_r1 = upper_bound(it_max, it_min + 1, line, dec_comp) - 1;
    if (dot(dir, hull.front().first) <= opt_val) {
      it_r2 = upper_bound(hull.begin(), it_max + 1, line, inc_comp) -
      ↪ 1;
    } else {
      it_r2 = upper_bound(it_min, hull.end(), line, inc_comp) - 1;
    }
  }
  return make_pair(it_r1, it_r2);
}                                                               %000
pair< pair< int, int >, pair< int, int > > diameter() {  // O(n)
  pair< pair< int, int >, pair< int, int > > res;
  ll dia_sq = 0;
  auto it1 = hull.begin();
  auto it2 = upper_begin;
  auto v1 = make_pair(hull.back().second.first -
  ↪ hull.back().first.first,
                      hull.back().second.second -
                      ↪ hull.back().first.second);
  while (it2 != hull.begin()) {
    auto v2 = make_pair((it2 - 1)->second.first - (it2 -
    ↪ 1)->first.first,
                        (it2 - 1)->second.second - (it2 -
                        ↪ 1)->first.second);                    #671
    ll decider = cross(v1, v2);
    if (decider > 0) break;
    --it2;
  }
  while (it2 != hull.end()) {  // check all antipodal pairs
    if (dist_sq(it1->first, it2->first) > dia_sq) {
      res = make_pair(it1->first, it2->first);
      dia_sq = dist_sq(res.first, res.second);
    }
    auto v1 =                                                   #674
        make_pair(it1->second.first - it1->first.first,
        ↪ it1->second.second - it1->first.second);
    auto v2 =
        make_pair(it2->second.first - it2->first.first,
        ↪ it2->second.second - it2->first.second);
    ll decider = cross(v1, v2);
    if (decider == 0) {  // report cross pairs at parallel lines.
      if (dist_sq(it1->second, it2->first) > dia_sq) {
        res = make_pair(it1->second, it2->first);
        dia_sq = dist_sq(res.first, res.second);
      }
      if (dist_sq(it1->first, it2->second) > dia_sq) {          #466
        res = make_pair(it1->first, it2->second);
        dia_sq = dist_sq(res.first, res.second);
      }
      ++it1;
      ++it2;
    } else if (decider < 0) {
      ++it1;
      } else {
        ++it2;
      }                                                          #502
    }
    return res;
  }
};                                                               %215
```

8 Aho Corasick $\mathcal{O}(|\text{alpha}|\sum \text{len})$

```
const int alpha_size=26;
struct node{
  node *nxt[alpha_size]; //May use other structures to move in trie
  node *suffix;
  node(){
    memset(nxt, 0, alpha_size*sizeof(node *));
  }
  int cnt=0;
};
node *aho_corasick(vector<vector<char> > &dict){                #480
  node *root= new node;
  root->suffix = 0;
  vector<pair<vector<char> *, node *> > cur_state;
  for(vector<char> &s : dict)
    cur_state.emplace_back(&s, root);
  for(int i=0; !cur_state.empty(); ++i){
    vector<pair<vector<char> *, node *> > nxt_state;
    for(auto &cur : cur_state){
      node *nxt=cur.second->nxt[(*cur.first)[i]];
      if(nxt){                                                   #888
        cur.second=nxt;
      }else{
        nxt = new node;
        cur.second->nxt[(*cur.first)[i]] = nxt;
        node *suf = cur.second->suffix;
        cur.second = nxt;
        nxt->suffix = root; //set correct suffix link
        while(suf){
          if(suf->nxt[(*cur.first)[i]]){
            nxt->suffix = suf->nxt[(*cur.first)[i]];             #786
            break;
          }
          suf=suf->suffix;
        }
      }
      if(cur.first->size() > i+1)
        nxt_state.push_back(cur);
    }
    cur_state=nxt_state;
  }                                                              #940
  return root;
}                                                                %064
//auxilary functions for searhing and counting
node *walk(node *cur, char c){ //longest prefix in dict that is suffix of walked string.
  while(true){
    if(cur->nxt[c])
      return cur->nxt[c];
    if(!cur->suffix)
      return cur;
    cur = cur->suffix;
  }
}                                                                %127
void cnt_matches(node *root, vector<char> &match_in){
  node *cur = root;
  for(char c : match_in){
    cur = walk(cur, c);
    ++cur->cnt;
  }
}                                                                %286
void add_cnt(node *root){ //After counting matches propagete ONCE to suffixes for final counts
  vector<node *> to_visit = {root};
  for(int i=0; i<to_visit.size(); ++i){
    node *cur = to_visit[i];
    for(int j=0; j<alpha_size; ++j){
      if(cur->nxt[j])
        to_visit.push_back(cur->nxt[j]);
    }
  }
  for(int i=to_visit.size()-1; i>0; --i)                         #865
    to_visit[i]->suffix->cnt += to_visit[i]->cnt;
}                                                                %313
int main(){ //http://codeforces.com/group/s3etJR5zZK/contest/212916/problem/4
  int n, len;
  scanf("%d %d", &len, &n);
  vector<char> a(len+1);
  scanf("%s", a.data());
  a.pop_back();
  for(char &c : a)
    c -= 'a';
  vector<vector<char> > dict(n);
  for(int i=0; i<n; ++i){
    scanf("%d", &len);
    dict[i].resize(len+1);
    scanf("%s", dict[i].data());
    dict[i].pop_back();
    for(char &c : dict[i])
      c -= 'a';
  }
  node *root = aho_corasick(dict);
  cnt_matches(root, a);
  add_cnt(root);
  for(int i=0; i<n; ++i){
    node *cur = root;
    for(char c : dict[i])
      cur = walk(cur, c);
    printf("%d\n", cur->cnt);
  }
}
```

9 Suffix automaton $\mathcal{O}((n+q)\log(|\textbf{alpha}|))$

```
class AutoNode {
 private:
  map< char, AutoNode * > nxt_char;  // Map is faster than hashtable and unsorted arrays
 public:
  int len; //Length of longest suffix in equivalence class.
  AutoNode *suf;
  bool has_nxt(char c) const {
    return nxt_char.count(c);
  }
  AutoNode *nxt(char c) {                                           #486
    if (!has_nxt(c))
      return NULL;
    return nxt_char[c];
  }
  void set_nxt(char c, AutoNode *node) {
    nxt_char[c] = node;
  }
  AutoNode *split(int new_len, char c) {
    AutoNode *new_n = new AutoNode;
    new_n->nxt_char = nxt_char;                                     #952
    new_n->len = new_len;
    new_n->suf = suf;
    suf = new_n;
    return new_n;
  }
  // Extra functions for matching and counting
  AutoNode *lower_depth(int depth) { //move to longest suffix of current with a maximum length of depth.
    if (suf->len >= depth)
      return suf->lower_depth(depth);
    return this;
  }                                                                 #795
  AutoNode *walk(char c, int depth, int &match_len) { //move to longest suffix of walked path that is a substring
    match_len = min(match_len, len); //includes depth limit(needed for finding matches)
    if (has_nxt(c)) {  //as suffixes are in classes match_len must be tracked externally
      ++match_len;
      return nxt(c)->lower_depth(depth);
    }
    if (suf)
      return suf->walk(c, depth, match_len);
    return this;
  }                                                                 #152
  int paths_to_end = 0;
  void set_as_end() { //All suffixes of current node are marked as ending nodes.
    paths_to_end = 1;
    if (suf) suf->set_as_end();
  }
  bool vis = false;
  void calc_paths_to_end() { //Call ONCE from ROOT. For each node calculates number of ways to reach an end node.
    if (!vis) {  //paths_to_end is ocurence count for any strings in current suffix equivalence class.
      vis = true;
      for (auto cur : nxt_char) {                                   #738
        cur.second->calc_paths_to_end();
        paths_to_end += cur.second->paths_to_end;
      }
    }
  }
};
struct SufAutomaton {
  AutoNode *last;
  AutoNode *root;
  void extend(char new_c) {                                         #885
    AutoNode *new_end = new AutoNode;
    new_end->len = last->len + 1;
    AutoNode *suf_w_nxt = last;
    while (suf_w_nxt && !suf_w_nxt->has_nxt(new_c)) {
      suf_w_nxt->set_nxt(new_c, new_end);
      suf_w_nxt = suf_w_nxt->suf;
    }
    if (!suf_w_nxt) {
      new_end->suf = root;
    } else {                                                        #873
      AutoNode *max_sbstr = suf_w_nxt->nxt(new_c);
      if (suf_w_nxt->len + 1 == max_sbstr->len) {
        new_end->suf = max_sbstr;
      } else {
        AutoNode *eq_sbstr = max_sbstr->split(suf_w_nxt->len + 1, new_c);
        new_end->suf = eq_sbstr
        AutoNode *w_edge_to_eq_sbstr = suf_w_nxt;
        while (w_edge_to_eq_sbstr != 0 && w_edge_to_eq_sbstr->nxt(new_c) == max_sbstr) {
          w_edge_to_eq_sbstr->set_nxt(new_c, eq_sbstr);
          w_edge_to_eq_sbstr = w_edge_to_eq_sbstr->suf;             #881
        }
      }
    }
    last = new_end;
  }
  SufAutomaton(string to_suffix) {
    root = new AutoNode;
    root->len = 0;
    root->suf = NULL;
    last = root;                                                    #935
    for (char c : to_suffix) extend(c);
  }
};                                                                    %543
```

```
#include <bits/stdc++.h>
using namespace std;
typedef long long              ll;\section{Dinic}

struct MaxFlow{
  typedef long long ll;
  const ll INF = 1e18;
  struct Edge{
    int u,v;
    ll c,rc;
    shared_ptr<ll> flow;
    Edge(int _u, int _v, ll _c, ll _rc = 0):u(_u),v(_v),c(_c),rc(_rc){
    }
  };                                                                  #787
  struct FlowTracker{
    shared_ptr<ll> flow;
    ll cap, rcap;
    bool dir;
    FlowTracker(ll _cap, ll _rcap, shared_ptr<ll> _flow, int _dir):cap(_cap),rcap(_rcap),flow(_flow),dir(_dir){ }
    ll rem() const {
      if(dir == 0){
        return cap-*flow;
      }
      else{                                                           #844
        return rcap+*flow;
      }
    }
    void add_flow(ll f){
      if(dir == 0)
        *flow += f;
      else
        *flow -= f;
      assert(*flow <= cap);
      assert(-*flow <= rcap);                                         #287
    }
    operator ll() const { return rem(); }
    void operator-=(ll x){ add_flow(x); }
    void operator+=(ll x){ add_flow(-x); }
  };
  int source,sink;
  vector<vector<int> > adj;
  vector<vector<FlowTracker> > cap;
  vector<Edge> edges;
  MaxFlow(int _source, int _sink):source(_source),sink(_sink){       #080
    assert(source != sink);
  }
  int add_edge(int u, int v, ll c, ll rc = 0){
    edges.push_back(Edge(u,v,c,rc));
    return edges.size()-1;
  }
  vector<int> now,lvl;
  void prep(){
    int max_id = max(source, sink);
    for(auto edge : edges)                                            #328
      max_id = max(max_id, max(edge.u, edge.v));
    adj.resize(max_id+1);
    cap.resize(max_id+1);
    now.resize(max_id+1);
    lvl.resize(max_id+1);
    for(auto &edge : edges){
      auto flow = make_shared<ll>(0);
      adj[edge.u].push_back(edge.v);
      cap[edge.u].push_back(FlowTracker(edge.c, edge.rc, flow, 0));
      if(edge.u != edge.v){                                           #717
        adj[edge.v].push_back(edge.u);
        cap[edge.v].push_back(FlowTracker(edge.c, edge.rc, flow, 1));
      }
      assert(cap[edge.u].back() == edge.c);
      edge.flow = flow;
    }
  }
  bool dinic_bfs(){
    fill(now.begin(),now.end(),0);
    fill(lvl.begin(),lvl.end(),0);                                    #038
    lvl[source] = 1;
    vector<int> bfs(1,source);
    for(int i = 0; i < bfs.size(); ++i){
      int u = bfs[i];
      for(int j = 0; j < adj[u].size(); ++j){
        int v = adj[u][j];
        if(cap[u][j] > 0 && lvl[v] == 0){
          lvl[v] = lvl[u]+1;
          bfs.push_back(v);
        }                                                             #010
      }
    }
    return lvl[sink] > 0;
  }
  ll dinic_dfs(int u, ll flow){
    if(u == sink)
      return flow;
    while(now[u] < adj[u].size()){
      int v = adj[u][now[u]];
      if(lvl[v] == lvl[u] + 1 && cap[u][now[u]] != 0){                #014
        ll res = dinic_dfs(v,min(flow,(ll)cap[u][now[u]]));
        if(res > 0){
          cap[u][now[u]] -= res;
          return res;
        }
      }
      ++now[u];
    }
    return 0;
  }                                                            #197
  ll calc_max_flow(){
    prep();
    ll ans = 0;
    while(dinic_bfs()){
      ll cur = 0;
      do{
        cur = dinic_dfs(source,INF);
        ans += cur;
      }while(cur > 0);
    }                                                          #817
    return ans;
  }
  ll flow_on_edge(int edge_index){
    assert(edge_index < edges.size());
    return *edges[edge_index].flow;
  }
};                                                             %583
int main(){
  int n,m;
  cin >> n >> m;
  vector<pair<int, pair<int, int> > > graph(m);
  for(int i=0; i<m; ++i){
    cin>>graph[i].second.first>>graph[i].second.second>>graph[i].first;
  }
  ll res=0;
  for(auto cur : graph){
    auto mf = MaxFlow(cur.second.first,cur.second.second); // arguments source and sink, memory usage O(largest node index + input size), sink doesn't need to be last index
    for(int i = 0; i < m; ++i){
      if(graph[i].first > cur.first){
        mf.add_edge(graph[i].second.first,graph[i].second.second,1,1); // store edge index if care about flow value
      }
    }
    res +=  mf.calc_max_flow();
  }
  cout<<res<<endl;
}
```

10 Min Cost Max Flow with succesive dijkstra $\mathcal{O}(\text{flow} \cdot n^2)$

```
const int nmax=1055;
const ll inf=1e14;
int t, n, v; //0 is source, v-1 sink
ll rem_flow[nmax][nmax]; //set [x][y] for directed capacity from x to y.
ll cost[nmax][nmax]; //set [x][y] for directed cost from x to y. SET TO inf IF NOT USED
ll min_dist[nmax];
int prev_node[nmax];
ll node_flow[nmax];
bool visited[nmax];                                            %576
ll tot_cost, tot_flow; //output
void min_cost_max_flow(){
  tot_cost=0;               //Does not work with negative cycles.
  tot_flow=0;
  ll sink_pot=0;
  min_dist[0] = 0;                                             %927
  for(int i=1; i<=v; ++i){ //incase of no negative edges Bellman-Ford can be removed.
    min_dist[i]=inf;
  }
  for(int i=0; i<v-1; ++i){
    for(int j=0; j<v; ++j){
      for(int k=0; k<v; ++k){
        if(rem_flow[j][k] > 0 && min_dist[j]+cost[j][k] < min_dist[k])
          min_dist[k] = min_dist[j]+cost[j][k];
      }
    }                                                          #599
  }
  for(int i=0; i<v; ++i){   //Apply potentials to edge costs.
    for(int j=0; j<v; ++j){
      if(cost[i][j]!=inf){
        cost[i][j]+=min_dist[i];
        cost[i][j]-=min_dist[j];
      }
    }
  }
  sink_pot+=min_dist[v-1]; //Bellman-Ford end.                 %849
  while(true){
    for(int i=0; i<=v; ++i){ //node after sink is used as start value for Dijkstra.
      min_dist[i]=inf;
      visited[i]=false;
    }
    min_dist[0]=0;
    node_flow[0]=inf;
    int min_node;
    while(true){ //Use Dijkstra to calculate potentials
      int min_node=v;                                          #782
      for(int i=0; i<v; ++i){
        if((!visited[i]) && min_dist[i]<min_dist[min_node])
          min_node=i;
      }
      if(min_node==v) break
      visited[min_node]=true;
      for(int i=0; i<v; ++i){
        if((!visited[i]) && min_dist[min_node]+cost[min_node][i] < min_dist[i]){
          min_dist[i]=min_dist[min_node]+cost[min_node][i];
          prev_node[i]=min_node;                               #881
          node_flow[i]=min(node_flow[min_node], rem_flow[min_node][i]);
        }
      }
    }
    if(min_dist[v-1]==inf) break
    for(int i=0; i<v; ++i){   //Apply potentials to edge costs.
      for(int j=0; j<v; ++j){ //Found path from source to sink becomes 0 cost.
        if(cost[i][j]!=inf){
          cost[i][j]+=min_dist[i];
          cost[i][j]-=min_dist[j];                              #083
        }
      }
    }
    sink_pot+=min_dist[v-1];
    tot_flow+=node_flow[v-1];
    tot_cost+=sink_pot*node_flow[v-1];
    int cur=v-1;
    while(cur!=0){ //Backtrack along found path that now has 0 cost.
      rem_flow[prev_node[cur]][cur]-=node_flow[v-1];
      rem_flow[cur][prev_node[cur]]+=node_flow[v-1];            #582
      cost[cur][prev_node[cur]]=0;
      if(rem_flow[prev_node[cur]][cur]==0)
        cost[prev_node[cur]][cur]=inf;
      cur=prev_node[cur];
    }
  }
}                                                               %803
int main(){//http://www.spoj.com/problems/GREED/
  cin>>t;
  for(int i=0; i<t; ++i){
    cin>>n;
    for(int j=0; j<nmax; ++j){
      for(int k=0; k<nmax; ++k){
        cost[j][k]=inf;
        rem_flow[j][k]=0;
      }
    }
    for(int j=1; j<=n; ++j){
      cost[j][2*n+1]=0;
      rem_flow[j][2*n+1]=1;
    }
    for(int j=1; j<=n; ++j){
      int card;
      cin>>card;
      ++rem_flow[0][card];
      cost[0][card]=0;
    }
    int ex_c;
    cin>>ex_c;
    for(int j=0; j<ex_c; ++j){
      int a, b;
      cin>>a>>b;
      if(b<a) swap(a,b);
      cost[a][b]=1;
      rem_flow[a][b]=nmax;
      cost[b][n+b]=0;
      rem_flow[b][n+b]=nmax;
      cost[n+b][a]=1;
      rem_flow[n+b][a]=nmax;
    }
    v=2*n+2;
    min_cost_max_flow();
    cout<<tot_cost<<'\n';
  }
}
```

11 Min Cost Max Flow with Cycle Cancelling $\mathcal{O}(\text{flow} \cdot nm)$

```
struct Network {
  struct Node;
  struct Edge {
    Node *u, *v;
    int f, c, cost;
    Node* from(Node* pos) {
      if(pos == u)
        return v;
      return u;
    }                                                           #042
    int getCap(Node* pos) {
      if(pos == u)
        return c-f;
      return f;
    }
    int addFlow(Node* pos, int toAdd) {
      if(pos == u) {
        f += toAdd;
        return toAdd * cost;
      } else {                                                  #965
        f -= toAdd;
        return -toAdd * cost;
      }
    }
  };
  struct Node {
    vector<Edge*> conn;
    int index;
  };
  deque<Node> nodes;                                            #534
  deque<Edge> edges;
  Node* addNode() {
    nodes.push_back(Node());
    nodes.back().index = nodes.size()-1;
    return &nodes.back();
  }
  Edge* addEdge(Node* u, Node* v, int f, int c, int cost) {
    edges.push_back({u, v, f, c, cost});
    u->conn.push_back(&edges.back());
    v->conn.push_back(&edges.back());                           #507
    return &edges.back();
  }
  //Assumes all needed flow has already been added
  int minCostMaxFlow() {
    int n = nodes.size();
    int result = 0;
    struct State {
      int p;
      Edge* used;
    };
    while(1) {                                                  #877
      vector<vector<State> > state(1, vector<State>(n, {0, 0}));
      for(int lev = 0; lev < n; lev++) {
        state.push_back(state[lev]);
        for(int i=0;i<n;i++){
          if(lev == 0 || state[lev][i].p < state[lev-1][i].p) {
            for(Edge* edge : nodes[i].conn){
              if(edge->getCap(&nodes[i]) > 0) {
                int np = state[lev][i].p + (edge->u == &nodes[i] ?
                ↪  edge->cost : -edge->cost);
                int ni = edge->from(&nodes[i])->index;
                if(np < state[lev+1][ni].p) {                   #281
                  state[lev+1][ni].p = np;
                  state[lev+1][ni].used = edge;
                }
              }
            }
          }
        }
      }
      //Now look at the last level
      bool valid = false;
      for(int i=0;i<n;i++)                                      #283
        if(state[n-1][i].p > state[n][i].p) {
          valid = true;
          vector<Edge*> path;
          int cap = 1000000000;
          Node* cur = &nodes[i];
          int clev = n;
          vector<bool> explr(n, false);
          while(!explr[cur->index]) {
            explr[cur->index] = true;
            State cstate = state[clev][cur->index];             #954
            cur = cstate.used->from(cur);
            path.push_back(cstate.used);
          }
          reverse(path.begin(), path.end() );
          {
            int i=0;
            Node* cur2 = cur;
            do {
              cur2 = path[i]->from(cur2);
              i++;                                              #990
            } while(cur2 != cur);
            path.resize(i);
          }
          for(auto edge : path) {
            cap = min(cap, edge->getCap(cur));
            cur = edge->from(cur);
          }
          for(auto edge : path) {
            result += edge->addFlow(cur, cap);
            cur = edge->from(cur);                              #599
          }
        }
      if(!valid) break;
    }
    return result;
  }
};                                                              %900
```

12 DMST $O(E \log V)$

```
struct EdgeDesc{
  int from, to, w;
};
struct DMST{
  struct Node;
  struct Edge{
    Node *from;
    Node *tar;
    int w;
    bool inc;                                                   #186
  };
  struct Circle{
    bool vis = false;
    vector<Edge *> contents;
    void clean(int idx);
  };
  const static greater<pair<ll, Edge *> > comp; //Can use inline static
  ↪  since C++17
  static vector<Circle> to_process;
  static bool no_dmst;
  static Node *root;                                            #536
  struct Node{
    Node *par = NULL;
    vector<pair<int, int> > out_cands; //Circ, edge idx
    vector<pair<ll, Edge *> > con;
    bool in_use = false;
    ll w = 0; //extra to add to edges in con
    Node *anc(){
      if(!par)
        return this;
      while(par->par)                                           #425
        par = par->par;
      return par;
    }
    void clean(){
      if(!no_dmst){
        in_use = false;
        for(auto &cur : out_cands)
          to_process[cur.first].clean(cur.second);
    }
  }                                                             #561
  Node *con_to_root(){
    if(anc() == root)
      return root;
    in_use = true;
    Node *super = this; //Will become root or the first Node encountered in a loop.
    while(super == this){
      while(!con.empty() && con.front().second->tar->anc() == anc()){
        pop_heap(con.begin(), con.end(), comp);
        con.pop_back();
      }                                                         #522
      if(con.empty()){
        no_dmst = true;
        return root;
      }
      pop_heap(con.begin(), con.end(), comp);
      auto nxt = con.back();
      con.pop_back();
      w = -nxt.first;
      if(nxt.second->tar->in_use){ //anc() wouldn't change anything
        super = nxt.second->tar->anc();                         #174
        to_process.resize(to_process.size()+1);
      } else {
        super = nxt.second->tar->con_to_root();
      }
      if(super != root){
        to_process.back().contents.push_back(nxt.second);
        out_cands.emplace_back(to_process.size()-1, to_process.back().contents.size()-1);
      } else { //Clean circles
        nxt.second->inc = true;
        nxt.second->from->clean();                              #629
      }
    }
    if(super != root){ //we are some loops non first Node.
      if(con.size() > super->con.size()){
        swap(con, super->con); //Largest con in loop should not be copied.
        swap(w, super->w);
      }
      for(auto cur : con){
        super->con.emplace_back(cur.first - super->w + w, cur.second);
        push_heap(super->con.begin(), super->con.end(), comp);  #375
      }
    }
    par = super; //root or anc() of first Node encountered in a loop
    return super;
  }
};
Node *cur_root;
vector<Node> graph;
vector<Edge> edges;
DMST(int n, vector<EdgeDesc> &desc, int r){ //Self loops and multiple edges are okay.  #076
  graph.resize(n);
  cur_root = &graph[r];
  for(auto &cur : desc) //Edges are reversed internally
    edges.push_back(Edge{&graph[cur.to], &graph[cur.from], cur.w});
  for(int i=0; i<desc.size(); ++i)
    graph[desc[i].to].con.emplace_back(desc[i].w, &edges[i]);
  for(int i=0; i<n; ++i)
    make_heap(graph[i].con.begin(), graph[i].con.end(), comp);
}
bool find(){                                                    #469
  root = cur_root;
  no_dmst = false;
  for(auto &cur : graph){
    cur.con_to_root();
    to_process.clear();
    if(no_dmst) return false;
  }
  return true;
}                                                               %732
ll weight(){
  ll res = 0;
  for(auto &cur : edges){
    if(cur.inc)
      res += cur.w;
  }
  return res;
}                                                               %477
};
void DMST::Circle::clean(int idx){
  if(!vis){
    vis = true;
    for(int i=0; i<contents.size(); ++i){
      if(i != idx){
        contents[i]->inc = true;
        contents[i]->from->clean();
      }
    }                                                           #711
  }
}
const greater<pair<ll, DMST::Edge *> > DMST::comp;
vector<DMST::Circle> DMST::to_process;
bool DMST::no_dmst;
DMST::Node *DMST::root;                                         %771
```

13 Bridges $\mathcal{O}(n)$

```
struct vert;
struct edge{
  bool exists = true;
  vert *dest;
  edge *rev;
  edge(vert *_dest) : dest(_dest){
    rev = NULL;
  }
  vert &operator*(){
    return *dest;                                         #955
  }
  vert *operator->(){
    return dest;
  }
  bool is_bridge();
};
struct vert{
  deque<edge> con;
  int val = 0;
  int seen;                                               #336
  int dfs(int upd, edge *ban){ //handles multiple edges
    if(!val){
      val = upd;
      seen = val;
      for(edge &nxt : con){
        if(nxt.exists  && (&nxt) != ban)
          seen = min(seen, nxt->dfs(upd+1, nxt.rev));
      }
    }
    return seen;                                          #673
  }                                                       %624
  void remove_adj_bridges(){
    for(edge &nxt : con){
      if(nxt.is_bridge())
        nxt.exists = false;
    }
  }                                                       %106
  int cnt_adj_bridges(){
    int res = 0;
    for(edge &nxt : con)
      res += nxt.is_bridge();
    return res;
  }                                                       %056
};
bool edge::is_bridge(){
  return exists && (dest->seen > rev->dest->val || dest->val < rev->dest->seen);
}                                                         %223
vert graph[nmax];
int main(){ //Mechanics Practice BRIDGES
  int n, m;
  cin>>n>>m;
  for(int i=0; i<m; ++i){
    int u, v;
    scanf("%d %d", &u, &v);
    graph[u].con.emplace_back(graph+v);
    graph[v].con.emplace_back(graph+u);
    graph[u].con.back().rev = &graph[v].con.back();
    graph[v].con.back().rev = &graph[u].con.back();
  }
  graph[1].dfs(1, NULL);
  int res = 0;
  for(int i=1; i<=n; ++i)
    res += graph[i].cnt_adj_bridges();
  cout<<res/2<<endl;
}
```

14 2-Sat $\mathcal{O}(n)$ and SCC $\mathcal{O}(n)$

```
struct Graph {
    int n;
    vector<vector<int> > conn;
    Graph(int nsize) {
        n = nsize;
        conn.resize(n);
    }
    void add_edge(int u, int v) {
        conn[u].push_back(v);
    }                                                     #078
    void _topsort_dfs(int pos, vector<int> &result, vector<bool> &explr, vector<vector<int> > &revconn) {
        if(explr[pos])
            return;
        explr[pos] = true;
        for(auto next : revconn[pos])
            _topsort_dfs(next, result, explr, revconn);
        result.push_back(pos);
    }
    vector<int> topsort() {
        vector<vector<int> > revconn(n);                  #346
        for(int u = 0; u < n; u++) {
            for(auto v : conn[u])
                revconn[v].push_back(u);
        }
        vector<int> result;
        vector<bool> explr(n, false);
        for(int i=0; i < n; i++)
            _topsort_dfs(i, result, explr, revconn);
        reverse(result.begin(), result.end());
        return result;                                    #991
    }
    void dfs(int pos, vector<int> &result, vector<bool> &explr) {
        if(explr[pos])
            return;
        explr[pos] = true;
        for(auto next : conn[pos])
            dfs(next, result, explr);
        result.push_back(pos);
    }                                                     %603
  vector<vector<int> > scc(){ // tested on https://www.hackerearth.com/practice/algorithms/graphs/strongly-connect
        vector<int> order = topsort();
    reverse(order.begin(),order.end());
```

```cpp
    vector<bool> explr(n, false);
  vector<vector<int> > results;
  for(auto it = order.rbegin(); it != order.rend(); ++it){
   vector<int> component;
   _topsort_dfs(*it,component,explr,conn);
   sort(component.begin(),component.end());
   results.push_back(component);                              #741
  }
  sort(results.begin(),results.end());
  return results;
 }
};                                                            %983
//Solution for: http://codeforces.com/group/PjzGiggT71/contest/221700/problem/C
int main() {
  int n, m;
  cin >> n >> m;
  Graph g(2*m);
  for(int i=0; i<n; i++) {
    int a, sa, b, sb;
    cin >> a >> sa >> b >> sb;
    a--, b--;
    g.add_edge(2*a + 1 - sa, 2*b + sb);
    g.add_edge(2*b + 1 - sb, 2*a + sa);
  }
  vector<int> state(2*m, 0);
  {
    vector<int> order = g.topsort();
    vector<bool> explr(2*m, false);
    for(auto u : order) {
      vector<int> traversed;
      g.dfs(u, traversed, explr);
      if(traversed.size() > 0 && !state[traversed[0]^1]) {
        for(auto c : traversed)
          state[c] = 1;
      }
    }
  }
  for(int i=0; i < m; i++) {
    if(state[2*i] == state[2*i+1]) {
      cout << "IMPOSSIBLE\n";
      return 0;
    }
  }
  for(int i=0; i < m; i++) {
    cout << state[2*i+1] << '\n';
  }
  return 0;
}
```

15 Lazy Segment Tree $\mathcal{O}(\log n)$ per query

```cpp
struct SegmentTree {
  struct Node {
    long long value = 0;
    int size = 1;
    int lazy_add = 0;
    bool lazy_set = false;
    int lazy_to_set = 0;
    void set(int to_set) {
      lazy_set = true;
      lazy_to_set = to_set;                                   #173
      lazy_add = 0;
    }
  };
  int n;
  vector<Node> nodes;
  void propagate(int pos) {
    Node& cur = nodes[pos];
    if(cur.lazy_set) {
      if(pos < n) {
        nodes[pos*2].set(cur.lazy_to_set);                    #388
        nodes[pos*2+1].set(cur.lazy_to_set);
      }
      cur.value = 1LL * cur.size * cur.lazy_to_set;
      cur.lazy_set = false;
    }
    if(cur.lazy_add != 0) {
      if(pos < n) {
        nodes[pos*2].lazy_add += cur.lazy_add;
        nodes[pos*2+1].lazy_add += cur.lazy_add;
      }                                                       #114
      cur.value += 1LL * cur.size * cur.lazy_add;
      cur.lazy_add = 0;
    }
  }
  long long get_value(int pos) {
    propagate(pos);
    return nodes[pos].value;
  }
  SegmentTree(int nsize) {
    n = 1;                                                    #759
    while(n < nsize) n*=2;
    nodes.resize(2*n);
    for(int i=n-1; i>0; i--)
      nodes[i].size = nodes[2*i].size * 2;
  }
  void set(int l, int r, int to_set, int pos = 1, int lb = 0, int rb = -1) {
    propagate(pos);
    if(rb == -1) rb = n;
    if(l <= lb && rb <= r) {
      nodes[pos].set(to_set);                                 #567
      return;
    }
    int mid = (lb + rb) / 2;
    if(l < mid)
      set(l, r, to_set, pos*2, lb, mid);
```

```
        if(mid < r)
            set(l, r, to_set, pos*2+1, mid, rb);
        nodes[pos].value = get_value(pos*2) + get_value(pos*2+1);
    }
    void add(int l, int r, int to_add, int pos = 1, int lb = 0, int rb = -1) {     #168
        propagate(pos);
        if(rb == -1) rb = n;
        if(l <= lb && rb <= r) {
            nodes[pos].lazy_add += to_add;
            return;
        }
        int mid = (lb + rb) / 2;
        if(l < mid)
            add(l, r, to_add, pos*2, lb, mid);
        if(mid < r)                                                                #620
            add(l, r, to_add, pos*2+1, mid, rb);
        nodes[pos].value = get_value(pos*2) + get_value(pos*2+1);
    }
    long long get(int l, int r, int pos = 1, int lb = 0, int rb = -1) {
        propagate(pos);
        if(rb == -1) rb = n;
        if(l <= lb && rb <= r) return get_value(pos);
        int mid = (lb + rb) / 2;
        long long result = 0;
        if(l < mid)                                                                #133
            result += get(l, r, pos*2, lb, mid);
        if(mid < r)
            result += get(l, r, pos*2+1, mid, rb);
        return result;
    }
};                                                                                 %280
//Solution for: http://codeforces.com/group/U01GDa2Gwb/contest/219104/problem/LAZY
int main() {
    int n, m;
    cin >> n >> m;
    SegmentTree stree(n);
    for(int i=0;i<n;i++) {
        int a;
        cin >> a;
        stree.set(i, i+1, a);
    }
    for(int i=0;i<m;i++) {
        int type;
        cin >> type;
        if(type == 1) {
            int l, r, d;
            cin >> l >> r >> d;
            stree.add(l-1, r, d);
        } else if(type == 2) {
            int l, r, x;
            cin >> l >> r >> x;
            stree.set(l-1, r, x);
        } else {
            int l, r;
            cin >> l >> r;
            cout << stree.get(l-1, r) << '\n';
        }
    }
}
```

16 Generic segment tree(lazy, noncommutative)

```
struct Segment{
  ll sum_val=0;
  ll min_val=0;
  void find_sum(int seg_len, ll &cur_sum){
    cur_sum = cur_sum + sum_val;
  }
  void find_min(int seg_len, ll &cur_min){
    cur_min = min(cur_min, min_val);
  }
  void recalc(int seg_len, const Segment &lhs_seg, const Segment &rhs_seg){      #599
    sum_val = lhs_seg.sum_val + rhs_seg.sum_val;
    min_val = min(lhs_seg.min_val, rhs_seg.min_val);
  }
};
struct Lazy{
  ll add_val;
  ll assign_val; //LLONG_MIN if no assign;
  void init(){
    add_val = 0;
    assign_val = LLONG_MIN;                                                       #577
  }
  Lazy(){ init(); }
  void apply_to_lazy(int seg_len, Lazy &child) const{
    if(assign_val != LLONG_MIN){
      child.add_val = 0;
      child.assign_val = assign_val;
    }
    child.add_val += add_val;
  }
  void apply_to_seg(int seg_len, Segment &cur) const{                             #523
    if(assign_val != LLONG_MIN){
      cur.min_val =  assign_val;
      cur.sum_val =  seg_len * assign_val;
    }
    cur.min_val += add_val;
    cur.sum_val += seg_len * add_val;
  } //Following code should not need to be modified                               %992
  void split(int seg_len, Lazy &lhs_lazy, Lazy &rhs_lazy){
    apply_to_lazy(seg_len, lhs_lazy); //Empty current and pass on to chidlren
    apply_to_lazy(seg_len, rhs_lazy);
    init();
  }
```

```
};
// Highly optimized generic segment tree with lazy propagation
class SegTree{ //indexes start from 0, ranges are [beg, end)
private:
  int offset;
  int height;                                                    #678
  Segment *segs;
  Lazy *lazys;
  vector<bool> is_lazy;
  void split(int len, int idx){
    is_lazy[idx] = false;
    lazys[idx].apply_to_seg(len/2, segs[2*idx]);
    lazys[idx].apply_to_seg(len/2, segs[2*idx+1]);
    lazys[idx].split(len/2, lazys[2*idx], lazys[2*idx+1]);
    is_lazy[2*idx] = true;
    is_lazy[2*idx+1] = true;                                     #984
  }
  void push(int bot_idx){
    for(int s = height-1; s>0; --s){
      int idx = bot_idx>>s;
      if(is_lazy[idx]){ //Lazys can be below other lazys
        split(1<<s, idx);
      }
    }
  }
  void build(int len, int idx){                                  #201
    for(; idx; len<<=1, idx>>=1){
      segs[idx].recalc(len, segs[2*idx], segs[2*idx+1]);
    }
  }
public:
  SegTree(int tree_size){
    offset = tree_size;
    height = 32 - __builtin_clz(tree_size);
    segs = new Segment[2*tree_size];
    lazys = new Lazy[2*tree_size];                               #920
    is_lazy.resize(2*tree_size, false);
  }
  ~SegTree(){
    delete[] segs;
    delete[] lazys;
  }
  void modify(int l, int r, const Lazy &upd){
    l+=offset;
    r+=offset;
    push(l);                                                     #744
    push(r-1);
    int len = 1;
    for(int l_tmp = l, r_tmp = r; l_tmp<r_tmp; l_tmp >>= 1, r_tmp >>= 1, len <<= 1){
      if(l_tmp & 1){
        upd.apply_to_lazy(len, lazys[l_tmp]);
        upd.apply_to_seg(len, segs[l_tmp]);
        is_lazy[l_tmp] = true;
        ++l_tmp;
      }
      if(r_tmp & 1){                                             #347
        --r_tmp;
        upd.apply_to_lazy(len, lazys[r_tmp]);
        upd.apply_to_seg(len, segs[r_tmp]);
        is_lazy[r_tmp] = true;
      }
    }
    len = 1<<(__builtin_ctz(l)+1);
    l >>=  __builtin_ctz(l) + 1;
    build(len, l);
    len = 1<<(__builtin_ctz(r)+1);                               #339
    r >>= __builtin_ctz(r) + 1;
    build(len, r);
  }
  template< typename ...QueryArgs >
  void query(int l, int r, void (Segment::*query_func)(int, QueryArgs...), QueryArgs &&...query_args){
    l+=offset;
    r+=offset;
    push(l);
    push(r-1);
    int len = 1;                                                 #008
    int r_orig = r;
    for(; l< r; l>>=1, r>>=1, len <<= 1){ //Segments apllied in order to querry
      if(l & 1){
        (segs[l++].*query_func)(len, query_args...);
      }
    }
    for(;r < r_orig;){
      r<<=1;
      len>>=1;
      if(r_orig & len){                                          #766
        (segs[r++].*query_func)(len, query_args...);
      }
    }
  }
};                                                               %509
int main(){
  int n, m; //solves Mechanics Practice LAZY
  cin>>n>>m;
  SegTree seg_tree(n);
  for(int i=0; i<n; ++i){
    Lazy tmp;
    scanf("%lld", &tmp.assign_val);
    seg_tree.modify(i, i+1, tmp);
  }
  for(int i=0; i<m; ++i){
    int o;
    int l, r;
    scanf("%d %d", &o, &l, &r);
    --l;
    if(o==1){
      Lazy tmp;
      scanf("%lld", &tmp.add_val);
      seg_tree.modify(l, r, tmp);
    } else if(o==2){
      Lazy tmp;
      scanf("%lld", &tmp.assign_val);
      seg_tree.modify(l, r, tmp);
    } else {
      ll res=0;
      seg_tree.query(l, r, &Segment::find_sum, res);
      printf("%lld\n",res);
    }
  }
}
```

17 Templated Persitent Segment Tree $\mathcal{O}(\log n)$ per query

```
template<typename T, typename comp>
class PersistentST {
  struct Node {
    Node *left, *right;
    int lend, rend;
    T value;
    Node (int position, T _value) {
      left = NULL;
      right = NULL;
      lend = position;                                    #479
      rend = position;
      value = _value;
    }
    Node (Node *_left, Node *_right) {
      left = _left;
      right = _right;
      lend = left->lend;
      rend = right->rend;
      value = comp()(left->value, right->value);
    }                                                     #373
    T query (int qleft, int qright) {
      qleft = max(qleft, lend);
      qright = min(qright, rend);
      if (qleft == lend && qright == rend) {
        return value;
      } else if (qleft > qright) {
        return comp().identity;
      } else {
        return comp()(left->query(qleft, qright), right->query(qleft, qright));
      }                                                   #766
    }
  };
  int size;
  Node **tree;
  vector<Node*> roots;
public:
  PersistentST () {}
  PersistentST (int _size, T initial) {
    for (int i = 0; i < 32; i++) {
      if ((1 << i) > _size) {                             #250
        size = 1 << i;
        break;
      }
    }
    tree = new Node* [2 * size + 5];
    for (int i = size; i < 2 * size; i++)
      tree[i] = new Node (i - size, initial);
    for (int i = size - 1; i > 0; i--)
      tree[i] = new Node (tree[2 * i], tree[2 * i + 1]);
    roots = vector<Node*> (1, tree[1]);                   #128
  }
  void set (int position, T _value) {
    tree[size + position] = new Node (position, _value);
    for (int i = (size + position) / 2; i >= 1; i /= 2)
      tree[i] = new Node (tree[2 * i], tree[2 * i + 1]);
    roots.push_back(tree[1]);
  }
  int last_revision () {
    return (int) roots.size() - 1;
  }                                                       #890
  T query (int qleft, int qright, int revision) {
    return roots[revision]->query(qleft, qright);
  }
  T query (int qleft, int qright) {
    return roots[last_revision()]->query(qleft, qright);
  }
};                                                        %280
```

18 Templated HLD $\mathcal{O}(M(n)\log n)$ per query

```
class dummy {
public:
  dummy () {}
  dummy (int, int) {}
  void set (int, int) {}
  int query (int left, int right) {
    cout << this << ' ' << left << ' ' << right << endl;
  }
};                                                        %932
/* T should be the type of the data stored in each vertex;
 * DS should be the underlying data structure that is used to peform the
 * group operation. It should have the following methods:
 * * DS () - empty constructor
 * * DS (int size, T initial) - constructs the structure with the given size,
 *   initially filled with initial.
 * * void set (int index, T value) - set the value at index `index` to `value`
```

```cpp
 * * T query (int left, int right) - return the "sum" of elements between left and right, inclusive.
 */
template<typename T, class DS>
class HLD {
  int vertexc;
  vector<int> *adj;
  vector<int> subtree_size;
  DS structure;
  DS aux;
  void build_sizes (int vertex, int parent) {
    subtree_size[vertex] = 1;
    for (int child : adj[vertex]) {                                      #037
      if (child != parent) {
        build_sizes(child, vertex);
        subtree_size[vertex] += subtree_size[child];
      }
    }
  }
  int cur;
  vector<int> ord;
  vector<int> chain_root;
  vector<int> par;                                                       #593
  void build_hld (int vertex, int parent, int chain_source) {
    cur++;
    ord[vertex] = cur;
    chain_root[vertex] = chain_source;
    par[vertex] = parent;
    if (adj[vertex].size() > 1) {
      int big_child, big_size = -1;
      for (int child : adj[vertex]) {
        if ((child != parent) && (subtree_size[child] > big_size)) {
          big_child = child;                                             #646
          big_size = subtree_size[child];
        }
      }
      build_hld(big_child, vertex, chain_source);
      for (int child : adj[vertex]) {
        if ((child != parent) && (child != big_child))
          build_hld(child, vertex, child);
      }
    }
  }                                                                      #738
public:
  HLD (int _vertexc) {
    vertexc = _vertexc;
    adj = new vector<int> [vertexc + 5];
  }
  void add_edge (int u, int v) {
    adj[u].push_back(v);
    adj[v].push_back(u);
  }
  void build (T initial) {                                               #841
    subtree_size = vector<int> (vertexc + 5);
    ord = vector<int> (vertexc + 5);
    chain_root = vector<int> (vertexc + 5);
    par = vector<int> (vertexc + 5);
    cur = 0;
    build_sizes(1, -1);
    build_hld(1, -1, 1);
    structure = DS (vertexc + 5, initial);
    aux = DS (50, initial);
  }                                                                      #793
  void set (int vertex, int value) {
    structure.set(ord[vertex], value);
  }
  T query_path (int u, int v) { /* returns the "sum" of the path u->v */
    int cur_id = 0;
    while (chain_root[u] != chain_root[v]) {
      if (ord[u] > ord[v]) {
        cur_id++;
        aux.set(cur_id, structure.query(ord[chain_root[u]], ord[u]));
        u = par[chain_root[u]];                                          #517
      } else {
        cur_id++;
        aux.set(cur_id, structure.query(ord[chain_root[v]], ord[v]));
        v = par[chain_root[v]];
      }
    }
    cur_id++;
    aux.set(cur_id, structure.query(min(ord[u], ord[v]), max(ord[u], ord[v])));
    return aux.query(1, cur_id);
  }                                                                      %257
  void print () {
    for (int i = 1; i <= vertexc; i++)
      cout << i << ' ' << ord[i] << ' ' << chain_root[i] << ' ' << par[i] << endl;
  }
};
int main () {
  int vertexc;
  cin >> vertexc;
  HLD<int, dummy> hld (vertexc);
  for (int i = 0; i < vertexc - 1; i++) {
    int u, v;
    cin >> u >> v;
    hld.add_edge(u, v);
  }
  hld.build(0);
  hld.print();
  int queryc;
  cin >> queryc;
  for (int i = 0; i < queryc; i++) {
    int u, v;
    cin >> u >> v;
    hld.query_path(u, v);
    cout << endl;
  }
}
```

19 Templated multi dimensional BIT $\mathcal{O}(\log(n)^{\mathbf{dim}})$ per query

```cpp
// Fully overloaded any dimensional BIT, use any type for coordinates,
    elements, return_value.
// Includes coordinate compression.
template < typename elem_t, typename coord_t, coord_t n_inf, typename
  ↪  ret_t >
class BIT {
  vector< coord_t > positions;
  vector< elem_t > elems;
  bool initiated = false;
 public:
  BIT() {
    positions.push_back(n_inf);
  }
  void initiate() {                                               #448
    if (initiated) {
      for (elem_t &c_elem : elems)
        c_elem.initiate();
    } else {
      initiated = true;
      sort(positions.begin(), positions.end());
      positions.resize(unique(positions.begin(), positions.end()) -
        ↪  positions.begin());
      elems.resize(positions.size());
    }
  }                                                               #036
  template < typename... loc_form >
  void update(coord_t cord, loc_form... args) {
    if (initiated) {
      int pos = lower_bound(positions.begin(), positions.end(), cord) -
        ↪  positions.begin();
      for (; pos < positions.size(); pos += pos & -pos)
        elems[pos].update(args...);
    } else {
      positions.push_back(cord);
    }
  }                                                               #154
  template < typename... loc_form >
  ret_t query(coord_t cord, loc_form... args) { //sum in open interval
    ↪  (-inf, cord)
    ret_t res = 0;
    int pos = (lower_bound(positions.begin(), positions.end(), cord) -
      ↪  positions.begin())-1;
    for (; pos > 0; pos -= pos & -pos)
      res += elems[pos].query(args...);
    return res;
  }
};
template < typename internal_type >                               #895
struct wrapped {
  internal_type a = 0;
  void update(internal_type b) {
    a += b;
  }
  internal_type query() {
    return a;
  }
  // Should never be called, needed for compilation
  void initiate() {
    cerr << 'i' << endl;                                          #560
  }
  void update() {
    cerr << 'u' << endl;
  }
};                                                                %714
int main() {
  // retun type should be same as type inside wrapped
  BIT< BIT< wrapped< ll >, int, INT_MIN, ll >, int, INT_MIN, ll >
    ↪  fenwick;
  int dim = 2;
  vector< tuple< int, int, ll > > to_insert;
  to_insert.emplace_back(1, 1, 1);
  // set up all positions that are to be used for update
  for (int i = 0; i < dim; ++i) {
    for (auto &cur : to_insert)
      fenwick.update(get< 0 >(cur), get< 1 >(cur));  // May include
        ↪  value which won't be used
    fenwick.initiate();
  }
  // actual use
  for (auto &cur : to_insert)
    fenwick.update(get< 0 >(cur), get< 1 >(cur), get< 2 >(cur));
  cout << fenwick.query(2, 2)<<'\n';
}
```

20 Treap $\mathcal{O}(\log n)$ per query

```cpp
mt19937 randgen;
struct Treap {
    struct Node {
        int key;
        int value;
        unsigned int priority;
        long long total;
        Node* lch;
        Node* rch;
        Node(int new_key, int new_value) {                        #698
            key = new_key;
            value = new_value;
            priority = randgen();
            total = new_value;
            lch = 0;
            rch = 0;
        }
        void update() {
            total = value;
            if(lch) total += lch->total;                            #295
            if(rch) total += rch->total;
        }
    };
    deque<Node> nodes;
    Node* root = 0;
    pair<Node*, Node*> split(int key, Node* cur) {
        if(cur == 0) return {0, 0};
        pair<Node*, Node*> result;
        if(key <= cur->key) {
            auto ret = split(key, cur->lch);                        #233
            cur->lch = ret.second;
            result = {ret.first, cur};
        } else {
            auto ret = split(key, cur->rch);
            cur->rch = ret.first;
            result = {cur, ret.second};
        }
        cur->update();
        return result;
    }                                                               #230
    Node* merge(Node* left, Node* right) {
        if(left == 0) return right;
        if(right == 0) return left;
        Node* top;
        if(left->priority < right->priority) {
            left->rch = merge(left->rch, right);
            top = left;
        } else {
            right->lch = merge(left, right->lch);
            top = right;                                            #510
        }
        top->update();
        return top;
    }
    void insert(int key, int value) {
        nodes.push_back(Node(key, value));
        Node* cur = &nodes.back();
        pair<Node*, Node*> ret = split(key, root);
        cur = merge(ret.first, cur);
        cur = merge(cur, ret.second);                               #760
        root = cur;
    }
    void erase(int key) {
        Node *left, *mid, *right;
        tie(left, mid) = split(key, root);
        tie(mid, right) = split(key+1, mid);
        root = merge(left, right);
    }
    long long sum_upto(int key, Node* cur) {
        if(cur == 0) return 0;                                      #634
        if(key <= cur->key) {
            return sum_upto(key, cur->lch);
        } else {
            long long result = cur->value + sum_upto(key, cur->rch);
            if(cur->lch) result += cur->lch->total;
            return result;
        }
    }
    long long get(int l, int r) {
        return sum_upto(r+1, root) - sum_upto(l, root);             #509
    }
};                                                                  %959
//Solution for:
↪ http://codeforces.com/group/U01GDa2Gwb/contest/219104/problem/TREAP
int main() {
    ios_base::sync_with_stdio(false);
    cin.tie(0);
    int m;
    Treap treap;
    cin >> m;
    for(int i=0;i<m;i++) {
        int type;
        cin >> type;
        if(type == 1) {
            int x, y;
            cin >> x >> y;
            treap.insert(x, y);
        } else if(type == 2) {
            int x;
            cin >> x;
            treap.erase(x);
        } else {
            int l, r;
            cin >> l >> r;
            cout << treap.get(l, r) << endl;
        }
    }
    return 0;
}
```

21 FFT 5M length/sec

```
struct Complex{
  double a=0, b=0;
  Complex &operator/=(const int &oth){
    a /= oth;
    b /= oth;
    return *this;
  }
};
Complex operator+(const Complex &lft, const Complex &rgt){
  return Complex {lft.a+rgt.a, lft.b+rgt.b};                        #384
}
Complex operator-(const Complex &lft, const Complex &rgt){
  return Complex {lft.a-rgt.a, lft.b-rgt.b};
}
Complex operator*(const Complex &lft, const Complex &rgt){
  return Complex {lft.a*rgt.a-lft.b*rgt.b, lft.a*rgt.b+lft.b*rgt.a};
}
void fft_rec(Complex *arr, Complex *root_pow, int len){
  if(len != 1){
    fft_rec(arr, root_pow, len>>1);                              #767
    fft_rec(arr+len, root_pow, len>>1);
  }
  root_pow += len;
  for(int i=0; i < len; ++i){
    Complex tmp = arr[i]+root_pow[i]*arr[i+len];
    arr[i+len] = arr[i]-root_pow[i]*arr[i+len];
    arr[i] = tmp;
  }
}
void fft(vector<Complex> &arr, int ord, bool invert){            #689
  assert(arr.size() == 1<<ord);
  static vector<Complex> root_pow(1);
  static int inc_pow = 1;
  static bool is_inv = false;
  if(inc_pow <= ord){
    int idx = root_pow.size();
    root_pow.resize(1<<ord);
    for(; inc_pow<=ord; ++inc_pow){
      for(int idx_p = 0; idx_p < 1<<(ord-1); idx_p += 1<<(ord-inc_pow), ++idx){
        root_pow[idx] = Complex {cos(-idx_p*M_PI/(1<<(ord-1))), sin(-idx_p*M_PI/(1<<(ord-1)))};   #830
        if(is_inv)
          root_pow[idx].b = -root_pow[idx].b;
      }
    }
  }
  if(invert != is_inv){
    is_inv = invert;
    for(Complex &cur : root_pow)
      cur.b = -cur.b;
  }                                                              #717
  int rev = 0;
  for(int i=0; i < (1<<ord)-1; ++i){
    if(i < rev)
      swap(arr[i], arr[rev]);
    int j=0;
    do{
      rev ^= 1<<(ord-1-j);
    } while(i & 1<<(j++));
  }
  fft_rec(arr.data(), root_pow.data(), 1<<(ord-1));              #351
  if(invert)
    for(int i=0; i< (1<<ord); ++i)
      arr[i] /= (1<<ord);
}                                                                %402
void mult_poly_mod(vector<int> &a, vector<int> &b, vector<int> &c){ // c += a*b
  static vector<Complex> arr[7]; //correct upto 0.5-2M elements(mod ~= 1e9)
  if(c.size() < 400){
    for(int i=0; i < (int)a.size(); ++i)
      for(int j=0; j < (int)b.size() && i+j < (int)c.size(); ++j)
        c[i+j] = ((ll)a[i]*b[j]+c[i+j])%mod;
  } else {
    int fft_ord = 32-__builtin_clz(c.size());
    if((int)arr[0].size() < 1<<fft_ord)
      for(int i=0; i<7; ++i)                                     #082
        arr[i].resize(1<<fft_ord);
    for(int i=0; i<7; ++i)
      fill(arr[i].begin(), arr[i].end(), Complex{});
    for(int &cur : a)
      if(cur < 0)
        cur += mod;
    for(int &cur : b)
      if(cur < 0)
        cur += mod;
    const int shift = 15;                                        #019
    const int mask = (1<<shift)-1;
    for(int i=0; i < (int)min(a.size(), c.size()); ++i){
      arr[0][i].a = a[i]&mask;
      arr[1][i].a = a[i]>>shift;
    }
    for(int i=0; i < (int)min(b.size(), c.size()); ++i){
      arr[2][i].a = b[i]&mask;
      arr[3][i].a = b[i]>>shift;
    }
    for(int i=0; i<4; ++i)                                       #432
      fft(arr[i], fft_ord, false);
    for(int i=0; i<2; ++i){
      for(int j=0; j<2; ++j){
        int tar = 4+i+j;
        for(int k=0; k<(1<<fft_ord); ++k)
          arr[tar][k] = arr[tar][k] + arr[i][k] * arr[2+j][k];
      }
    }
    for(int i=4; i<7; ++i){
      fft(arr[i], fft_ord, true);                                #272
      for(int k=0; k<(int)c.size(); ++k)
        c[k] = (c[k]+(((ll)(arr[i][k].a+0.5)%mod)<<(shift*(i-4))))%mod;
    }
  }
}                                                                %089
```

22 Rabbin Miller prime check

```
__int128 pow_mod(__int128 a, ll n, __int128 mod) {
  __int128 res = 1;
  for (ll i = 0; i < 64; ++i) {
    if (n & (1LL << i))
      res = (res * a) % mod;
    a = (a * a) % mod;
  }
  return res;
}
bool is_prime(ll n) { //guaranteed for 64 bit numbers                 #280
  if (n == 2 || n == 3) return true;
  if (!(n & 1) || n == 1) return false;
  static vector< char > witnesses = {2, 3, 5, 7, 11, 13, 17, 19, 23,
  ↪  29, 31, 37};
  ll s = __builtin_ctz(n - 1);
  ll d = (n - 1) >> s;
  __int128 mod = n;
  for (__int128 a : witnesses) {
    if (a >= mod) break;
    a = pow_mod(a, d, mod);
    if (a == 1 || a == mod - 1) continue;                              #667
    for (ll r = 1; r < s; ++r) {
      a = a * a % mod;
      if (a == 1) return false;
      if (a == mod - 1) break;
    }
    if (a != mod - 1) return false;
  }
  return true;
}                                                                      %083
```

Useful formulas

$\binom{n}{k} = \frac{n!}{k!(n-k)!}$ — number of ways to choose k objects out of n

$\binom{n+k-1}{k-1}$ — number of ways to choose k objects out of n with repetitions

$\left[{n \atop m}\right]$ — Stirling numbers of the first kind; number of permutations of n elements with k cycles

$\left[{n+1 \atop m}\right] = n\left[{n \atop m}\right] + \left[{n \atop m-1}\right]$

$(x)_n = x(x-1)\ldots x-n+1 = \sum\limits_{k=0}^{n} (-1)^{n-k}\left[{n \atop k}\right]x^k$

$\left\{{n \atop m}\right\}$ — Stirling numbers of the second kind; number of partitions of set $1,\ldots,n$ into k disjoint subsets.

$\left\{{n+1 \atop m}\right\} = k\left\{{n \atop k}\right\} + \left\{{n \atop k-1}\right\}$

$\sum\limits_{k=0}^{n} \left\{{n \atop k}\right\}(x)_k = x^n$

$C_n = \frac{1}{n+1}\binom{2n}{n}$ — Catalan numbers

$C(x) = \frac{1-\sqrt{1-4x}}{2x}$

Binomial transform

If $a_n = \sum\limits_{k=0}^{n} \binom{n}{k} b_k$, then $b_n = \sum\limits_{k=0}^{n} (-1)^{n-k}\binom{n}{k} a_k$

- $a = (1, x, x^2, \ldots), b = (1, (x+1), (x+1)^2, \ldots)$
- $a_i = i^k, b_i = \left\{{n \atop i}\right\} i!$

Burnside's lemma

Let G be a group of *action* on set X (Ex.: cyclic shifts of array, rotations and symmetries of $n \times n$ matrix, ...)

Call two objects x and y *equivalent* if there is an action f that transforms x to y: $f(x) = y$.

The number of equivalence classes then can be calculated as follows: $C = \frac{1}{|G|} \sum\limits_{f \in G} |X^f|$, where X^f is the set of *fixed points* of f: $X^f = \{x | f(x) = x\}$

Generating functions

Ordinary generating function (o.g.f.) for sequence $a_0, a_1, \ldots, a_n, \ldots$ is $A(x) = \sum\limits_{n=0}^{\infty} a_i x^i$

Exponential generating function (e.g.f.) for sequence $a_0, a_1, \ldots, a_n, \ldots$ is $A(x) = \sum\limits_{n=0}^{\infty} a_i x^i$

$B(x) = A'(x), b_{n-1} = n \cdot a_n$

$c_n = \sum\limits_{k=0}^{n} a_k b_{n-k}$ (o.g.f. convolution)

$c_n = \sum\limits_{k=0}^{n} \binom{n}{k} a_k b_{n-k}$ (e.g.f. convolution, compute with FFT using $\widetilde{a_n} = \frac{a_n}{n!}$)

General linear recurrences

If $a_n = \sum\limits_{k=1}^{n} b_k a_{n-k}$, then $A(x) = \frac{a_0}{1-B(x)}$. We also can compute all a_n with Divide-and-Conquer algorithm in $O(n \log^2 n)$.

Inverse polynomial modulo x^l

Given $A(x)$, find $B(x)$ such that $A(x)B(x) = 1 + x^l \cdot Q(x)$ for some $Q(x)$

1. Start with $B_0(x) = \frac{1}{a_0}$
2. Double the length of $B(x)$: $B_{k+1}(x) = (-B_k(x)^2 A(x) + 2B_k(x)) \mod x^{2^{k+1}}$

Fast subset convolution

Given array a_i of size 2^k, calculate $b_i = \sum\limits_{j \& i = i} b_j$

```
for b = 0..k-1
  for i = 0..2^k-1
    if (i & (1 << b)) != 0:
      a[i + (1 << b)] += a[i]
```

Hadamard transform

Treat array a of size 2^k as k-dimentional array of size $2 \times 2 \times \ldots \times 2$, calculate FFT of that array:

```
for b = 0..k-1
  for i = 0..2^k-1
    if (i & (1 << b)) != 0:
      u = a[i], v = a[i + (1 << b)]
      a[i] = u + v
      a[i + (1 << b)] = u - v
```