目录

数学

快速求逆元 (内含 exgcd)

使用条件：$x \in [0, mod)$ 并且 x 与 mod 互质

```
LL exgcd(LL a, LL b, LL &x, LL &y) {
  if(!b) return x = 1, y = 0, a;
  else {
    LL d = exgcd(b, a % b, x, y);
    LL t = x;  x = y;
    y = t - a / b * y;
    return d;
  }
}

LL inv(LL a, LL p) {
  LL d, x, y;
  exgcd(a, p, d, x, y);
  return d == 1 ? (x + p) % p : -1;
}
```

中国剩余定理

返回结果：$x \equiv r_i (mod\ \ p_i)\ \ (0 \le i < n)$

```
LL china(int n, int *a, int *m) {
  LL M = 1, d, x = 0, y;
  for(int i = 0; i < n; i++)
    M *= m[i];
  for(int i = 0; i < n; i++) {
    LL w = M / m[i];
    d = exgcd(m[i], w, d, y);
    y = (y % M + M) % M;
    x = (x + y * w % M * a[i]) % M;
  }
  while(x < 0)x += M;
  return x;
}

//merge Ax=B and ax=b to A'x=B'
void merge(LL &A,LL &B,LL a,LL b){
  LL x,y;
  sol(A,-a,b-B,x,y);
  A=lcm(A,a);
  B=(a*y+b)%A;
  B=(B+A)%A;
}
```

小步大步

返回结果：$a^x = b\ \ (mod\ \ p)$ 使用条件：p 为质数

```
LL BSGS(LL a,LL b,LL p){
  LL m=0;for(;m*m<=p;m++);
  map<LL,int>hash;hash[1]=0;
  LL e=1,amv=inv(pw(a,m,p),p);
  for(int i=1;i<m;i++){
    e=e*a%p;
    if(!hash.count(e))
      hash[e]=i;
    else break;
  }
  for(int i=0;i<m;i++){
    if(hash.count(b))
      return hash[b]+i*m;
    b=b*amv%p;
  }
  return -1;
}
LL solve2(LL a,LL b,LL p){
  //a^x=b (mod p)
  b%=p;
  LL e=1%p;
  for(int i=0;i<100;i++){
    if(e==b)return i;
    e=e*a%p;
  }
  int r=0;
  while(gcd(a,p)!=1){
    LL d=gcd(a,p);
    if(b%d)return -1;
    p/=d;b/=d;b=b*inv(a/d,p);
    r++;
  }LL res=BSGS(a,b,p);
  if(res==-1)return -1;
  return res+r;
}
```

Miller Rabin 素数测试

```
const int BASE[12] = {2, 3, 5, 7, 11, 13, 17, 19, 23, 29, 31, 37};
bool check(long long n, int base) {
  long long n2 = n - 1, res; int s = 0;
  while(n2 % 2 == 0) n2 >>= 1, s++;
  res = pw(base, n2, n);
  if((res == 1) || (res == n - 1)) return 1;
  while(s--) {
    res = mul(res, res, n);
```

```
    if(res == n - 1) return 1;
  }
  return 0; // n is not a strong pseudo prime
}
bool isprime(const long long &n) {
  if(n == 2) return true;
  if(n < 2 || n % 2 == 0) return false;
  for(int i = 0; i < 12 && BASE[i] < n; i++)
    if(!check(n, BASE[i])) return false;
  return true;
}
```

Pollard Rho 大数分解

```
LL prho(LL n, LL c) {
  LL i = 1, k = 2, x = rand() % (n - 1) + 1, y = x;
  while(1) {
    i++; x = (x * x % n + c) % n;
    LL d = __gcd((y - x + n) % n, n);
    if(d > 1 && d < n)return d;
    if(y == x)return n;
    if(i == k)y = x, k <<= 1;
  }
}
void factor(LL n, vector<LL>&fat) {
  if(n == 1)return;
  if(isprime(n)) {fat.push_back(n); return;}
  LL p = n;
  while(p >= n)p = prho(p, rand() % (n - 1) + 1);
  factor(p, fat); factor(n / p, fat);
}
```

快速数论变换 (zky)

返回结果: $c_i = \sum_{0\le j\le i} a_j \cdot b_{i-j}(mod) \quad (0 \le i < n)$

```
/*{(mod,G)}={(81788929,7),(101711873,3),(167772161,3)
      ,(377487361,7),(998244353,3),(1224736769,3)
      ,(1300234241,3),(1484783617,5)}*/
int mo = 998244353, G = 3;
void NTT(int a[], int n, int f) {
  for(register int i = 0; i < n; i++)
    if(i < rev[i]) swap(a[i], a[rev[i]]);
  for (register int i = 2; i <= n; i <<= 1) {
    static int exp[maxn];
    exp[0] = 1;
    exp[1] = pw(G, (mo - 1) / i);
    if(f == -1)exp[1] = pw(exp[1], mo - 2);
    for(register int k = 2; k < (i >> 1); k++)
      exp[k] = 1LL * exp[k - 1] * exp[1] % mo;
    for(register int j = 0; j < n; j += i) {
      for(register int k = 0; k < (i >> 1); k++) {
        register int &pA = a[j + k], &pB = a[j + k + (i >> 1)];
        register int A = pA, B = 1LL * pB * exp[k] % mo;
        pA = (A + B) % mo; pB = (A - B + mo) % mo;
      }
    }
  }
  if(f == -1) {
    int rv = pw(n, mo - 2) % mo;
    for(int i = 0; i < n; i++) a[i] = 1LL * a[i] * rv % mo;
  }
}
void mul(int m, int a[], int b[], int c[]) {
  int n = 1, len = 0;
  while(n < m)n <<= 1, len++;
  for (int i = 1; i < n; i++)
    rev[i] = (rev[i >> 1] >> 1) | ((i & 1) << (len - 1));
  NTT(a, n, 1); NTT(b, n, 1);
  for(int i = 0; i < n; i++) c[i] = 1LL * a[i] * b[i] % mo;
  NTT(c, n, -1);
}
```

原根

```
vector<LL>fct;
bool check(LL x, LL g) {
  for(int i = 0; i < fct.size(); i++)
    if(pw(g, (x - 1) / fct[i], x) == 1)
      return 0;
  return 1;
}
LL findrt(LL x) {
  LL tmp = x - 1;
  for(int i = 2; i * i <= tmp; i++) {
    if(tmp % i == 0) {
      fct.push_back(i);
      while(tmp % i == 0)tmp /= i;
    }
  }
  if(tmp > 1) fct.push_back(tmp);
  // x is 1,2,4,p^n,2p^n
  // x has phi(phi(x)) primitive roots
  for(int i = 2; i < int(1e9); i++)
    if(check(x, i)) return i;
  return -1;
}
```

线性递推

//已知 $a_0, a_1, ..., a_{m-1}\\$
$a_n = c_0 * a_{n-m} + ... + c_{m-1} * a_{n-1}\\$
求 $a_n = v_0 * a_0 + v_1 * a_1 + ... + v_{m-1} * a_{m-1}\\$

```
void linear_recurrence(long long n, int m, int a[], int c[], int p) {
  long long v[M] = {1 % p}, u[M << 1], msk = !!n;
  for(long long i(n); i > 1; i >>= 1)  msk <<= 1;
  for(long long x(0); msk; msk >>= 1, x <<= 1) {
    fill_n(u, m << 1, 0);
    int b(!!(n & msk));
    x |= b;
    if(x < m) u[x] = 1 % p;
    else {
      for(int i(0); i < m; i++)
```

```
        for(int j(0), t(i + b); j < m; j++, t++)
          u[t] = (u[t] + v[i] * v[j]) % p;
      for(int i((m << 1) - 1); i >= m; i--)
        for(int j(0), t(i - m); j < m; j++, t++)
          u[t] = (u[t] + c[j] * u[i]) % p;
    }
    copy(u, u + m, v);
  }
  //a[n] = v[0] * a[0] + v[1] * a[1] + ... + v[m - 1] * a[m - 1].
  for(int i(m); i < 2 * m; i++) {
    a[i] = 0;
    for(int j(0); j < m; j++)
      a[i] = (a[i] + (long long)c[j] * a[i + j - m]) % p;
  }
  for(int j(0); j < m; j++) {
    b[j] = 0;
    for(int i(0); i < m; i++) b[j] = (b[j] + v[i] * a[i + j]) % p;
  }
  for(int j(0); j < m; j++) a[j] = b[j];
}
```

直线下整点个数

返回结果：$\sum_{0\le i<n}\lfloor\frac{a+b\cdot i}{m}\rfloor$　使用条件：$n,m>0$，$a,b\ge 0$　时间复杂度：$\mathcal{O}(nlogn)$

```
LL solve(LL n, LL a, LL b, LL m) {
  if(b == 0)
    return n * (a / m);
  if(a >= m || b >= m)
    return n * (a / m) + (n - 1) * n / 2 * (b / m) + solve(n, a % m, b % m, m);
  return solve((a + b * n) / m, (a + b * n) % m, m, b);
}
```

高斯消元

```
void Gauss(){
  int r,k;
  for(int i=0;i<n;i++){
    r=i;
    for(int j=i+1;j<n;j++)
      if(fabs(A[j][i])>fabs(A[r][i]))r=j;
    if(r!=i)for(int j=0;j<=n;j++)swap(A[i][j],A[r][j]);
    for(int k=i+1;k<n;k++){
      double f=A[k][i]/A[i][i];
      for(int j=i;j<=n;j++)A[k][j]-=f*A[i][j];
    }
  }
  for(int i=n-1;i>=0;i--){
    for(int j=i+1;j<n;j++)
      A[i][n]-=A[j][n]*A[i][j];
    A[i][n]/=A[i][i];
  }
}
bool Gauss(){
  for(int i=1;i<=n;i++){
    int r=0;
    for(int j=i;j<=m;j++)
    if(a[j][i]){r=j;break;}
    if(!r)return 0;
    ans=max(ans,r);
    swap(a[i],a[r]);
    for(int j=i+1;j<=m;j++)
    if(a[j][i])a[j]^=a[i];
  }for(int i=n;i>=1;i--){
    for(int j=i+1;j<=n;j++)if(a[i][j])
    a[i][n+1]=a[i][n+1]^a[j][n+1];
  }return 1;
}
int Gauss(){//求秩
  int r,now=-1;
  int ans=0;
  for(int i = 0; i <n; i++){
    r = now + 1;
    for(int j = now + 1; j < m; j++)
      if(fabs(A[j][i]) > fabs(A[r][i]))
        r = j;
    if (!sgn(A[r][i])) continue;
    ans++;
    now++;
    if(r != now)
      for(int j = 0; j < n; j++)
        swap(A[r][j], A[now][j]);
    for(int k = now + 1; k < m; k++){
      double t = A[k][i] / A[now][i];
      for(int j = 0; j < n; j++){
        A[k][j] -= t * A[now][j];
      }
    }
  }
  return ans;
}
```

1e9+7 FFT

```
// double 精度对 10^9 + 7 取模最多可以做到 2^20
const int MOD = 1000003;
const double PI = acos(-1);
typedef complex<double> Complex;
const int N = 65536, L = 15, MASK = (1 << L) - 1;
Complex w[N];
void FFTInit() {
  for (int i = 0; i < N; ++i)
    w[i] = Complex(cos(2 * i * PI / N), sin(2 * i * PI / N));
}
void FFT(Complex p[], int n) {
  for (int i = 1, j = 0; i < n - 1; ++i) {
    for (int s = n; j ^= s >>= 1, ~j & s;);
    if (i < j) swap(p[i], p[j]);
  }
  for (int d = 0; (1 << d) < n; ++d) {
    int m = 1 << d, m2 = m * 2, rm = n >> (d + 1);
```

```
    for (int i = 0; i < n; i += m2) {
      for (int j = 0; j < m; ++j) {
        Complex &p1 = p[i + j + m], &p2 = p[i + j];
        Complex t = w[rm * j] * p1;
        p1 = p2 - t, p2 = p2 + t;
      } } }
}
Complex A[N], B[N], C[N], D[N];
void mul(int a[N], int b[N]) {
  for (int i = 0; i < N; ++i) {
    A[i] = Complex(a[i] >> L, a[i] & MASK);
    B[i] = Complex(b[i] >> L, b[i] & MASK);
  }
  FFT(A, N), FFT(B, N);
  for (int i = 0; i < N; ++i) {
    int j = (N - i) % N;
    Complex da = (A[i] - conj(A[j])) * Complex(0, -0.5),
        db = (A[i] + conj(A[j])) * Complex(0.5, 0),
        dc = (B[i] - conj(B[j])) * Complex(0, -0.5),
        dd = (B[i] + conj(B[j])) * Complex(0.5, 0);
    C[j] = da * dd + da * dc * Complex(0, 1);
    D[j] = db * dd + db * dc * Complex(0, 1);
  }
  FFT(C, N), FFT(D, N);
  for (int i = 0; i < N; ++i) {
    long long da = (long long)(C[i].imag() / N + 0.5) % MOD,
          db = (long long)(C[i].real() / N + 0.5) % MOD,
          dc = (long long)(D[i].imag() / N + 0.5) % MOD,
          dd = (long long)(D[i].real() / N + 0.5) % MOD;
    a[i] = ((dd << (L * 2)) + ((db + dc) << L) + da) % MOD;
  }
}
```

FWT

```
void FWT(LL *a, int n) {
  for(int h = 2; h <= n; h <<= 1)
    for(int j = 0; j < n; j += h)
      for(int k = j; k < j + h / 2; k++) {
        LL u = a[k], v = a[k + h / 2];
        // xor: a[k] = (u + v) % MOD; a[k + h / 2] = (u - v + mo) % MOD;
        // and: a[k] = (u + v) % MOD; a[k + h / 2] = v;
        // or: a[k] = u; a[k + h / 2] = (u + v) % MOD;
      }
}
void IFWT(LL *a, int n) {
  for(int h = 2; h <= n; h <<= 1)
    for(int j = 0; j < n; j += h)
      for(int k = j; k < j + h / 2; k++) {
        LL u = a[k], v = a[k + h / 2];
        // xor: a[k] = mul((u + v) % MOD, inv2);
        //    a[k + h / 2] = mul((u - v + MOD) % MOD, inv2);
        // and: a[k] = (u - v + MOD) % MOD; a[k + h / 2] = v;
        // or: a[k] = u; a[k + h / 2] = (u - v + MOD) % MOD;
      }
}
void multiply(LL *a, LL *b, LL *c, int len) {
  int l = 1; while(l < len) l <<= 1;
  len = l; FWT(a, len); FWT(b, len);
  for(int i = 0; i < len; i++) c[i] = mul(a[i], b[i]);
  IFWT(c, len);
}
```

自适应辛普森

```
double area(const double &left, const double &right) {
  double mid = (left + right) / 2;
  return (right - left) * (calc(left) + 4 * calc(mid) + calc(right)) / 6;
}
double simpson(const double &left, const double &right,
      const double &eps, const double &area_sum) {
  double mid = (left + right) / 2;
  double area_left = area(left, mid);
  double area_right = area(mid, right);
  double area_total = area_left + area_right;
  if (std::abs(area_total - area_sum) < 15 * eps)
    return area_total + (area_total - area_sum) / 15;
  return simpson(left, mid, eps / 2, area_left)
     + simpson(mid, right, eps / 2, area_right);
}
double simpson(const double &left, const double &right, const double &eps) {
  return simpson(left, right, eps, area(left, right));
}
```

多项式求根

```
const double eps=1e-12;
double a[10][10];
typedef vector<double> vd;
int sgn(double x) { return x < -eps ? -1 : x > eps; }
double mypow(double x,int num){
  double ans=1.0;
  for(int i=1;i<=num;++i) ans*=x;
  return ans;
}
double f(int n,double x){
  double ans=0;
  for(int i=n;i>=0;--i) ans+=a[n][i]*mypow(x,i);
  return ans;
}
double getRoot(int n,double l,double r){
  if(sgn(f(n,l))==0)return l;
  if(sgn(f(n,r))==0)return r;
  double temp;
  if(sgn(f(n,l))>0)temp=-1; else temp=1;
  for(int i=1;i<=10000;++i){
    double m=(l+r)/2;
    double mid=f(n,m);
    if(sgn(mid)==0) return m;
    if(mid*temp<0)l=m; else r=m;
  }
  return (l+r)/2;
}
```

```
vd did(int n){
  vd ret;
  if(n==1){
    ret.push_back(-1e10);
    ret.push_back(-a[n][0]/a[n][1]);
    ret.push_back(1e10);
    return ret;
  }
  vd mid=did(n-1);
  ret.push_back(-1e10);
  for(int i=0;i+1<mid.size();++i){
    int t1=sgn(f(n,mid[i])),t2=sgn(f(n,mid[i+1]));
    if(t1*t2>0)continue;
    ret.push_back(getRoot(n,mid[i],mid[i+1]));
  }
  ret.push_back(1e10);
  return ret;
}
int main(){
  int n; scanf("%d",&n);
  for(int i=n;i>=0;--i) scanf("%lf",&a[n][i]);
  for(int i=n-1;i>=0;--i)
    for(int j=0;j<=i;++j)a[i][j]=a[i+1][j+1]*(j+1);
  vd ans=did(n);
  sort(ans.begin(),ans.end());
  for(int i=1;i+1<ans.size();++i)printf("%.10f\n",ans[i]);
  return 0;
}
```

数据结构

lct

```
struct LCT{
  int fa[N], c[N][2], rev[N], sz[N];
  void update(int o)
    {sz[o] = sz[c[o][0]] + sz[c[o][1]] + 1;}
  void pushdown(int o) {
    if(!rev[o]) return;
    rev[o] = 0;
    rev[c[o][0]] ^= 1;
    rev[c[o][1]] ^= 1;
    swap(c[o][0], c[o][1]);
  }
  bool ch(int o)
    {return o == c[fa[o]][1];}
  bool isroot(int o)
    {return c[fa[o]][0] != o && c[fa[o]][1] != o;}
  void setc(int x, int y, bool d) {
    if(x) fa[x] = y;
    if(y) c[y][d] = x;
  }
  void rotate(int x) {
    if(isroot(x)) return;
    int p = fa[x], d = ch(x);
    if(isroot(p)) fa[x] = fa[p];
    else setc(x, fa(p), ch(p));
    setc(c[x][d^1], p, d);
    setc(p, x, d^1);
    update(p); update(x);
  }
  void splay(int x) {
    static int q[N], top;
    int y = q[top = 1] = x;
    while(!isroot(y)) q[++top] = y = fa[y];
    while(top) pushdown(q[top--]);
    while(!isroot(x)) {
      if(!isroot(fa[x]))  rotate(ch(fa[x]) == ch(x) ? fa[x] : x);
      rotate(x);
    }
  }
  void access(int x) {
    for(int y = 0; x; y = x, x = fa[x])
      splay(x), c[x][1] = y, update(x);
  }
  void makeroot(int x)
    {access(x), splay(x), rev(x) ^= 1;}
  void link(int x, int y)
    {makeroot(x), fa[x] = y, splay(x);}
  void cut(int x, int y) {
    makeroot(x); access(y);
    splay(y); c[y][0] = fa[x] = 0;
  }
};
```

树上莫队

```
int n, m, w[N], bid[N << 1];
vector<int> g[N];
struct Query{
  int l, r, extra, i;
  friend bool operator < (const Query &a, const Query &b) {
    if(bid[a.l] != bid[b.l]) return bid[a.l] < bid[b.l];
    return a.r < b.r;
  }
} q[M];
void input(){
  vector<int> vs;
  scanf("%d%d", &n, &m);
  for(int i = 1; i <= n; i++){
    scanf("%d", &w[i]);
    vs.push_back(w[i]);
  }
  sort(vs.begin(), vs.end());
  vs.resize(unique(vs.begin(), vs.end()) - vs.begin());
  for(int i = 1; i <= n; i++)
    w[i] = lower_bound(vs.begin(), vs.end(), w[i]) - vs.begin() + 1;
  for(int a, b, i = 2; i <= n; i++){
    scanf("%d%d", &a, &b);
    g[a].push_back(b); g[b].push_back(a);
  }
  for(int i = 1; i <= m; i++){
```

```
    scanf("%d%d", &q[i].l, &q[i].r);
    q[i].i = i;
  }
}
int dfs_clock, st[N], ed[N], fa[N][LOGN], dep[N], col[N << 1], id[N << 1];
void dfs(int x, int p){
  col[st[x] = ++dfs_clock] = w[x];
  id[st[x]] = x;
  fa[x][0] = p; dep[x] = dep[p] + 1;
  for(int i = 0; fa[x][i]; i++)
    fa[x][i + 1] = fa[fa[x][i]][i];
  for(auto y: g[x])
    if(y != p) dfs(y, x);
  col[ed[x] = ++dfs_clock] = w[x];
  id[ed[x]] = x;
}
int lca(int x, int y){
  if(dep[x] < dep[y]) swap(x, y);
  for(int i = LOGN - 1; i >= 0; i--)
    if(dep[fa[x][i]] >= dep[y])  x = fa[x][i];
  if(x == y) return x;
  for(int i = LOGN - 1; i >= 0; i--)
    if(fa[x][i] != fa[y][i]) x = fa[x][i], y = fa[y][i];
  return fa[x][0];
}
void prepare(){
  dfs_clock = 0;
  dfs(1, 0);
  int BS = (int)sqrt(dfs_clock + 0.5);
  for(int i = 1; i <= dfs_clock; i++)
    bid[i] = (i + BS - 1) / BS;
  for(int i = 1; i <= m; i++){
    int a = q[i].l, b = q[i].r, c = lca(a, b);
    if(st[a] > st[b]) swap(a, b);
    if(c == a){
      q[i].l = st[a];
      q[i].r = st[b];
      q[i].extra = 0;
    }
    else{
      q[i].l = ed[a];
      q[i].r = st[b];
      q[i].extra = c;
    }
  }
  sort(q + 1, q + m + 1);
}
int curans, ans[M], cnt[N];
bool state[N];
void rev(int x){
  int &c = cnt[col[x]];
  curans -= !!c;
  c += (state[id[x]] ^= 1) ? 1 : -1;
  curans += !!c;
}
void solve(){
  prepare();
  curans = 0;
  memset(cnt, 0, sizeof(cnt));
  memset(state, 0, sizeof(state));
  int l = 1, r = 0;
  for(int i = 1; i <= m; i++){
    while(l < q[i].l) rev(l++);
    while(l > q[i].l) rev(--l);
    while(r < q[i].r) rev(++r);
    while(r > q[i].r) rev(r--);
    if(q[i].extra) rev(st[q[i].extra]);
    ans[q[i].i] = curans;
    if(q[i].extra) rev(st[q[i].extra]);
  }
  for(int i = 1; i <= m; i++) printf("%d\n", ans[i]);
}
```

树状数组 kth

```
int find(int k){
  int cnt=0,ans=0;
  for(int i=22;i>=0;i--){
    ans+=(1<<i);
    if(ans>n || cnt+d[ans]>=k)ans-=(1<<i);
    else cnt+=d[ans];
  }
  return ans+1;
}
```

虚树

```
int a[maxn*2],sta[maxn*2],top=0,k;
void build(){
  top=0;
  sort(a,a+k,bydfn);
  k=unique(a,a+k)-a;
  sta[top++]=1;_n=k;
  for(int i=0;i<k;i++){
    int LCA=lca(a[i],sta[top-1]);
    while(dep[LCA]<dep[sta[top-1]]){
      if(dep[LCA]>=dep[sta[top-2]]){
        add_edge(LCA,sta[--top]);
        if(sta[top-1]!=LCA) sta[top++]=LCA;
        break;
      }add_edge(sta[top-2],sta[top-1]); top--;
    }if(sta[top-1]!=a[i]) sta[top++]=a[i];
  }
  while(top>1) add_edge(sta[top-2],sta[top-1]),top--;
  for(int i=0;i<k;i++)inr[a[i]]=1;
}
```

图论

点双连通分量 (lyx)

```
#define SZ(x) ((int)x.size())
const int N = 400005, M = 200005; //N 开 2 倍点数
```

```
vector<int> g[N], bcc[N],  G[N];
int bccno[N], bcc_cnt;
bool iscut[N];
struct Edge {
  int u, v;
} stk[M << 2];
int top, dfn[N], low[N], dfs_clock;// 注意栈大小为边数 4 倍
void dfs(int x, int fa)
{
  low[x] = dfn[x] = ++dfs_clock;
  int child = 0;
  for(int i = 0; i < SZ(g[x]); i++) {
    int y = g[x][i];
    if(!dfn[y]) {
      child++;
      stk[++top] = (Edge){x, y};
      dfs(y, x);
      low[x] = min(low[x], low[y]);
      if(low[y] >= dfn[x]) {
        iscut[x] = true;
        bcc[++bcc_cnt].clear();
        for(;;) {
          Edge e = stk[top--];
          if(bccno[e.u]!=bcc_cnt){bcc[bcc_cnt].push_back(e.u);bccno[e.u]=bcc_cnt;}
          if(bccno[e.v]!=bcc_cnt){bcc[bcc_cnt].push_back(e.v);bccno[e.v]=bcc_cnt;}
          if(e.u == x && e.v == y) break;
        }
      }
    } else if(y != fa && dfn[y] < dfn[x]) {
      stk[++top] = (Edge){x, y};
      low[x] = min(low[x], dfn[y]);
    }
  }
  if(fa == 0 && child == 1) iscut[x] = false;
}
void find_bcc() // 求点双联通分量，需要时手动 1 到 n 清空，1-based
{
  memset(dfn, 0, sizeof(dfn));
  memset(iscut, 0, sizeof(iscut));
  memset(bccno, 0, sizeof(bccno));
  dfs_clock = bcc_cnt = 0;
  for(int i = 1; i <= n; i++)
    if(!dfn[i])  dfs(i, 0);
}
void prepare() { // 建出缩点后的树
  for(int i = 1; i <= n + bcc_cnt; i++)
    G[i].clear();
  for(int i = 1; i <= bcc_cnt; i++) {
    int x = i + n;
    for(int j = 0; j < SZ(bcc[i]); j++) {
      int y = bcc[i][j];
      G[x].push_back(y);
      G[y].push_back(x);
    }
  }
}
```

Hopcoft-Karp 求最大匹配

```
int matchx[N], matchy[N], level[N];
bool dfs(int x) {
  for (int i = 0; i < (int)edge[x].size(); ++i) {
    int y = edge[x][i], w = matchy[y];
    if (w == -1 || level[x] + 1 == level[w] && dfs(w)) {
      matchx[x] = y;
      matchy[y] = x;
      return true;
    }
  }
  level[x] = -1;
  return false;
}
int solve() {
  std::fill(matchx, matchx + n, -1);
  std::fill(matchy, matchy + m, -1);
  for (int answer = 0; ; ) {
    std::vector<int> queue;
    for (int i = 0; i < n; ++i) {
      if (matchx[i] == -1) {
        level[i] = 0;
        queue.push_back(i);
      } else level[i] = -1;
    }
    for (int head = 0; head < (int)queue.size(); ++head) {
      int x = queue[head];
      for (int i = 0; i < (int)edge[x].size(); ++i) {
        int y = edge[x][i], w = matchy[y];
        if (w != -1 && level[w] < 0) {
          level[w] = level[x] + 1;
          queue.push_back(w);
        }
      }
    }
    int delta = 0;
    for (int i = 0; i < n; ++i)
      if (matchx[i] == -1 && dfs(i))
        delta++;
    if (delta == 0) return answer;
    else answer += delta;
  }
}
```

KM 带权匹配

注意事项： 最小权完美匹配，复杂度为 $\mathcal{O}(|V|^3)$。

```
int DFS(int x){
  visx[x] = 1;
  for (int y = 1;y <= ny;y ++){
    if (visy[y]) continue;
    int t = lx[x] + ly[y] - w[x][y];
```

```
    if (t == 0) {
      visy[y] = 1;
      if (link[y] == -1||DFS(link[y])){
        link[y] = x;
        return 1;
      }
    }
    else slack[y] = min(slack[y],t);
  }
  return 0;
}
int KM(){
  int i,j;
  memset(link,-1,sizeof(link));
  memset(ly,0,sizeof(ly));
  for (i = 1; i <= nx; i++)
    for (j = 1, lx[i] = -inf; j <= ny; j++)
      lx[i] = max(lx[i],w[i][j]);
  for (int x = 1; x <= nx; x++){
    for (i = 1; i <= ny; i++) slack[i] = inf;
    while (true) {
      memset(visx, 0, sizeof(visx));
      memset(visy, 0, sizeof(visy));
      if (DFS(x)) break;
      int d = inf;
      for (i = 1; i <= ny;i++)
        if (!visy[i] && d > slack[i]) d = slack[i];
      for (i = 1; i <= nx; i++)
        if (visx[i]) lx[i] -= d;
      for (i = 1; i <= ny; i++)
        if (visy[i]) ly[i] += d;
        else slack[i] -= d;
    }
  }
  int res = 0;
  for (i = 1;i <= ny;i ++)
    if (link[i] > -1) res += w[link[i]][i];
  return res;
}
```

2-SAT 问题

```
int stamp, comps, top;
int dfn[N], low[N], comp[N], stack[N];
void add(int x, int a, int y, int b) {
  edge[x << 1 | a].push_back(y << 1 | b);
}
void tarjan(int x) {
  dfn[x] = low[x] = ++stamp;
  stack[top++] = x;
  for (int i = 0; i < (int)edge[x].size(); ++i) {
    int y = edge[x][i];
    if (!dfn[y]) {
      tarjan(y);
      low[x] = std::min(low[x], low[y]);
    } else if (!comp[y])
      low[x] = std::min(low[x], dfn[y]);
  }
  if (low[x] == dfn[x]) {
    comps++;
    do {
      int y = stack[--top];
      comp[y] = comps;
    } while (stack[top] != x);
  }
}
bool solve() {
  int counter = n + n + 1;
  stamp = top = comps = 0;
  std::fill(dfn, dfn + counter, 0);
  std::fill(comp, comp + counter, 0);
  for (int i = 0; i < counter; ++i) {
    if (!dfn[i]) tarjan(i);
  }
  for (int i = 0; i < n; ++i) {
    if (comp[i << 1] == comp[i << 1 | 1]) return false;
    answer[i] = (comp[i << 1 | 1] < comp[i << 1]);
  }
  return true;
}
```

有根树的同构

```
const unsigned long long MAGIC = 4423;
unsigned long long magic[N];
std::pair<unsigned long long, int> hash[N];
void solve(int root) {
  magic[0] = 1;
  for (int i = 1; i <= n; ++i) {
    magic[i] = magic[i - 1] * MAGIC;
  }
  std::vector<int> queue;
  queue.push_back(root);
  for (int head = 0; head < (int)queue.size(); ++head) {
    int x = queue[head];
    for (int i = 0; i < (int)son[x].size(); ++i) {
      int y = son[x][i];
      queue.push_back(y);
    }
  }
  for (int index = n - 1; index >= 0; --index) {
    int x = queue[index];
    hash[x] = std::make_pair(0, 0);
    std::vector<std::pair<unsigned long long, int> > value;
    for (int i = 0; i < (int)son[x].size(); ++i) {
      int y = son[x][i];
      value.push_back(hash[y]);
    }
    std::sort(value.begin(), value.end());

    hash[x].first = hash[x].first * magic[1] + 37;
    hash[x].second++;
```

```
    for (int i = 0; i < (int)value.size(); ++i) {
      hash[x].first = hash[x].first * magic[value[i].second] + value[i].first;
      hash[x].second += value[i].second;
    }
    hash[x].first = hash[x].first * magic[1] + 41;
    hash[x].second++;
  }
}
```

Dominator Tree

```
class Edge{
public:
  int size, begin[MAXN], dest[MAXM], next[MAXM];
  void clear(int n){
    size = 0;
    fill(begin, begin + n, -1);
  }
  Edge(int n = MAXN){  clear(n); }
  void add_edge(int u, int v){
    dest[size] = v;
    next[size] = begin[u];
    begin[u] = size++;
  }
};
class dominator{
public:
  int dfn[MAXN],sdom[MAXN],idom[MAXN],id[MAXN],f[MAXN],fa[MAXN],smin[MAXN],stamp;
  void predfs(int x, const Edge &succ){
    id[dfn[x] = stamp++] = x;
    for(int i = succ.begin[x]; ~i; i = succ.next[i]){
      int y = succ.dest[i];
      if(dfn[y] < 0)
        f[y] = x, predfs(y, succ);
    }
  }
  int getfa(int x){
    if(fa[x] == x) return x;
    int ret = getfa(fa[x]);
    if(dfn[sdom[smin[fa[x]]]] < dfn[sdom[smin[x]]])
      smin[x] = smin[fa[x]];
    return fa[x] = ret;
  }
  void solve(int s, int n, const Edge &succ){
    fill(dfn, dfn + n, -1);
    fill(idom, idom + n, - 1);
    static Edge pred, tmp;
    pred.clear(n);
    for(int i = 0; i < n; ++i)
      for(int j = succ.begin[i]; ~j; j = succ.next[j])
        pred.add_edge(succ.dest[j], i);
    stamp = 0;
    tmp.clear(n);
    predfs(s, succ);
    for(int i = 0; i < stamp; ++i)
      fa[id[i]] = smin[id[i]] = id[i];
    for(int o = stamp - 1; o >= 0; --o){
      int x = id[o];
      if(o){
        sdom[x] = f[x];
        for(int i = pred.begin[x]; ~i; i = pred.next[i]){
          int p = pred.dest[i];
          if(dfn[p] < 0) continue;
          if(dfn[p] > dfn[x]){
            getfa(p);
            p = sdom[smin[p]];
          }
          if(dfn[sdom[x]] > dfn[p])
            sdom[x] = p;
        }
        tmp.add_edge(sdom[x], x);
      }
      while(~tmp.begin[x]){
        int y = tmp.dest[tmp.begin[x]];
        tmp.begin[x] = tmp.next[tmp.begin[x]];
        getfa(y);
        if(x != sdom[smin[y]]) idom[y] = smin[y];
        else idom[y] = x;
      }
      for(int i = succ.begin[x]; ~i; i = succ.next[i])
        if(f[succ.dest[i]] == x) fa[succ.dest[i]] = x;
    }
    idom[s] = s;
    for(int i = 1; i < stamp; ++i){
      int x = id[i];
      if(idom[x] != sdom[x]) idom[x] = idom[idom[x]];
    }
  }
};
```

无向图最小割

```
int node[N], dist[N];
bool visit[N];
int solve(int n) {
  int answer = INT_MAX;
  for (int i = 0; i < n; ++i) node[i] = i;
  while (n > 1) {
    int max = 1;
    for (int i = 0; i < n; ++i) {
      dist[node[i]] = graph[node[0]][node[i]];
      if (dist[node[i]] > dist[node[max]]) max = i;
    }
    int prev = 0;
    memset(visit, 0, sizeof(visit));
    visit[node[0]] = true;
    for (int i = 1; i < n; ++i) {
      if (i == n - 1) {
        answer = std::min(answer, dist[node[max]]);
        for (int k = 0; k < n; ++k) {
          graph[node[k]][node[prev]] =
            (graph[node[prev]][node[k]] += graph[node[k]][node[max]]);
```

```
        }
        node[max] = node[--n];
      }
      visit[node[max]] = true;
      prev = max;
      max = -1;
      for (int j = 1; j < n; ++j) {
        if (!visit[node[j]]) {
          dist[node[j]] += graph[node[prev]][node[j]];
          if (max == -1 || dist[node[max]] < dist[node[j]]) max = j;
        }
      }
    }
  }
  return answer;
}
```

带花树

```
int match[N], belong[N], next[N], mark[N], visit[N];
std::vector<int> queue;
int find(int x) {
  if (belong[x] != x)  belong[x] = find(belong[x]);
  return belong[x];
}
void merge(int x, int y) {
  x = find(x); y = find(y);
  if (x != y)  belong[x] = y;
}
int lca(int x, int y) {
  static int stamp = 0;
  stamp++;
  while (true) {
    if (x != -1) {
      x = find(x);
      if (visit[x] == stamp) return x;
      visit[x] = stamp;
      if (match[x] != -1) x = next[match[x]];
      else x = -1;
    }
    std::swap(x, y);
  }
}
void group(int a, int p) {
  while (a != p) {
    int b = match[a], c = next[b];
    if (find(c) != p) next[c] = b;
    if (mark[b] == 2) {
      mark[b] = 1;
      queue.push_back(b);
    }
    if (mark[c] == 2) {
      mark[c] = 1;
      queue.push_back(c);
    }
    merge(a, b); merge(b, c); a = c;
  }
}
void augment(int source) {
  queue.clear();
  for (int i = 0; i < n; ++i) {
    next[i] = visit[i] = -1;
    belong[i] = i;
    mark[i] = 0;
  }
  mark[source] = 1;
  queue.push_back(source);
  for (int head = 0; head < (int)queue.size() && match[source] == -1; ++head){
    int x = queue[head];
    for (int i = 0; i < (int)edge[x].size(); ++i) {
      int y = edge[x][i];
      if (match[x] == y || find(x) == find(y) || mark[y] == 2) continue;
      if (mark[y] == 1) {
        int r = lca(x, y);
        if (find(x) != r) next[x] = y;
        if (find(y) != r) next[y] = x;
        group(x, r); group(y, r);
      } else if (match[y] == -1) {
        next[y] = x;
        for (int u = y; u != -1; ) {
          int v = next[u], mv = match[v];
          match[v] = u; match[u] = v;  u = mv;
        }
        break;
      } else {
        next[y] = x; mark[y] = 2;
        mark[match[y]] = 1;
        queue.push_back(match[y]);
      }
    }
  }
}
int solve() {
  std::fill(match, match + n, -1);
  for (int i = 0; i < n; ++i)
    if (match[i] == -1) augment(i);
  int answer = 0;
  for (int i = 0; i < n; ++i) answer += (match[i] != -1);
  return answer;
}
```

字符串

扩展 KMP 算法

```
//nex[i] 表示 s 和其后缀 s[i, n] 的 lcp 的长度
void getnext(char s[], int n, int nex[]){
  nex[1] = n;
  int &t = nex[2] = 0;
  for(; t + 2 <= n && s[1 + t] == s[2 + t]; t++);
  int pos = 2;
  for(int i = 3; i <= n; i++){
```

```
    if(i + nex[i - pos + 1] < pos + nex[pos]) nex[i] = nex[i - pos + 1];
    else{
      int j = max(0, nex[pos] + pos - i);
      for(;i + j <= n && s[i + j] == s[j + 1]; j++);
      nex[i] = j; pos = i;
    }
  }
}
//extend[i] 表示 s2 和 s1 后缀 s1[i, n] 的 lcp 的长度
void getextend(char s1[], char s2[], int extend[]){
  int n = strlen(s1 + 1), m = strlen(s2 + 1);
  getnext(s2, m, next);
  int &t = extend[1] = 0, pos = 1;
  for(; t < n && t < m && s1[1 + t] == s2[1 + t]; t++);
  for(int i = 2; i <= n; i++){
    if(i + nex[i - pos + 1] < pos + extend[pos]) extend[i] = nex[i - pos + 1];
    else{
      int j = max(0, extend[pos] + pos - i);
      for(; i + j <= n && j < m && s1[i + j] == s2[j + 1]; j++);
      extend[i] = j; pos = i;
    }
  }
}
```

AC 自动机

```
const int C = 26, L = 1e5 + 5, N = 5e5+10;
int n, root, cnt, fail[N], son[N][26], num[N];
char s[L];
inline int newNode(){
  cnt++; fail[cnt] = num[cnt] = 0;
  memset(son[cnt], 0, sizeof(son[cnt]));
  return cnt;
}
void insert(char *s){
  int n = strlen(s + 1), now = 1;
  for(int i = 1; i <= n; i++){
    int c = s[i] - 'a';
    if(!son[now][c]) son[now][c] = newNode();
    now = son[now][c];
  }
  num[now]++;
}
void getfail(){
  static queue<int> Q;
  fail[root] = 0;
  Q.push(root);
  while(!Q.empty()){
    int now = Q.front();
    Q.pop();
    for(int i = 0; i < C; i++)
      if(son[now][i]){
        Q.push(son[now][i]);
        int p = fail[now];
        while(!son[p][i]) p = fail[p];
        fail[son[now][i]] = son[p][i];
      }
      else son[now][i] = son[fail[now]][i];
  }
}
int main(){
  cnt = 0; root = newNode();
  scanf("%d", &n);
  for(int i = 0; i < C; i++) son[0][i] = 1;
  for(int i = 1; i <= n; i++)
    scanf("%s", s + 1), insert(s);
  getfail();
  return 0;
}
```

后缀自动机

广义后缀自动机（多串）

注意事项：空间是插入字符串总长度的 2 倍并请注意字符集大小。

```
const int N = 251010, C = 26;
int tot, las, root;
struct Node{
  int son[C], len, par;
  void clear(){
    memset(son, 0, sizeof(son));
    par = len = 0;
  }
}node[N << 1];
inline int newNode(){return node[++tot].clear(), tot;}
void extend(int c) {
  int p = las;
  if (node[p].son[c]) {
    int q = node[p].son[c];
    if (node[p].len + 1 == node[q].len)  las = q;
    else{
      int nq = newNode();
      las = nq; node[nq] = node[q];
      node[nq].len = node[p].len + 1;  node[q].par = nq;
      for (; p && node[p].son[c] == q; p = node[p].par)
        node[p].son[c] = nq;
    }
  }
  else{ // Naive Suffix Automaton
    int np = newNode();
    las = np; node[np].len = node[p].len + 1;
    for (; p && !node[p].son[c]; p = node[p].par)
      node[p].son[c] = np;
    if (!p) node[np].par = root;
    else{
      int q = node[p].son[c];
      if (node[p].len + 1 == node[q].len)  node[np].par = q;
      else{
        int nq = newNode();
        node[nq] = node[q];
        node[nq].len = node[p].len + 1;
        node[q].par = node[np].par = nq;
```

```
        for (; p && node[p].son[c] == q; p = node[p].par)
          node[p].son[c] = nq;
      }
    }
  }
}
void add(char *s){
  int len = strlen(s + 1); las = root;
  for(int i = 1; i <= len; i++) extend(s[i] - 'a');
}
```

sam-ypm

sam-nsubstr

```
//SAM 利用后缀树进行计算，由儿子向 parert 更新
void extend(int c);//传入转化为数字之后的字符，从 0 开始
int main(){
  static char s[N];
  while(scanf("%s", s + 1) == 1){
    tot = 0; root = las = newNode();
    int n = strlen(s + 1);
    for(int i = 1;i <= n; i++) extend(s[i] - 'a');
    static int cnt[N], order[N << 1];
    memset(cnt, 0, sizeof(*cnt) * (n + 5));
    for(int  i = 1; i <= tot; i++) cnt[node[i].len]++;
    for(int i = 1; i <= n; i++) cnt[i] += cnt[i - 1];
    for(int i = tot; i; i--) order[ cnt[node[i].len]-- ] = i;
    static int dp[N]; memset(dp, 0, sizeof(dp));
    //dp[i] 为长度为 i 的子串中出现次数最多的串的出现次数
    for(int now = root, i = 1;  i <= n; i++){
      now = node[now].son[s[i] - 'a'];
      node[now].count++;
    }
    for(int i = tot; i; i--){
      Node &now = node[order[i]];
      dp[now.len] = max(dp[now.len], now.count);
      node[now.par].count += now.count;
    }
    for(int i = n - 1; i; i--) dp[i] = max(dp[i], dp[i + 1]);
    for(int i = 1; i <= n; i++) printf("%d\n", dp[i]);
  }
}
```

sam-lcs

```
int main(){
  static char s[N];
  scanf("%s", s + 1);
  tot = 0; root = las = newNode();
  int n = strlen(s + 1);
  for(int i = 1;i <= n; i++)
    extend(s[i] - 'a');
  static int cnt[N], order[N << 1];
  memset(cnt, 0, sizeof(*cnt) * (n + 5));
  for(int i = 1; i <= tot; i++) cnt[node[i].len]++;
  for(int i = 1; i <= n; i++) cnt[i] += cnt[i - 1];
  for(int i = tot; i; i--) order[ cnt[node[i].len]-- ] = i;
  static int ANS[N << 1], dp[N << 1];
  memset(dp, 0, sizeof(*dp) * (tot + 5));
  for(int i = 1; i <= tot; i++) ANS[i] = node[i].len;
  while(scanf("%s", s + 1) == 1){
    n = strlen(s + 1);
    for(int now = root, len = 0, i = 1; i <= n; i++){
      int c = s[i] - 'a';
      while(now != root && !node[now].son[c]) now = node[now].par;
      if(node[now].son[c]){
        len = min(len, node[now].len) + 1;
        now = node[now].son[c];
      }
      else len = 0;
      dp[now] = max(dp[now], len);
    }
    for(int i = tot; i; i--){
      int now = order[i];
      dp[node[now].par] = max(dp[node[now].par], dp[now]);
      ANS[now] = min(ANS[now], dp[now]);
      dp[now] = 0;
    }
  }
  int ans = 0;
  for(int i = 1; i<= tot; i++) ans = max(ans, ANS[i]);
  printf("%d\n", ans);
}
```

后缀数组

注意事项： $\mathcal{O}(n\log n)$ 倍增构造。

```
#define ws wws
const int MAXN = 201010;
int wa[MAXN], wb[MAXN], wv[MAXN], ws[MAXN];
int sa[MAXN], rk[MAXN], height[MAXN];
char s[MAXN];
inline bool cmp(int *r, int a, int b, int l)
  {return r[a] == r[b] && r[a + l] == r[b + l];}
void SA(char *r, int *sa, int n, int m){
  int *x = wa, *y = wb;
  for(int i = 1; i <= m; i++)ws[i] = 0;
  for(int i = 1; i <= n; i++)ws[x[i] = r[i]]++;
  for(int i = 1; i <= m; i++)ws[i] += ws[i - 1];
  for(int i = n; i > 0; i--)sa[ ws[x[i]]-- ] = i;
  for(int j = 1, p = 0; p < n; j <<= 1, m = p){
    p = 0;
    for(int i = n - j + 1; i <= n; i++)y[++p] = i;
    for(int i = 1; i <= n; i++)if(sa[i] > j) y[++p] = sa[i] - j;
    for(int i = 1; i <= n; i++)wv[i] = x[y[i]];
    for(int i = 1; i <= m; i++)ws[i] = 0;
    for(int i = 1; i <= n; i++)ws[wv[i]]++;
    for(int i = 1; i <= m; i++)ws[i] += ws[i - 1];
    for(int i = n; i > 0; i--)sa[ ws[wv[i]]-- ] = y[i];
    swap(x, y); x[sa[1]] = p = 1;
    for(int i = 2; i <= n; i++)
      x[sa[i]] = cmp(y, sa[i - 1], sa[i], j) ? p : ++p;
```

```
  }
}
void getheight(char *r, int *sa, int *rk, int *h, int n){
  for(int i = 1; i <= n; i++) rk[sa[i]] = i;
  for(int i = 1, p = 0; i <= n; i++, p ? p-- : 0){
    int j = sa[rk[i] - 1];
    while(r[i + p] == r[j + p]) p++;
    h[rk[i]] = p;
  }
}
```

Manacher

注意事项：1-based 算法，请注意下标。

```
void manacher(char *st){
  static char s[N << 1];
  static int p[N << 1];
  int n = strlen(st + 1);
  s[0] = '$'; s[1] = '#';
  for(int i = 1; i <= n; i++)
    s[i << 1] = st[i], s[(i << 1) + 1] = '#';
  s[(n = n * 2 + 1) + 1] = 0;
  int pos, mx = 0, res = 0;
  for(int i = 1; i <= n; i++){
    p[i] = (mx > i) ? min(p[pos * 2 - i], mx - i) : 1;
    while(s[i + p[i]] == s[i - p[i]]) p[i]++;
    if(p[i] + i - 1 > mx) mx = p[i] + i - 1, pos = i;
  }
}
```

循环串的最小表示

注意事项：0-Based 算法，请注意下标。

```
int getmin(char *s, int n){// 0-base
  int i = 0, j = 1, k = 0;
  while(i < n && j < n && k < n){
    int x = i + k; if(x >= n) x -= n;
    int y = j + k; if(y >= n) y -= n;
    if(s[x] == s[y]) k++;
    else{
      if(s[x] > s[y]) i += k + 1;
      else j += k + 1;
      if(i == j) j++;
      k = 0;
    }
  }
  return min(i ,j);
}
```

计算几何

二维几何

```
// 求圆与直线的交点
bool isCL(Circle a, Line l, P &p1, P &p2) {
  D x = (l.s - a.o) % l.d,
    y = l.d.sqrlen(),
    d = x * x - y * ((l.s - a.o).sqrlen() - a.r * a.r);
  if (sign(d) < 0) return false;
  P p = l.s - x / y * l.d, delta = sqrt(max((D)0., d)) / y * l.d;
  p1 = p + delta, p2 = p - delta;
  return true;
}
// 求圆与圆的交面积
D areaCC(const Circle &c1, const Circle &c2) {
  D d = (c1.o - c2.o).len();
  if (sign(d - (c1.r + c2.r)) >= 0) {
    return 0;
  }
  if (sign(d - abs(c1.r - c2.r)) <= 0) {
    D r = min(c1.r, c2.r);
    return r * r * pi;
  }
  D x = (d * d + c1.r * c1.r - c2.r * c2.r) / (2 * d),
       t1 = acos(min(1., max(-1., x / c1.r))), t2 = acos(min(1., max(-1., (d - x) /
↪  c2.r)));
  return c1.r * c1.r * t1 + c2.r * c2.r * t2 - d * c1.r * sin(t1);
}
// 求圆与圆的交点，注意调用前要先判定重圆
bool isCC(Circle a, Circle b, P &p1, P &p2) {
  D s1 = (a.o - b.o).len();
  if (sign(s1 - a.r - b.r) > 0 || sign(s1 - abs(a.r - b.r)) < 0) return false;
  D s2 = (a.r * a.r - b.r * b.r) / s1;
  D aa = (s1 + s2) * 0.5, bb = (s1 - s2) * 0.5;
  P o = aa / (aa + bb) * (b.o - a.o) + a.o;
  P delta = sqrt(max(0., a.r * a.r - aa * aa)) * (b.o - a.o).zoom(1).rev();
  p1 = o + delta, p2 = o - delta;
  return true;
}
// 求点到圆的切点，按关于点的顺时针方向返回两个点，rev 必须是 (-y, x)
bool tanCP(const Circle &c, const P &p0, P &p1, P &p2) {
  D x = (p0 - c.o).sqrlen(), d = x - c.r * c.r;
  if (d < eps) return false; // 点在圆上认为没有切点
  P p = c.r * c.r / x * (p0 - c.o);
  P delta = (-c.r * sqrt(d) / x * (p0 - c.o)).rev();
  p1 = c.o + p + delta;
  p2 = c.o + p - delta;
  return true;
}
// 求圆到圆的外共切线，按关于 c1.o 的顺时针方向返回两条线，rev 必须是 (-y, x)
vector<Line> extanCC(const Circle &c1, const Circle &c2) {
  vector<Line> ret;
  if (sign(c1.r - c2.r) == 0) {
    P dir = c2.o - c1.o;
    dir = (c1.r / dir.len() * dir).rev();
    ret.push_back(Line(c1.o + dir, c2.o - c1.o));
    ret.push_back(Line(c1.o - dir, c2.o - c1.o));
  } else {
    P p = 1. / (c1.r - c2.r) * (-c2.r * c1.o + c1.r * c2.o);
    P p1, p2, q1, q2;
```

```cpp
    if (tanCP(c1, p, p1, p2) && tanCP(c2, p, q1, q2)) {
      if (c1.r < c2.r) swap(p1, p2), swap(q1, q2);
      ret.push_back(Line(p1, q1 - p1));
      ret.push_back(Line(p2, q2 - p2));
    }
  }
  return ret;
}
// 求圆到圆的内共切线，按关于 c1.o 的顺时针方向返回两条线，rev 必须是 (-y, x)
vector<Line> intanCC(const Circle &c1, const Circle &c2) {
  vector<Line> ret;
  P p = 1. / (c1.r + c2.r) * (c2.r * c1.o + c1.r * c2.o);
  P p1, p2, q1, q2;
  if (tanCP(c1, p, p1, p2) && tanCP(c2, p, q1, q2)) { // 两圆相切认为没有切线
    ret.push_back(Line(p1, q1 - p1));
    ret.push_back(Line(p2, q2 - p2));
  }
  return ret;
}
bool contain(vector<P> poly, P p) { // 判断点 p 是否被多边形包含，包括落在边界上
  int ret = 0, n = poly.size();
  for(int i = 0; i < n; ++ i) {
    P u = poly[i], v = poly[(i + 1) % n];
    if (onSeg(p, u, v)) return true; // 在边界上
    if (sign(u.y - v.y) <= 0) swap(u, v);
    if (sign(p.y - u.y) > 0 || sign(p.y - v.y) <= 0) continue;
    ret += sign((v - p) * (u - p)) > 0;
  }
  return ret & 1;
}
vector<P> convexCut(const vector<P>&ps, Line l) {
 ↪  // 用半平面 (s,d) 的逆时针方向去切凸多边形
  vector<P> qs;
  int n = ps.size();
  for (int i = 0; i < n; ++i) {
    Point p1 = ps[i], p2 = ps[(i + 1) % n];
    int d1 = sign(l.d * (p1 - l.s)), d2 = sign(l.d * (p2 - l.s));
    if (d1 >= 0) qs.push_back(p1);
    if (d1 * d2 < 0) qs.push_back(isLL(Line(p1, p2 - p1), l));
  }
  return qs;
}
```

凸包

```cpp
inline bool turn_left(const Point &a, const Point &b, const Point &c) {
  return sgn(det(b - a, c - a)) >= 0;
}
void convex_hull(vector<Data> p, vector<Data> &res) {
  int n = (int)p.size(), cnt = 0;
  sort(p.begin(), p.end(), [&](const Data &a, const Data &b) {
      if(fabs(a.p.x - b.p.x) < eps) return a.p.y > b.p.y;
      return a.p.x < b.p.x; });
  res.clear();
  for(int i = 0; i < n; i++) {
    while(cnt > 1 && turn_left(res[cnt - 2].p, p[i].p, res[cnt - 1].p)) {
      cnt--;
      res.pop_back();
    }
    res.push_back(p[i]);
    ++cnt;
  }
  int fixed = cnt;
  for(int i = n - 2; i >= 0; i--) {
    while(cnt > fixed && turn_left(res[cnt - 2].p, p[i].p, res[cnt - 1].p)) {
      --cnt;
      res.pop_back();
    }
    res.push_back(p[i]);
    ++cnt;
  }
}
```

阿波罗尼茨圆

硬币问题：易知两两相切的圆半径为 r1, r2, r3, 求与他们都相切的圆的半径 r4
分母取负号，答案再取绝对值，为外切圆半径
分母取正号为内切圆半径
// $r_4^{\pm} = \frac{r_1r_2r_3}{r_1r_2+r_1r_3+r_2r_3\pm2\sqrt{r_1r_2r_3(r_1+r_2+r_3)}}$

三角形与圆交

```cpp
// 反三角函数要在 [-1, 1] 中，sqrt 要与 0 取 max 别忘了取正负
// 改成周长请用注释，res1 为直线长度，res2 为弧线长度
// 多边形与圆求交时，相切精度比较差
D areaCT(P pa, P pb, D r) { //, D & res1, D & res2) {
    if (pa.len() < pb.len()) swap(pa, pb);
    if (sign(pb.len()) == 0) return 0;
 ↪  // if (sign(pb.len()) == 0) { res1 += min(r, pa.len()); return; }
    D a = pb.len(), b = pa.len(), c = (pb - pa).len();
    D sinB = fabs(pb * (pb - pa)), cosB = pb % (pb - pa), area = fabs(pa * pb);
    D S, B = atan2(sinB, cosB), C = atan2(area, pa % pb);
    sinB /= a * c; cosB /= a * c;
    if (a > r) {
        S = C / 2 * r * r; D h = area / c;//res2 += -1 * sgn * C * r; D h = area / c;
        if (h < r && B < pi / 2) {
            //res2 -= -1 * sgn * 2 * acos(max((D)-1., min((D)1., h / r))) * r;
            //res1 += 2 * sqrt(max((D)0., r * r - h * h));
            S -= (acos(max((D)-1., min((D)1., h / r))) * r * r - h * sqrt(max((D)0.
 ↪  ,r * r - h * h));
        }
    } else if (b > r) {
        D theta = pi - B - asin(max((D)-1., min((D)1., sinB / r * a)));
        S = a * r * sin(theta) / 2 + (C - theta) / 2 * r * r;
        //res2 += -1 * sgn * (C - theta) * r;
        //res1 += sqrt(max((D)0., r * r + a * a - 2 * r * a * cos(theta)));
    } else S = area / 2; //res1 += (pb - pa).len();
    return S;
}
```

圆并

```
struct Event {
  P p; D ang; int delta;
  Event (P p = Point(0, 0), D ang = 0, int delta = 0) : p(p), ang(ang), delta(delta) {}
};
bool operator < (const Event &a, const Event &b) { return a.ang < b.ang; }
void addEvent(const Circle &a, const Circle &b, vector<Event> &evt, int &cnt) {
  D d2 = (a.o - b.o).sqrlen(), dRatio = ((a.r - b.r) * (a.r + b.r) / d2 + 1) / 2,
    pRatio = sqrt(max((D)0., -(d2 - sqr(a.r - b.r)) * (d2 - sqr(a.r + b.r)) / (d2 * d2 * 4)));
  P d = b.o - a.o, p = d.rot(pi / 2),
    q0 = a.o + d * dRatio + p * pRatio,
    q1 = a.o + d * dRatio - p * pRatio;
  D ang0 = (q0 - a.o).ang(), ang1 = (q1 - a.o).ang();
  evt.emplace_back(q1, ang1, 1); evt.emplace_back(q0, ang0, -1);
  cnt += ang1 > ang0;
}
bool issame(const Circle &a, const Circle &b) { return sign((a.o - b.o).len()) == 0 && sign(a.r - b.r) == 0; }
bool overlap(const Circle &a, const Circle &b) { return sign(a.r - b.r - (a.o - b.o).len()) >= 0; }
bool intersect(const Circle &a, const Circle &b) { return sign((a.o - b.o).len() - a.r - b.r) < 0; }
int C;
Circle c[N];
double area[N];
void solve() { // 返回覆盖至少 k 次的面积
  memset(area, 0, sizeof(D) * (C + 1));
  for (int i = 0; i < C; ++i) {
    int cnt = 1;
    vector<Event> evt;
    for (int j = 0; j < i; ++j) if (issame(c[i], c[j])) ++cnt;
    for (int j = 0; j < C; ++j)
      if (j != i && !issame(c[i], c[j]) && overlap(c[j], c[i]))
        ++cnt;
    for (int j = 0; j < C; ++j)
      if (j != i && !overlap(c[j], c[i]) && !overlap(c[i], c[j]) && intersect(c[i], c[j]))
        addEvent(c[i], c[j], evt, cnt);
    if (evt.empty()) area[cnt] += PI * c[i].r * c[i].r;
    else {
      sort(evt.begin(), evt.end());
      evt.push_back(evt.front());
      for (int j = 0; j + 1 < (int)evt.size(); ++j) {
        cnt += evt[j].delta;
        area[cnt] += det(evt[j].p, evt[j + 1].p) / 2;
        D ang = evt[j + 1].ang - evt[j].ang;
        if (ang < 0) ang += PI * 2;
        area[cnt] += ang * c[i].r * c[i].r / 2 - sin(ang) * c[i].r * c[i].r / 2;
} } } }
```

整数半平面交

```
typedef __int128 J; // 坐标 |1e9| 就要用 int128 来判断
struct Line {
  bool include(P a) const { return (a - s) * d >= 0; } // 严格去掉 =
  bool include(Line a, Line b) const {
    J l1(a.d * b.d);
    if(!l1)  return true;
    J x(l1 * (a.s.x - s.x)), y(l1 * (a.s.y - s.y));
    J l2((b.s - a.s) * b.d);
    x += l2 * a.d.x; y += l2 * a.d.y;
    J res(x * d.y - y * d.x);
    return l1 > 0 ? res >= 0 : res <= 0; // 严格去掉 =
  }
};
bool HPI(vector<Line> v) { // 返回 v 中每个射线的右侧的交是否非空
  sort(v.begin(), v.end());// 按方向排极角序
  { // 同方向取最严格的一个
    vector<Line> t; int n(v.size());
    for(int i(0), j; i < n; i = j) {
      LL mx(-9e18); int mxi;
      for(j = i; j < n && v[i].d * v[j].d == 0; j++) {
        LL tmp(v[j].s * v[i].d);
        if(tmp > mx)
          mx = tmp, mxi = j;
      }
      t.push_back(v[mxi]);
    }
    swap(v, t);
  }
  deque<Line> res;
  bool emp(false);
  for(auto i : v) {
    if(res.size() == 1) {
      if(res[0].d * i.d == 0 && !i.include(res[0].s))  {
        res.pop_back();
        emp = true;
      }
    } else if(res.size() >= 2) {
      while(res.size() >= 2u && !i.include(res.back(), res[res.size() - 2])) {
        if(i.d * res[res.size() - 2].d == 0 || !res.back().include(i, res[res.size() - 2])) {
          emp = true;
          break;
        }
        res.pop_back();
      }
      while(res.size() >= 2u && !i.include(res[0], res[1])) res.pop_front();
    }
    if(emp) break;
    res.push_back(i);
  }
  while (res.size() > 2u && !res[0].include(res.back(), res[res.size() - 2])) res.pop_back();
  return !emp;// emp: 是否为空, res 按顺序即为半平面交
}
```

三角形

```
P fermat(const P& a, const P& b, const P& c) {
  D ab((b - a).len()), bc((b - c).len()), ca((c - a).len());
  D cosa((b - a) % (c - a) / ab / ca);
  D cosb((a - b) % (c - b) / ab / bc);
  D cosc((b - c) % (a - c) / ca / bc);
  P mid; D sq3(sqrt(3) / 2);
  if(sign((b - a) * (c - a)) < 0) swap(b, c);
  if(sign(cosa + 0.5) < 0) mid = a;
  else if(sign(cosb + 0.5) < 0) mid = b;
  else if(sign(cosc + 0.5) < 0) mid = c;
  else mid = intersection(Line(a, c + (b - c).rot(sq3) - a), Line(c, b + (a -
↪   b).rot(sq3) - c));
  return mid;
  // mid 为三角形 abc 费马点，要求 abc 非退化
  length = (mid - a).len() + (mid - b).len() + (mid - c).len();
  // 以下求法仅在三角形三个角均小于 120 度时，可以求出 ans 为费马点到 abc 三点距离和
  length = (a - c - (b - c).rot(sq3)).len();
}
P inCenter(const P & A, const P & B, const P & C) { // 内心
  D a = (B - C).len(), b = (C - A).len(), c = (A - B).len(),
    s = abs((B - A) * (C - A)),
    r = s / (a + b + c); // 内接圆半径
  return 1. / (a + b + c) * (A * a + B * b + C * c);
↪   // 偏心则将对应点前两个加号改为减号
}
P circumCenter(const P & a, const P & b, const P & c) { // 外心
  P bb = b - a, cc = c - a;
  // 半径为 a * b * c / 4 / S, a, b, c 为边长, S 为面积
  D db = bb.sqrlen(), dc = cc.sqrlen(), d = 2 * (bb * cc);
  return a - 1. / d * P(bb.y * dc - cc.y * db, cc.x * db - bb.x * dc);
}
P othroCenter(const P & a, const P & b, const P & c) { // 垂心
  P ba = b - a, ca = c - a, bc = b - c;
  D Y = ba.y * ca.y * bc.y,
       A = ca.x * ba.y - ba.x * ca.y,
       x0 = (Y + ca.x * ba.y * b.x - ba.x * ca.y * c.x) / A,
       y0 = -ba.x * (x0 - c.x) / ba.y + ca.y;
  return P(x0, y0);
}
```

经纬度求球面最短距离

```
double sphereDis(double lon1, double lat1, double lon2, double lat2, double R) {
  return R * acos(cos(lat1) * cos(lat2) * cos(lon1 - lon2) + sin(lat1) * sin(lat2));
}
```

长方体表面两点最短距离

```
int r;
void turn(int i, int j, int x, int y, int z,int x0, int y0, int L, int W, int H) {
  if (z==0) { int R = x*x+y*y; if (R<r) r=R;
  } else {
    if(i>=0 && i< 2) turn(i+1, j, x0+L+z, y, x0+L-x, x0+L, y0, H, W, L);
    if(j>=0 && j< 2) turn(i, j+1, x, y0+W+z, y0+W-y, x0, y0+W, L, H, W);
    if(i<=0 && i>-2) turn(i-1, j, x0-z, y, x-x0, x0-H, y0, H, W, L);
    if(j<=0 && j>-2) turn(i, j-1, x, y0-z, y-y0, x0, y0-H, L, H, W);
  }
}
int main(){
  int L, H, W, x1, y1, z1, x2, y2, z2;
  cin >> L >> W >> H >> x1 >> y1 >> z1 >> x2 >> y2 >> z2;
  if (z1!=0 && z1!=H) if (y1==0 || y1==W)
     swap(y1,z1), std::swap(y2,z2), std::swap(W,H);
  else swap(x1,z1), std::swap(x2,z2), std::swap(L,H);
  if (z1==H) z1=0, z2=H-z2;
  r=0x3fffffff;
  turn(0,0,x2-x1,y2-y1,z2,-x1,-y1,L,W,H);
  cout<<r<<endl;
}
```

点到凸包切线

```
P lb(P x, vector<P> & v, int le, int ri, int sg) {
  if (le > ri) le = ri;
  int s(le), t(ri);
  while (le != ri) {
    int mid((le + ri) / 2);
    if (sign((v[mid] - x) * (v[mid + 1] - v[mid])) == sg)
      le = mid + 1; else ri = mid;
  }
  return x - v[le]; // le 即为下标，按需返回
}
// v[0] 为顺时针上凸壳，v[1] 为顺时针下凸壳，均允许起始两个点横坐标相同
// 返回值为真代表严格在凸包外，顺时针旋转在 d1 方向先碰到凸包
bool getTan(P x, vector<P> * v, P & d1, P & d2) {
  if (x.x < v[0][0].x) {
    d1 = lb(x, v[0], 0, sz(v[0]) - 1, 1);
    d2 = lb(x, v[1], 0, sz(v[1]) - 1, -1);
    return true;
  } else if(x.x > v[0].back().x) {
    d1 = lb(x, v[1], 0, sz(v[1]) - 1, 1);
    d2 = lb(x, v[0], 0, sz(v[0]) - 1, -1);
    return true;
  } else {
    for(int d(0); d < 2; d++) {
      int id(lower_bound(v[d].begin(), v[d].end(), x,
      [&](const P & a, const P & b) {
        return d == 0 ? a < b : b < a;
      }) - v[d].begin());
      if (id && (id == sz(v[d]) || (v[d][id - 1] - x) * (v[d][id] - x) > 0)) {
        d1 = lb(x, v[d], id, sz(v[d]) - 1, 1);
        d2 = lb(x, v[d], 0, id, -1);
        return true;
      }
    }
  }
  return false;
}
```

直线与凸包的交点

```
// a 是顺时针凸包, i1 为 x 最小的点, j1 为 x 最大的点 需保证 j1 > i1
// n 是凸包上的点数, a 需复制多份或写循环数组类
int lowerBound(int le, int ri, const P & dir) {
  while (le < ri) {
    int mid((le + ri) / 2);
    if (sign((a[mid + 1] - a[mid]) * dir) <= 0) {
      le = mid + 1;
    } else ri = mid;
  }
  return le;
}
int boundLower(int le, int ri, const P & s, const P & t) {
  while (le < ri) {
    int mid((le + ri + 1) / 2);
    if (sign((a[mid] - s) * (t - s)) <= 0) {
      le = mid;
    } else ri = mid - 1;
  }
  return le;
}
void calc(P s, P t) {
  if(t < s) swap(t, s);
  int i3(lowerBound(i1, j1, t - s)); // 和上凸包的切点
  int j3(lowerBound(j1, i1 + n, s - t)); // 和下凸包的切点
  int i4(boundLower(i3, j3, s, t));
↪  // 如果有交则是右侧的交点, 与 a[i4]~a[i4+1] 相交 要判断是否有交的话 就手动 check 一下
  int j4(boundLower(j3, i3 + n, t, s)); // 如果有交左侧的交点, 与 a[j4]~a[j4+1] 相交
  // 返回的下标不一定在 [0 ~ n-1] 内
}
```

平面最近点对

```
// Create: 2017-10-22 20:15:34
#include <bits/stdc++.h>
using namespace std;
const int N = 100005;
struct Data {
  double x, y;
};
double sqr(double x) {
  return x * x;
}
double dis(Data a, Data b) {
  return sqrt(sqr(a.x - b.x) + sqr(a.y - b.y));
}
int n;
Data p[N], q[N];
double solve(int l, int r) {
  if(l == r) return 1e18;
  if(l + 1 == r) return dis(p[l], p[r]);
  int m = (l + r) / 2;
  double d = min(solve(l, m), solve(m + 1, r));
  int qt = 0;
  for(int i = l; i <= r; i++) {
    if(fabs(p[m].x - p[i].x) <= d) {
      q[++qt] = p[i];
    }
  }
  sort(q + 1, q + qt + 1, [&](const Data &a, const Data &b) {
      return a.y < b.y; });
  for(int i = 1; i <= qt; i++) {
    for(int j = i + 1; j <= qt; j++) {
      if(q[j].y - q[i].y >= d) break;
      d = min(d, dis(q[i], q[j]));
    }
  }
  return d;
}
int main()
{
  while(scanf("%d", &n) == 1 && n) {
    for(int i = 1; i <= n; i++) {
      scanf("%lf%lf", &p[i].x, &p[i].y);
    }
    sort(p + 1, p + n + 1, [&](const Data &a, const Data &b) {
        return a.x < b.x || (a.x == b.x && a.y < b.y); });
    double ans = solve(1, n);
    printf("%.2f\n", ans / 2);
  }
  return 0;
}
```

三维几何

```
/* 大拇指指向 x 轴正方向时, 4 指弯曲由 y 轴正方向指向 z 轴正方向
   大拇指沿着原点到点 (x, y, z) 的向量, 4 指弯曲方向旋转 w 度 */
/* (x, y, z) * A = (x_new, y_new, z_new), 行向量右乘转移矩阵 */
void calc(D x, D y, D z, D w) {
  w = w * pi / 180;
  memset(a, 0, sizeof(a));
  s1 = x * x + y * y + z * z;
  a[0][0] = ((y*y+z*z)*cos(w)+x*x)/s1; a[0][1] = x*y*(1-cos(w))/s1+z*sin(w)/sqrt(s1);
↪   a[0][2] = x*z*(1-cos(w))/s1-y*sin(w)/sqrt(s1);
  a[1][0] = x*y*(1-cos(w))/s1-z*sin(w)/sqrt(s1); a[1][1] = ((x*x+z*z)*cos(w)+y*y)/s1;
↪   a[1][2] = y*z*(1-cos(w))/s1+x*sin(w)/sqrt(s1);
  a[2][0] = x*z*(1-cos(w))/s1+y*sin(w)/sqrt(s1); a[2][1] =
↪   y*z*(1-cos(w))/s1-x*sin(w)/sqrt(s1); a[2][2] = ((x*x+y*y)*cos(w)+z*z)/s1;
}
// 求平面和直线的交点
Point3D intersection(const Point3D &a, const Point3D &b, const Point3D &c, const
↪   Point3D &l0, const Point3D &l1) {
  Point3D p = pVec(a, b, c); // 平面法向量
  double t = (p.x * (a.x - l0.x) + p.y * (a.y - l0.y) + p.z * (a.z - l0.z)) / (p.x *
↪   (l1.x - l0.x) + p.y * (l1.y - l0.y) + p.z * (l1.z - l0.z));
  return l0 + (l1 - l0) * t;
}
```

其他

最小树形图

```
const int maxn=1100;
int n,m , g[maxn][maxn] , used[maxn] , pass[maxn] , eg[maxn] , more , queue[maxn];
void combine (int id , int &sum ) {
  int tot = 0 , from , i , j , k ;
  for ( ; id!=0 && !pass[ id ] ; id=eg[id] ) {
    queue[tot++]=id ; pass[id]=1;
  }
  for ( from=0; from<tot && queue[from]!=id ; from++);
  if  ( from==tot ) return ;
  more = 1 ;
  for ( i=from ; i<tot ; i++) {
    sum+=g[eg[queue[i]]][queue[i]] ;
    if ( i!=from ) {
      used[queue[i]]=1;
      for ( j = 1 ; j <= n ; j++) if ( !used[j] )
        if ( g[queue[i]][j]<g[id][j] ) g[id][j]=g[queue[i]][j] ;
    }
  }
  for ( i=1; i<=n ; i++) if ( !used[i] && i!=id ) {
    for ( j=from ; j<tot ; j++){
      k=queue[j];
      if ( g[i][id]>g[i][k]-g[eg[k]][k] ) g[i][id]=g[i][k]-g[eg[k]][k];
    }
  }
}

int mdst( int root ) { // return the total length of MDST
  int i , j , k , sum = 0 ;
  memset ( used , 0 , sizeof ( used ) ) ;
  for ( more =1; more ; ) {
    more = 0 ;
    memset (eg,0,sizeof(eg)) ;
    for ( i=1 ; i <= n ; i ++) if ( !used[i] && i!=root ) {
      for ( j=1 , k=0 ; j <= n ; j ++) if ( !used[j] && i!=j )
        if ( k==0 || g[j][i] < g[k][i] ) k=j ;
      eg[i] = k ;
    }
    memset(pass,0,sizeof(pass));
    for ( i=1; i<=n ; i++) if ( !used[i] && !pass[i] && i!= root ) combine ( i , sum
↪  ) ;
  }
  for ( i =1; i<=n ; i ++) if ( !used[i] && i!= root ) sum+=g[eg[i]][i];
  return sum ;
}
```

DLX

```
int n,m,K;
struct DLX{
  int L[maxn],R[maxn],U[maxn],D[maxn];
  int sz,col[maxn],row[maxn],s[maxn],H[maxn];
  bool vis[233];
  int ans[maxn],cnt;
void init(int m){
  for(int i=0;i<=m;i++){
    L[i]=i-1;R[i]=i+1;
    U[i]=D[i]=i;s[i]=0;
  }
  memset(H,-1,sizeof H);
  L[0]=m;R[m]=0;sz=m+1;
}
void Link(int r,int c){
  U[sz]=c;D[sz]=D[c];U[D[c]]=sz;D[c]=sz;
  if(H[r]<0)H[r]=L[sz]=R[sz]=sz;
  else{
    L[sz]=H[r];R[sz]=R[H[r]];
    L[R[H[r]]]=sz;R[H[r]]=sz;
  }
  s[c]++;col[sz]=c;row[sz]=r;sz++;
}
void remove(int c){
  for(int i=D[c];i!=c;i=D[i])
    L[R[i]]=L[i],R[L[i]]=R[i];
}
void resume(int c){
  for(int i=U[c];i!=c;i=U[i])
    L[R[i]]=R[L[i]]=i;
}
int A(){
  int res=0;
  memset(vis,0,sizeof vis);
  for(int i=R[0];i;i=R[i])if(!vis[i]){
    vis[i]=1;res++;
    for(int j=D[i];j!=i;j=D[j])
      for(int k=R[j];k!=j;k=R[k])
        vis[col[k]]=1;
  }
  return res;
}
void dfs(int d,int &ans){
  if(R[0]==0){ans=min(ans,d);return;}
  if(d+A()>=ans)return;
  int tmp=23333,c;
  for(int i=R[0];i;i=R[i])
    if(tmp>s[i])tmp=s[i],c=i;
  for(int i=D[c];i!=c;i=D[i]){
    remove(i);
    for(int j=R[i];j!=i;j=R[j])remove(j);
    dfs(d+1,ans);
    for(int j=L[i];j!=i;j=L[j])resume(j);
    resume(i);
  }
}
void del(int c){//exactly cover
  L[R[c]]=L[c];R[L[c]]=R[c];
  for(int i=D[c];i!=c;i=D[i])
    for(int j=R[i];j!=i;j=R[j])
      U[D[j]]=U[j],D[U[j]]=D[j],--s[col[j]];
```

```
  }
  void add(int c){  //exactly cover
    R[L[c]]=L[R[c]]=c;
    for(int i=U[c];i!=c;i=U[i])
      for(int j=L[i];j!=i;j=L[j])
        ++s[col[U[D[j]]=D[U[j]]=j]];
  }
  bool dfs2(int k){//exactly cover
    if(!R[0]){
      cnt=k;return 1;
    }
    int c=R[0];
    for(int i=R[0];i;i=R[i])
      if(s[c]>s[i])c=i;
    del(c);
    for(int i=D[c];i!=c;i=D[i]){
      for(int j=R[i];j!=i;j=R[j])
        del(col[j]);
      ans[k]=row[i];if(dfs2(k+1))return true;
      for(int j=L[i];j!=i;j=L[j])
        add(col[j]);
    }
    add(c);
    return 0;
  }
}dlx;
int main(){
  dlx.init(n);
  for(int i=1;i<=m;i++)
    for(int j=1;j<=n;j++)
      if(dis(station[i],city[j])<mid-eps)
        dlx.Link(i,j);
      dlx.dfs(0,ans);
}
```

某年某月某日是星期几

```
int solve(int year, int month, int day) {
  int answer;
  if (month == 1 || month == 2) {
    month += 12;
    year--;
  }
  if ((year < 1752) || (year == 1752 && month < 9) ||
    (year == 1752 && month == 9 && day < 3)) {
    answer = (day + 2 * month + 3 * (month + 1) / 5 + year + year / 4 + 5) % 7;
  } else {
    answer = (day + 2 * month + 3 * (month + 1) / 5 + year + year / 4
         - year / 100 + year / 400) % 7;
  }
  return answer;
}
```

枚举大小为 k 的子集

使用条件：$k > 0$

```
void solve(int n, int k) {
  for (int comb = (1 << k) - 1; comb < (1 << n); ) {
    int x = comb & -comb, y = comb + x;
    comb = (((comb & ~y) / x) >> 1) | y;
  }
}
```

环状最长公共子串

```
int n, a[N << 1], b[N << 1];
bool has(int i, int j) {
  return a[(i - 1) % n] == b[(j - 1) % n];
}
const int DELTA[3][2] = {{0, -1}, {-1, -1}, {-1, 0}};
int from[N][N];
int solve() {
  memset(from, 0, sizeof(from));
  int ret = 0;
  for (int i = 1; i <= 2 * n; ++i) {
    from[i][0] = 2;
    int left = 0, up = 0;
    for (int j = 1; j <= n; ++j) {
      int upleft = up + 1 + !!from[i - 1][j];
      if (!has(i, j)) {
        upleft = INT_MIN;
      }
      int max = std::max(left, std::max(upleft, up));
      if (left == max) {
        from[i][j] = 0;
      } else if (upleft == max) {
        from[i][j] = 1;
      } else {
        from[i][j] = 2;
      }
      left = max;
    }
    if (i >= n) {
      int count = 0;
      for (int x = i, y = n; y; ) {
        int t = from[x][y];
        count += t == 1;
        x += DELTA[t][0];
        y += DELTA[t][1];
      }
      ret = std::max(ret, count);
      int x = i - n + 1;
      from[x][0] = 0;
      int y = 0;
      while (y <= n && from[x][y] == 0) {
        y++;
      }
      for (; x <= i; ++x) {
        from[x][y] = 0;
        if (x == i) {
          break;
        }
```

```
        for (; y <= n; ++y) {
          if (from[x + 1][y] == 2) {
            break;
          }
          if (y + 1 <= n && from[x + 1][y + 1] == 1) {
            y++;
            break;
          }
        }
      }
    }
  }
  return ret;
}
```

LLMOD STL 内存清空开栈

```
LL multiplyMod(LL a, LL b, LL P) { // `需要保证 a 和 b 非负`
  LL t = (a * b - LL((long double)a / P * b + 1e-3) * P) % P;
  return t < 0 : t + P : t;
}

template <typename T>
__inline void clear(T& container) {
  container.clear(); // 或者删除了一堆元素
  T(container).swap(container);
}

register char *_sp __asm__("rsp");
int main() {
  const int size = 400 << 20;//400MB
  static char *sys, *mine(new char[size] + size - 4096);
  sys = _sp; _sp = mine; _main(); _sp = sys;
}
```

vimrc

```
set ru nu cin ts=4 sts=4 sw=4 hls is ar acd bs=2 mouse=a ls=2 fdm=syntax fdl=100
set makeprg=g++\ %:r.cpp\ -o\ %:r\ -g\ -std=c++11\ -Wall\ -Wextra\ -Wconversion
nmap <C-A> ggVG
vmap <C-C> "+y
noremap <C-V> "+P
map <F3> :vnew %:r.in<cr>
map <F4> :!gedit %<cr>
map <F5> :!time ./%:r<cr>
map <F8> :!time ./%:r < %:r.in<cr>
map <F9> :make<cr>
map <C-F9> :!g++ %:r.cpp -o %:r -g -O2 -std=c++11<cr>
map <F10> :!gdb ./%:r<cr>
```

上下界网络流

无源汇的上下界可行流

建立超级源点 S^* 和超级汇点 T^*，对于原图每条边 (u,v) 在新网络中连如下三条边：$S^* \to v$，容量为 $B(u,v)$；$u \to T^*$，容量为 $B(u,v)$；$u \to v$，容量为 $C(u,v) - B(u,v)$。最后求新网络的最大流，判断从超级源点 S^* 出发的边是否都满流即可，边 (u,v) 的最终解中的实际流量为 $G(u,v) + B(u,v)$。

有源汇的上下界可行流

从汇点 T 到源点 S 连一条上界为 ∞，下界为 0 的边。按照**无源汇的上下界可行流**一样做即可，流量即为 $T \to S$ 边上的流量。

有源汇的上下界最大流

1. 在**有源汇的上下界可行流**中，从汇点 T 到源点 S 的边改为连一条上界为 ∞，下届为 x 的边。x 满足二分性质，找到最大的 x 使得新网络存在**无源汇的上下界可行流**即为原图的最大流。
2. 从汇点 T 到源点 S 连一条上界为 ∞，下界为 0 的边，变成无源汇的网络。按照**无源汇的上下界可行流**的方法，建立超级源点 S^* 和超级汇点 T^*，求一遍 $S^* \to T^*$ 的最大流，再将从汇点 T 到源点 S 的这条边拆掉，求一次 $S \to T$ 的最大流即可。

有源汇的上下界最小流

1. 在**有源汇的上下界可行流**中，从汇点 T 到源点 S 的边改为连一条上界为 x，下界为 0 的边。x 满足二分性质，找到最小的 x 使得新网络存在**无源汇的上下界可行流**即为原图的最小流。
2. 按照**无源汇的上下界可行流**的方法，建立超级源点 S^* 与超级汇点 T^*，求一遍 $S^* \to T^*$ 的最大流，但是注意这一次不加上汇点 T 到源点 S 的这条边，即不使之改为无源汇的网络去求解。求完后，再加上那条汇点 T 到源点 S 上界 ∞ 的边。因为这条边下界为 0，所以 S^*，T^* 无影响，再直接求一次 $S^* \to T^*$ 的最大流。若超级源点 S^* 出发的边全部满流，则 $T \to S$ 边上的流量即为原图的最小流，否则无解。

上下界费用流

来源：BZOJ 3876 设汇 t，源 s，超级源 S，超级汇 T，本质是每条边的下界为 1，上界为 MAX，跑一遍有源汇的上下界最小费用最小流。（因为上界无穷大，所以只要满足所有下界的最小费用最小流）

1. 对每个点 x：从 x 到 t 连一条费用为 0，流量为 MAX 的边，表示可以任意停止当前的剧情（接下来的剧情从更优的路径去走，画个样例就知道了）

2. 对于每一条边权为 z 的边 x->y：

- 从 S 到 y 连一条流量为 1，费用为 z 的边，代表这条边至少要被走一次。
- 从 x 到 y 连一条流量为 MAX，费用为 z 的边，代表这条边除了至少走的一次之外还可以随便走。
- 从 x 到 T 连一条流量为 1，费用为 0 的边。（注意是每一条 x->y 的边都连，或者你可以记下 x 的出边数 Kx，连一次流量为 Kx，费用为 0 的边）。

建完图后从 S 到 T 跑一遍费用流，即可。（当前跑出来的就是满足上下界的最小费用最小流了）

Bernoulli 数

1. 初始化：$B_0(n)=1$
2. 递推公式：$B_m(n)=n^m-\sum_{k=0}^{m-1}\binom{m}{k}\frac{B_k(n)}{m-k+1}$
3. 应用：$\sum_{k=1}^{n}k^m=\frac{1}{m+1}\sum_{k=0}^{m}\binom{m+1}{k}n^{m+1-k}$

Java Hints

```java
import java.util.*;
import java.math.*;
import java.io.*;
public class Main{
  static class Task{
    void solve(int testId, InputReader cin, PrintWriter cout) {
      // Write down the code you want
    }
  };

  public static void main(String args[]) {
    InputStream inputStream = System.in;
    OutputStream outputStream = System.out;
    InputReader in = new InputReader(inputStream);
    PrintWriter out = new PrintWriter(outputStream);
//    Scanner cin = new Scanner(System.in);
//    cin.nextLong();
//    System.out.println(AnsA+" "+AnsB);
  }

  static class InputReader {
    public BufferedReader reader;
    public StringTokenizer tokenizer;
    public InputReader(InputStream stream) {
      reader = new BufferedReader(new InputStreamReader(stream), 32768);
      tokenizer = null;
    }
    public String next() {
      while (tokenizer == null || !tokenizer.hasMoreTokens()) {
        try {
          tokenizer = new StringTokenizer(reader.readLine());
        } catch (IOException e) {
          throw new RuntimeException(e);
        }
      }
      return tokenizer.nextToken();
    }
    public int nextInt() {
      return Integer.parseInt(next());
    }
  }
};
// Arrays
int a[];
.fill(a[, int fromIndex, int toIndex],val); | .sort(a[, int fromIndex, int toIndex])
// String
String s;
.charAt(int i); | compareTo(String) | compareToIgnoreCase () | contains(String) |
length () | substring(int l, int len)
// BigInteger
.abs() | .add() | bitLength () | subtract () | divide () | remainder () |
↪  divideAndRemainder () | modPow(b, c) |
pow(int) | multiply () | compareTo () |
gcd() | intValue () | longValue () | isProbablePrime(int c) (1 - 1/2^c) |
nextProbablePrime () | shiftLeft(int) | valueOf ()
// BigDecimal
.ROUND_CEILING | ROUND_DOWN_FLOOR | ROUND_HALF_DOWN | ROUND_HALF_EVEN | ROUND_HALF_UP
↪  | ROUND_UP
.divide(BigDecimal b, int scale , int round_mode) | doubleValue () |
↪  movePointLeft(int) | pow(int) |
setScale(int scale , int round_mode) | stripTrailingZeros ()
 BigDecimal.setScale()方法用于格式化小数点
setScale(1)表示保留一位小数,默认用四舍五入方式
setScale(1,BigDecimal.ROUND_DOWN)直接删除多余的小数位,如 2.35会变成 2.3
setScale(1,BigDecimal.ROUND_UP)进位处理,2.35变成 2.4
setScale(1,BigDecimal.ROUND_HALF_UP)四舍五入,2.35变成 2.4
setScaler(1,BigDecimal.ROUND_HALF_DOWN)四舍五入,2.35变成 2.3,如果是 5 则向下舍
setScaler(1,BigDecimal.ROUND_CEILING)接近正无穷大的舍入
setScaler(1,BigDecimal.ROUND_FLOOR)接近负无穷大的舍入,数字>0=ROUND_UP,数字<0=ROUND_DOWN
setScaler(1,BigDecimal.ROUND_HALF_EVEN)向最接近的数字舍入,如果距离相等则向相邻的偶数舍入
// StringBuilder
StringBuilder sb = new StringBuilder ();
sb.append(elem) | out.println(sb)
```

数学

常用数学公式

求和公式

1. $\sum_{k=1}^{n}(2k-1)^2=\frac{n(4n^2-1)}{3}$
2. $\sum_{k=1}^{n}k^3=[\frac{n(n+1)}{2}]^2$
3. $\sum_{k=1}^{n}(2k-1)^3=n^2(2n^2-1)$

4. $\sum_{k=1}^{n} k^4 = \frac{n(n+1)(2n+1)(3n^2+3n-1)}{30}$

5. $\sum_{k=1}^{n} k^5 = \frac{n^2(n+1)^2(2n^2+2n-1)}{12}$

6. $\sum_{k=1}^{n} k(k+1) = \frac{n(n+1)(n+2)}{3}$

7. $\sum_{k=1}^{n} k(k+1)(k+2) = \frac{n(n+1)(n+2)(n+3)}{4}$

8. $\sum_{k=1}^{n} k(k+1)(k+2)(k+3) = \frac{n(n+1)(n+2)(n+3)(n+4)}{5}$

斐波那契数列

1. $fib_0 = 0, fib_1 = 1, fib_n = fib_{n-1} + fib_{n-2}$

2. $fib_{n+2} \cdot fib_n - fib_{n+1}^2 = (-1)^{n+1}$

3. $fib_{-n} = (-1)^{n-1} fib_n$

4. $fib_{n+k} = fib_k \cdot fib_{n+1} + fib_{k-1} \cdot fib_n$

5. $gcd(fib_m, fib_n) = fib_{gcd(m,n)}$

6. $fib_m | fib_n^2 \Leftrightarrow nfib_n | m$

错排公式

1. $D_n = (n-1)(D_{n-2} - D_{n-1})$

2. $D_n = n! \cdot (1 - \frac{1}{1!} + \frac{1}{2!} - \frac{1}{3!} + \ldots + \frac{(-1)^n}{n!})$

莫比乌斯函数

$g(n) = \sum_{d|n} f(d) \Leftrightarrow f(n) = \sum_{d|n} \mu(d) g(\frac{n}{d})$ $g(x) = \sum_{n=1}^{[x]} f(\frac{x}{n}) \Leftrightarrow f(x) = \sum_{n=1}^{[x]} \mu(n) g(\frac{x}{n})$

伯恩赛德引理

设 G 是一个有限群,作用在集合 X 上。对每个 g 属于 G,令 X^g 表示 X 中在 g 作用下的不动元素,轨道数(记作 $|X/G|$)由如下公式给出:$|X/G| = \frac{1}{|G|} \sum_{g \in G} |X^g|$.

五边形数定理

设 $p(n)$ 是 n 的拆分数,有 $p(n) = \sum_{k \in \mathbb{Z} \setminus \{0\}} (-1)^{k-1} p\left(n - \frac{k(3k-1)}{2}\right)$

树的计数

1. 有根树计数:$n+1$ 个结点的有根树的个数为 $a_{n+1} = \frac{\sum_{j=1}^{n} j \cdot a_j \cdot S_{n,j}}{n}$ 其中,$S_{n,j} = \sum_{i=1}^{n/j} a_{n+1-ij} = S_{n-j,j} + a_{n+1-j}$

2. 无根树计数:当 n 为奇数时,n 个结点的无根树的个数为 $a_n - \sum_{i=1}^{n/2} a_i a_{n-i}$ 当 n 为偶数时,n 个结点的无根树的个数为 $a_n - \sum_{i=1}^{n/2} a_i a_{n-i} + \frac{1}{2} a_{\frac{n}{2}} (a_{\frac{n}{2}} + 1)$

3. n 个结点的完全图的生成树个数为 n^{n-2}

4. 矩阵 - 树定理:图 G 由 n 个结点构成,设 $\boldsymbol{A}[G]$ 为图 G 的邻接矩阵、$\boldsymbol{D}[G]$ 为图 G 的度数矩阵,则图 G 的不同生成树的个数为 $\boldsymbol{C}[G] = \boldsymbol{D}[G] - \boldsymbol{A}[G]$ 的任意一个 $n-1$ 阶主子式的行列式值。

欧拉公式

平面图的顶点个数、边数和面的个数有如下关系:$V - E + F = C + 1$ 其中,V 是顶点的数目,E 是边的数目,F 是面的数目,C 是组成图形的连通部分的数目。当图是单连通图的时候,公式简化为:$V - E + F = 2$

皮克定理

给定顶点坐标均是整点(或正方形格点)的简单多边形,其面积 A 和内部格点数目 i、边上格点数目 b 的关系:$A = i + \frac{b}{2} - 1$

牛顿恒等式

设 $\prod_{i=1}^{n} (x - x_i) = a_n + a_{n-1}x + \cdots + a_1 x^{n-1} + a_0 x^n$ $p_k = \sum_{i=1}^{n} x_i^k$ 则 $a_0 p_k + a_1 p_{k-1} + \cdots + a_{k-1} p_1 + k a_k = 0$

特别地,对于 $|\boldsymbol{A} - \lambda \boldsymbol{E}| = (-1)^n (a_n + a_{n-1}\lambda + \cdots + a_1 \lambda^{n-1} + a_0 \lambda^n)$ 有 $p_k = Tr(\boldsymbol{A}^k)$

平面几何公式

三角形

1. 面积 $S = \frac{a \cdot H_a}{2} = \frac{ab \cdot sinC}{2} = \sqrt{p(p-a)(p-b)(p-c)}$

2. 中线 $M_a = \frac{\sqrt{2(b^2+c^2)-a^2}}{2} = \frac{\sqrt{b^2+c^2+2bc \cdot cosA}}{2}$

3. 角平分线 $T_a = \frac{\sqrt{bc \cdot [(b+c)^2 - a^2]}}{b+c} = \frac{2bc}{b+c} cos\frac{A}{2}$

4. 高线 $H_a = bsinC = csinB = \sqrt{b^2 - (\frac{a^2+b^2-c^2}{2a})^2}$

5. 内切圆半径

$$r = \frac{S}{p} = \frac{arcsin\frac{B}{2} \cdot sin\frac{C}{2}}{sin\frac{B+C}{2}} = 4R \cdot sin\frac{A}{2} sin\frac{B}{2} sin\frac{C}{2}$$
$$= \sqrt{\frac{(p-a)(p-b)(p-c)}{p}} = p \cdot tan\frac{A}{2} tan\frac{B}{2} tan\frac{C}{2}$$

6. 外接圆半径 $R = \frac{abc}{4S} = \frac{a}{2sinA} = \frac{b}{2sinB} = \frac{c}{2sinC}$

四边形

D_1, D_2 为对角线，M 对角线中点连线，A 为对角线夹角，p 为半周长

1. $a^2+b^2+c^2+d^2=D_1^2+D_2^2+4M^2$
2. $S=\frac{1}{2}D_1D_2sinA$
3. 对于圆内接四边形 $ac+bd=D_1D_2$
4. 对于圆内接四边形 $S=\sqrt{(p-a)(p-b)(p-c)(p-d)}$

正 n 边形

R 为外接圆半径，r 为内切圆半径

1. 中心角 $A=\frac{2\pi}{n}$
2. 内角 $C=\frac{n-2}{n}\pi$
3. 边长 $a=2\sqrt{R^2-r^2}=2R\cdot sin\frac{A}{2}=2r\cdot tan\frac{A}{2}$
4. 面积 $S=\frac{nar}{2}=nr^2\cdot tan\frac{A}{2}=\frac{nR^2}{2}\cdot sinA=\frac{na^2}{4\cdot tan\frac{A}{2}}$

圆

1. 弧长 $l=rA$
2. 弦长 $a=2\sqrt{2hr-h^2}=2r\cdot sin\frac{A}{2}$
3. 弓形高 $h=r-\sqrt{r^2-\frac{a^2}{4}}=r(1-cos\frac{A}{2})=\frac{1}{2}\cdot arctan\frac{A}{4}$
4. 扇形面积 $S_1=\frac{rl}{2}=\frac{r^2A}{2}$
5. 弓形面积 $S_2=\frac{rl-a(r-h)}{2}=\frac{r^2}{2}(A-sinA)$

棱柱

1. 体积 $V=Ah$ A 为底面积，h 为高
2. 侧面积 $S=lp$ l 为棱长，p 为直截面周长
3. 全面积 $T=S+2A$

棱锥

1. 体积 $V=Ah$ A 为底面积，h 为高
2. 正棱锥侧面积 $S=lp$ l 为棱长，p 为直截面周长
3. 正棱锥全面积 $T=S+2A$

棱台

1. 体积 $V=(A_1+A_2+\sqrt{A_1A_2})\cdot\frac{h}{3}$ A_1, A_2 为上下底面积，h 为高
2. 正棱台侧面积 $S=\frac{p_1+p_2}{2}l$ p_1, p_2 为上下底面周长，l 为斜高
3. 正棱台全面积 $T=S+A_1+A_2$

圆柱

1. 侧面积 $S=2\pi rh$
2. 全面积 $T=2\pi r(h+r)$
3. 体积 $V=\pi r^2h$

圆锥

1. 母线 $l=\sqrt{h^2+r^2}$
2. 侧面积 $S=\pi rl$
3. 全面积 $T=\pi r(l+r)$
4. 体积 $V=\frac{\pi}{3}r^2h$

圆台

1. 母线 $l=\sqrt{h^2+(r_1-r_2)^2}$
2. 侧面积 $S=\pi(r_1+r_2)l$
3. 全面积 $T=\pi r_1(l+r_1)+\pi r_2(l+r_2)$
4. 体积 $V=\frac{\pi}{3}(r_1^2+r_2^2+r_1r_2)h$

球台

1. 侧面积 $S=2\pi rh$
2. 全面积 $T=\pi(2rh+r_1^2+r_2^2)$
3. 体积 $V=\frac{\pi h[3(r_1^2+r_2^2)+h^2]}{6}$

球扇形

1. 全面积 $T=\pi r(2h+r_0)$ h 为球冠高，r_0 为球冠底面半径
2. 体积 $V=\frac{2}{3}\pi r^2h$

积分表

$\int \frac{1}{1+x^2} dx = \tan^{-1} x$

$\int \frac{1}{a^2+x^2} dx = \frac{1}{a} \tan^{-1} \frac{x}{a}$

$\int \frac{x}{a^2+x^2} dx = \frac{1}{2} \ln |a^2 + x^2|$

$\int \frac{x^2}{a^2+x^2} dx = x - a \tan^{-1} \frac{x}{a}$

$\int \sqrt{x^2 \pm a^2} dx = \frac{1}{2} x \sqrt{x^2 \pm a^2} \pm \frac{1}{2} a^2 \ln \left| x + \sqrt{x^2 \pm a^2} \right|$

$\int \sqrt{a^2 - x^2} dx = \frac{1}{2} x \sqrt{a^2 - x^2} + \frac{1}{2} a^2 \tan^{-1} \frac{x}{\sqrt{a^2-x^2}}$

$\int \frac{x^2}{\sqrt{x^2 \pm a^2}} dx = \frac{1}{2} x \sqrt{x^2 \pm a^2} \mp \frac{1}{2} a^2 \ln \left| x + \sqrt{x^2 \pm a^2} \right|$

$\int \frac{1}{\sqrt{x^2 \pm a^2}} dx = \ln \left| x + \sqrt{x^2 \pm a^2} \right|$

$\int \frac{1}{\sqrt{a^2 - x^2}} dx = \sin^{-1} \frac{x}{a}$

$\int \frac{x}{\sqrt{x^2 \pm a^2}} dx = \sqrt{x^2 \pm a^2}$

$\int \frac{x}{\sqrt{a^2 - x^2}} dx = -\sqrt{a^2 - x^2}$

$\int \sqrt{ax^2 + bx + c} dx = \frac{b+2ax}{4a} \sqrt{ax^2 + bx + c} + \frac{4ac-b^2}{8a^{3/2}} \ln \left| 2ax + b + 2\sqrt{a(ax^2 + bx^+c)} \right|$

$\int x^n e^{ax} \mathrm{d}x = \dfrac{x^n e^{ax}}{a} - \dfrac{n}{a} \int x^{n-1} e^{ax} \mathrm{d}x$

$\int \sin^2 ax dx = \frac{x}{2} - \frac{1}{4a} \sin 2ax$

$\int \sin^3 ax dx = -\frac{3 \cos ax}{4a} + \frac{\cos 3ax}{12a}$

$\int \cos^2 ax dx = \frac{x}{2} + \frac{\sin 2ax}{4a}$

$\int \cos^3 ax dx = \frac{3 \sin ax}{4a} + \frac{\sin 3ax}{12a}$

$\int \tan ax dx = -\frac{1}{a} \ln \cos ax$

$\int \tan^2 ax dx = -x + \frac{1}{a} \tan ax$

$\int x \cos ax dx = \frac{1}{a^2} \cos ax + \frac{x}{a} \sin ax$

$\int x^2 \cos ax dx = \frac{2x \cos ax}{a^2} + \frac{a^2x^2-2}{a^3} \sin ax$

$\int x \sin ax dx = -\frac{x \cos ax}{a} + \frac{\sin ax}{a^2}$

$\int x^2 \sin ax dx = \frac{2-a^2x^2}{a^3} \cos ax + \frac{2x \sin ax}{a^2}$

博弈游戏

巴什博奕

1. 只有一堆 n 个物品，两个人轮流从这堆物品中取物，规定每次至少取一个，最多取 m 个。最后取光者得胜。

2. 显然，如果 $n = m + 1$，那么由于一次最多只能取 m 个，所以，无论先取者拿走多少个，后取者都能够一次拿走剩余的物品，后者取胜。因此我们发现了如何取胜的法则：如果 $n = \square m + 1 \square r + s \square$r 为任意自然数，$s \le m$)，那么先取者要拿走 s 个物品，如果后取者拿走 $k(k \le m)$ 个，那么先取者再拿走 $m + 1 - k$ 个，结果剩下 $(m + 1)(r - 1)$ 个，以后保持这样的取法，那么先取者肯定获胜。总之，要保持给对手留下 $(m + 1)$ 的倍数，就能最后获胜。

威佐夫博弈

1. 有两堆各若干个物品，两个人轮流从某一堆或同时从两堆中取同样多的物品，规定每次至少取一个，多者不限，最后取光者得胜。

2. 判断一个局势 (a, b) 为奇异局势（必败态）的方法：$a_k = [k(1+\sqrt{5})/2], b_k = a_k + k$

阶梯博奕

1. 博弈在一列阶梯上进行，每个阶梯上放着自然数个点，两个人进行阶梯博弈，每一步则是将一个阶梯上的若干个点（至少一个）移到前面去，最后没有点可以移动的人输。

2. 解决方法：把所有奇数阶梯看成 N 堆石子，做 NIM。（把石子从奇数堆移动到偶数堆可以理解为拿走石子，就相当于几个奇数堆的石子在做 Nim）

图上删边游戏

链的删边游戏

1. 游戏规则：对于一条链，其中一个端点是根，两人轮流删边，脱离根的部分也算被删去，最后没边可删的人输。

2. 做法：$sg[i] = n - dist(i) - 1$（其中 n 表示总点数，$dist(i)$ 表示离根的距离）

树的删边游戏

1. 游戏规则：对于一棵有根树，两人轮流删边，脱离根的部分也算被删去，没边可删的人输。

2. 做法：叶子结点的 $sg = 0$，其他节点的 sg 等于儿子结点的 $sg + 1$ 的异或和。

局部连通图的删边游戏

1. 游戏规则：在一个局部连通图上，两人轮流删边，脱离根的部分也算被删去，没边可删的人输。局部连通图的构图规则是，在一棵基础树上加边得到，所有形成的环保证不共用边，且只与基础树有一个公共点。

2. 做法：去掉所有的偶环，将所有的奇环变为长度为 1 的链，然后做树的删边游戏。