Standard Code Library

Part3 - String

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Contents

Section.5 字符串

后缀自动机

- 广义后缀自动机如果直接使用以下代码的话会产生一些冗余状态（置 last 为 1），所以要用拓扑排序。用 len 基数排序不能。
- 字符集大的话要使用 *map*。
- 树上 dp 时注意边界（root 和 null）。
- rsort 中的数组 a 是拓扑序 [1, sz)

```cpp
struct SAM{
    int ch[N << 1][26], fa[N << 1], len[N << 1], vis[N << 1];
    int last, tot;
    SAM(): last(1), tot(1) {}
    inline void extend(int x){ //* 单字符扩展
        int p = last, np = last = ++tot;
        len[np] = len[p] + 1, vis[np] = 1;
        for(; p && !ch[p][x]; p = fa[p]) ch[p][x] = np;
        if(!p) fa[np] = 1;
        else{
            int q = ch[p][x];
            if(len[q] == len[p] + 1) fa[np] = q;
            else {
                int nq = ++tot;
                for(int i = 0; i < 26; i++) ch[nq][i] = ch[q][i]; //for(int i = 0; i < 26; i++) ch[nq][i] = ch[q][i];
                fa[nq] = fa[q], fa[np] = fa[q] = nq, len[nq] = len[p] + 1;
                for(; ch[p][x] == q; p = fa[p]) ch[p][x] = nq;
            }
        }
    }
}sam;
```

- 最长公共子串

```cpp
//* 最长公共子串
string lcs(const string &T) {
    int v = 0, l = 0, best = 0, bestpos = 0;
    for (int i = 0; i < T.size(); i++) {
        while (v && !sam.ch[v][T[i] - 'a']) {
            v = sam.fa[v];
            l = sam.len[v];
        }
        if (sam.ch[v][T[i] - 'a']) {
            v = sam.ch[v][T[i] - 'a'];
            l++;
        }
        if (l > best) {
            best = l;
            bestpos = i;
        }
    }
    return T.substr(bestpos - best + 1, best);
}
```

- 真·广义后缀自动机

```cpp
int t[M][26], len[M] = {-1}, fa[M], sz = 2, last = 1;
LL cnt[M][2];
void ins(int ch, int id) {
    int p = last, np = 0, nq = 0, q = -1;
    if (!t[p][ch]) {
        np = sz++;
        len[np] = len[p] + 1;
        for (; p && !t[p][ch]; p = fa[p]) t[p][ch] = np;
    }
    if (!p) fa[np] = 1;
    else {
        q = t[p][ch];
        if (len[p] + 1 == len[q]) fa[np] = q;
        else {
            nq = sz++; len[nq] = len[p] + 1;
            memcpy(t[nq], t[q], sizeof t[0]);
```

```
17        fa[nq] = fa[q];
18        fa[np] = fa[q] = nq;
19        for (; t[p][ch] == q; p = fa[p]) t[p][ch] = nq;
20      }
21    }
22    last = np ? np : nq ? nq : q;
23    cnt[last][id] = 1;
24 }
```

- 按字典序建立后缀树注意逆序插入
- rsort2 里的 a 不是拓扑序，需要拓扑序就去树上做

```
1  void ins(int ch, int pp) {
2      int p = last, np = last = sz++;
3      len[np] = len[p] + 1; one[np] = pos[np] = pp;
4      for (; p && !t[p][ch]; p = fa[p]) t[p][ch] = np;
5      if (!p) { fa[np] = 1; return; }
6      int q = t[p][ch];
7      if (len[q] == len[p] + 1) fa[np] = q;
8      else {
9          int nq = sz++; len[nq] = len[p] + 1; one[nq] = one[q];
10         memcpy(t[nq], t[q], sizeof t[0]);
11         fa[nq] = fa[q];
12         fa[q] = fa[np] = nq;
13         for (; p && t[p][ch] == q; p = fa[p]) t[p][ch] = nq;
14     }
15 }
16
17 int up[M], c[256] = {2}, a[M];
18 void rsort2() {
19     FOR (i, 1, 256) c[i] = 0;
20     FOR (i, 2, sz) up[i] = s[one[i] + len[fa[i]]];
21     FOR (i, 2, sz) c[up[i]]++;
22     FOR (i, 1, 256) c[i] += c[i - 1];
23     FOR (i, 2, sz) a[--c[up[i]]] = i;
24     FOR (i, 2, sz) G[fa[a[i]]].push_back(a[i]);
25 }
```

- 广义后缀自动机建后缀树，必须反向插入

```
1  int t[M][26], len[M] = {0}, fa[M], sz = 2, last = 1;
2  char* one[M];
3  void ins(int ch, char* pp) {
4      int p = last, np = 0, nq = 0, q = -1;
5      if (!t[p][ch]) {
6          np = sz++; one[np] = pp;
7          len[np] = len[p] + 1;
8          for (; p && !t[p][ch]; p = fa[p]) t[p][ch] = np;
9      }
10     if (!p) fa[np] = 1;
11     else {
12         q = t[p][ch];
13         if (len[p] + 1 == len[q]) fa[np] = q;
14         else {
15             nq = sz++; len[nq] = len[p] + 1; one[nq] = one[q];
16             memcpy(t[nq], t[q], sizeof t[0]);
17             fa[nq] = fa[q];
18             fa[np] = fa[q] = nq;
19             for (; t[p][ch] == q; p = fa[p]) t[p][ch] = nq;
20         }
21     }
22     last = np ? np : nq ? nq : q;
23 }
24 int up[M], c[256] = {2}, aa[M];
25 vector<int> G[M];
26 void rsort() {
27     FOR (i, 1, 256) c[i] = 0;
28     FOR (i, 2, sz) up[i] = *(one[i] + len[fa[i]]);
29     FOR (i, 2, sz) c[up[i]]++;
30     FOR (i, 1, 256) c[i] += c[i - 1];
31     FOR (i, 2, sz) aa[--c[up[i]]] = i;
32     FOR (i, 2, sz) G[fa[aa[i]]].push_back(aa[i]);
```

```
33    }
```

● 匹配

```
1    int u = 1, l = 0;
2    FOR (i, 0, strlen(s)) {
3        int ch = s[i] - 'a';
4        while (u && !t[u][ch]) { u = fa[u]; l = len[u]; }
5        ++l; u = t[u][ch];
6        if (!u) u = 1;
7        if (l) // do something...
8    }
```

● 获取子串状态

```
1    int get_state(int l, int r) {
2        int u = rpos[r], s = r - l + 1;
3        FORD (i, SP - 1, -1) if (len[pa[u][i]] >= s) u = pa[u][i];
4        return u;
5    }
```

● 配合 LCT

```
1    namespace lct_sam {
2        extern struct P *const null;
3        const int M = N;
4        struct P {
5            P *fa, *ls, *rs;
6            int last;
7
8            bool has_fa() { return fa->ls == this || fa->rs == this; }
9            bool d() { return fa->ls == this; }
10           P*& c(bool x) { return x ? ls : rs; }
11           P* up() { return this; }
12           void down() {
13               if (ls != null) ls->last = last;
14               if (rs != null) rs->last = last;
15           }
16           void all_down() { if (has_fa()) fa->all_down(); down(); }
17       } *const null = new P{0, 0, 0, 0}, pool[M], *pit = pool;
18       P* G[N];
19       int t[M][26], len[M] = {-1}, fa[M], sz = 2, last = 1;
20
21       void rot(P* o) {
22           bool dd = o->d();
23           P *f = o->fa, *t = o->c(!dd);
24           if (f->has_fa()) f->fa->c(f->d()) = o; o->fa = f->fa;
25           if (t != null) t->fa = f; f->c(dd) = t;
26           o->c(!dd) = f->up(); f->fa = o;
27       }
28       void splay(P* o) {
29           o->all_down();
30           while (o->has_fa()) {
31               if (o->fa->has_fa())
32                   rot(o->d() ^ o->fa->d() ? o : o->fa);
33               rot(o);
34           }
35           o->up();
36       }
37       void access(int last, P* u, P* v = null) {
38           if (u == null) { v->last = last; return; }
39           splay(u);
40           P *t = u;
41           while (t->ls != null) t = t->ls;
42           int L = len[fa[t - pool]] + 1, R = len[u - pool];
43
44           if (u->last) bit::add(u->last - R + 2, u->last - L + 2, 1);
45           else bit::add(1, 1, R - L + 1);
46           bit::add(last - R + 2, last - L + 2, -1);
47
48           u->rs = v;
49           access(last, u->up()->fa, u);
50       }
```

```
51        void insert(P* u, P* v, P* t) {
52            if (v != null) { splay(v); v->rs = null; }
53            splay(u);
54            u->fa = t; t->fa = v;
55        }
56
57        void ins(int ch, int pp) {
58            int p = last, np = last = sz++;
59            len[np] = len[p] + 1;
60            for (; p && !t[p][ch]; p = fa[p]) t[p][ch] = np;
61            if (!p) fa[np] = 1;
62            else {
63                int q = t[p][ch];
64                if (len[p] + 1 == len[q]) { fa[np] = q; G[np]->fa = G[q]; }
65                else {
66                    int nq = sz++; len[nq] = len[p] + 1;
67                    memcpy(t[nq], t[q], sizeof t[0]);
68                    insert(G[q], G[fa[q]], G[nq]);
69                    G[nq]->last = G[q]->last;
70                    fa[nq] = fa[q];
71                    fa[np] = fa[q] = nq;
72                    G[np]->fa = G[nq];
73                    for (; t[p][ch] == q; p = fa[p]) t[p][ch] = nq;
74                }
75            }
76            access(pp + 1, G[np]);
77        }
78
79        void init() {
80            ++pit;
81            FOR (i, 1, N) {
82                G[i] = pit++;
83                G[i]->ls = G[i]->rs = G[i]->fa = null;
84            }
85            G[1] = null;
86        }
87    }
```

- 维护区间本质不同字符串数目
- 给你一个长度为 n 的字符串 s，m 次询问，第 i 次询问 s 上的一个区间 $[l_i, r_i]$ 上有多少个本质不同的子串

```
1   #include<bits/stdc++.h>
2   using namespace std;
3   #define Re register int
4   typedef long long ll;
5
6   const int N = 200005;
7   struct info
8   {
9       int id, t;
10  };
11  int n, m, lst, num, res, g[N], ls[N], len[N], lk[N], ch[N][28], lt[N], son[N][2];
12  char s[N];
13  bool lz[N];
14  ll sum[N << 2], ad[N << 2], ans[N];
15  vector<info> q[N];
16
17  inline int read()
18  {
19      char c = getchar();
20      int ans = 0;
21      while (c < 48 || c > 57) c = getchar();
22      while (c >= 48 && c <= 57) ans = (ans << 3) + (ans << 1) + (c ^ 48), c = getchar();
23      return ans;
24  }
25
26  inline void write(ll x)
27  {
28      int num = 0;
29      char sc[25];
30      if (!x) sc[num = 1] = 48;
```

```cpp
    while (x) sc[++num] = x % 10 + 48, x /= 10;
    while (num) putchar(sc[num--]);
    putchar('\n');
}

inline void push_down(int id, int l, int mid, int r)
{
    sum[id << 1] += ad[id] * (mid - l + 1), sum[id << 1 | 1] += ad[id] * (r - mid);
    ad[id << 1] += ad[id], ad[id << 1 | 1] += ad[id];
    ad[id] = 0;
}

inline void modfy(int id, int l, int r, int x, int y, int z)
{
    if (x <= l && r <= y)
    {
        sum[id] += 1ll * z * (r - l + 1), ad[id] += z;
        return;
    }
    int mid = l + r >> 1;
    if (ad[id]) push_down(id, l, mid, r);
    if (x <= mid) modfy(id << 1, l, mid, x, y, z);
    if (y > mid) modfy(id << 1 | 1, mid + 1, r, x, y, z);
    sum[id] = sum[id << 1] + sum[id << 1 | 1];
}

inline ll que(int id, int l, int r, int x, int y)
{
    if (x <= l && r <= y) return sum[id];
    int mid = l + r >> 1;
    ll ans = 0;
    if (ad[id]) push_down(id, l, mid, r);
    if (x <= mid) ans = que(id << 1, l, mid, x, y);
    if (y > mid) ans += que(id << 1 | 1, mid + 1, r, x, y);
    return ans;
}

inline bool check(int x)
{
    return son[lk[x]][0] == x || son[lk[x]][1] == x;
}

inline void pushdown(int x)
{
    if (son[x][0]) lt[son[x][0]] = lt[x], lz[son[x][0]] = 1;
    if (son[x][1]) lt[son[x][1]] = lt[x], lz[son[x][1]] = 1;
    lz[x] = 0;
}

inline void rotate(int x)
{
    int y = lk[x], z = lk[y];
    bool t = son[y][1] ^ x;
    if (check(y)) son[z][son[z][1] == y] = x;
    lk[x] = z, lk[y] = x;
    if (son[x][t]) lk[son[x][t]] = y;
    son[y][t ^ 1] = son[x][t], son[x][t] = y;
}

inline void splay(int x)
{
    g[res = 1] = x;
    while (check(g[res])) g[res + 1] = lk[g[res]], ++res;
    while (res)
    {
        if (lz[g[res]]) pushdown(g[res]);
        --res;
    }
    while (check(x))
    {
        int y = lk[x];
```

```cpp
            if (check(y)) rotate(((son[y][1] == x) ^ (son[lk[y]][1] == y)) ? x : y);
            rotate(x);
        }
    }

    inline int find(int x)
    {
        if (!x) return 0;
        splay(x);
        while (son[x][1]) x = son[x][1];
        return len[x];
    }

    inline void access(int x, int y)
    {
        for (Re i = 0; x; x = lk[i = x])
        {
            splay(x);
            if (lz[x]) pushdown(x);
            if (lt[x]) modfy(1, 1, n, lt[x] - len[x] + 1, lt[x] - len[lk[x]], -1);
            son[x][1] = i;
        }
        splay(1), lt[1] = y, lz[1] = 1;
    }

    inline void ins(int x)
    {
        int y = ++num;
        len[y] = len[lst] + 1;
        while (lst && !ch[lst][x]) ch[lst][x] = y, lst = lk[lst];
        if (lst)
        {
            int q = ch[lst][x];
            if (len[q] == len[lst] + 1) lk[y] = q;
            else
            {
                len[++num] = len[lst] + 1, lk[num] = lk[q], lk[q] = lk[y] = num;
                memcpy(ch[num], ch[q], sizeof ch[num]);
                while (lst && ch[lst][x] == q) ch[lst][x] = num, lst = lk[lst];
            }
        }
        else lk[y] = 1;
        lst = y;
    }

    int main()
    {
        scanf("%s", s + 1);
        n = strlen(s + 1), m = read();
        for (Re i = 0; i < m; ++i)
        {
            int u = read(), v = read();
            q[v].push_back(info{i, u});
        }
        lst = num = 1;
        for (Re i = 1; i <= n; ++i) ins(s[i] - 97), ls[i] = lst;
        for (Re i = 1; i <= n; ++i)
        {
            access(ls[i], i), modfy(1, 1, n, 1, i, 1);
            int u = q[i].size();
            for (Re j = 0; j < u; ++j) ans[q[i][j].id] = que(1, 1, n, q[i][j].t, i);
        }
        for (Re i = 0; i < m; ++i) write(ans[i]);
        return 0;
    }
```

回文自动机

- num 是该结点表示的前缀的回文后缀个数

- cnt 是该结点表示的回文串在原串中的出现次数（使用前需要向父亲更新）

```
namespace pam {
    int t[N][26], fa[N], len[N], rs[N], cnt[N], num[N];
    int sz, n, last;
    int _new(int l) {
        len[sz] = l; cnt[sz] = num[sz] = 0;
        return sz++;
    }
    void init() {
        memset(t, 0, sz * sizeof t[0]);
        rs[n = sz = 0] = -1;
        last = _new(0);
        fa[last] = _new(-1);
    }
    int get_fa(int x) {
        while (rs[n - 1 - len[x]] != rs[n]) x = fa[x];
        return x;
    }
    void ins(int ch) {
        rs[++n] = ch;
        int p = get_fa(last);
        if (!t[p][ch]) {
            int np = _new(len[p] + 2);
            num[np] = num[fa[np]] = t[get_fa(fa[p])][ch] + 1;
            t[p][ch] = np;
        }
        ++cnt[last = t[p][ch]];
    }
}
```

manacher

```
int RL[N];
void manacher(int* a, int n) { // "abc" => "#a#b#a#"
    int r = 0, p = 0;
    FOR (i, 0, n) {
        if (i < r) RL[i] = min(RL[2 * p - i], r - i);
        else RL[i] = 1;
        while (i - RL[i] >= 0 && i + RL[i] < n && a[i - RL[i]] == a[i + RL[i]])
            RL[i]++;
        if (RL[i] + i - 1 > r) { r = RL[i] + i - 1; p = i; }
    }
    FOR (i, 0, n) --RL[i];
}

```

哈希

内置了自动双哈希开关（小心 TLE）。

```
#include <bits/stdc++.h>
using namespace std;

#define ENABLE_DOUBLE_HASH

typedef long long LL;
typedef unsigned long long ULL;

const int x = 135;
const int N = 4e5 + 10;
const int p1 = 1e9 + 7, p2 = 1e9 + 9;
ULL xp1[N], xp2[N], xp[N];

void init_xp() {
    xp1[0] = xp2[0] = xp[0] = 1;
    for (int i = 1; i < N; ++i) {
        xp1[i] = xp1[i - 1] * x % p1;
        xp2[i] = xp2[i - 1] * x % p2;
        xp[i] = xp[i - 1] * x;
```

```
20          }
21     }
22
23     struct String {
24          char s[N];
25          int length, subsize;
26          bool sorted;
27          ULL h[N], hl[N];
28
29          ULL hash() {
30              length = strlen(s);
31              ULL res1 = 0, res2 = 0;
32              h[length] = 0;   // ATTENTION!
33              for (int j = length - 1; j >= 0; --j) {
34          #ifdef ENABLE_DOUBLE_HASH
35                  res1 = (res1 * x + s[j]) % p1;
36                  res2 = (res2 * x + s[j]) % p2;
37                  h[j] = (res1 << 32) | res2;
38          #else
39                  res1 = res1 * x + s[j];
40                  h[j] = res1;
41          #endif
42                  // printf("%llu\n", h[j]);
43              }
44              return h[0];
45          }
46
47          //  获取子串哈希，左闭右开区间
48          ULL get_substring_hash(int left, int right) const {
49              int len = right - left;
50          #ifdef ENABLE_DOUBLE_HASH
51              // get hash of s[left...right-1]
52              unsigned int mask32 = ~(0u);
53              ULL left1 = h[left] >> 32, right1 = h[right] >> 32;
54              ULL left2 = h[left] & mask32, right2 = h[right] & mask32;
55              return ((((left1 - right1 * xp1[len] % p1 + p1) % p1) << 32) |
56                      (((left2 - right2 * xp2[len] % p2 + p2) % p2)));
57          #else
58              return h[left] - h[right] * xp[len];
59          #endif
60          }
61
62          void get_all_subs_hash(int sublen) {
63              subsize = length - sublen + 1;
64              for (int i = 0; i < subsize; ++i)
65                  hl[i] = get_substring_hash(i, i + sublen);
66              sorted = 0;
67          }
68
69          void sort_substring_hash() {
70              sort(hl, hl + subsize);
71              sorted = 1;
72          }
73
74          bool match(ULL key) const {
75              if (!sorted) assert (0);
76              if (!subsize) return false;
77              return binary_search(hl, hl + subsize, key);
78          }
79
80          void init(const char *t) {
81              length = strlen(t);
82              strcpy(s, t);
83          }
84     };
85
86     int LCP(const String &a, const String &b, int ai, int bi) {
87          // Find LCP of a[ai...] and b[bi...]
88          int l = 0, r = min(a.length - ai, b.length - bi);
89          while (l < r) {
90              int mid = (l + r + 1) / 2;
```

```
91          if (a.get_substring_hash(ai, ai + mid) == b.get_substring_hash(bi, bi + mid))
92              l = mid;
93          else r = mid - 1;
94      }
95      return l;
96  }
97
98  int check(int ans) {
99      if (T.length < ans) return 1;
100     T.get_all_subs_hash(ans); T.sort_substring_hash();
101     for (int i = 0; i < S.length - ans + 1; ++i)
102         if (!T.match(S.get_substring_hash(i, i + ans)))
103             return 1;
104     return 0;
105 }
106
107 int main() {
108     init_xp();  // DON'T FORGET TO DO THIS!
109
110     for (int tt = 1; tt <= kases; ++tt) {
111         scanf("%d", &n); scanf("%s", str);
112         S.init(str);
113         S.hash(); T.hash();
114     }
115 }
```

二维哈希

```
1  struct Hash2D { // 1-index
2      static const LL px = 131, py = 233, MOD = 998244353;
3      static LL pwx[N], pwy[N];
4      int a[N][N];
5      LL hv[N][N];
6      static void init_xp() {
7          pwx[0] = pwy[0] = 1;
8          FOR (i, 1, N) {
9              pwx[i] = pwx[i - 1] * px % MOD;
10             pwy[i] = pwy[i - 1] * py % MOD;
11         }
12     }
13     void init_hash(int n, int m) {
14         FOR (i, 1, n + 1) {
15             LL s = 0;
16             FOR (j, 1, m + 1) {
17                 s = (s * py + a[i][j]) % MOD;
18                 hv[i][j] = (hv[i - 1][j] * px + s) % MOD;
19             }
20         }
21     }
22     LL h(int x, int y, int dx, int dy) {
23         --x; --y;
24         LL ret = hv[x + dx][y + dy] + hv[x][y] * pwx[dx] % MOD * pwy[dy]
25                 - hv[x][y + dy] * pwx[dx] - hv[x + dx][y] * pwy[dy];
26         return (ret % MOD + MOD) % MOD;
27     }
28 } ha, hb;
29 LL Hash2D::pwx[N], Hash2D::pwy[N];
```

后缀数组

构造时间：$O(L \log L)$；查询时间 $O(\log L)$。**suffix** 数组是排好序的后缀下标，**suffix** 的反数组是后缀数组。

```
1  #include <bits/stdc++.h>
2  using namespace std;
3
4  const int N = 2e5 + 10;
5  const int Nlog = 18;
6
7  struct SuffixArray {
8      const int L;
9      vector<vector<int> > P;
```

```cpp
        vector<pair<pair<int, int>, int> > M;
        int s[N], sa[N], rank[N], height[N];
        // s: raw string
        // sa[i]=k: s[k...L-1] ranks i (0 based)
        // rank[i]=k: the rank of s[i...L-1] is k (0 based)
        // height[i] = lcp(sa[i-1], sa[i])

        SuffixArray(const string &raw_s) : L(raw_s.length()), P(1, vector<int>(L, 0)), M(L) {
            for (int i = 0; i < L; i++)
                P[0][i] = this->s[i] = int(raw_s[i]);
            for (int skip = 1, level = 1; skip < L; skip *= 2, level++) {
                P.push_back(vector<int>(L, 0));
                for (int i = 0; i < L; i++)
                    M[i] = make_pair(make_pair(P[level - 1][i], i + skip < L ? P[level - 1][i + skip] : -1000), i);
                sort(M.begin(), M.end());
                for (int i = 0; i < L; i++)
                    P[level][M[i].second] = (i > 0 && M[i].first == M[i - 1].first) ? P[level][M[i - 1].second] : i;
            }
            for (unsigned i = 0; i < P.back().size(); ++i) {
                rank[i] = P.back()[i];
                sa[rank[i]] = i;
            }
        }

        // This is a traditional way to calculate LCP
        void getHeight() {
            memset(height, 0, sizeof height);
            int k = 0;
            for (int i = 0; i < L; ++i) {
                if (rank[i] == 0) continue;
                if (k) k--;
                int j = sa[rank[i] - 1];
                while (i + k < L && j + k < L && s[i + k] == s[j + k]) ++k;
                height[rank[i]] = k;
            }
            rmq_init(height, L);
        }

        int f[N][Nlog];
        inline int highbit(int x) {
            return 31 - __builtin_clz(x);
        }

        int rmq_query(int x, int y) {
            int p = highbit(y - x + 1);
            return min(f[x][p], f[y - (1 << p) + 1][p]);
        }

        // arr has to be 0 based
        void rmq_init(int *arr, int length) {
            for (int x = 0; x <= highbit(length); ++x)
                for (int i = 0; i <= length - (1 << x); ++i) {
                    if (!x) f[i][x] = arr[i];
                    else f[i][x] = min(f[i][x - 1], f[i + (1 << (x - 1))][x - 1]);
                }
        }

        #ifdef NEW
        // returns the length of the longest common prefix of s[i...L-1] and s[j...L-1]
        int LongestCommonPrefix(int i, int j) {
            int len = 0;
            if (i == j) return L - i;
            for (int k = (int) P.size() - 1; k >= 0 && i < L && j < L; k--) {
                if (P[k][i] == P[k][j]) {
                    i += 1 << k;
                    j += 1 << k;
                    len += 1 << k;
                }
            }
            return len;
        }
```

```
81          #else
82          int LongestCommonPrefix(int i, int j) {
83              // getHeight() must be called first
84              if (i == j) return L - i;
85              if (i > j) swap(i, j);
86              return rmq_query(i + 1, j);
87          }
88          #endif
89
90          int checkNonOverlappingSubstring(int K) {
91              // check if there is two non-overlapping identical substring of length K
92              int minsa = 0, maxsa = 0;
93              for (int i = 0; i < L; ++i) {
94                  if (height[i] < K) {
95                      minsa = sa[i]; maxsa = sa[i];
96                  } else {
97                      minsa = min(minsa, sa[i]);
98                      maxsa = max(maxsa, sa[i]);
99                      if (maxsa - minsa >= K) return 1;
100                 }
101             }
102             return 0;
103         }
104
105         int checkBelongToDifferentSubstring(int K, int split) {
106             int minsa = 0, maxsa = 0;
107             for (int i = 0; i < L; ++i) {
108                 if (height[i] < K) {
109                     minsa = sa[i]; maxsa = sa[i];
110                 } else {
111                     minsa = min(minsa, sa[i]);
112                     maxsa = max(maxsa, sa[i]);
113                     if (maxsa > split && minsa < split) return 1;
114                 }
115             }
116             return 0;
117         }
118
119     } *S;
120
121     int main() {
122         string s, t;
123         cin >> s >> t;
124         int sp = s.length();
125         s += "*" + t;
126         S = new SuffixArray(s);
127         S->getHeight();
128         int left = 0, right = sp;
129         while (left < right) {
130             int mid = (left + right + 1) / 2;
131             if (S->checkBelongToDifferentSubstring(mid, sp))
132                 left = mid;
133             else right = mid - 1;
134         }
135         printf("%d\n", left);
136     }
```

- SA-IS
- 仅在后缀自动机被卡内存或者卡常且需要 O(1) LCA 的情况下使用（比赛中敲这个我觉得不行）
- UOJ 35

```
1   // rk [0..n-1] -> [1..n], sa/ht [1..n]
2   // s[i] > 0 && s[n] = 0
3   // b: normally as bucket
4   // c: normally as bucket1
5   // d: normally as bucket2
6   // f: normally as cntbuf
7
8   template<size_t size>
9   struct SuffixArray {
10      bool t[size << 1];
```

```cpp
        int b[size], c[size];
        int sa[size], rk[size], ht[size];
        inline bool isLMS(const int i, const bool *t) { return i > 0 && t[i] && !t[i - 1]; }
        template<class T>
        inline void inducedSort(T s, int *sa, const int n, const int M, const int bs,
                                bool *t, int *b, int *f, int *p) {
            fill(b, b + M, 0); fill(sa, sa + n, -1);
            FOR (i, 0, n) b[s[i]]++;
            f[0] = b[0];
            FOR (i, 1, M) f[i] = f[i - 1] + b[i];
            FORD (i, bs - 1, -1) sa[--f[s[p[i]]]] = p[i];
            FOR (i, 1, M) f[i] = f[i - 1] + b[i - 1];
            FOR (i, 0, n) if (sa[i] > 0 && !t[sa[i] - 1]) sa[f[s[sa[i] - 1]]++] = sa[i] - 1;
            f[0] = b[0];
            FOR (i, 1, M) f[i] = f[i - 1] + b[i];
            FORD (i, n - 1, -1) if (sa[i] > 0 && t[sa[i] - 1]) sa[--f[s[sa[i] - 1]]] = sa[i] - 1;
        }
        template<class T>
        inline void sais(T s, int *sa, int n, bool *t, int *b, int *c, int M) {
            int i, j, bs = 0, cnt = 0, p = -1, x, *r = b + M;
            t[n - 1] = 1;
            FORD (i, n - 2, -1) t[i] = s[i] < s[i + 1] || (s[i] == s[i + 1] && t[i + 1]);
            FOR (i, 1, n) if (t[i] && !t[i - 1]) c[bs++] = i;
            inducedSort(s, sa, n, M, bs, t, b, r, c);
            for (i = bs = 0; i < n; i++) if (isLMS(sa[i], t)) sa[bs++] = sa[i];
            FOR (i, bs, n) sa[i] = -1;
            FOR (i, 0, bs) {
                x = sa[i];
                for (j = 0; j < n; j++) {
                    if (p == -1 || s[x + j] != s[p + j] || t[x + j] != t[p + j]) { cnt++, p = x; break; }
                    else if (j > 0 && (isLMS(x + j, t) || isLMS(p + j, t))) break;
                }
                x = (~x & 1 ? x >> 1 : x - 1 >> 1), sa[bs + x] = cnt - 1;
            }
            for (i = j = n - 1; i >= bs; i--) if (sa[i] >= 0) sa[j--] = sa[i];
            int *s1 = sa + n - bs, *d = c + bs;
            if (cnt < bs) sais(s1, sa, bs, t + n, b, c + bs, cnt);
            else FOR (i, 0, bs) sa[s1[i]] = i;
            FOR (i, 0, bs) d[i] = c[sa[i]];
            inducedSort(s, sa, n, M, bs, t, b, r, d);
        }
        template<typename T>
        inline void getHeight(T s, const int n, const int *sa) {
            for (int i = 0, k = 0; i < n; i++) {
                if (rk[i] == 0) k = 0;
                else {
                    if (k > 0) k--;
                    int j = sa[rk[i] - 1];
                    while (i + k < n && j + k < n && s[i + k] == s[j + k]) k++;
                }
                ht[rk[i]] = k;
            }
        }
        template<class T>
        inline void init(T s, int n, int M) {
            sais(s, sa, ++n, t, b, c, M);
            for (int i = 1; i < n; i++) rk[sa[i]] = i;
            getHeight(s, n, sa);
        }
    };

    const int N = 2E5 + 100;
    SuffixArray<N> sa;

    int main() {
        string s; cin >> s; int n = s.length();
        sa.init(s, n, 128);
        FOR (i, 1, n + 1) printf("%d%c", sa.sa[i] + 1, i == _i - 1 ? '\n' : ' ');
        FOR (i, 2, n + 1) printf("%d%c", sa.ht[i], i == _i - 1 ? '\n' : ' ');
    }
```

KMP

- 前缀函数（每一个前缀的最长 border）

```
1  void get_pi(int a[], char s[], int n) {
2      int j = a[0] = 0;
3      FOR (i, 1, n) {
4          while (j && s[i] != s[j]) j = a[j - 1];
5          a[i] = j += s[i] == s[j];
6      }
7  }
```

- Z 函数（每一个后缀和该字符串的 LCP 长度）

```
1  void get_z(int a[], char s[], int n) {
2      int l = 0, r = 0; a[0] = n;
3      FOR (i, 1, n) {
4          a[i] = i > r ? 0 : min(r - i + 1, a[i - l]);
5          while (i + a[i] < n && s[a[i]] == s[i + a[i]]) ++a[i];
6          if (i + a[i] - 1 > r) { l = i; r = i + a[i] - 1; }
7      }
8  }
```

Trie

```
1  namespace trie {
2      int t[N][26], sz, ed[N];
3      void init() { sz = 2; memset(ed, 0, sizeof ed); }
4      int _new() { memset(t[sz], 0, sizeof t[sz]); return sz++; }
5      void ins(char* s, int p) {
6          int u = 1;
7          FOR (i, 0, strlen(s)) {
8              int c = s[i] - 'a';
9              if (!t[u][c]) t[u][c] = _new();
10             u = t[u][c];
11         }
12         ed[u] = p;
13     }
14 }
```

AC 自动机

```
1  const int N = 1e6 + 100, M = 26;
2
3  int mp(char ch) { return ch - 'a'; }
4
5  struct ACA {
6      int ch[N][M], danger[N], fail[N];
7      int sz;
8      void init() {
9          sz = 1;
10         memset(ch[0], 0, sizeof ch[0]);
11         memset(danger, 0, sizeof danger);
12     }
13     void insert(const string &s, int m) {
14         int n = s.size(); int u = 0, c;
15         FOR (i, 0, n) {
16             c = mp(s[i]);
17             if (!ch[u][c]) {
18                 memset(ch[sz], 0, sizeof ch[sz]);
19                 danger[sz] = 0; ch[u][c] = sz++;
20             }
21             u = ch[u][c];
22         }
23         danger[u] |= 1 << m;
24     }
25     void build() {
26         queue<int> Q;
27         fail[0] = 0;
28         for (int c = 0, u; c < M; c++) {
29             u = ch[0][c];
```

```
30            if (u) { Q.push(u); fail[u] = 0; }
31        }
32        while (!Q.empty()) {
33            int r = Q.front(); Q.pop();
34            danger[r] |= danger[fail[r]];
35            for (int c = 0, u; c < M; c++) {
36                u = ch[r][c];
37                if (!u) {
38                    ch[r][c] = ch[fail[r]][c];
39                    continue;
40                }
41                fail[u] = ch[fail[r]][c];
42                Q.push(u);
43            }
44        }
45    }
46 } ac;
47
48 char s[N];
49
50 int main() {
51    int n; scanf("%d", &n);
52    ac.init();
53    while (n--) {
54        scanf("%s", s);
55        ac.insert(s, 0);
56    }
57    ac.build();
58
59    scanf("%s", s);
60    int u = 0; n = strlen(s);
61    FOR (i, 0, n) {
62        u = ac.ch[u][mp(s[i])];
63        if (ac.danger[u]) {
64            puts("YES");
65            return 0;
66        }
67    }
68    puts("NO");
69    return 0;
70 }
```