Memperbaiki *Vigènere Cipher* dengan Menggunakan Kubus *Vigènere*

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Abstract – Vigènere Cipher sebenarnya dianggap sebagai salah satu cipher yang cukup aman. Akan tetapi, kerena pengulangan kunci yang digunakan, timbul suatu kelemahan.

Karena Vigènere Cipher termasuk cipher yang paling dikenal, sudah ada begitu banyak variasi yang berusaha menghilangkan kelemahan Vigènere Cipher. Tentunya dengan catatan bahwa variasi tersebut tetap mempertahankan kesederhanaan Vigènere Cipher sebagai cipher klasik. Akan tetapi, dari sekian banyak variasi, belum ada yang dapat menghilangkan kelemahan sekaligus mempertahankan kesederhanaanya. One Time Pad Vigènere termasuk yang paling kuat tetapi dianggap tidak sederhana lagi.

Cipher usulan ini salah satu varian dari Vigènere Cipher yang berusaha menghilangkan kelemahan sekaligus mempertahankan kesederhanaanya. Dan ternyata setelah diimplementasikan, cipher usulan ini dirasa kuat, dan masih sederhana (look-up). Sehingga prosesnya (dekripsi dan enkripsi) dapat dilakukan secara manual.

Yang cukup rumit adalah pembuatan Kubus Vigènere yang menjadi bagian terpenting dalam cipher usulan ini. Kubus Vigènere yang dianggap kuat, telah berhasil dibentuk dengan bantuan program. Kubus ini telah terbukti berhasil diimplementasikan menjadi bagian dari cipher usulan ini.

Kata Kunci: Vigènere, cipher, plaintext, ciphertext, look-up.

1. PENDAHULUAN

Vigènere sebenarnya dianggap sebagai salah satu *cipher* yang cukup aman. Hal ini dikarenakan *Vigènere* sebenarnya sudah menggunakan konsep yang mirip S-box yaitu pada persegi / bujur sangkar *Vigènere*. Dengan adanya tabel subtitusi ini, frekuensi kemunculan dari suatu huruf dapat diratakan.

Akan tetapi, kerena pengulangan kunci yang digunakan, timbul suatu kelemahan. Kelemahan ini berupa adanya perulangan dalam kemunculan kemunculan dua huruf, triplet, bahkan quadruplet yang muncul dalam *cipher*text. Kemunculan yang berulang ini mungkin merupakan kemunculan dua huruf, triplet, dan quadruplet dalam *plaintext* dengan jarak yang merupakan kelipatan dari panjang kunci. Dengan mengetahui panjang kunci (menggunakan metode Kasiski), analisis frekuensi dapat diterapkan untuk mengkripanalisis *cipher*text yang dienkripsi dengan kunci yang sama (*cipher*text yang berjarak sepanjang kunci).
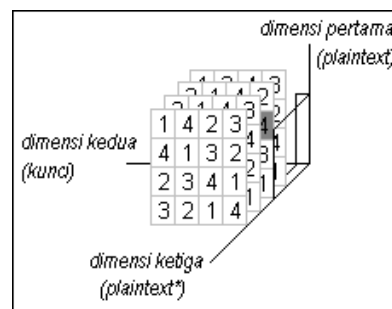
Walupun cukup sederhana (masih dimungkinkan enkripsi-dekripsi secara manual karena berbasiskan look-up table), *cipher* usulan diharapkan dapat memperbesar keuntungan dalam penggunaan persegi *Vigènere*, sekaligus memperkecil kelemahan dari pengulangan kunci. "Tabel" subtitusi yang akan digunakan memiliki lebih dari dua dimensi. Tidak hanya melibatkan *plaintext* (dimensi pertama) dan kunci (dimensi kedua), tetapi juga melibatkan satu dimensi tambahan (dimensi ketiga) yaitu hasil gabungan dari bagian kunci (mengambil konsep kunci internal) dan *plaintext* sebelumnya (mengambil konsep *Auto-key Vigènere Cipher*).

2. ANALISIS DAN PERANCANGAN

Usulan perbaikan ini sebenarnya terbagi dalam dua bagian besar. Bagian pertama membahas proses (enkripsi dan dekripsi) yang berjalan, bagian kedua membahas kubus *Vigènere* yang dipakai pada bagian pertama.

2.1. Proses dari *cipher* usulan

Cipher usulan merupakan varian dari *Vigènere Cipher*. Perbedaan muncul pada jumlah dimensinya. Jika pada *Vigènere* kita akan mengambil nilai (lookup) dari tabel (dua dimensi: *plaintext* dan kunci), pada *cipher* usulan kita akan mengambil nilai (lookup) dari datacube (tiga dimensi: *plaintext*, kunci, dan *plaintext**).

Gambar 1: *Look-up* pada Kubus *Vigènere*

Gambar di atas menunjukan Kubus *Vigènere* sebagai

pengganti persegi *Vigènere*. Kubus ini harus bersifat sama dengan persegi *Vigènere*, yakni dapat dipakai untuk mengenkripsi sekaligus dekripsi. Proses membentuk kubus *Vigènere* dengan sifat seperti ini (atau lebih baik) akan dibahasi di bagian selanjutnya.

Dapat dilihat, *plaintext*=3, kunci=1, *plaintext**=2 akan menghasilkan *cipher*text=4 (berwarna abu-abu).

Dimensi ketiga (*plaintext**) adalah huruf ke-n sebelumnya pada plain text, dimana n = (panjang kunci) - 1. Pemilihan n sedemikian rupa ditujukan meminimalkan frekuensi keterulangan pola pada *cipher*text. Dengan kata lain memperpanjang periode keterulangan pola pada *cipher*text.

Dengan dimensi tambahan ini, kripanalis tidak dapat lagi menggunakan (metode kasiski) analisis kemunculan kemunculan 2 huruf, triplet, dan quadruplet pada *cipher* text. Dan dengan melibatkan *plaintext* sebelumnya, kita juga menambahkan sifat diffusion pada *Vigènere Cipher* (walaupun bukan melibatkan feedback berupa *cipher*text sebelumnya, seperti kebanyakan algoritma kriptografi moderen).

Dipilih n = (panjang kunci)-1 karena n pasti relatif prima terhadap (n+1) (untuk n>1). Dengan *cipher* usulan akan menghasilkan pola keterulangan setiap interval n*(n+1). Pada kasus terburuk (kasus yang paling menguntungkan kripanalis), pengulangan pada *cipher*text (yang benar merupakan pengulangan di *plaintext* dan kunci) mempunyai periode minimal = n*(n+1).

Untuk *plaintext** awal, akan mendapat perlakuan khusus (karena tidak mempunyai n huruf sebelumnya pada plain text). Hal ini diatasi dengan menggunakan initiation vector. Initiation vector ini tidak akan di-hard code pada program, melainkan pengolahan kunci itu sendiri (mengambil konsep kunci internal). Kunci dibuang satu huruf yang paling depan. Pembuangan satu huruf yang paling depan ditujukan untuk memperkecil keterkaitan dimensi ketiga (*plaintext**) dengan dimensi kedua (kunci) di pada n posisi paling depan.

Tabel 1. Proses mengenkrip

plaintext	3	1	4	1	3	3	1	4	2
kunci	1	2	3	1	2	3	1	2	3
plaintext*	2	3	3	1	4	1	3	3	1
ciphertext	4	...							

Gambar di atas menunjukan dua nilai awal *plaintext** berasal dari kunci (123) yang dibuang satu karakter paling depannya. Selanjutnya, *plaintext** adalah huruf ke-2 (panjang kunci=3) sebelumnya pada *plaintext*.

Sebagai tambahan, dalam *Vigènere*, proses enkripsi dan dekripsi umumnya menggunakan satu persegi *Vigènere* yang sama. Akan tetapi dengan menbuat suatu persegi *Vigènere* yang lain (yang bersifat inverse dari persegi *Vigènere* pertama), kita dapat mempercepat proses dekripsi. Proses dekripsi satu huruf yang tadinya harus mencari dari n banyak data secara linier (dengan kompleksitas O(n)), dapat ditekan menjadi look-up (dengan kompleksitas O(1)). Waktu yang diperlukan untuk dekripsi akan lebih cepat (sama dengan enkripsi) sebagai balasan penggunaan memori yang lebih besar.

2.2. Kubus *Vigènere* yang baik
Karena kubus *Vigènere* sebenarnya mirip dengan persegi *Vigènere* (kecuali dalam banyaknya dimensi), pertama-tama kita lihat terlebih dahulu persegi *Vigènere*. Agar dapat digunakan untuk meng-enkripsi dan men-dekripsi, persegi *Vigènere* haruslah memenuhi sifat (syarat minimal) berikut:
- Dimensi pertama (*plaintext*) haruslah berkorespondensi satu ke satu dengan nilai (*cipher*text).

Artinya, dalam persegi *Vigènere*, suatu *plaintext* haruslah menentukan *cipher*text dan sebaliknya. Untuk dimensi kedua (kunci) yang sama, dimensi pertama (*plaintext*) haruslah menentukan nilai (*cipher*text). Jika dimensi kedua (kunci) tetap sementara dimensi pertama (*plaintext*) berubah, maka nilai (*cipher*text) harus berubah. Begitu pula sebaliknya.

Akan tetapi persegi *Vigènere* seperti itu masih kurang bagus karena dimensi kedua (kunci) terlihat kurang berperan. Hal ini bisa kita lihat pada gambar persegi *Vigènere* berikut ini.

Tabel 2. Persegi *Vigènere* yang sangat jelek (sangat lemah)

Persegi *Vigènere* di atas memenuhi syarat minimal. Suatu nilai hanya muncul sekali pada satu kolom manapun. Akan tetapi dapat dilihat untuk dimensi kedua (kunci) yang manapun, nilai (*cipher*text) 'd' akan berkorespondensi dengan dimensi pertama (*plaintext*) 'b'. Untuk seorang kripanalis, hal ini dapat dimanfaatkan. Karena persegi *Vigènere* dan algoritmanya adalah hal yang dipublikasikan (diketahui semua orang), kripanalis dapat menganalisis persegi *Vigènere* tersebut dan menarik kesimpulan bahwa *cipher*text 'd' pasti bersesuaian

dengan *plaintext* 'b'. Tidak peduli apapun kuncinya.

Walaupun contoh di atas merupakan kasus terburuk, akan tetapi kelemahan sejenis dapat dimanfaatkan oleh kripanalis. Hal ini bisa kita lihat pada gambar persegi *Vigènere* berikut ini.

Tabel 3. Persegi *Vigènere* yang jelek (lemah)

dimensi kedua

(kunci)

	a	b	c	d	e
a	b	e	a	e	c
b	d	d	d	d	e
c	a	b	b	c	d
d	e	c	e	a	b
e	c	a	c	b	a

dimensi pertama (plaintext)

Persegi *Vigènere* di atas juga memenuhi syarat minimal. Akan tetapi dapat dilihat untuk sebagian besar dimensi kedua (kunci), nilai (*cipher*text) 'd' akan berkorespondensi dengan dimensi pertama (*plaintext*) 'b'. Dengan alasan yang sama dengan di atas, kripanalis dapat menganalisis persegi *Vigènere* tersebut dan menarik kesimpulan bahwa *cipher*text 'd' kemungkinan besar (4/5 = 80%) bersesuaian dengan *plaintext* 'b'.

Persegi *Vigènere* dapat dibuat lebih baik dengan menambahkan sifat berikut:
- Keseluruhan dimensi haruslah berkorespondensi satu ke satu dengan nilai (*cipher*).

Jika satu dimensi berubah sementara dimensi lainnya tetap, nilai (*cipher*) haruslah berubah. Begitu pula sebaliknya.

Contoh persegi *Vigènere* yang lebih baik tersebut dapat dilihat sebagai berikut.

Tabel 4. Persegi *Vigènere* yang baik (kuat)

dimensi kedua

(kunci)

	a	b	c	d	e
a	b	e	a	d	c
b	d	b	e	c	a
c	a	d	c	b	d
d	e	c	d	a	e
e	c	a	b	e	d

dimensi pertama (plaintext)

Persegi *Vigènere* di atas memenuhi syarat sebagai persegi *Vigènere* yang lebih baik. Suatu nilai hanya muncul sekali pada satu kolom dan baris manapun. Kripanalisis yang menganalisis persegi *Vigènere* tersebut akan mendapatkan kesimpulan yang tidak dapat dipakai untuk mengkripanalisis. Kemungkinan

*cipher*text berkorespondensi dengan suatu *plaintext* akan sama besar dengan kemungkinan *cipher*text (yang sama) berkorespondensi dengan suatu *plaintext* yang lain.

Kubus *Vigènere* yang baik haruslah memiliki sifat yang sejenis dengan persegi *Vigènere* yang baik. Perbedaannya hanyalah pada banyaknya dimensi. Suatu nilai hanya muncul sekali pada satu kolom, baris, dan tingkat kedalaman manapun (lebih banyak 1 dimensi). Pertanyaan selanjutnya, bagaimana cara membentuk kubus *Vigènere* yang baik tersebut?

2.3. Cara Memmbangun kubus *Vigènere* yang baik
Pertama-tama kita bentuk sebuah kubus *Vigènere* yang secara trivial dapat kita pastikan merupakan kubus *Vigènere* yang baik. Contoh kubus *Vigènere* yang baik tersebut dapat dilihat sebagai berikut:

Tabel 5. Kubus *Vigènere* yang baik (kuat) tetapi terpola

Dimensi ketiga (plain*): a

dimensi kedua

(kunci)

	a	b	c
a	a	b	c
b	b	c	a
c	c	a	b

dimensi pertama (plaintext)

Dimensi ketiga (plain*): b

dimensi kedua

(kunci)

	a	b	c
a	b	c	a
b	c	a	b
c	a	b	c

dimensi pertama (plaintext)

Dimensi ketiga (plain*): c

dimensi kedua

(kunci)

	a	b	c
a	c	a	b
b	a	b	c
c	b	c	a

dimensi pertama (plaintext)

Dari kubus *Vigènere* yang sudah pasti merupakan kubus *Vigènere* yang baik tersebut, barulah kita tranformasi (dengan suatu operator) sedemikian sehingga nilai di dalamnya tidak mempunyai pola, tetapi tetap memenuhi sifat kubus *Vigènere* yang baik.

Transformasi yang dilakukan bisa dengan menukarkan satu layer (sel-sel dalam kubus *Vigènere* yang memiliki satu dimensi yang sama). Misalnya saja menukarkan layer dimensi pertama (*plaintext*)='a' dengan layer dimensi pertama (*plaintext*)='b'. Atau menukarkan layer dimensi kedua (kunci)='b' dengan layer dimensi kedua (kunci)='c'.

Hal ini dapat dibayangkan seperti menukarkan posisi 2 lembar kartu pada setumpukan kartu. Kedua hal tersebut identik kecuali dalam banyaknya jenis layer. Pada tumpukan kartu hanya ada 1 jenis layer, sedangkan pada kubus *Vigènere* ada tiga jenis layer (hasil pemotongan terhadap penampang x-y, penampang x-z, dan penampang y-z).

Dengan melakukan berulang-ulang tranformasi tersebut (layer mana yang dipertukarkan dan jenis layer mana yang dipakai akan di-generate secara random dari suatu seed), akan diperoleh kubus *Vigènere* yang tidak terlihat polanya (oleh manusia) tetapi tetap memenuhi sifat kubus *Vigènere* yang baik.

Implementasi dari proses pembuatan kubus *Vigènere* ini dapat dilihat di lampiran (*Vigènere*_cube_generator.cpp), yang nantinya akan digunakan oleh proses utama (*Vigènere*_cube.cpp).

3. HASIL DAN PEMBAHASAN

Yang telah dicoba dan dapat dibahas terbagi dalam dua bagian besar. Bagian pertama membahas hasil proses (enkripsi dan dekripsi) beserta analisis terhadap hasil tersebut, bagian kedua membahas kekuatan dari *cipher* usulan.

3.1. Analisis proses *cipher* usulan
Sesuai dengan sifat *cipher* klasik, *cipher* usulan memiliki proses yang cukup sederhana. Dalam artian proses dekripsi dan enkripsi masih dapat dilakukan secara manual, tanpa bantuan komputer. Karena, seperti yang disebutkan di atas, proses enkripsi dan dekripsinya sebenarnya hanya berbasiskan *look-up table*. Hal tersebut dapat dilakukan secara manual jika "tabel"-nya diberikan.

Lebih dari itu, dalam implementasinya karakter yang ditangani (di enkripsi dan didekripsi) hanyalah 26 karakter huruf besar ('A' sampai 'Z'), karena itu, tabelnya "hanya" berukuran 26^3 *cell* (yang jika dicetak kurang dari 30 halaman). Hasil kubus *Vigènere* juga dapat dilihat di *Vigènere*_cube.txt.

Selain itu, proses enkripsi maupun dekripsi memakan waktu yang sangat singkat. Terutama dengan adanya kubus *Vigènere* tambahan untuk menghemat waktu dekripsi.

Hasil dari proses enkripsi dan dekripsi dapat dilihat di lampiran (*cipher*.txt dan plain2.txt).

3.2. Analisis kekuatan *cipher* usulan
Metode seperti Kasiski, analisis frekuensi telah dicoba untuk mengkripanalisis *cipher* text. Hasilnya, tidak ada informasi yang dapat diperoleh. Baik informasi tentang *plaintext*, kunci, ataupun sekedar panjang kunci. Dengan kata lain, *cipher*text yang dihasilkan *cipher* usulan lebih kuat jika dibandingkan *cipher*text yang dihasilkan varian *Vigènere* lainnya (kecuali One Time Pad *Vigènere*).

Vigènere dasar memiliki kelemahan yang berasal dari panjang kunci yang dapat dicari. Seperti yang telah dijelaskan pada abstraksi. *Cipher* usulan memperkecil kelemahan ini dengan menambahkan suatu dimensi tambahan yaitu dimensi ketiga (*plaintext**). Seperti yang dijelaskan pada bagian *cipher* usulan, pengulangan pada *cipher*text (yang benar merupakan pengulangan di *plaintext* dan kunci) mempunyai periode minimal = n*(n+1). Dimana n = (panjang kunci) – 1. Sementara itu *Vigènere Cipher* mempunyai periode minimal (n+1). Hal ini berarti *cipher* usulan ini n kali lebih sulit dalam menemukan panjang kunci, jika dibandingkan *Vigènere Cipher*.

Seandainya panjang kunci dapat diketahui pun, kripanalis tidak dapat langsung menerapkan analisis frekuensi terhadap huruf tunggal biasa (seperti kemunculan *cipher* paling banyak, dalam kelipatan panjang kunci, berkorespondensi dengan *plaintext* 'e' dalam bahasa Inggris). Kripanalisis harus membuat tabel frekuensi baru yang berisi frekuensi kemunculan sepasang huruf (yang saling berjarak n) dari suatu bahasa, barulah mengkripanalisis.

Dengan kunci yang beragam panjangnya, kripanalis memerlukan usaha tambahan untuk membuat tabel frekuensi baru. Itupun seandainya kripanalis berhasil menebak panjang kunci, mengingat metode Kasiski tidak dapat digunakan.

Untuk kunci yang panjang (panjang kunci > panjang rata-rata kata dalam suatu bahasa) terdapat banyak penyimpangan. Huruf x1, yaitu n huruf sebelum suatu huruf x2 (huruf pasangannya), jelas memiliki hubungan yang sangat kecil mengingat kemungkinan besar x1 berada pada kata yang berbeda (tepat sebelum, atau bahkan jauh sebelum) dibanding kata tempat huruf x1 berada.

Pada Auto-key *Vigènere Cipher*, sebenarnya yang perlu ditebak oleh kripanalis tidak perlu menebak kunci sama sekali (terutama pada kasus dimana kunci cukup pendek). Karena untuk *cipher*text dengan

posisi>(n+1), kunci sama sekali tidak memiliki andil dalam mengenkrip ataupun mendekrip. Dalam *cipher* usulan ini, kunci akan memiliki andil terhadap setiap bagian *cipher*text (karena adanya dimensi kedua (kunci) yang diulang-ulang).

*Cipher*text hasil percobaan menunjukan *plaintext* "TH" (pasangan huruf yang sering muncul dalam bahasa Inggris) yang muncul 22 kali pada *plaintext*, menghasilkan pasangan *cipher*text (pada posisi yang yang sesuai) yang berbeda satu sama lain (QF, BZ, AO, AT, ZH, EP, PH, QB, LE, WX, XO, UE, AB, ZA, AW, QP, IE, XA, VA, PL, HG, dan QI). Hasil ini dapat dilihat di lampiran (*cipher*.txt).

4. KESIMPULAN

Dengan menggunakan *cipher* usulan, yang menggabungkan konsep *Vigènere* dasar dan Auto-key *Vigènere Cipher*, kita dapat memperkecil kelemahan kedua konsep tersebut.

Lebih dari itu, *cipher* usulan tetap mempertahankan kesederhanaan prosesnya (enkripsi dan dekripsi) sehingga tetap dapat dilakukan secara manual.

DAFTAR REFERENSI

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Lampiran

plain.txt

```
HUNDREDS OF BANDUNG RESIDENTS FLOCKED TO THE BOSSCHA OBSERVATORY IN LEMBANG
NORTH BANDUNG TO CATCH A GLIMPSE OF THE TOTAL LUNAR ECLIPSE ON TUESDAY
OBSERVATION ACTIVITIES WERE FOCUSSED AT THE VANALBADA CENTER AND AIRED LIVE
BY TVRI STATE RUN TELEVISION STATION THE EIGHT BOSSCHA ASTRONOMERS WHO
CONDUCTED THE OBSERVATIONS AID THEY WERE SATISFIED ALTHOUGH THE TELESCOPES
WERE ONLY EFFECTIVE TEN MINUTES INTO THE PEAK OF THE TOTAL LUNAR ECLIPSE
WITH TRAFFIC BACKED UP ONE KILO METER ALONG THE ROAD LEADING TO THE
OBSERVATORY ASTRONOMERS WERE FORCED TO SHARE THE VIXEN TELESCOPE WITH
VISITORS OBSERVATIONS WERE CONDUCTED ATOP THE VANALBADA CENTER BY USING TWO
CELESTRON TELESCOPES AND ONE WILLIAM OPTICS MEASURING TWENTY CM AND SEVEN
CM IN DIAMETER RESPECTIVELY IT WAS THE SECOND TIME ASTRONOMERS HAD INVITED
THE PUBLIC TO AN EVENT AND ALLOWED IT TO BROADCAST LIVE ON TV AFTER THE
PREVIOUS MARS FULL MOON PHENOMENON ON AUGUST A GEGER KALONG RESIDENT RINDA
CAME WITH SIX OF HER ROOMMATES BY PUBLIC BUS TO WITNESS THE SPECTACLE
```

cipher.txt (dengan kunci HADISALOKO)

```
PTEZBBRRKTBVSICQFWZDLOEUWFZRNOPWQXVQFBNHZUZEEUTDCZIMMVFQYQDFFJJRZCICBZWDZOPJ
OHBFOHYTKDJKKEGAWOAOFKXCTKJQPIPBEMVIEFOVLXIMYKJZEVBXEUADFPZQWOXSXELFLDAFWRTN
SLLMZWATVXMGDGAVYOERZLQAUWDSQEFXLAZIEFQVZGVXZJBEBVOUHRTLGZCRQVXXOMJZHYFWIBKV
SKZQDVNVUWNSTPTIFZLJKJFBAOKMREPPVQUZGBGQMJEQKMTPHUNLJMQQEKWSFLSBMCQBXPLPLEDX
BKBLNREWXOQRPOQDSYATWQKYHAFSIVYRWDDBQXGSWXUJFGWLYXOWXKWLVHWWXYMDNQTCLJFUEFQA
KXIEYYOPYDUVKPGCTRRTTTLNUDAPDABWEVCAPTWXQVNLZZAXRAMNAQEKVWXQZFWVGDBATWKHSFLO
IHFIFPQBWCRAWJFHLNKUUHDXTYFFOFQPEPYRWBYVLLNEUCJBWDKWZNFRZSYOGXBNMMVNYIEJCUQP
MKERZZYDABCTCIJLEZFDPKZNFHSEQJASFWHDWIUVKLQGFBLLYGUKNRUBEBERTOCZPDVUPSTIXSZS
GXNOLYJORAZWOFNVYYXPLIRYIMQFXNSPCUYLVXAHTUIFHZQVQEPYEEMNLJNSXWEAUFUFWEYVAOSM
JSWCIATWMAQCPVQCGLQAUDNYHVUHSBXHZVCZFQWNZOGDWIXZTPLDXSZIQPWAOUTUHLVZDKOVWLRV
UJXFGWLQCSHNDPKLANROXKUVQMZCGIHBLDXQBJHCTMFZMHGPQUZXMKNHXCAEPKYVCGTDTMXQGSBG
JHRSZFEMQIOMRPBWMTQW
```

plain2.txt (dengan kunci HADISALOKO)

```
HUNDREDSOFBANDUNGRESIDENTSFLOCKEDTOTHEBOSSCHAOBSERVATORYINLEMBANGNORTHBANDUN
GTOCATCHAGLIMPSEOFTHETOTALLUNARECLIPSEONTUESDAYOBSERVATIONACTIVITIESWEREFOCU
SSEDATTHEVANALBADACENTERANDAIREDLIVEBYTVRISTATERUNTELEVISIONSTATIONTHEEIGHTB
OSSCHAASTRONOMERSWHOCONDUCTEDTHEOBSERVATIONSAIDTHEYWERESATISFIEDALTHOUGHTHET
ELESCOPESWEREONLYEFFECTIVETENMINUTESINTOTHEPEAKOFTHETOTALLUNARECLIPSEWITHTRA
FFICBACKEDUPONEKILOMETERALONGTHEROADLEADINGTOTHEOBSERVATORYASTRONOMERSWEREFO
RCEDTOSHARETHEVIXENTELESCOPEWITHVISITORSOBSERVATIONSWERECONDUCTEDATOPTHEVANA
LBADACENTERBYUSINGTWOCELESTRONTELESCOPESANDONEWILLIAMOPTICSMEASURINGTWENTYCM
ANDSEVENCMINDIAMETERRESPECTIVELYITWASTHESECONDTIMEASTRONOMERSHADINVITEDTHEPU
BLICTOANEVENTANDALLOWEDITTOBROADCASTLIVEONTVAFTERTHEPREVIOUSMARSFULLMOONPHEN
OMENONONAUGUSTAGEGERKALONGRESIDENTRINDACAMEWITHSIXOFHERROOMMATESBYPUBLICBUST
OWITNESSTHESPECTACLE
```

vigenere_cube.cpp

```cpp
#include<stdio.h>
#include<string.h>
#include<queue>

#include "vigenere_cube.txt"

using namespace std;
```

```c
int main(int argc,char **argv)
{
 char *mode;
 char *kunci;
 int panjang_kunci;
 char *nama_berkas_masukan,*nama_berkas_keluaran;
 FILE *berkas_masukan,*berkas_keluaran;
 char karakter_masukan,karakter_kunci,karakter_keluaran;
 int i;
 queue<int> antrian_param3;

 if(argc<3)
  {
   printf("ERR1: jumlah parameter<3\n");
   return 1;
  }
 mode=argv[1];
 if((strcmp(mode,"e"))&&(strcmp(mode,"d")))
  {
   printf("ERR2: parameter mode salah\n");
   return 2;
  }
 kunci=argv[2];
 panjang_kunci=strlen(kunci);
 if(panjang_kunci<2)
  {
   printf("ERR3: panjang kunci<2\n");
   return 3;
  }
 nama_berkas_masukan=argv[3];
 berkas_masukan=fopen(nama_berkas_masukan,"rt");
 if(!berkas_masukan)
  {
   printf("ERR4: file masukan \"%s\" tidak dapat dibuka\n",nama_berkas_masukan);
   return 4;
  }
 nama_berkas_keluaran=argv[4];
 berkas_keluaran=fopen(nama_berkas_keluaran,"wt");
 if(!berkas_keluaran)
  {
   printf("ERR5: file keluaran \"%s\" tidak dapat dibentuk\n",nama_berkas_keluaran);
   return 5;
  }

 for(i=1;i<panjang_kunci;i++)
  {
   antrian_param3.push(kunci[i]);
  }

 i=0;
 while(fscanf(berkas_masukan,"%c",&karakter_masukan)==1)
  {
   if((karakter_masukan>='A')&&(karakter_masukan<='Z'))
    {
     if(!strcmp(mode,"e"))
      {
       karakter_keluaran=vigenere_cube_e[karakter_masukan-'A'][kunci[i%panjang_kunci]-
'A'][antrian_param3.front()-'A']+'A';
       antrian_param3.push(karakter_masukan);
```

```
      }
    else if(!strcmp(mode,"d"))
      {
       karakter_keluaran=vigenere_cube_d[karakter_masukan-'A'][kunci[i%panjang_kunci]-
'A'][antrian_param3.front()-'A']+'A';
      antrian_param3.push(karakter_keluaran);
      }
    fprintf(berkas_keluaran,"%c",karakter_keluaran);
    antrian_param3.pop();
    i++;
    }
  }

  fclose(berkas_masukan);
  fclose(berkas_keluaran);
  return 0;
}
```

vigenere_cube_generator.cpp

```
#include<stdio.h>
#include<stdlib.h>
#define banyak_jenis_karakter 26
#define seed 13504157
#define banyak_pengacakan 26*26*26

int main(int argc,char **argv)
{
 char *nama_berkas_keluaran;
 FILE *berkas_keluaran;
 int vigenere_cube[banyak_jenis_karakter][banyak_jenis_karakter][banyak_jenis_karakter];
 int vigenere_cube2[banyak_jenis_karakter][banyak_jenis_karakter][banyak_jenis_karakter];
 int temp_vigenere_cell;
 int i,j,k;
 int m,n;
 int o,p;

 if(argc<2)
  {
   printf("ERR1: jumlah parameter<2\n");
   return 1;
  }
 nama_berkas_keluaran=argv[1];
 berkas_keluaran=fopen(nama_berkas_keluaran,"wt");
 if(!berkas_keluaran)
  {
   printf("ERR2: file keluaran \"%s\" tidak dapat dibentuk\n",nama_berkas_keluaran);
   return 2;
  }
 for(i=0;i<banyak_jenis_karakter;i++)
  {
   for(j=0;j<banyak_jenis_karakter;j++)
    {
     for(k=0;k<banyak_jenis_karakter;k++)
      {
       vigenere_cube[i][j][k]=(i+j+k)%banyak_jenis_karakter;
      }
    }
  }
```

```c
  srand(seed);
  for(p=0;p<banyak_pengacakan;p++)
  {
   m=rand()%banyak_jenis_karakter;
   n=rand()%banyak_jenis_karakter;
   o=rand()%3;

   if(o==0)
    {
     for(i=0;i<banyak_jenis_karakter;i++)
      {
       for(j=0;j<banyak_jenis_karakter;j++)
        {
         temp_vigenere_cell=vigenere_cube[m][i][j];
         vigenere_cube[m][i][j]=vigenere_cube[n][i][j];
         vigenere_cube[n][i][j]=temp_vigenere_cell;
        }
      }
    }
   else if(o==1)
    {
     for(i=0;i<banyak_jenis_karakter;i++)
      {
       for(j=0;j<banyak_jenis_karakter;j++)
        {
         temp_vigenere_cell=vigenere_cube[i][m][j];
         vigenere_cube[i][m][j]=vigenere_cube[i][n][j];
         vigenere_cube[i][n][j]=temp_vigenere_cell;
        }
      }
    }
   else if(o==2)
    {
     for(i=0;i<banyak_jenis_karakter;i++)
      {
       for(j=0;j<banyak_jenis_karakter;j++)
        {
         temp_vigenere_cell=vigenere_cube[i][j][m];
         vigenere_cube[i][j][m]=vigenere_cube[i][j][n];
         vigenere_cube[i][j][n]=temp_vigenere_cell;
        }
      }
    }
  }

  fprintf(berkas_keluaran,"int
vigenere_cube_e[%i][%i][%i]={\n",banyak_jenis_karakter,banyak_jenis_karakter,banyak_jenis_karakter);
  for(i=0;i<banyak_jenis_karakter;i++)
  {
   fprintf(berkas_keluaran,"\t{\n");
   for(j=0;j<banyak_jenis_karakter;j++)
   {
    fprintf(berkas_keluaran,"\t\t{");
    for(k=0;k<banyak_jenis_karakter;k++)
     {
      fprintf(berkas_keluaran,"%2i%c",vigenere_cube[i][j][k],((k==(banyak_jenis_karakter-1))?' ':','));
      vigenere_cube2[vigenere_cube[i][j][k]][j][k]=i;
     }
    fprintf(berkas_keluaran,"}%s",((j==(banyak_jenis_karakter-1))?"\n":",\n"));
```

```c
    }
    fprintf(berkas_keluaran,"\t}%s",((i==(banyak_jenis_karakter-1))?"\n":",\n"));
  }
  fprintf(berkas_keluaran,"};\n");

  fprintf(berkas_keluaran,"int
vigenere_cube_d[%i][%i][%i]={\n",banyak_jenis_karakter,banyak_jenis_karakter,banyak_jenis_karakter);
  for(i=0;i<banyak_jenis_karakter;i++)
  {
    fprintf(berkas_keluaran,"\t{\n");
    for(j=0;j<banyak_jenis_karakter;j++)
    {
      fprintf(berkas_keluaran,"\t\t{");
      for(k=0;k<banyak_jenis_karakter;k++)
      {
        fprintf(berkas_keluaran,"%2i%c",vigenere_cube2[i][j][k],((k==(banyak_jenis_karakter-1))?' ':','));
      }
      fprintf(berkas_keluaran,"}%s",((j==(banyak_jenis_karakter-1))?"\n":",\n"));
    }
    fprintf(berkas_keluaran,"\t}%s",((i==(banyak_jenis_karakter-1))?"\n":",\n"));
  }
  fprintf(berkas_keluaran,"};\n");

  fclose(berkas_keluaran);
  return 0;
}
```

vigenere_cube.txt

```
int vigenere_cube_e[26][26][26]={

  {
    { 3,17,12,14, 8, 4,25,24, 0,23, 5,13,18,21, 7,20,16,19,10,15,22,11, 9, 2, 6, 1 },
    {16, 4,25, 1,21,17,12,11,13,10,18, 0, 5, 8,20, 7, 3, 6,23, 2, 9,24,22,15,19,14 },
    {17, 5, 0, 2,22,18,13,12,14,11,19, 1, 6, 9,21, 8, 4, 7,24, 3,10,25,23,16,20,15 },
    { 5,19,14,16,10, 6, 1, 0, 2,25, 7,15,20,23, 9,22,18,21,12,17,24,13,11, 4, 8, 3 },
    {24,12, 7, 9, 3,25,20,19,21,18, 0, 8,13,16, 2,15,11,14, 5,10,17, 6, 4,23, 1,22 },
    { 2,16,11,13, 7, 3,24,23,25,22, 4,12,17,20, 6,19,15,18, 9,14,21,10, 8, 1, 5, 0 },
    {15, 3,24, 0,20,16,11,10,12, 9,17,25, 4, 7,19, 6, 2, 5,22, 1, 8,23,21,14,18,13 },
    {14, 2,23,25,19,15,10, 9,11, 8,16,24, 3, 6,18, 5, 1, 4,21, 0, 7,22,20,13,17,12 },
    {25,13, 8,10, 4, 0,21,20,22,19, 1, 9,14,17, 3,16,12,15, 6,11,18, 7, 5,24, 2,23 },
    { 8,22,17,19,13, 9, 4, 3, 5, 2,10,18,23, 0,12,25,21,24,15,20, 1,16,14, 7,11, 6 },
    {10,24,19,21,15,11, 6, 5, 7, 4,12,20,25, 2,14, 1,23, 0,17,22, 3,18,16, 9,13, 8 },
    {20, 8, 3, 5,25,21,16,15,17,14,22, 4, 9,12,24,11, 7,10, 1, 6,13, 2, 0,19,23,18 },
    {21, 9, 4, 6, 0,22,17,16,18,15,23, 5,10,13,25,12, 8,11, 2, 7,14, 3, 1,20,24,19 },
    {11,25,20,22,16,12, 7, 6, 8, 5,13,21, 0, 3,15, 2,24, 1,18,23, 4,19,17,10,14, 9 },
    { 9,23,18,20,14,10, 5, 4, 6, 3,11,19,24, 1,13, 0,22,25,16,21, 2,17,15, 8,12, 7 },
    { 6,20,15,17,11, 7, 2, 1, 3, 0, 8,16,21,24,10,23,19,22,13,18,25,14,12, 5, 9, 4 },
    {23,11, 6, 8, 2,24,19,18,20,17,25, 7,12,15, 1,14,10,13, 4, 9,16, 5, 3,22, 0,21 },
    {22,10, 5, 7, 1,23,18,17,19,16,24, 6,11,14, 0,13, 9,12, 3, 8,15, 4, 2,21,25,20 },
    {18, 6, 1, 3,23,19,14,13,15,12,20, 2, 7,10,22, 9, 5, 8,25, 4,11, 0,24,17,21,16 },
    {13, 1,22,24,18,14, 9, 8,10, 7,15,23, 2, 5,17, 4, 0, 3,20,25, 6,21,19,12,16,11 },
    { 0,14, 9,11, 5, 1,22,21,23,20, 2,10,15,18, 4,17,13,16, 7,12,19, 8, 6,25, 3,24 },
    { 4,18,13,15, 9, 5, 0,25, 1,24, 6,14,19,22, 8,21,17,20,11,16,23,12,10, 3, 7, 2 },
    { 7,21,16,18,12, 8, 3, 2, 4, 1, 9,17,22,25,11,24,20,23,14,19, 0,15,13, 6,10, 5 },
    {19, 7, 2, 4,24,20,15,14,16,13,21, 3, 8,11,23,10, 6, 9, 0, 5,12, 1,25,18,22,17 },
    {12, 0,21,23,17,13, 8, 7, 9, 6,14,22, 1, 4,16, 3,25, 2,19,24, 5,20,18,11,15,10 },
    { 1,15,10,12, 6, 2,23,22,24,21, 3,11,16,19, 5,18,14,17, 8,13,20, 9, 7, 0, 4,25 }
  },
  {
    {23,11, 6, 8, 2,24,19,18,20,17,25, 7,12,15, 1,14,10,13, 4, 9,16, 5, 3,22, 0,21 },
    {10,24,19,21,15,11, 6, 5, 7, 4,12,20,25, 2,14, 1,23, 0,17,22, 3,18,16, 9,13, 8 },
    {11,25,20,22,16,12, 7, 6, 8, 5,13,21, 0, 3,15, 2,24, 1,18,23, 4,19,17,10,14, 9 },
    {25,13, 8,10, 4, 0,21,20,22,19, 1, 9,14,17, 3,16,12,15, 6,11,18, 7, 5,24, 2,23 },
    {18, 6, 1, 3,23,19,14,13,15,12,20, 2, 7,10,22, 9, 5, 8,25, 4,11, 0,24,17,21,16 },
    {22,10, 5, 7, 1,23,18,17,19,16,24, 6,11,14, 0,13, 9,12, 3, 8,15, 4, 2,21,25,20 },
    { 9,23,18,20,14,10, 5, 4, 6, 3,11,19,24, 1,13, 0,22,25,16,21, 2,17,15, 8,12, 7 },
    { 8,22,17,19,13, 9, 4, 3, 5, 2,10,18,23, 0,12,25,21,24,15,20, 1,16,14, 7,11, 6 },
    {19, 7, 2, 4,24,20,15,14,16,13,21, 3, 8,11,23,10, 6, 9, 0, 5,12, 1,25,18,22,17 },
    { 2,16,11,13, 7, 3,24,23,25,22, 4,12,17,20, 6,19,15,18, 9,14,21,10, 8, 1, 5, 0 },
    { 4,18,13,15, 9, 5, 0,25, 1,24, 6,14,19,22, 8,21,17,20,11,16,23,12,10, 3, 7, 2 },
    {14, 2,23,25,19,15,10, 9,11, 8,16,24, 3, 6,18, 5, 1, 4,21, 0, 7,22,20,13,17,12 },
    {15, 3,24, 0,20,16,11,10,12, 9,17,25, 4, 7,19, 6, 2, 5,22, 1, 8,23,21,14,18,13 },
    { 5,19,14,16,10, 6, 1, 0, 2,25, 7,15,20,23, 9,22,18,21,12,17,24,13,11, 4, 8, 3 },
```

```
int vigenere_cube_d[26][26][26]={

  {
    { 8,17, 4,19, 9,14, 7,13, 0,11,15,21, 2,20, 3,18,22,16,10,23, 6, 5,12,25, 1,24 },
    {22,14, 7,24,20,17, 4, 5,21,10, 2, 0,15, 9,18, 3, 8, 1,11,25,12,13, 6,23,16,19 },
    {17,15, 0,25, 6, 2,21, 4,19, 5,16,24, 1,12,20, 9,14, 3,13, 8,10, 7,11,22,18,23 },
    {15,16,19,22,10, 1,24, 0,25, 7, 3,23,18,11,12, 6, 2,20, 4,17,13,21, 5,14, 9, 8 },
    {13, 4, 3,12, 8, 7,18,16,20, 2, 0, 9,21,22,25,23, 5,19,15,10,17, 1,14,11,24, 6 },
    {25,22, 5,21, 3, 8,13,11, 7, 6,14, 4,17,18, 1,16,23, 2,12,19,20,10, 9,24,15, 0 },
    {23, 8,13, 0,18,22, 5,10, 4,12,17, 7,14, 3,16, 1,25,15, 6,24, 9,11,20,19, 2,21 },
    {19,25,11, 7,16,23,10,12, 5, 9,22,13, 8, 1, 2,15,24,14,20, 0, 3, 6,18,21,17, 4 },
    { 7,21, 9,10,14, 0,20,18, 6,16,24,12,19,17, 8,22, 4,23, 1, 5, 2, 3,15,13,25,11 },
    { 9, 6,17,16,21,12,14, 8,15,25,10, 2,11, 0, 4, 7,20,13,23,18,24,22,19, 3, 5, 1 },
    {10,13,16,20,23, 5, 1,15, 3,14, 4,18, 7,25,19,24,11, 0,17, 6, 8, 2,22,12,21, 9 },
    {18, 9, 8,15, 7,20,22,23,17,19, 6,14,12, 4,13, 5, 3,10,24, 1,21,25, 0,16,11, 2 },
    {20,12,14, 1, 0, 6,17,22, 2,23,11,15,10,21, 7, 4, 9, 5,25, 3,19, 8,24,18,13,16 },
    { 5, 7,18, 6,22, 4, 3, 1, 9,15,21,20, 0, 8,23,25,13,24, 2,11,14,16,17,10,19,12 },
    {12,11, 2,18,19,10,15,14, 1, 8, 5,16,13,24,21, 0, 6, 7,22,20,25,17,23, 9, 4, 3 },
    { 1,18,23,17, 5, 3,25,24, 8, 0, 9,22,20,13,10,11,16, 6,21, 2, 7,19, 4,15,12,14 },
    {11, 5, 1, 9,25,13,16, 2,18,17, 7, 3, 4,23,24,19,10,21,14,12,22,15, 8, 6, 0,20 },
    { 6,10,15, 3,24,11, 2,17,16,22,13, 1, 5,19, 0,21,12, 4, 8, 9,23,14,25,20, 7,18 },
    { 2, 1,24, 8,11,16,19,21,23, 4,18,25, 3,10, 6,12,15, 9, 7,14, 5, 0,13,17,20,22 },
    {21,24, 6,13, 2,19,12, 9,10, 3,23,11,25,15,17,14, 0, 8,18, 7, 1,20,16, 4,22, 5 },
    { 0,19,12, 5,15,24, 6,20,11,18,25,10,23, 2,14,17,21,22, 3, 4,16, 9, 1, 7, 8,13 },
    {14, 2,21,23,12,15, 0, 7,24,13, 1,19,16, 6, 9,20,17,18, 5,22,11, 4,10, 8, 3,25 },
    { 3,20,22, 2, 4, 9, 8,25,14,24,12,17, 6, 7, 5,13,18,11,19,16, 0,23,21, 1,10,15 },
    {16, 3,25,14,13,18,23,19,22,21,20, 8, 9, 5,11,10, 1,12, 0,15, 4,24, 7, 2, 6,17 },
    { 4, 0,20,11,17,21, 9, 3,12, 1,19, 6,24,14,22, 8, 7,25,16,13,15,18, 2, 5,23,10 },
    {24,23,10, 4, 1,25,11, 6,13,20, 8, 5,22,16,15, 2,19,17, 9,21,18,12, 3, 0,14, 7 }
  },
  {
    {25,22, 5,21, 3, 8,13,11, 7, 6,14, 4,17,18, 1,16,23, 2,12,19,20,10, 9,24,15, 0 },
    {23, 8,13, 0,18,22, 5,10, 4,12,17, 7,14, 3,16, 1,25,15, 6,24, 9,11,20,19, 2,21 },
    {22,14, 7,24,20,17, 4, 5,21,10, 2, 0,15, 9,18, 3, 8, 1,11,25,12,13, 6,23,16,19 },
    {14, 2,21,23,12,15, 0, 7,24,13, 1,19,16, 6, 9,20,17,18, 5,22,11, 4,10, 8, 3,25 },
    {11, 5, 1, 9,25,13,16, 2,18,17, 7, 3, 4,23,24,19,10,21,14,12,22,15, 8, 6, 0,20 },
    {24,23,10, 4, 1,25,11, 6,13,20, 8, 5,22,16,15, 2,19,17, 9,21,18,12, 3, 0,14, 7 },
    {19,25,11, 7,16,23,10,12, 5, 9,22,13, 8, 1, 2,15,24,14,20, 0, 3, 6,18,21,17, 4 },
    {21,24, 6,13, 2,19,12, 9,10, 3,23,11,25,15,17,14, 0, 8,18, 7, 1,20,16, 4,22, 5 },
    {13, 4, 3,12, 8, 7,18,16,20, 2, 0, 9,21,22,25,23, 5,19,15,10,17, 1,14,11,24, 6 },
    { 3,20,22, 2, 4, 9, 8,25,14,24,12,17, 6, 7, 5,13,18,11,19,16, 0,23,21, 1,10,15 },
    {12,11, 2,18,19,10,15,14, 1, 8, 5,16,13,24,21, 0, 6, 7,22,20,25,17,23, 9, 4, 3 },
    {16, 3,25,14,13,18,23,19,22,21,20, 8, 9, 5,11,10, 1,12, 0,15, 4,24, 7, 2, 6,17 },
    {18, 9, 8,15, 7,20,22,23,17,19, 6,14,12, 4,13, 5, 3,10,24, 1,21,25, 0,16,11, 2 },
    {10,13,16,20,23, 5, 1,15, 3,14, 4,18, 7,25,19,24,11, 0,17, 6, 8, 2,22,12,21, 9 },
```

```
{ 3,17,12,14, 8, 4,25,24, 0,23, 5,13,18,21, 7,20,16,19,10,15,22,11, 9, 2, 6, 1 },
{ 0,14, 9,11, 5, 1,22,21,23,20, 2,10,15,18, 4,17,13,16, 7,12,19, 8, 6,25, 3,24 },
{17, 5, 0, 2,22,18,13,12,14,11,19, 1, 6, 9,21, 8, 4, 7,24, 3,10,25,23,16,20,15 },
{16, 4,25, 1,21,17,12,11,13,10,18, 0, 5, 8,20, 7, 3, 6,23, 2, 9,24,22,15,19,14 },
{12, 0,21,23,17,13, 8, 7, 9, 6,14,22, 1, 4,16, 3,25, 2,19,24, 5,20,18,11,15,10 },
{ 7,21,16,18,12, 8, 3, 2, 4, 1, 9,17,22,25,11,24,20,23,14,19, 0,15,13, 6,10, 5 },
{20, 8, 3, 5,25,21,16,15,17,14,22, 4, 9,12,24,11, 7,10, 1, 6,13, 2, 0,19,23,18 },
{24,12, 7, 9, 3,25,20,19,21,18, 0, 8,13,16, 2,15,11,14, 5,10,17, 6, 4,23, 1,22 },
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