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1  /*
2  PROJECT      : Lab 1
3  FILE        : main.c
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5  LAST MODIFIED : May 20, 2017
6  DESCRIPTION  : This program decrypts a given ciphertext using a simple
7                  shift cipher algorithm and frequency analysis (english
                        alphabet).
8  */
9
10 #include <stdio.h>
11 #include <string.h>
12 #include <stdlib.h>
13 #include <ctype.h>
14
15
16 #define ALPHABET_LENGTH 26
17 double A[ALPHABET_LENGTH]; // letter frequencies
18
19 // function prototypes
20 char  encrypt(char, int);
21 char * decrypt(char*, int);
22 double * innerProduct(int[], int *);
23 int ciphertext_length;
24
25 int main()
26 {
27     // english alphabet letter frequencies
28     A[0] = 0.08167;
29     A[1] = 0.01492;
30     A[2] = 0.02782;
31     A[3] = 0.04253;
32     A[4] = 0.12702;
33     A[5] = 0.02228;
34     A[6] = 0.02015;
35     A[7] = 0.06094;
36     A[8] = 0.06996;
37     A[9] = 0.00153;
38     A[10] = 0.00772;
39     A[11] = 0.04025;
40     A[12] = 0.02406;
41     A[13] = 0.06749;
42     A[14] = 0.07507;
43     A[15] = 0.01929;
44     A[16] = 0.00095;
45     A[17] = 0.05987;
46     A[18] = 0.06327;
47     A[19] = 0.09056;
48     A[20] = 0.02758;
49     A[21] = 0.00978;
50     A[22] = 0.02360;
51     A[23] = 0.00150;
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52     A[24] = 0.01974;
53     A[25] = 0.00074;
54
55     // given text to decrypt
56     char * ciphertext =
57         "PYNVZVATNALZREVGSBEGUNGCNFGFREIVPRNAQJVGUZBERZRAGVBABSENAPRBSORYTVHZBSTYB
58         ELBSUBABHENAQBSFHPUXVAQERQGU VATFGURLUNQRZOENPRQRNPUBGUREURNEGVYVYLAQGURPBAIR
59         EFNGVBAUNQRAQRQNFGBJUNGVGUNQNYORRANOBHGYVRHGRANAGQHOBFPJNFFGVYVYVAGURQNEOXH
60         GGBUVZUNQORRAQRRTNGRQGRQGLBSFRRVATBSSZCBVEBGOLGURGNHEHFRKCERFFNAQURJNFPN
61         EELVATVGBHGJVGUNYYGURMRNYNAQNEQBHEORSVGGVATNLBHATBSSVPREJVGUNCEBZVFVATPNERR
62         ENURNQBSUVZGBQNLVFFHAQNLFNQYVRHGRANAGQHOBFPGBZBEEBJZBAQNLIRAVATLBHJVYYORV
63         AFGNZOBHYVGJNFABGGURSVFEGGVZRURUNQZNQRGUVFBOFREINGV";
64
65     ciphertext_length = strlen(ciphertext);
66     int W[ALPHABET_LENGTH] = { 0 };
67     int key = 0;
68
69     printf("\n\nCiphertext: \n\n%s\n\n", ciphertext);
70
71     // count occurrences
72     // Note 'A' = 65 in ascii code. So to put 'A' in position 0, subtract 65.
73     for (int i = 0; i < ciphertext_length; i++)
74         W[(int)ciphertext[i] - 65] += 1; // using -65 in order to fit ascii
75         characters in array positions 0-25. i.e., 'L' = 76 in ascii. W[76]
76         would throw error...
77
78     // compute inner product W . Ai, and find the key
79     double * inner_product = innerProduct(W, &key);
80
81     printf("\n\nPlaintext:\n\n%s\n\n", decrypt(ciphertext, key));
82
83     getchar();
84     return 0;
85 }
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95         : Description    : The key-shifted character
96 *****/
97 char encrypt(char ch, int key)
98 {
99     if (!isalpha(ch)) return ch;
100    char offset = isupper(ch) ? 'A' : 'a';
101    return (char)((((ch + key) - offset) % 26) + offset); // shift cipher
102 }
103
104
105
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107
108 *****/
109 FUNCTION      : decrypt
110
111 DESCRIPTION    : This function decrypts each character of the ciphertext using
112 the
113                given key parameter.
114
115 INPUT          : Type      : char *
116                : Description : The ciphertext.
117
118                : Type      : int
119                : Description : The shift key.
120
121 OUTPUT         : Type      : char *
122                : Description : The decrypted text
123 *****/
124 char * decrypt(char * text, int key)
125 {
126     int text_length = strlen(text);
127     char * plaintext = (char*)malloc(text_length + 1);
128
129     for (int i = 0; i < text_length; i++)
130         plaintext[i] = encrypt(text[i], key);
131
132     plaintext[text_length] = '\0'; // add null termination character
133
134     return plaintext;
135 }
136
137
138
139
140 *****/
141 FUNCTION      : innerProduct
142
143 DESCRIPTION    : This function uses the frequencies of letters expected
144 in an english message that has been Caesar-shifted i
145 letters to the left by a 26-dimensional vector, A.

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146
147         One of these vectors should agree fairly closely with the
148         frequencies of letters we see in our ciphertext.
149         Which vector that is tells us the shift amount for our      ↗
            sampling,
150         and the first letter of our keyword.
151
152         To find the vector in the previous list above that most closely
153         matches the vector u, we recall that the dot product of two
154         vectors is connected to the angle  $\theta$  between those two vectors
155         in the following way:
156
157          $W \cdot A = |W| |A| \cos \theta$ 
158
159         If we want to find the two vectors W and Ai that most closely
160         match, we want to find the two vectors with the smallest
161         angle between them.
162
163         Noting that smaller angles produce larger cosine values and
164         also noting that the magnitude of the denominator is the same
165         for every vi as the same 26 numbers are involved each time
166         (just in different orders), we can simply seek the two vectors      ↗
            W
167         and Ai whose dot product is largest.
168
169
170 INPUT          : Type          : int[]
171                 : Description   : The letter frequencies of the ciphertext.
172
173                 : Type          : int *
174                 : Description   : A reference to the encryption key.
175
176 OUTPUT          : Type          : double *
177                 : Description   : The array of innerproducts.
178 *****/
179 double * innerProduct(int W[], int * key)
180 {
181     double inner_product[ALPHABET_LENGTH] = { 0 };
182     double sum = 0;
183     int j;
184
185
186     for (int i = 0; i < ALPHABET_LENGTH; i++)
187     {
188         for (j = 0; j < ALPHABET_LENGTH; j++)
189             sum += W[j] * A[(j + i) % ALPHABET_LENGTH]; // shift the frequency      ↗
                array
190
191         inner_product[i] = sum/ ciphertext_length;
192
193         // find the largest innerproduct. This will be the key.
194         if (inner_product[*key] < inner_product[i]) *key = i;

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195
196     // reset counter and sum
197     j = 0;
198     sum = 0;
199 }
200
201 printf("Inner products: \n\n");
202 for (size_t i = 0; i < 26; i++)
203     printf("W[%d] = %f\n", i+1, inner_product[i]);
204
205 return inner_product;
206 }
207
208
```