Lab 8

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Encrypt/decrypt a character

How to encrypt a character?

The following code encrypts a character `char` using a non-negative integer `key`.

[2]:
```
cc_n = 1114112


def cc_encrypt_character(char, key):
    """
    Return the encryption of a character by an integer key using Caesar cipher.

    Parameters
    ----------
    char: str
        a unicode (UTF-8) character to be encrypted.
    key int:
        secret key to encrypt char.
    """
    char_code = ord(char)
    shifted_char_code = (char_code + key) % cc_n
    encrypted_char = chr(shifted_char_code)
    return encrypted_char
```

For example, to encrypt the letter `'A'` using a secret key `5`:

[3]:
```
cc_encrypt_character("A", 5)
```

[3]:
```
'F'
```

ord() and chr()

- The ord() function returns the number representing the unicode code of a specified character.
- The chr() function returns the character that represents the specified unicode.

```
x=ord('a')
print(x)
y=chr(x)
print(y)
```

executed in 4ms, finished 08:34:18 2020

```
97
a
```

Encryption process

The character `'A'` is encrypted to the character `'F'` as follows:

1. `ord(char)` return the integer `65`, which is the code point (integer representation) of the unicode of `'A'`.
2. `(char_code + key) % cc_n` cyclic shifts the code by the key `5`.
3. `chr(shifted_char_code)` converts the shifted code back to a character, which is `'F'`.

Encryption steps

`char`	...	A	B	C	D	E	F	...
`ord(char)`	...	**65**	66	67	68	69	70	...
`(ord(char) + key) % cc_n`	...	**70**	71	72	73	74	75	...
`chr((ord(char) + key) % cc_n)`	...	**F**	G	H	I	J	K	...

How to decrypt a character?

Mathematically, we define the encryption and decryption of a character for Caesar cipher as

$$\begin{aligned} f_k(x) &:= x + k \mod n \quad \text{(encryption)} \\ g_k(y) &:= y - k \mod n \quad \text{(decryption)}, \end{aligned} \tag{1}$$

where x is the character code and k is the secret key, both of which are in $\{0, \ldots, n-1\}$. `mod` operator above is the modulo operator. In Mathematics, it has a lower precedence than addition and multiplication and is typeset with an extra space accordingly.

The encryption and decryption satisfy the recoverability condition

$$g_k(f_k(x)) = x \tag{2}$$

so two people with a common secret key can encrypt and decrypt a character, but others without the key cannot. This defines a *symmetric cipher*.

The following code decrypts a character using a key.

5]:

```
def cc_decrypt_character(char, key):
    '''
    Return the decryption of a character by the key using Caesar cipher.

    Parameters
    ----------
    char (str): a unicode (UTF-8) character to be decrypted.
    key (int): secret key to decrypt char.
    '''
    char_code = ord(char)
    shifted_char_code = (char_code - key) % cc_n
    decrypted_char = chr(shifted_char_code)
    return decrypted_char
```

For instance, to decrypt the letter `'F'` by the secret key `5`:

6]:

```
cc_decrypt_character('F',5)
```

6]: 'A'

Decryption process

The character `'F'` is decrypted back to `'A'` because `(char_code - key) % cc_n` reverse cyclic shifts the code by the key `5`.

Encryption steps									Decryption steps
`char`	…	A	B	C	D	E	F	…	`chr((ord(char) - key) % cc_n)`
`ord(char)`	…	**65**	66	67	68	69	70	…	`(ord(char) - key) % cc_n`
`(ord(char) + key) % cc_n`	…	**70**	71	72	73	74	75	…	`ord(char)`
`chr((ord(char) + key) % cc_n)`	…	**F**	G	H	I	J	K	…	`char`

Exercise 1

Why did we set `cc_n = 1114112` ? Explain whether the recoverability property may fail if we set `cc_n` to a bigger number or remove `% cc_n` for both `cc_encrypt_character` and `cc_decrypt_character` .

YOUR ANSWER HERE

Summarize your own answer by referring to the link below (not limited to)
https://unicodebook.readthedocs.io/unicode.html

Encrypt a plaintext and decrypt a ciphertext

Of course, it is more interesting to encrypt a string instead of a character. The following code implements this in one line.

[ ]:
```
def cc_encrypt(plaintext, key):
    """
    Return the ciphertext of a plaintext by the key using the Caesar cipher.

    Parameters
    ----------
    plaintext: str
        A unicode (UTF-8) message to be encrypted.
    public_key: int
        Public key to encrypt plaintext.
    """
    return "".join([chr((ord(char) + key) % cc_n) for char in plaintext])
```

The above function encrypts a message, referred to as the *plaintext*, by replacing each character with its encryption.
This is referred to as a *substitution cipher*.

Exercise 2

Define a function `cc_decrypt` that

- takes a string `ciphertext` and an integer `key`, and
- returns the plaintext that encrypts to `ciphertext` by the key using Caesar cipher.

]:
```python
def cc_decrypt(ciphertext, key):
    """
    Return the plaintext that encrypts to ciphertext by the key using Caesar cipher.

    Parameters
    ----------
    ciphertext: str
        message to be decrypted.
    key: int
        secret key to decrypt the ciphertext.
    """
    # YOUR CODE HERE
    raise NotImplementedError()
```

]:
```python
# tests
assert cc_decrypt(r"bcdefghijklmnopqrstuvwxyz{", 1) == "abcdefghijklmnopqrstuvwxyz"
assert cc_decrypt(r"Mjqqt1%\twqi&", 5) == "Hello, World!"
```

This is a challenging question

Another symmetric key cipher is the *columnar transposition cipher*. A transposition cipher encrypts a text by permuting instead of substituting characters.

Exercise 3

Study and implement the irregular case of the *columnar transposition cipher* as described in the Wikipedia page. Define the functions

- `ct_encrypt(plaintext, key)` for encryption, and
- `ct_decrypt(ciphertext, key)` for decryption.

You can assume the plaintext is in uppercase and has no spaces/punctuations.

Hint

[ ]:
```
# YOUR CODE HERE
raise NotImplementedError
```

[ ]:
```
# tests
key = "ZEBRAS"
plaintext = "WEAREDISCOVEREDFLEEATONCE"
ciphertext = "EVLNACDTESEAROFODEECWIREE"
assert ct_encrypt(plaintext, key) == ciphertext
assert ct_decrypt(ciphertext, key) == plaintext
```

Let's analyze the code step-by-step

```
def argsort(seq):
    '''A helper function that returns the tuple of indices that would sort the
    sequence seq.'''
    return tuple(x[0] for x in sorted(enumerate(seq), key=lambda x: x[1]))

key = 'ZEBRAS'
plaintext = 'WEAREDISCOVEREDFLEEATONCE'
ciphertext = 'EVLNACDTESEAROFODEECWIREE'
print(argsort(key))
```

```
(4, 2, 1, 3, 5, 0)
```

Create this cell in a new notebook for testing, do not modify the original notebook

Running the above code, you'll get:

(4, 2, 1, 3, 5, 0) → What does it mean?

key: Z E B R A S

index: 0 1 2 3 4 5

after sort: A B E R S Z

so the index of the sorted sequence is: 4 2 1 3 5 0

Hint

See the test cases for examples of `plaintext`, `key`, and the corresponding `ciphertext`. The following is a solution template:

```
def argsort(seq):
    '''A helper function that returns the tuple of indices that would sort the
    sequence seq.'''
    return tuple(x[0] for x in sorted(enumerate(seq), key=lambda x: x[1]))


def ct_idx(length, key):
    '''A helper function that returns the tuple of indices that would permute
    the letters of a message according to the key using the irregular case of
    columnar transposition cipher.'''
    seq = tuple(range(length))
    return [i for j in argsort(key) for i in ___]


def ct_encrypt(plaintext, key):
    '''
    Return the ciphertext of a plaintext by the key using the irregular case
    of columnar transposition cipher.

    Parameters
    ----------
    plaintext: str
        a message in uppercase without punctuations/spaces.
    key: str
        secret key to encrypt plaintext.
    '''
    return ''.join([plaintext[i] for i in ct_idx(len(plaintext), key)])


def ct_decrypt(ciphertext, key):
    '''
    Return the plaintext of the ciphertext by the key using the irregular case
    of columnar transposition cipher.

    Parameters
    ----------
    ciphertext: str
        a string in uppercase without punctuations/spaces.
    key: str
        secret key to decrypt ciphertext.
    '''
    return ___
```

Complete this function

Complete this function

[3]:
```
def ct_idx(length, key):
    '''A helper function that returns the tuple of indices that would permute
    the letters of a message according to the key using the irregular case of
    columnar transposition cipher.'''
    seq = tuple(range(length))
    return [i for j in argsort(key) for i in ...]

key = 'ZEBRAS'
plaintext = 'WEAREDISCOVEREDFLEEATONCE'
ciphertext = 'EVLNACDTESEAROFODEECWIREE'
print(ct_idx(len(plaintext), key))
```

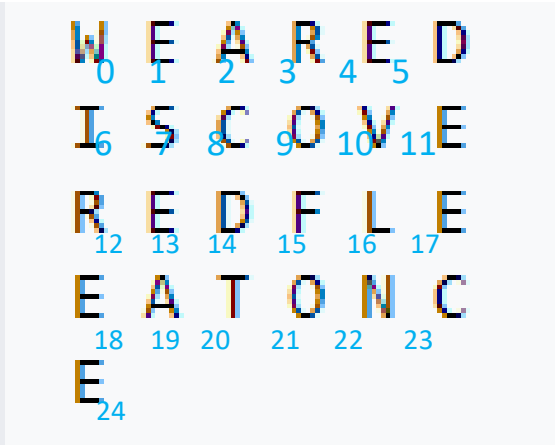
```
[4, 10, 16, 22, 2, 8, 14, 20, 1, 7, 13, 19, 3, 9, 15, 21, 5, 11, 17, 23, 0, 6, 12, 18, 24]
```

If your code is correct, after running the above code, you'll get:

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

What does it mean?

	Z	E	B	R	A	S
Index:	0	1	2	3	4	5



Based on columnar transposition cipher,
we first take out the letters in Column 'A' (index 4): E(4) V(10) L(16) N(22)
Then column 'B' (index 2): A(2) C(8) D(14) T(20)
Then column 'E' (index 1): E(1) S(7) E(13) A(19)
Then column 'R' (index 3): R(3) O(9) F(15) O(21)
Then column 'S' (index 5): D(5) E(11) E(17) C(23)
Then column 'Z' (index 0): W(0) I(6) R(12) E(18) E(24)

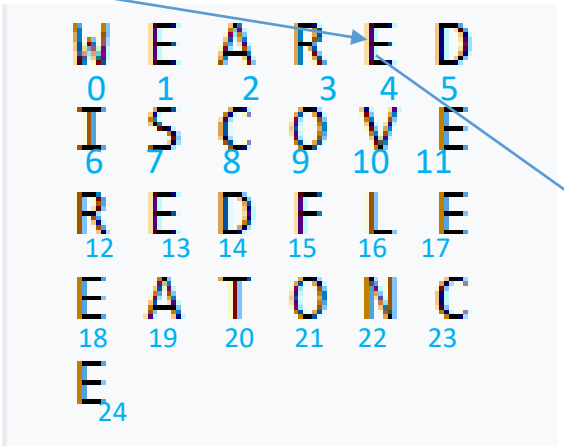
```
]: def ct_encrypt(plaintext, key):
       '''
       Return the ciphertext of a plaintext by the key using the irregular case
       of columnar transposition cipher.

       Parameters
       ----------
       plaintext: str
           a message in uppercase without punctuations/spaces.
       key: str
           secret key to encrypt plaintext.
       '''
       return ''.join([plaintext[i] for i in ct_idx(len(plaintext), key)])

key = 'ZEBRAS'
plaintext = 'WEAREDISCOVEREDFLEEATONCE'
ciphertext = 'EVLNACDTESEAROFODEECWIREE'
print(ct_encrypt(plaintext,key))
```

```
EVLNACDTESEAROFODEECWIREE
```

How to encrypt?

Pick the letters from the matrix based on their index and concatenate them together

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



EVLNACDTESEAROFODEECWIREE

```
def ct_decrypt(ciphertext, key):
    '''
    Return the plaintext of the ciphertext by the key using the irregular case
    of columnar transposition cipher.

    Parameters
    ----------
    ciphertext (str): a string in uppercase without punctuations/spaces.
    key (str): secret key to decrypt ciphertext.
    '''

    #write your code here
```

Students you need to figure out by yourselves to get the mark.

The explanation in the slide should be enough for you to figure out the solution. It may take you some time beyond the lesson but is worthy and challenging.

How to decrypt?

Put the letters in ciphertext back based on their location

EVLNACDTESEAROFODEECWIREE

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

[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]

Index: 0 1 2 3 4 5 6 7 8 9 10 24

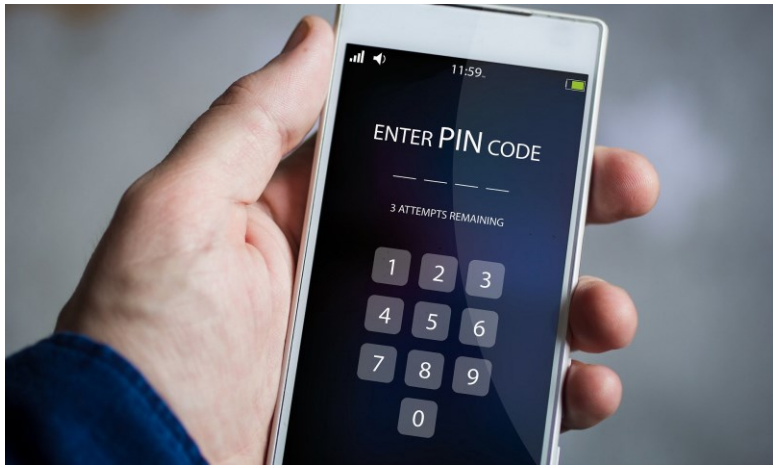
[W E A R E D I S C O V E R E D F L E E A T O N C E]

Then convert it to a string → 'WEAREDISCOVEREDFLEEATONCE'

Next, we learn how to break a cipher

- In cryptography, a brute-force attack consists of an attacker submitting many passwords or passphrases with the hope of eventually guessing correctly.

0000
1111
…
1234
2345
3456
6789
…..
9999



Brute-force attack

Create an English dictionary

You will launch a brute-force attack to guess the key that encrypts an English text. The idea is simple:

- You try decrypting the ciphertext with different keys, and
- see which of the resulting plaintexts make the most sense (most English-like).

To check whether a plaintext is English-like, we need to have a list of English words. One way is to type them out but this is tedious. Alternatively, we can obtain the list from the *Natural Language Toolkit (NLTK)*:

```
!pip install nltk
```

```
Collecting nltk
  Downloading nltk-3.8.1-py3-none-any.whl (1.5 MB)
     ---------------------------------------- 1.5/1.5 MB 24.4 MB/s eta 0:00:0000:01
Requirement already satisfied: click in /opt/conda/lib/python3.11/site-packages (from nltk) (8.1.7)
Collecting joblib (from nltk)
  Obtaining dependency information for joblib from https://files.pythonhosted.org/packages/10/40/d551139c85db202f1f384ba8bcf96aca2f329440a844f924c8a0040b6d02/joblib-1.3.2-py3-none-any.wh
  Downloading joblib-1.3.2-py3-none-any.whl.metadata (5.4 kB)
Requirement already satisfied: regex>=2021.8.3 in /opt/conda/lib/python3.11/site-packages (from nltk) (2023.10.3)
Requirement already satisfied: tqdm in /opt/conda/lib/python3.11/site-packages (from nltk) (4.66.1)
Downloading joblib-1.3.2-py3-none-any.whl (302 kB)
     ---------------------------------------- 302.2/302.2 kB 9.4 MB/s eta 0:00:00
Installing collected packages: joblib, nltk
Successfully installed joblib-1.3.2 nltk-3.8.1
```

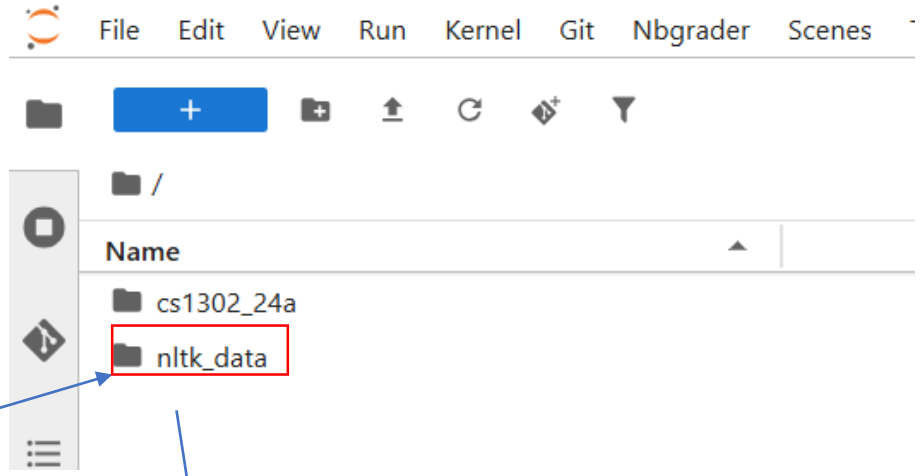
```
import nltk

nltk.download("words")
from nltk.corpus import words
```

```
[nltk_data] Downloading package words to /home/jovyan/nltk_data...
[nltk_data]   Unzipping corpora/words.zip.
```

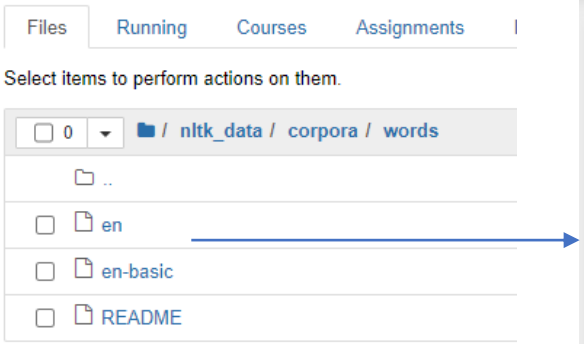
`words.words()` returns a list of words. We can check whether a string is in the list using the operator `in`.

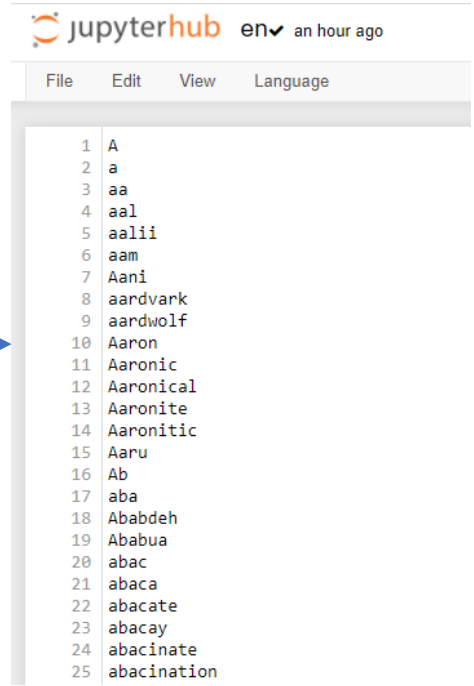
```
for word in "Ada", "ada", "Hello", "hello":
    print("{!r} in dictionary? {}".format(word, word in words.words()))
```

Downloaded here



from nltk.corpus import words





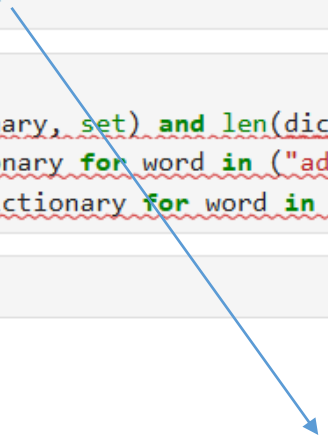
Exercise 4

Using the method `lower` of `str` and the constructor `set`, assign `dictionary` to a set of lowercase English words from `words.words()`.

[ ]:
```
# YOUR CODE HERE
raise NotImplementedError
```

[ ]:
```
# tests
assert isinstance(dictionary, set) and len(dictionary) == 234377
assert all(word in dictionary for word in ("ada", "hello"))
assert all(word not in dictionary for word in ("Ada", "hola"))
```

[ ]:
```
# hidden tests
```



Write your code here, you should assign your result to a variable called dictionary because dictionary will be used latter

Identify English-like text

To determine how English-like a text is, we calculate the following score:

$$\frac{\text{number of English words in the text}}{\text{number of tokens in the text}}$$

where tokens are substrings, not necessarily English words, separated by white space characters in the text.

```
def tokenizer(text):
    """Returns the list of tokens of the text."""
    return text.split()


def get_score(text):
    """Returns the fraction of tokens which appear in dictionary."""
    tokens = tokenizer(text)
    words = [token for token in tokens if token in dictionary]
    return len(words) / len(tokens)


# tests
get_score("hello world"), get_score("Hello, World!")
```

```
---------------------------------------------------------------------------
NameError                                 Traceback (most recent call last)
Cell In[8], line 14
     10     return len(words) / len(tokens)
     13 # tests
---> 14 get_score("hello world"), get_score("Hello, World!")

Cell In[8], line 9, in get_score(text)
      7 """Returns the fraction of tokens which appear in dictionary."""
      8 tokens = tokenizer(text)
----> 9 words = [token for token in tokens if token in dictionary]
     10 return len(words) / len(tokens)

Cell In[8], line 9, in <listcomp>(.0)
      7 """Returns the fraction of tokens which appear in dictionary."""
      8 tokens = tokenizer(text)
----> 9 words = [token for token in tokens if token in dictionary]
     10 return len(words) / len(tokens)

NameError: name 'dictionary' is not defined
```

This is what happens if your previous exercise is incorrect

Exercise 5

Define a function `tokenizer` that

- takes a string `text` as an argument, and
- returns a `list` of tokens obtained by
  1. splitting `text` into a list using `split()`;
  2. removing leading/trailing punctuations in `string.punctuation` using the `strip` method; and
  3. converting all items of the list to lowercase using `lower()`.

[ ]:
```
import string


def tokenizer(text):
    """Returns the list of tokens of the text such that
    1) each token has no leading or trailing spaces/punctuations, and
    2) all letters in each token are in lowercase."""
    # YOUR CODE HERE
    raise NotImplementedError
```

[ ]:
```
# tests
assert tokenizer("Hello, World!") == ["hello", "world"]
assert get_score("Hello, World!") >= 0.99999
assert tokenizer("Do you know Jean-Pierre?") == ["do", "you", "know", "jean-pierre"]
assert get_score("Do you know Jean-Pierre?") >= 0.99999
```

[ ]:
```
# hidden tests
```

You need to use string.punctuation

- In Python, string.punctuation will give the all sets of punctuation.
- Use it directly, it's not a function, i.e., string.punctuation is correct but string.punctuation() is wrong
- More information here https://www.geeksforgeeks.org/string-punctuation-in-python/

In [5]:
```
import string
all_punctuation =  string.punctuation
print(all_punctuation)

s1="!hello world!"
#this is how to remove all leading/trailing punctuations
s2=s1.strip(string.punctuation)
print(s1)
print(s2)
```

executed in 4ms, finished 13:34:13 2021-04-08

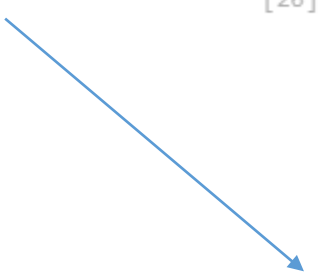
```
!"#$%&'()*+,-./:;<=>?@[\]^_`{|}~
!hello world!
hello world
```

Exercise 6

Define the function `cc_attack` that

- takes as arguments
  - a string `ciphertext`,
  - a floating point number `threshold` in the interval $(0, 1)$ with a default value of 0.6, and
- returns a generator that
  - generates one-by-one in ascending order guesses of the key that
  - decrypt `ciphertext` to texts with scores at least the `threshold`.

If your code is correct, this
Is what you get



[28]:
```
def cc_attack(ciphertext, threshold=0.6):
    """Returns a generator that generates the next guess of the key that
    decrypts the ciphertext to a text with get_score(text) at least the threshold.
    """
    # YOUR CODE HERE
    raise NotImplementedError
```

[26]:
```
# tests
ciphertext = cc_encrypt("Hello, World!", 12345)
key_generator = cc_attack(ciphertext)
key_guess = next(key_generator)
assert key_guess == 12345
text = cc_decrypt(ciphertext, key_guess)
print("guess of the key: {}\nscore: {}\ntext :{}".format(key_guess, get_score(text), text))
```

```
guess of the key: 12345
score: 1.0
text :Hello, World!
```