Cryptology for IoT

Modules M4, M7, M9
Session of 27th April, 2022.

M4.3 Briefing to the session
M4.4 Introduction to the ciphers: Substitution , Transposition and mixed ciphers
M4.5 Methodology using Cryptool

Prof.: Guillermo Botella

Cryptology for IoT

Modules M4, M7, M9
Session of 27th April, 2022.

M4.3 Briefing to the session

M4.4 Introduction to the ciphers: Substitution , Transposition and mixed ciphers

M4.5 Methodology using Cryptool

Prof.: Guillermo Botella

M4.3 Briefing of today

- Starting with basic Cryptography and Cryptoanalysis
  - Slides and supplementary videos
- We go to the rooms. Practical Session I.
  - Assignments (They will be specified when we start).
  - Work in groups (Same than usual)
- First quiz at Socrative (around 25 questions)
  - Room number will be specified when we start
  - Individual work

Cryptology for IoT

Modules M4, M7, M9
Session of 27th April, 2022.

M4.3 Briefing to the session

M4.4 Introduction to the ciphers: Substitution , Transposition and mixed ciphers

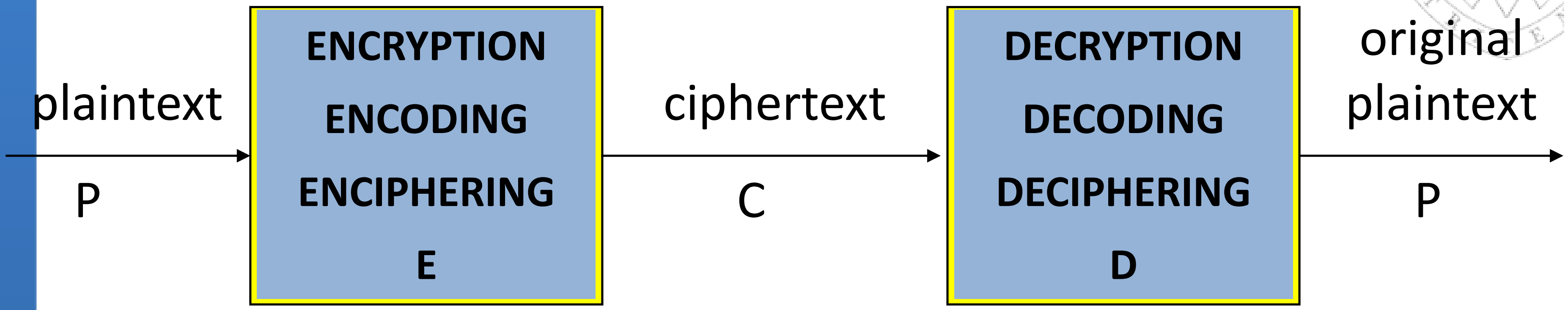
M4.5 Methodology using Cryptool

Prof.: Guillermo Botella

Organization of the M4.4

- Notation
- Ciphers (families)
- Substitution ciphers
  - Monoalphabetic Substitution
  - Polyalphabetic Substitution
- Transposition Ciphers
- Mixed Ciphers

Formal Notation



- C = E(P)   E – encryption rule/algorithm
- P = D(C)   D – decryption rule/algorithm

- We need a cryptosystem, where:
  - P = D(C)= D(E(P))
    - i.e., able to get the original message back

Representing Characters

- Letters (uppercase only) represented by numbers 0-25 (modulo 26).

```
A B C D ...  X  Y  Z
0 1 2 3 ... 23 24 25
```

- Operations on letters:

```
A + 2 = C
X + 4 = B
...
```

(circular!)

Basic Types of Ciphers

- Substitution ciphers
  - Letters of P replaced with other letters by E
- Transposition (permutation) ciphers
  - *Order* of letters in P rearranged by E
- Product ciphers
  - E “=” E_1 “+” E_2 “+” ... “+” E_n
    - Combine two or more ciphers to enhance the security of the cryptosystem

Substitution Ciphers

- **Substitution Ciphers:**
  - **Letters of P replaced with other letters by E**

The Caesar Cipher (1)

- $c_i = E(p_i) = p_i + 3 \bmod 26$ (*26* letters in the English alphabet)

  Change each letter to the third letter following it (circularly)

  A → D, B → E, ... X → A, Y → B, Z → C

- Can represent as a permutation π: $\pi(i) = i+3 \bmod 26$

  $\pi(0)=3$, $\pi(1)=4$, ...,

  $\pi(23)=26 \bmod 26=0$, $\pi(24)=1$, $\pi(25)=2$

- Key = 3, or key = 'D' (because D represents 3)

The Caesar Cipher (2)

- Example
  - P (plaintext): HELLO WORLD
  - C (ciphertext): khoor zruog

- Caesar Cipher is a monoalphabetic substitution cipher (= simple substitution cipher)

  One key is used

  One letter substitutes the letter in P

Attacking a Substitution Cipher

- Exhaustive search
  - If the key space is small enough, try all possible keys until you find the right one
  - Cæsar cipher has 26 possible keys
    from A to Z OR: from 0 to 25
- Statistical analysis (attack)
  - Compare to so called 1-gram (unigram) model of English
    - 1-gram: It shows frequency of (single) characters in English
  - The longer the C, the more effective statistical analysis would be

1-grams (Unigrams) for English

a	0.080	h	0.060	n	0.070	t	0.090
b	0.015	i	0.065	o	0.080	u	0.030
c	0.030	j	0.005	p	0.020	v	0.010
d	0.040	k	0.005	q	0.002	w	0.015
e	0.130	l	0.035	r	0.065	x	0.005
f	0.020	m	0.030	s	0.060	y	0.020
g	0.015					z	0.002

Statistical Attack – Step 1

- Compute frequency f(c) of each letter c in ciphertext
- Example: c = ‘khoor zruog’
  - 10 characters: 3 * ‘o’, 2 * ‘r’, 1 * {k, h, z, u, g}
  - f(c):

    f(g)=0.1 f(h)=0.1 f(k)=0.1 f(o)=0.3 f(r)= 0.2

    f(u)=0.1 f(z)=0.1 $f(c_i) = 0$ for any other c_i

- Apply 1-gram model of English
  - Frequency of (single) characters in English
  - 1-grams on previous slide

Statistical Analysis – Step 2

- phi $\varphi(i)$ - correlation of frequency of letters *in ciphertext* with frequency of corresponding letters *in English* —for key i
- For key i: $\varphi(i) = \Sigma_{0 \le c \le 25}\, f(c) * p(c - i)$
  - *c* representation of character (a-0, ..., z-25)
  - f(c) is frequency of letter c in ciphertext C
  - *p*(*x*) is frequency of character *x* in English
  - Intuition: sum of probabilities for words in P, if i were the key

c is a letter in ciphertext thus c-i is the letter in plaintext.

- Example: C = 'khoor zruog' (P = 'HELLO WORLD')

f(c): f(g)=0.1, f(h)=0.1, f(k)=0.1, f(o)=0.3, f(r)=0.2, f(u)=0.1, f(z)=0.1

c: g - 6, h - 7, k - 10, o - 14, r - 17, u - 20, z - 25

$$\varphi(i) = 0.1p(6 - i) + 0.1p(7 - i) + 0.1p(10 - i) + $$
$$+ 0.3p(14 - i) + 0.2p(17 - i) + 0.1p(20 - i) +$$
$$+ 0.1p(25 - i)$$

Statistical Attack – Step 2a (Calculations)

- Correlation φ(i) for 0≤ i ≤25

i	φ(*i*)	*i*	φ(*i*)	*i*	φ(*i*)	*i*	φ(*i*)
0	0.0482	7	0.0442	13	0.0520	19	0.0315
1	0.0364	8	0.0202	14	0.0535	20	0.0302
2	0.0410	9	0.0267	15	0.0226	21	0.0517
3	0.0575	10	0.0635	16	0.0322	22	0.0380
4	0.0252	11	0.0262	17	0.0392	23	0.0370
5	0.0190	12	0.0325	18	0.0299	24	0.0316
6	0.0660					25	0.0430

Statistical Attack – Step 3 (The Result)

- Most probable keys (largest $\varphi(i)$ values):
  - *$i = 6$, $\varphi(i) = 0.0660$*
    - *plaintext EBIIL TLOLA*
  - *$i = 10$, $\varphi(i) = 0.0635$*
    - *plaintext AXEEH PHKEW*
  - *$i = 3$, $\varphi(i) = 0.0575$*
    - *plaintext HELLO WORLD*
  - *$i = 14$, $\varphi(i) = 0.0535$*
    - *plaintext WTAAD LDGAS*
- Only English phrase is for i = 3
  - *That's the key (3 or 'D') – code broken*

Caesar's Problem

- Conclusion: Key is too short
  - 1-char key – monoalphabetic substitution
    - Can be found by exhaustive search
    - Statistical frequencies not concealed well by short key
      - They look too much like 'regular' English letters
- Solution: Make the key longer
  - n-char key ($n \geq 2$) – polyalphabetic substitution
    - Makes exhaustive search much more difficult
    - Statistical frequencies concealed much better
      - Makes cryptanalysis harder

Other Substitution Ciphers

n-char key:

- Polyalphabetic substitution ciphers
- Vigenere Tableaux cipher

Polyalphabetic Substitution - Examples

- Flatten (difuse) *somewhat* the frequency distribution of letters by combining high and low distributions

- Example – 2-key substitution:

	A	B	C	D	E	F	G	H	I	J	K	L	M
Key1:	a	d	g	j	m	p	s	v	y	b	e	h	k
Key2:	n	s	x	c	h	m	r	w	b	g	l	q	v

	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
Key1:	n	q	t	w	z	c	f	i	l	o	r	u	x
Key2:	a	f	k	p	u	z	e	j	o	t	y	d	i

- **Question**:

  How Key1 and Key2 were defined?

Polyalphabetic Substitution - Examples

- ...
- Example:

	A	B	C	D	E	F	G	H	I	J	K	L	M
Key1:	a	d	g	j	m	p	s	v	y	b	e	h	k
Key2:	n	s	x	c	h	m	r	w	b	g	l	q	v

	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
Key1:	n	q	t	w	z	c	f	i	l	o	r	u	x
Key2:	a	f	k	p	u	z	e	j	o	t	y	d	i

- Answer:

  Key1 – start with ‘a’, skip 2, take next,
  skip 2, take next letter, ... (circular)

  Key2 - start with ‘n’ (2nd half of alphabet), skip 4,
  take next, skip 4, take next, ... (circular)

Polyalphabetic Substitution - Examples

– Example:

	A	B	C	D	E	F	G	H	I	J	K	L	M
Key1:	a	d	g	j	m	p	s	v	y	b	e	h	k
Key2:	n	s	x	c	h	m	r	w	b	g	l	q	v

	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
Key1:	n	q	t	w	z	c	f	i	l	o	r	u	x
Key2:	a	f	k	p	u	z	e	j	o	t	y	d	i

– **Plaintext: TOUGH STUFF**

– **Ciphertext: ffirv zfjpm**

use n (=2) keys in turn for consecutive P chars in P

- Note:
  – Different chars mapped into the same one: **T, O → f**
  – Same char mapped into different ones: **F → p, m**
  – '**f**' most frequent in C (0.30); in English: f(**f**) = 0.02 << f(**e**) = 0.13

Vigenère Tableaux (1)

Note: Row A – shift 0 (a->a)
Row B – shift 1 (a->b)
Row C – shift 2 (a->c)
...
Row Z – shift 25 (a->z)

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	p
A	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	0
B	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	a	1
C	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	a	b	2
D	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	a	b	c	3
E	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	a	b	c	d	4
F	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	a	b	c	d	e	5
G	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	a	b	c	d	e	f	6
H	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	a	b	c	d	e	f	g	7
I	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	a	b	c	d	e	f	g	h	8
J	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	a	b	c	d	e	f	g	h	i	9
K	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	a	b	c	d	e	f	g	h	i	j	10
L	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	a	b	c	d	e	f	g	h	i	j	k	11
M	m	n	o	p	q	r	s	t	u	v	w	x	y	z	a	b	c	d	e	f	g	h	i	j	k	l	12
N	n	o	p	q	r	s	t	u	v	w	x	y	z	a	b	c	d	e	f	g	h	i	j	k	l	m	13
O	o	p	q	r	s	t	u	v	w	x	y	z	a	b	c	d	e	f	g	h	i	j	k	l	m	n	14
P	p	q	r	s	t	u	v	w	x	y	z	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	15
Q	q	r	s	t	u	v	w	x	y	z	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	16
R	r	s	t	u	v	w	x	y	z	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	17
S	s	t	u	v	w	x	y	z	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	18
T	t	u	v	w	x	y	z	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	19
U	u	v	w	x	y	z	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	20
V	v	w	x	y	z	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	21
W	w	x	y	z	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	22
X	x	y	z	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	23
Y	y	z	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	24
Z	z	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	25

Vigenère Tableaux (2)

- Example

  Key:

  EXODUS

  Plaintext P:

  YELLOW SUBMARINE FROM YELLOW RIVER

  Extended keyword (re-applied to mimic words in P):

  YELLOW SUBMARINE FROM YELLOW RIVER

  EXODUS EXODUSEXO DUSE XODUSE XODUS

  Ciphertext:

  cbxoio wlppujmks ilgq vsofhb owyyj

Vigenère Tableaux (3)

- Example

  …

  Extended keyword (re-applied to mimic words in P):

  YELLOW SUBMARINE FROM YELLOW RIVER

  EXODUS EXODUSEXO DUSE XODUSE XODUS

  Ciphertext:

  cbzoio wlppujmks ilgq vsofhb owyyj

- Answer:

  c from P indexes row

  c from extended key indexes column

  e.g.: row Y and column e → 'c'

  row E and column x → 'b'

  row L and column o → 'z'

  …

Transposition Ciphers (1)

- Rearrange letters in plaintext to produce ciphertext
- Example 1a and 1b: Columnar transposition
  - Plaintext: **HELLO WORLD**
  - Transposition onto: (a) 3 columns:

    HEL
    LOW
    ORL
    DXX   **XX** - padding

    (b) onto 2 columns:

    HE
    LL
    OW
    OR
    LD
  - Ciphertext (read column-by column):

    (a) **hlodeorxlwlx**   (b) **hloolelwrd**
  - What is the key?
    - Number of columns: (a) key = 3 and (b) key = 2

Transposition Ciphers (2)

- Example 2: Rail-Fence Cipher
  - Plaintext: **HELLO WORLD**
  - Transposition into 2 rows (rails) column-by-column:

    HLOOL

    ELWRD
  - Ciphertext: **hloolelwrd** (Does it look familiar?)
  - What is the key?
    - Number of rails key = 2

Product Ciphers

- A.k.a. combination ciphers
- Built of multiple blocks, each is:
  - Substitution

or:

  - Transposition
- Example: two-block product cipher
  - $E_2(E_1(P, K_{E1}), K_{E2})$
- Product cipher might *not* necessarily be stronger than its individual components used separately!
  - Might not be even as strong as individual components

Identifying the type of a cipher

- Not always possible without further knowledge about the cipher's origin and background
  - – Voynich Manuscript – a book of the 15th century encrypted and written using an unknown alphabet
- To identify the type of the cipher we have seen to check out:
  - – Frequency test component: visualizes the letter distribution of a given text
  - – Friedman test component (kappa test)

Friedman Test (Kappa Test)

- The “**Frequency test” (a.k.a Kappa test)** component visualizes the letter distribution of a given texts
- It uses the index of coincidence, which measures the unevenness of the cipher letter frequencies to break the cipher
- The key length of a polyalphabetic cipher can be estimated by knowing two issues:
  - the probability (Kp) that any two randomly chosen source-language letters are the same (around 0.067 for English)
  - the probability (Kr) of a coincidence for a uniform random selection from the alphabet (1/26 = 0.0385 for English)

Friedman Test (Kappa Test)

- The key length can be estimated as the following:

$$\frac{\kappa_p - \kappa_r}{\kappa_o - \kappa_r}$$

- From the observed coincidence rate (*Ko*):

$$\kappa_o = \frac{\sum_{i=1}^{c} n_i(n_i - 1)}{N(N-1)}$$

Friedman Test (Kappa Test)

- Observed coincidence rate (*Ko*):

$$\kappa_o = \frac{\sum_{i=1}^{c} n_i(n_i - 1)}{N(N-1)}$$

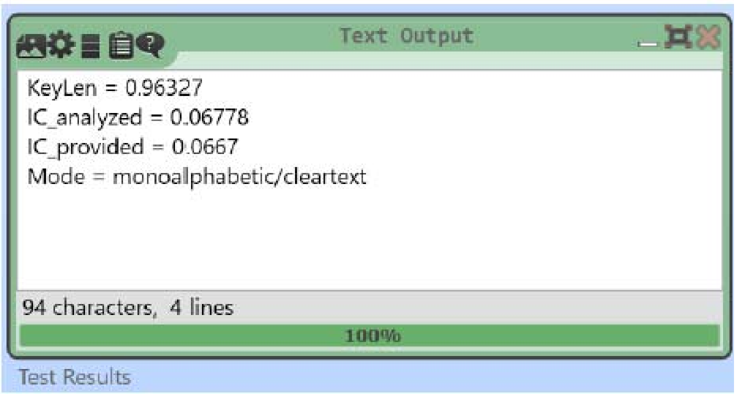
- ***c*** is the size of the alphabet (26 for English), ***N*** is the length of the text and ***n*** to ***n*** are the observed ciphertext letter frequencies, as integers

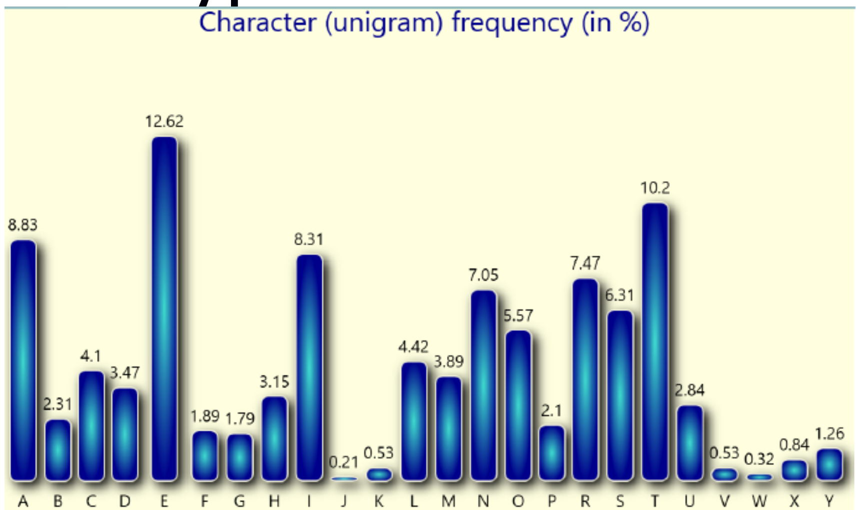
- That is, however, only an approximation; its accuracy increases with the length of the text

- It would, in practice, be necessary to try various key lengths that are close to the estimate

Friedman Test (Kappa Test)

- Computational tools to do (CT2):
- IC is the probability of two randomly drawn letters out of a text to be identical
- Useful to differentiate between plaintext (or transposed or monoalphabetic substituted text) and polyalphabetic encrypted texts





Friedman Test (Kappa Test)

- I.e example:
  - For English texts IC is 6.6%
  - For German texts IC is 7.8%

- Using **simple monoalphabetic encryption**, where a single letter is replaced by another letter, **does not change the IC of the text**

Friedman Test (Kappa Test)

- **Same applies to all transposition ciphers**, since these do not change the text frequencies

- **Homophone substitution** also aims at changing the letter distribution of a text to become the uniform distribution, but **here the IC is about 1/n** , where n is the amount of different symbols in the text

Friedman Test (Kappa Test)

- Thus, having an IC close to **6.6%** indicates that we have either a plaintext, a **monoalphabetic substituted text**, or a **transposed text**
- On the other hand, having an IC close to **3.8%** indicates that we have a **polyalphabetic encrypted text**
- Clearly, the IC is more accurate having long ciphertexts
- Identification of homophone ciphers can be done by counting the number of different used letters or symbols
- If the number is above the expected alphabet size, it is probably a **homophone substitution**

Criteria for "Good" Ciphers

- "Good" depends on intended application
  - Substitution
    - C hides chars of P
    - If > 1 key, C dissipates high frequency chars
  - Transposition
    - C scrambles text => hides n-grams for n > 1
  - Product ciphers
    - Can do all of the above
  - What is more important for your app?
    What facilities available to sender/receiver?
    - E.g., no supercomputer support on the battlefield

Criteria for "Good" Ciphers

- **Commercial Principles of Sound Encryption Systems**
  1. Sound mathematics
     - Proven vs. not broken so far
  2. Verified by expert analysis
     - Including outside experts
  3. Stood the test of time
     - Long-term success is not a guarantee
       - Still. Flows in many E's discovered soon after their release
- Examples of popular commercial encryption (We will see them at next M7 module):
  - DES / RSA / AES

DES = Data Encryption Standard
RSA = Rivest-Shamir-Adelman
AES = Advanced Encryption Standard (rel. new)

Cryptology for IoT

Modules M4, M7, M9

Session of 27th April, 2022.

M4.3 Briefing to the session

M4.4 Introduction to the ciphers: Substitution , Transposition and mixed ciphers

M4.5 Methodology using Cryptool

Prof.: Guillermo Botella

Step-by-step approach methodology for classical ciphers

- **First step →** Make the cipher processable for CT2, so we create a digital transcription of the ciphertext
- **Second step →** Identify the type of the cipher
- **Third step →** Try to break the cipher

Step-by-step approach methodology: i) Create a transcription

- There are two ways to create a transcription of a ciphertext for CT2
- The first method is to manually assign to each ciphertext symbol a letter by hand outside of CT2, e.g. with Windows Notepad.
  - The transcription is saved as a simple text file
  - This file can be loaded into CT2 by using the FileInput component and then be processed further

Step-by-step approach methodology: i) Create a transcription

- The second method to create a transcription uses the CT2 component "*Transcriptor*"
- With the transcriptor, a user can load a picture, e.g. a scan of a document

Step-by-step approach methodology: i) Create a transcription

- Finally, the transcriptor is able to output the complete transcription.
- It supports the user in two different ways:
  – It automatically guesses, which symbol the user just had marked by showing the most likely symbols
  – It can be set to semiautomatic mode. In semi-automatic mode, it automatically marks all other symbols that are similar to the one just marked by the user

Step-by-step approach methodology: ii) Identify the cipher

- Several analysis:
- **Text frequency analysis**
- **Friedman test analysis**

Step-by-step approach methodology: ii) Identify the cipher

- **Text frequency analysis.**

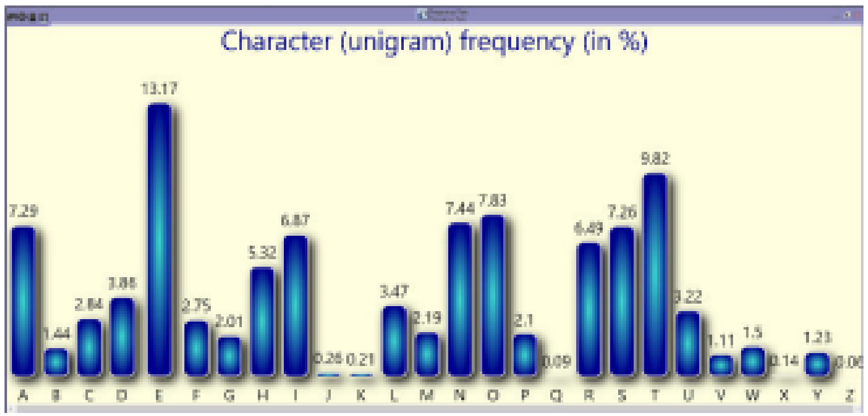
For that, CT2 contains a Frequency Test component

It can be configured to show:

- unigram distribution
- bigram distribution
- etc.

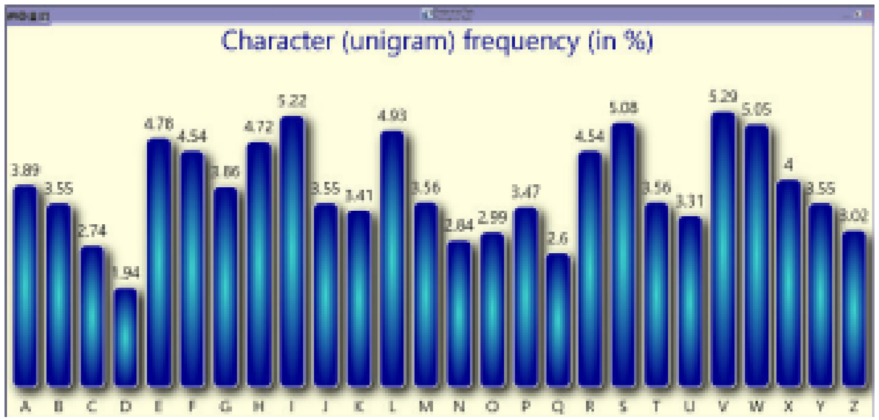
Step-by-step approach methodology: ii) Identify the cipher

- Example: Distribution of plain text. ("*The Declaration of Independence*" of the US)
- The text follows the letter distribution of the English., i.e. the 'E' is the most frequent letter, the letters 'X', 'Q', and 'Z' are very rare



Step-by-step approach methodology: ii) Identify the cipher

- Distribution of cipher text. Same text encrypted with Vigenere cipher
- Here, all letters are more or less equally distributed, showing the cryptanalyst that it is possibly a polyalphabetic substitution cipher

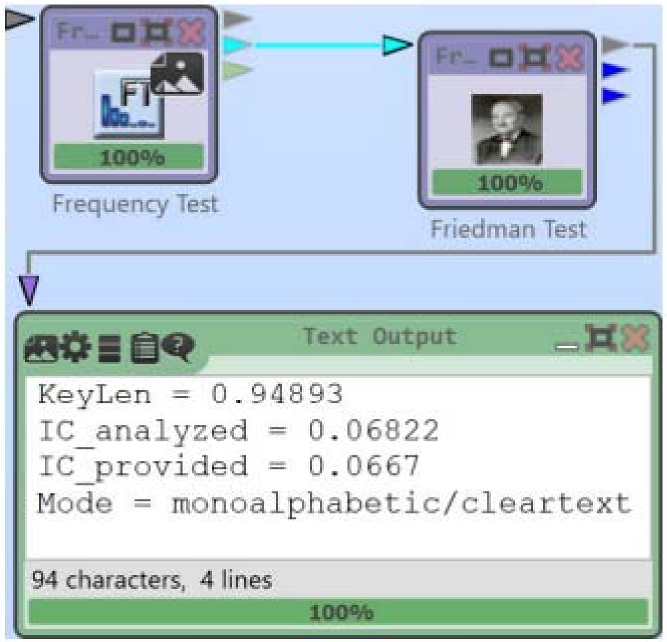


Step-by-step approach methodology: ii) Identify the cipher

- **Friedman test analysis.**

For that, CT2 contains a Friedman Test component

- With this test the key length (number of letters of a key word or phrase) of a polyalphabetic cipher can be calculated



Step-by-step approach methodology: ii) Identify the cipher

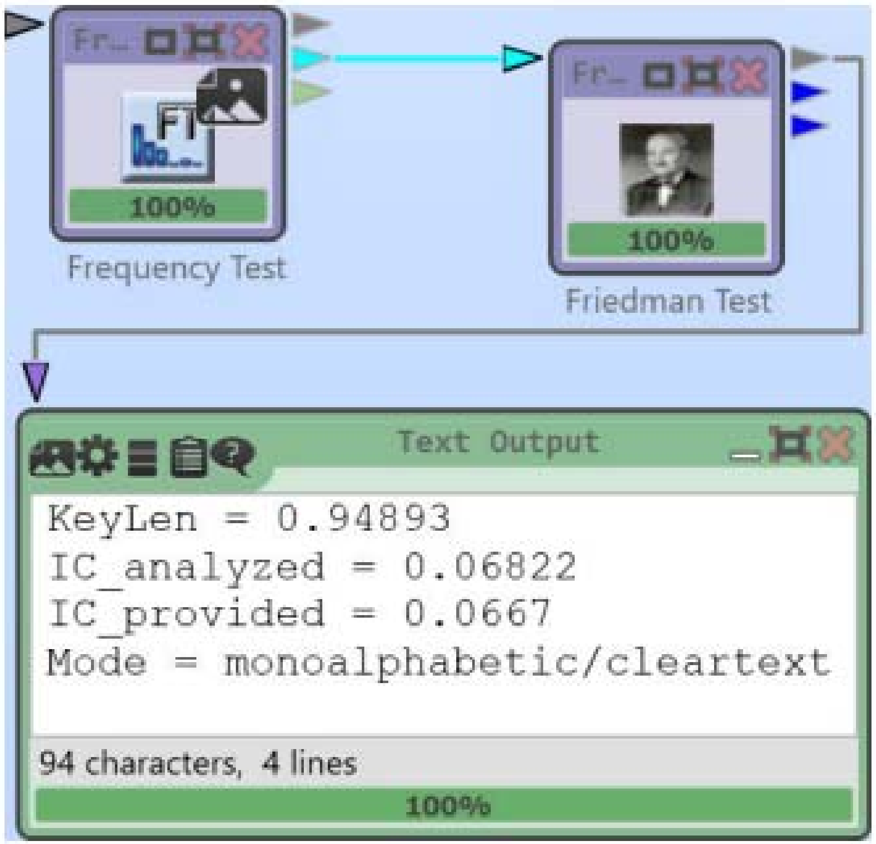
- **Friedman test analysis.**

For that, CT2 contains a Friedman Test component

- Same text (plain text)
- This text is possibly plaintext or a monoalphabetic substitution
- The ciphertext could be transposed since the transposition does not change the letter distribution

Step-by-step approach methodology: ii) Identify the cipher

- **Friedman test analysis.**

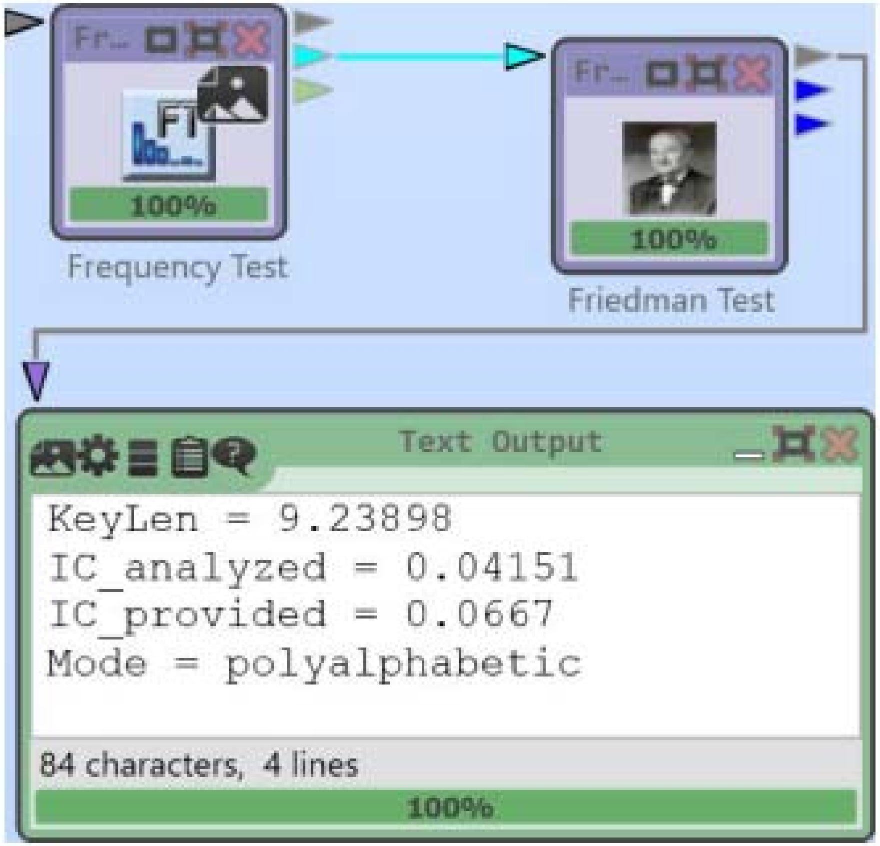


Step-by-step approach methodology: ii) Identify the cipher

- **<u>Friedman test analysis.</u>**
- Same text (ciphertext)
- Vigenere cipher
- It shows that the given text is possibly ciphertext and polyalphabetic
- The ciphertext could be transposed since the transposition does not change the letter distribution

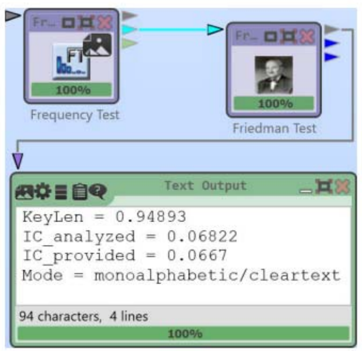
Step-by-step approach methodology: ii) Identify the cipher

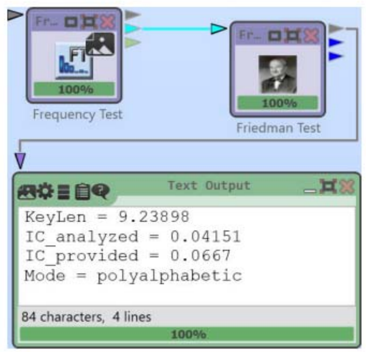
- **Friedman test analysis.**



Step-by-step approach methodology: ii) Identify the cipher

- **<u>Friedman test analysis.</u>**
- Additionally, it shows that the estimated 33 key length is about 9
- The component needs a provided IC (IC provided) which is used as a reference value for the analyzed IC (IC analyzed)





Step-by-step approach methodology: iii) Break the cipher

- **Break the cipher**

We use the help of different cryptanalysis components:

- Monoalphabetic substitution cipher
- Vigenere cipher
- Columnar transposition cipher

Step-by-step approach methodology: iii) Break the cipher

- **Using the properly solver**

Analysis

Start Time:	1/21/2018 8:28:57 PM	End Time:	1/21/2018 8:29:25 PM
Elapsed Time:	00:00:27	Keys/second:	10,119
		Current analyzed keylength:	9

Bestlist

#	Value	Key	Key Length	Text
1	8.91458977542657E	KEYWORD	7	THEDECLARATIONOFINDEPENDENCE
2	2.65449346106438E	DKEKEOKEY	9	ABYPOFEGXVFSVMKZCLOLOENNQXV
3	2.65599400712501E	DDKEDOEO	8	AISVPFKWSVFSCCUVDGHRPANNXYJ
4	2.65713062562153E	DKEKODKEY	9	ABYPEQEGXVFSVCVZCLOLOEDYQXVE
5	2.65946172261918E+	DKEKEODDO	9	ABYPOFLHHVFSVMKGDVOLOENNXYF
6	2.66189596613086E	DKEKEEOEO	9	ABYPOPAGHVFSVMUVCVOLOENXMK
7	2.66951117085202E	DKEKEO	6	ABYPOFLAROLICGUZCVOLOENNXRP
8	2.67115879404954E	DKEDRDKEY	9	ABYWBQEGXVFSCZVZCLOLOLAYQXV
9	2.68405716599966E+	DKKEO	5	ABSVEQEARKMMVMKGWZNHPEHXM
10	2.68657440185661E+	DOKDEO	6	AISWOFLHLVLICNOGCVOSILNNXYJEC

Sec

Step-by-step approach methodology: iii) Break the cipher

- **Using solvers**
- The solver automatically tested every key length between 5 and 20 using hill climbing
- Only about ten seconds are needed for the component to automatically break the cipher
- The decrypted text is automatically outputted by the component and can be displayed by an TextOutput component

Step-by-step approach methodology: iii) Break the cipher

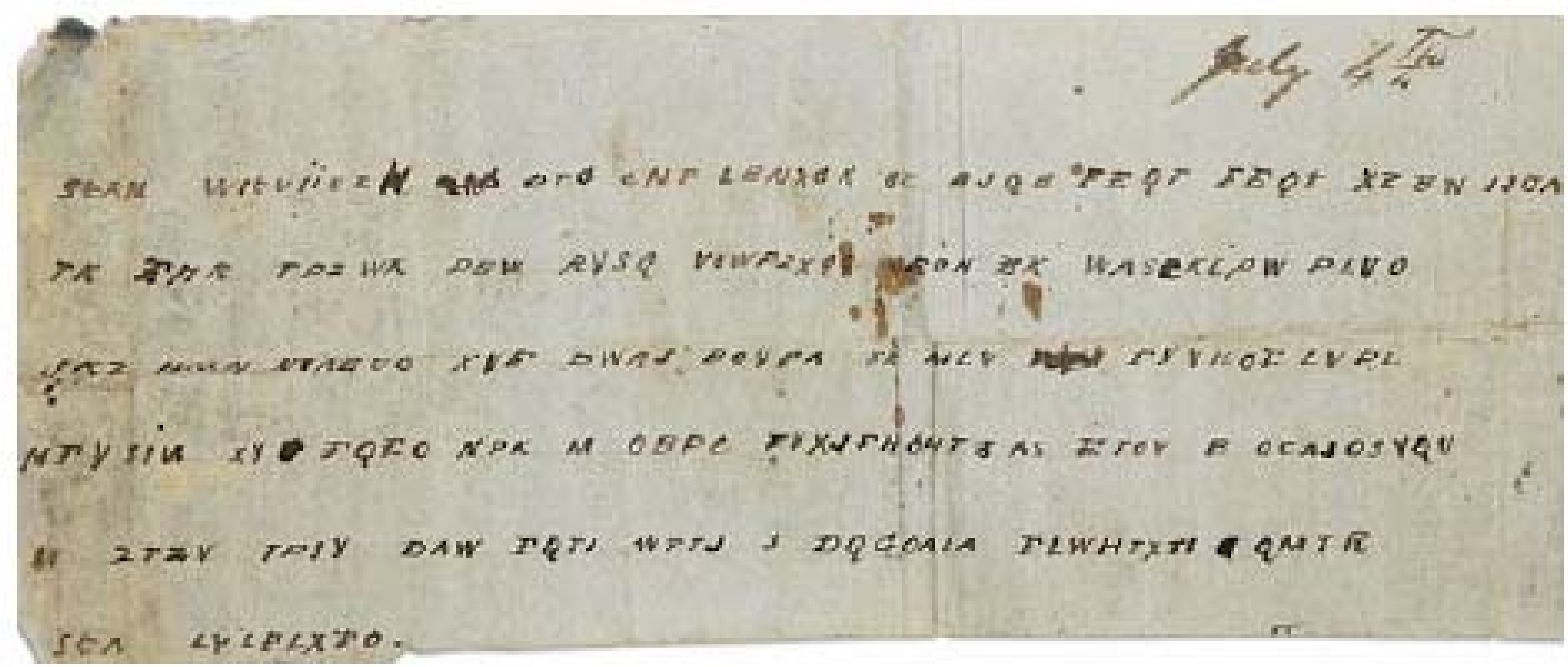
- **Using solvers**
- All automatic cryptanalysis components have the same style of user interface
- Besides start and end-time, the elapsed time for the analysis is shown
- Furthermore, some components estimate the time for the remaining automatic analysis

Examples using this methodology

- **<u>Message in a bottle (US Civil War, 1863)</u>**
- It was sent in a bottle by a Confederate commander at the 4th of July 1863 in Vicksburg to General Pemberton
- It was broken by the retired CIA codebreaker David Gaddy in 2010
- We here use this message (221 letters) as our first real-world example for breaking classical ciphers with CT2

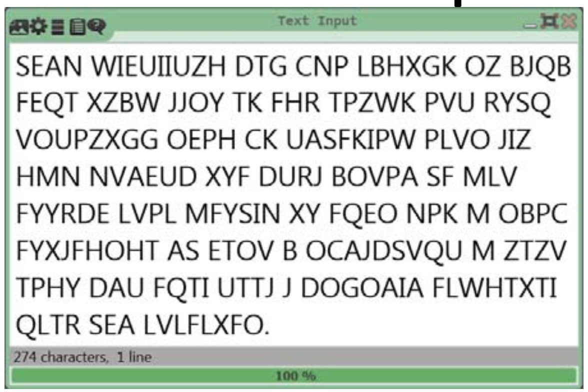
Examples using this methodology

- **<u>Message in a bottle (US Civil War, 1863)</u>**



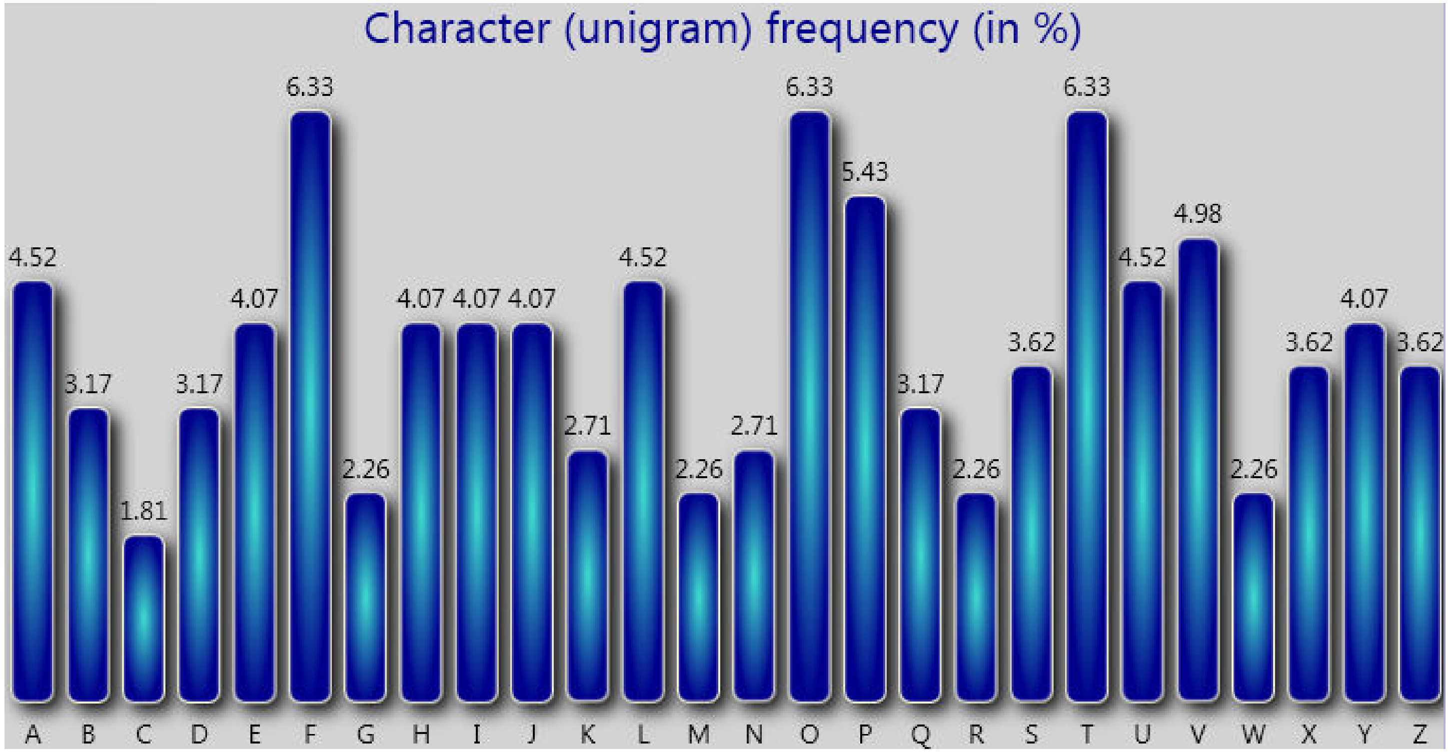
Examples using this methodology

- **<u>Transcript (Message in a bottle)</u>**
- Just using "Transcriptor" component or do it manually
- Since the letters are written differently, the scanned image has only a low resolution, and the message contains ink spots, it was used manually



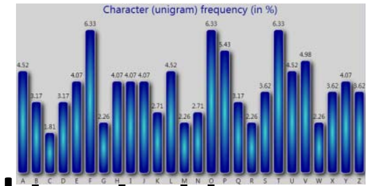
Examples using this methodology

- **Cipher Identification (Message in a bottle)**
- First, we created a letter frequency



Examples using this methodology

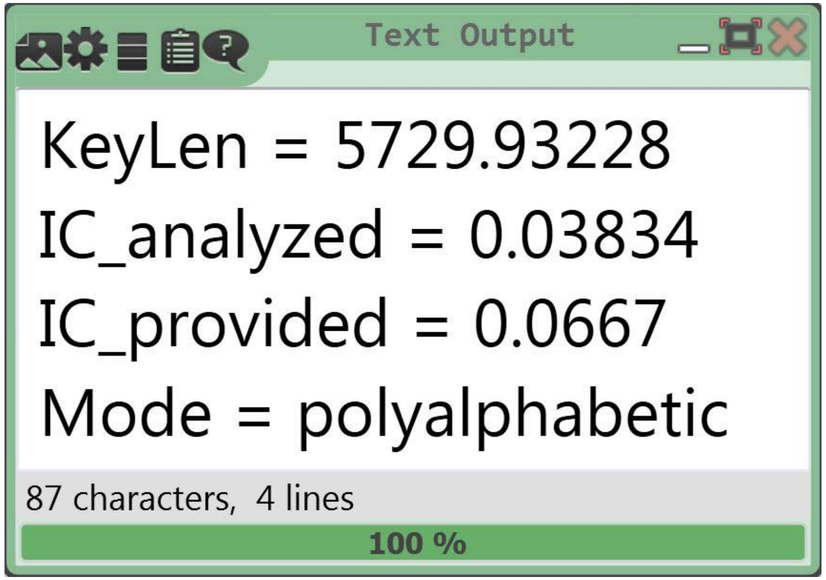
- **<u>Cipher Identification (Message in a bottle)</u>**
- First, we created a letter frequency

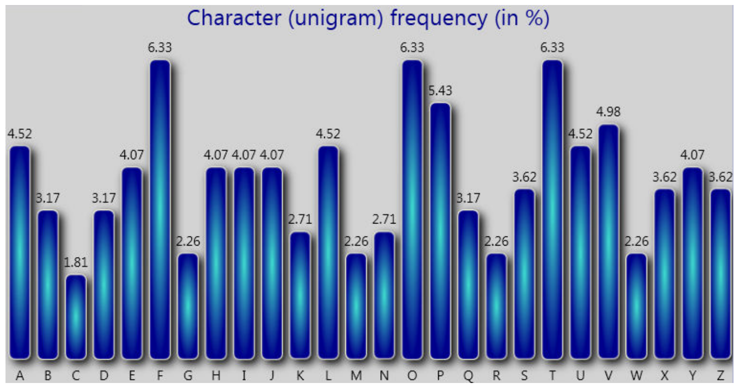


- The distribution of letters indicated that the message is not encrypted with monoalphabetic substitution and possibly not transposed
- Based on the more or less equal distribution of the letters we assume that the message is encrypted with a polyalphabetic cipher

Examples using this methodology

- **Cipher Identification (Message in a bottle)**
- To further strengthen our assumption, we applied the Friedman test and calculated the IC





Examples using this methodology

- **<u>Cipher Identification (Message in a bottle)</u>**
- The IC equal to 0.03834 indicated that the message is possibly encrypted with a polyalphabetic cipher
- The estimated length of the key is ≈ 5730, which is impossible for a text of only 221 letters

Examples using this methodology

- **<u>Cipher Identification (Message in a bottle)</u>**
- Thus, the message is either encrypted with a running key cipher, meaning one of the two cases:
  - the key length is infinity
  - or the Friedman test just fails because of the short length of the message
- Since we know that in the Civil War the Vigenere cipher was often used, we assumed it could be encrypted with it
- Other possibilities would be a codebook or a homophone cipher

Examples using this methodology

- **<u>Cipher Identification (Message in a bottle)</u>**
- Thus, the message is either encrypted with a running key cipher, meaning one of the two cases:
  - the key length is infinity
  - or the Friedman test just fails because of the short length of the message
- Since we know that in the Civil War the Vigenere cipher was often used, we assumed it could be encrypted with it
- Other possibilities would be a codebook or a homophone cipher

Examples using this methodology

- **<u>Cipher Break (Message in a bottle)</u>**
- Using “Vigenere Analyzer” component to break it
- We automatically test all key lengths between 1 and 20

Analysis

Start Time:	1/22/2018 3:50:00 PM	End Time:	1/22/2018 3:50:05 PM
Elapsed Time:	00:00:05	Keys/second:	286,222
		Current analyzed keylength:	20

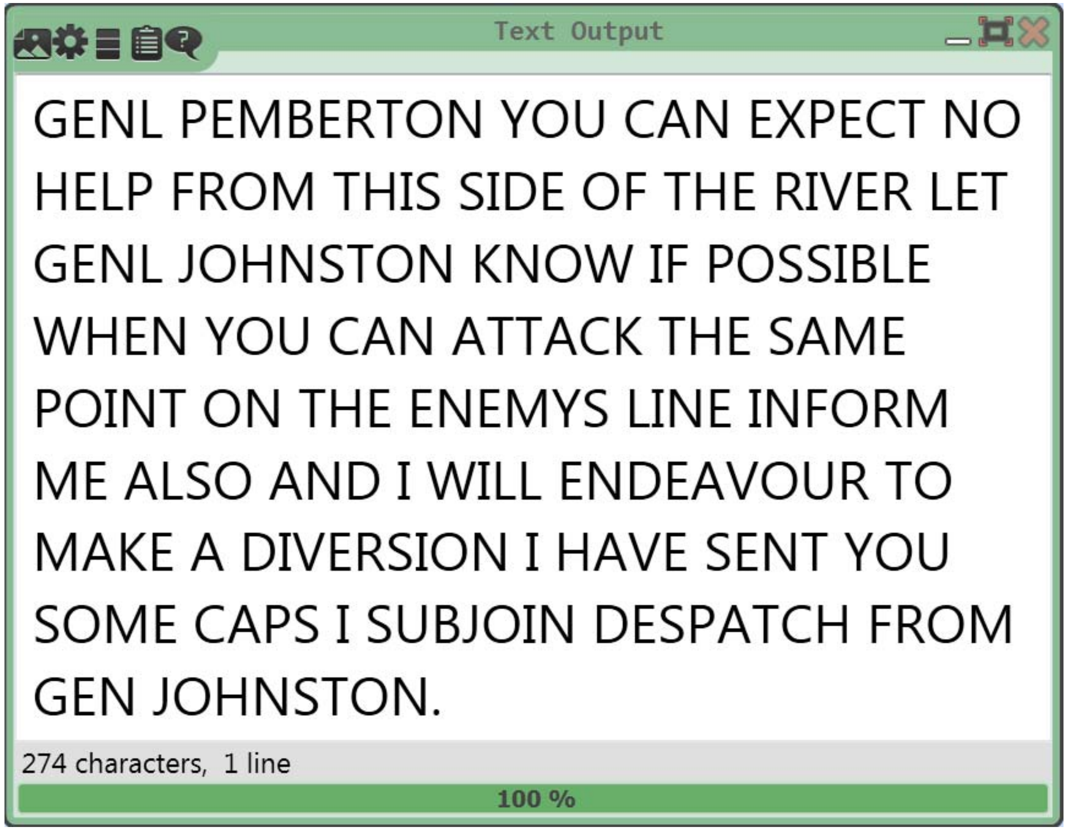
#	Value	Key	Key Length	Text
1	2961.54527050132	MANCHESTERBLUFF	15	GENLPEMBERTONYOUCANEXPECTNOHELPI
2	3038.2004460357	MANCHESTERBLUPZ	15	GENLPEMBERTONOUUCANEXPECTNOHURI
3	3241.10477872893	MANCHESTLEBLUPZ	15	GENLPEMBXETONOUUCANEXPEVGNOHURI
4	3298.457165819	MANCHEOLLEBLUFF	15	GENLPEQJXETONYOUCANEXTMVGNOHELP
5	3781.77629491449	BDILPODRFUBLULIMEHLZ	20	RBSCHUBDDOTONSLUYGEMAEPVVAWKEW

Examples using this methodology

- **<u>Cipher Break (Message in a bottle)</u>**
- The component displays a toplist of “best” decryptions based on a cost function that rates the quality of the decrypted texts
- The higher the cost value (sum of *n-gram* probabilities of English language) the higher the place in the toplist

Examples using this methodology

- **Cipher Break (Message in a bottle)**

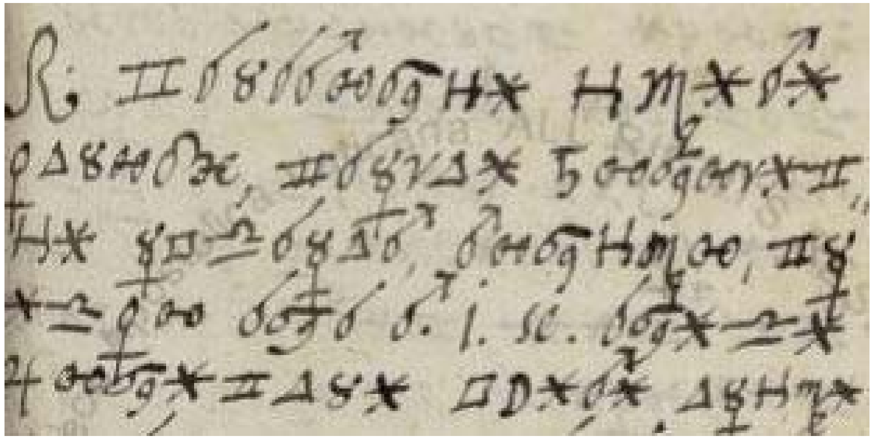


Examples using this methodology

- **<u>Cipher Break (Message in a bottle)</u>**
- Furthermore, the component shows the used keyword or pass phrase
- With "MANCHESTERBLUFF" (15 letters), the message can be broken
- The analysis run took 5 seconds on a standard desktop computer with 2.4 GHz

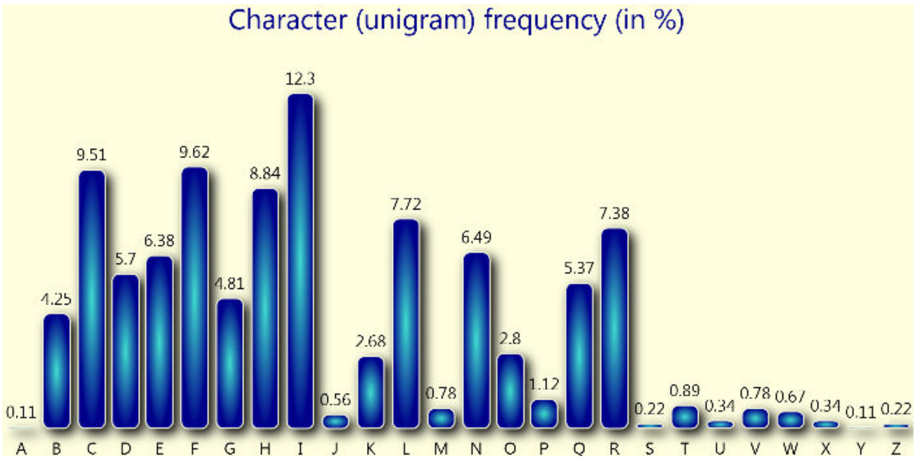
Examples using this methodology

- **<u>Borg Cipher (Vatican library, 17th century)</u>**
- The Borg cipher is a 408 pages manuscript, from the 17th century located at the Biblioteca Apostolica Vaticana
- It is written using special ciphertext symbols



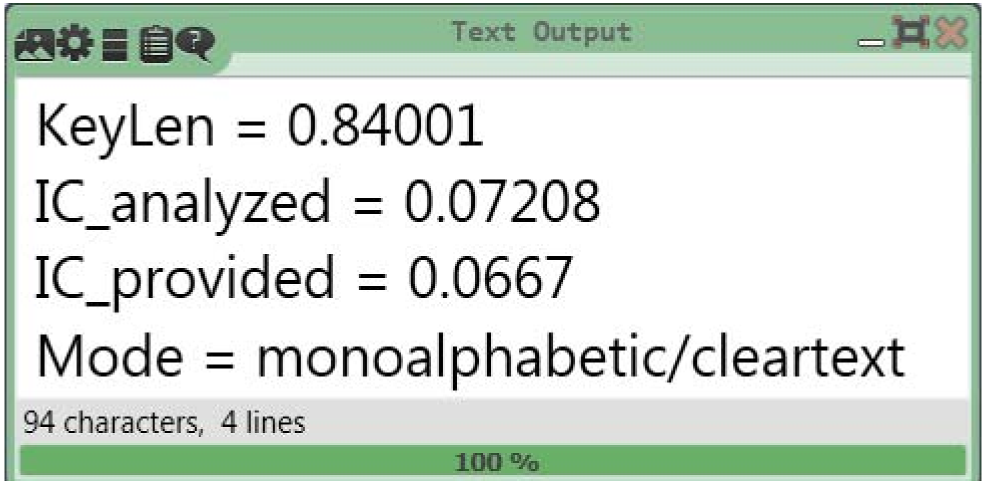
Examples using this methodology

- **Transcript (Borg Cipher)**
- We took the complete transcription
  - Took from (Aldarrab *et al*., 2018)
    - Nada Aldarrab, Kevin Knight, and Beata Megyesi. 2018. The Borg.lat.898 Cipher. http://stplingfil.uu.se/~bea/borg/
- **Cipher Identification (Borg Cipher)**



Examples using this methodology

- **<u>Cipher Identification (Borg Cipher)</u>**
- Then, we applied the Friedman test on the ciphertext and computed the IC
- Both indicated, that the Borg cipher is encrypted using the monoalphabetic substitution



Examples using this methodology

- **Cipher Breaking (Borg Cipher)**
- Thus, we finally used the Monoalphabetic Substitution Analyzer component

Local			
Start:	1/22/2018 5:38:42 PM	End:	1/22/2018 5:38:50 PM
Elapsed:	00:00:08		

Top Ten

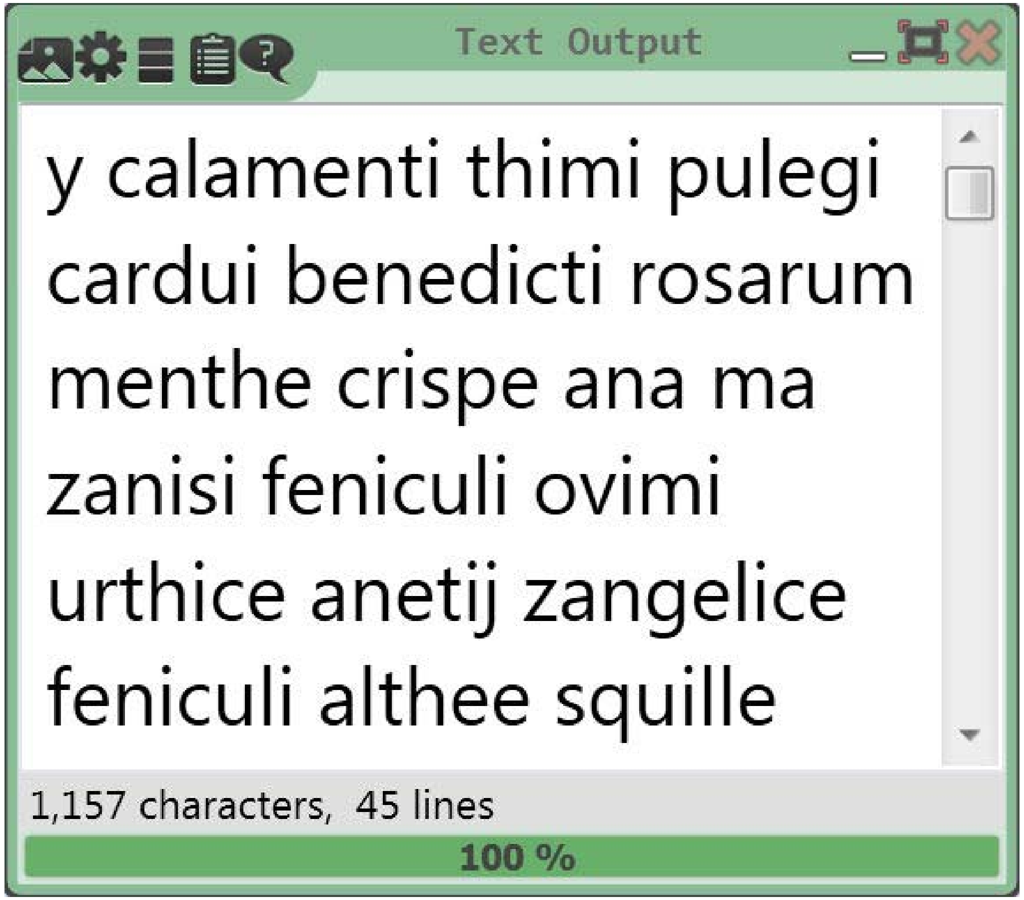
#	Value	Attack	Key	
0	3.99246	G	ycalmentihpugrdboszfvjqwkx	y calamenti thimi pulegi cardui benedic ti rc
1	4.09066	D	dmelrantifguhjcboskpqvwxyz	d meleranti tfiri gulahi mejcui banacim ti jos
2	4.10200	D	jaklmentiqpugrdbosvfwyhzcx	j aklkmenti tqimi pulegi akrdui benedia ti ro
3	4.10353	D	jaklmentiqpugrdbosvfwxhycz	j aklkmenti tqimi pulegi akrdui benedia ti ro
4	4.10676	D	abeltonmidpugrcfcshjkqvwcx	a beletonmi mditi pulogi bercui fonocib mi
5	4.10836	D	bmdlfentihpugrcvosjkqwayzx	b mdldfenti thifi pulegi mdrcui venecim ti rc
6	4.11962	D	bahljentikpugrdmosqfvwyzcx	b ahlhjenti tkiji pulegi ahrdui menedia ti ros

Examples using this methodology

- **Cipher Breaking (Borg Cipher)**
- We tested different languages to be used by the analyzer
- Latin produced the best results, since the original text is Latin
- The analysis run took 8 seconds

Examples using this methodology

- **Cipher Breaking (Borg Cipher)**



Module 4: Cryptology for IoT

Cryptology for IoT

Modules M4, M7, M9

Session of 27th April, 2022.

M4.3 Briefing to the session

M4.4 Introduction to the ciphers: Substitution , Transposition and mixed ciphers

M4.5 Methodology using Cryptool

Prof.: Guillermo Botella

Sec