

## **Part V**

### **Grid-based ciphers**

## Unit 69

### Polybius cipher

If we cram the alphabet into a  $5 \times 5$  matrix, we have a *Polybius square*. Unfortunately, the English alphabet has more than  $5^2$  letters, so we may have to jettison one of them. Usually, we will put 'I' and 'J' in the same spot.

Now, if we add labels to the rows and columns, we can use the Polybius square to make a cipher, which we will call the *Polybius cipher* or *Polybius-square cipher*.

	0	1	2	3	4
0	A	B	C	D	E
1	F	G	H	I, J	K
2	L	M	N	O	P
3	Q	R	S	T	U
4	V	W	X	Y	Z

The application of the cipher is obvious: we replace a letter of the plaintext with the row and column labels of its location in the grid. For example, with the matrix above, we can encipher this short message:

THIS MESSAGE WAS ENCRYPTED WITH A GRID CIPHER  
33121332 21043232001104 410032 042202314324330403 41133312 00 11311303 021324120431

The ciphertext is

3312133221043232001104410032042202314324330403411333120011311303021324120431

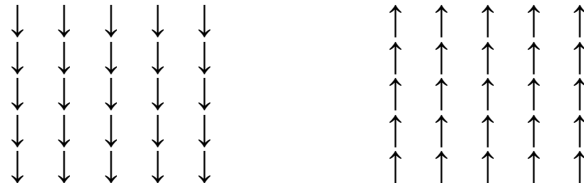
We are not forced to use the digits 0, ..., 4 as our labels, and we are not constrained to use the same labels for rows as for columns. The only constraint is that all row labels must be different, and all column labels must be different.

The cipher can be keyed by using a mixed alphabet. In Unit 26 we saw several ways to construct mixed alphabets from keywords. With this new cipher, we add a new dimension. There are many ways to lay the mixed alphabet into the matrix. Here are just a few:

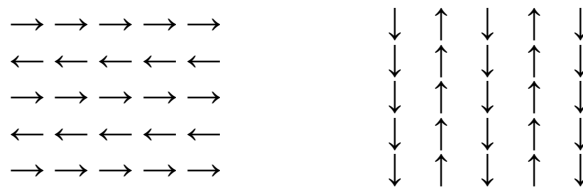
- by rows



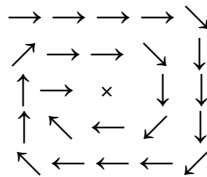
- by columns



- boustrophedon (by rows or columns in alternating directions)



- spiral, outside-in or inside-out, clockwise or counterclockwise



At this point, you should realize that no matter how we mix the alphabet and no matter how we place the mixed alphabet into the grid, all we have done is replace each letter with a two-character string (a code word). By listing all two-character strings in the ciphertext and assigning a letter to each, we convert the Polybius cipher to a monoalphabetic substitution cipher. In Unit 28 we saw a method for solving monoalphabetic substitutions automatically.

## Reading and references

Practical Cryptography, [practicalcryptography.com/ciphers/polybius-square-cipher](http://practicalcryptography.com/ciphers/polybius-square-cipher)

Fred B. Wrixon, *Codes, Ciphers & Other Cryptic & Clandestine Communication*, New York: Black Dog & Leventhal, 1998, pages 190-191.

David Kahn, *The Codebreakers: The Story of Secret Writing*, New York: Simon & Schuster, 1967, revised and updated 1996, page 83.

## Programming tasks

1. Write a function to fill a Polybius square. Allow for many options on how to generate the mixed alphabet and on how to fill the grid.
2. Write a function or script to encipher a plaintext with the Polybius cipher with a keyword, an alphabet-mixing method, and a grid-filling method.
3. Write a function or script to decipher a ciphertext with the Polybius cipher with a keyword, an alphabet-mixing method, and a grid-filling method.
4. Implement the attack mentioned above.

## Exercises

1. Decipher this ciphertext with the keyword POLYBIUS. The mixed alphabet is constructed by adding letters that come alphabetically after the last letter of the keyword (in this case, start with 'T'). The grid is filled by columns. Labels are as in the example above.

```
241002314332310232212431211043324403023221013100102030
400111214201004313442132441313322130311042443242043220
203010112413130301213242010043134431131231314332310121
201024331324101133432310443010113110404413320431431314
102410322000433240133101422111402131013111310110244201
00431344
```

2. Break this ciphertext from the 2019 British National Cipher Challenge:

```
FBGAI AGCFE KEFEK CIAGC FCGAF CIBHD HEFCF AFBFA GDFCH
DFEKC IAKCI BGBGC IAHAf EKCFa KAIAG CFBFA GBFBI AFBHE
IAGCK CIAFC IBHDF EGAGA FCHDI AHEIA FCKDF CFAIA KCFBF
AIAGC FEHEF CICFB FEIAH EFDKA HBHDF CIEKA IDKCH DHEFB
HEKEF CFCHA FEKEK CHEHA KAGEF CKCIA GCFBF AGBFC GAIAG
CFEHE FCICF BFEIA FEHAH BFBHD FEIDK CHEHE IAFCG DFEKE
FDKAG CFBHE KEFEK CIAGC IAGCF EIBHE HEHDG AFEFE KEHEF
CFAIA GCFEK CFAGB FEHDI AGCKC IAIDF EHEIA FBHDI BHBID
FBIAG CFEKC KDGCi DKCHD IDFEG AFBGB GCIAF BFAFB IAHEH
BIBHB HBFEI AHEIA KCIAF EHEID FEGCK CICFE IAHDf BFEKE
IAFCK DFCFA IAKCF BFAFB IAFDI BIAFB FAFCI DHDFE KCGEF
BHEFE IAGCK CIAID FEKDK CFAFC FAGEK AKEFE GAFEK CIAFB
IAIAG CFEID KCKAI DFEGA FCIBG BGCIA GAKCH EKDFB HEHAF
DKAIA KCGDF BFAGB FCFaF BIAHE HAFBG BGCIA FBFAF CHBFE
FAIDK CHDFC IBHDH BFCGE FBIAF BKDFB KCFaH EGCKC ICFEH
EGCHD IBFAG DGAHD FCHAI AGCFE KDFCF AGAGE FBKDI AKCFA
KEIAG CFEKA FAFEF EKEKC HDFEK CHEFC FAIAF CKDFC FAGaH
DFCFA IAIAG CFefe ICFBG E
```

## Challenge

A 20x20 grid of 400 black and white icons. The icons are a mix of symbols including hearts, stars, crosses, and various geometric shapes, arranged in a complex, non-repeating pattern.

## Unit 70

### Playfair cipher

The *Playfair cipher* was not invented by Lord Playfair, but rather by Charles Wheatstone. At any rate, it is a *digram substitution cipher*, which means that it makes substitutions two letters at a time. It has little tolerance for double letters, so before we can apply the cipher, we have to prepare the plaintext by putting an 'X' between all adjacent pairs of identical letters. Since it works on pairs, we also need to add an 'X' to the end of the plaintext if it has an odd number of characters. (We do not need to put an 'X' between letters if they are in different digrams.)

The main engine of the Playfair cipher is a Polybius square. We fill it with a mixed alphabet that was generated in whatever way we like. Typically, 'J' is merged with 'I,' but some prefer to merge 'Z' in to 'Y.' The plaintext is processed two letters at a time, according to these rules:

- If the two letters appear in the same column of the Polybius square, then each is enciphered to the letter below it. If the letter is on the bottom row, then we use the letter at the top of the column.
- If the two letters appear in the same row of the square, then each is enciphered to the letter to its right. If the letter is in the last column, then we use the first letter in the row.
- If neither of the previous two cases hold, then a rectangle is observed in the grid such that the two letters are at two of its corners. They are enciphered to the letters in the other two corners. Each is enciphered to the letter in the other corner in the same row.

(Mathematicians in the audience recognize a torus when they see one.)

Now for an example. Here is our plaintext:

THIS MESSAGE WAS ENCRYPTED WITH A GRID CIPHER

First, we prepare it with nulls, one between the two 'S's and one at the end.

TH IS ME SX SA GE WA SE NC RY PT ED WI TH AG RI DC IP HE RX

Let's use the keyword POLYBIUS to mix our alphabet, and let's not do anything fancy about how we lay it into the square:

P	O	L	Y	B
I	U	S	A	C
D	E	F	G	H
K	M	N	Q	R
T	V	W	X	Z

The first two letters of the ciphertext, TH, are enciphered to ZD:

P	O	L	Y	B
I	U	S	A	C
D	E	F	G	H
K	M	N	Q	R
T	V	W	X	Z

The next two, IS, are enciphered to UA:

P	O	L	Y	B
I	U	S	A	C
D	E	F	G	H
K	M	N	Q	R
T	V	W	X	Z

This continues, and the ciphertext is

ZDUAVMAWACHFXSUFERSQBIPFETSZDGQKCHIDIDFQZ

To detect whether we have a ciphertext that has been encrypted with a grid-based digram substitution cipher, we look to see if there are at most 25 different letters and whether the length of the ciphertext is a multiple of two (to disguise the cipher, however, one might change some 'I's to 'J's, so be careful). If there are any long repeated sequences of characters, then the starting character of each needs to be an even number of letters apart. Furthermore, if we plot the index of coincidence as a function of period, as we did in Unit 31, we often see a slight increase in the even periods over the odd periods (do not take this to mean that the cipher is periodic, just that this is a differential tool).

## Reading and references

Helen Fouché Gaines, *Cryptanalysis: a study of ciphers and their solution*, New York: Dover, 1956; previously titled *Elementary Cryptanalysis* and published by American Photographic in 1939; [archive.org/details/cryptanalysis00gain](https://archive.org/details/cryptanalysis00gain); chapter XXI.

American Cryptogram Association, [www.cryptogram.org/downloads/aca.info/ciphers/Playfair.pdf](http://www.cryptogram.org/downloads/aca.info/ciphers/Playfair.pdf)

Wikipedia, [en.wikipedia.org/wiki/Playfair\\_cipher](https://en.wikipedia.org/wiki/Playfair_cipher)

Practical Cryptography, [practicalcryptography.com/ciphers/playfair-cipher](http://practicalcryptography.com/ciphers/playfair-cipher)

United States Army, Field Manual 34-40-2, chapter 7, "Solution to Polygraphic Substitution Systems," Basic Cryptanalysis, U.S. Department of Army, [www.umich.edu/~umich/fm-34-40-2/ch7.pdf](http://www.umich.edu/~umich/fm-34-40-2/ch7.pdf)

Fred B. Wrixon, *Codes, Ciphers & Other Cryptic & Clandestine Communication*, New York: Black Dog & Leventhal, 1998, pages 217-219.

Fletcher Pratt, *Secret and Urgent: The Story of Codes and Ciphers*, New York: Bobbs-Merrill, 1939, chapter XII, section I.

David Kahn, *The Codebreakers: The Story of Secret Writing*, New York: Simon & Schuster, 1967, revised and updated 1996, pages 198-202.

Joseph O. Mauborgne, *An Advanced Problem in Cryptography and Its Solution*, Fort Leavenworth (Kansas): Press of the Army Service Schools, 1914, [www.marshallfoundation.org/library/digital-archive/advanced-problem-cryptography-solution](http://www.marshallfoundation.org/library/digital-archive/advanced-problem-cryptography-solution)

W. W. Smith, "Solution of the Playfair Cipher," in part IV of André Langie, *Cryptography*, translated by James C. H. Macbeth, London: Constable & Company, 1922, HDL: [2027/uc1.32106002774104](https://nbn-resolving.org/urn:nbn:de:hbz:5:1-63888-p0071-9) and [2027/uc2.ark:/13960/t0tq62t29](https://nbn-resolving.org/urn:nbn:de:hbz:5:1-63888-p0071-9)

## Programming tasks

1. Write a function that returns a boolean value representing whether it is likely that a given ciphertext has been encrypted with a grid-based digram substitution cipher.
2. Implement an encryptor for the Playfair cipher.
3. Implement a decryptor for the Playfair cipher.
4. Implement a dictionary attack. Remember to allow for many possibilities for the method of mixing the alphabet from a keyword and for the method of laying the mixed alphabet into the square.

## Exercises

1. Encipher this text with the keyword **TRENDING**. Fill the square with whatever method you like.

The point I advance, if it need confirmation,  
I'll prove by a witness that few will dispute,  
A pink of perfection and truth in the nation  
Where fashion and folly are all of a suit.

(from *Nothing to Eat* by Horatio Alger and Thomas Chandler Haliburton)

2. Decipher this ciphertext with the keyword **GROCERIES**. The alphabet was mixed by starting at the beginning of the standard alphabet after the keyword. The mixed alphabet was laid in by rows from left to right.



MDSOASOGTGKCDRBZEVSKYMHFVIBDSKYMHCOROCGODGABUICQMROR  
AOEAIHPEVFHPDMQCXCNDPUMRKBBPASZKGQPLABKENPNBVIQCASYQWB  
GZGUAKEYKBSHIQBUFSCPVLQOEGUPBBNEQRFQYQCKSZGDCGUQSSIDC  
KGOGKRXZEQDKFVSAUCOCLNMRRCHWCMOBVFPDNBLVXCPEDRMHFVPDFV  
OVRCEAHRFSRLXCZMGQUQBKXGGSOBPUNPMDSHQBUIFNSGDUDUDCOWGS  
RFYTCYMRDSLTRDBXARZRQGDQITVPLFVOIASDPQWQRDRXCPEGEQCRVF  
EDPLCDSDMCBAIQDQPLCOBNVBOZURBYXCNURQBXNQWSEKQUTCIAELT  
FICZEQSHOGHWGENLTMTCPLEKBAUNAEOW

3. Apply a dictionary attack to break this ciphertext.

CQAHUBVNTIZNTODRBAFRCEAWRKKRNODRVTCNZITVTUBKHQCXEPRBN  
TZFRZHMBABNOXEQGBTWRTZPODRCUQZOPKVUFDWONTZDRNKFWFKEDR  
BANOPGVBIWMTAWRKXEPRVTLQPUDKOMKATZMXZIKDVTUDARPTBISBA  
QCTPMKCKDBZNBTYCGNRLXVBNRABHFRLZKRQFKHQFPDOPZNDKMOQRTZ  
PVBLLHBFOTVRADTBZNVPCDVTOMBADTBISCLOTEVILTODRBNRAVNMC  
NZFRRAEARKNKTOELRKCQBVKRIQMHRQDKQKBLITETKBDBQCPQRKQFKH  
ZNPVZBLFDBQCZNPITZDABDEVQHASIAWQPOYBAOPUKKHRLGPZIVQFR  
EHVQGERAKVTZ

## Unit 71

### Hill-climbing attack on the Playfair cipher

We are going to begin with Cowan's attack ("simulated annealing") and make some improvements. In his method, fitness is measured as the sum of tetragram frequencies. A parent key (in the Polybius square) is set, and from it a child key is generated by swapping individual letters, swapping two rows, swapping two columns, or flipping the entire square. If the fitness of the decrypted plaintext from the child key is greater than the parent, then the child becomes the parent. This is a step upwards. However, it is easy with the Playfair cipher to become trapped in a local maximum fitness. To allow the algorithm to escape such a fate, a "temperature" is added by allowing a step to go downwards in fitness if the distance down is smaller than a random variable that drops off exponentially and which depends on temperature. As the temperature is reduced, the jitter in the motion in key space gets smaller and the distance downward that is allowed gets smaller. The temperature is allowed to slowly decrease to zero. If the algorithm has not found the global maximum fitness at that point, then it starts over with a high temperature. The algorithm actually does not know if it has found the global maximum, and requires human interference to stop it.

The first improvement that we make on this algorithm is to use tetragram fitness as described in Unit 9. Our definition of it is an average over all tetragrams in the decrypted text. As an average, it is not dependent on the length of the text. Therefore, it can give the algorithm a clear indication that it has found the maximum and can stop. A threshold above which we are confident that we have English text was found in the exercises of Unit 9. For the Playfair cipher, we remove all 'X's before evaluating the fitness, since they would have been added between any double letters.

Our second improvement is to use a constant margin of error for downward steps. In our algorithm, a downward step is allowed if the distance downward is less than a fixed amount and if a random variable is within a predetermined interval. That margin is 0.5, and downward steps are allowed only if the random variable lands in 5% of its range. The global maximum will be steep enough that the algorithm cannot walk downward out of it. So we can terminate if we have reached a point from which we cannot step upwards within a large number of tries (around 10,000).

Here is the full algorithm:

1. set the parent key to a Polybius square with an unmixed alphabet
2. set the best fitness to the fitness of the unmodified ciphertext
3. set the counter to 0
4. while the counter is less than 10,000

- a. copy the parent key into a child key
  - b. randomly choose one of these modifications to the child key:
    - i. swap two randomly selected elements
    - ii. swap two randomly selected rows
    - iii. swap two randomly selected columns
    - iv. flip the square around the diagonal that runs from upper left to lower right
    - v. flip the square vertically
    - vi. flip the square horizontally
  - c. decipher the ciphertext with the child key to find a new plaintext
  - d. calculate the new fitness of the new plaintext
  - e. if (the new fitness exceeds the best fitness) or  
((the new fitness exceed the best fitness minus the margin) and  
(we roll a 1 on a 20-sided die))
    - i. copy the new fitness to the best fitness
    - ii. copy the child key into the parent key
    - iii. set the counter to 0
  - f. increment the counter
5. output the parent key

## Reading and references

Michael J. Cowan, "Breaking Short Playfair Ciphers with the Simulated Annealing Algorithm," *Cryptologia*, 32:1 (2008) 71-83, DOI: [10.1080/01611190701743658](https://doi.org/10.1080/01611190701743658)

## Programming tasks

1. Implement the attack. If you used a different logarithm base, you will want to experiment with different values for the margin.

## Exercises

1. Break this ciphertext. What is the keyword?

UDSDAEEPVFHPKNNMPILPBMNGDOOGHPGDVFHIVQRSURBETIREAFHPAV  
 KFREHRRMFANFPUDMRAAUIAGPEXFTGRUODWRBNFNDOTGPWQGDMNLQV  
 WEUWHGLDFAUNOQPUALZSDZDGUFABEZDRBDFDVVQRSGMBEIZTDFNOP  
 PLPUUVRBAUGTVEHRARFKDRBEODUDVEUCAWRBPRDSNEBXSLTPWQGRA  
 FAKGLPUWHGLZBFREIEREZLRETZWGYNLPDUFPECPZZDMUGUUTICGUIA  
 RAODOQGDUGIZGHUALZMUBVZDDMZDRBGUFAEFBRDMARDFOPBRPRNLOM  
 SDSRXNOREBRADMGKANMHKIDZUMOAPLOAAFUNRZARSIGHUSMGZDRDEP  
 UWBEIFREOPLSFNBWAUMPTLMGNLRZARSIPIAUXGZDPR

2. This ciphertext is from the British National Cipher Challenge before it was national (2001). Figure out how it was disguised. Break it. Make sure your decryption is a clean one; otherwise you may have made a mistake with its disguise. Can you find the keyword?

NZTFM YKDID MYLCY NSGZK VXKMX ALZDP MYLCY NSGYK VXKMX  
AGKOG LCYUR EGPNY TFMZK DMNGL HWCLL DKYAB IYYKV XKMXA  
DYOSJ PCDHU GDKIK UVXKM XADYO SJPCD KUJAS DLBEU VTNZT  
FMZKD ZIKMG JLCEU DAYNV XKMXA IYGKP EJGHL HMAII YYKVX  
KMXAI ZQSNJ OLHKJ VIKVX KMXAL YNJYG PDHLI YMCBS YLKCE  
GYOSX XANJD NLKDP LIQZD KHGJG XANJD NLKDP LIQZL YDSGK  
DWDOE JANEBS DAVV GKDCT GIZLY LSDFG DOEJA NEBSD AVXAG  
LXADS TFEKI MCDMX XAOSD SJELX KMPEH CQDKS GZKDQ SIZGI  
VMDSJ EGXKC ZMGPG LKUYM JGKYK IMZFN XADPN YKIZK IMKZY  
GELJN YMIDN JDMOK IKYOL HDPOL LEDPC LSDYJ EUAGK DQISO  
QDMGJ ZGEGO SDGLH FGPMC SBPEJ GUGXE JKSII MXAKY KZCMG  
FWKKN PHJSK DSMBS FKHMD GQYKD MGMZG JIKJT GIZGE BYNAG  
KDSNB DEDGL AWKDJ NIGYG GIXAK OAGBQ XKGIM TGEKB ZKJTG  
IYNGJ CHYGX RKYOL LEHQK IBGEW GJQOK THCBS XALKB SMZNH  
PDJMG FWKKN SMGMB GSDYQ NZTFQ IZIBX NEAXJ QBJZN GWKDK  
USMVX DPDET FXD

3. Break this ciphertext. What is the keyword (hint: it is a name)?

BIPAFKWLIFETHACPEGKWCKKPIUDQCWPMLKBIAMSFFSAFQDANHOBQTB  
BOKOSCBTBQCFWUHHACPATIRFYKWUBQOIRHOOKUPZPQVONLCPKWOMK  
GRCRKQVIPUBICMHACPATNLHWHFPMHOIQQTQNKNOIXSFRCCRKRQYQYUQKT  
CBCPKPAFGYSLPKCMQEKPUHAUDAIKQBIAQQMINQCBICUKUOKMROWGY  
FSAFQDHORFUPKKFAIXBCPGARUZCUHXBKIMKWOHFQTRABNWOARTAOB  
OUINTGUCQYOKMRQBCPKPFELPKCMQEKPUHAUMIHACPTQAQNEQKPAKP  
UKQHHOFXQALNQAPZPUHDKRUKOKVNBKUAZBFFKFYKWYLAQNQVNHOF  
QDUCQYOKMRQY

## Challenge

Not square.

G0IJVEFCDLZMDECBNAV4VIWGBRCEACKTVETFCKEWDBIZPMRFNETSZ0VCJPL  
KIEIPYCKTDIZUHTNBUEFTGTCAFCNTIJTSGFCGATKLVFE2FUY2FGAJTNZ  
GZKTCIFVTFEXACKTJCUYUVNUTCRFRFKT2FJBENIVGLJEGDDLCTP00BCACBV  
GJCKKVFCEAILFCUFNELFIEFCPL2FTQCENGIRFCUFNELFSFVNCEGNBNAQC  
TFGAFCCKITEYSA2FCFBJFBGAFCFBETBFIVKLPHNGPLFATAG0NGPL2FTQCEF  
RFBKZFCKFVJZEXVIWCIVKLNHRDTH3FYANGTF2HPECWNODBCFJVENGTCVJ  
NZGONJTFANK0FBNEYFNBBENRKFJKYFGAQGFNJCNNZ0Z5JGTFSDLCIFVNBO  
PVEXCLHEXTHHZZEVMTKGACEDBCAKTAYJCAVF2NSCRVCVILK5JK0FBNEVEJC  
NVCICNNZ0Z5JGTGFRJFSDLCIGFILJPLKIEFCPL2FTQCEJCUFVIFCEAPLNSC  
GLIHLCCFREJNTLISTEBKZPMRFRCTNVUTFBKENTAHTCNNZOZE0CESTEQUFNE  
CGCNEBVGFCWEFGOPIVKLCINAPHCINSCNEAIDMUVFTNEZJBTCNGIRJOCNECH

PXCIRPLCT0Z2FGZLPXCHQJ0VIICIJYFILJPLKIEFCPL2FTQCENGFPGBWGGN  
OPBDIPVULHPGKTNAJPLKIEFCAVPJZEFSIVCKCECGIVGAFCONSACEGNBZJEBJ  
QFCXJBTCNGIRJOCNECECBCLNACIRILFCDTDBPDCEZFQCTCCILFE0CESTE  
FCZJEBFPKENAQCASIJHUECJGKTWEK0FBNEUYVEENGLCBZVEKGJOTJTERVCV  
IFVKTECNBVIZUJ00BJHFTJRRKCICSRKCEGZKCYTKGVPHCIBFTDGTJDNBDI  
CGPOCGTJXEJZTBCNEBQGTSCNBCKQ

## Unit 72

### Vertical two-square cipher

The *vertical two-square cipher* is a digram substitution cipher that uses two Polybius squares, one above the other. The plaintext is padded to an even length and divided into digrams. The first letter in each pair is found in the upper square, while the second is found in the lower square. The ciphertext letters are taken according to the rules:

- If the plaintext letters are in the same column, then the ciphertext letters are the same as the plaintext letters.
- If the plaintext letters are in different columns, then we find the rectangle that has them at two of the corners. The ciphertext letters are at the other two corners. The first ciphertext letter of the digram is taken from the upper square, the second from the lower.

An example couldn't hurt. Take this plaintext:

THIS MESSAGE WAS ENCRYPTED WITH A GRID CIPHER

It has an even number of letters, so we do not need to pad it. Let's use the keywords POLYBIUS and KEYWORD, and fill the first square by rows and the second by columns.

P	O	L	Y	B
I	U	S	A	C
D	E	F	G	H
K	M	N	Q	R
T	V	W	X	Z

K	R	F	M	T
E	D	G	N	U
Y	A	H	P	V
W	B	I	Q	X
O	C	L	S	Z

The first plaintext digram is TH. It defines a rectangle and we find the ciphertext digram WY:

P	O	L	Y	B
---	---	---	---	---

I	U	S	A	C
D	E	F	G	H
K	M	N	Q	R
T	V	W	X	Z
K	R	F	M	T
E	D	G	N	U
Y	A	H	P	V
W	B	I	Q	X
O	C	L	S	Z

The last plaintext digram is ER. They appear in the same column, so the ciphertext digram is also ER.

P	O	L	Y	B
I	U	S	A	C
D	E	F	G	H
K	M	N	Q	R
T	V	W	X	Z
K	R	F	M	T
E	D	G	N	U
Y	A	H	P	V
W	B	I	Q	X
O	C	L	S	Z

The full ciphertext is

WY AOKDAL SNDBASGDUTYPTEDWC KEVEMUESXLYER

Decipherment with the vertical two-square cipher is the same process as encipherment.

## Reading and references

Félix Delastelle, *Traité élémentaire de cryptographie*, 1901.

Wikipedia, [en.wikipedia.org/wiki/Two-square\\_cipher](https://en.wikipedia.org/wiki/Two-square_cipher)

Crypto Corner, [crypto.interactive-maths.com/two-square-cipher.html](https://crypto.interactive-maths.com/two-square-cipher.html)

Warren Thomas McCready (“Machiavelli”), “The Twosquare Cipher,” *The Cryptogram*, Nov-Dec 1972, 152-153.

## Programming tasks

1. Implement an encryptor. Remember that there are many ways to mix an alphabet with a keyword and many ways to lay a mixed alphabet into a Polybius square.

2. Implement a decryptor. Remember that there are many ways to mix an alphabet with a keyword and many ways to lay a mixed alphabet into a Polybius square.
3. Implement a dictionary attack. Remember that there are many ways to mix an alphabet with a keyword and many ways to lay a mixed alphabet into a Polybius square.

## Exercises

1. Encipher this text with keywords HUDSON and EXPLORE. Use the same methods for mixing the alphabets and for laying them into the squares as in the example above.

I take for granted that you are tolerably well acquainted with the different modes of life and traveling peculiar to European nations. I also presume that you know something of the inhabitants of the East; and, it may be, a good deal of the Americans in general.

(from *Hudson Bay* by R.M. Ballantyne)

2. Decipher this text with keywords MAPLE and LEAVES. Use the same methods for mixing the alphabets and for laying them into the squares as in the example above.

XCSOKGSOMYHBMQBWSOLYEWLYMXPRHZSTNZQCMZLGMBMPWILWQQBPVG  
ICHVPPRQKIQMAMHMZXBHZAYHUHDBWVDTIMBAYNYVDNTIYUHTKEHP  
PGCNSCEVXCSOSMKXPWIRACTTHEQCVDSSNNZELDBIYPGYTKEITKGSOLZ  
OWHTMFLZHELOITDIITWRACTOSCMZSOLGFLRDLYAXSOLYHFLYSOAZTB  
TWIYDBMXMKIQBXRXTNLMNKZSOPYPCHTTRMWQQIQT BVGTWKZTBVGIY  
YBIXPZNLQZMZMBPPBINTICMBKGBISIDZVDMOKGDWNTHEKEDUVDZQ

3. Perform a dictionary attack on this ciphertext. The keywords are short.

DUDAMXTENUICFGMPRLUBGGAMFQQIMXOLLWQQOMESITRSSGLQLIHMS  
DAXQOIRXTMBDNHKDOUMODUWCRLFGGSBPILBOSXECTERWECNLVPNSMK  
QDOFESQQLWHMESBALMQQBOSZDALOMNDOXGSPEGREFGECGXCBFVUMI  
DNNCGGQQSPKDATDBXDSPGSOUHCNXASHTFQSINITSFEEKIASLISPGGBH  
FFBPDZGCDGTLQXHTFQMNQNREMTDHHDRXOMLSAZQBFIXGGSPEGREAT  
LPECQDHMFQMNQNMISPHFLQSPMTSQMEDGSIPKBWSXFRCP EGLNWEDAVG  
YTESELVETGMBQIELBPSPSPATESMOSPHEQQMLGGLWAEHEBZQEFWTCB  
FFGGTYHEDUECLAOXEDDQWEWCUDSLNRLBWMIBOSXECQBNSMCEOPQPI  
BPFOLNLGNNDBLVDEAEFEYSFGFEBPQQAFTHREECIXTLLPGUHSYGCED  
GGQQSPKDATDBXDSPBPTXHTDUQPHEOUMIEDBSQDTLGUDABVOSRMQDOF  
ESDIRETMNUFDSPDBBALM



## Unit 73

### Horizontal two-square cipher

The *horizontal two-square cipher* is a digram substitution cipher that uses two Polybius squares, one on the left and one on the right. The plaintext is padded to an even length and divided into digrams. The first letter in each pair is found in the left square, while the second is found in the right square. The ciphertext letters are taken according to the rules:

- If the plaintext letters are in the same row, then the ciphertext letters are the same as the plaintext letters but in reverse order
- If the plaintext letters are in different columns, then we find the rectangle that has them at two of the corners. The ciphertext letters are at the other two corners. The first ciphertext letter of the digram is taken from the right square, the second from the left.

An example couldn't hurt. Take this plaintext:

THIS MESSAGE WAS ENCRYPTED WITH A GRID CIPHER

It has an even number of letters, so we do not need to pad it. Let's use the keywords POLYBIUS and KEYWORD, and fill the first square by rows and the second by columns.

P	O	L	Y	B	K	R	F	M	T
I	U	S	A	C	E	D	G	N	U
D	E	F	G	H	Y	A	H	P	V
K	M	N	Q	R	W	B	I	Q	X
T	V	W	X	Z	O	C	L	S	Z

The first plaintext digram is TH. It defines a rectangle and we find the ciphertext digram LD:

P	O	L	Y	B	K	R	F	M	T
I	U	S	A	C	E	D	G	N	U
D	E	F	G	H	Y	A	H	P	V
K	M	N	Q	R	W	B	I	Q	X
T	V	W	X	Z	O	C	L	S	Z

Then IS → NT, ME → WU, and SS → NW. But then AG is on a single row, so it is enciphered to GA.

P	O	L	Y	B	K	R	F	M	T
I	U	S	A	C	E	D	G	N	U
D	E	F	G	H	Y	A	H	P	V
K	M	N	Q	R	W	B	I	Q	X
T	V	W	X	Z	O	C	L	S	Z

The full ciphertext is

LDNTWUNWGAYMNXPUDBMGIOYKUPAHAYDIGRFDAO

Decipherment is the same process as encipherment, with the two squares swapped.

## Reading and references

American Cryptogram Association, [www.cryptogram.org/downloads/aca.info/ciphers/TwoSquare.pdf](http://www.cryptogram.org/downloads/aca.info/ciphers/TwoSquare.pdf)

Wikipedia, [en.wikipedia.org/wiki/Two-square\\_cipher](http://en.wikipedia.org/wiki/Two-square_cipher)

Crypto Corner, [crypto.interactive-maths.com/two-square-cipher.html](http://crypto.interactive-maths.com/two-square-cipher.html)

(Note: They reverse the order of each digram, compared to our method of encipherment.)

Fred B. Wrixon, *Codes, Ciphers & Other Cryptic & Clandestine Communication*, New York: Black Dog & Leventhal, 1998, pages 219-220.

## Programming tasks

1. Implement an encryptor. Remember that there are many ways to mix an alphabet with a keyword and many ways to lay a mixed alphabet into a Polybius square.
2. Implement a decryptor. Remember that there are many ways to mix an alphabet with a keyword and many ways to lay a mixed alphabet into a Polybius square.
3. Implement a dictionary attack. Remember that there are many ways to mix an alphabet with a keyword and many ways to lay a mixed alphabet into a Polybius square.

## Exercises

1. Encipher this text with keywords **BACON** and **CIPHER**. Use the same methods for mixing the alphabets and for laying them into the squares as in the example above.

For months and months the eye has been assailed by paragraphs and pages in the literature of two worlds, contending for or against the existence in the Shakespeare plays of a cipher that would assign the honor of their authorship to Lord Bacon.

(from *The Little Cryptogram* by J. Gilfin Pyle)

2. Decipher this text with keywords POLYBIUS and SQUARE. Use the same methods for mixing the alphabets and for laying them into the squares as in the example above.

FLSHXESUORPOHLSVUAMYBIVMFQONAXPQYTDQVQFGHCELDDBSEGMOSK  
KHKLLIOOSOFNTYSEBLPMQTUOLSDORDBBBCPUKDNLSBDICWYCUCOPW  
CBUNTEQVNTOVCBDFISQPTDKHNAQNDNDQYQVNIQXCBYUNTOZCBQF  
EPKHSVUXUMTIUONFUWM00VCBDBQXCUNVLIDBOVURFKUOUVFOX00UTD  
EBNFNHPMQXCMNAOPUMQFDBUKDNLIXMQXOVCBLLIOMUVHFNABWSVBG  
UVRKNIELKLLIEVLDDOFLDBMDQLUOBLODUNUXUMFPPMQTUMDNODKEKF  
MULIIVBGCMBYPEKFNAQNOWUVNHPWOUIDKLOFABNMDBAMWRNIUXCOBB  
OFPBNAGYOUUVNXNDALLSOULIXMIDIPOVNTCBENNTLFLISEFKQPSDFP  
OFDCQXIVMXFLVLXMUMABLIOOBGCMUQKALEURKNICMODKEKFMUNIE  
PHEPUWMOLIIVNAUPMHDURVNIQGPWCBBQKHNXBDTDLICMNABUUMDNVR  
LICMUORTBELDMUEVLIOMUVHFNAAOGDDBLIXMBXFPYCQXUPBQCPOTMV  
URTTCBODKEKFMUEVQYQKLIUVMONANHASBONWMULIOELIUUVURDNRRNS  
MVSKPZQKVF

3. Perform a dictionary attack on this ciphertext.

NIUGOTANORETOTQLWAQNLATSKAASARQNTHSARPQVLTTCIEMXUNELTLA  
NTPMQDLGKTDEBBDEESSHINKGADXSSEINKGMMLPTSKAASKCSFKBNDAAO  
DRLTHRRFZUSLXSRGBKUUDNELSFHGOIBWFRGWAKZNPNOKARFLEONDN  
STSASUUPPDBKTZNPEBHRLATSEMAENEUOSEGDGOLZNPINHNTKAWBLNUG  
AETTDNQNTHTSAUGONFORFUDNEUGBGPDSSTZUSLROOELROTQFTHCNT  
ARRGODNTKAVHQLSEHDKGFORGDKSURGNTGOLZMMRFFHHVNICNLZLEUD  
NETSKUMLROAEAMVNNGHUBREOMPOOHRBEMDESEUGANUHLUEOPOOMLP

## Unit 74

### Hill-climbing attack on the two-square ciphers

A hill-climbing attack uses two mixed alphabets and the parent key/child key paradigm that we saw for the Playfair cipher. When it comes time to modify the child key, we randomly choose to swap two characters in the first or in the second alphabet. It is not necessary to flip squares or swap rows or columns. To avoid being trapped in a local maximum, a margin of 0.2 works well.

Here is the algorithm:

1. set the two parent squares however you like
2. set the best fitness as the fitness of the unmodified ciphertext
3. set the counter to 0
4. while the counter is less than 10,000
  - a. copy the parent squares into two child squares
  - b. randomly choose which child square to modify
  - c. modify that child square by swapping two randomly chosen elements in it
  - d. decipher the ciphertext with the child squares to get a new plaintext
  - e. calculate the new fitness of the new plaintext
  - f. if (the new fitness exceeds the best fitness) or  
((the new fitness exceeds the best fitness minus 0.2) and  
(we roll a 1 on a 20-sided die))
    - i. set the best fitness to be equal to the new fitness
    - ii. copy the child squares into the parent squares
    - iii. set the counter to 0
  - g. increment the counter
5. output the parent squares

Once a key is found with a hill-climbing attack, we can recover the keywords by swapping rows and columns. For example, if we find this (half) key:

T	P	R	Q	O
E	M	S	U	A
N	I	L	K	H
G	B	F	C	D

Z W Y X V

then we can rearrange columns to make the last row more orderly.

O P Q R T  
A M U S E  
H I K L N  
D B C F G  
V W X Y Z

Now we can reorder the rows:

A M U S E  
D B C F G  
H I K L N  
O P Q R T  
V W X Y Z

It appears that one of the keywords is AMUSED.

### Programming tasks

1. Increment the attack for the vertical two-square cipher. Remember that there are many ways to mix an alphabet with a keyword and to lay the alphabet into a square.
2. Increment the attack for the horizontal two-square cipher. Remember that there are many ways to mix an alphabet with a keyword and to lay the alphabet into a square.

### Exercises

1. Break this ciphertext which was encrypted with a vertical two-square cipher. What are the keywords?

MEXESAEPQHNPLAOKMGBSUNUTXTDCALPTOUE RPTGHNVGHNBOQISPQFT  
REF0IHREKLF0IHREGRDHQFOQISQXMEIBHUMQLHNAUNNACEIHMTIHRE  
WEREALPQRDRESADCRDREPQNFNMHSDKKLEQNWHIBTPTFOUNRHCAREHS  
CPDIFOSLYTHISLKLNXCQBSWHRENXMEHHDHPTGHEPTYFHOKDMIZGHKL  
NXMEHBAERMGIVEICIVCQALREADWSTRPMGCONMESATRTNGCHQCWMGWT  
LLIZKLGADBNEMEIHCEIHKHRDRRGKORPTEHDHPTGHHMDCDBPTEISNVT  
DHPFTRPTEBTRQTCCHLFOPTOUE RMPSTUTMCIAUNBSMFORSTAIHDCLT  
NAESCEIHAMTNTOMGUTNHSADCHQINDBHQGCOKDNXTDCREGRFHGSL LX T  
QYLHPTADRHGIKLNHTXAHBBHLGCHLTTIAKHHUBGTRXEULIZADCWKLFQ  
PSFWBTKLNELDFOGHQTNAWHECYTIHGAKDONDMIESX

2. Break this ciphertext which was encrypted with a horizontal two-square cipher. Can you untangle the keywords?

QMHCPVUNGIPBYNTNDKCIXGCITHMBKNVLQMEBGITRBPKNTSSFGPAPIS  
HPTSMFQMFNMVFNHCMDSNICHCOFFHMOESFCPETIRRHCQINGBATIESWH  
SXNITQCNLPNAIMPBGDBPBOEDQPDGEWTIPPCRADLQPPWRKPPIDDOCTOC  
WHMBKNQMDHRPUAYPHPGDPSILWHBWESSNDHEDMEPBLIEHRIPSBHMDQA  
QAEBICDFILGHCTOYDISOWNECESQMDHWYILWHADIIHHPDGEYYSGNMDQA  
DFGNSHC00CPSBDEQPBGAXCBIMBESASUCTMDQTSQSPIBDEYZSQSMHID  
QPSXIDCSMVFPFIEIXEAESEBPEZEIHTICQVPAPCRKNFUFPTYRAPEHBPV  
MCUPEHAPTSQMYNWYMFPIQEHMPMBSTIADIAHPTCVRBBNADAPUSCIZEIH  
AHEBLFDHKUHPSTRXCOIPKQAHPWMBQIDKFPFUUFZPEDUPAHQIDGTIER  
MBSPETOYAKIVKCGPMNDAHCGUQMDHDFDYEHLCRMCIKNOCNMIYPPIBD  
ELVPHHQMFPAKIVKCGPPCWUSRHPVQPUCQMDHQAQMFEEDLQMYNDEHP  
PSNMBOERURPEWNQMFNSOQIDRUCNAQMIHWHTSQMDHAHESWHPSMPCIEH  
DIEHODHIADMFCSEISPHU

## Unit 75

### Four-square cipher

The *four-square cipher* uses four Polybius squares, arranged in a two-by-two layout. The upper left and lower right are the plaintext squares; their alphabets are not mixed. The other two are the ciphertext squares and contain mixed alphabets. The plaintext is padded to an even length and divided into digrams. The first letter of a plaintext digram is located in the upper left square, the second in the lower right. They form the corners of a rectangle. The other two corners hold the ciphertext letters, the first in the upper right square and second in the lower left.

Let's encipher this message:

this message is encrypted with a grid cipher

Its length is even, so no padding is needed. We will use the keywords POLYBIUS and KEYWORD, and fill the ciphertext squares in an unimaginative manner:

a	b	c	d	e	P	O	L	Y	B
f	g	h	i	k	I	U	S	A	C
l	m	n	o	p	D	E	F	G	H
q	r	s	t	u	K	M	N	Q	R
v	w	x	y	z	T	V	W	X	Z
KEYWORD					a	b	c	d	e
R	D	A	B	C	f	g	h	i	k
F	G	H	I	L	l	m	n	o	p
M	N	P	Q	S	q	r	s	t	u
T	U	V	X	Z	v	w	x	y	z

The first digram **th** is enciphered to **NB**.

a	b	c	d	e	P	O	L	Y	B
f	g	h	i	k	I	U	S	A	C
l	m	n	o	p	D	E	F	G	H
q	r	s	t	u	K	M	N	Q	R
v	w	x	y	z	T	V	W	X	Z

K	E	Y	W	O	a	b	c	d	e
R	D	A	B	C	f	g	h	i	k
F	G	H	I	L	l	m	n	o	p
M	N	P	Q	S	q	r	s	t	u
T	U	V	X	Z	v	w	x	y	z

This continues, and the final ciphertext is

NBSQHENPOROZLMLLOPZIRWOXAQIYUNAWYAFCOS

## Reading and references

American Cryptogram Association, [www.cryptogram.org/downloads/aca.info/ciphers/Foursquare.pdf](http://www.cryptogram.org/downloads/aca.info/ciphers/Foursquare.pdf)

William Maxwell Bowers, *Digraphic substitution: the Playfair cipher, the four square cipher*, American Cryptogram Association, 1959, page 25.

Wikipedia, [en.wikipedia.org/wiki/Four-square\\_cipher](http://en.wikipedia.org/wiki/Four-square_cipher)

Practical Cryptography, [practicalcryptography.com/ciphers/four-square-cipher](http://practicalcryptography.com/ciphers/four-square-cipher)

Crypto Corner, [crypto.interactive-maths.com/four-square-cipher.html](http://crypto.interactive-maths.com/four-square-cipher.html)

Fred B. Wrixon, *Codes, Ciphers & Other Cryptic & Clandestine Communication*, New York: Black Dog & Leventhal, 1998, pages 221-222.

## Programming tasks

1. Implement an encryptor. Remember that there are many ways to mix an alphabet with a keyword and to lay an alphabet into a square.
2. Implement a decryptor. Remember that there are many ways to mix an alphabet with a keyword and to lay an alphabet into a square.
3. Implement a dictionary attack. Remember that there are many ways to mix an alphabet with a keyword and to lay an alphabet into a square.
4. Implement a hill-climbing attack. Except for the decryption routine and margin, it can be the same as for the two-square ciphers. The margin should be about 0.2 when the fitness is lower than a threshold, but near zero above the threshold. Experiment with it until you find a threshold that works well for you.

## Exercises



1. Encipher this text with keywords WINDY and WEATHER. Use the same methods for mixing the alphabets and for laying them into the squares as in the example above.

We all held the string as fast as we could, and tried to pull down the Kite; but it was impossible, for instead of bringing her down, we were all three dragged along down the meadow slope.

(from *Adventure of a Kite* by Harriet Myrtle)

2. Decipher this text with keywords NUMERAL and CIPHER. Use the same methods for mixing the alphabets and for laying them into the squares as in the example above.

CTBTLONUTEISIVRHSB0INKEUHTMNMMPNUUNGSBISDPEKEYFDMCDMDP  
PKMUOPDITPZCOIHCDMDPQQXTTHHQGUMUUSLHEUAPOHFGKSKI0IHOBM  
QDUEIHYMACKIQSURUNQUPHMuKEFGEEKTOHIPXAAMEUDPTIBTILEMPE  
PHSUQDEOQDBTBMTSTIPBTIEOUUMCRS0IEXCTNGSLLQNEOMYDHPTIMO  
MUQDNNMNCQCLBOQELLMUOPDIQX

3. Perform a dictionary attack on this ciphertext.

EQVOMWHHQSP E HMLWCGEINSBEPEILCQFDCDXCSBAIROTWBPPPLQCRW  
XCGLFHQPFTYTCDIPLARQROMWROQPOKBRMITABAFWSKGGUKHMG LHMNS  
IZLAPNFHROPEGGHMFQAWQNUKGSPEGSILLHGGTWBEROFLRWPEGSLAVO  
MIAELAPDTAQKAMFWMLHMSKUCBRPPIRROTZGFHRTOGLGZKAHPHATNQE  
FWLFOBDWHLARZIGAMBQEDKEQOWGKFQHIKQIPEIABBNKGLZOROCBFT  
AOHQKQRWPEHFQHIMQPAWZQRWHQAWCVLLDTCYLZISSKQIKNGDPEHMPE  
LLGGTBROFGCDTGKAIMHAFTAAIRKMLLSKHLFPaweIQCYLFPawCWGAIG  
HSROKNFGPSGGHEFWSSQQEDWMBFWETBWBGVYGGSQAWHEFPawFCQPQIUG  
CQFDCD

4. Perform a hill-climbing attack on this ciphertext. What are the keywords?

DSVNOOSGDPFOHMLETLEOLWSFFLMHSTCIAKNSMRSVACAILZRGGKUNAM  
THTNGKCIENSFRMGSEOSAMHNOISACMSFOTFHkuORALTLZAPLCACLUCS  
LMACUEMHVFLFNLKNKKILZDHTOYFSNACLWTNGPBXAPAMNSCDSIFOPC  
PZLTYINOXDKAGKUNAMCIFKGRGLYDRARAUMATSANKKOPLMOAPTRAGNO  
XQYFOMLAMSBRNSCDRAPMACPwMOPZLTYINOYFOMGSPCELGFSTDSHNMX  
YFOMLWPMFWZKHNMXYFOMGWNSGQUQQIACWYNSMKFNSIMRFOBSVNVWRR  
MIHOTHKSSGPFGTksULDtFOYDToHNMRFOfONCLTFSSRMEFLRACSRACS  
MVRAONMRBRNSCDRAPMACGSE00AONBQACQIYSDHBEMSLCGPFOUQGWE0  
RALZCSLMACHARAPBLCEIYICPUEVWFOMMRATTOASMSFOUNMEPZLTRR  
GEGSFODGCDATTWHHBADRAMNNMRFOTNNNINLTGLDGTHTNYENSOHEYAT  
FOEOLSPLAGGLRAAMBSVKHOACAIPZLTTNTSRFGLCISIRAALXWNKVNHRH  
PZLTLEGEKRQLNNQDGLCIRALMQTDZSDZKSFFCDXSGPOHEISKQHNMXYF  
MOLTfPHKMORMUNMEPZLKNKRACICQZNTNTNMMSQGLHADGKDABGKNLOD  
ISNNLIBSAKNRGGKHylTGhNNRAGLPZEIEOASMMFLMRMSFODFASUQRA  
CSAMLMFWOOMOGAQOPMFwZKRQOODWRACSDfOWHNVNOOVKCITOUSUORD  
LZNSMKTHAMRACSPWXSCINPZRSVROISNOGSFOHAFKSDIGQXAPYDRANS  
OIPLRFCIENMOCMLZNODSFOTNZORNCsATMHRQPMCKAPSAENSAKI

## Unit 76

### Phillips cipher

In the *Phillips cipher*, a Polybius square is filled, and from it, seven more squares are generated. Each square is used to encipher five letters at a time. The second, third, fourth, and fifth squares are generated from the first by shifting the top row downward one, two, three, or four rows. The sixth, seventh, and eighth squares are generated by shifting the top row of the fifth square downward one, two, or three rows. A square enciphers a letter by replacing it with the letter that is in the next column and next row, with wrap-around.

An example is essential when the explanation is as poor as the one above. Let's begin by filling a Polybius square with the keyword POLYBIUS and generating the remaining seven squares.

0	1	2	3
P O L Y B	I U S A C	I U S A C	I U S A C
I U S A C	P O L Y B	D E F G H	D E F G H
D E F G H	D E F G H	P O L Y B	K M N Q R
K M N Q R	K M N Q R	K M N Q R	P O L Y B
T V W X Z	T V W X Z	T V W X Z	T V W X Z
4	5	6	7
I U S A C	D E F G H	D E F G H	D E F G H
D E F G H	I U S A C	K M N Q R	K M N Q R
K M N Q R	K M N Q R	I U S A C	T V W X Z
T V W X Z	T V W X Z	T V W X Z	I U S A C
P O L Y B	P O L Y B	P O L Y B	P O L Y B

Notice that squares 0 and 4 have the same effect, as do squares 1 and 7. Now let's encipher a short message. The first letter enciphered with each square is highlighted with pink in the square and below. Notice the wrap-around used in enciphering 'T' to 'O' in square 0.

plaintext:	T	H	I	S	M	E	S	S	A	G	E	W	A	S	E	N	C	R	P	T	E	D	W	I	T	H	A	P	H	I	L	L	I	P	S	C	I	P	H	E	R	
square:	0	0	0	0	0	1	1	1	1	2	2	2	3	3	3	3	4	4	4	5	5	5	5	5	6	6	6	6	6	7	7	7	7	7	0	0						
ciphertext:	O	K	E	G	W	N	Y	Y	B	R	L	A	H	G	L	Y	D	P	Z	V	O	N	M	Y	E	O	I	R	E	I	V	G	G	V	E	Y	P	O	E	K	N	T

### Reading and references

Helen Fouché Gaines, *Cryptanalysis: a study of ciphers and their solution*, New York: Dover, 1956; previously titled *Elementary Cryptanalysis* and published by American Photographic in 1939; [archive.org/details/cryptanalysis00gain](http://archive.org/details/cryptanalysis00gain); chapter XIX.

American Cryptogram Association, [www.cryptogram.org/downloads/aca.info/ciphers/Phillips.pdf](http://www.cryptogram.org/downloads/aca.info/ciphers/Phillips.pdf)

## Programming tasks

1. Implement an encryptor for the Phillips cipher. Allow for several choices on how to mix the alphabet and how to lay the mixed alphabet into the square.
2. Implement a decryptor for the Phillips cipher. Allow for several choices on how to mix the alphabet and how to lay the mixed alphabet into the square.
3. Implement a dictionary attack.

## Exercises

1. Encipher this text with the keyword EDGAR. Use the same method for mixing the alphabet and for laying it into the square as in the example above.

Now the irony is this. In this walk, so many times repeated, the world's greatest master of the terrible and the bizarre was obliged to pass a particular house on the eastern side of the street; a dingy, antiquated structure perched on the abruptly rising side hill, with a great unkempt yard dating from a time when the region was partly open country.

(from *The Shunned House* by Howard Phillips Lovecraft)

2. Decipher this text with the keyword RHYMES. Use the same method for mixing the alphabet and for laying it into the square as in the example above.

UBSS00WGUHWHTWFUVHVYDIVLSPGFOWPGFWSNKHAXSAQWAUWUIFKNGU  
HQLRQYVGWOIAWGLFGWPFSIYUWNFMQYSHUYNFGIONVYRGYVSIFQNKUW  
SFGWSFUYHUIFCMSASQVUQLNGXIGRCUEASGUQWVMIFUIFGWAKWVFQVU  
BSGFRYKHGIBNIBUVXPAIYSIVUCZHWGKZBANRGFIFUMWEIYXUNOGWHR  
WUZYAUSIAUIHGFMQSIBAUYKYMV

3. Use your dictionary attack to break this ciphertext.

RAPSZUHLHMRIXQGAPPHIZURAQKOHXLGHLYGOLKAUPSFALURHMSZUXN  
KAESXZZBRAYHUBHIKCLYDCDOZUDKALSBSMHMNTUSZVBVZIXAIZARIB  
UKXHFCVPSHMI FLZAXBSIHLKHSTVUIZAGIBUCXHXUBSFGHWLUGKLDV  
DPHKEIKAXZQKAEIZVWAZZIXQKLHYSTHYRHUHPHVRDFAZHBSRQNUDI  
MSZERAVCKYDIZSHFYSLUHXHZUZ

## Unit 77

### Hill-climbing attack on the Phillips cipher

Our hill-climbing attack on the Phillips cipher is similar to the one for the monoalphabetic substitution in Unit 28. The parent and child keys will be mixed alphabets, not sets of filled squares. To avoid getting stuck in a local maximum, we will use a margin, as we have done before. A good value for the margin is 0.5. Here is the algorithm:

1. calculate the best fitness as the fitness of the unmodified ciphertext
2. set the parent key to the alphabet without 'J'
3. set counter to 0
4. while counter is less than 10,000
  - a. copy the parent key to the child key
  - b. randomly swap two letters of the child key
  - c. generate the eight squares from the child key
  - d. decrypt a plaintext using the eight squares
  - e. calculate the new fitness of the plaintext
  - f. if (the new fitness exceeds the best fitness) or  
((the new fitness exceeds the best fitness minus the margin) and  
(we roll a 1 on a 20-sided die))
    - i. copy the new fitness to the best fitness
    - ii. copy the child key into the parent key
    - iii. set the counter to 0
  - g. increment the counter
5. output the parent key

Once we have a key, we may not have *the* key. The reason for this is that if we roll the entire square to the left or right, then the cipher has the same effect. For the example in the previous unit, these versions of the first square (square 0) are equivalent. No matter which of these you choose, when you generate the remaining seven squares and encipher a text, the ciphertext will be the same.

P O L Y B	O L Y B P	L Y B P O	Y B P O L	B P O L Y
I U S A C	U S A C I	S A C I U	A C I U S	C I U S A
D E F G H	E F G H D	F G H D E	G H D E F	H D E F G
K M N Q R	M N Q R K	N Q R K M	Q R K M N	R K M N Q

T V W X Z      V W X Z T      W X Z T V      X Z T V W      Z T V W X

If we find, for example, that the key is LYBPOSACIUFGHDENQRKMWXZTV, then we can lay it into a square and roll it until it appears to be in order, and thereby recover the keyword.

## Programming tasks

1. Implement the attack. Use tetragram fitness.

## Exercises

1. Break this ciphertext. What is the keyword?

DWCFPHQAZAXMZZLZPLYARDZDMEHHDUUGLFGZPSKMFDWLHOIKIHRFOM  
TLCQXCDZPCSLBREHQQZKDLNMAQLFEABIGVZHSMTNMWXBSASBZCWUKU  
DGHSOZFHQAFQDHFLOAKRATQSLZLLZTZKMLQLFKAAIVBDFHULICCGZF  
CBOAKFCATTILKV TALQLQDHIUULRIKUSLPZIQGKHCFQSZUGLZMZGMSO  
WQVWQSZQLGDHCCGWPSOALCGFDFHMLTHQSWCLMAMZHZLYOCVZZICUDU  
VHGDLHAWGHQCWLBI CGHNRMGPLYWQLQSELHWULGLPHIHGUANGKACGBQ  
LTGKWCRNTLRLWYVBLMLHGKGKRGHAHIGDZHKGMSDBCOSZSHQNZKQVASZ  
AVFHQDOUGBIIWKZFH

2. Break this ciphertext. What is the keyword?

BVGHUUWZKGDQLDDFZUFYVMUIVLNZKUXALMRWGHKWGHVABNNSNGHERZ  
FYFOBFRBCBILBPNVMHPMUZIKSZFVMULFZZWOUWETFPXIFZAMZECGHM  
MVFMRXEIVVHKFABURURHVQRQIPNOZYZUVMURHZPFVHKUGHMRURHVQC  
XIKNHODARQVFRYVXNNZFGHBVIVLFAUHPBADNHOKICBVWKKZWGHQVRA  
IZUIFMZEFZQVLCXEVFAEGHNNVMUPNFAZH KDQINZZFOHIERHZGFVOLF  
AFMPNFAZH KR NHAHVLHAKUQLFPXNNIUUHUHHVUCNHEUALKHPNSAHVE  
BAKUHOFTNVNWHWWHBVURFHZNV LKMRUBWFXNWABNNKWAVSDFUNGUBF  
RHVEMZPFFUUCUGHKUISVURFZFP MZWPZSGFRDQYZFPXVBUBMVKUFZUQ  
INXUWRHKCXFFLR SVLRQRRXFFLRWUZ FQINQUNCHKXZMHFVKRWBCVFSW  
ZZW00WFRRXIRXYLRMBLNFAGFELK

## Unit 78 (optional)

### Phillips-RC cipher

The *Phillips-RC cipher* is a modification of the Phillips cipher in which rows and columns are shifted when generating the eight Polybius squares. The encipherment proceeds as in the Phillips.

Here is an example starting with the same first square as our example for the Phillips cipher:

0	1	2	3
P O L Y B	U I S A C	U S I A C	U S A I C
I U S A C	O P L Y B	E F D G H	E F G D H
D E F G H	E D F G H	O L P Y B	M N Q K R
K M N Q R	M K N Q R	M N K Q R	O L Y P B
T V W X Z	V T W X Z	V W T X Z	V W X T Z
4	5	6	7
U S A C I	F E G H D	F G E H D	F G H E D
E F G H D	S U A C I	N Q M R K	N Q R M K
M N Q R K	N M Q R K	S A U C I	W X Z V T
V W X Z T	W V X Z T	W X V Z T	S A C U I
O L Y B P	L O Y B P	L Y O B P	L Y B O P

If we can break a Phillips-RC ciphertext, then the keyword may not be obvious. We can roll the square until it becomes apparent, as explained in the last unit, but for the Phillips-RC we must roll horizontally and vertically.

### Reading and references

American Cryptogram Association, [www.cryptogram.org/downloads/aca.info/ciphers/PhillipsRC.pdf](http://www.cryptogram.org/downloads/aca.info/ciphers/PhillipsRC.pdf)

### Programming tasks

1. Implement an encryptor for the Phillips-RC cipher. Allow for several choices on how to mix the alphabet and how to lay the mixed alphabet into the square. Feel free to copy and modify your implementation of the Phillips cipher.
2. Implement a decryptor for the Phillips cipher. Allow for several choices on how to mix the alphabet and how to lay the mixed alphabet into the square. Feel free to copy and modify your implementation of the Phillips cipher.
3. Implement a dictionary attack.

## Exercises

1. Encipher this text with the keyword **STORY**. Use the same method for mixing the alphabet and for laying it into the square as in the example above.

Once upon a time there lived a cat of marvellous beauty, with a skin as soft and shining as silk, and wise green eyes, that could see even in the dark. His name was Gon, and he belonged to a music teacher, who was so fond and proud of him that he would not have parted with him for anything in the world.

(from *Japanische Marchen und Sagen* by David Brauns)

2. Decipher this text with the keyword **FRIENDS**. Use the same method for mixing the alphabet and for laying it into the square as in the example above.

ZQCUBXHDEFKYZOHTOVMLZZQCBQMPXKSUHOAWFMNMBDPLMUMZXOUNXI  
OPFQLFQCUBSZMQVYULZCYDEHIUCZQBOQXFXPUZORULZFBVXZQCUBXGE  
PTVYDQUZLHEZALXLDIZOMOWPZUQKAQNMCKBACQZXOPMMRULPEULACZ  
WZQMTLHQZOULIYPFNLZACCIBHCMZUHRNHHZLHFCLAGQXKEDEEEYPZN  
HLXXNQBOGHVTZSUHGSOMULZZUCOWWFMOEXXUPUMFNILKKMNLGQTMM  
LGQSUMFEIVBPQZLHDOLHIZIUOYNWALKICDZVYZXULOYGIFXXHPDLI  
CIEDECZIUQYIVKFQLZMWVGQZBMTLGQAKZOMNCLKZK

3. Use your dictionary attack to break this ciphertext.

NGQFUQBVQLVAVWKHKTAEFGFZETVMHMRUOVYQZZVSPZQOQMZZRPOA  
MAQDKWUSBUQAXBZGNSRYRZVUBBCNUIQPRLWPRMFETEXDWQUSQIMVB  
MUNSRGOTRVFTQZPRUELAZVUAMHRWPNTNQZGQVUUGBFOXUGVEXRVSQC  
BFEZIEXRSRZRZUVOFYIBZBFINCEUGVPNNEWZRKAURPYXQHRYQVSRZY  
VUTXFQBYUGYLMORNSRIFMMEWQZNFUSRFTTKMZKBXYTNGQYQZMCBNR  
RVPLMAZRRPPYQQFVBYFRZDKVVSTYVRUNFHPCUGBHSPMRMELAHEZCND  
QVSRMFLVQMHQRQOTQFPYTNLZHMIRNPHEZSVSQTBCCEHD

## Unit 79

### Double Playfair cipher

For the *double Playfair cipher*, two Polybius squares are used. Each is filled with a mixed alphabet from its own keyword. The two squares are set next to each other. In addition, the key for the cipher includes a period, which is simply an integer. The plaintext is first padded with an 'X' if its length is odd, then divided into blocks that are twice the period in length. The last block is not padded to twice the period. Each block is written in two equal-length rows; this is called *seriation*. Each pair of letters formed by taking one from the top row and the one below it from the bottom row is enciphered together. The method of encipherment is to identify the top letter in the first square and the bottom letter in the second square. Then,

- if the two letters are in the same row, encipher them to the letter just left of the second plaintext letter in the second square (with wrap-around) and the letter just to the left of the first plaintext letter in the first square (with wrap-around)
- if the two letters are in different rows, form a rectangle with them at two corners; the ciphertext letters are the letters at the other two corners, with the one from the second square first

The resulting pair is enciphered *again* with the same rules.

Time for an example. Take this plaintext:

THIS MESSAGE WAS ENCRYPTED WITH A GRID CIPHER

It has an even number of letters, so we do not need to pad it. Let's use the keywords POLYBIUS and KEYWORD, and fill the first square by rows and the second by columns.

P	O	L	Y	B	K	R	F	M	T
I	U	S	A	C	E	D	G	N	U
D	E	F	G	H	Y	A	H	P	V
K	M	N	Q	R	W	B	I	Q	X
T	V	W	X	Z	O	C	L	S	Z

Suppose our period is seven. Divide the plaintext into blocks and write them in rows:

THISMES    ENCRYPT    GRIDC



SAGEWAS EDWITHA IPHER

The first pair is TS. They are on the same row, so we take the letters to their left, with wrap-around, and get LZ:

P	O	L	Y	B	K	R	F	M	T
I	U	S	A	C	E	D	G	N	U
D	E	F	G	H	Y	A	H	P	V
K	M	N	Q	R	W	B	I	Q	X
T	V	W	X	Z	O	C	L	S	Z

Repeat with LZ to get TW:

P	O	L	Y	B	K	R	F	M	T
I	U	S	A	C	E	D	G	N	U
D	E	F	G	H	Y	A	H	P	V
K	M	N	Q	R	W	B	I	Q	X
T	V	W	X	Z	O	C	L	S	Z

This continues until we have the completed ciphertext:

TWFAATNIOYRAXMTAMZAOMRIVASEAPRIGAAFQAK

## Reading and references

NOVA Online, “Decoding Nazi Secrets: The Double Playfair Cipher,” [www.pbs.org/wgbh/nova/decoding/doubplayfair.html](http://www.pbs.org/wgbh/nova/decoding/doubplayfair.html)

Noel Curren-Briggs, “Some of ultra's poor relations in Algeria, Tunisia, Sicily and Italy,” *Intelligence and National Security* 2:2 (1987) 274-290, DOI: [10.1080/02684528708431890](https://doi.org/10.1080/02684528708431890)

## Programming tasks

1. Implement an encryptor.
2. Implement a decryptor.
3. Implement a dictionary attack. Remember that there are many ways to mix an alphabet with a keyword and many ways to fill a Polybius square. You will have to input the period or try several periods in your attack.

## Exercises

1. Encipher this text with keywords DOMESTIC and FOREIGN and period 5. Mix the alphabets by adding letters after the keyword from the beginning of the standard alphabet. Lay the mixed alphabets into the squares by rows.

Not being, at this moment, in the pay of any press, whether foreign or domestic, I will not, at this my third landing in English country, be in haste to accomplish the correspondent's office of extroversion, and to expose all the inner processes of thought and of nature to the gaze of an imaginary public, often, alas! a delusory one, and difficult to be met with.

(from *From the Oak to the Olive* by Julia Ward Howe)

2. Decipher this ciphertext with keywords GRIDIRON and FOOTBALL and period 6. Mix the alphabets by adding letters after the keyword from the beginning of the standard alphabet. Lay the mixed alphabets into the squares by rows.

DTQFQAKMGIMEAEQHRVZDATAANIFOHUTMFIBXTTRFQMFIFIHDGURWTI  
PSSBIKTEDFLAKVANUSOHIMQBVASSACONLDVEALAEHNGIGUELPEESGP  
CBFNFIRFSIKVITNGQMDXQBXISIAHIAASHAIGKLBECQAFMMGUTTFDNK  
EIDBSIHUCDNCOMKKGIMMGXTTBTBRCBDBPBDLZZLDQEDPBMSMRAFF  
ELMESSBDOCEEREPELBIIPGQBTFTTKBTBXSCKGUQHFNUDQRDYL

3. Perform a dictionary attack on this ciphertext from the 2004 British National Cipher Challenge. The keywords are taken from this list:

ANSCHLUSS  
BLITZKRIEG  
DEUTSCHLAND  
DIRSCHAU  
FATHERLAND  
FEUERZAUBER  
LEBENSRAUM  
NORDWEST  
RHEINTOCHTER  
SONDERAKTION  
WASSERFALL

ZONOP UXRFO VMNUS VERUZ XPPLS VOHMZ XGZBK TTQWL LFWAC  
FTKTA HULIP LYBUP DUURL FXHXW TOSTZ IBODK WYLFQ FWYNF  
EDZVQ RBOME SFHGT AHUUV QBIZR GFZNE WXWMV FCXMF WBLST  
DISQA NGTPM CHISA CLVWX IKLFM OZCKW XHRNW MELKB GSNSA  
MECOL KWEYP TPZDI DWKCW VFWOI ZSCID GLMTT PNUIS TVMII  
SEKMI WLZBT CXXLF ZADTT BFQAE UGWMM XRWME VLVVF ZTDNP  
ICPIZ LLICO GIHDN UBIOI OHNGZ WLGWU QFMBT PEWBO CDZPU  
TZBKS PXFFT GYUG ZUVEV LCAAQ FMPSO OMBVE TLZEW ISAQL  
CPKIH ZVDSU TLVEL FCQUV VIMFS WWYOZ ICTSZ MSVZN HBNOX  
SQFTD LFMCC AMMLI MXLLF ZCICO YGEFU TCABO WRAQQ IYXLI  
PUHIS ACLWM UVDGH PZISR QIWQT AUFQF SLOWV XWTWQ VMNOA  
HCFME ZKFRF WFAMF QWFQM ZUFUU TPMHA QHFFF CNGGS UKDWL  
EIIIQ ITKQI KDIMB OVUXP FMSLC PYXZM UMLIS W

## Unit 80

### Nihilist substitution cipher

The *Nihilist substitution cipher* begins with an alphabet mixed by a keyword and laid into a Polybius square. The row and column labels are 1, 2, 3, 4, 5. The letters of the plaintext are converted to two-digit numbers by taking the row label followed by the column label. A second keyword is used in a manner similar to the Vigenère cipher. Its letters are also converted to numbers with the same Polybius square. Those new numbers are added to the plaintext numbers. Optionally, any sum that exceeds 100 is written without the leading 1; this does not lead to any ambiguities.

You are probably expecting an example at this point. Let's begin with the keywords POLYBIUS and KEYWORD. If we fill the square in the least imaginative way, we have:

	1	2	3	4	5
1	P	O	L	Y	B
2	I	U	S	A	C
3	D	E	F	G	H
4	K	M	N	Q	R
5	T	V	W	X	Z

Our usual plaintext for this part of the book:

THIS MESSAGE WAS ENCRYPTED WITH A GRID CIPHER

And here are the gory details (at least some of them):

plaintext:	T	H	I	S	M	E	S	S	A	G	E	W	A	S	...
plaintext numbers:	51	35	21	23	42	32	23	23	24	34	32	53	24	23	...
keyword:	K	E	Y	W	O	R	D	K	E	Y	W	O	R	D	...
keyword numbers:	41	32	14	53	12	45	31	41	32	14	53	12	45	31	...
ciphertext:	92	67	35	76	54	77	54	64	56	48	85	65	69	54	...

The full ciphertext:

92 67 35 76 54 77 54 64 56 48 85 65 69 54 73 75 39 98 26  
56 82 73 63 67 74 63 80 55 75 77 35 84 37 66 42 76 64 59

## Reading and references

Wikipedia, [en.wikipedia.org/wiki/Nihilist\\_cipher](https://en.wikipedia.org/wiki/Nihilist_cipher)

American Cryptogram Association,  
[www.cryptogram.org/downloads/aca.info/ciphers/NihilistSubstitution.pdf](http://www.cryptogram.org/downloads/aca.info/ciphers/NihilistSubstitution.pdf)

David Kahn, *The Codebreakers: The Story of Secret Writing*, New York: Simon & Schuster, 1967, revised and updated 1996, pages 619-621.

## Programming tasks

1. Implement an encryptor. Remember that there are many ways to mix an alphabet and to lay it into a square.
2. Implement a decryptor. Remember that there are many ways to mix an alphabet and to lay it into a square.
3. Implement a dictionary attack.
4. Modify the two-stage attack on the quagmire 1 cipher to make an attack on the Nihilist substitution cipher.

## Exercises

1. Encipher this text with keywords RUSSIAN (in the square) and FREEDOM. Use the least imaginative way of setting up the Polybius square.

O God, how easy it is for a king to kill his people by thousands, but we cannot rid ourselves of one crowned man in Europe! What is there of awful majesty in these men which makes the hand unsteady, the dagger treacherous, the pistol-hot harmless? Are they not men of like passions with ourselves, vulnerable to the same diseases, of flesh and blood not different from our own?

(from *Vera, or The Nihilists* by Oscar Wilde)

2. Decipher this text with keywords ANARCHY (in the square) and NIHILISM. Use the least imaginative way of setting up the Polybius square.

44 77 59 47 45 66 78 57 36 53 56 83 47 76 89 76 44 83  
38 63 58 67 65 79 53 44 26 76 66 47 55 87 36 76 60 43  
79 56 67 80 53 53 56 83 45 77 67 67 37 57 39 45 58 44  
89 80 44 67 39 76 66 85 55 79 34 56 60 45 45 53 68 58  
34 53 50 43 78 77 85 88 44 86 68 64 79 47 97 50 53 67  
47 85 45 76 68 47 43 43 46 56 57 85 76 80 27 73 60 47

58 45 88 67 24 43 57 66 75 77 55 66 23 64 27 76 79 44  
 76 49 27 73 49 43 78 46 99 46 25 73 40 45 85 76 88 67  
 23 64 68 43 78 85 85 48 57 47 26 67 66 66 78 67 53 44  
 56 57 47 83 66 69 36 76 26 44 57 77 59 59 65 47 56 66  
 58 73 69 67 57 64 57 66 58 55 75 59 35 77 56 77 49 56  
 58 46 63 76 39 73 59 47 95 70 23 44 49 64 56 56 57 80  
 33 64 27 45 85 76 88 67 23 67 26 76 79 73 97 67 66 65  
 27 56 87 77 59 67 56 43 27 55 49 56 55 69 56 73 48 44  
 58 85 89 50 23 77 56 77 49 56 57 70 36 67 37 56 47 76  
 85 60 57 47 39 76 75 46 76 59 57 53 30 43 57 66 55 48  
 43 56 59 83 69 76 89 50 63 76 57 66 58 55 75 59 35 43  
 40 77 58 45 55 88 27 64 49 56 66 47 55 69 37 76 66 76  
 76 56 58 80 36 55 30 64 69 43 56 58 56 73 59 56 48 45  
 68 80 36 55 50 53 65 73 78 58 44 44 26 74 68 43 58 59  
 45 44 56 85 46 73 56 69 33 77 56 67 55 76 68 69 37

3. Break this ciphertext with a dictionary attack. Both keywords end in -IST.

46 86 52 67 74 45 74 42 36 65 45 66 36 45 57 35 103 54  
 56 55 68 73 52 64 48 38 106 52 64 35 74 85 55 74 44 46  
 86 52 64 56 38 73 43 56 64 54 94 42 64 47 74 74 42 64  
 54 45 74 42 64 46 57 83 34 37 74 47 66 63 47 45 35 64  
 63 47 35 65 64 44 36 45 37 97 72 37 54 44 94 32 43 46  
 54 75 55 53 64 46 64 44 56 54 44 97 55 34 74 45 83 43  
 36 65 48 75 55 53 68 54 84 33 67 54 46 86 52 53 65 56  
 67 42 44 57 54 74 64 53 36 44 66 36 37 77 46 86 52 35  
 38 37 74 43 43 37 64 74 64 53 37 58 73 63 55 35 55 66  
 66 53 37 38 93 33 44 46 55 64 66 35 54 48 75 33 36 45  
 45 64 34 43 37 46 83 52 64 46 44 97 52 37 77 75 73 44  
 56 54 37 65 55 34 46 57 83 66 36 65 48 84 33 67 64 37  
 74 33 67 46 35 84 34 34 38 35 94 75 66 74 44 75 52 36  
 66 37 97 44 54 68 35 93 63 36 46 44 63 52 44 35 36 73  
 52 45 77 44 04 35 44 55 35 97 44 73 65 37 75 52 53 65  
 35 03 54 56 46 35 93 35 57 54 45 64 62 53 37 36 96 72  
 36 44 65 75 35 64 36 54 74 35 63 35 65 85 44 56 54 64  
 74 33 34 65 37 84 44 53 68 44 04 52 64 46 35 03 44 36  
 65 48 06 33 73 68 64 64 44 56 54 68 66 63 47 44 75 83  
 66 53 64 74 65 55 63 35 68 83 42 64 68 74 74 43 43 37  
 65 74 33 35 44 54 75 75 45 57 37 94 42 44 74 45 03 35  
 37 75 44 75 55 34 74 68 65 33 73 65 46 97 75 63 54 65  
 75 55 53 68 54 73 53 34 74 65 77 54 67 54 37 75 35 47  
 34 37 94 44 36 56 54 84 66 34 64 44 75 35 64 48 45 86  
 35 37 38 47 83 54 37 37 48 84 33 67 77 35 03 44 34 48  
 35 75 55 53 45 37 93 52 76 35 74 04 42 37 38 57 66 32  
 53 35 65 83 32 53 68 77 85 66 53 37 46 66 46 33 37 65  
 75 35 55 54 46 86 35 45 77 35 03 73 43 38 38 76 52 36  
 47 38 83 44 34 45 66 83 35 57 68 74 74 43 43 37 65 84  
 36 73 54 65 75 36 76 44 65 66 43 56 35 68 75 44 43 64  
 54

4. Break this ciphertext with the two-stage attack.

34 80 57 87 47 63 47 25 88 56 78 76 44 58 24 60 65 57  
45 34 86 44 58 95 75 63 44 86 25 67 57 57 45 36 57 43  
77 86 87 47 34 89 27 56 65 77 66 33 50 24 66 86 58 43  
65 50 36 77 65 77 64 65 56 36 60 64 64 77 57 67 55 66  
78 75 63 54 69 44 88 64 65 67 36 57 47 67 55 67 63 76  
67 47 89 74 75 75 66 66 27 90 68 74 67 35 59 25 88 86  
65 44 54 69 66 68 55 75 45 33 67 56 76 65 86 55 35 48  
47 89 74 56 73 67 47 53 60 86 56 76 37 60 44 96 56 65  
66 56 79 43 58 75 64 73 37 47 56 67 78 87 43 44 59 56  
88 65 78 46 66 50 55 58 87 54 47 34 79 43 89 74 56 76  
53 48 27 57 75 56 75 37 46 34 79 77 87 63 37 78 25 97  
74 58 84 53 48 56 76 56 55 53 37 49 25 57 65 87 45 37  
47 24 67 57 75 56 44 69 64 76 56 87 63 35 47 55 77 78  
67 45 34 48 46 99 77 65 55 37 47 44 80 68 75 67 66 66  
25 77 78 87 45 34 48 55 89 86 58 43 53 80 33 67 78 75  
76 76 50 24 68 58 75 75 66 48 24 60 88 86 66 76 78 56  
57 75 94 64 57 60 23 60 55 78 47 66 50 24 77 56 87 86  
53 57 63 58 56 78 46 35 57 63 60 55 56 46 37 47 53 57  
56 87 45 57 49 25 59 87 58 64 43 76 24 60 94 56 77 63  
50 47 89 74 56 45 75 67 55 89 75 78 57 37 47 26 58 55  
58 43 65 50 36 77 56 87 86 54 79 44 88 65 84 66 44 67  
47 80 65 55 44 44 79 44 96 56 95 63 37 78 25 77 78 87  
45 34 48 55 89 77 75 45 65 67 47 89 74 56 53 37 56 25  
80 87 58 77 65 59 43 67 55 65 56 66 48 24 60 54 87 63  
35 46 34 69 87 86 84 53 67 36 76 75 87 44 35 69 34 89  
56 86 53 67 59 43 60 54 75 76 54 78 47 60 95 54 47 34  
79 43 58 54 75 44 65 79 56 77 64 56 57 54 86 25 80 87  
58 76 53 48 53 90 66 77 64 46 67 43 67 94 56 46 34 57  
64 80 88 84 47 57 79 43 58 55 56 56 37 47 26 88 58 54  
76 53 48 36 67 86 56 53 44 49 25 77 78 67 47 67 47 56  
68 88 87 53 37 47 25 58 86 84 45 46 67 34 79 77 97 77  
63 50 47 89 74 56 44 35 76 27 57 87 86 53 44 49 25 89  
58 64 45 36 80 24 77 78 68 76 53 48 53 57 58 68 44 35  
78 55 60 54 87 63 35 67 47 96 56 86 76 54 60 34 89 75  
58 67 45 89 56 76 56 64 54 57 89 26 58 87 56 56 66 67  
63 58 86 95 63 37 87 25 57 56 95 47 34 68 44 80 68 88  
67 36 48 24 66 97 57 64 34 48 36 89 75 58 67

## Unit 81

### Bifid cipher

The *bifid cipher* is one of Félix Delastelle's inventions. It uses a keyword to fill a Polybius square and a period to determine how the plaintext is divided into units that are enciphered together. The only way to adequately explain is through an example. Here is our short message:

THIS MESSAGE WAS ENCRYPTED WITH A GRID CIPHER

We will use the keyword POLYBIUS and a period of seven. In the simplest way, we can fill the square thusly:

	0	1	2	3	4
0	P	O	L	Y	B
1	I	U	S	A	C
2	D	E	F	G	H
3	K	M	N	Q	R
4	T	V	W	X	Z

Next, we divide the plaintext into blocks of length equal to the period seven. The last block is short, but that's OK. We can encipher it in the same way as a full block.

THISMES SAGEWAS ENCRYPT EDWITHA GRIDCIP HER

Now let's encipher the first block. We write below each letter the row and column labels that address that letter in the square:

T	H	I	S	M	E	S
4	2	1	1	3	2	1
0	4	0	2	1	1	2

Next, read off the coordinates from the upper row and follow it with the lower row. We divide it into pairs, and remap those pairs back into letters by using the same square.

42	11	32	10	40	21	12
W	U	N	I	T	E	S

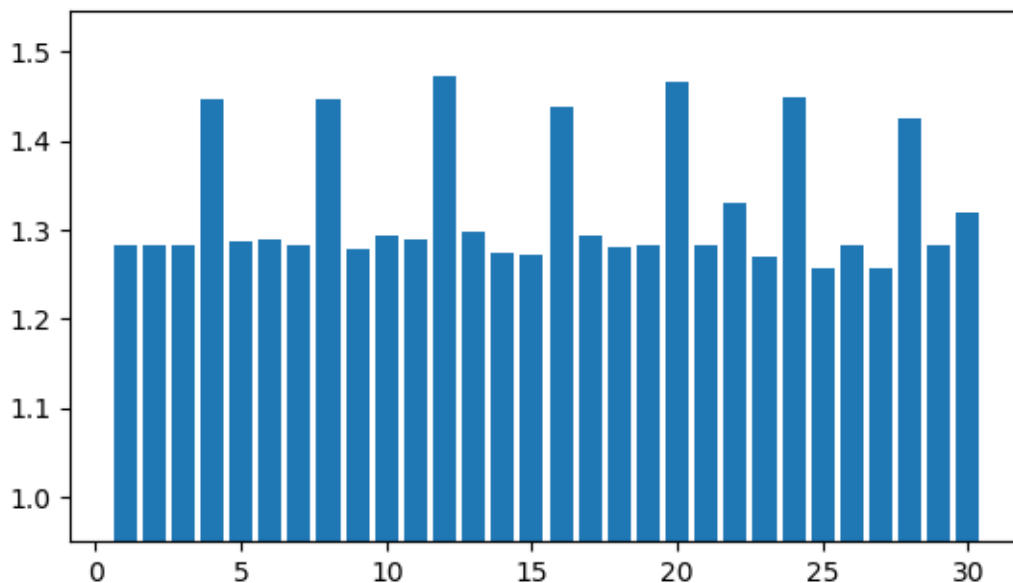
The full ciphertext is

WUNITESUFVSQSNGAPVHXPFVWULPXGSUYTBPFRC

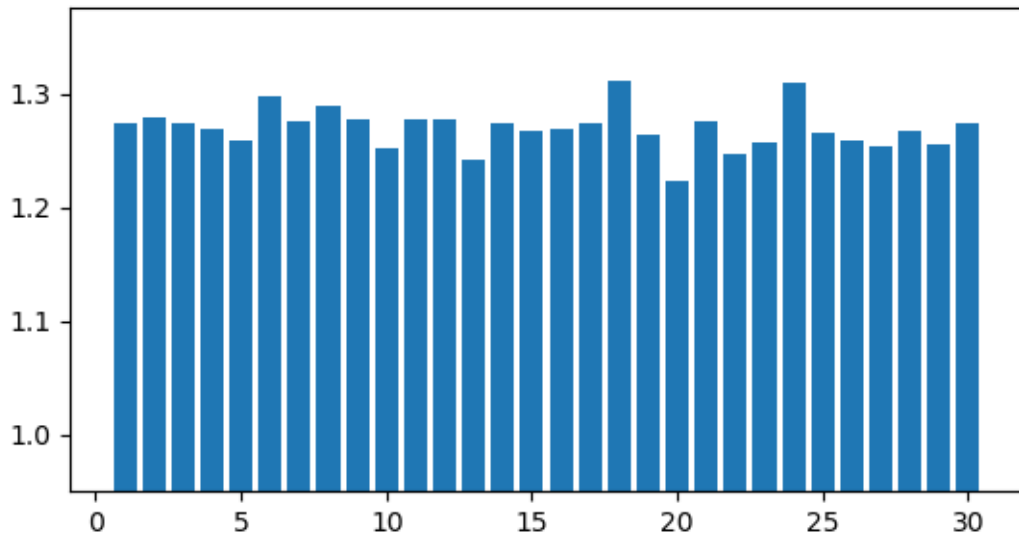
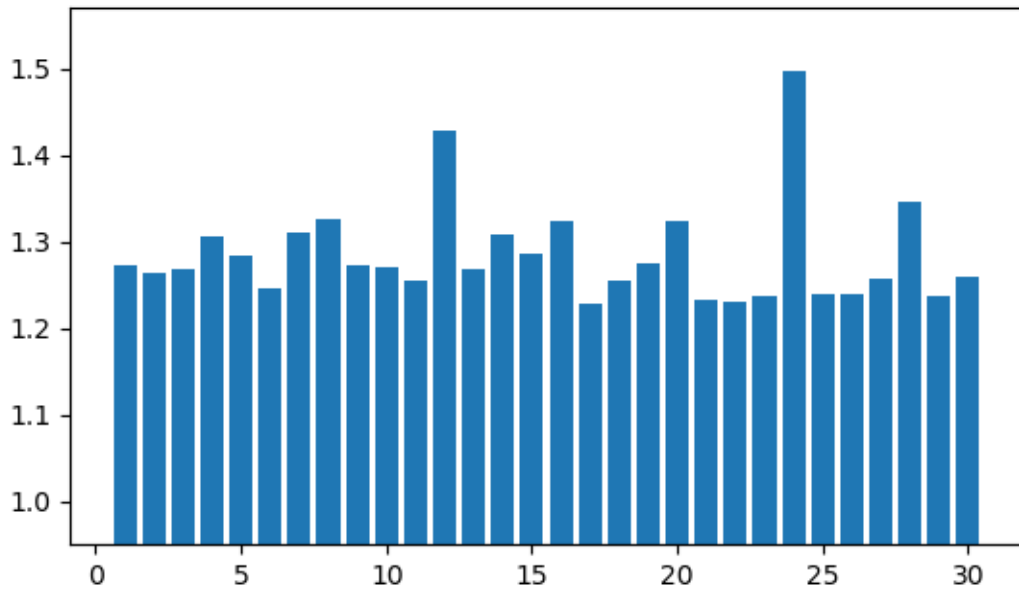
If the period is specified as zero, then the convention is that the entire plaintext is enciphered as one block.

The breaking of letters into smaller parts (in this case two base-5 digits) and separating the parts of each letter from each other is called *fractionation*. We will see this again.

If we are given a ciphertext and want to break it, the first thing we need to do is find its period. One approach to this question is to graph the index of coincidence as a function of the period in the same way as we did when examining the polyalphabetic substitution cipher in Unit 31. Here are three examples from real ciphertexts that have periods four, twelve, and zero. As you can see, the peaks are not as large as they were in our analysis of the polyalphabetic substitution, and it is not always easy to find the correct period in the graph.







Once the period is known (or guessed), we can apply a hill-climbing attack that strongly resembles the one we built for the Playfair cipher in Unit 71. We need to change the decryptor function, of course, but the rest of the algorithm remains unchanged.

---

Suppose now that we use a different grid to read out the ciphertext characters from the one used to read in the plaintext characters. This cipher is the *CM bifid cipher* (or *conjugated matrix bifid*). Let's rework our example to see how this works. Start with the same plaintext:

THIS MESSAGE WAS ENCRYPTED WITH A GRID CIPHER

Use the keywords POLYBIUS and SQUARE to fill two grids:

	0	1	2	3	4		0	1	2	3	4	
0	P	O	L	Y	B		0	S	E	V	M	G
1	I	U	S	A	C		1	Q	Z	T	L	F
2	D	E	F	G	H		2	U	Y	P	K	D
3	K	M	N	Q	R		3	A	X	O	I	C
4	T	V	W	X	Z		4	R	W	N	H	B

The period remains as seven. Divide the plaintext into blocks:

THISMES SAGEWAS ENCRYPT EDWITHA GRIDCIP HER

Now let's reencipher the first block. We write below each letter the row and column labels that address that letter in the first square:

T	H	I	S	M	E	S
4	2	1	1	3	2	1
0	4	0	2	1	1	2

Next, read off the coordinates from the upper row and follow it with the lower row. Divide it into pairs, and remap those pairs back into letters by using the second square:

42	11	32	10	40	21	12
N	Z	O	Q	R	Y	T

The full ciphertext is

NZOQRYTZPWTITOKLSWDHSPWNZVSHKTZMRGSPCF

An astute reader may notice that this ciphertext differs from the original by a simple monoalphabetic substitution. If we think of the bifid cipher as a compound cipher, consisting of (in this order) an (inverse) monoalphabetic substitution, a polybius cipher, a columnar transposition (two columns), an inverse polybius cipher, and a final substitution cipher, then the CM bifid differs from the bifid cipher only in the final substitution. Whereas the bifid uses two substitutions that are inverses of each other, the CM bifid uses two different substitutions.

A hill-climbing attack on the CM bifid could use the same technique as used for the bifid. However, rather than maximizing textual fitness, we could maximize the index of coincidence. A large IoC, near 1.7, means that we are only a monoalphabetic substitution away from the solution. The second stage of the attack is to break the remaining substitution with the technique from Unit 28.

## Reading and references

Helen Fouché Gaines, *Cryptanalysis: a study of ciphers and their solution*, New York: Dover, 1956; previously titled *Elementary Cryptanalysis* and published by American Photographic in 1939; [archive.org/details/cryptanalysis00gain](http://archive.org/details/cryptanalysis00gain); pages 210-211.

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Practical Cryptography,  
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For other approaches to cryptanalysis, see:

Practical Cryptography,  
[practicalcryptography.com/cryptanalysis/stochastic-searching/cryptanalysis-bifid-cipher](http://practicalcryptography.com/cryptanalysis/stochastic-searching/cryptanalysis-bifid-cipher)

António Machiavelo and Rogério Reis, “Automated ciphertext-only cryptanalysis of the bifid cipher,” Universidade do Porto technical report DCC-2006-1, [www.dcc.fc.up.pt/~nam/publica/dcc-2006-01.pdf](http://www.dcc.fc.up.pt/~nam/publica/dcc-2006-01.pdf)

## Programming tasks

1. Implement an encryptor for the bifid cipher. Remember that there are many ways to mix an alphabet from a keyword and to lay it into a Polybius square.
2. Implement a decryptor. Remember that there are many ways to mix an alphabet from a keyword and to lay it into a Polybius square.
3. Write a function to take a ciphertext and try to find the period. It will be similar to your function for the polyalphabetic substitution, but you will need a new way to detect a peak.
4. Implement a dictionary attack.
5. Implement the hill-climbing attack by modifying a copy of your attack on the Playfair cipher.
6. Implement an encryptor and decryptor for the CM bifid cipher.
7. Implement the two-stage hill-climbing attack on the CM bifid cipher.

## Exercises

1. Encipher this text with keyword SOCIETY and period five. Fill the grid in the simplest way, as we did in the example above.

How self-contradictory, in the first place, is the nature of man! How sociable he is! also how unsociable! We have among animals the gregarious and the solitary. But man is of all animals at once the most gregarious and the most solitary.

(from *Modern Society* by Julia Ward Howe)

2. Encipher the text in Exercise 1 with the same keyword but with period zero.
3. Decipher this ciphertext with keyword ROBERT and period 6.

RRHIKFERHMKSUFBPEVBETUFWEAOALEQERYMKHBTSLCR BANVTTRKNNP  
VFBEHALCBFNVRSDNNTTFNPETERHMKSPPENBMRHBKSLTLGCAWFNBETV  
ODKSTFVOAURLIVRVQUHQHEUGLAREWZHHPEARHRCYLASRHYUEHAOAVN  
ORAZETA0OVNZOPCRBNBRPVNUOPCRBNBRWVNAPBCNL0LKBWLWFDGRME  
RBBLVBPSEAEAPRBUGVBEDPRTROFQPTNEASAFCECTSTOISAVRDOHTQC  
LICRRHNNNPBZRRHIKFERHMKSPINQDTABLYVFPNRY SAPICBRPABNG  
FVORQDXORNUGHKLGOYBAOSQPFNHTSEWPCANNHSNWYFEEEA

4. Decipher this ciphertext with keyword SAMUEL and period zero.

FQAVKKIOQSEUWUKSURZICUSQINORBSRLYSILSPYUSSLRUYUSSLRGRS  
UAVKUEOGCHOHATFDMQAWFBAERKQUSVRBILMZCVOTSQZUDTIYMVYUTN  
HYBYUTNHYWFKZPOZYT0PDNYFN

5. Break this ciphertext with a dictionary attack.

REKTAXKSIIZVNC0GE00MEKGUFQUKXMSPYBTBBRVYKGSOMSVHTOLDXP  
AYODCNEHVDTCVYAKHPSBWVXKBBOVYICWOLVITUHTWEFTVPUUBDUPPL  
RMFYUYCKUHVWWCQNETERWOZANOOPPTLDQTP0FCHSRCCTAHRCIKZVNG  
WCWNEHUCQXQOWQKQNFYFDGVSVDLSEEZHBONAIQWFBYUQYMDRLRZNY  
HEEIEQXVMHTCEFTVPDWBFDHPWVFEWSWLGNEPAATVHROHCKOQSQHI  
TFRIELFOUAPUTFABREUCOSBQLELFZEEKBSRTITEMWZVIACVEVKNSKM  
PIXPBDCQGONFSHNOVFTVYPMGYUEPMQBMXLDCQGONBSHHZVFCGSZAK

6. Find the period of this ciphertext. Then break it with your hill-climbing attack. What is the keyword?

GRRVYGI0LRGTSCYNRTYWYHVYGUMLRREN0UVRVEERIYITRLVOACOTD  
EYYGNMTVBECVEERSYWIRFRONCUCPARIYIVDNVCBKXGADXETDRYGOEG  
TPGYFRRMOQCUSQBYDFVTGFMRR0MCSDWEAIBGWTHFYAVBYCHTBAEXCU  
MRO0ACIDIVIYIVVOGVRHRQADGGQRY0HAQXMEYND0DYSQYYEYPVYGUM  
DGRKYLDGIYIVYIYIAIUVRME0GZQPOEZDDUBYCAROAK0EGIMNGTMSS  
UIDLEGTYTVEDVUIDIYXVKRFGNMRAAHTFBNBEUCHAWCFMWAAQYPAXZ  
OOGCOWGVUCTGAMGDQGYNDUYPPRANMWAFSHHYVUX0IVRMLYERNGHN  
VBPCROUTRIPDRYASNYMNUUCGOZUIHIGQZVSCFKPBEUQYAPOARGGOAC  
PCXFFTBR0YCDURROTKSLKRBBAZYQRRIBVLPUYCAF00ITICFFYOY  
EYLRRALPORWIHLYGUMNGTMRAAHTKFYAAHXFOHZAOKVOGCAIYIVADXE  
CRREPFYRDHZGRDEUICIFLPERPXETATSYGEMFPDWZDYNNPBD0VUCTGI  
GIEDWERAEDBNTAIYIWSCYYAIUIAVUMNQTYSTNFB0WBNGHNLCREPAEX

CRMARNACVOYCYGNOUIAIIURGOZCYRAKYGVUIHICTASQRZOTYTVAGXMRD  
EYYGNMRYEDCQAZIDIZTARVM

7. Break this ciphertext which was encrypted with the CM bifid cipher. Recover both keywords.

DQVAGNHSFVAPSSLLEOTUYWVGUAGOVIIYAYRXTAZAKFQUPUCUKSDUZGG  
WVDTUPLEXANTZHAZPSIDIESTVDZAPDUVDRWOLTCISPVYXVFASGXFT  
WPXLYNDQNAGSXDRBULTOQVKUNYDUMPGRMYSXIYBRLUSVQPUAAVDXCT  
ZMVVWEHTSTSYCNXWELRLAUPCGYAVTVSGMTDLOSCGWSISYYKBPOTTYO  
EAYZCBXSWEADEQPUUVWRRMMDRLALVYOBTTPNIGLRSTUUTXKWIKRZTU  
TBEDRZSGYZZRZVZ000TWDVMAGSDSUHICKTXZULTBTYSNLDMSLRLHGKW  
MFULARVDSUPLYTOISYHTRMREYSMIZYZLWKPQTXSAANFZRIURDDQTL  
WALOEZYRGRHVLUNSAXLLPQDRWAFRYDUAGGRUWPOUIITIVZRH0IYXHI  
YKRZUZTBUGTASOXGELQNRSRDANSCCLSAIQUHPTUZUGUFITCCVPVTSR  
WEGCSXPIWTXLPNWIELZVZUOIGEUBVUVNWGMIAOEDYEGDHVOZTTBOSQ  
MECICSUGCNVPXYDTPGVDAHTUYQLRSIVYHEWSVLICHZBTVVNAURNRAV  
NRNDSKADBDANACLURWNRYTEVCAUPYAWZLLIVLWLHIEFWUAZLQYXMS  
IKIULUZQGUCAYVQOGUVVEBPLLGFYVPXLZSWOMZUMSQRICXEYWURYIV  
PNKOYMUVCCLGOAYDEGLNDVXPGFUTGTALKNYPTWIELLAACNHPZTNZUXY  
NTUUNAUAKVLUUCLFWHIUTITLNP SOAWALUEZSQTTCNL SLWXCONIYAZI  
XGDRAVGKGDWPSLIFTWTUOVIVUTUKAFZITUUSYNYMMTZTVVHEKDDRR  
VSSYTTYAWIXLSINIDRTWUFONVKVAZUCGDTQSGSTZTFLGSRAAMQYDUT  
DWANLETAZLXGQQTPENIFLOIYYHODTDTLAGLACPRGYDMNZLNLIKGGYY  
PVNTWHNNATVXCLQAATTXCLTFZNIUULEIOUQINTXHNNUKLQ

## Unit 82

### Trifid cipher

The *trifid cipher* is a generalization of the bifid cipher to three dimensions. Yes, Félix Delastelle invented it, too. Instead of the Polybius square, a mixed alphabet is placed in a  $3 \times 3 \times 3$  cube. Breaking the plaintext into blocks of equal length is the same, and period zero means the whole text is one block, but the fractionation is done with three base-3 coordinates. Since we have 27 spaces in the cube, we do not need to drop any letters, and need to add one. The new character can be space or some item of punctuation.

Here is an example. Suppose we want to encipher this message with keyword **KEYWORD** and period eleven.

THIS MESSAGE WAS ENCRYPTED WITH A GRID CIPHER

The mixed alphabet can be **KEYWORDABCFGHIJLMNPQSTUVXZ\_**, and we can put it in a cube so:

	0			1			2		
	0	1	2	0	1	2	0	1	2
0	K	E	Y	C	F	G	P	Q	S
1	W	O	R	H	I	J	T	U	V
2	D	A	B	L	M	N	X	Z	

The coordinates of a letter are the layer number, the row number, and the column number. So ‘G’ has coordinates 1, 0, 2. We divide the plaintext into eleven-letter blocks, and write the coordinates under each letter.

```
THISMESSAGE WASENCRYPTED WITH A GRID CIPHER
21121022010 00201100220 00121010101 12100
11102000200 12002010010 21111201120 10101
00121122121 01212022001 00100122100 10012
```

The coordinates under the first block are read out by rows and broken into sets of three. Each triplet is remapped to a letter in the cube.

```
211 210 220 101 110 200 020 000 121 122 121
U   T   X   F   H   P   D   K   M   N   M
```

The full ciphertext is

UTXFHPDKMNMYYOYQPQEEVBEETFRILJKCNCMEWHR

## Reading and references

Félix-Marie Delastelle, *Traité Élémentaire de Cryptographie*. Paris: Gauthier-Villars, 1902, [archive.org/details/8VSUP3207b](https://archive.org/details/8VSUP3207b)

Helen Fouché Gaines, *Cryptanalysis: a study of ciphers and their solution*, New York: Dover, 1956; previously titled *Elementary Cryptanalysis* and published by American Photographic in 1939; [archive.org/details/cryptanalysis00gain](https://archive.org/details/cryptanalysis00gain); pages 210-211.

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Practical Cryptography, [practicalcryptography.com/ciphers/trifid-cipher](http://practicalcryptography.com/ciphers/trifid-cipher)

## Programming tasks

1. Implement an encryptor.
2. Implement a decryptor.
3. Write a function to take a ciphertext and try to find the period. It can be the same as the function you wrote for the bifid cipher.
4. Implement a dictionary attack. There are many ways to place a mixed alphabet into the cube; just use the simplest one.
5. Implement a hill-climbing attack. The modifications to the cube that you need to consider are swapping two element, swapping two planes in any of three directions, and flipping in any of three directions (up-down, right-left, front-back). Feel free to make a modified copy of your attack on the bifid cipher. For the fitness function, you may want to strip out any of the 27<sup>th</sup> character in plaintext. The margin of error for stepping downward should be variable, and about 5% of the fitness.

## Exercises

1. Encipher this text with keyword FAIRY and period 8.

The children who read fairy books, or have fairy books read to them, do not read prefaces, and the parents, aunts, uncles, and cousins, who give fairy books to their daughters, nieces, and cousins, leave prefaces unread. For whom, then, are prefaces written?

(from *The Orange Fairy Book* by Andrew Lang)

2. Encipher the text from Exercise 1 with period zero.
3. Decipher this text with keyword VIRTUE and period 5.

TPHVXTTZXYSK\_FAAGJVRIIDN\_VRDVEVZJFPDFBIPIN\_AYII\_RIKEVW  
BYKKVPDPFGDIONZITBSCOFRMQOHXIAFVDHCXSV\_IQTBHLSVMEQDQIU  
WAHXIAFVDHCXWTPPAAWDSGSBHDSVMEQDVRAKRUCOGTDTUEZBDALKRR

4. Decipher this text with keyword CIRCLE and period zero.

VEDGTIACIGQLVCCCYOAJGCRPCNVRLTDLYOAJPCFGBJVJMGCORGBJLL  
SDCTBEWDOAHMZLQCKMGIGMLTSGIJJICIGKNIGMLTUINCEIGEC\_QHKS  
EIHQTJCKEEGVEOIFPHURNTSAIMPYZMAIHNMWWMJWNMPYZHKPNMMEPK  
MJIZNMMFOXWPMK

5. Find the period (not so easy) of this ciphertext and break it with a dictionary attack.

NMINDWATDAOAEAPYHH\_IMALEWTJUPNP\_QUKFNUAPGNERKEIK\_KPEX  
GWFLV\_SGTHHN\_CRGYGGZPMDPYKGDTBIUIMAGHNNJOFHVEEDIMKPNHN  
N\_CQTABYWQUJWMIWHJPTNVTCQGFPGDJCAQADEKLQIYFXLWFHPNLCGB  
LPJJCENIRJPLVP\_HPADLPGEFHMNBHANZLQUSIPCGIEAHCBKMPTNVTC  
QGFSGPJCHAUKAGTGPNIEOVNIZBPIEQDDDLVLCGAD00WLCDRSKDZNACE  
YHQWGNYTDBTZISEOLJIRR\_LXGBQRIZUPPDWASMZXPPEBEBZJAXIHUP  
XPSHSBABNZFERLIJHCENBFJPLYGTXYVOIZBYFPLNDCBTIMTUSKSLG  
WONVAPTMGEFFUKBICSIHIFVPPRCHUWXBKHIE00YQNISHS\_JUKJPRDP  
WVPYHPEDOIWLUUKEXASDUETZJPXINKJIBPBHIFVGPXCKAFIIPUXDHE  
YABHNSKADTMPQCAYEJSPAPJ

6. Find the period of this ciphertext and break it with a hill-climbing attack. What is the keyword?

RUPHNRDTHBYKTTTRTQUXCAKYINADHLHT\_BXOQRLWZNBZHZOMSVAFYWR  
SDFYEIEIRNHSSUGTXNMNAFHMQTETDBTYPMHDIJYKZHBKEQOFMYJ\_TH  
YUGQEXUAG\_WYYUPYCANTFTFDF\_DSKATHOPDNRKMPRICTOOFHIPAIRU  
IAYIOYPFOQZ\_S\_RGFPEVUCSYAHAXWXPNGMHQBKVACI\_DBDCBJQATT  
CUTODHIKMGQHQPQXAHA\_TMEUJOIHNKT\_HBYKTPRQRYYLJPEKEOUSZH  
SWDOTIDMMDLAFTUXI\_RFFPLCUTLPMDNNWCARHVMAERURHMPDVVGA  
SDZRRVUKHDDJJOJQOVTSBMPFNUYHAZFKH\_Z\_EIASHXSSSAUGSXPSFI  
ERENHZWYYYYXUDSAQXX\_X\_FEEDQDIQOQOBDENPODWJHHNJUTCOANXT  
AZIVPIT\_YDJTCNTPGYAXHZUSQRHVMAERGB0IPILCDQPDPNXEQQOAH  
K\_CKNHRBTZYWPYPKNMCFYHNJM\_DEPFSAKSCTCQAPXTHHRRVP\_INRXP  
RH\_SSVFYHDNMDBGHQ\_RSKKJHINI\_AMQMAPDKLGOAYYWZJYKPFK\_FQA



DUGIETADUGFBAXHQLXQY\_TUEFIH\_RLGEBIFQFLBHWNFLOXYSTLHUXI  
CFVISOJKITNYYZTTYBHHSUQDRREBH\_\_NQQFVKRPDPYBPQFKTCIJIPH  
MWUTCYHDETFJQN0UBIPARJV00TGACPKPUEBPHSHSRTOQBKXZZXSYKL  
KDAPEYWYGRTEISIIYMRSIILBAOQSYLUDYIYWMTCJVD0AHTSX0KUDCC  
YHY\_WDQEOXSRXTVYIIIEH\_\_TDBQHMTDSHDPVKWAA0WVQORJKK0HDIIX  
POCQCXTRDYQPFNIKKPARJTU0FOCRLUXESZXHADINCGYAZQZSBRHEPL  
WISCAYYKRQNNPHPNQXE0FSIHFJVU0ETL

## Unit 83

### ADFGX cipher

The *ADFGX cipher* is a Polybius cipher with row and column labels A, D, F, G, X followed by a columnar transposition which may be keyed with a keyword. Decipherment must be done in reverse order. The choice of the labels A, D, F, G, X is due to their low likelihood of being mistaken when transmitted in Morse code.

Some use a variation in which the transposition stage is a permutation cipher rather than a columnar transposition.

One way to attack the ADFGX cipher is to modify the hill-climbing attack on the columnar transposition cipher. However, since we do not know the contents of the Polybius square in advance, we cannot use tetragram fitness. Therefore, we use the index of coincidence as the function that we wish to maximize. For each permutation that we try, we decipher the ciphertext with a grid containing ABCDEFGHIJKLMNOPQRSTUVWXYZ and evaluate the IoC. If we can maximize the IoC at a value resembling the IoC of English, then what remains is a monoalphabetic substitution, and we can use the attack from Unit 28. For permutations of length greater than five, there is a complication: There may be more than one permutation that gives the same maximum IoC. In that case, we will have to try several candidate permutations until we find the right one.

### Reading and references

Practical Cryptography, [practicalcryptography.com/ciphers/adfgx-cipher](https://practicalcryptography.com/ciphers/adfgx-cipher)

David Kahn, *The Codebreakers: The Story of Secret Writing*, New York: Simon & Schuster, 1967, revised and updated 1996, pages 339-344.

### Programming tasks

1. Implement an encryptor.
2. Implement a decryptor.
3. Implement the attack described above.

## Exercises

1. Encipher this text with the keywords PINK for the square and FLOYD for the transposition.

It's been three months of lockdown. Please, someone send vegan brownies to Old Pink, in care of the Funny Farm, England.

2. Decipher this text with the keywords FRANCE for the square and PRUSSIA for the transposition.

AFAAGAGGFGADFXFFGFAGFDAAFFFGAGAAFXAFDXFAAAGFGAFGDXGFF  
FXFAAGAGXXGAAXAAAFDXGXFFFGXXDDFGGFFXFDAAGFGDGXXFDADADA  
ADGAGDGADADADAGGDDFAGGAAGDGXDDADDDDFDDDDFXDGFGDAXAFFG  
GADFXADDDAGFFAAGAFGDGDAFDGADAAAGXAAAGAGGGFGDDAFAAFDGDF  
DADFFDAFADAGDFFDFDFFDXAGFFAAGGXAADFAADDFFAGDFFAFGGXAGG  
XFGFXDGXGGFGGAADXDDGAFXADGAAGXFFFDGGAAXDXXFFAFGXAGDGGF  
AGDDFFGXAAFFAGXAAAXDFFGAFXDGXXXAAAAXFGGDDAGAXFGAXDXAG  
FGAAFGFGXFFAGADFADDGAAFDGXXGFAFDGFGDXGDDFFDAFDADAAAAGF  
DFDFDDFAGADDFGFGAADFXAFGGXXDGGDGGFDD

3. Break this ciphertext. What are the keywords?

DXGAGFDAAAXAAAADAFADAAGFDADGAAAGFAGADAGFDGAGFGAGAAADAA  
GDAGADADFFADDDDAXDAFFGDDDXADAAGAGFXDADXFDAADAGDAFAAFAD  
AGFFFDADADAGXAADDFAAAAGXGFGDGGDAFDXDDGDFDDDAFFDAGA  
AGDXADAAXDADFDXDADGGFDFDAGGXGDGXGDDGXGDDAGDFFXFFDFXGDG  
DFDXGDFFDFAFGAFGFFXGDGDFFXGXFXFFFGXFDGXFFXGDDFFAXAGGX  
DXDDGGFGGAGGADAXDGDXDFFFDGDAXFDXGXGDFXGGDFDGDXXFXGX  
DGGDDXGADFFDAGFXDGFDAXDXDAGFFGXADGFGXXDFDGDGFFDXGDF  
FXFFGAFDXXDGGGFADFFXFFDGFGXDGXXXFGDGGDDFGAGDFFDAXDFF  
AGDAFXADGAGDXADGXFGGXDAFFFXGAXGGDGGFGXXXGADGGFAAGAGFD  
GGGDAXXXDDGXAGDDGDXXAGDFFGFGFDGXXXFDXAFGFFDDXFFFDGFGGG  
XADFFXFXXGGGDXXFDGDDGFGFGXXFAAADADFAXXGDADDAAGDDDXAAG  
AFDAAADXGAGDADFDXAAADDFFGAXDDDAGFDXDXAGXFFAAGAGDADDA  
GADADDDDDAAGFFADGFAAFADDDGFDDDDAAGADAGDDAGFDFAADDXADDA  
AAFDAAGAADDAAGAGDFGAADFADAXGDGDAGAFFDAAADDAFXFGAAAAAGF  
DADDXDXFXFXGDXXFXDFAGXDXFFDDXXFGFGXGXGFXADGXGXDXDXDAX  
FDAGXFFFXGDFDDAXAFGADFGDGDGFDXDXDGDFFGDAGDFFGFGGDXXFDX  
FXDADGDFXXXFXDAXFFGGGFGXDDGDFFFDDFXDDADGDDGXGDXXFXGFD  
FGGGDFFXXDGFDDGAFFDDXGXFFXADAGADAFXDFFDAAADFADAGADDAX  
XGAAXDADADADFDADGDFGFAAADGAADDFAADADDDADGFDAAAADADAA  
GXDGDAADAAFAFXDAAADDDGAAAGDDDDGFGDDFAADXAAAADAADDXDAGAG  
ADDAGDFAFGAAFFGXAAAAGXAAXGGXXGAAGGXDAFFGADDDDDAAXADXA  
AA

4. Break this ciphertext. What are the keywords?

AAAFXAFFGAAXDDGGAAAXDGGFGDAAGADAGGDFDDFGAFGDGADDDGAFXG  
DAFXDAXDFADADAFFGGDFGAGFGADFAFFAXAFAXFAXFAGAXDAFFXXAGX  
GFDFGDDDXAXXAXAXFAFXFXXGDXXAFFADFFFFAAFAFAXADXAXGGGAFXDF  
FDFDDGGGDADDGGADAAADFFGGXAAAFGADFDXGDAGDADGFFFFGAAGDGDF  
DDFDXFGAGDADDGDGFDDAAAAGFFAGAFGDFGAXFGDDAGGFDAFDGDDAFA  
DDGGAXFGDGGDXAADDGFFGDAGAGGAAGDAFFDGFAGDDAGGAFGDDDFGAA  
GGAGDFXGDFFDAXFDXAGFAXAXXDAFXXADXDAXFADGXADDADGAGFXDX  
XXXAXFXAXFFXFAGDXADGAAGFGAXXXGDGADGFAAGFADXGAXAGFDFAAF  
AFXAADFGXAXGFXFDADGAAXDXFGXAADGGAGGDXFXAXFAXFADFXXXDA  
DGD FXDAGGGDDDXGAGAFGGDDGAXAXAAF GFAGDXADGGDXDFDXGXDFAGA  
XFDGFXDADXXFDDAFAXXXDXAXFAGGGGF AFDDXDFGFAGDAFADDGXXDFA  
AAADAGDAFGAFXDXGGFGGGFFDDADAAGFGGGAGDGAGFGFDAGFDADDADA

## Unit 84

### ADFGVX cipher

The *ADFGVX cipher* is the extension of the ADFGX cipher by using a 6×6 Polybius square. Because the square has 36 places, it holds the full English alphabet and all ten digits. The choice of the labels A, D, F, G, V, X is due to their low likelihood of being mistaken when transmitted in Morse code.

Some use a variation in which the transposition stage is a permutation cipher.

An approach to breaking the ADFGVX is to look for a columnar permutation that results in the fewest distinct digrams. We are looking for a decryption with mostly letters and few or none of the digits. After the transposition, the Polybius cipher is broken as usual, if possible.

Another approach to breaking the cipher is to extend the attack on the ADFGX to use 36-character alphabets and a 6×6 Polybius square.

### Reading and references

Practical Cryptography, [practicalcryptography.com/ciphers/adfgvx-cipher](https://practicalcryptography.com/ciphers/adfgvx-cipher)

General Solution for the ADFGVX Cipher System, Washington D.C.: U.S. Government Printing Office, 1934, [www.nsa.gov/Portals/70/documents/news-features/declassified-documents/friedman-documents/publications/FOLDER\\_269/41784769082379.pdf](https://www.nsa.gov/Portals/70/documents/news-features/declassified-documents/friedman-documents/publications/FOLDER_269/41784769082379.pdf), [archive.org/details/41784769082379](https://archive.org/details/41784769082379)

David Kahn, *The Codebreakers: The Story of Secret Writing*, New York: Simon & Schuster, 1967, revised and updated 1996, pages 339-346.

### Programming tasks

1. Implement an encryptor.
2. Implement a decryptor.
3. Implement the first attack described above. The length of the permutation is an input.

4. Implement the second attack described above. The length of the permutation is an input. As a subproject, implement the attack from Unit 28 for an alphabet of 36 characters. In calculating the fitness, it is acceptable to delete digits from the text.

## Exercises

1. Encipher this text with the keywords **WEATHER** for the square and **PICNIC** for the transposition (remove repeated letters in the keywords).

To give a picnic party a fair chance of success, it must be almost impromptu: projected at twelve o'clock at night at the earliest, executed at twelve o'clock on the following day at the latest; and even then the odds are fearfully against it. The climate of England is not remarkable for knowing its own mind; nor is the weather "so fixed in its resolve" but that a bright August moon, suspended in a clear sky, may be lady-usher to a morn of fog, sleet, and drizzle.

from "The Picnic Party" by Horace Smith

2. Decipher this text with the keywords **MUNCHKINS** for the square and **CYCLONE** for the transposition (remove repeated letters in the keywords).

DGDADVAADDDDDGGDFVDGDVFGDGDFFADDADGDDGDDDAGDADAGDDDDDD  
GADFFGADGDDDGADAFFGDAAFAGGDAGAADAGDDFGDFDDADDGDAGFDGFG  
GADGFFDDADGFAAFDAFDFGFGFFGAFADAAFDGGGDGDDFDDFADFADG  
ADXDFFGDGVVFGXFADVFXGFFXAXVAFGXVFAFVFFVGGXDFVXVVVXX  
FVXVGVFXDFVAXVAVDGVVAFFFAVFVXDFGDDDVXDAXFFAGXFVAVGVDX  
FXVVXFDVGVVFFDXDFVFFVDXFXDFFAFDXFGXFDXXADVDDVDVDFVAD  
VDDADGDDDFDADADGADFGAADADFAFDAAADDAGDGGFADGGADDDGDGGDF  
ADGFGDFDFDFGAAADDDVGADFDGDAGADDFFAFDGGFAGAAADAAGGDFFA  
ADFFDDDFAGDDGFDDDDADDDDFADFDFDGFADGDFDFAADDFADDADDGDAG  
FFDDGDDADDAFADAGDDFGADFDFAADFADGGDAGDDADDAADGGAFDAA  
AFDAFFAAGDGAADFDDDDDFDVGADDDDAFDDGGFGDDAGDDGADADDADFF  
DFDGDFAFAGADDGAGGGDGFAGDGDGDGDDVDVDDFADADDVFGFFGDFGGG  
DFDADDVFVXVFVDDXFXDVAVFVFGFAVVVGDAVFGFDDVFFAXDFVGFFVVV  
FVXFFFVFDGAGVAVDGFFVXAFADVFXVFXVFDVFFVFFDVVDVDVXAFFVV  
AVFVAGVDDFAADVFFVFXDXFVXVXVAGADXDFAFVVVVVVXDXVFXFXF  
XFDGDDXVDVFXAVXDVFDFXFFVAVFXADFDFVXDVXXDFFDXDVXFVDXVV  
FDFFFVVFDAVGFFFXFFVFXVAGVFDDFVGFFXDVFAAFVAFAGDDDDFFAF  
XFVVAFGFDAXDDVXXFAFVVVGFFXVVFVGFGGGVAXFFVXGFDDXDAGDFG  
DFVVDXDAFVF

3. Break this ciphertext. The transposition has length nine. What are the keywords?

GFAADFVAGDXFVAADFADGDDFAADAXAVDAADAGAAADAXDAVGAVFDAGFVA  
XDDDGDXGDAGAFVXDFAAAGXDFDADFVFFADAAGVDADXAXFAAVADA  
XDADFDDFXFFADFVADAAGAAAGAFGVFGVDAAGDAAXDFAAADAAGVGAG  
AAADVFXDDFADGDAAAAGGDDFAAAAFVDXDAGXGDAAVGA AVADDXDAAF

VDGADDFGAGVFVDXAGDVDAAGGXAAAFVDGFDGFGADGADDAFFDGGXAAG  
FGGFDAADFDAADGAAFDGGGXAFDGAFAFFFDGADAGGDFDGXAFADAAA  
GAADXAVFXDGFVAGDDAVAXFAAXDXGDDVGGGVFXDADDAFDVFDVDDVDGDDA  
GAXDVAGAAGVFAAVDVDDAVDAFGDFDXAAAAAADAAAFADAGAFGADADDD  
XGDDXAAGXADAXAAFAAXGDAVDGGAFAFFDAAADAXFGFADXFDDAAGFXG  
DFDGFFAGGAAGXAAGXAVADDGDXFGGAADDGAGDAGDAXAVDAGAADXDAV  
GVAADDFVAGDADXGXDAAXDAFADAAAAAXGFFDDXAVAVFADADDAADAA  
AGAFDVGXFAFXGXFAGXAXADVADFXAXAVDVGVFGAXGGGFFGAADXAVAA  
AFDGGXDGVFDGDxDAAFAAFXFGAAFAFDAAAAFAAXAADGGXAXAAGVDA  
AADADADVADAXDFGXAGGFDFVGGDAXAADXAXAAAGAVAGDGFAXAADFFA  
AVDADAGADA AVAXFFDADAAAAXFAFVAFDXFADVDGDGAADXAA