Cryptography: Overview and Classical Ciphers

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- **Cryptanalysis**: Breaking the disguise.
- **Cryptology**: Study of secret codes and ciphers.

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- Mobile phones, DVD players, pay-TV decoders, game consoles, car keys, burglar alarms.

Intended content

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- Symmetric (secret) keys

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- **Brute force attack**: Try every possible key.

Kerchoff's Principle

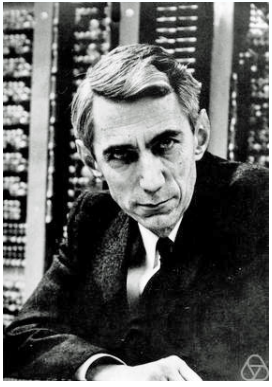
"It must not be required to be secret, and it must be able to fall into the hands of the enemy without inconvenience."

— **Auguste Kerckhoffs**, 1883

Shannon's Maxim

"The enemy knows the system."

— **Claude Shannon**, 1916-2001



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- Caesar Cipher
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Modern ciphers:

- Symmetric key and Public key
- Symmetric Key (Secret Key): DES and AES (Rijndael)
- Public Key: RSA named after its inventors Rivest, Shamir and Adleman.

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- 'Fiberglass thermostats melt cheese'

Classical ciphers: Rail Fence

m		t		e		a		i		a	
	a		h		m		t		c		l

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	a		h		m		t		c		l

- We generate the ciphertext by reading the top rail first, followed by the second rail.
- For the plaintext '`mathematical`', this would generate the ciphertext '`MTEAIAAHMTCL`'.

Classical ciphers: Rail Fence

- We can also increase the number of rails in the cipher. For example, with three rails, the word 'mathematical' becomes 'MEIAHMTCLTAA'.

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- Rail ciphers are quite similar to another type of transposition cipher, called a Scytale cipher.

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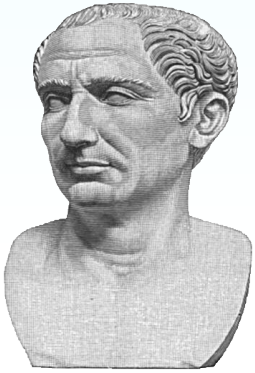
- During the Gallic Wars secrecy was vital, so Caesar wanted to disguise written messages and devised a Shift Cipher.

Classical ciphers: Caesar's Cipher



- The plain alphabet is written above the cipher alphabet but shifted by a number of places.
- The original Caesar cipher was shifted by 3 places, as shown below.

plaintext	a	b	c	d	e	f	g	h	i	j	k	l	m
ciphertext	D	E	F	G	H	I	J	K	L	M	N	O	P
plaintext	n	o	p	q	r	s	t	u	v	w	x	y	z
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- Using a shift of 3, encrypt the plaintext `invasion`.

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- We read off each of the letters in turn from the table to create the ciphertext:

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- We read off each of the letters in turn from the table to create the ciphertext: `L`

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plaintext	a	b	c	d	e	f	g	h	i	j	k	l	m
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ciphertext	Q	R	S	T	U	V	W	X	Y	Z	A	B	C

- Using a shift of 3, encrypt the plaintext `invasion`.
- We read off each of the letters in turn from the table to create the ciphertext: `LQ`

Classical ciphers: Caesar's Cipher

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

- Using a shift of 3, encrypt the plaintext `invasion`.
- We read off each of the letters in turn from the table to create the ciphertext: `LQY`

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plaintext	a	b	c	d	e	f	g	h	i	j	k	l	m
ciphertext	D	E	F	G	H	I	J	K	L	M	N	O	P
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- There are 25 possible keys for this cipher (different shift values).

Caesar's Cipher: Modular Arithmetic

- We can see the Caesar cipher as a simple application of modular arithmetic.

a	b	c	d	e	f	g	h	i	j	k	l	m
0	1	2	3	4	5	6	7	8	9	10	11	12
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- The use of mod 26 is what allows the shift to 'wrap around' when it gets to Z.

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0	1	2	3	4	5	6	7	8	9	10	11	12
n	o	p	q	r	s	t	u	v	w	x	y	z
13	14	15	16	17	18	19	20	21	22	23	24	25

- The cipher relies on a shift number k, which acts as the key.
- This shift k is an element of the set $\{1, 2, 3, 4, \ldots, 25\}$.
- If α represents the corresponding number from the table above of a single letter in our message, then the encryption function is given by

$$E(\alpha, k) = \alpha + k \mod 26.$$

- The use of mod 26 is what allows the shift to 'wrap around' when it gets to Z.
- Julius Caesar's version of the cipher had a shift value of $k = 3$. Obviously, a trivial shift value of $k = 0$ won't be very effective!

Caesar's Cipher: Modular Arithmetic

- We can see the Caesar cipher as a simple application of modular arithmetic.

a	b	c	d	e	f	g	h	i	j	k	l	m
0	1	2	3	4	5	6	7	8	9	10	11	12
n	o	p	q	r	s	t	u	v	w	x	y	z
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- Julius Caesar's version of the cipher had a shift value of $k = 3$. Obviously, a trivial shift value of $k = 0$ won't be very effective!
- The decryption key works in much the same way but using subtraction.

Classical ciphers: Substitution Ciphers

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- E.g., using `ALEXANDER` as the key we first remove any repeated letters: `ALEXNDR`. And then fill in the rest of the alphabet in order following `R`.
- This reduces the number of keys, but makes the cipher more practical to implement. It can also lead to letters being insecurely encrypted, e.g., 'a' as 'A'.

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

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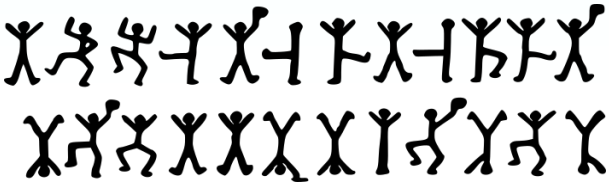

- The men with the flags represent the ends of words and this deciphers to: `Elsie prepare to meet thy god`.
- Even using symbols doesn't make this method secure, as Mary Queen of Scots found out as part of the Babington Plot. Similarly, Anne Lister's diaries were eventually decoded after being discovered by a distant relative.

Frequency Analysis

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- It is also much easier if the spaces are kept between words.

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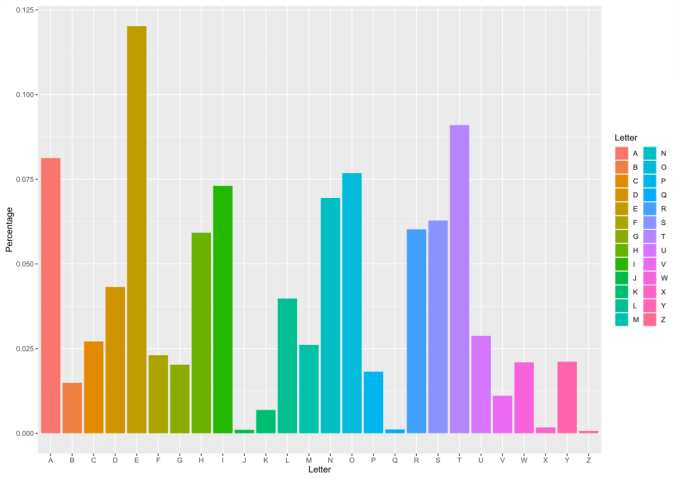

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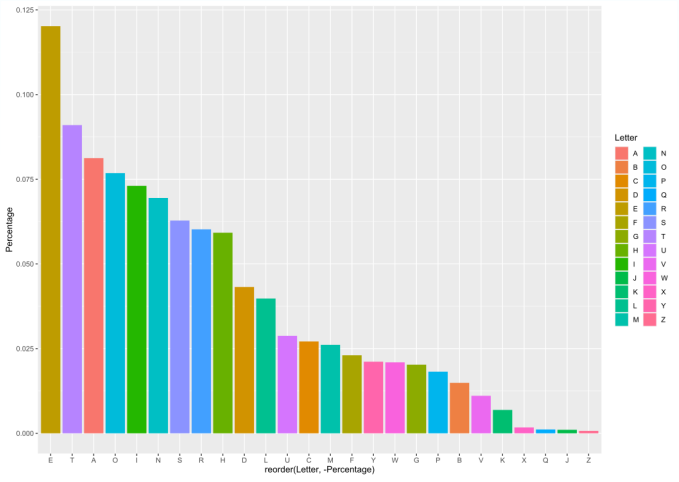

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- If spaces are left in it becomes easier to identify the small words.

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- Initial letters: `t`, `o`, `a`, `w`, `b`, `c`, `d`.
- Final letters: `e`, `s`, `t`, `d`, `d`, `n`, `r`, `y`.

Frequency Analysis: An Example

- Below are 655 characters of ciphertext encrypted using a substitution cipher. Spaces are left in to make it slightly easier to decrypt.

```
TKNKQBX GCUHT CJ QBH ICTPQ KY QBH ANHDQ FDJPDP LNDCNCHP VCQB SJRGH BHJNX VBK
VDP D YDNIHN DJT DSJQ HI VBK VDP QBH YDNIHNP VCYH QBHCN BKSPH VDP PIDGG YKN
QBH GSIOHN QK OSCGT CQ BDT QK OH RDNNCHT OX VDAKJ IDJX ICGHP QBHNH VHNH YKSN
VDGGP D YGKKN DJT D NKKY VBCRB IDTH KJH NKKI DJT QBCP NKKI RKJQDCJHT D NSPQX
GKKFCJA RKKFPQKUH D RSLOKDNT YKN QBH TCPBHP D QDOGH QBNHH KN YKSN RBDCNP DJT
QBH OHTP SJRGH BHJNX DJT DSJQ HI BDT D OCA OHT CJ KJH RKNJHN DJT TKNKQBX D
GCQQGH OHT CJ DJKQBHN RKNJHN QBHNH VDP JK ADNNHQ DQ DGG DJT JK RHGGDN HWRHLQ
D PIDGG BKGH TSA CJ QBH ANKSJT RDGGHT D RXRGKJH RHGGDN VBHNH QBH YDICGX
RKSGT AK CJ RDPH KJH KY QBKPH ANHDQ VBCNGVCJTP DNKPH ICABQX HJKSAB QK RNSPB
DJX OSCGTCJA CJ CQP LDQB CQ VDP NHDRBHT OX D QNDL TKKN CJ QBH ICTTGH KY QBH
YGKKN YNKI VBCRB D GDTTHN GHT TKVJ CJQK QBH PIDGG TDNF BKGH
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GCQQGH OHT CJ DJKQBHN RKNJHN QBHNH VDP JK ADNNHQ DQ DGG DJT JK RHGGDN HWRHLQ
D PIDGG BKGH TSA CJ QBH ANKSJT RDGGHT D RXRGKJH RHGGDN VBHNH QBH YDICGX
RKSGT AK CJ RDPH KJH KY QBKPH ANHDQ VBCNGVCJTP DNKPH ICABQX HJKSAB QK RNSPB
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VDP D YDNIeN DJT DSJQ eI VBK VDP QBe YDNIeNP VCYe QBeCN BKSPe VDP PIDGG YKN
QBe GSIOeN QK OSCGT CQ BDT QK Oe RDNNCeT OX VDAKJ IDJX ICGeP QBeNe VeNe YKSN
VDGGP D YGKKN DJT D NKKY VBCRB IDTe KJe NKKI DJT QBCP NKKI RKJQDCJeT D NSPQX
GKKFCJA RKKFPQKUe D RSLOKDNT YKN QBe TCPBeP D QDOGe QBNee KN YKSN RBDCNP DJT
QBe OeTP SJRGe BeJNX DJT DSJQ eI BDT D OCA OeT CJ KJe RKNJeN DJT TKNKQBX D
GCQQGe OeT CJ DJKQBeN RKNJeN QBeNe VDP JK ADNNeQ DQ DGG DJT JK ReGGDN eWReLQ
D PIDGG BKGe TSA CJ QBe ANKSJT RDGGeT D RXRGKJe ReGGDN VBeNe QBe YDICGX
RKSGT AK CJ RDPe KJe KY QBKPe ANeDQ VBCNGVCJTP DNKPe ICABQX eJKSAB QK RNSPB
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TKNKQBX GCUeT CJ QBe ICTPQ KY QBe ANeaQ FaJPaP LNaCNCeP VCQB SJRGe BeJNX VBK
VaP a YaNIeN aJT aSJQ eI VBK VaP QBe YaNIeNP VCYe QBeCN BKSPe VaP PIaGG YKN
QBe GSIOeN QK OSCGT CQ BaT QK Oe RaNNCeT OX VaAKJ IaJX ICGeP QBeNe VeNe YKSN
VaGGP a YGKKN aJT a NKKY VBCRB IaTe KJe NKKI aJT QBCP NKKI RKJQaCJeT a NSPQX
GKKFCJA RKKFPQKUe a RSLOKaNT YKN QBe TCPBeP a QaOGe QBNee KN YKSN RBaCNP aJT
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GCQQGe OeT CJ aJKQBeN RKNJeN QBeNe VaP JK AaNNeQ aQ aGG aJT JK ReGGaN eWReLQ
a PIaGG BKGe TSA CJ QBe ANKSJT RaGGeT a RXRGKJe ReGGaN VBeNe QBe YaICGX
RKSGT AK CJ RaPe KJe KY QBKPe ANeaQ VBCNGVCJTP aNKPe ICABQX eJKSAB QK RNSPB
aJX OSCGTCJA CJ CQP LaQB CQ VaP NeaRBeT OX a QNaL TKKN CJ QBe ICTTGe KY QBe
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TKNKthX GCUeT CJ the ICTPt KY the ANeat FaJPaP LNaCNCeP VCth SJRGe heJNX VhK
VaP a YaNIeN aJT aSJt eI VhK VaP the YaNIeNP VCYe theCN hKSPe VaP PIaGG YKN
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the OeTP SJRGe heJNX aJT aSJt eI haT a OCA OeT CJ KJe RKNJeN aJT TKNKthX a
GCttGe OeT CJ aJKtheN RKNJeN theNe VaP JK AaNNet at aGG aJT JK ReGGaN eWReLt
a PIaGG hKGe TSA CJ the ANKSJT RaGGeT a RXRGKJe ReGGaN VheNe the YaICGX
RKSGT AK CJ RaPe KJe KY thKPe ANeat VhCNGVCJTP aNKPe ICAhtX eJKSAh tK RNSPh
aJX OSCGTCJA CJ CtP Lath Ct VaP NeaRheT OX a tNaL TKKN CJ the ICTTGe KY the
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Frequency Analysis: An Example

dKNKthX GCUed Cn the ICdPt KY the ANeat FanPaP LNaCNCeP VCth SnRGe henNX VhK
VaP a YaNIeN and aSnt eI VhK VaP the YaNIeNP VCYe theCN hKSPe VaP PIaGG YKN
the GSIOeN tK OSCGd Ct had tK Oe RaNNCed OX VaAKn IanX ICGeP theNe VeNe YKSN
VaGGP a YGKKN and a NKKY VhCRh Iade Kne NKKI and thCP NKKI RKntaCned a NSPtX
GKKFCnA RKKFPtKUe a RSLOKaNd YKN the dCPheP a taOGe thNee KN YKSN RhaCNP and
the OedP SnRGe henNX and aSnt eI had a OCA Oed Cn Kne RKNneN and dKNKthX a
GCttGe Oed Cn anKtheN RKNneN theNe VaP nK AaNNet at aGG and nK ReGGaN eWReLt
a PIaGG hKGe dSA Cn the ANKSnd RaGGed a RXRGKne ReGGaN VheNe the YaICGX
RKSGd AK Cn RaPe Kne KY thKPe ANeat VhCNGVCndP aNKPe ICAhtX enKSAh tK RNSPh
anX OSCGdCnA Cn CtP Lath Ct VaP NeaRhed OX a tNaL dKKN Cn the ICddGe KY the
YGKKN YNKI VhCRh a GaddeN Ged dKVn CntK the PIaGG daNF hKGe

Frequency Analysis: An Example

dorothX GiUed in the IidPt oY the Areat FanPaP LrairieP Vith SncGe henrX Vho VaP a YarIer and aSnt eI Vho VaP the YarIerP ViYe their hoSPe VaP PIaGG Yor the GSIOer to OSiGd it had to Oe carried OX VaAon IanX IiGeP there Vere YoSr VaGGP a YGoor and a rooY Vhich Iade one rooI and thiP rooI contained a rSPtX GooFinA cooFPtoUe a cSLOoard Yor the diPheP a taOGe three or YoSr chairP and the OedP SncGe henrX and aSnt eI had a OiA Oed in one corner and dorothX a GittGe Oed in another corner there VaP no Aarret at aGG and no ceGGar eWceLt a PIaGG hoGe dSA in the AroSnd caGGed a cXcGone ceGGar Vhere the YaIiGX coSGd Ao in caPe one oY thoPe Areat VhirGVindP aroPe IiAhtX enoSAh to crSPh anX OSiGdinA in itP Lath it VaP reached OX a traL door in the IiddGe oY the YGoor YroI Vhich a Gadder Ged doVn into the PIaGG darF hoGe

Frequency Analysis: An Example

dorothy lived in the midst of the great kansas prairies with uncle henry who was a farmer and aunt em who was the farmers wife their house was small for the lumber to build it had to be carried by wagon many miles there were four walls a floor and a roof which made one room and this room contained a rusty looking cookstove a cupboard for the dishes a table three or four chairs and the beds uncle henry and aunt em had a big bed in one corner and dorothy a little bed in another corner there was no garret at all and no cellar except a small hole dug in the ground called a cyclone cellar where the family could go in case one of those great whirlwinds arose mighty enough to crush any building in its path it was reached by a trap door in the middle of the floor from which a ladder led down into the small dark hole

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- The problem is when a letter is replaced by another it remains the same throughout. E.g., if a = J, then it stays as a J.
- If we could use more than one alphabet, then a would not always end up as J.

Is there anything odd here...?

If Youth, throughout all history, had had a champion to stand up for it; to show a doubting world that a child can think; and, possibly, do it practically; you wouldn't constantly run across folks today who claim that ''a child don't know anything.'' A child's brain starts functioning at birth; and has, amongst its many infant convolutions, thousands of dormant atoms, into which God has put a mystic possibility for noticing an adult's act, and figuring out its purport.

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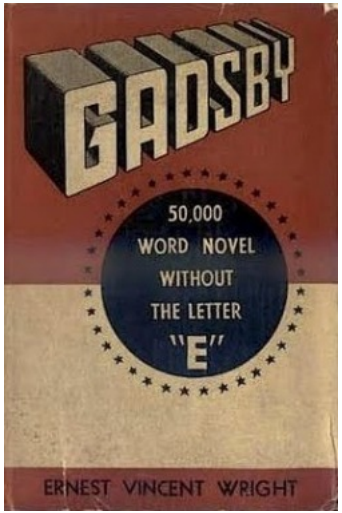

Tutorials

In the tutorial this week we will:

- Create a spreadsheet to perform encryption using a Caesar cipher.
- Create and use a spreadsheet to perform frequency analysis attacks on general substitution ciphers.