Lecture 13: Vigenère, Vernam, and DES

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+ key	TIG	ERTIG	ERTIG	ERT	IGERT	IGER	TIG	ERTI	GER
ciphertext	MPK	ULBKQ	FIHET	JFQ	RAQGL	WBII	MPK	PRSG	JSX

Attacking the Vigenère Cipher

- Kasiski: Look at distances between identical pieces of ciphertext.

Attacking the Vigenère Cipher

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- Idea: the key length probably divides this distance.

Example 10.2.3

A Vigenère cipher has been used on English source text which has removed punctuation and blanks. The following ciphertext was produced:

offset	ciphertext									
0	UPVZB	BVUPN	KKFOL	OGAKU	FBTKF	LFXUJ	VIPZV	KFZXO	FIDLO	ONLUP
50	KKFUZ	OMQFQ	MQXKU	AFIUP	VVVVK	KFDFL	DMFIU	PVVFI	ZVTMU	XDBZY
100	FVVYF	ZTHBA	ZQHEY	LTXVU	JVXFM	IDRSQ	EJNCI	PVZZQ	HQEYJ	BZQHB
150	YHTWL	OUWND	OLVUJ	VREZA	JHTWW	VPTZW	VLVDM	TROPV	XWIMN	KJBVE
200	FITKV	XRQEL	FZOBY	HSMND	TVFOJ	DZQHB	YLOOZ	QTQXK	UISLS	LNLUP
250	RESWB	HOEZQ	HERVC	MRWJV	XWIMR	LSISR	WMIHF	TZQHN	CXUBV	UJVXF
300	JZTOJ	VXGJA	REMMU	GPEEG	PEEWP	BYHXI	KHS			

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150	YHTWL	OUWND	OLVUJ	VREZA	JHTWW	VPTZW	VLVDM	TROPV	XWIMN	KJBVE
200	FITKV	XRQEL	FZOBY	HSMND	TVFOJ	DZQHB	YLOOZ	QTQXK	UISLS	LNLUP
250	RESWB	HOEZQ	HERVC	MRWJV	XWIMR	LSISR	WMIHF	TZQHN	CXUBV	UJVXF
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ℓ	submessage offsets	frequencies of letters in submessage sorted																								
2		F	V	U	Z	J	T	X	R	S	P	H	N	E	K	M	O	Y	D	I	B	C	L	W	G	A	Q
	0, 2, 4,...	19	16	12	12	11	10	9	8	8	7	6	6	5	5	5	5	5	4	4	3	2	2	2	1	0	0
		Q	V	L	B	I	O	E	K	W	H	M	Z	P	U	A	D	X	G	T	Y	F	J	N	R	C	S
	1, 3, 5, ...	14	14	13	10	10	10	9	9	9	8	8	7	6	6	5	5	5	3	3	3	2	2	2	2	1	0
4	0, 4, 8, ...	12	10	10	7	6	6	6	5	5	4	2	2	2	1	1	1	1	1	1	1	0	0	0	0	0	0
	1, 5, 9, ...	10	9	8	7	5	5	5	5	5	5	4	3	3	2	2	2	1	1	1	0	0	0	0	0	0	0
	2, 6, 10, ...	12	11	8	8	7	5	5	5	4	4	2	2	2	2	2	1	1	1	1	0	0	0	0	0	0	0
	3, 7, 11, ...	9	9	8	8	7	5	5	5	4	3	3	3	3	3	2	2	2	1	1	0	0	0	0	0	0	0

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	1, 3, 5, ...	14	14	13	10	10	10	9	9	9	8	8	7	6	6	5	5	5	3	3	3	2	2	2	2	1	0
4		F	J	U	P	H	S	T	M	O	V	B	D	I	C	E	G	N	W	X	Z	A	K	L	Q	R	Y
	0, 4, 8, ...	12	10	10	7	6	6	6	5	5	4	2	2	2	1	1	1	1	1	1	1	0	0	0	0	0	0
		B	V	M	I	A	E	L	P	Q	Z	W	0	T	D	N	X	C	J	U	F	G	H	K	R	S	Y
	1, 5, 9, ...	10	9	8	7	5	5	5	5	5	5	4	3	3	2	2	2	1	1	1	0	0	0	0	0	0	0
		V	Z	R	X	F	K	N	Y	E	T	D	I	L	S	U	B	C	J	W	A	G	H	M	O	P	Q
	2, 6, 10, ...	12	11	8	8	7	5	5	5	4	4	2	2	2	2	2	1	1	1	1	0	0	0	0	0	0	0
		K	Q	H	L	O	U	V	W	E	D	G	I	X	Y	F	R	Z	J	P	A	B	C	M	N	S	T
	3, 7, 11, ...	9	9	8	8	7	5	5	5	4	3	3	3	3	3	2	2	2	1	1	0	0	0	0	0	0	0

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4		F	J	U	P
	0, 4, 8, ...	12	10	10	7
		B	V	M	I
	1, 5, 9, ...	10	9	8	7
		V	Z	R	X
	2, 6, 10, ...	12	11	8	8
		K	Q	H	L
	3, 7, 11, ...	9	9	8	8

common ciphertext letters for $\ell = 4$

FJUP
BVMI
VZRX
KQHL

$(c - \text{`}e\text{'}) \mod 26$ →

corresponding key letters

BFQL
XRIE
RVNT
GMDH


44=256 attempts later...

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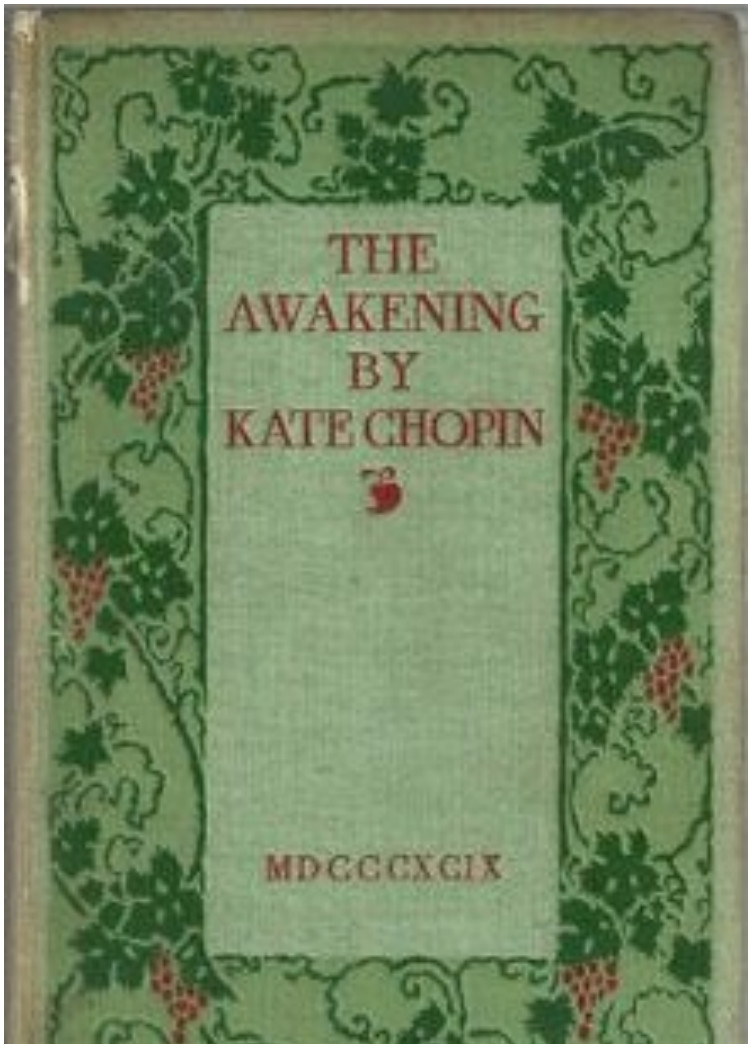
ciphertext	UPVZB	BVUPN	KKFOL	OGAKU	FBTKF	LFXUJ	VIPZV	KFZXO	FIDLO	ONLUP
+ key	BIRDB	IRDBI	RDBIR	DBIRD	BIRDB	IRDBI	RDBIR	DBIRD	BIRDB	IRDBI
plaintext	thewa	terof	thegu	lfstr	etche	doutb	efore	hergl	eamin	gwith

Source:



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If we use the alphabet $\mathcal{A} = \{0, 1\}$ like this, then the encryption and decryption functions operate on blocks of length 5.

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- Example: 1011+0100=1011$\oplus$0100 = 1111.

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- If each digit of k is chosen randomly with probability $1/2$, Vernam cipher is known as the *one-time pad*.
- Completely secure, but also completely impractical (how would you send secure messages to all your contacts?).

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Diffusion: spread the structure present in the plaintext so that a ciphertext depends on a lot of plaintext bits.

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&\vdots \qquad\qquad\qquad\qquad \vdots \\
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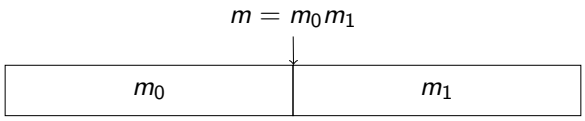
3. The interchange allows decryption to use the same form of the r rounds but with the subkeys in reverse order.

Feistel Network Diagram



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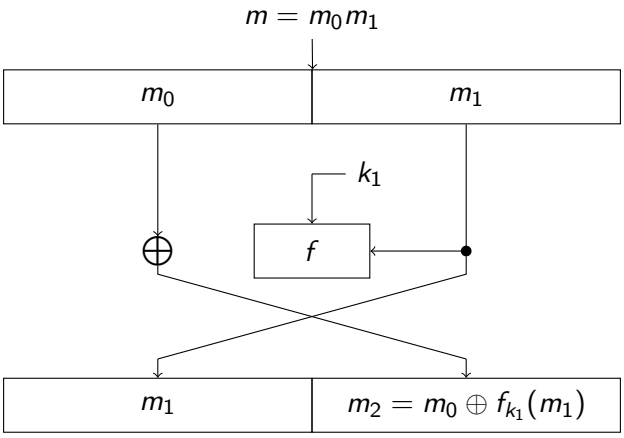

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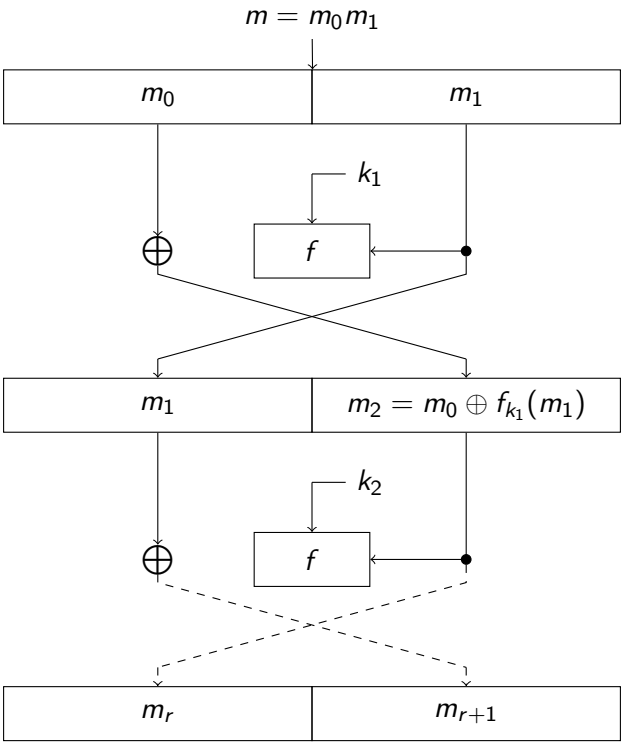

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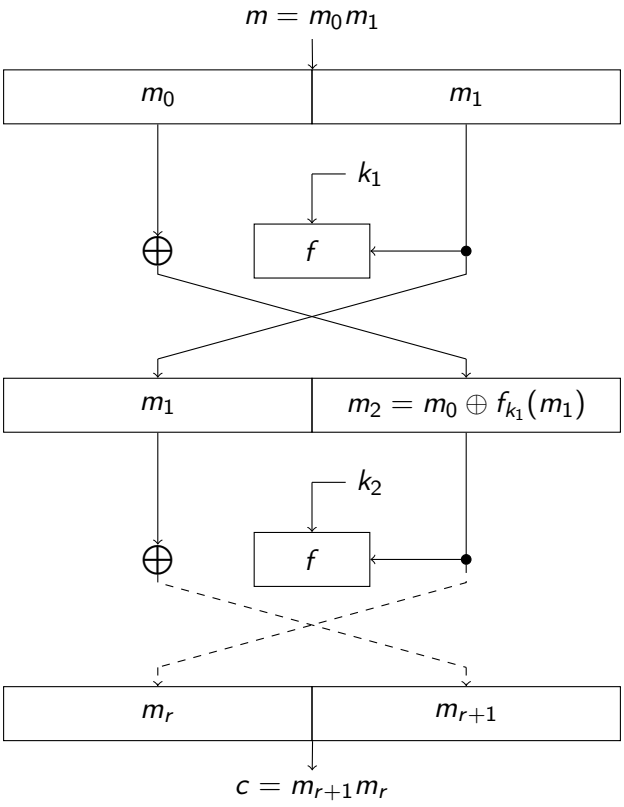

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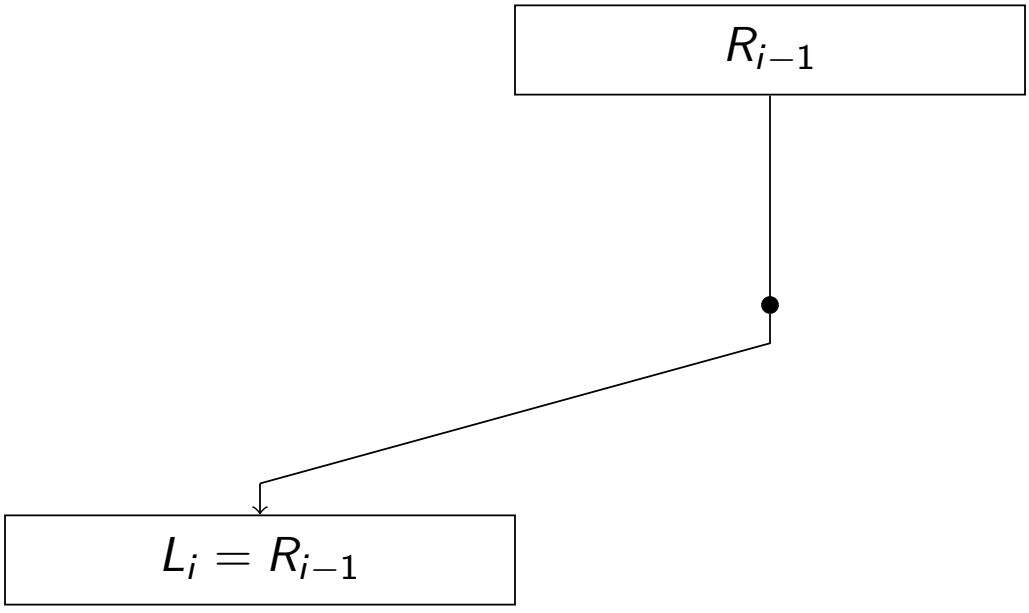

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Building blocks: for round i, given input $x = (L_{i-1}, R_{i-1})$ and round key k:

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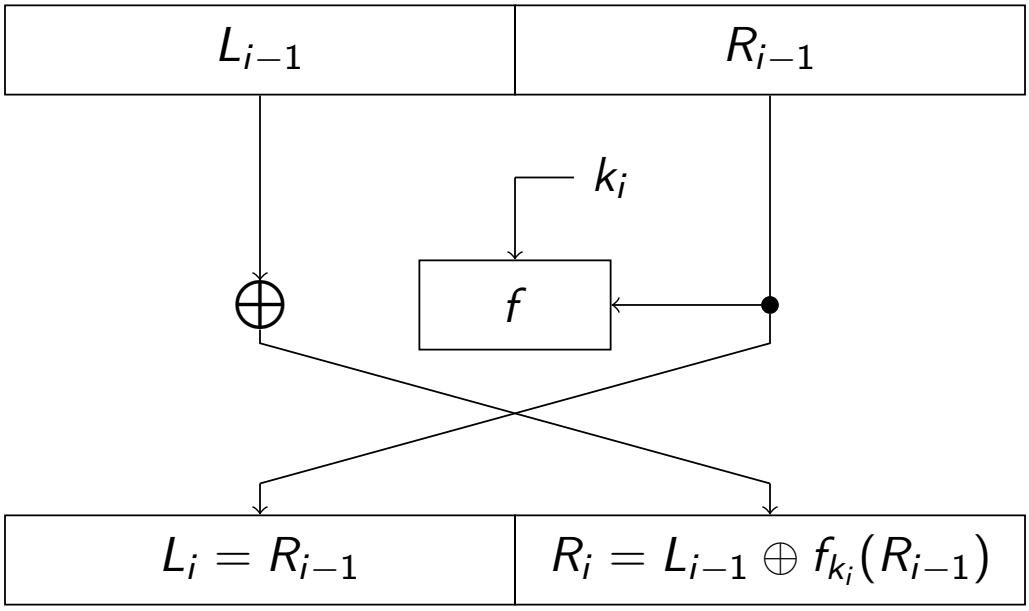

Feistel Networks (Simplified from book)

The basic algorithm for a Feistel Network with j rounds, cipher input $x = (L_0, R_0)$ and key k is:

1. Use k to calculate the **key schedule**: $k_1, k_2, \ldots k_j$. (In other words, calculate the keys that will be used in each round.)
2. For i $= 1$ to j:
   a. $L_i = R_{i-1}$
   b. $R_i = L_{i-1} \oplus f_i(R_{i-1})$
3. Return $x := (L_j, R_j)$

Feistel Networks (Simplified from book)

The basic algorithm for a Feistel Network with j rounds, cipher input $x = (L_0, R_0)$ and key k is:

1. Use k to calculate the **key schedule**: $k_1, k_2, \ldots k_j$. (In other words, calculate the keys that will be used in each round.)
2. For i = 1 to j:
   a. $L_i = R_{i-1}$
   b. $R_i = L_{i-1} \oplus f_i(R_{i-1})$
3. Return $x := (L_j, R_j)$

Since $R_{i-1} = L_i$ and $L_{i-1} = R_i \oplus f_i(R_{i-1})$, the Feistel network is always invertible.

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- FIPS approval for DES was withdrawn in 2005 primarily because of short key length.
- Principles employed by DES are still used in the current encryption standards (e.g. AES and Triple-DES)

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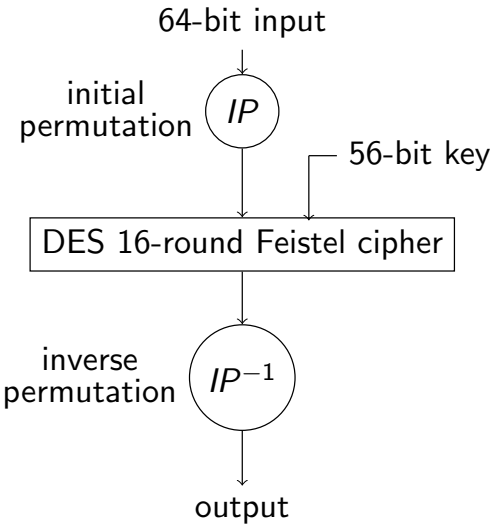
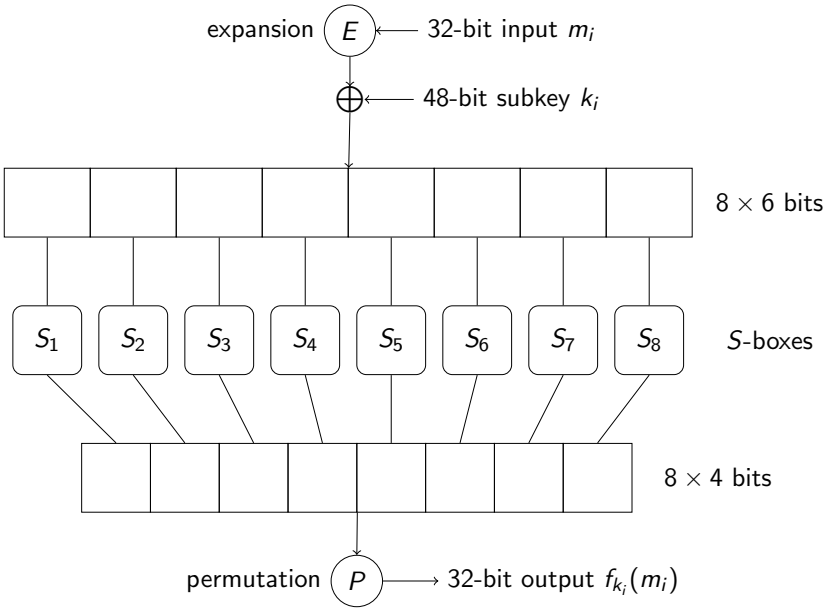
  - 32-bit input is expanded to 48 bits
  - "confusion" step results in 32-bit string

DES Schematics



(a) DES Structure



(b) Feistel inner function

Schematics for the DES

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