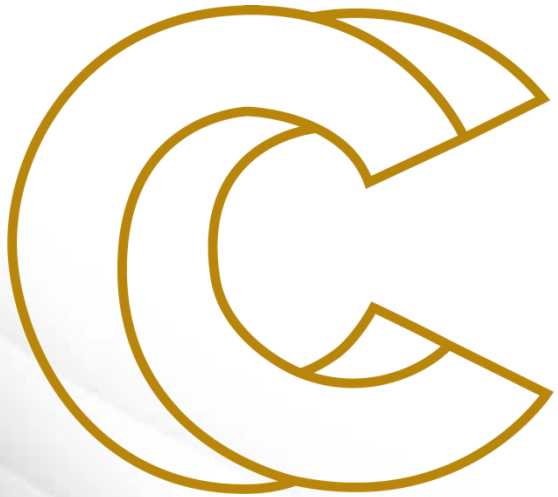

EURO^2

GPU Optimization of Advanced Encryption Standard

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Lesson 2: Advanced Encryption Standard

Data Encryption Standard (DES)

- Designed by IBM in 1970s, based on an earlier design by Feistel.
- In 1976, NSA tweaked the algorithm by changing its S-boxes.
  - **Block Size:** 64 bits
  - **Key Length:** 56 bits
  - **Rounds:** 16
- Currently known as Data Encryption Algorithm (DEA) since it is no longer a standard.
- Became useless after 1990s since its short key is susceptible to brute force attacks.

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Short Keys

- An attacker that captures a single ciphertext, can try to decrypt it with every possible key to check if it provides a meaningful plaintext.
- Such an attack is called exhaustive search or brute force attack.
- Exhaustive search is a generic attack, i.e. valid for every cipher.
- For a **k**-bit keyed cipher, the attacker is required to perform at most $\mathbf{2^k}$ encryptions/decryptions.
- Thus, security of a block cipher is upper bounded by exhaustive search.

Lesson 2: Advanced Encryption Standard

Short Keys

2^{56} =	72,057,594,037,927,936
2^{80} =	1,208,925,819,614,629,174,706,176
2^{128} =	340,282,366,920,938,463,463,374,607,431,768,211,456
2^{192} =	6,277,101,735,386,680,763,835,789,423,207,666,416,102,355,444,464,034,512,896
2^{256} =	115,792,089,237,316,195,423,570,985,008,687,907,853,269,984,665,640,564,039,457,584,007,913,129,639,936

Lesson 2: Advanced Encryption Standard

Advanced Encryption Standard (AES)

- Rijndael is designed by Joan Daemen and Vincent Rijmen.
- Standardized in 2001 by NIST (winner of the AES competition) and named AES.
  - **Block Size:** 128 bits
  - **Key Length:** 128, 192, 256 bits
  - **Rounds:** 10, 12, 14 (depends on the key length)
  - **Type:** SPN
- Known attacks are ineffective.

Lesson 2: Advanced Encryption Standard

Advanced Encryption Standard (AES)

Byte ordering of AES

0	4	8	12
1	5	9	13
2	6	10	14
3	7	11	15

A byte can be treated in two ways when dealing with AES:

1. A byte can be viewed as a string of 8 bits
2. A byte can be viewed as an element of Galois Field GF(2^8)

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Arithmetic in *GF(2^8)*

- AES uses the Galois Field defined by the irreducible polynomial

$$R_p = X^8 + X^4 + X^3 + X + 1$$

- A byte can be represented by a degree 7 polynomial where the bits of the byte corresponds to coefficients of this polynomial.
- Now we can perform addition and multiplication on these polynomials modulo R_p
- This more mathematical representation is better to understand the security of the cipher

Lesson 2: Advanced Encryption Standard

Round Function of AES

Round function of AES contains the following operations:

1. **Key Addition (AK):** XOR the 128-bit round key with the input
2. **Sub Bytes (SB):** Apply 8x8 S-box on 16 bytes
3. **Shift Rows (SR):** Rotate rows to the left
4. **Mix Columns (MC):** Multiply by matrix M

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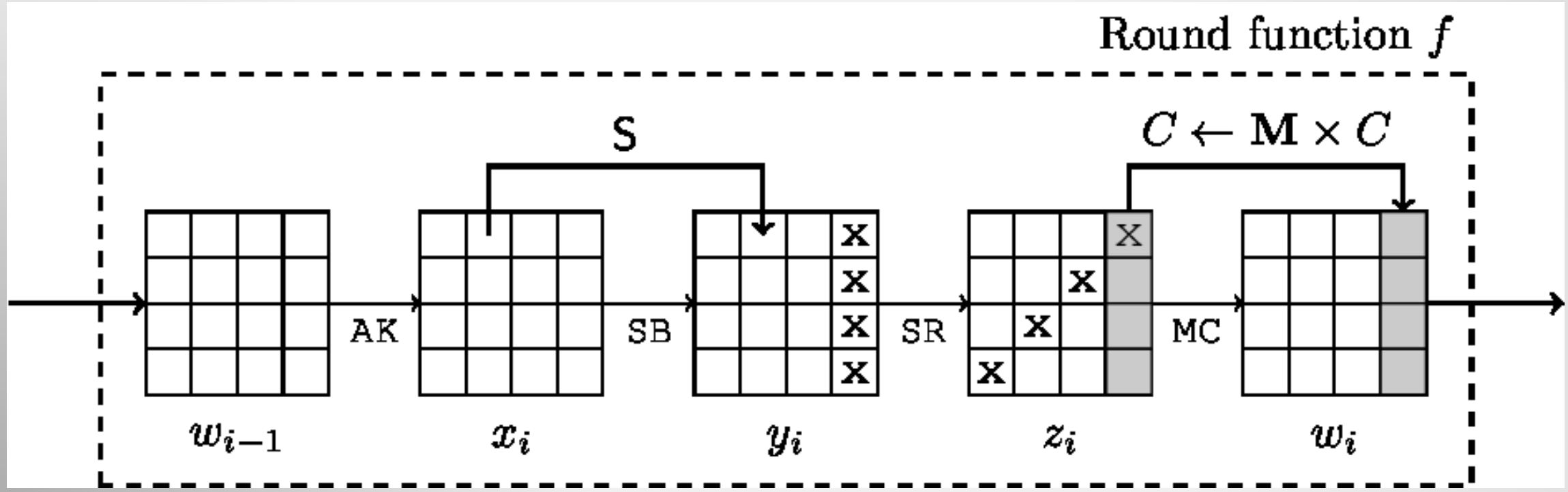
Advanced Encryption Standard (AES)



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	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f
0	63	7c	77	7b	f2	6b	6f	c5	30	01	67	2b	fe	d7	ab	76
1	ca	82	c9	7d	fa	59	47	f0	ad	d4	a2	af	9c	a4	72	c0
2	b7	fd	93	26	36	3f	f7	cc	34	a5	e5	f1	71	d8	31	15
3	04	c7	23	c3	18	96	05	9a	07	12	80	e2	eb	27	b2	75
4	09	83	2c	1a	1b	6e	5a	a0	52	3b	d6	b3	29	e3	2f	84
5	53	d1	00	ed	20	fc	b1	5b	6a	cb	be	39	4a	4c	58	cf
6	d0	ef	aa	fb	43	4d	33	85	45	f9	02	7f	50	3c	9f	a8
7	51	a3	40	8f	92	9d	38	f5	bc	b6	da	21	10	ff	f3	d2
8	cd	0c	13	ec	5f	97	44	17	c4	a7	7e	3d	64	5d	19	73
9	60	81	4f	dc	22	2a	90	88	46	ee	b8	14	de	5e	0b	db
a	e0	32	3a	0a	49	06	24	5c	c2	d3	ac	62	91	95	e4	79
b	e7	c8	37	6d	8d	d5	4e	a9	6c	56	f4	ea	65	7a	ae	08
c	ba	78	25	2e	1c	a6	b4	c6	e8	dd	74	1f	4b	bd	8b	8a
d	70	3e	b5	66	48	03	f6	0e	61	35	57	b9	86	c1	1d	9e
e	e1	f8	98	11	69	d9	8e	94	9b	1e	87	e9	ce	55	28	df
f	8c	a1	89	0d	bf	e6	42	68	41	99	2d	0f	b0	54	bb	16

S-box of AES

Input $3b$ means the 3rd row and bth column (i.e. $S(3b) = e2$)

Lesson 2: Advanced Encryption Standard

Mix Columns (MC) *(Omitted in the last round!)*

$$M = \begin{pmatrix} 0x02 & 0x03 & 0x01 & 0x01 \\ 0x01 & 0x02 & 0x02 & 0x01 \\ 0x01 & 0x01 & 0x03 & 0x03 \\ 0x02 & 0x01 & 0x01 & 0x02 \end{pmatrix} \begin{pmatrix} x_0 \\ x_1 \\ x_2 \\ x_3 \end{pmatrix} = \begin{pmatrix} y_0 \\ y_1 \\ y_2 \\ y_3 \end{pmatrix}$$

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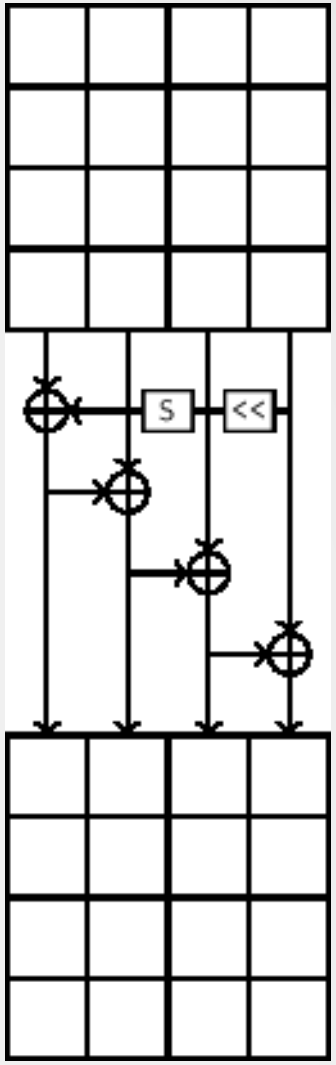
Key Schedule

- The 128-bit master key is also the first round key
- Next round key is obtained by the previous one by performing:
  1. Byte rotation
  2. Four S-box operation
  3. Round Constant Addition
  4. XOR of 32-bit values



Next lecture

Mode of Operations for Block Ciphers

- When we use a block cipher, we need to choose a mode of operation to determine how we encrypt plaintext that is larger than a single block.
- Some mode of operations are not secure.
- Some mode of operations allow parallelization.

Thanks

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