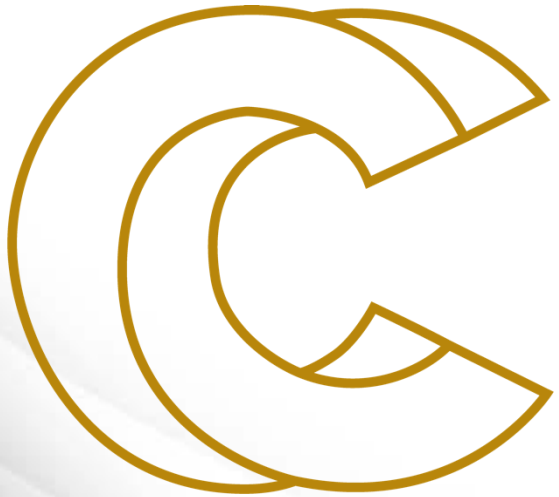

EURO^2

GPU Optimization of Advanced Encryption Standard

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Lesson 4: Reference C and CUDA Implementation of AES

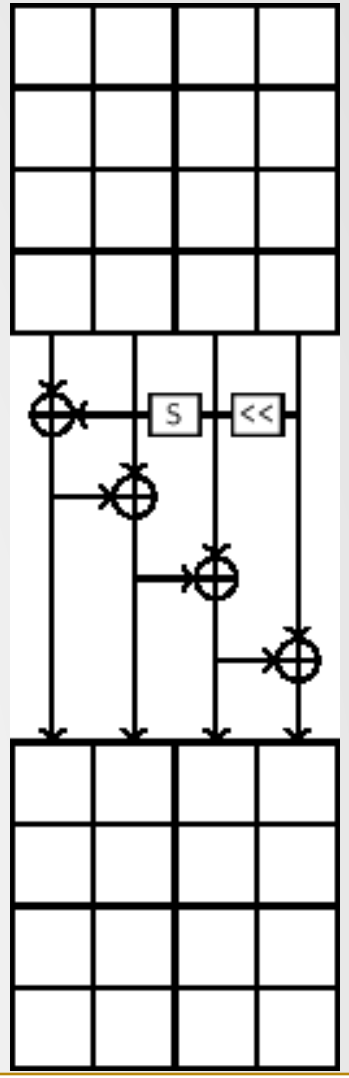
Type Definitions

```
typedef unsigned char       u8;
typedef unsigned short      u16;
typedef unsigned int        u32;
typedef unsigned long long  u64;


u32 RCON32[RCON_SIZE] = {
        0x01000000, 0x02000000, 0x04000000, 0x08000000,
        0x10000000, 0x20000000, 0x40000000, 0x80000000,
        0x1B000000, 0x36000000, 0x6C000000, 0xD8000000,
        0xAB000000, 0x4D000000, 0x9A000000
};
```

Lesson 4: Reference C and CUDA Implementation of AES

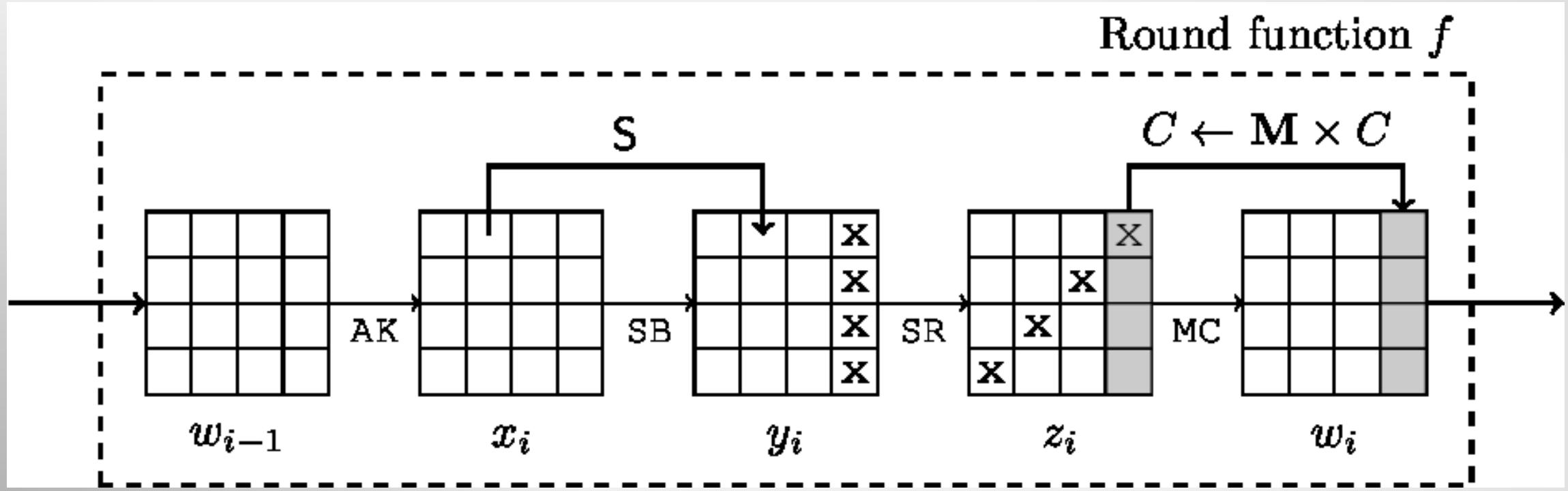
AES Key Schedule

```
__host__ void keyExpansion(u32* key, u32* rk) {
        u32 rk0, rk1, rk2, rk3;
        rk0 = key[0]; rk1 = key[1]; rk2 = key[2]; rk3 = key[3];
        rk[0] = rk0; rk[1] = rk1; rk[2] = rk2; rk[3] = rk3;

        for (u8 roundCount = 0; roundCount < ROUND_COUNT; roundCount++) {
                u32 temp = rk3;
                rk0 = rk0 ^ T4_3[(temp >> 16) & 0xff] ^ T4_2[(temp >> 8) & 0xff] ^
                T4_1[(temp) & 0xff] ^ T4_0[(temp >> 24)] ^ RCON32[roundCount];
                rk1 = rk1 ^ rk0;
                rk2 = rk2 ^ rk1;
                rk3 = rk2 ^ rk3;
                rk[roundCount * 4 + 4] = rk0;
                rk[roundCount * 4 + 5] = rk1;
                rk[roundCount * 4 + 6] = rk2;
                rk[roundCount * 4 + 7] = rk3;
                }
}
```



Lesson 4: Reference C and CUDA Implementation of AES

Advanced Encryption Standard (AES)



Store columns as four 32-bit values

Lesson 4: Reference C and CUDA Implementation of AES

	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. $S(3b) = e2$)

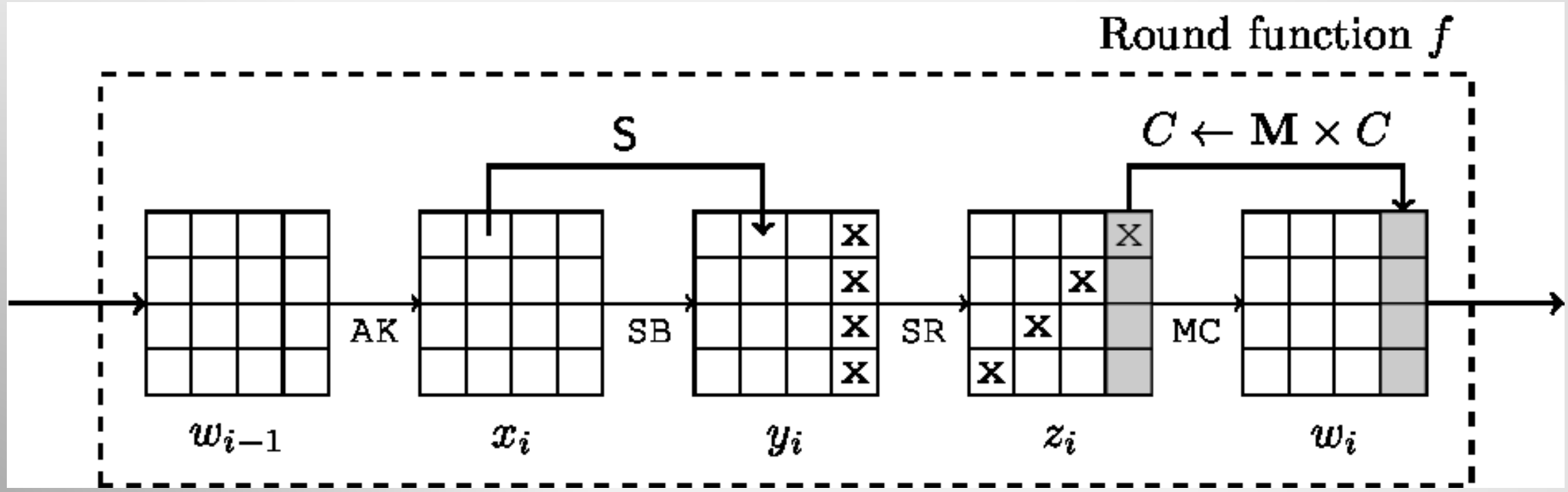
Lesson 4: Reference C and CUDA Implementation of AES

AES S-box as an Array

```
u8 SAES[256] = {0x63,0x7c,0x77,0x7b,0xf2,0x6b,0x6f,0xc5, 0x30, 0x01, 0x67, 0x2b, 0xfe, 0xd7, 0xab,
        0x76,0xca,0x82,0xc9,0x7d,0xfa,0x59,0x47,0xf0, 0xad, 0xd4, 0xa2, 0xaf, 0x9c, 0xa4, 0x72,
        0xc0,0xb7,0xfd,0x93,0x26,0x36,0x3f,0xf7,0xcc, 0x34, 0xa5, 0xe5, 0xf1, 0x71, 0xd8, 0x31,
        0x15,0x04,0xc7,0x23,0xc3,0x18,0x96,0x05,0x9a, 0x07, 0x12, 0x80, 0xe2, 0xeb, 0x27, 0xb2,
        0x75,0x09,0x83,0x2c,0x1a,0x1b,0x6e,0x5a,0xa0, 0x52, 0x3b, 0xd6, 0xb3, 0x29, 0xe3, 0x2f,
        0x84,0x53,0xd1,0x00,0xed,0x20,0xfc,0xb1,0x5b, 0x6a, 0xcb, 0xbe, 0x39, 0x4a, 0x4c, 0x58,
        0xcf,0xd0,0xef,0xaa,0xfb,0x43,0x4d,0x33,0x85, 0x45, 0xf9, 0x02, 0x7f, 0x50, 0x3c, 0x9f,
        0xa8,0x51,0xa3,0x40,0x8f,0x92,0x9d,0x38,0xf5, 0xbc, 0xb6, 0xda, 0x21, 0x10, 0xff, 0xf3,
        0xd2,0xcd,0x0c,0x13,0xec,0x5f,0x97,0x44,0x17, 0xc4, 0xa7, 0x7e, 0x3d, 0x64, 0x5d, 0x19,
        0x73,0x60,0x81,0x4f,0xdc,0x22,0x2a,0x90,0x88, 0x46, 0xee, 0xb8, 0x14, 0xde, 0x5e, 0x0b,
        0xdb,0xe0,0x32,0x3a,0x0a,0x49,0x06,0x24,0x5c, 0xc2, 0xd3, 0xac, 0x62, 0x91, 0x95, 0xe4,
        0x79,0xe7,0xc8,0x37,0x6d,0x8d,0xd5,0x4e,0xa9, 0x6c, 0x56, 0xf4, 0xea, 0x65, 0x7a, 0xae,
        0x08,0xba,0x78,0x25,0x2e,0x1c,0xa6,0xb4,0xc6, 0xe8, 0xdd, 0x74, 0x1f, 0x4b, 0xbd, 0x8b,
        0x8a,0x70,0x3e,0xb5,0x66,0x48,0x03,0xf6,0x0e, 0x61, 0x35, 0x57, 0xb9, 0x86, 0xc1, 0x1d,
        0x9e,0xe1,0xf8,0x98,0x11,0x69,0xd9,0x8e,0x94, 0x9b, 0x1e, 0x87, 0xe9, 0xce, 0x55, 0x28,
        0xdf,0x8c,0xa1,0x89,0x0d,0xbf,0xe6,0x42,0x68, 0x41, 0x99, 0x2d, 0x0f, 0xb0, 0x54, 0xbb, 0x16 };
```

Lesson 4: Reference C and CUDA Implementation of AES

Advanced Encryption Standard (AES)



Lesson 4: Reference C and CUDA Implementation of AES

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

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

Lesson 4: Reference C and CUDA Implementation of AES

AES S-box as an Array

```
u32 multiply2[256]= {
        0x00,0x02,0x04,0x06,0x08,0x0a,0x0c,0x0e,0x10,0x12,0x14,0x16,0x18,0x1a,0x1c,0x1e,
        0x20,0x22,0x24,0x26,0x28,0x2a,0x2c,0x2e,0x30,0x32,0x34,0x36,0x38,0x3a,0x3c,0x3e,
        0x40,0x42,0x44,0x46,0x48,0x4a,0x4c,0x4e,0x50,0x52,0x54,0x56,0x58,0x5a,0x5c,0x5e,
        0x60,0x62,0x64,0x66,0x68,0x6a,0x6c,0x6e,0x70,0x72,0x74,0x76,0x78,0x7a,0x7c,0x7e,
        0x80,0x82,0x84,0x86,0x88,0x8a,0x8c,0x8e,0x90,0x92,0x94,0x96,0x98,0x9a,0x9c,0x9e,
        0xa0,0xa2,0xa4,0xa6,0xa8,0xaa,0xac,0xae,0xb0,0xb2,0xb4,0xb6,0xb8,0xba,0xbc,0xbe,
        0xc0,0xc2,0xc4,0xc6,0xc8,0xca,0xcc,0xce,0xd0,0xd2,0xd4,0xd6,0xd8,0xda,0xdc,0xde,
        0xe0,0xe2,0xe4,0xe6,0xe8,0xea,0xec,0xee,0xf0,0xf2,0xf4,0xf6,0xf8,0xfa,0xfc,0xfe,
        0x1b,0x19,0x1f,0x1d,0x13,0x11,0x17,0x15,0x0b,0x09,0x0f,0x0d,0x03,0x01,0x07,0x05,
        0x3b,0x39,0x3f,0x3d,0x33,0x31,0x37,0x35,0x2b,0x29,0x2f,0x2d,0x23,0x21,0x27,0x25,
        0x5b,0x59,0x5f,0x5d,0x53,0x51,0x57,0x55,0x4b,0x49,0x4f,0x4d,0x43,0x41,0x47,0x45,
        0x7b,0x79,0x7f,0x7d,0x73,0x71,0x77,0x75,0x6b,0x69,0x6f,0x6d,0x63,0x61,0x67,0x65,
        0x9b,0x99,0x9f,0x9d,0x93,0x91,0x97,0x95,0x8b,0x89,0x8f,0x8d,0x83,0x81,0x87,0x85,
        0xbb,0xb9,0xbf,0xbd,0xb3,0xb1,0xb7,0xb5,0xab,0xa9,0xaf,0xad,0xa3,0xa1,0xa7,0xa5,
        0xdb,0xd9,0xdf,0xdd,0xd3,0xd1,0xd7,0xd5,0xcb,0xc9,0xcf,0xcd,0xc3,0xc1,0xc7,0xc5,
        0xfb,0xf9,0xff,0xfd,0xf3,0xf1,0xf7,0xf5,0xeb,0xe9,0xef,0xed,0xe3,0xe1,0xe7,0xe5};
```

Lesson 4: Reference C and CUDA Implementation of AES

AES S-box as an Array

```
u32 multiply3[256]= {
        0x00,0x03,0x06,0x05,0x0c,0x0f,0x0a,0x09,0x18,0x1b,0x1e,0x1d,0x14,0x17,0x12,0x11,
        0x30,0x33,0x36,0x35,0x3c,0x3f,0x3a,0x39,0x28,0x2b,0x2e,0x2d,0x24,0x27,0x22,0x21,
        0x60,0x63,0x66,0x65,0x6c,0x6f,0x6a,0x69,0x78,0x7b,0x7e,0x7d,0x74,0x77,0x72,0x71,
        0x50,0x53,0x56,0x55,0x5c,0x5f,0x5a,0x59,0x48,0x4b,0x4e,0x4d,0x44,0x47,0x42,0x41,
        0xc0,0xc3,0xc6,0xc5,0xcc,0xcf,0xca,0xc9,0xd8,0xdb,0xde,0xdd,0xd4,0xd7,0xd2,0xd1,
        0xf0,0xf3,0xf6,0xf5,0xfc,0xff,0xfa,0xf9,0xe8,0xeb,0xee,0xed,0xe4,0xe7,0xe2,0xe1,
        0xa0,0xa3,0xa6,0xa5,0xac,0xaf,0xaa,0xa9,0xb8,0xbb,0xbe,0xbd,0xb4,0xb7,0xb2,0xb1,
        0x90,0x93,0x96,0x95,0x9c,0x9f,0x9a,0x99,0x88,0x8b,0x8e,0x8d,0x84,0x87,0x82,0x81,
        0x9b,0x98,0x9d,0x9e,0x97,0x94,0x91,0x92,0x83,0x80,0x85,0x86,0x8f,0x8c,0x89,0x8a,
        0xab,0xa8,0xad,0xae,0xa7,0xa4,0xa1,0xa2,0xb3,0xb0,0xb5,0xb6,0xbf,0xbc,0xb9,0xba,
        0xfb,0xf8,0xfd,0xfe,0xf7,0xf4,0xf1,0xf2,0xe3,0xe0,0xe5,0xe6,0xef,0xec,0xe9,0xea,
        0xcb,0xc8,0xcd,0xce,0xc7,0xc4,0xc1,0xc2,0xd3,0xd0,0xd5,0xd6,0xdf,0xdc,0xd9,0xda,
        0x5b,0x58,0x5d,0x5e,0x57,0x54,0x51,0x52,0x43,0x40,0x45,0x46,0x4f,0x4c,0x49,0x4a,
        0x6b,0x68,0x6d,0x6e,0x67,0x64,0x61,0x62,0x73,0x70,0x75,0x76,0x7f,0x7c,0x79,0x7a,
        0x3b,0x38,0x3d,0x3e,0x37,0x34,0x31,0x32,0x23,0x20,0x25,0x26,0x2f,0x2c,0x29,0x2a,
        0x0b,0x08,0x0d,0x0e,0x07,0x04,0x01,0x02,0x13,0x10,0x15,0x16,0x1f,0x1c,0x19,0x1a};
```

Next lecture

CUDA Optimization of AES

- This C reference implementation can be turned into a CUDA code easily
- We are going to see table-based implementation technique for AES
- And we will see a method to remove shared memory bank conflicts

Thanks

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