摘要

本实验基于 RISC-V 架构，对 SM4 加密算法进行汇编层面的优化，并在设备上完成了性能测试。实验通过优化汇编代码逻辑（包括轮密钥预反转、寄存器高效利用、循环展开等策略），显著减少了加解密指令数量。在 Spike+PK 仿真环境下，加密指令数减少 8.912%，解密指令数减少 15.160%；在香橙派开发板实际测试中，加密性能提升约 11.489%；解密性能提升约 9.503%。此外，我们还尝试了基于 bitslicing 的并行优化方案。最终结果表明汇编优化对 SM4 算法性能实现了提升。

Abstract

Based on the RISC-V architecture, this experiment optimized the SM4 encryption algorithm at the assembly level and completed performance testing on the device. The experiment significantly reduced the number of encryption and decryption instructions by optimizing the assembly code logic (including round key pre-inversion, efficient use of registers, loop unrolling and other strategies). In the Spike+PK simulation environment, the number of encryption instructions decreased by 8.912%, and the number of decryption instructions decreased by 15.160%; in the actual test of the Orange Pi development board, the encryption performance increased by about 11.489%, and the decryption performance increased by about 9.053%. In addition, we also tried a parallel optimization solution based on bitslicing. The final results show that assembly optimization has improved the performance of the SM4 algorithm.

目录

1 软硬件环境

1. 软件环境

- RISC-V 仿真器：Spike
- 操作系统：RISC-V
- 工具链依赖：

  交叉编译器 g++-riscv64-linux-gnu、gcc-riscv64-linux-gnu；

  依赖库 libsctp-dev；

  构建工具 cmake、make、git 等

2. 硬件环境

- 香橙派开发板
- Milk-V Meles 开发板

2 环境配置

根据实验指导依次完成下述编译：
1. 安装依赖项
2. 编译 libboundscheck 源码
3. 编译 openhitls 源码

3 汇编层面优化

基于 RISC-V 架构和 openhitls 上的项目代码，我们编写相应的汇编指令来完成相应的优化：

3.1 代码实现

具体汇编代码详见附录。

3.2 代码分析

- 最小化内存访问

  代码大量使用寄存器 t0-t6、a0-a7 进行中间计算和数据存储，很大程度上减少了内存访问；另外当前状态字始终保留在 a3-a6 中，XBOX 基地址仅加载一次并存储，实现了 s 盒查找的快速访问。

- 轮密钥预反转

  将轮密钥进行预反转，使反转开销转移到预计算阶段，减少加解密过程中的开销。

- 向量指令

  在 CBC 模式的实现中，将逐字节异或操作部分优化为使用 RISC-V 向量指令完成，通过 vle8.v 指令一次性加载 16 字节到向量寄存器，并利用 vxor.vv 实现向量级别的并行异或计算，最后通过 vse8.v 将结果存回内存。该优化显著减少了指令数量和内存访问次数，发挥了 RISC-V 向量扩展的并行计算优势，实现了高效的 CBC 块处理。

Listing 1: **sm4.c**

```
static inline void cbc_xor_block(uint8_t *block, const uint8_t *in1, const uint8_t *in2)
{
    asm volatile (
                                           // 设置向量寄存器配置：使用 e8 (8 位元素），m1 组，向量长度 16
        "li     t0, 16              \n\t"    // 将立即数 16 (块大小) 加载到 t0
        "vsetvli t1, t0, e8, m1      \n\t"  // 根据 t0 设置向量长度，保证加载 16 个 8 位元素

        "vle8.v v0, (%1)            \n\t"    // 从内存 in1 加载 16 个 8-bit 元素到 v0
        "vle8.v v1, (%2)            \n\t"    // 从内存 in2 加载 16 个 8-bit 元素到 v1

        "vxor.vv v0, v0, v1         \n\t"    // v0 = v0 XOR v1

        "vse8.v v0, (%0)            \n\t"    // 将 v0 中的数据存储到内存 block
        :
```

```
        : "r"(block), "r"(in1), "r"(in2)
        : "t0", "t1", "v0", "v1", "memory"
    );
}
```

- 循环展开

  汇编代码中，我们采用循环展开 8 次的方式进行优化，通过该优化增加了 i-cache 的命中率。

Listing 2: **sm4.S**

```
SM4_ENCrypt_S:
    PROLOGUE
    Get_XBOX

    li t6, 4
.L1:
    ENC_ROUND_FUNCTION3 t0 t1 t2 t3
    ENC_ROUND_FUNCTION3 t0 t1 t2 t3
    addi t6, t6, -1
    bgt t6, zero, .L1

    EPILOGUE
```

- 指令细节

  在进行乘 4 操作时，使用移位操作 slli，使运算效率更高。

- 值得注意的是

  在实现 SM4 算法时，为了解决端序问题，并确保其计算逻辑与项目源代码中的 CRYPT_SM4_ROUND 函数保持严格一致:

  首先，如果内存中原始输入数据 in[0:4] 为 0xaabbccdd，在 C 语言逻辑中将其作为 32 位字 X[0] 时可能被视为 0xddccbbaa，但在汇编寄存器它会直接存储为 0xaabbccdd。

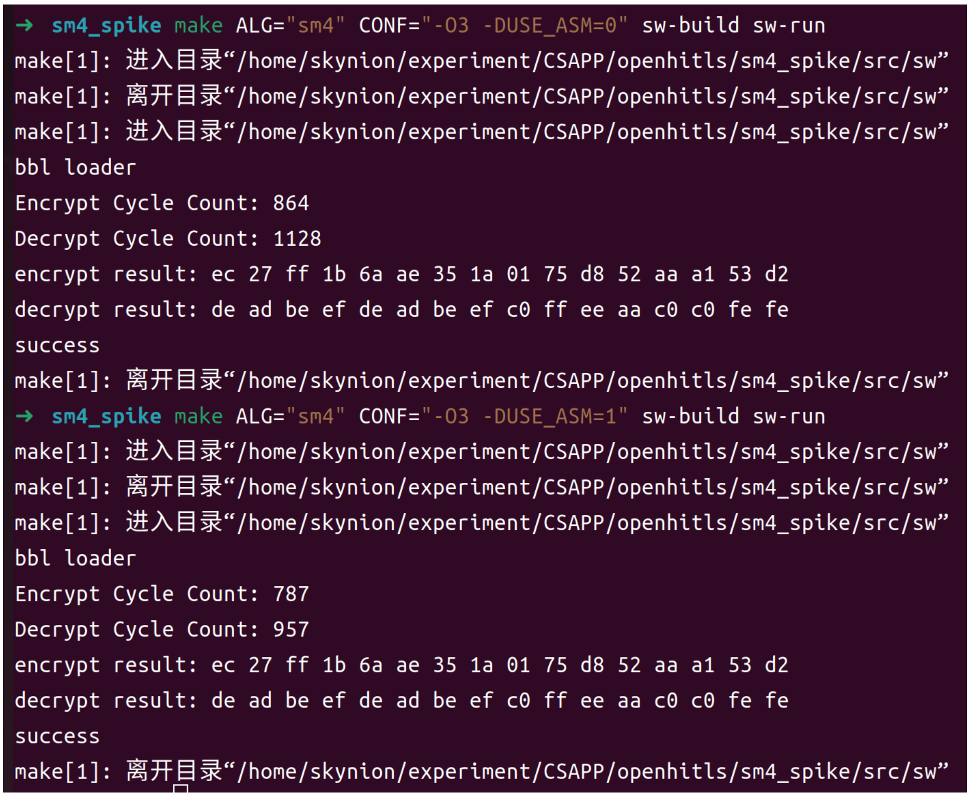
  然后我们采取如下操作:

  在将轮密钥提供给汇编函数之前，每一个 32 位的轮密钥都必须进行一次 8 位字节的逆序处理（如果原始的轮密钥在逻辑上是 0xR0R1R2R3，那么在汇编函数实际加载和使用它时，必须确保其在寄存器中的表示是 0xR3R2R1R0）。通过这种处理，所使用的轮密钥与源代码字节序一致。

  另一方面，XBOX 中存储的所有 S 盒查找数据同样需要进行逆序处理，此时在进行 $a7 = x1 \oplus x2 \oplus x3 \oplus rk$ 时，a7 就与 c 源码中 CRYPT_SM4_ROUND 中的 t 逆序。由于 (XBOX_3)[((t) » 24) & 0xff] 且 a7 是 t 的逆序，所以在汇编的 CRYPT_SM4_ROUND 中先取 a7 的低 8bit 查 XBOX3，其他以此类推。

3.3 Spike+PK 测试

3.3.1 测试结果



```
➜ sm4_spike make ALG="sm4" CONF="-O3 -DUSE_ASM=0" sw-build sw-run
make[1]: 进入目录“/home/skynion/experiment/CSAPP/openhitls/sm4_spike/src/sw”
make[1]: 离开目录“/home/skynion/experiment/CSAPP/openhitls/sm4_spike/src/sw”
make[1]: 进入目录“/home/skynion/experiment/CSAPP/openhitls/sm4_spike/src/sw”
bbl loader
Encrypt Cycle Count: 864
Decrypt Cycle Count: 1128
encrypt result: ec 27 ff 1b 6a ae 35 1a 01 75 d8 52 aa a1 53 d2
decrypt result: de ad be ef de ad be ef c0 ff ee aa c0 c0 fe fe
success
make[1]: 离开目录“/home/skynion/experiment/CSAPP/openhitls/sm4_spike/src/sw”
➜ sm4_spike make ALG="sm4" CONF="-O3 -DUSE_ASM=1" sw-build sw-run
make[1]: 进入目录“/home/skynion/experiment/CSAPP/openhitls/sm4_spike/src/sw”
make[1]: 离开目录“/home/skynion/experiment/CSAPP/openhitls/sm4_spike/src/sw”
make[1]: 进入目录“/home/skynion/experiment/CSAPP/openhitls/sm4_spike/src/sw”
bbl loader
Encrypt Cycle Count: 787
Decrypt Cycle Count: 957
encrypt result: ec 27 ff 1b 6a ae 35 1a 01 75 d8 52 aa a1 53 d2
decrypt result: de ad be ef de ad be ef c0 ff ee aa c0 c0 fe fe
success
make[1]: 离开目录“/home/skynion/experiment/CSAPP/openhitls/sm4_spike/src/sw”
```

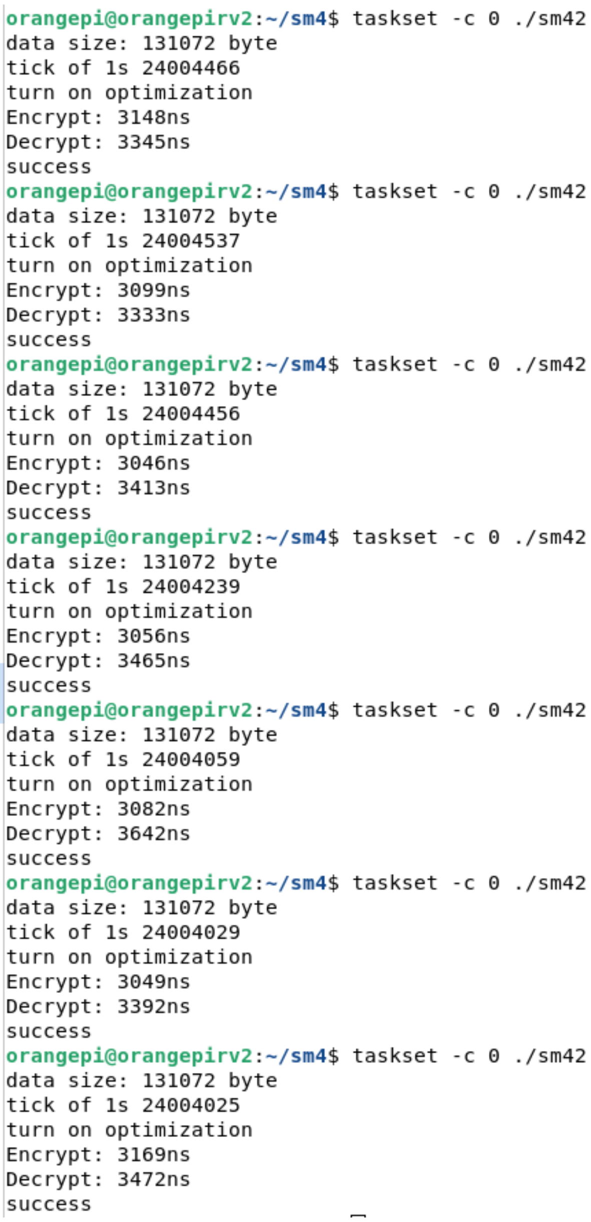
图 1: Spike+PK 测试结果

3.3.2 结果分析

通过汇编语言层次的优化, 我们在 Spike+PK 环境上测试了加解密的指令数量，显示加密指令数量减少了 8.912%；解密指令数量减少了 15.160%，实现了一定程度上的优化。

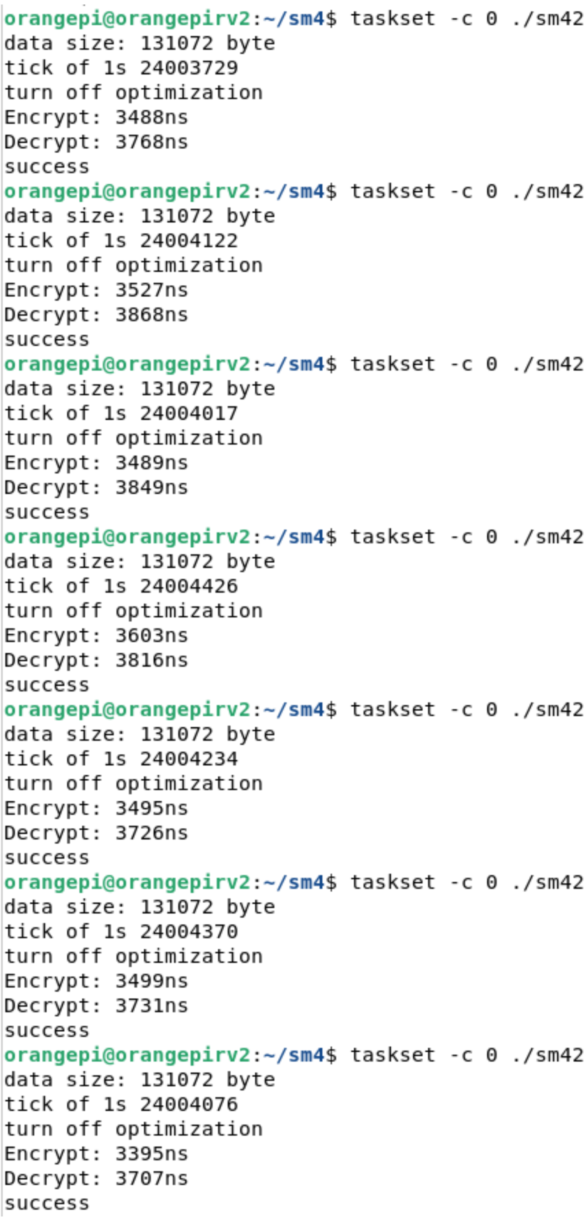
3.4 香橙派开发板测试

3.4.1 测试结果



```
orangepi@orangepirv2:~/sm4$ taskset -c 0 ./sm42
data size: 131072 byte
tick of 1s 24004466
turn on optimization
Encrypt: 3148ns
Decrypt: 3345ns
success
orangepi@orangepirv2:~/sm4$ taskset -c 0 ./sm42
data size: 131072 byte
tick of 1s 24004537
turn on optimization
Encrypt: 3099ns
Decrypt: 3333ns
success
orangepi@orangepirv2:~/sm4$ taskset -c 0 ./sm42
data size: 131072 byte
tick of 1s 24004456
turn on optimization
Encrypt: 3046ns
Decrypt: 3413ns
success
orangepi@orangepirv2:~/sm4$ taskset -c 0 ./sm42
data size: 131072 byte
tick of 1s 24004239
turn on optimization
Encrypt: 3056ns
Decrypt: 3465ns
success
orangepi@orangepirv2:~/sm4$ taskset -c 0 ./sm42
data size: 131072 byte
tick of 1s 24004059
turn on optimization
Encrypt: 3082ns
Decrypt: 3642ns
success
orangepi@orangepirv2:~/sm4$ taskset -c 0 ./sm42
data size: 131072 byte
tick of 1s 24004029
turn on optimization
Encrypt: 3049ns
Decrypt: 3392ns
success
orangepi@orangepirv2:~/sm4$ taskset -c 0 ./sm42
data size: 131072 byte
tick of 1s 24004025
turn on optimization
Encrypt: 3169ns
Decrypt: 3472ns
success
```

图 2: 测试结果 1



```
orangepi@orangepirv2:~/sm4$ taskset -c 0 ./sm42
data size: 131072 byte
tick of 1s 24003729
turn off optimization
Encrypt: 3488ns
Decrypt: 3768ns
success
orangepi@orangepirv2:~/sm4$ taskset -c 0 ./sm42
data size: 131072 byte
tick of 1s 24004122
turn off optimization
Encrypt: 3527ns
Decrypt: 3868ns
success
orangepi@orangepirv2:~/sm4$ taskset -c 0 ./sm42
data size: 131072 byte
tick of 1s 24004017
turn off optimization
Encrypt: 3489ns
Decrypt: 3849ns
success
orangepi@orangepirv2:~/sm4$ taskset -c 0 ./sm42
data size: 131072 byte
tick of 1s 24004426
turn off optimization
Encrypt: 3603ns
Decrypt: 3816ns
success
orangepi@orangepirv2:~/sm4$ taskset -c 0 ./sm42
data size: 131072 byte
tick of 1s 24004234
turn off optimization
Encrypt: 3495ns
Decrypt: 3726ns
success
orangepi@orangepirv2:~/sm4$ taskset -c 0 ./sm42
data size: 131072 byte
tick of 1s 24004370
turn off optimization
Encrypt: 3499ns
Decrypt: 3731ns
success
orangepi@orangepirv2:~/sm4$ taskset -c 0 ./sm42
data size: 131072 byte
tick of 1s 24004076
turn off optimization
Encrypt: 3395ns
Decrypt: 3707ns
success
```

图 3: 测试结果 2

测试	**加密（ns）**		**解密（ns）**	
	未优化	优化	未优化	优化
1	3488	3084	3768	3435
2	3527	3148	3868	3345
3	3489	3099	3849	3333
4	3603	3046	3816	3413
5	3495	3056	3726	3465
6	3499	3082	3731	3642
7	3395	3049	3707	3392
8	3438	3169	3798	3472

表 1: SM4 加密与解密在优化前后的执行时间

3.4.2 结果分析

通过汇编语言层次的优化，我们在香橙派开发板上测试了加解密运算的周期数，显示加密性能提升了 11.489%；解密性能提升了 9.503%，实现了一定程度上的优化。

3.5 Milk-V Meles 开发板测试

另外，我们还尝试在 Milk-V Meles 开发板上进行代码测试，由于环境配置较为复杂，测试未能成功实现。

4 bitslicing 优化

在本实验中，参考论文《How Fast Can SM4 be in Software?》，我们了解到一种使用 bitslicing 方法实现的 SM4 优化方案。该方法的核心思想是将 SM4 的处理单元从“块”变为“位”，然后利用 SIMD 指令并行处理多个数据块实现加速。

首先我们将这 n 个明文块中对应位置的比特重新打包到一组寄存器中，形成所谓的“slice”。例如在处理第 i 位时，某个 slice 中将包含所有明文块第 i 位的值。这可以使得每个逻辑指令同时作用于多个数据块，从而实现并行。

此时，SM4 轮函数中的轮密钥异或、S 盒非线性变换以及线性变换也均需修改为对 slice 进行操作。论文中提到，S 盒部分使用基于塔域分解和 Boyar 逻辑优化的方法，将查找表转化为逻辑电路，从而实现加速。线性变换通过位移和异或在 slice 间完成。轮函数的整体执行顺序保持不变，只是处理单位发生变化。

加密完成后，slice 数据需要按照刚刚所描述的相反的操作，从存储 slice 的寄存器中逐比特提取数据，然后将它们重新组合成 n 个密文数据块，得到正常的密文。解密过程同理。整个过程实现了对数据块的并行处理，极大提高了运行效率。

5 总结 Summary

本实验基于 RISC-V 架构，通过优化汇编代码，成功实现了 SM4 加解密算法的性能提升。在 Spike+PK 仿真环境下，加密指令数减少 8.9123%，解密指令数减少 15.160%；在香橙派开发板的测试中，加密效率提高 11.489%；解密效率提高 9.503%。此外，实验初步探索了基于 bitslicing 的并行优化方案。最终结果表明汇编优化对 SM4 算法性能实现了提升。

This experiment is based on the RISC-V architecture. By optimizing the assembly code, the performance of the SM4 encryption and decryption algorithm was successfully improved. In the Spike+PK simulation environment, the number of encryption instructions was reduced by 8.9123%, and the number of decryption instructions was reduced by 15.160%. In the test of the Orange Pi development board, the encryption efficiency was improved by 11.489%, and the decryption efficiency was improved by 9.503%. In addition, the experiment preliminarily explored the parallel optimization scheme based on bitslicing. The final results show that assembly optimization has improved the performance of the SM4 algorithm.

附录 Appendix

Listing 3: **sm4.S**

```
// a0 -> out
// a1 -> in
// a2 -> rk
// a3 -> XBOX_0
// a4 -> XBOX_1 = XBOX_0 + 1024
// a5 -> XBOX_2 = XBOX_0 + 2048
// a6 -> XBOX_3 = XBOX_0 + 3072
// a7 -> temp
// extern void SM4_Crypt_S(uint8_t *out, const uint8_t *in, const uint32_t *rk);
// t0 -> in[ 0: 4] = x0
// t1 -> in[ 4: 8] = x1
// t2 -> in[ 8:12] = x2
// t3 -> in[12:16] = x3

.macro PROLOGUE
    // load input
    lwu   t0,         0(a1)    // t0 -> in[ 0: 4]
    lwu   t1,         4(a1)    // t1 -> in[ 4: 8]
    lwu   t2,         8(a1)    // t2 -> in[ 8:12]
    lwu   t3,        12(a1)    // t3 -> in[12:16]

.endm

.macro EPILOGUE
    // save output
    sw    t3,         0(a0)    // t3 -> out[ 0: 4]
    sw    t2,         4(a0)    // t2 -> out[ 4: 8]
    sw    t1,         8(a0)    // t1 -> out[ 8:12]
    sw    t0,        12(a0)    // t0 -> out[12:16]

    ret                        // return
.endm

.macro Get_XBOX
    la    a3,   XBOX           // a3 -> XBOX_0
    addi  a4,    a3,   1024    // a4 -> XBOX_1 = XBOX_0 + 1024
    addi  a5,    a4,   1024    // a5 -> XBOX_2 = XBOX_0 + 2048
    addi  a6,    a5,   1024    // a6 -> XBOX_3 = XBOX_0 + 3072
.endm

.macro CRYPT_SM4_ROUND x0, x1, x2, x3, rk_ofst
```

```
    lwu   a7,  \rk_ofst(a2)    // load rk 可以一次load 64bit rk 分两次用
    xor   a7,    a7,     \x1
    xor   a7,    a7,     \x2
    xor   a7,    a7,     \x3    // a7 = x1 ^ x2 ^ x3 ^ rk

    andi  t4,    a7,    0xFF    // t4 = a7 低 8bit
    slli  t4,    t4,       2
    add   t5,    t4,      a6    // a6 -> XBOX_3
    lwu   t6,  0(t5)            // t4 = XBOX_3[t5(a7 & 0xff)]
    xor  \x0,   \x0,      t6
    srli  a7,    a7,       6

    andi  t4,    a7,   0x3FC    // t4 = a7 & 0b1111111100
    add   t5,    t4,      a5    // a5 -> XBOX_2
    lwu   t6,  0(t5)            // t4 = XBOX_2[t5((a7 >> 8) & 0xff)]
    xor  \x0,   \x0,      t6
    srli  a7,    a7,       8

    andi  t4,    a7,   0x3FC    // t4 = a7 低 8bit
    add   t5,    t4,      a4    // a4 -> XBOX_1
    lwu   t6,  0(t5)            // t4 = XBOX_1[t5((a7 >> 16) & 0xff)]
    xor  \x0,   \x0,      t6
    srli  a7,    a7,       8

    andi  t4,    a7,   0x3FC    // t4 = a7 低 8bit
    add   t5,    t4,      a3    // a3 -> XBOX_0
    lwu   t6,  0(t5)            // t4 = XBOX_0[t5((a7 >> 24) & 0xff)]
    xor  \x0,   \x0,      t6
.endm

.macro CRYPT_SM4_ROUND2 x0, x1, x2, x3, rk_ofst
    ld    a7,  \rk_ofst(a2)    // load rk
    xor   t4,   \x1,     \x2
    xor   a7,    a7,     \x3
    xor   a7,    a7,      t4    // a7 = x1 ^ x2 ^ x3 ^ rk

    andi  t4,    a7,    0xFF    // t4 = a7 低 8bit
    slli  t4,    t4,       2
    add   t5,    t4,      a6    // a6 -> XBOX_3
    lwu   t6,  0(t5)            // t4 = XBOX_3[t5(a7 & 0xff)]
    xor  \x0,   \x0,      t6
    srli  a7,    a7,       6
```

```

andi  t4,    a7,  0x3FC    // t4 = a7 & 0b1111111100
add   t5,    t4,     a5    // a5 -> XBOX_2
lwu   t6,  0(t5)           // t4 = XBOX_2[t5((a7 >> 8) & 0xff)]
xor  \x0,   \x0,     t6
srli  a7,    a7,      8

andi  t4,    a7,  0x3FC    // t4 = a7 低 8bit
add   t5,    t4,     a4    // a4 -> XBOX_1
lwu   t6,  0(t5)           // t4 = XBOX_1[t5((a7 >> 16) & 0xff)]
xor  \x0,   \x0,     t6
srli  a7,    a7,      8

andi  t4,    a7,  0x3FC    // t4 = a7 低 8bit
add   t5,    t4,     a3    // a3 -> XBOX_0
lwu   t6,  0(t5)           // t4 = XBOX_0[t5((a7 >> 24) & 0xff)]
xor  \x0,   \x0,     t6

srli  a7,    a7,     10
xor   a7,    a7,    \x2
xor   a7,    a7,    \x3
xor   a7,    a7,    \x0    // a7 = x1 ^ x2 ^ x3 ^ rk

andi  t4,    a7,   0xFF    // t4 = a7 低 8bit
slli  t4,    t4,      2
add   t5,    t4,     a6    // a6 -> XBOX_3
lwu   t6,  0(t5)           // t4 = XBOX_3[t5(a7 & 0xff)]
xor  \x1,   \x1,     t6
srli  a7,    a7,      6

andi  t4,    a7,  0x3FC    // t4 = a7 & 0b1111111100
add   t5,    t4,     a5    // a5 -> XBOX_2
lwu   t6,  0(t5)           // t4 = XBOX_2[t5((a7 >> 8) & 0xff)]
xor  \x1,   \x1,     t6
srli  a7,    a7,      8

andi  t4,    a7,  0x3FC    // t4 = a7 低 8bit
add   t5,    t4,     a4    // a4 -> XBOX_1
lwu   t6,  0(t5)           // t4 = XBOX_1[t5((a7 >> 16) & 0xff)]
xor  \x1,   \x1,     t6
srli  a7,    a7,      8

```

```
    andi  t4,    a7,  0x3FC    // t4 = a7 低 8bit
    add   t5,    t4,      a3    // a3 -> XBOX_0
    lwu   t6,  0(t5)           // t4 = XBOX_0[t5((a7 >> 24) & 0xff)]
    xor  \x1,   \x1,      t6
.endm

.macro CRYPT_SM4_ROUND3 x0, x1, x2, x3
    ld    a7,  0(a2)    // load rk
    xor   t4,   \x1,     \x2
    xor   a7,    a7,     \x3
    xor   a7,    a7,      t4    // a7 = x1 ^ x2 ^ x3 ^ rk

    andi  t4,    a7,   0xFF    // t4 = a7 低 8bit
    slli  t4,    t4,       2
    add   t5,    t4,      a6    // a6 -> XBOX_3
    lwu   t5,  0(t5)           // t4 = XBOX_3[t5(a7 & 0xff)]
    srli  a7,    a7,       6
    xor  \x0,   \x0,      t5

    andi  t4,    a7,  0x3FC    // t4 = a7 & 0b1111111100
    add   t5,    t4,      a5    // a5 -> XBOX_2
    lwu   t5,  0(t5)           // t4 = XBOX_2[t5((a7 >> 8) & 0xff)]
    srli  a7,    a7,       8
    xor  \x0,   \x0,      t5

    andi  t4,    a7,  0x3FC    // t4 = a7 低 8bit
    add   t5,    t4,      a4    // a4 -> XBOX_1
    lwu   t5,  0(t5)           // t4 = XBOX_1[t5((a7 >> 16) & 0xff)]
    srli  a7,    a7,       8
    xor  \x0,   \x0,      t5

    andi  t4,    a7,  0x3FC    // t4 = a7 低 8bit
    add   t5,    t4,      a3    // a3 -> XBOX_0
    lwu   t5,  0(t5)           // t4 = XBOX_0[t5((a7 >> 24) & 0xff)]
    xor  \x0,   \x0,      t5

    srli  a7,    a7,      10
    xor   a7,    a7,     \x2
    xor   a7,    a7,     \x3
    xor   a7,    a7,     \x0    // a7 = x1 ^ x2 ^ x3 ^ rk

    andi  t4,    a7,   0xFF    // t4 = a7 低 8bit
    slli  t4,    t4,      2
    add   t5,    t4,     a6    // a6 -> XBOX_3
    lwu   t5,  0(t5)          // t4 = XBOX_3[t5(a7 & 0xff)]
    srli  a7,    a7,      6
    xor  \x1,   \x1,     t5

    andi  t4,    a7,  0x3FC    // t4 = a7 & 0b1111111100
    add   t5,    t4,     a5    // a5 -> XBOX_2
    lwu   t5,  0(t5)          // t4 = XBOX_2[t5((a7 >> 8) & 0xff)]
    srli  a7,    a7,      8
    xor  \x1,   \x1,     t5

    andi  t4,    a7,  0x3FC    // t4 = a7 低 8bit
    add   t5,    t4,     a4    // a4 -> XBOX_1
    lwu   t5,  0(t5)          // t4 = XBOX_1[t5((a7 >> 16) & 0xff)]
    srli  a7,    a7,      8
    xor  \x1,   \x1,     t5

    andi  t4,    a7,  0x3FC    // t4 = a7 低 8bit
    add   t5,    t4,     a3    // a3 -> XBOX_0
    lwu   t5,  0(t5)          // t4 = XBOX_0[t5((a7 >> 24) & 0xff)]
    xor  \x1,   \x1,     t5
.endm
.macro ENC_ROUND_FUNCTION x0, x1, x2, x3, rk_ofst
    CRYPT_SM4_ROUND \x0, \x1, \x2, \x3, \rk_ofst
    CRYPT_SM4_ROUND \x1, \x2, \x3, \x0, \rk_ofst + 4
    CRYPT_SM4_ROUND \x2, \x3, \x0, \x1, \rk_ofst + 8
    CRYPT_SM4_ROUND \x3, \x0, \x1, \x2, \rk_ofst + 12
.endm

.macro ENC_ROUND_FUNCTION2 x0, x1, x2, x3, rk_ofst
    CRYPT_SM4_ROUND2 \x0, \x1, \x2, \x3, \rk_ofst
    CRYPT_SM4_ROUND2 \x2, \x3, \x0, \x1, \rk_ofst + 8
.endm

.macro ENC_ROUND_FUNCTION3 x0, x1, x2, x3
    CRYPT_SM4_ROUND3 \x0, \x1, \x2, \x3
    addi  a2,  a2,  8
    CRYPT_SM4_ROUND3 \x2, \x3, \x0, \x1
    addi  a2,  a2,  8
.endm

```

```

.macro DEC_ROUND_FUNCTION x0, x1, x2, x3, rk_ofst
    CRYPT_SM4_ROUND \x0, \x1, \x2, \x3, \rk_ofst + 12
    CRYPT_SM4_ROUND \x1, \x2, \x3, \x0, \rk_ofst + 8
    CRYPT_SM4_ROUND \x2, \x3, \x0, \x1, \rk_ofst + 4
    CRYPT_SM4_ROUND \x3, \x0, \x1, \x2, \rk_ofst
.endm

.section .data

.align 3

XBOX:
    // XBOX_0
    .word 0x8e5b5bd5, 0xd0424292, 0x4da7a7ea, 0x06fbfbfd, 0xfc3333cf, 0x658787e2, 0xc9f4f43d, 0x6bdedeb5
    .word 0x4e585816, 0x6edadab4, 0x44505014, 0xca0b0bc1, 0x88a0a028, 0x17efeff8, 0x9cb0b02c, 0x11141405
    .word 0x87acac2b, 0xfb9d9d66, 0xf26a6a98, 0xaed9d977, 0x82a8a82a, 0x46fafabc, 0x14101004, 0xcf0f0fc0
    .word 0x02aaaaa8, 0x54111145, 0x5f4c4c13, 0xbe989826, 0x6d252548, 0x9e1a1a84, 0x1e181806, 0xfd66669b
    .word 0xec72729e, 0x4a090943, 0x10414151, 0x24d3d3f7, 0xd5464693, 0x53bfbfec, 0xf862629a, 0x92e9e97b
    .word 0xffcccc33, 0x04515155, 0x272c2c0b, 0x4f0d0d42, 0x59b7b7ee, 0xf33f3fcc, 0x1cb2b2ae, 0xea898963
    .word 0x749393e7, 0x7fceceb1, 0x6c70701c, 0x0da6a6ab, 0xed2727ca, 0x28202008, 0x48a3a3eb, 0xc1565697
    .word 0x80020282, 0xa37f7fdc, 0xc4525296, 0x12ebebf9, 0xa1d5d574, 0xb33e3e8d, 0xc3fcfc3f, 0x3e9a9aa4
    .word 0x5b1d1d46, 0x1b1c1c07, 0x3b9e9ea5, 0x0cf3f3ff, 0x3fcfcff0, 0xbfcdcd72, 0x4b5c5c17, 0x52eaeab8
    .word 0x8f0e0e81, 0x3d656558, 0xccf0f03c, 0x7d646419, 0x7e9b9be5, 0x91161687, 0x733d3d4e, 0x08a2a2aa
    .word 0xc8a1a169, 0xc7adad6a, 0x85060683, 0x7acacab0, 0xb5c5c570, 0xf4919165, 0xb26b6bd9, 0xa72e2e89
    .word 0x18e3e3fb, 0x47afafe8, 0x333c3c0f, 0x672d2d4a, 0xb0c1c171, 0x0e595957, 0xe976769f, 0xe1d4d435
    .word 0x6678781e, 0xb4909024, 0x3638380e, 0x2679795f, 0xef8d8d62, 0x38616159, 0x954747d2, 0x2a8a8aa0
    .word 0xb1949425, 0xaa888822, 0x8cf1f17d, 0xd7ecec3b, 0x05040401, 0xa5848421, 0x98e1e179, 0x9b1e1e85
    .word 0x845353d7, 0x00000000, 0x5e191947, 0x0b5d5d56, 0xe37e7e9d, 0x9f4f4fd0, 0xbb9c9c27, 0x1a494953
    .word 0x7c31314d, 0xeed8d836, 0x0a080802, 0x7b9f9fe4, 0x208282a2, 0xd41313c7, 0xe82323cb, 0xe67a7a9c
    .word 0x42ababe9, 0x43fefebd, 0xa22a2a88, 0x9a4b4bd1, 0x40010141, 0xdb1f1fc4, 0xd8e0e038, 0x61d6d6b7
    .word 0x2f8e8ea1, 0x2bdfdff4, 0x3acbcbf1, 0xf63b3bcd, 0x1de7e7fa, 0xe5858560, 0x41545415, 0x258686a3
    .word 0x608383e3, 0x16babaac, 0x2975755c, 0x349292a6, 0xf76e6e99, 0xe4d0d034, 0x7268681a, 0x01555554
    .word 0x19b6b6af, 0xdf4e4e91, 0xfac8c832, 0xf0c0c030, 0x21d7d7f6, 0xbc32328e, 0x75c6c6b3, 0x6f8f8fe0
    .word 0x6974741d, 0x2edbdbf5, 0x6a8b8be1, 0x96b8b82e, 0x8a0a0a80, 0xfe999967, 0xe22b2bc9, 0xe0818161
    .word 0xc00303c3, 0x8da4a429, 0xaf8c8c23, 0x07aeaea9, 0x3934340d, 0x1f4d4d52, 0x7639394f, 0xd3bdbd6e
    .word 0x815757d6, 0xb76f6fd8, 0xebdcdc37, 0x51151544, 0xa67b7bdd, 0x09f7f7fe, 0xb63a3a8c, 0x93bcbc2f
    .word 0x0f0c0c03, 0x03fffffc, 0xc2a9a96b, 0xbac9c973, 0xd9b5b56c, 0xdcb1b16d, 0x376d6d5a, 0x15454550
    .word 0xb936368f, 0x776c6c1b, 0x13bebead, 0xda4a4a90, 0x57eeeeb9, 0xa97777de, 0x4cf2f2be, 0x83fdfd7e
    .word 0x55444411, 0xbd6767da, 0x2c71715d, 0x45050540, 0x637c7c1f, 0x50404010, 0x3269695b, 0xb86363db
    .word 0x2228280a, 0xc50707c2, 0xf5c4c431, 0xa822228a, 0x319696a7, 0xf93737ce, 0x97eded7a, 0x49f6f6bf
    .word 0x99b4b42d, 0xa4d1d175, 0x904343d3, 0x5a484812, 0x58e2e2ba, 0x719797e6, 0x64d2d2b6, 0x70c2c2b2
    .word 0xad26268b, 0xcda5a568, 0xcb5e5e95, 0x6229294b, 0x3c30300c, 0xce5a5a94, 0xabdddd76, 0x86f9f97f
    .word 0xf1959564, 0x5de6e6bb, 0x35c7c7f2, 0x2d242409, 0xd11717c6, 0xd6b9b96f, 0xde1b1bc5, 0x94121286
    .word 0x78606018, 0x30c3c3f3, 0x89f5f57c, 0x5cb3b3ef, 0xd2e8e83a, 0xac7373df, 0x7935354c, 0xa0808020
    .word 0x9de5e578, 0x56bbbbed, 0x237d7d5e, 0xc6f8f83e, 0x8b5f5fd4, 0xe72f2fc8, 0xdde4e439, 0x68212149

    // XBOX_1
    .word 0xd58e5b5b, 0x92d04242, 0xea4da7a7, 0xfd06fbfb, 0xcffc3333, 0xe2658787, 0x3dc9f4f4, 0xb56bdede
    .word 0x164e5858, 0xb46edada, 0x14445050, 0xc1ca0b0b, 0x2888a0a0, 0xf817efef, 0x2c9cb0b0, 0x05111414
    .word 0x2b87acac, 0x66fb9d9d, 0x98f26a6a, 0x77aed9d9, 0x2a82a8a8, 0xbc46fafa, 0x04141010, 0xc0cf0f0f
    .word 0xa802aaaa, 0x45541111, 0x135f4c4c, 0x26be9898, 0x486d2525, 0x849e1a1a, 0x061e1818, 0x9bfd6666
    .word 0x9eec7272, 0x434a0909, 0x51104141, 0xf724d3d3, 0x93d54646, 0xec53bfbf, 0x9af86262, 0x7b92e9e9
    .word 0x33ffcccc, 0x55045151, 0x0b272c2c, 0x424f0d0d, 0xee59b7b7, 0xccf33f3f, 0xae1cb2b2, 0x63ea8989
    .word 0xe7749393, 0xb17fcece, 0x1c6c7070, 0xab0da6a6, 0xcaed2727, 0x08282020, 0xeb48a3a3, 0x97c15656
    .word 0x82800202, 0xdca37f7f, 0x96c45252, 0xf912ebeb, 0x74a1d5d5, 0x8db33e3e, 0x3fc3fcfc, 0xa43e9a9a
    .word 0x465b1d1d, 0x071b1c1c, 0xa53b9e9e, 0xff0cf3f3, 0xf03fcfcf, 0x72bfcdcd, 0x174b5c5c, 0xb852eaea
    .word 0x818f0e0e, 0x583d6565, 0x3cccf0f0, 0x197d6464, 0xe57e9b9b, 0x87911616, 0x4e733d3d, 0xaa08a2a2
    .word 0x69c8a1a1, 0x6ac7adad, 0x83850606, 0xb07acaca, 0x70b5c5c5, 0x65f49191, 0xd9b26b6b, 0x89a72e2e
    .word 0xfb18e3e3, 0xe847afaf, 0x0f333c3c, 0x4a672d2d, 0x71b0c1c1, 0x570e5959, 0x9fe97676, 0x35e1d4d4
    .word 0x1e667878, 0x24b49090, 0x0e363838, 0x5f267979, 0x62ef8d8d, 0x59386161, 0xd2954747, 0xa02a8a8a
    .word 0x25b19494, 0x22aa8888, 0x7d8cf1f1, 0x3bd7ecec, 0x01050404, 0x21a58484, 0x7998e1e1, 0x859b1e1e
    .word 0xd7845353, 0x00000000, 0x475e1919, 0x560b5d5d, 0x9de37e7e, 0xd09f4f4f, 0x27bb9c9c, 0x531a4949
    .word 0x4d7c3131, 0x36eed8d8, 0x020a0808, 0xe47b9f9f, 0xa2208282, 0xc7d41313, 0xcbe82323, 0x9ce67a7a
    .word 0xe942abab, 0xbd43fefe, 0x88a22a2a, 0xd19a4b4b, 0x41400101, 0xc4db1f1f, 0x38d8e0e0, 0xb761d6d6
    .word 0xa12f8e8e, 0xf42bdfdf, 0xf13acbcb, 0xcdf63b3b, 0xfa1de7e7, 0x60e58585, 0x15415454, 0xa3258686
    .word 0xe3608383, 0xac16baba, 0x5c297575, 0xa6349292, 0x99f76e6e, 0x34e4d0d0, 0x1a726868, 0x54015555
    .word 0xaf19b6b6, 0x91df4e4e, 0x32fac8c8, 0x30f0c0c0, 0xf621d7d7, 0x8ebc3232, 0xb375c6c6, 0xe06f8f8f
    .word 0x1d697474, 0xf52edbdb, 0xe16a8b8b, 0x2e96b8b8, 0x808a0a0a, 0x67fe9999, 0xc9e22b2b, 0x61e08181
    .word 0xc3c00303, 0x298da4a4, 0x23af8c8c, 0xa907aeae, 0x0d393434, 0x521f4d4d, 0x4f763939, 0x6ed3bdbd
    .word 0xd6815757, 0xd8b76f6f, 0x37ebdcdc, 0x44511515, 0xdda67b7b, 0xfe09f7f7, 0x8cb63a3a, 0x2f93bcbc
    .word 0x030f0c0c, 0xfc03ffff, 0x6bc2a9a9, 0x73bac9c9, 0x6cd9b5b5, 0x6ddcb1b1, 0x5a376d6d, 0x50154545
    .word 0x8fb93636, 0x1b776c6c, 0xad13bebe, 0x90da4a4a, 0xb957eeee, 0xdea97777, 0xbe4cf2f2, 0x7e83fdfd
    .word 0x11554444, 0xdabd6767, 0x5d2c7171, 0x40450505, 0x1f637c7c, 0x10504040, 0x5b326969, 0xdbb86363
    .word 0x0a222828, 0xc2c50707, 0x31f5c4c4, 0x8aa82222, 0xa7319696, 0xcef93737, 0x7a97eded, 0xbf49f6f6
    .word 0x2d99b4b4, 0x75a4d1d1, 0xd3904343, 0x125a4848, 0xba58e2e2, 0xe6719797, 0xb664d2d2, 0xb270c2c2
    .word 0x8bad2626, 0x68cda5a5, 0x95cb5e5e, 0x4b622929, 0x0c3c3030, 0x94ce5a5a, 0x76abdddd, 0x7f86f9f9
    .word 0x64f19595, 0xbb5de6e6, 0xf235c7c7, 0x092d2424, 0xc6d11717, 0x6fd6b9b9, 0xc5de1b1b, 0x86941212
    .word 0x18786060, 0xf330c3c3, 0x7c89f5f5, 0xef5cb3b3, 0x3ad2e8e8, 0xdfac7373, 0x4c793535, 0x20a08080
    .word 0x789de5e5, 0xed56bbbb, 0x5e237d7d, 0x3ec6f8f8, 0xd48b5f5f, 0xc8e72f2f, 0x39dde4e4, 0x49682121

    // XBOX_2
    .word 0x5bd58e5b, 0x4292d042, 0xa7ea4da7, 0xfbfd06fb, 0x33cffc33, 0x87e26587, 0xf43dc9f4, 0xdeb56bde
    .word 0x58164e58, 0xdab46eda, 0x50144450, 0x0bc1ca0b, 0xa02888a0, 0xeff817ef, 0xb02c9cb0, 0x14051114
    .word 0xac2b87ac, 0x9d66fb9d, 0x6a98f26a, 0xd977aed9, 0xa82a82a8, 0xfabc46fa, 0x10041410, 0x0fc0cf0f
    .word 0xaaa802aa, 0x11455411, 0x4c135f4c, 0x9826be98, 0x25486d25, 0x1a849e1a, 0x18061e18, 0x669bfd66
    .word 0x729eec72, 0x09434a09, 0x41511041, 0xd3f724d3, 0x4693d546, 0xbfec53bf, 0x629af862, 0xe97b92e9
    .word 0xcc33ffcc, 0x51550451, 0x2c0b272c, 0x0d424f0d, 0xb7ee59b7, 0x3fccf33f, 0xb2ae1cb2, 0x8963ea89
    .word 0x93e77493, 0xceb17fce, 0x701c6c70, 0xa6ab0da6, 0x27caed27, 0x20082820, 0xa3eb48a3, 0x5697c156
    .word 0x02828002, 0x7fdca37f, 0x5296c452, 0xebf912eb, 0xd574a1d5, 0x3e8db33e, 0xfc3fc3fc, 0x9aa43e9a
    .word 0x1d465b1d, 0x1c071b1c, 0x9ea53b9e, 0xf3ff0cf3, 0xcff03fcf, 0xcd72bfcd, 0x5c174b5c, 0xeab852ea
    .word 0x0e818f0e, 0x65583d65, 0xf03cccf0, 0x64197d64, 0x9be57e9b, 0x16879116, 0x3d4e733d, 0xa2aa08a2
    .word 0xa169c8a1, 0xad6ac7ad, 0x06838506, 0xcab07aca, 0xc570b5c5, 0x9165f491, 0x6bd9b26b, 0x2e89a72e
    .word 0xe3fb18e3, 0xafe847af, 0x3c0f333c, 0x2d4a672d, 0xc171b0c1, 0x59570e59, 0x769fe976, 0xd435e1d4
    .word 0x781e6678, 0x9024b490, 0x380e3638, 0x795f2679, 0x8d62ef8d, 0x61593861, 0x47d29547, 0x8aa02a8a
    .word 0x9425b194, 0x8822aa88, 0xf17d8cf1, 0xec3bd7ec, 0x04010504, 0x8421a584, 0xe17998e1, 0x1e859b1e
    .word 0x53d78453, 0x00000000, 0x19475e19, 0x5d560b5d, 0x7e9de37e, 0x4fd09f4f, 0x9c27bb9c, 0x49531a49
    .word 0x314d7c31, 0xd836eed8, 0x08020a08, 0x9fe47b9f, 0x82a22082, 0x13c7d413, 0x23cbe823, 0x7a9ce67a
    .word 0xabe942ab, 0xfebd43fe, 0x2a88a22a, 0x4bd19a4b, 0x01414001, 0x1fc4db1f, 0xe038d8e0, 0xd6b761d6
    .word 0x8ea12f8e, 0xdff42bdf, 0xcbf13acb, 0x3bcdf63b, 0xe7fa1de7, 0x8560e585, 0x54154154, 0x86a32586
    .word 0x83e36083, 0xbaac16ba, 0x755c2975, 0x92a63492, 0x6e99f76e, 0xd034e4d0, 0x681a7268, 0x55540155
    .word 0xb6af19b6, 0x4e91df4e, 0xc832fac8, 0xc030f0c0, 0xd7f621d7, 0x328ebc32, 0xc6b375c6, 0x8fe06f8f
    .word 0x741d6974, 0xdbf52edb, 0x8be16a8b, 0xb82e96b8, 0x0a808a0a, 0x9967fe99, 0x2bc9e22b, 0x8161e081
    .word 0x03c3c003, 0xa4298da4, 0x8c23af8c, 0xaea907ae, 0x340d3934, 0x4d521f4d, 0x394f7639, 0xbd6ed3bd
    .word 0x57d68157, 0x6fd8b76f, 0xdc37ebdc, 0x15445115, 0x7bdda67b, 0xf7fe09f7, 0x3a8cb63a, 0xbc2f93bc
    .word 0x0c030f0c, 0xfffc03ff, 0xa96bc2a9, 0xc973bac9, 0xb56cd9b5, 0xb16ddcb1, 0x6d5a376d, 0x45501545
    .word 0x368fb936, 0x6c1b776c, 0xbead13be, 0x4a90da4a, 0xeeb957ee, 0x77dea977, 0xf2be4cf2, 0xfd7e83fd
    .word 0x44115544, 0x67dabd67, 0x715d2c71, 0x05404505, 0x7c1f637c, 0x40105040, 0x695b3269, 0x63dbb863
    .word 0x280a2228, 0x07c2c507, 0xc431f5c4, 0x228aa822, 0x96a73196, 0x37cef937, 0xed7a97ed, 0xf6bf49f6
    .word 0xb42d99b4, 0xd175a4d1, 0x43d39043, 0x48125a48, 0xe2ba58e2, 0x97e67197, 0xd2b664d2, 0xc2b270c2
    .word 0x268bad26, 0xa568cda5, 0x5e95cb5e, 0x294b6229, 0x300c3c30, 0x5a94ce5a, 0xdd76abdd, 0xf97f86f9
    .word 0x9564f195, 0xe6bb5de6, 0xc7f235c7, 0x24092d24, 0x17c6d117, 0xb96fd6b9, 0x1bc5de1b, 0x12869412
    .word 0x60187860, 0xc3f330c3, 0xf57c89f5, 0xb3ef5cb3, 0xe83ad2e8, 0x73dfac73, 0x354c7935, 0x8020a080
    .word 0xe5789de5, 0xbbed56bb, 0x7d5e237d, 0xf83ec6f8, 0x5fd48b5f, 0x2fc8e72f, 0xe439dde4, 0x21496821

    // XBOX_3
    .word 0x5b5bd58e, 0x424292d0, 0xa7a7ea4d, 0xfbfbfd06, 0x3333cffc, 0x8787e265, 0xf4f43dc9, 0xdedeb56b
    .word 0x5858164e, 0xdadab46e, 0x50501444, 0x0b0bc1ca, 0xa0a02888, 0xefeff817, 0xb0b02c9c, 0x14140511
    .word 0xacac2b87, 0x9d9d66fb, 0x6a6a98f2, 0xd9d977ae, 0xa8a82a82, 0xfafabc46, 0x10100414, 0x0f0fc0cf
    .word 0xaaaaa802, 0x11114554, 0x4c4c135f, 0x989826be, 0x2525486d, 0x1a1a849e, 0x1818061e, 0x66669bfd
    .word 0x72729eec, 0x0909434a, 0x41415110, 0xd3d3f724, 0x464693d5, 0xbfbfec53, 0x62629af8, 0xe9e97b92
    .word 0xcccc33ff, 0x51515504, 0x2c2c0b27, 0x0d0d424f, 0xb7b7ee59, 0x3f3fccf3, 0xb2b2ae1c, 0x898963ea
    .word 0x9393e774, 0xceceb17f, 0x70701c6c, 0xa6a6ab0d, 0x2727caed, 0x20200828, 0xa3a3eb48, 0x565697c1
    .word 0x02028280, 0x7f7fdca3, 0x525296c4, 0xebebf912, 0xd5d574a1, 0x3e3e8db3, 0xfcfc3fc3, 0x9a9aa43e
    .word 0x1d1d465b, 0x1c1c071b, 0x9e9ea53b, 0xf3f3ff0c, 0xcfcff03f, 0xcdcd72bf, 0x5c5c174b, 0xeaeab852
    .word 0x0e0e818f, 0x6565583d, 0xf0f03ccc, 0x6464197d, 0x9b9be57e, 0x16168791, 0x3d3d4e73, 0xa2a2aa08
    .word 0xa1a169c8, 0xadad6ac7, 0x06068385, 0xcacab07a, 0xc5c570b5, 0x919165f4, 0x6b6bd9b2, 0x2e2e89a7
    .word 0xe3e3fb18, 0xafafe847, 0x3c3c0f33, 0x2d2d4a67, 0xc1c171b0, 0x5959570e, 0x76769fe9, 0xd4d435e1
    .word 0x78781e66, 0x909024b4, 0x38380e36, 0x79795f26, 0x8d8d62ef, 0x61615938, 0x4747d295, 0x8a8aa02a
    .word 0x949425b1, 0x888822aa, 0xf1f17d8c, 0xecec3bd7, 0x04040105, 0x848421a5, 0xe1e17998, 0x1e1e859b
    .word 0x5353d784, 0x00000000, 0x1919475e, 0x5d5d560b, 0x7e7e9de3, 0x4f4fd09f, 0x9c9c27bb, 0x4949531a
    .word 0x31314d7c, 0xd8d836ee, 0x0808020a, 0x9f9fe47b, 0x8282a220, 0x1313c7d4, 0x2323cbe8, 0x7a7a9ce6
    .word 0xababe942, 0xfefebd43, 0x2a2a88a2, 0x4b4bd19a, 0x01014140, 0x1f1fc4db, 0xe0e038d8, 0xd6d6b761
    .word 0x8e8ea12f, 0xdfdff42b, 0xcbcbf13a, 0x3b3bcdf6, 0xe7e7fa1d, 0x858560e5, 0x54541541, 0x8686a325
    .word 0x8383e360, 0xbabaac16, 0x75755c29, 0x9292a634, 0x6e6e99f7, 0xd0d034e4, 0x68681a72, 0x55555401
    .word 0xb6b6af19, 0x4e4e91df, 0xc8c832fa, 0xc0c030f0, 0xd7d7f621, 0x32328ebc, 0xc6c6b375, 0x8f8fe06f
    .word 0x74741d69, 0xdbdbf52e, 0x8b8be16a, 0xb8b82e96, 0x0a0a808a, 0x999967fe, 0x2b2bc9e2, 0x818161e0
    .word 0x0303c3c0, 0xa4a4298d, 0x8c8c23af, 0xaeaea907, 0x34340d39, 0x4d4d521f, 0x39394f76, 0xbdbd6ed3
    .word 0x5757d681, 0x6f6fd8b7, 0xdcdc37eb, 0x15154451, 0x7b7bdda6, 0xf7f7fe09, 0x3a3a8cb6, 0xbcbc2f93
    .word 0x0c0c030f, 0xfffffc03, 0xa9a96bc2, 0xc9c973ba, 0xb5b56cd9, 0xb1b16ddc, 0x6d6d5a37, 0x45455015
    .word 0x36368fb9, 0x6c6c1b77, 0xbebead13, 0x4a4a90da, 0xeeeeb957, 0x7777dea9, 0xf2f2be4c, 0xfdfd7e83
    .word 0x44441155, 0x6767dabd, 0x71715d2c, 0x05054045, 0x7c7c1f63, 0x40401050, 0x69695b32, 0x6363dbb8
    .word 0x28280a22, 0x0707c2c5, 0xc4c431f5, 0x22228aa8, 0x9696a731, 0x3737cef9, 0xeded7a97, 0xf6f6bf49
    .word 0xb4b42d99, 0xd1d175a4, 0x4343d390, 0x4848125a, 0xe2e2ba58, 0x9797e671, 0xd2d2b664, 0xc2c2b270
    .word 0x26268bad, 0xa5a568cd, 0x5e5e95cb, 0x29294b62, 0x30300c3c, 0x5a5a94ce, 0xdddd76ab, 0xf9f97f86
    .word 0x959564f1, 0xe6e6bb5d, 0xc7c7f235, 0x2424092d, 0x1717c6d1, 0xb9b96fd6, 0x1b1bc5de, 0x12128694
    .word 0x60601878, 0xc3c3f330, 0xf5f57c89, 0xb3b3ef5c, 0xe8e83ad2, 0x7373dfac, 0x35354c79, 0x808020a0
    .word 0xe5e5789d, 0xbbbbed56, 0x7d7d5e23, 0xf8f83ec6, 0x5f5fd48b, 0x2f2fc8e7, 0xe4e439dd, 0x21214968

.section .text

.global SM4_ENCrypt_S, SM4_DECrypt_S

SM4_ENCrypt_S:
    PROLOGUE
    Get_XBOX

    li t6, 4
.L1:
    ENC_ROUND_FUNCTION3 t0 t1 t2 t3
    ENC_ROUND_FUNCTION3 t0 t1 t2 t3
    addi t6, t6, -1
    bgt t6, zero, .L1


    EPILOGUE
```

```

SM4_DECrypt_S:
    PROLOGUE
    Get_XBOX

    DEC_ROUND_FUNCTION t0 t1 t2 t3 112
    DEC_ROUND_FUNCTION t0 t1 t2 t3 96
    DEC_ROUND_FUNCTION t0 t1 t2 t3 80
    DEC_ROUND_FUNCTION t0 t1 t2 t3 64
    DEC_ROUND_FUNCTION t0 t1 t2 t3 48
    DEC_ROUND_FUNCTION t0 t1 t2 t3 32
    DEC_ROUND_FUNCTION t0 t1 t2 t3 16
    DEC_ROUND_FUNCTION t0 t1 t2 t3 0

    EPILOGUE
```

参考文献

[1] Xin Miao, Chun Guo, Meiqin Wang, and Weijia Wang. 2022. How Fast Can SM4 be innbsp;Software? In Information Security and Cryptology: 18th International Conference, Inscrypt 2022, Beijing, China, December 11–13, 2022, Revised Selected Papers. Springer-Verlag, Berlin, Heidelberg, 3–22. https://doi.org/10.1007/978-3-031-26553-2_1