SM4 基础实现 +SIMD+T-table

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1 SM4 基础实现

1.1 实验目的

实现 SM4 基础算法。

1.2 实验过程

- 首先根据 SM4 算法描述，SM4 算法对 4 个输入字 (128bit) 进行操作，SM4 算法需要 32 次轮迭代和 1 次反序变换。首先根据密钥生成算法生成每一轮的轮密钥。

  密钥生成算法：将初始密钥 MK 和 FK 的每个字 (32bit) 分别进行异或得到 K。

  接着利用公式

  $$rk_i = K_{i+4} = K_i \bigoplus T'(K_{i+1} \bigoplus K_{i+2} \bigoplus K_{i+3} \bigoplus CK_i), i = 0, 1, \cdots, 31$$

  计算轮密钥。其中 T2 和加密算法中合成置换 T1 相同。

```
/********************密钥拓展实现*********************/
string KeySet(string MK)
{
        string K[36] = { XOR(MK.substr(0,8),FK[0]),XOR(MK.substr(8,8),FK[1]),XOR(MK.substr(16,8),FK[2]),XC
        string rkey = "";
        for (int i = 0; i < 32; i++)
    {
                K[i + 4] = XOR(K[i], T2(XOR(XOR(XOR(K[i + 1], K[i + 2]), K[i + 3]), CK[i])));
                rkey += K[i + 4];
        }
        return rkey;
}
```

- 得到轮密钥后，对明文字进行加密。利用 F 函数，输入四个字和每轮的轮密钥得到一个新的字，迭代 32 轮，最终得到 36 个字，将后四个字反序输出。其中每一轮的 F 函数根据公式

  $$F(X_i, X_{i+1}, X_{i+2}, X_{i+3}, rk_i) = X_i \oplus T(X_{i+1} \oplus X_{i+2} \oplus X_{i+3} \oplus rk_i)$$

  计算得到。

```
/*********************加密函数实现**********************/
string Encryption(string plain, string key)
{
        string cipher[36] = { plain.substr(0,8),plain.substr(8,8),plain.substr(16,8),plain.substr(24) };
        string rkey = KeySet(key);
        for (int i = 0; i < 32; i++)
    {
                cipher[i + 4] = XOR(cipher[i], T1(XOR(XOR(XOR(cipher[i + 1], cipher[i + 2]), cipher[i + 3]
        }
        return cipher[35] + cipher[34] + cipher[33] + cipher[32];
}
```

- 在上述加密函数中引用了 T 函数，T 函数主要包括非线性变化 t 和线性变换 L 两个过程。

  非线性变化 t 是指对输入的每一个字节进行过 S-box 运算。线性变换 L 是指将过 S-box 后得到的结果循环左移，左移公式如下：

$$B = L(B) = B \oplus (B <<< 2) \oplus (B <<< 10) \oplus (B <<< 18) \oplus (B <<< 24)$$

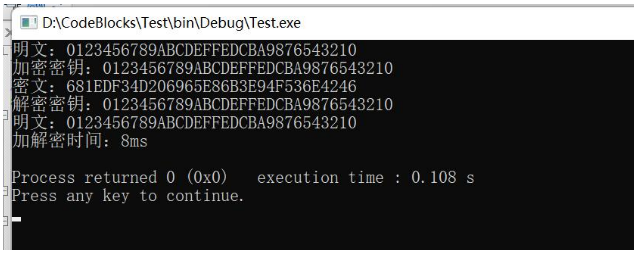
```
/**********非线性变换t函数实现************/
string NLTransform(string str) {

        string res = "";
        for (int i = 0; i < 4; i++) {
                res = res + Sbox[HexToDec(str[2 * i])][HexToDec(str[2 * i + 1])];
        }
        return res;
}

/**********用于加解密算法中的合成置换T函数实现*********/
string T1(string str)
{
    string str1 = "";
    string str2 = "";
    str1 = NLTransform(str);
    str2 = XOR(XOR(XOR(XOR(str1, LeftShift(str1, 2)), LeftShift(str1, 10)), LeftShift(str1, 18)), LeftShif
    return str2;
}
```

1.3 实验结果

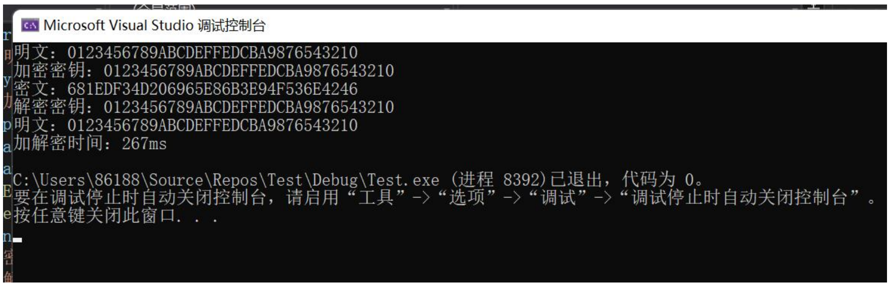
在做实验的过程中，我发现了一个很有趣的事情。我分别在 CodeBlocks 和 VS 上实现了该代码，但是它们的运行时间相差很多，但我并不知道为什么。在两个编译环境下的实验结果如下图：



```
明文：0123456789ABCDEFFEDCBA9876543210
加密密钥：0123456789ABCDEFFEDCBA9876543210
密文：681EDF34D206965E86B3E94F536E4246
解密密钥：0123456789ABCDEFFEDCBA9876543210
明文：0123456789ABCDEFFEDCBA9876543210
加解密时间：8ms

Process returned 0 (0x0)   execution time : 0.108 s
Press any key to continue.
```

图 1: CodeBlocks 上 SM4 基础实现



```
明文：0123456789ABCDEFFEDCBA9876543210
加密密钥：0123456789ABCDEFFEDCBA9876543210
密文：681EDF34D206965E86B3E94F536E4246
解密密钥：0123456789ABCDEFFEDCBA9876543210
明文：0123456789ABCDEFFEDCBA9876543210
加解密时间：267ms

C:\Users\86188\Source\Repos\Test\Debug\Test.exe (进程 8392)已退出，代码为 0。
要在调试停止时自动关闭控制台，请启用“工具”->“选项”->“调试”->“调试停止时自动关闭控制台”。
按任意键关闭此窗口. . .
```

图 2: VS 上 SM4 基础实现

2 SIMD+T-table 实现

2.1 实验目的

最大限度加速 SM4 算法。

2.2 实验过程

首先构造 T-table，将线性变换 L 和过 S-box 这两个过程合并为一个过程，即直接过 4 个 256x32bit 的查找表 (T-table)。这里我将 T-tables 直接列出，方便后续查找。

```
static const uint32_t Table0[] =
{
    0xD55B5B8E, 0x924242D0, 0xEAA7A74D, 0xFDFBFB06, 0xCF3333FC, 0xE2878765,
    0x3DF4F4C9, 0xB5DEDE6B, 0x1658584E, 0xB4DADA6E, 0x14505044, 0xC10B0BCA,
    0x28A0A088, 0xF8EFEF17, 0x2CB0B09C, 0x05141411, 0x2BACAC87, 0x669D9DFB,
    0x986A6AF2, 0x77D9D9AE, 0x2AA8A882, 0xBCFAFA46, 0x04101014, 0xC00F0FCF,
    0xA8AAAA02, 0x45111154, 0x134C4C5F, 0x269898BE, 0x4825256D, 0x841A1A9E,
    0x0618181E, 0x9B6666FD, 0x9E7272EC, 0x4309094A, 0x51414110, 0xF7D3D324,
    0x934646D5, 0xECBFBF53, 0x9A6262F8, 0x7BE9E992, 0x33CCCCFF, 0x55515104,
    0x0B2C2C27, 0x420D0D4F, 0xEEB7B759, 0xCC3F3FF3, 0xAEB2B21C, 0x638989EA,
    0xE7939374, 0xB1CECE7F, 0x1C70706C, 0xABA6A60D, 0xCA2727ED, 0x08202028,
    0xEBA3A348, 0x975656C1, 0x82020280, 0xDC7F7FA3, 0x965252C4, 0xF9EBEB12,
    0x74D5D5A1, 0x8D3E3EB3, 0x3FFCFCC3, 0xA49A9A3E, 0x461D1D5B, 0x071C1C1B,
    0xA59E9E3B, 0xFFF3F30C, 0xF0CFCF3F, 0x72CDCDBF, 0x175C5C4B, 0xB8EAEA52,
    0x810E0E8F, 0x5865653D, 0x3CF0F0CC, 0x1964647D, 0xE59B9B7E, 0x87161691,
    0x4E3D3D73, 0xAAA2A208, 0x69A1A1C8, 0x6AADADC7, 0x83060685, 0xB0CACA7A,
    0x70C5C5B5, 0x659191F4, 0xD96B6BB2, 0x892E2EA7, 0xFBE3E318, 0xE8AFAF47,
    0x0F3C3C33, 0x4A2D2D67, 0x71C1C1B0, 0x5759590E, 0x9F7676E9, 0x35D4D4E1,
    0x1E787866, 0x249090B4, 0x0E383836, 0x5F797926, 0x628D8DEF, 0x59616138,
    0xD2474795, 0xA08A8A2A, 0x259494B1, 0x228888AA, 0x7DF1F18C, 0x3BECECD7,
    0x01040405, 0x218484A5, 0x79E1E198, 0x851E1E9B, 0xD7535384, 0x00000000,
    0x4719195E, 0x565D5D0B, 0x9D7E7EE3, 0xD04F4F9F, 0x279C9CBB, 0x5349491A,
    0x4D31317C, 0x36D8D8EE, 0x0208080A, 0xE49F9F7B, 0xA2828220, 0xC71313D4,
    0xCB2323E8, 0x9C7A7AE6, 0xE9ABAB42, 0xBDFEFE43, 0x882A2AA2, 0xD14B4B9A,
    0x41010140, 0xC41F1FDB, 0x38E0E0D8, 0xB7D6D661, 0xA18E8E2F, 0xF4DFDF2B,
    0xF1CBCB3A, 0xCD3B3BF6, 0xFAE7E71D, 0x608585E5, 0x15545441, 0xA3868625,
    0xE3838360, 0xACBABA16, 0x5C757529, 0xA6929234, 0x996E6EF7, 0x34D0D0E4,
    0x1A686872, 0x54555501, 0xAFB6B619, 0x914E4EDF, 0x32C8C8FA, 0x30C0C0F0,
    0xF6D7D721, 0x8E3232BC, 0xB3C6C675, 0xE08F8F6F, 0x1D747469, 0xF5DBDB2E,
    0xE18B8B6A, 0x2EB8B896, 0x800A0A8A, 0x679999FE, 0xC92B2BE2, 0x618181E0,
    0xC30303C0, 0x29A4A48D, 0x238C8CAF, 0xA9AEAE07, 0x0D343439, 0x524D4D1F,
    0x4F393976, 0x6EBDBDD3, 0xD6575781, 0xD86F6FB7, 0x37DCDCEB, 0x44151551,
    0xDD7B7BA6, 0xFEF7F709, 0x8C3A3AB6, 0x2FBCBC93, 0x030C0C0F, 0xFCFFFF03,
    0x6BA9A9C2, 0x73C9C9BA, 0x6CB5B5D9, 0x6DB1B1DC, 0x5A6D6D37, 0x50454515,
    0x8F3636B9, 0x1B6C6C77, 0xADBEBE13, 0x904A4ADA, 0xB9EEEE57, 0xDE7777A9,
    0xBEF2F24C, 0x7EFDFD83, 0x11444455, 0xDA6767BD, 0x5D71712C, 0x40050545,
    0x1F7C7C63, 0x10404050, 0x5B696932, 0xDB6363B8, 0x0A282822, 0xC20707C5,
    0x31C4C4F5, 0x8A2222A8, 0xA7969631, 0xCE3737F9, 0x7AEDED97, 0xBFF6F649,
    0x2DB4B499, 0x75D1D1A4, 0xD3434390, 0x1248485A, 0xBAE2E258, 0xE6979771,
    0xB6D2D264, 0xB2C2C270, 0x8B2626AD, 0x68A5A5CD, 0x955E5ECB, 0x4B292962,
    0x0C30303C, 0x945A5ACE, 0x76DDDDAB, 0x7FF9F986, 0x649595F1, 0xBBE6E65D,
    0xF2C7C735, 0x0924242D, 0xC61717D1, 0x6FB9B9D6, 0xC51B1BDE, 0x86121294,
    0x18606078, 0xF3C3C330, 0x7CF5F589, 0xEFB3B35C, 0x3AE8E8D2, 0xDF7373AC,
    0x4C353579, 0x208080A0, 0x78E5E59D, 0xEDBBBB56, 0x5E7D7D23, 0x3EF8F8C6,
    0xD45F5F8B, 0xC82F2FE7, 0x39E4E4DD, 0x49212168
};
static const uint32_t Table1[] =
{
    0x5B5B8ED5, 0x4242D092, 0xA7A74DEA, 0xFBFB06FD, 0x3333FCCF, 0x878765E2,
    0xF4F4C93D, 0xDEDE6BB5, 0x58584E16, 0xDADA6EB4, 0x50504414, 0x0B0BCAC1,
    0xA0A08828, 0xEFEF17F8, 0xB0B09C2C, 0x14141105, 0xACAC872B, 0x9D9DFB66,
    0x6A6AF298, 0xD9D9AE77, 0xA8A8822A, 0xFAFA46BC, 0x10101404, 0x0F0FCFC0,
    0xAAAA02A8, 0x11115445, 0x4C4C5F13, 0x9898BE26, 0x25256D48, 0x1A1A9E84,
    0x18181E06, 0x6666FD9B, 0x7272EC9E, 0x09094A43, 0x41411051, 0xD3D324F7,
    0x4646D593, 0xBFBF53EC, 0x6262F89A, 0xE9E9927B, 0xCCCCFF33, 0x51510455,
    0x2C2C270B, 0x0D0D4F42, 0xB7B759EE, 0x3F3FF3CC, 0xB2B21CAE, 0x8989EA63,
    0x939374E7, 0xCECE7FB1, 0x70706C1C, 0xA6A60DAB, 0x2727EDCA, 0x20202808,
    0xA3A348EB, 0x5656C197, 0x02028082, 0x7F7FA3DC, 0x5252C496, 0xEBEB12F9,
    0xD5D5A174, 0x3E3EB38D, 0xFCFCC33F, 0x9A9A3EA4, 0x1D1D5B46, 0x1C1C1B07,
    0x9E9E3BA5, 0xF3F30CFF, 0xCFCF3FF0, 0xCDCDBF72, 0x5C5C4B17, 0xEAEA52B8,
    0x0E0E8F81, 0x65653D58, 0xF0F0CC3C, 0x64647D19, 0x9B9B7EE5, 0x16169187,
    0x3D3D734E, 0xA2A208AA, 0xA1A1C869, 0xADADC76A, 0x06068583, 0xCACA7AB0,
    0xC5C5B570, 0x9191F465, 0x6B6BB2D9, 0x2E2EA789, 0xE3E318FB, 0xAFAF47E8,
    0x3C3C330F, 0x2D2D674A, 0xC1C1B071, 0x59590E57, 0x7676E99F, 0xD4D4E135,
    0x7878661E, 0x9090B424, 0x3838360E, 0x7979265F, 0x8D8DEF62, 0x61613859,
    0x474795D2, 0x8A8A2AA0, 0x9494B125, 0x8888AA22, 0xF1F18C7D, 0xECECD73B,
    0x04040501, 0x8484A521, 0xE1E19879, 0x1E1E9B85, 0x535384D7, 0x00000000,
    0x19195E47, 0x5D5D0B56, 0x7E7EE39D, 0x4F4F9FD0, 0x9C9CBB27, 0x49491A53,
    0x31317C4D, 0xD8D8EE36, 0x08080A02, 0x9F9F7BE4, 0x828220A2, 0x1313D4C7,
    0x2323E8CB, 0x7A7AE69C, 0xABAB42E9, 0xFEFE43BD, 0x2A2AA288, 0x4B4B9AD1,
    0x01014041, 0x1F1FDBC4, 0xE0E0D838, 0xD6D661B7, 0x8E8E2FA1, 0xDFDF2BF4,
    0xCBCB3AF1, 0x3B3BF6CD, 0xE7E71DFA, 0x8585E560, 0x54544115, 0x868625A3,
    0x838360E3, 0xBABA16AC, 0x7575295C, 0x929234A6, 0x6E6EF799, 0xD0D0E434,
    0x6868721A, 0x55550154, 0xB6B619AF, 0x4E4EDF91, 0xC8C8FA32, 0xC0C0F030,
    0xD7D721F6, 0x3232BC8E, 0xC6C675B3, 0x8F8F6FE0, 0x7474691D, 0xDBDB2EF5,
    0x8B8B6AE1, 0xB8B8962E, 0x0A0A8A80, 0x9999FE67, 0x2B2BE2C9, 0x8181E061,
    0x0303C0C3, 0xA4A48D29, 0x8C8CAF23, 0xAEAE07A9, 0x3434390D, 0x4D4D1F52,
    0x3939764F, 0xBDBDD36E, 0x575781D6, 0x6F6FB7D8, 0xDCDCEB37, 0x15155144,
    0x7B7BA6DD, 0xF7F709FE, 0x3A3AB68C, 0xBCBC932F, 0x0C0C0F03, 0xFFFF03FC,
    0xA9A9C26B, 0xC9C9BA73, 0xB5B5D96C, 0xB1B1DC6D, 0x6D6D375A, 0x45451550,
    0x3636B98F, 0x6C6C771B, 0xBEBE13AD, 0x4A4ADA90, 0xEEEE57B9, 0x7777A9DE,
    0xF2F24CBE, 0xFDFD837E, 0x44445511, 0x6767BDDA, 0x71712C5D, 0x05054540,
    0x7C7C631F, 0x40405010, 0x6969325B, 0x6363B8DB, 0x2828220A, 0x0707C5C2,
    0xC4C4F531, 0x2222A88A, 0x969631A7, 0x3737F9CE, 0xEDED977A, 0xF6F649BF,
    0xB4B4992D, 0xD1D1A475, 0x434390D3, 0x48485A12, 0xE2E258BA, 0x979771E6,
    0xD2D264B6, 0xC2C270B2, 0x2626AD8B, 0xA5A5CD68, 0x5E5ECB95, 0x2929624B,
    0x30303C0C, 0x5A5ACE94, 0xDDDDAB76, 0xF9F9867F, 0x9595F164, 0xE6E65DBB,
    0xC7C735F2, 0x24242D09, 0x1717D1C6, 0xB9B9D66F, 0x1B1BDEC5, 0x12129486,
    0x60607818, 0xC3C330F3, 0xF5F5897C, 0xB3B35CEF, 0xE8E8D23A, 0x7373ACDF,
    0x3535794C, 0x8080A020, 0xE5E59D78, 0xBBBB56ED, 0x7D7D235E, 0xF8F8C63E,
    0x5F5F8BD4, 0x2F2FE7C8, 0xE4E4DD39, 0x21216849
};
static const uint32_t Table2[] =
{
    0x5B8ED55B, 0x42D09242, 0xA74DEAA7, 0xFB06FDFB, 0x33FCCF33, 0x8765E287,
    0xF4C93DF4, 0xDE6BB5DE, 0x584E1658, 0xDA6EB4DA, 0x50441450, 0x0BCAC10B,
    0xA08828A0, 0xEF17F8EF, 0xB09C2CB0, 0x14110514, 0xAC872BAC, 0x9DFB669D,
    0x6AF2986A, 0xD9AE77D9, 0xA8822AA8, 0xFA46BCFA, 0x10140410, 0x0FCFC00F,
    0xAA02A8AA, 0x11544511, 0x4C5F134C, 0x98BE2698, 0x256D4825, 0x1A9E841A,
    0x181E0618, 0x66FD9B66, 0x72EC9E72, 0x094A4309, 0x41105141, 0xD324F7D3,
    0x46D59346, 0xBF53ECBF, 0x62F89A62, 0xE9927BE9, 0xCCFF33CC, 0x51045551,
    0x2C270B2C, 0x0D4F420D, 0xB759EEB7, 0x3FF3CC3F, 0xB21CAEB2, 0x89EA6389,
    0x9374E793, 0xCE7FB1CE, 0x706C1C70, 0xA60DABA6, 0x27EDCA27, 0x20280820,
    0xA348EBA3, 0x56C19756, 0x02808202, 0x7FA3DC7F, 0x52C49652, 0xEB12F9EB,
    0xD5A174D5, 0x3EB38D3E, 0xFCC33FFC, 0x9A3EA49A, 0x1D5B461D, 0x1C1B071C,
    0x9E3BA59E, 0xF30CFFF3, 0xCF3FF0CF, 0xCDBF72CD, 0x5C4B175C, 0xEA52B8EA,
    0x0E8F810E, 0x653D5865, 0xF0CC3CF0, 0x647D1964, 0x9B7EE59B, 0x16918716,
    0x3D734E3D, 0xA208AAA2, 0xA1C869A1, 0xADC76AAD, 0x06858306, 0xCA7AB0CA,
    0xC5B570C5, 0x91F46591, 0x6BB2D96B, 0x2EA7892E, 0xE318FBE3, 0xAF47E8AF,
    0x3C330F3C, 0x2D674A2D, 0xC1B071C1, 0x590E5759, 0x76E99F76, 0xD4E135D4,
    0x78661E78, 0x90B42490, 0x38360E38, 0x79265F79, 0x8DEF628D, 0x61385961,
    0x4795D247, 0x8A2AA08A, 0x94B12594, 0x88AA2288, 0xF18C7DF1, 0xECD73BEC,
    0x04050104, 0x84A52184, 0xE19879E1, 0x1E9B851E, 0x5384D753, 0x00000000,
    0x195E4719, 0x5D0B565D, 0x7EE39D7E, 0x4F9FD04F, 0x9CBB279C, 0x491A5349,
    0x317C4D31, 0xD8EE36D8, 0x080A0208, 0x9F7BE49F, 0x8220A282, 0x13D4C713,
    0x23E8CB23, 0x7AE69C7A, 0xAB42E9AB, 0xFE43BDFE, 0x2AA2882A, 0x4B9AD14B,
    0x01404101, 0x1FDBC41F, 0xE0D838E0, 0xD661B7D6, 0x8E2FA18E, 0xDF2BF4DF,
    0xCB3AF1CB, 0x3BF6CD3B, 0xE71DFAE7, 0x85E56085, 0x54411554, 0x8625A386,
    0x8360E383, 0xBA16ACBA, 0x75295C75, 0x9234A692, 0x6EF7996E, 0xD0E434D0,
    0x68721A68, 0x55015455, 0xB619AFB6, 0x4EDF914E, 0xC8FA32C8, 0xC0F030C0,
    0xD721F6D7, 0x32BC8E32, 0xC675B3C6, 0x8F6FE08F, 0x74691D74, 0xDB2EF5DB,
    0x8B6AE18B, 0xB8962EB8, 0x0A8A800A, 0x99FE6799, 0x2BE2C92B, 0x81E06181,
    0x03C0C303, 0xA48D29A4, 0x8CAF238C, 0xAE07A9AE, 0x34390D34, 0x4D1F524D,
    0x39764F39, 0xBDD36EBD, 0x5781D657, 0x6FB7D86F, 0xDCEB37DC, 0x15514415,
    0x7BA6DD7B, 0xF709FEF7, 0x3AB68C3A, 0xBC932FBC, 0x0C0F030C, 0xFF03FCFF,
    0xA9C26BA9, 0xC9BA73C9, 0xB5D96CB5, 0xB1DC6DB1, 0x6D375A6D, 0x45155045,
    0x36B98F36, 0x6C771B6C, 0xBE13ADBE, 0x4ADA904A, 0xEE57B9EE, 0x77A9DE77,
    0xF24CBEF2, 0xFD837EFD, 0x44551144, 0x67BDDA67, 0x712C5D71, 0x05454005,
    0x7C631F7C, 0x40501040, 0x69325B69, 0x63B8DB63, 0x28220A28, 0x07C5C207,
    0xC4F531C4, 0x22A88A22, 0x9631A796, 0x37F9CE37, 0xED977AED, 0xF649BFF6,
    0xB4992DB4, 0xD1A475D1, 0x4390D343, 0x485A1248, 0xE258BAE2, 0x9771E697,
    0xD264B6D2, 0xC270B2C2, 0x26AD8B26, 0xA5CD68A5, 0x5ECB955E, 0x29624B29,
    0x303C0C30, 0x5ACE945A, 0xDDAB76DD, 0xF9867FF9, 0x95F16495, 0xE65DBBE6,
    0xC735F2C7, 0x242D0924, 0x17D1C617, 0xB9D66FB9, 0x1BDEC51B, 0x12948612,
    0x60781860, 0xC330F3C3, 0xF5897CF5, 0xB35CEFB3, 0xE8D23AE8, 0x73ACDF73,
    0x35794C35, 0x80A02080, 0xE59D78E5, 0xBB56EDBB, 0x7D235E7D, 0xF8C63EF8,
    0x5F8BD45F, 0x2FE7C82F, 0xE4DD39E4, 0x21684921
};
static const uint32_t Table3[] =
{
    0x8ED55B5B, 0xD0924242, 0x4DEAA7A7, 0x06FDFBFB, 0xFCCF3333, 0x65E28787,
    0xC93DF4F4, 0x6BB5DEDE, 0x4E165858, 0x6EB4DADA, 0x44145050, 0xCAC10B0B,
    0x8828A0A0, 0x17F8EFEF, 0x9C2CB0B0, 0x11051414, 0x872BACAC, 0xFB669D9D,
    0xF2986A6A, 0xAE77D9D9, 0x822AA8A8, 0x46BCFAFA, 0x14041010, 0xCFC00F0F,
    0x02A8AAAA, 0x54451111, 0x5F134C4C, 0xBE269898, 0x6D482525, 0x9E841A1A,
    0x1E061818, 0xFD9B6666, 0xEC9E7272, 0x4A430909, 0x10514141, 0x24F7D3D3,
    0xD5934646, 0x53ECBFBF, 0xF89A6262, 0x927BE9E9, 0xFF33CCCC, 0x04555151,
    0x270B2C2C, 0x4F420D0D, 0x59EEB7B7, 0xF3CC3F3F, 0x1CAEB2B2, 0xEA638989,
    0x74E79393, 0x7FB1CECE, 0x6C1C7070, 0x0DABA6A6, 0xEDCA2727, 0x28082020,
    0x48EBA3A3, 0xC1975656, 0x80820202, 0xA3DC7F7F, 0xC4965252, 0x12F9EBEB,
    0xA174D5D5, 0xB38D3E3E, 0xC33FFCFC, 0x3EA49A9A, 0x5B461D1D, 0x1B071C1C,
    0x3BA59E9E, 0x0CFFF3F3, 0x3FF0CFCF, 0xBF72CDCD, 0x4B175C5C, 0x52B8EAEA,
    0x8F810E0E, 0x3D586565, 0xCC3CF0F0, 0x7D196464, 0x7EE59B9B, 0x91871616,
    0x734E3D3D, 0x08AAA2A2, 0xC869A1A1, 0xC76AADAD, 0x85830606, 0x7AB0CACA,
    0xB570C5C5, 0xF4659191, 0xB2D96B6B, 0xA7892E2E, 0x18FBE3E3, 0x47E8AFAF,
    0x330F3C3C, 0x674A2D2D, 0xB071C1C1, 0x0E575959, 0xE99F7676, 0xE135D4D4,
    0x661E7878, 0xB4249090, 0x360E3838, 0x265F7979, 0xEF628D8D, 0x38596161,
    0x95D24747, 0x2AA08A8A, 0xB1259494, 0xAA228888, 0x8C7DF1F1, 0xD73BECEC,
    0x05010404, 0xA5218484, 0x9879E1E1, 0x9B851E1E, 0x84D75353, 0x00000000,
    0x5E471919, 0x0B565D5D, 0xE39D7E7E, 0x9FD04F4F, 0xBB279C9C, 0x1A534949,
    0x7C4D3131, 0xEE36D8D8, 0x0A020808, 0x7BE49F9F, 0x20A28282, 0xD4C71313,
    0xE8CB2323, 0xE69C7A7A, 0x42E9ABAB, 0x43BDFEFE, 0xA2882A2A, 0x9AD14B4B,
    0x40410101, 0xDBC41F1F, 0xD838E0E0, 0x61B7D6D6, 0x2FA18E8E, 0x2BF4DFDF,
    0x3AF1CBCB, 0xF6CD3B3B, 0x1DFAE7E7, 0xE5608585, 0x41155454, 0x25A38686,
    0x60E38383, 0x16ACBABA, 0x295C7575, 0x34A69292, 0xF7996E6E, 0xE434D0D0,
    0x721A6868, 0x01545555, 0x19AFB6B6, 0xDF914E4E, 0xFA32C8C8, 0xF030C0C0,
    0x21F6D7D7, 0xBC8E3232, 0x75B3C6C6, 0x6FE08F8F, 0x691D7474, 0x2EF5DBDB,
    0x6AE18B8B, 0x962EB8B8, 0x8A800A0A, 0xFE679999, 0xE2C92B2B, 0xE0618181,
    0xC0C30303, 0x8D29A4A4, 0xAF238C8C, 0x07A9AEAE, 0x390D3434, 0x1F524D4D,
    0x764F3939, 0xD36EBDBD, 0x81D65757, 0xB7D86F6F, 0xEB37DCDC, 0x51441515,
    0xA6DD7B7B, 0x09FEF7F7, 0xB68C3A3A, 0x932FBCBC, 0x0F030C0C, 0x03FCFFFF,
    0xC26BA9A9, 0xBA73C9C9, 0xD96CB5B5, 0xDC6DB1B1, 0x375A6D6D, 0x15504545,
    0xB98F3636, 0x771B6C6C, 0x13ADBEBE, 0xDA904A4A, 0x57B9EEEE, 0xA9DE7777,
    0x4CBEF2F2, 0x837EFDFD, 0x55114444, 0xBDDA6767, 0x2C5D7171, 0x45400505,
    0x631F7C7C, 0x50104040, 0x325B6969, 0xB8DB6363, 0x220A2828, 0xC5C20707,
    0xF531C4C4, 0xA88A2222, 0x31A79696, 0xF9CE3737, 0x977AEDED, 0x49BFF6F6,
    0x992DB4B4, 0xA475D1D1, 0x90D34343, 0x5A124848, 0x58BAE2E2, 0x71E69797,
    0x64B6D2D2, 0x70B2C2C2, 0xAD8B2626, 0xCD68A5A5, 0xCB955E5E, 0x624B2929,
    0x3C0C3030, 0xCE945A5A, 0xAB76DDDD, 0x867FF9F9, 0xF1649595, 0x5DBBE6E6,
    0x35F2C7C7, 0x2D092424, 0xD1C61717, 0xD66FB9B9, 0xDEC51B1B, 0x94861212,
    0x78186060, 0x30F3C3C3, 0x897CF5F5, 0x5CEFB3B3, 0xD23AE8E8, 0xACDF7373,
    0x794C3535, 0xA0208080, 0x9D78E5E5, 0x56EDBBBB, 0x235E7D7D, 0xC63EF8F8,
    0x8BD45F5F, 0xE7C82F2F, 0xDD39E4E4, 0x68492121
};
```

利用 SIMD 进行加速的实质是使其多线程化，即我们可以将原本需要串行的操作并行化，这里我选择利用 256bit 的向量寄存器。

因为 SM4 是以字节为单位进行加密的，即每 32bit 就需要进行移位等操作，因此利用 256bit 的向量寄存器即可存储 8 组 32bit 的字，这样就可以使得这 8 组字同时进行操作。

首先我们在 main 函数中实现了密钥扩展方案，实现方法和 SM4 基础实现相同，这里不多加赘述。

接着我们实现加密函数。

首先我们需要将数据 load 进寄存器中 (SIMD 指令特点，需要 load 和 store，相当于计组中的从存储器像寄存器中存取数的指令)。

接下来我们定义一个数组变量 x，分别对应第 i 个分组 (每组 8 个 32bit 字)。

然后就像实现 SM4 基础实现一样，我们需要经过 32 轮迭代 (和 SM4 基础实现中公式相同)。

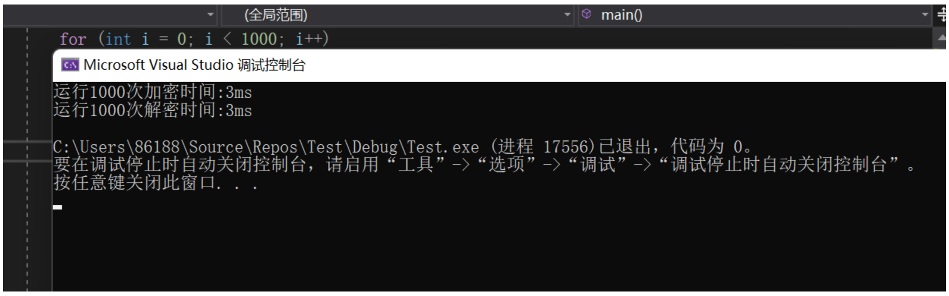
在迭代过程中，我利用 SSE 中的 shuffle_epi8 指令替换掉了非线性变换 t，线性变换 L 和过 S-box 也替换成了查 T-table，代码段中 for(0-32) 循环即为查表阶段。

最后从寄存器中 store 出数据到存储器中。

```
void SM4_Encrypt(uint8_t* cin, uint8_t* out, uint32_t* sm4_key)
{
    __m256i x[4];
    __m256i temp[4];
    __m256i ff;
    __m256i* cin_ = (__m256i*)cin;
    ff = _mm256_set1_epi32(0xFF);
    temp[0] = _mm256_loadu_si256(cin_ + 0);
    temp[1] = _mm256_loadu_si256(cin_ + 1);
    temp[2] = _mm256_loadu_si256(cin_ + 2);
    temp[3] = _mm256_loadu_si256(cin_ + 3);
    x[0] = MM256_EPI32_0(temp[0], temp[1], temp[2], temp[3]);
    x[1] = MM256_EPI32_1(temp[0], temp[1], temp[2], temp[3]);
    x[2] = MM256_EPI32_2(temp[0], temp[1], temp[2], temp[3]);
    x[3] = MM256_EPI32_3(temp[0], temp[1], temp[2], temp[3]);
    __m256i vindex = _mm256_setr_epi8(2, 3, 1, 0, 7, 6, 5, 4, 11, 10, 9, 8, 15, 14, 13, 12, 2, 3, 1, 0, 7, 6, 5
    x[0] = _mm256_shuffle_epi8(x[0], vindex);
    x[1] = _mm256_shuffle_epi8(x[1], vindex);
    x[2] = _mm256_shuffle_epi8(x[2], vindex);
    x[3] = _mm256_shuffle_epi8(x[3], vindex);
    for (int i = 0; i < 32; i++)
    {
        __m256i k = _mm256_set1_epi32(sm4_key[i]);
        temp[0] = _mm256_xor_si256(_mm256_xor_si256(x[1], x[2]), _mm256_xor_si256(x[3], k));
        temp[1] = _mm256_xor_si256(x[0], _mm256_i32gather_epi32((const int*)Table0, _mm256_and_si256(temp[0], f
        temp[0] = _mm256_srli_epi32(temp[0], 8);
        temp[1] = _mm256_xor_si256(temp[1], _mm256_i32gather_epi32((const int*)Table1, _mm256_and_si256(temp[0]
        temp[0] = _mm256_srli_epi32(temp[0], 8);
        temp[1] = _mm256_xor_si256(temp[1], _mm256_i32gather_epi32((const int*)Table2, _mm256_and_si256(temp[0]
        temp[0] = _mm256_srli_epi32(temp[0], 8);
        temp[1] = _mm256_xor_si256(temp[1], _mm256_i32gather_epi32((const int*)Table3, _mm256_and_si256(temp[0]
        x[0] = x[1];
        x[1] = x[2];
        x[2] = x[3];
        x[3] = temp[1];
    }
    x[0] = _mm256_shuffle_epi8(x[0], vindex);
    x[1] = _mm256_shuffle_epi8(x[1], vindex);
    x[2] = _mm256_shuffle_epi8(x[2], vindex);
    x[3] = _mm256_shuffle_epi8(x[3], vindex);
    _mm256_storeu_si256((__m256i*)out + 0, MM256_EPI32_0(x[3], x[2], x[1], x[0]));
    _mm256_storeu_si256((__m256i*)out + 1, MM256_EPI32_1(x[3], x[2], x[1], x[0]));
    _mm256_storeu_si256((__m256i*)out + 2, MM256_EPI32_2(x[3], x[2], x[1], x[0]));
    _mm256_storeu_si256((__m256i*)out + 3, MM256_EPI32_3(x[3], x[2], x[1], x[0]));
}
```

2.3 实验结果

由于 CodeBlocks 的编译环境，我未能成功导入 immintrin.h 头文件，导致无法实现 SIMD 指令集的加速，所以我仅仅实现了在 VS 环境中的，请注意结果的时间是加解密 1000 次以后的结果。



```
for (int i = 0; i < 1000; i++)
```

```
运行1000次加密时间:3ms
运行1000次解密时间:3ms

C:\Users\86188\Source\Repos\Test\Debug\Test.exe (进程 17556)已退出，代码为 0。
要在调试停止时自动关闭控制台，请启用“工具”->“选项”->“调试”->“调试停止时自动关闭控制台”。
按任意键关闭此窗口. . .
```

图 3: VS 上 SM4 基础实现

3 参考文献

3.1 基础实现

国密 SM4 算法
SM4 算法的 C++ 实现

3.2 SIMD+T-table 实现

SM4 SIMD 指令集优化 (intel)
SM4 的快速软件实现技术

4 附录

4.1 SM4 基础代码实现

```
#include <iostream>
#include <string>
#include <cmath>
#include <time.h>

using namespace std;

string Sbox[16][16] = { {"D6","90","E9","FE","CC","E1","3D","B7","16","B6","14","C2","28","FB","2C","05"},
                        {"2B","67","9A","76","2A","BE","04","C3","AA","44","13","26","49","86","06",
                        {"9C","42","50","F4","91","EF","98","7A","33","54","0B","43","ED","CF","AC",
                        {"E4","B3","1C","A9","C9","08","E8","95","80","DF","94","FA","75","8F","3F",
                        {"47","07","A7","FC","F3","73","17","BA","83","59","3C","19","E6","85","4F",
                        {"68","6B","81","B2","71","64","DA","8B","F8","EB","0F","4B","70","56","9D",
                        {"1E","24","0E","5E","63","58","D1","A2","25","22","7C","3B","01","21","78",
                        {"D4","00","46","57","9F","D3","27","52","4C","36","02","E7","A0","C4","C8",
                        {"EA","BF","8A","D2","40","C7","38","B5","A3","F7","F2","CE","F9","61","15",
                        {"E0","AE","5D","A4","9B","34","1A","55","AD","93","32","30","F5","8C","B1",
                        {"1D","F6","E2","2E","82","66","CA","60","C0","29","23","AB","0D","53","4E",
                        {"D5","DB","37","45","DE","FD","8E","2F","03","FF","6A","72","6D","6C","5B",
                        {"8D","1B","AF","92","BB","DD","BC","7F","11","D9","5C","41","1F","10","5A",
                        {"0A","C1","31","88","A5","CD","7B","BD","2D","74","D0","12","B8","E5","B4",
                        {"89","69","97","4A","0C","96","77","7E","65","B9","F1","09","C5","6E","C6",
                        {"18","F0","7D","EC","3A","DC","4D","20","79","EE","5F","3E","D7","CB","39",
string FK[4] = { "A3B1BAC6", "56AA3350", "677D9197", "B27022DC" };
string CK[32] = { "00070E15", "1C232A31", "383F464D", "545B6269",
                  "70777E85", "8C939AA1", "A8AFB6BD", "C4CBD2D9",
                  "E0E7EEF5", "FC030A11", "181F262D", "343B4249",
                  "50575E65", "6C737A81", "888F969D", "A4ABB2B9",
                  "C0C7CED5", "DCE3EAF1", "F8FF060D", "141B2229",
                  "30373E45", "4C535A61", "686F767D", "848B9299",
                  "A0A7AEB5", "BCC3CAD1", "D8DFE6ED", "F4FB0209",
                  "10171E25", "2C333A41", "484F565D", "646B7279" };

/***************2进制转16进制****************/
string BinToHex(string str)
{
        string hex = "";
        int temp = 0;
        while(str.size() % 4 != 0)
```

```
    {
                str = "0" + str;
        }
        for (int i = 0; i < str.size(); i += 4)
    {
                temp = (str[i] - '0') * 8 + (str[i + 1] - '0') * 4 + (str[i + 2] - '0') * 2 + (str[i + 3] - '0'
                if (temp < 10)
                {
                        hex += to_string(temp);
                }
                else
                {
                        hex += 'A' + (temp - 10);
                }
        }
        return hex;
}

/***************16进制转2进制*****************/
string HexToBin(string str)
{
        string bin = "";
        string table[16] = { "0000","0001","0010","0011","0100","0101","0110","0111","1000","1001","1010","1011
        for (int i = 0; i < str.size(); i++)
    {
                if (str[i] >= 'A'&&str[i] <= 'F')
                {
                        bin += table[str[i] - 'A' + 10];
                }
                else
                {
                        bin += table[str[i] - '0'];
                }
        }
        return bin;
}

/***************16进制转10进制*****************/
int HexToDec(char str)
{
        int dec = 0;
        if (str >= 'A' && str <= 'F')
    {
                dec += (str - 'A' + 10);
        }
        else
        {
                dec += (str - '0');
        }
        return dec;
}

/************循环左移len位函数实现**************/
string LeftShift(string str, int len) {
        string res = HexToBin(str);
        res = res.substr(len) + res.substr(0, len);
        res = BinToHex(res);
        return res;
}
```

```

/*************字符串异或函数实现***************/
string XOR(string str1, string str2)
{
        string res1 = HexToBin(str1);
        string res2 = HexToBin(str2);
        string res = ””;
        for (int i = 0; i < res1.size(); i++)
        {
                if (res1[i] == res2[i])
        {
                        res += ”0”;
                }
                else
                {
                        res += ”1”;
                }
        }
        res = BinToHex(res);
        return res;
}

/**********非线性变换t函数实现************/
string NLTransform(string str) {

        string res = ””;
        for (int i = 0; i < 4; i++) {
                res = res + Sbox[HexToDec(str[2 * i])][HexToDec(str[2 * i + 1])];
        }
        return res;
}

/**********用于加解密算法中的合成置换T函数实现*********/
string T1(string str)
{
    string str1 = ””;
    string str2 = ””;
    str1 = NLTransform(str);
    str2 = XOR(XOR(XOR(XOR(str1, LeftShift(str1, 2)), LeftShift(str1, 10)), LeftShift(str1, 18)), LeftShift(str1
    return str2;
}

/**********用于密钥拓展算法中的合成置换T函数实现*********/
string T2(string str)
{
    string str1 = ””;
    string str2 = ””;
    str1 = NLTransform(str);
    str2 = XOR(XOR(str1, LeftShift(str1, 13)), LeftShift(str1, 23));
    return str2;
}

/*******************密钥拓展实现********************/
string KeySet(string MK)
{
        string K[36] = { XOR(MK.substr(0,8),FK[0]),XOR(MK.substr(8,8),FK[1]),XOR(MK.substr(16,8),FK[2]),XOR(MK.
        string rkey = ””;
        for (int i = 0; i < 32; i++)
    {
```

```
                K[i + 4] = XOR(K[i], T2(XOR(XOR(XOR(K[i + 1], K[i + 2]), K[i + 3]), CK[i])));
                rkey += K[i + 4];
        }
        return rkey;
}

/*********************加密函数实现***********************/
string Encryption(string plain, string key)
{
        string cipher[36] = { plain.substr(0,8),plain.substr(8,8),plain.substr(16,8),plain.substr(24) };
        string rkey = KeySet(key);
        for (int i = 0; i < 32; i++)
     {
                cipher[i + 4] = XOR(cipher[i], T1(XOR(XOR(XOR(cipher[i + 1], cipher[i + 2]), cipher[i + 3]), rke
        }
        return cipher[35] + cipher[34] + cipher[33] + cipher[32];
}

/*********************解密函数实现***********************/
string Decryption(string cipher, string key)
{
        string plain[36] = { cipher.substr(0,8),cipher.substr(8,8), cipher.substr(16,8), cipher.substr(24,8) };
        string rkey = KeySet(key);
        for (int i = 0; i < 32; i++)
     {
                plain[i + 4] = XOR(plain[i], T1(XOR(XOR(XOR(plain[i + 1], plain[i + 2]), plain[i + 3]), rkey.su
        }
        return plain[35] + plain[34] + plain[33] + plain[32];
}

int main()
{
        string str = "0123456789ABCDEFFEDCBA9876543210";
        cout << "明文: " << str << endl;
        string key = "0123456789ABCDEFFEDCBA9876543210";
        cout << "加密密钥: " << key << endl;
        string cipher;
        string plain;
        double start = clock();
     cipher = Encryption(str, key);
     plain = Decryption(cipher, key);
        double finish = clock();
        cout << "密文: " << cipher << endl;
        cout << "解密密钥: " << key << endl;
        cout << "明文: " << plain << endl;
        cout << "加解密时间: " << finish - start << "ms" << endl;
        return 0;
}
```

4.2 SIMD+T-table 代码实现

```
#include <iostream>
#include <string>
#include <cmath>
#include <thread>
#include <immintrin.h>
#include <time.h>

```

```
#define MM256_EPI32_0(a, b, c, d) _mm256_unpacklo_epi64(_mm256_unpacklo_epi32(a, b),_mm256_unpacklo_epi32(c, d)
#define MM256_EPI32_1(a, b, c, d) _mm256_unpackhi_epi64(_mm256_unpacklo_epi32(a, b),_mm256_unpacklo_epi32(c, d)
#define MM256_EPI32_2(a, b, c, d) _mm256_unpacklo_epi64(_mm256_unpackhi_epi32(a, b),_mm256_unpackhi_epi32(c, d)
#define MM256_EPI32_3(a, b, c, d) _mm256_unpackhi_epi64(_mm256_unpackhi_epi32(a, b),_mm256_unpackhi_epi32(c, d)

using namespace std;

static uint32_t FK[4] = { 0xa3b1bac6, 0x56aa3350, 0x677d9197, 0xb27022dc };
static uint32_t CK[32] =
{
    0x00070e15, 0x1c232a31, 0x383f464d, 0x545b6269, 0x70777e85, 0x8c939aa1,
    0xa8afb6bd, 0xc4cbd2d9, 0xe0e7eef5, 0xfc030a11, 0x181f262d, 0x343b4249,
    0x50575e65, 0x6c737a81, 0x888f969d, 0xa4abb2b9, 0xc0c7ced5, 0xdce3eaf1,
    0xf8ff060d, 0x141b2229, 0x30373e45, 0x4c535a61, 0x686f767d, 0x848b9299,
    0xa0a7aeb5, 0xbcc3cad1, 0xd8dfe6ed, 0xf4fb0209, 0x10171e25, 0x2c333a41,
    0x484f565d, 0x646b7279
};
static uint8_t S_box[256] =
{
    0xD6, 0x90, 0xE9, 0xFE, 0xCC, 0xE1, 0x3D, 0xB7, 0x16, 0xB6, 0x14, 0xC2,
    0x28, 0xFB, 0x2C, 0x05, 0x2B, 0x67, 0x9A, 0x76, 0x2A, 0xBE, 0x04, 0xC3,
    0xAA, 0x44, 0x13, 0x26, 0x49, 0x86, 0x06, 0x99, 0x9C, 0x42, 0x50, 0xF4,
    0x91, 0xEF, 0x98, 0x7A, 0x33, 0x54, 0x0B, 0x43, 0xED, 0xCF, 0xAC, 0x62,
    0xE4, 0xB3, 0x1C, 0xA9, 0xC9, 0x08, 0xE8, 0x95, 0x80, 0xDF, 0x94, 0xFA,
    0x75, 0x8F, 0x3F, 0xA6, 0x47, 0x07, 0xA7, 0xFC, 0xF3, 0x73, 0x17, 0xBA,
    0x83, 0x59, 0x3C, 0x19, 0xE6, 0x85, 0x4F, 0xA8, 0x68, 0x6B, 0x81, 0xB2,
    0x71, 0x64, 0xDA, 0x8B, 0xF8, 0xEB, 0x0F, 0x4B, 0x70, 0x56, 0x9D, 0x35,
    0x1E, 0x24, 0x0E, 0x5E, 0x63, 0x58, 0xD1, 0xA2, 0x25, 0x22, 0x7C, 0x3B,
    0x01, 0x21, 0x78, 0x87, 0xD4, 0x00, 0x46, 0x57, 0x9F, 0xD3, 0x27, 0x52,
    0x4C, 0x36, 0x02, 0xE7, 0xA0, 0xC4, 0xC8, 0x9E, 0xEA, 0xBF, 0x8A, 0xD2,
    0x40, 0xC7, 0x38, 0xB5, 0xA3, 0xF7, 0xF2, 0xCE, 0xF9, 0x61, 0x15, 0xA1,
    0xE0, 0xAE, 0x5D, 0xA4, 0x9B, 0x34, 0x1A, 0x55, 0xAD, 0x93, 0x32, 0x30,
    0xF5, 0x8C, 0xB1, 0xE3, 0x1D, 0xF6, 0xE2, 0x2E, 0x82, 0x66, 0xCA, 0x60,
    0xC0, 0x29, 0x23, 0xAB, 0x0D, 0x53, 0x4E, 0x6F, 0xD5, 0xDB, 0x37, 0x45,
    0xDE, 0xFD, 0x8E, 0x2F, 0x03, 0xFF, 0x6A, 0x72, 0x6D, 0x6C, 0x5B, 0x51,
    0x8D, 0x1B, 0xAF, 0x92, 0xBB, 0xDD, 0xBC, 0x7F, 0x11, 0xD9, 0x5C, 0x41,
    0x1F, 0x10, 0x5A, 0xD8, 0x0A, 0xC1, 0x31, 0x88, 0xA5, 0xCD, 0x7B, 0xBD,
    0x2D, 0x74, 0xD0, 0x12, 0xB8, 0xE5, 0xB4, 0xB0, 0x89, 0x69, 0x97, 0x4A,
    0x0C, 0x96, 0x77, 0x7E, 0x65, 0xB9, 0xF1, 0x09, 0xC5, 0x6E, 0xC6, 0x84,
    0x18, 0xF0, 0x7D, 0xEC, 0x3A, 0xDC, 0x4D, 0x20, 0x79, 0xEE, 0x5F, 0x3E,
    0xD7, 0xCB, 0x39, 0x48
};
static const uint32_t Table0[] =
{
    0xD55B5B8E, 0x924242D0, 0xEAA7A74D, 0xFDFBFB06, 0xCF3333FC, 0xE2878765,
    0x3DF4F4C9, 0xB5DEDE6B, 0x1658584E, 0xB4DADA6E, 0x14505044, 0xC10B0BCA,
    0x28A0A088, 0xF8EFEF17, 0x2CB0B09C, 0x05141411, 0x2BACAC87, 0x669D9DFB,
    0x986A6AF2, 0x77D9D9AE, 0x2AA8A882, 0xBCFAFA46, 0x04101014, 0xC00F0FCF,
    0xA8AAAA02, 0x45111154, 0x134C4C5F, 0x269898BE, 0x4825256D, 0x841A1A9E,
    0x0618181E, 0x9B6666FD, 0x9E7272EC, 0x4309094A, 0x51414110, 0xF7D3D324,
    0x934646D5, 0xECBFBF53, 0x9A6262F8, 0x7BE9E992, 0x33CCCCFF, 0x55515104,
    0x0B2C2C27, 0x420D0D4F, 0xEEB7B759, 0xCC3F3FF3, 0xAEB2B21C, 0x638989EA,
    0xE7939374, 0xB1CECE7F, 0x1C70706C, 0xABA6A60D, 0xCA2727ED, 0x08202028,
    0xEBA3A348, 0x975656C1, 0x82020280, 0xDC7F7FA3, 0x965252C4, 0xF9EBEB12,
    0x74D5D5A1, 0x8D3E3EB3, 0x3FFCFCC3, 0xA49A9A3E, 0x461D1D5B, 0x071C1C1B,
    0xA59E9E3B, 0xFFF3F30C, 0xF0CFCF3F, 0x72CDCDBF, 0x175C5C4B, 0xB8EAEA52,
    0x810E0E8F, 0x5865653D, 0x3CF0F0CC, 0x1964647D, 0xE59B9B7E, 0x87161691,
    0x4E3D3D73, 0xAAA2A208, 0x69A1A1C8, 0x6AADADC7, 0x83060685, 0xB0CACA7A,
    0x70C5C5B5, 0x659191F4, 0xD96B6BB2, 0x892E2EA7, 0xFBE3E318, 0xE8AFAF47,
    0x0F3C3C33, 0x4A2D2D67, 0x71C1C1B0, 0x5759590E, 0x9F7676E9, 0x35D4D4E1,
    0x1E787866, 0x249090B4, 0x0E383836, 0x5F797926, 0x628D8DEF, 0x59616138,
    0xD2474795, 0xA08A8A2A, 0x259494B1, 0x228888AA, 0x7DF1F18C, 0x3BECECD7,
    0x01040405, 0x218484A5, 0x79E1E198, 0x851E1E9B, 0xD7535384, 0x00000000,
    0x4719195E, 0x565D5D0B, 0x9D7E7EE3, 0xD04F4F9F, 0x279C9CBB, 0x5349491A,
    0x4D31317C, 0x36D8D8EE, 0x0208080A, 0xE49F9F7B, 0xA2828220, 0xC71313D4,
    0xCB2323E8, 0x9C7A7AE6, 0xE9ABAB42, 0xBDFEFE43, 0x882A2AA2, 0xD14B4B9A,
    0x41010140, 0xC41F1FDB, 0x38E0E0D8, 0xB7D6D661, 0xA18E8E2F, 0xF4DFDF2B,
    0xF1CBCB3A, 0xCD3B3BF6, 0xFAE7E71D, 0x608585E5, 0x15545441, 0xA3868625,
    0xE3838360, 0xACBABA16, 0x5C757529, 0xA6929234, 0x996E6EF7, 0x34D0D0E4,
    0x1A686872, 0x54555501, 0xAFB6B619, 0x914E4EDF, 0x32C8C8FA, 0x30C0C0F0,
    0xF6D7D721, 0x8E3232BC, 0xB3C6C675, 0xE08F8F6F, 0x1D747469, 0xF5DBDB2E,
    0xE18B8B6A, 0x2EB8B896, 0x800A0A8A, 0x679999FE, 0xC92B2BE2, 0x618181E0,
    0xC30303C0, 0x29A4A48D, 0x238C8CAF, 0xA9AEAE07, 0x0D343439, 0x524D4D1F,
    0x4F393976, 0x6EBDBDD3, 0xD6575781, 0xD86F6FB7, 0x37DCDCEB, 0x44151551,
    0xDD7B7BA6, 0xFEF7F709, 0x8C3A3AB6, 0x2FBCBC93, 0x030C0C0F, 0xFCFFFF03,
    0x6BA9A9C2, 0x73C9C9BA, 0x6CB5B5D9, 0x6DB1B1DC, 0x5A6D6D37, 0x50454515,
    0x8F3636B9, 0x1B6C6C77, 0xADBEBE13, 0x904A4ADA, 0xB9EEEE57, 0xDE7777A9,
    0xBEF2F24C, 0x7EFDFD83, 0x11444455, 0xDA6767BD, 0x5D71712C, 0x40050545,
    0x1F7C7C63, 0x10404050, 0x5B696932, 0xDB6363B8, 0x0A282822, 0xC20707C5,
    0x31C4C4F5, 0x8A2222A8, 0xA7969631, 0xCE3737F9, 0x7AEDED97, 0xBFF6F649,
    0x2DB4B499, 0x75D1D1A4, 0xD3434390, 0x1248485A, 0xBAE2E258, 0xE6979771,
    0xB6D2D264, 0xB2C2C270, 0x8B2626AD, 0x68A5A5CD, 0x955E5ECB, 0x4B292962,
    0x0C30303C, 0x945A5ACE, 0x76DDDDAB, 0x7FF9F986, 0x649595F1, 0xBBE6E65D,
    0xF2C7C735, 0x0924242D, 0xC61717D1, 0x6FB9B9D6, 0xC51B1BDE, 0x86121294,
    0x18606078, 0xF3C3C330, 0x7CF5F589, 0xEFB3B35C, 0x3AE8E8D2, 0xDF7373AC,
    0x4C353579, 0x208080A0, 0x78E5E59D, 0xEDBBBB56, 0x5E7D7D23, 0x3EF8F8C6,
    0xD45F5F8B, 0xC82F2FE7, 0x39E4E4DD, 0x49212168
};
static const uint32_t Table1[] =
{
    0x5B5B8ED5, 0x4242D092, 0xA7A74DEA, 0xFBFB06FD, 0x3333FCCF, 0x878765E2,
    0xF4F4C93D, 0xDEDE6BB5, 0x58584E16, 0xDADA6EB4, 0x50504414, 0x0B0BCAC1,
    0xA0A08828, 0xEFEF17F8, 0xB0B09C2C, 0x14141105, 0xACAC872B, 0x9D9DFB66,
    0x6A6AF298, 0xD9D9AE77, 0xA8A8822A, 0xFAFA46BC, 0x10101404, 0x0F0FCFC0,
    0xAAAA02A8, 0x11115445, 0x4C4C5F13, 0x9898BE26, 0x25256D48, 0x1A1A9E84,
    0x18181E06, 0x6666FD9B, 0x7272EC9E, 0x09094A43, 0x41411051, 0xD3D324F7,
    0x4646D593, 0xBFBF53EC, 0x6262F89A, 0xE9E9927B, 0xCCCCFF33, 0x51510455,
    0x2C2C270B, 0x0D0D4F42, 0xB7B759EE, 0x3F3FF3CC, 0xB2B21CAE, 0x8989EA63,
    0x939374E7, 0xCECE7FB1, 0x70706C1C, 0xA6A60DAB, 0x2727EDCA, 0x20202808,
    0xA3A348EB, 0x5656C197, 0x02028082, 0x7F7FA3DC, 0x5252C496, 0xEBEB12F9,
    0xD5D5A174, 0x3E3EB38D, 0xFCFCC33F, 0x9A9A3EA4, 0x1D1D5B46, 0x1C1C1B07,
    0x9E9E3BA5, 0xF3F30CFF, 0xCFCF3FF0, 0xCDCDBF72, 0x5C5C4B17, 0xEAEA52B8,
    0x0E0E8F81, 0x65653D58, 0xF0F0CC3C, 0x64647D19, 0x9B9B7EE5, 0x16169187,
    0x3D3D734E, 0xA2A208AA, 0xA1A1C869, 0xADADC76A, 0x06068583, 0xCACA7AB0,
    0xC5C5B570, 0x9191F465, 0x6B6BB2D9, 0x2E2EA789, 0xE3E318FB, 0xAFAF47E8,
    0x3C3C330F, 0x2D2D674A, 0xC1C1B071, 0x59590E57, 0x7676E99F, 0xD4D4E135,
    0x7878661E, 0x9090B424, 0x3838360E, 0x7979265F, 0x8D8DEF62, 0x61613859,
    0x474795D2, 0x8A8A2AA0, 0x9494B125, 0x8888AA22, 0xF1F18C7D, 0xECECD73B,
    0x04040501, 0x8484A521, 0xE1E19879, 0x1E1E9B85, 0x535384D7, 0x00000000,
    0x19195E47, 0x5D5D0B56, 0x7E7EE39D, 0x4F4F9FD0, 0x9C9CBB27, 0x49491A53,
    0x31317C4D, 0xD8D8EE36, 0x08080A02, 0x9F9F7BE4, 0x828220A2, 0x1313D4C7,
    0x2323E8CB, 0x7A7AE69C, 0xABAB42E9, 0xFEFE43BD, 0x2A2AA288, 0x4B4B9AD1,
    0x01014041, 0x1F1FDBC4, 0xE0E0D838, 0xD6D661B7, 0x8E8E2FA1, 0xDFDF2BF4,
    0xCBCB3AF1, 0x3B3BF6CD, 0xE7E71DFA, 0x8585E560, 0x54544115, 0x868625A3,
    0x838360E3, 0xBABA16AC, 0x7575295C, 0x929234A6, 0x6E6EF799, 0xD0D0E434,
    0x6868721A, 0x55550154, 0xB6B619AF, 0x4E4EDF91, 0xC8C8FA32, 0xC0C0F030,
    0xD7D721F6, 0x3232BC8E, 0xC6C675B3, 0x8F8F6FE0, 0x7474691D, 0xDBDB2EF5,
    0x8B8B6AE1, 0xB8B8962E, 0x0A0A8A80, 0x9999FE67, 0x2B2BE2C9, 0x8181E061,
    0x0303C0C3, 0xA4A48D29, 0x8C8CAF23, 0xAEAE07A9, 0x3434390D, 0x4D4D1F52,
    0x3939764F, 0xBDBDD36E, 0x575781D6, 0x6F6FB7D8, 0xDCDCEB37, 0x15155144,
    0x7B7BA6DD, 0xF7F709FE, 0x3A3AB68C, 0xBCBC932F, 0x0C0C0F03, 0xFFFF03FC,
    0xA9A9C26B, 0xC9C9BA73, 0xB5B5D96C, 0xB1B1DC6D, 0x6D6D375A, 0x45451550,
    0x3636B98F, 0x6C6C771B, 0xBEBE13AD, 0x4A4ADA90, 0xEEEE57B9, 0x7777A9DE,
    0xF2F24CBE, 0xFDFD837E, 0x44445511, 0x6767BDDA, 0x71712C5D, 0x05054540,
    0x7C7C631F, 0x40405010, 0x6969325B, 0x6363B8DB, 0x2828220A, 0x0707C5C2,
    0xC4C4F531, 0x2222A88A, 0x969631A7, 0x3737F9CE, 0xEDED977A, 0xF6F649BF,
    0xB4B4992D, 0xD1D1A475, 0x434390D3, 0x48485A12, 0xE2E258BA, 0x979771E6,
    0xD2D264B6, 0xC2C270B2, 0x2626AD8B, 0xA5A5CD68, 0x5E5ECB95, 0x2929624B,
    0x30303C0C, 0x5A5ACE94, 0xDDDDAB76, 0xF9F9867F, 0x9595F164, 0xE6E65DBB,
    0xC7C735F2, 0x24242D09, 0x1717D1C6, 0xB9B9D66F, 0x1B1BDEC5, 0x12129486,
    0x60607818, 0xC3C330F3, 0xF5F5897C, 0xB3B35CEF, 0xE8E8D23A, 0x7373ACDF,
    0x3535794C, 0x8080A020, 0xE5E59D78, 0xBBBB56ED, 0x7D7D235E, 0xF8F8C63E,
    0x5F5F8BD4, 0x2F2FE7C8, 0xE4E4DD39, 0x21216849
};
static const uint32_t Table2[] =
{
    0x5B8ED55B, 0x42D09242, 0xA74DEAA7, 0xFB06FDFB, 0x33FCCF33, 0x8765E287,
    0xF4C93DF4, 0xDE6BB5DE, 0x584E1658, 0xDA6EB4DA, 0x50441450, 0x0BCAC10B,
    0xA08828A0, 0xEF17F8EF, 0xB09C2CB0, 0x14110514, 0xAC872BAC, 0x9DFB669D,
    0x6AF2986A, 0xD9AE77D9, 0xA8822AA8, 0xFA46BCFA, 0x10140410, 0x0FCFC00F,
    0xAA02A8AA, 0x11544511, 0x4C5F134C, 0x98BE2698, 0x256D4825, 0x1A9E841A,
    0x181E0618, 0x66FD9B66, 0x72EC9E72, 0x094A4309, 0x41105141, 0xD324F7D3,
    0x46D59346, 0xBF53ECBF, 0x62F89A62, 0xE9927BE9, 0xCCFF33CC, 0x51045551,
    0x2C270B2C, 0x0D4F420D, 0xB759EEB7, 0x3FF3CC3F, 0xB21CAEB2, 0x89EA6389,
    0x9374E793, 0xCE7FB1CE, 0x706C1C70, 0xA60DABA6, 0x27EDCA27, 0x20280820,
    0xA348EBA3, 0x56C19756, 0x02808202, 0x7FA3DC7F, 0x52C49652, 0xEB12F9EB,
    0xD5A174D5, 0x3EB38D3E, 0xFCC33FFC, 0x9A3EA49A, 0x1D5B461D, 0x1C1B071C,
    0x9E3BA59E, 0xF30CFFF3, 0xCF3FF0CF, 0xCDBF72CD, 0x5C4B175C, 0xEA52B8EA,
    0x0E8F810E, 0x653D5865, 0xF0CC3CF0, 0x647D1964, 0x9B7EE59B, 0x16918716,
    0x3D734E3D, 0xA208AAA2, 0xA1C869A1, 0xADC76AAD, 0x06858306, 0xCA7AB0CA,
    0xC5B570C5, 0x91F46591, 0x6BB2D96B, 0x2EA7892E, 0xE318FBE3, 0xAF47E8AF,
    0x3C330F3C, 0x2D674A2D, 0xC1B071C1, 0x590E5759, 0x76E99F76, 0xD4E135D4,
    0x78661E78, 0x90B42490, 0x38360E38, 0x79265F79, 0x8DEF628D, 0x61385961,
    0x4795D247, 0x8A2AA08A, 0x94B12594, 0x88AA2288, 0xF18C7DF1, 0xECD73BEC,
    0x04050104, 0x84A52184, 0xE19879E1, 0x1E9B851E, 0x5384D753, 0x00000000,
    0x195E4719, 0x5D0B565D, 0x7EE39D7E, 0x4F9FD04F, 0x9CBB279C, 0x491A5349,
    0x317C4D31, 0xD8EE36D8, 0x080A0208, 0x9F7BE49F, 0x8220A282, 0x13D4C713,
    0x23E8CB23, 0x7AE69C7A, 0xAB42E9AB, 0xFE43BDFE, 0x2AA2882A, 0x4B9AD14B,
    0x01404101, 0x1FDBC41F, 0xE0D838E0, 0xD661B7D6, 0x8E2FA18E, 0xDF2BF4DF,
    0xCB3AF1CB, 0x3BF6CD3B, 0xE71DFAE7, 0x85E56085, 0x54411554, 0x8625A386,
    0x8360E383, 0xBA16ACBA, 0x75295C75, 0x9234A692, 0x6EF7996E, 0xD0E434D0,
    0x68721A68, 0x55015455, 0xB619AFB6, 0x4EDF914E, 0xC8FA32C8, 0xC0F030C0,
    0xD721F6D7, 0x32BC8E32, 0xC675B3C6, 0x8F6FE08F, 0x74691D74, 0xDB2EF5DB,
    0x8B6AE18B, 0xB8962EB8, 0x0A8A800A, 0x99FE6799, 0x2BE2C92B, 0x81E06181,
    0x03C0C303, 0xA48D29A4, 0x8CAF238C, 0xAE07A9AE, 0x34390D34, 0x4D1F524D,
    0x39764F39, 0xBDD36EBD, 0x5781D657, 0x6FB7D86F, 0xDCEB37DC, 0x15514415,
    0x7BA6DD7B, 0xF709FEF7, 0x3AB68C3A, 0xBC932FBC, 0x0C0F030C, 0xFF03FCFF,
    0xA9C26BA9, 0xC9BA73C9, 0xB5D96CB5, 0xB1DC6DB1, 0x6D375A6D, 0x45155045,
    0x36B98F36, 0x6C771B6C, 0xBE13ADBE, 0x4ADA904A, 0xEE57B9EE, 0x77A9DE77,
    0xF24CBEF2, 0xFD837EFD, 0x44551144, 0x67BDDA67, 0x712C5D71, 0x05454005,
    0x7C631F7C, 0x40501040, 0x69325B69, 0x63B8DB63, 0x28220A28, 0x07C5C207,
    0xC4F531C4, 0x22A88A22, 0x9631A796, 0x37F9CE37, 0xED977AED, 0xF649BFF6,
    0xB4992DB4, 0xD1A475D1, 0x4390D343, 0x485A1248, 0xE258BAE2, 0x9771E697,
    0xD264B6D2, 0xC270B2C2, 0x26AD8B26, 0xA5CD68A5, 0x5ECB955E, 0x29624B29,
    0x303C0C30, 0x5ACE945A, 0xDDAB76DD, 0xF9867FF9, 0x95F16495, 0xE65DBBE6,
    0xC735F2C7, 0x242D0924, 0x17D1C617, 0xB9D66FB9, 0x1BDEC51B, 0x12948612,
    0x60781860, 0xC330F3C3, 0xF5897CF5, 0xB35CEFB3, 0xE8D23AE8, 0x73ACDF73,
    0x35794C35, 0x80A02080, 0xE59D78E5, 0xBB56EDBB, 0x7D235E7D, 0xF8C63EF8,
    0x5F8BD45F, 0x2FE7C82F, 0xE4DD39E4, 0x21684921
};
static const uint32_t Table3[] =
{
    0x8ED55B5B, 0xD0924242, 0x4DEAA7A7, 0x06FDFBFB, 0xFCCF3333, 0x65E28787,
    0xC93DF4F4, 0x6BB5DEDE, 0x4E165858, 0x6EB4DADA, 0x44145050, 0xCAC10B0B,
    0x8828A0A0, 0x17F8EFEF, 0x9C2CB0B0, 0x11051414, 0x872BACAC, 0xFB669D9D,
    0xF2986A6A, 0xAE77D9D9, 0x822AA8A8, 0x46BCFAFA, 0x14041010, 0xCFC00F0F,
    0x02A8AAAA, 0x54451111, 0x5F134C4C, 0xBE269898, 0x6D482525, 0x9E841A1A,
    0x1E061818, 0xFD9B6666, 0xEC9E7272, 0x4A430909, 0x10514141, 0x24F7D3D3,
    0xD5934646, 0x53ECBFBF, 0xF89A6262, 0x927BE9E9, 0xFF33CCCC, 0x04555151,
    0x270B2C2C, 0x4F420D0D, 0x59EEB7B7, 0xF3CC3F3F, 0x1CAEB2B2, 0xEA638989,
    0x74E79393, 0x7FB1CECE, 0x6C1C7070, 0x0DABA6A6, 0xEDCA2727, 0x28082020,
    0x48EBA3A3, 0xC1975656, 0x80820202, 0xA3DC7F7F, 0xC4965252, 0x12F9EBEB,
    0xA174D5D5, 0xB38D3E3E, 0xC33FFCFC, 0x3EA49A9A, 0x5B461D1D, 0x1B071C1C,
    0x3BA59E9E, 0x0CFFF3F3, 0x3FF0CFCF, 0xBF72CDCD, 0x4B175C5C, 0x52B8EAEA,
    0x8F810E0E, 0x3D586565, 0xCC3CF0F0, 0x7D196464, 0x7EE59B9B, 0x91871616,
    0x734E3D3D, 0x08AAA2A2, 0xC869A1A1, 0xC76AADAD, 0x85830606, 0x7AB0CACA,
    0xB570C5C5, 0xF4659191, 0xB2D96B6B, 0xA7892E2E, 0x18FBE3E3, 0x47E8AFAF,
    0x330F3C3C, 0x674A2D2D, 0xB071C1C1, 0x0E575959, 0xE99F7676, 0xE135D4D4,
    0x661E7878, 0xB4249090, 0x360E3838, 0x265F7979, 0xEF628D8D, 0x38596161,
    0x95D24747, 0x2AA08A8A, 0xB1259494, 0xAA228888, 0x8C7DF1F1, 0xD73BECEC,
    0x05010404, 0xA5218484, 0x9879E1E1, 0x9B851E1E, 0x84D75353, 0x00000000,
    0x5E471919, 0x0B565D5D, 0xE39D7E7E, 0x9FD04F4F, 0xBB279C9C, 0x1A534949,
    0x7C4D3131, 0xEE36D8D8, 0x0A020808, 0x7BE49F9F, 0x20A28282, 0xD4C71313,
    0xE8CB2323, 0xE69C7A7A, 0x42E9ABAB, 0x43BDFEFE, 0xA2882A2A, 0x9AD14B4B,
    0x40410101, 0xDBC41F1F, 0xD838E0E0, 0x61B7D6D6, 0x2FA18E8E, 0x2BF4DFDF,
    0x3AF1CBCB, 0xF6CD3B3B, 0x1DFAE7E7, 0xE5608585, 0x41155454, 0x25A38686,
    0x60E38383, 0x16ACBABA, 0x295C7575, 0x34A69292, 0xF7996E6E, 0xE434D0D0,
    0x721A6868, 0x01545555, 0x19AFB6B6, 0xDF914E4E, 0xFA32C8C8, 0xF030C0C0,
    0x21F6D7D7, 0xBC8E3232, 0x75B3C6C6, 0x6FE08F8F, 0x691D7474, 0x2EF5DBDB,
    0x6AE18B8B, 0x962EB8B8, 0x8A800A0A, 0xFE679999, 0xE2C92B2B, 0xE0618181,
    0xC0C30303, 0x8D29A4A4, 0xAF238C8C, 0x07A9AEAE, 0x390D3434, 0x1F524D4D,
    0x764F3939, 0xD36EBDBD, 0x81D65757, 0xB7D86F6F, 0xEB37DCDC, 0x51441515,
    0xA6DD7B7B, 0x09FEF7F7, 0xB68C3A3A, 0x932FBCBC, 0x0F030C0C, 0x03FCFFFF,
    0xC26BA9A9, 0xBA73C9C9, 0xD96CB5B5, 0xDC6DB1B1, 0x375A6D6D, 0x15504545,
    0xB98F3636, 0x771B6C6C, 0x13ADBEBE, 0xDA904A4A, 0x57B9EEEE, 0xA9DE7777,
    0x4CBEF2F2, 0x837EFDFD, 0x55114444, 0xBDDA6767, 0x2C5D7171, 0x45400505,
    0x631F7C7C, 0x50104040, 0x325B6969, 0xB8DB6363, 0x220A2828, 0xC5C20707,
    0xF531C4C4, 0xA88A2222, 0x31A79696, 0xF9CE3737, 0x977AEDED, 0x49BFF6F6,
    0x992DB4B4, 0xA475D1D1, 0x90D34343, 0x5A124848, 0x58BAE2E2, 0x71E69797,
    0x64B6D2D2, 0x70B2C2C2, 0xAD8B2626, 0xCD68A5A5, 0xCB955E5E, 0x624B2929,
    0x3C0C3030, 0xCE945A5A, 0xAB76DDDD, 0x867FF9F9, 0xF1649595, 0x5DBBE6E6,
    0x35F2C7C7, 0x2D092424, 0xD1C61717, 0xD66FB9B9, 0xDEC51B1B, 0x94861212,
    0x78186060, 0x30F3C3C3, 0x897CF5F5, 0x5CEFB3B3, 0xD23AE8E8, 0xACDF7373,
    0x794C3535, 0xA0208080, 0x9D78E5E5, 0x56EDBBBB, 0x235E7D7D, 0xC63EF8F8,
    0x8BD45F5F, 0xE7C82F2F, 0xDD39E4E4, 0x68492121
};

void SM4_Encrypt(uint8_t* cin, uint8_t* out, uint32_t* sm4_key)
{
    __m256i x[4];
    __m256i temp[4];
    __m256i ff;
    __m256i* cin_ = (__m256i*)cin;
    ff = _mm256_set1_epi32(0xFF);
    temp[0] = _mm256_loadu_si256(cin_ + 0);
    temp[1] = _mm256_loadu_si256(cin_ + 1);
    temp[2] = _mm256_loadu_si256(cin_ + 2);
    temp[3] = _mm256_loadu_si256(cin_ + 3);
    x[0] = MM256_EPI32_0(temp[0], temp[1], temp[2], temp[3]);
    x[1] = MM256_EPI32_1(temp[0], temp[1], temp[2], temp[3]);
    x[2] = MM256_EPI32_2(temp[0], temp[1], temp[2], temp[3]);
    x[3] = MM256_EPI32_3(temp[0], temp[1], temp[2], temp[3]);
    __m256i vindex = _mm256_setr_epi8(2, 3, 1, 0, 7, 6, 5, 4, 11, 10, 9, 8, 15, 14, 13, 12, 2, 3, 1, 0, 7, 6, 5
    x[0] = _mm256_shuffle_epi8(x[0], vindex);
    x[1] = _mm256_shuffle_epi8(x[1], vindex);
    x[2] = _mm256_shuffle_epi8(x[2], vindex);
    x[3] = _mm256_shuffle_epi8(x[3], vindex);
    for (int i = 0; i < 32; i++)
    {
        __m256i k = _mm256_set1_epi32(sm4_key[i]);
        temp[0] = _mm256_xor_si256(_mm256_xor_si256(x[1], x[2]), _mm256_xor_si256(x[3], k));
        temp[1] = _mm256_xor_si256(x[0], _mm256_i32gather_epi32((const int*)Table0, _mm256_and_si256(temp[0], f
        temp[0] = _mm256_srli_epi32(temp[0], 8);
        temp[1] = _mm256_xor_si256(temp[1], _mm256_i32gather_epi32((const int*)Table1, _mm256_and_si256(temp[0]
        temp[0] = _mm256_srli_epi32(temp[0], 8);
        temp[1] = _mm256_xor_si256(temp[1], _mm256_i32gather_epi32((const int*)Table2, _mm256_and_si256(temp[0]
        temp[0] = _mm256_srli_epi32(temp[0], 8);
        temp[1] = _mm256_xor_si256(temp[1], _mm256_i32gather_epi32((const int*)Table3, _mm256_and_si256(temp[0]
        x[0] = x[1];
        x[1] = x[2];
        x[2] = x[3];
        x[3] = temp[1];
    }
    x[0] = _mm256_shuffle_epi8(x[0], vindex);
    x[1] = _mm256_shuffle_epi8(x[1], vindex);
    x[2] = _mm256_shuffle_epi8(x[2], vindex);
    x[3] = _mm256_shuffle_epi8(x[3], vindex);
    _mm256_storeu_si256((__m256i*)out + 0, MM256_EPI32_0(x[3], x[2], x[1], x[0]));
    _mm256_storeu_si256((__m256i*)out + 1, MM256_EPI32_1(x[3], x[2], x[1], x[0]));
    _mm256_storeu_si256((__m256i*)out + 2, MM256_EPI32_2(x[3], x[2], x[1], x[0]));
    _mm256_storeu_si256((__m256i*)out + 3, MM256_EPI32_3(x[3], x[2], x[1], x[0]));
}

void SM4_Decrypt(uint8_t* out, uint8_t* cin, uint32_t* sm4_key)
{
    __m256i x[4];
    __m256i temp[4];
    __m256i ff;
    __m256i* out_ = (__m256i*)out;
    ff = _mm256_set1_epi32(0xFF);
    temp[0] = _mm256_loadu_si256(out_ + 0);
    temp[1] = _mm256_loadu_si256(out_ + 1);
    temp[2] = _mm256_loadu_si256(out_ + 2);
    temp[3] = _mm256_loadu_si256(out_ + 3);
    x[0] = MM256_EPI32_0(temp[0], temp[1], temp[2], temp[3]);
    x[1] = MM256_EPI32_1(temp[0], temp[1], temp[2], temp[3]);
    x[2] = MM256_EPI32_2(temp[0], temp[1], temp[2], temp[3]);
    x[3] = MM256_EPI32_3(temp[0], temp[1], temp[2], temp[3]);
    __m256i vindex = _mm256_setr_epi8(2, 3, 1, 0, 7, 6, 5, 4, 11, 10, 9, 8, 15, 14, 13, 12, 2, 3, 1, 0, 7, 6, 5
    x[0] = _mm256_shuffle_epi8(x[0], vindex);
    x[1] = _mm256_shuffle_epi8(x[1], vindex);
    x[2] = _mm256_shuffle_epi8(x[2], vindex);
    x[3] = _mm256_shuffle_epi8(x[3], vindex);
    for (int i = 0; i < 32; i++)
    {
```

```c
        __m256i k = _mm256_set1_epi32(sm4_key[31 - i]);
        temp[0] = _mm256_xor_si256(_mm256_xor_si256(x[1], x[2]), _mm256_xor_si256(x[3], k));
        temp[1] = _mm256_xor_si256(x[0], _mm256_i32gather_epi32((const int*)Table0, _mm256_and_si256(temp[0], f
        temp[0] = _mm256_srli_epi32(temp[0], 8);
        temp[1] = _mm256_xor_si256(temp[1], _mm256_i32gather_epi32((const int*)Table1, _mm256_and_si256(temp[0]
        temp[0] = _mm256_srli_epi32(temp[0], 8);
        temp[1] = _mm256_xor_si256(temp[1], _mm256_i32gather_epi32((const int*)Table2, _mm256_and_si256(temp[0]
        temp[0] = _mm256_srli_epi32(temp[0], 8);
        temp[1] = _mm256_xor_si256(temp[1], _mm256_i32gather_epi32((const int*)Table3, _mm256_and_si256(temp[0]
        x[0] = x[1];
        x[1] = x[2];
        x[2] = x[3];
        x[3] = temp[1];
    }
    x[0] = _mm256_shuffle_epi8(x[0], vindex);
    x[1] = _mm256_shuffle_epi8(x[1], vindex);
    x[2] = _mm256_shuffle_epi8(x[2], vindex);
    x[3] = _mm256_shuffle_epi8(x[3], vindex);
    _mm256_storeu_si256((__m256i*)cin + 0, MM256_EPI32_0(x[3], x[2], x[1], x[0]));
    _mm256_storeu_si256((__m256i*)cin + 1, MM256_EPI32_1(x[3], x[2], x[1], x[0]));
    _mm256_storeu_si256((__m256i*)cin + 2, MM256_EPI32_2(x[3], x[2], x[1], x[0]));
    _mm256_storeu_si256((__m256i*)cin + 3, MM256_EPI32_3(x[3], x[2], x[1], x[0]));
}

int main()
{
    unsigned char key[128] = { 0xaa, 0xaa, 0xaa, 0xaa, 0xaa, 0xaa, 0xaa, 0xaa, 0xbb, 0xbb, 0xbb, 0xbb, 0xbb, 0xb
    unsigned char cin[128] = { 0x01, 0x23, 0x45, 0x67, 0x89, 0xab, 0xcd, 0xef, 0xfe, 0xdc, 0xba, 0x98, 0x76, 0x5
    uint32_t* sm4_key = (uint32_t*)malloc(32 * sizeof(uint32_t));
    if (sm4_key)
    {
        uint32_t k[4];
        uint32_t tmp;
        uint8_t* tmp_8 = (uint8_t*)&tmp;
        for (int i = 0; i < 4; i++)
        {
            int j = 4 * i;
            k[i] = (key[j + 0] << 24) | (key[j + 1] << 16) | (key[j + 2] << 8) | (key[j + 3]);
            k[i] = k[i] ^ FK[i];
        }
        for (int i = 0; i < 32; i++)
        {
            tmp = k[1] ^ k[2] ^ k[3] ^ CK[i];
            for (int j = 0; j < 4; j++)
            {
                tmp_8[j] = S_box[tmp_8[j]];
            }
            sm4_key[i] = k[0] ^ tmp ^ (tmp << 13) ^ (tmp >> 23);
            k[0] = k[1];
            k[1] = k[2];
            k[2] = k[3];
            k[3] = sm4_key[i];
        }
        double start = clock();
        for (int i = 0; i < 1000; i++)
        {
            SM4_Encrypt(cin, cin, sm4_key);
        }
        double end = clock();
        cout << "运行1000次加密时间:" << end - start << "ms" << endl;
        start = clock();
        for (int i = 0; i < 1000; i++)
        {
            SM4_Decrypt(cin, cin, sm4_key);
        }
        end = clock();
        cout << "运行1000次解密时间:" << end - start << "ms" << endl;
        free(sm4_key);
    }
    return 0;
}
```