
Cryptographic S/W Modules with C

Design, Implementation, and Integration of Core Crypto Modules

Secure, Efficient, High-Performance Cryptographic Software Modules

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Chapter 1

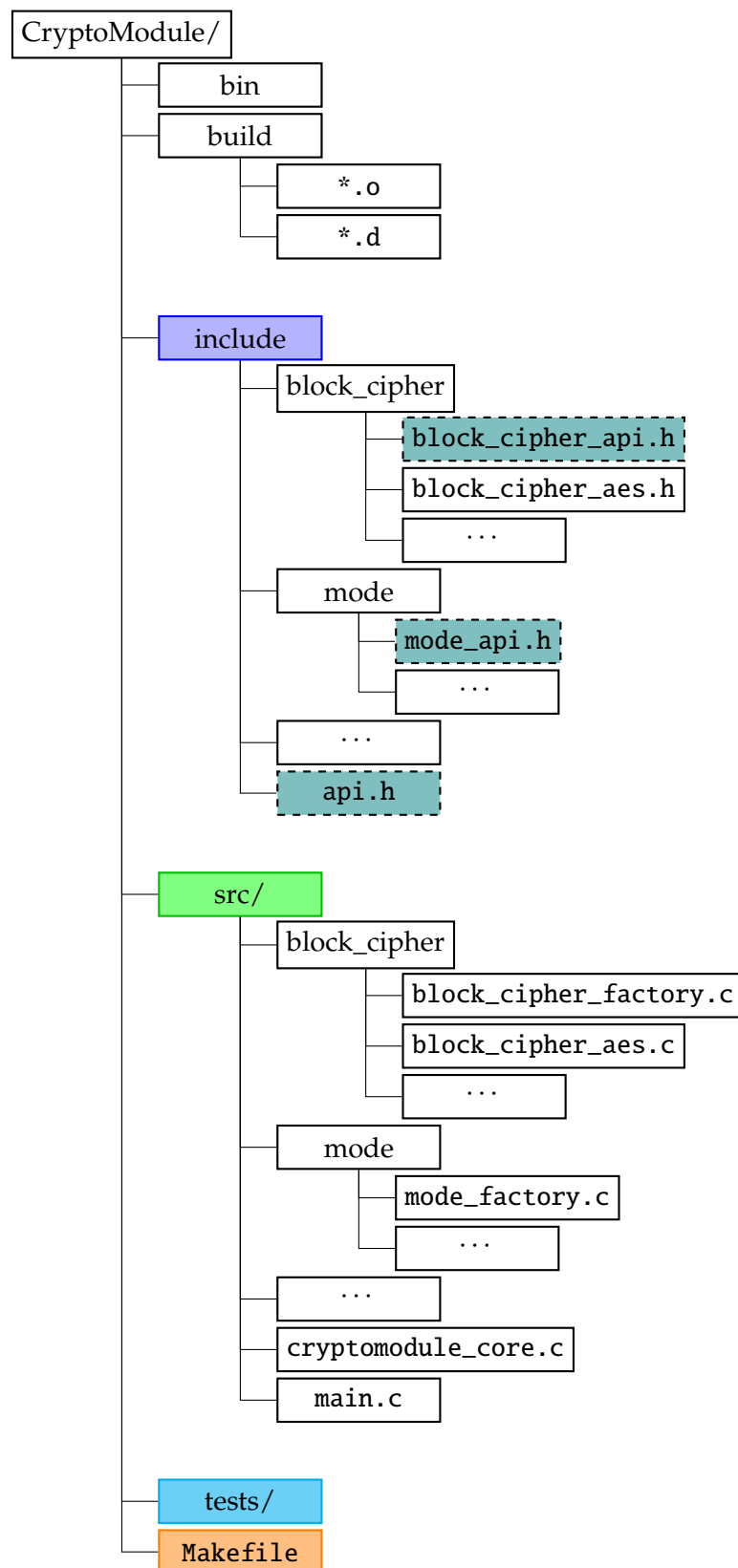
Project Overview

I have developed a cryptographic software module in the C language, with an emphasis on high performance and efficiency. This document provides a comprehensive guide to the design, implementation, and integration of cryptographic modules written in C (sometimes assembly).

Key Objectives:

- Describing the cryptographic primitives and algorithms (block ciphers, hash functions, MACs, signature algorithms, etc.).
- Explaining the structure of the source files and headers.
- Providing guidelines for building, testing, and integrating these modules into larger software systems.

1.1 Directory Structure



1.2 My Development Environment

- **Operating System:**

```
@>$ cat /etc/os-release
NAME="Linux Mint"
VERSION="21.3 (Virginia)"
ID=linuxmint
ID_LIKE="ubuntu debian"
PRETTY_NAME="Linux Mint 21.3"
VERSION_ID="21.3"
HOME_URL="https://www.linuxmint.com/"
SUPPORT_URL="https://forums.linuxmint.com/"
BUG_REPORT_URL="http://linuxmint-troubleshooting-guide.readthedocs.io/en/latest/"
PRIVACY_POLICY_URL="https://www.linuxmint.com/"
VERSION_CODENAME=virginia
UBUNTU_CODENAME=jammy
```

- **Compiler:**

```
@>$ gcc --version
gcc (Ubuntu 11.4.0-1ubuntu1~22.04) 11.4.0
Copyright (C) 2021 Free Software Foundation, Inc.
This is free software; see the source for copying conditions. There is NO
warranty; not even for MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.
```

- **Hardware:**

```
@>$ lscpu
Architecture:          x86_64
CPU op-mode(s):        32-bit, 64-bit
Address sizes:          48 bits physical, 48 bits virtual
Byte Order:             Little Endian
CPU(s):                 16
On-line CPU(s) list:    0-15
Vendor ID:              AuthenticAMD
Model name:             AMD Ryzen 7 5800X3D 8-Core Processor
CPU family:             25
Model:                  33
Thread(s) per core:     2
CPU max MHz:            3400.0000
CPU min MHz:            2200.0000
```

- **Additional Tools:**

- valgrind for memory checks,
- gdb for debugging,
- and TBA

Chapter 2

Cryptographic Software Module

2.1 Block Cipher

A **block cipher** is a keyed family of permutations over a fixed-size data block.

- Let k be a fixed key size and n be a fixed block size.
- Let $\mathcal{K} = \{0, 1\}^k$ be the set of possible k -bit keys (each key is chosen from this set).
- Let $\mathcal{M} = \{0, 1\}^n$ be the set of all n -bit messages (plaintext blocks).
- Let $\mathcal{C} = \{0, 1\}^n$ be the set of all n -bit ciphertext blocks.

A **block cipher** is have two efficient induced functions:

$$E : \mathcal{K} \times \mathcal{M} \rightarrow \mathcal{C} \quad \text{and} \quad D : \mathcal{K} \times \mathcal{C} \rightarrow \mathcal{M},$$

referred to as the **encryption** and **decryption** functions, respectively. These must satisfy:

1. *Invertibility (permutation property)*: For each fixed key $k \in \mathcal{K}$, the encryption function

$$E_k(\cdot) = E(k, \cdot) : \mathcal{M} \rightarrow \mathcal{C} \quad \text{is a bijection (i.e., permutation) on } \{0, 1\}^n.$$

In other words, for every key k , there is a unique inverse $D_k(\cdot) = D(k, \cdot) : \mathcal{C} \rightarrow \mathcal{M}$ s.t.

$$D_k(E_k(m)) = m \quad \text{and} \quad E_k(D_k(c)) = c \quad \text{for every } m \in \mathcal{M} \text{ and } c \in \mathcal{C}.$$

2. *Keyed operation*: The cipher's behavior depends on the choice of key k . Changing k results in a different permutation over the n -bit block space.

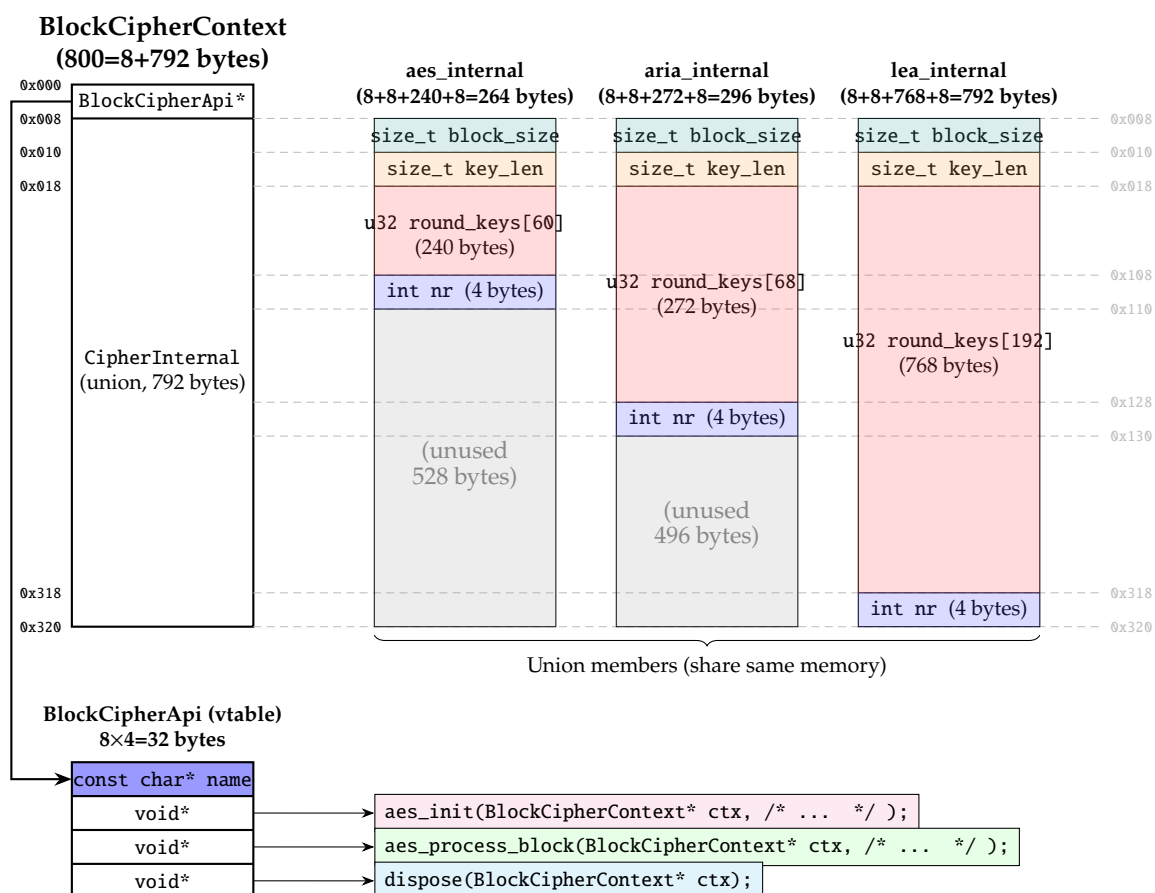
Alg.	n (bit)	k (bit)	# of Rounds	RK Size (bit)	# of RKs	Total RK Size (bit)
AES-128	128	128	10	128 (4-word)	11	1408 (44-word)
AES-192	128	192	12	128 (4-word)	13	1664 (52-word)
AES-256	128	256	14	128 (4-word)	15	1920 (60-word)
ARIA-128	128	128	12	128 (4-word)	13	1664 (52-word)
ARIA-192	128	192	14	128 (4-word)	15	1920 (60-word)
ARIA-256	128	256	16	128 (4-word)	17	2176 (68-word)
LEA-128	128	128	24	192 (6-word)	24	4608 (144-word)
LEA-192	128	192	28	192 (6-word)	28	5376 (168-word)
LEA-256	128	256	32	192 (6-word)	32	6144 (192-word)

Table 2.1: Comparison of AES, ARIA, and LEA parameters for 128-, 192-, and 256-bit keys.

```

1 typedef struct __BlockCipherApi__ {
2     const char *name;
3     void (*init)(BlockCipherContext* ctx, /* ... */);
4     void (*process_block)(BlockCipherContext* ctx, /* ... */);
5     void (*dispose)(BlockCipherContext* ctx);
6 } BlockCipherApi;
7
8 typedef union __CipherInternal__ {
9     struct __aes_internal__ {
10         /* ... */
11     } aes_internal;
12     struct __aria_internal__ {
13         /* ... */
14     } aria_internal;
15     struct __lea_internal__ {
16         /* ... */
17     } lea_internal;
18 } CipherInternal;
19
20 typedef struct __BlockCipherContext__ {
21     const BlockCipherApi *api;
22     CipherInternal internal_data; /* Generic internal state for any cipher */
23 } BlockCipherContext;

```



BlockCipherApi (vtable, 40 bytes)															
0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
const char* name								int* init							
void* encrypt_block								void* decrypt_block							
void* dispose															

2.1.1 AES (Advanced Encryption Standard)

Table 2.2: Parameters of the Block Cipher AES (1-word = 32-bit)

Algorithms	Block Size (N_b -word)	Key Length (N_k -word)	Number of Rounds (N_r)	Round-Key Length (word)	Number of Round-Keys ($N_r + 1$)	Total Size of Round-Keys ($N_b(N_r + 1)$)
AES-128	4	4	10	4	11	44 (176-byte)
AES-192	4	6	12	4	13	52 (208-byte)
AES-256	4	8	14	4	15	60 (240-byte)

Code 2.1: include/block_cipher/block_cipher.h

```

1  /* Forward declaration for the context. */
2  typedef struct BlockCipherContext BlockCipherContext;
3
4  /* The vtable or function pointer set describing any block cipher. */
5  typedef struct BlockCipherApi {
6      const char *name; /* e.g. "AES" or "MyCipher" */
7
8      /* Initialize the cipher with the chosen block size and key. */
9      int (*init)(
10         BlockCipherContext* ctx,
11         size_t block_size,
12         const u8* key,
13         size_t key_len
14     );
15     /* Encrypt exactly one block. */
16     void (*encrypt_block)(
17         BlockCipherContext* ctx,
18         const u8* plaintext,
19         u8* ciphertext
20     );
21     /* Decrypt exactly one block. */
22     void (*decrypt_block)(
23         BlockCipherContext* ctx,
24         const u8* ciphertext,
25         u8* plaintext
26     );
27     /* Clean up resources, if needed. */
28     void (*dispose)(

```



```

29         BlockCipherContext* ctx
30     );
31
32 } BlockCipherApi;
33
34 /* The context structure storing state. */
35 struct BlockCipherContext {
36     const BlockCipherApi *api;
37     u8 internal_data[256]; /* Example placeholder for key schedule, etc. */
38 };

```

Code 2.2: include/block_cipher/block_cipher_aes.h

```

1 const BlockCipherApi* get_aes_api(void);

```

Code 2.3: src/block_cipher/block_cipher_aes.c

```

1 typedef struct AesInternal {
2     size_t block_size; /* Typically must be 16 for AES */
3     size_t key_len; /* 16, 24, or 32 for AES-128/192/256 */
4     u32 round_keys[60];
5     int nr; /* e.g., 10 for AES-128, 12, or 14... */
6 } AesInternal;

```

2.1.2 ARIA (Academy, Research Institute, and Agency)

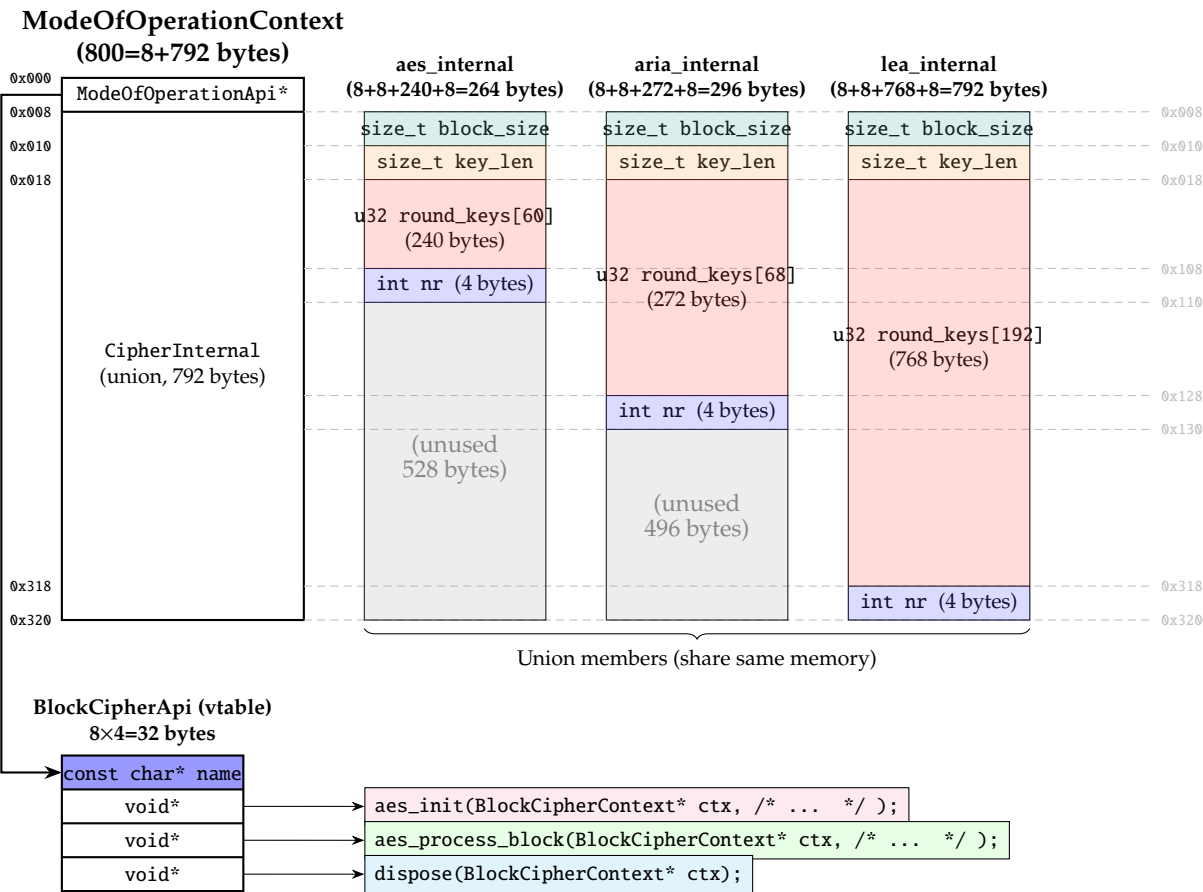
2.1.3 LEA (Lightweight Encryption Algorithm)

2.2 Modes of Operation

```

1 typedef struct __ModeOfOperationApi__ {
2     const char *name;
3     void (*init)( /* ... */ );
4     void (*process)( /* ... */ );
5     void (*dispose)( /* ... */ );
6 } ModeOfOperationApi;
7
8 typedef union __ModeInternal__ {
9     struct __cbc_internal__ {
10         /* ... */
11     } cbc_internal;
12     struct __ctr_internal__ {
13         /* ... */
14     } ctr_internal;
15     struct __gcm_internal__ {
16         /* ... */
17     } gcm_internal;
18     struct __ecb_internal__ {
19         /* ... */
20     } ecb_internal;
21 } ModeInternal;
22
23
24 typedef struct __ModeOfOperationContext__ {
25     const ModeOfOperationApi *api; // Pointer to the mode API
26     BlockCipherContext cipher_ctx; // Block cipher context
27     ModeInternal internal_data; // Internal state for the mode
28 } ModeOfOperationContext;

```



2.2.1 ECB

2.2.2 CBC

2.2.3 CTR

2.2.4 GCM

2.3 Random Number Generator**2.4 Hash Functions****2.5 Message Authentication Codes****2.6 Key Derivation Functions****2.7 Key Exchange****2.8 Signature Algorithms**

Chapter 3

Build and Integration

Chapter 4

Testing

Appendices