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

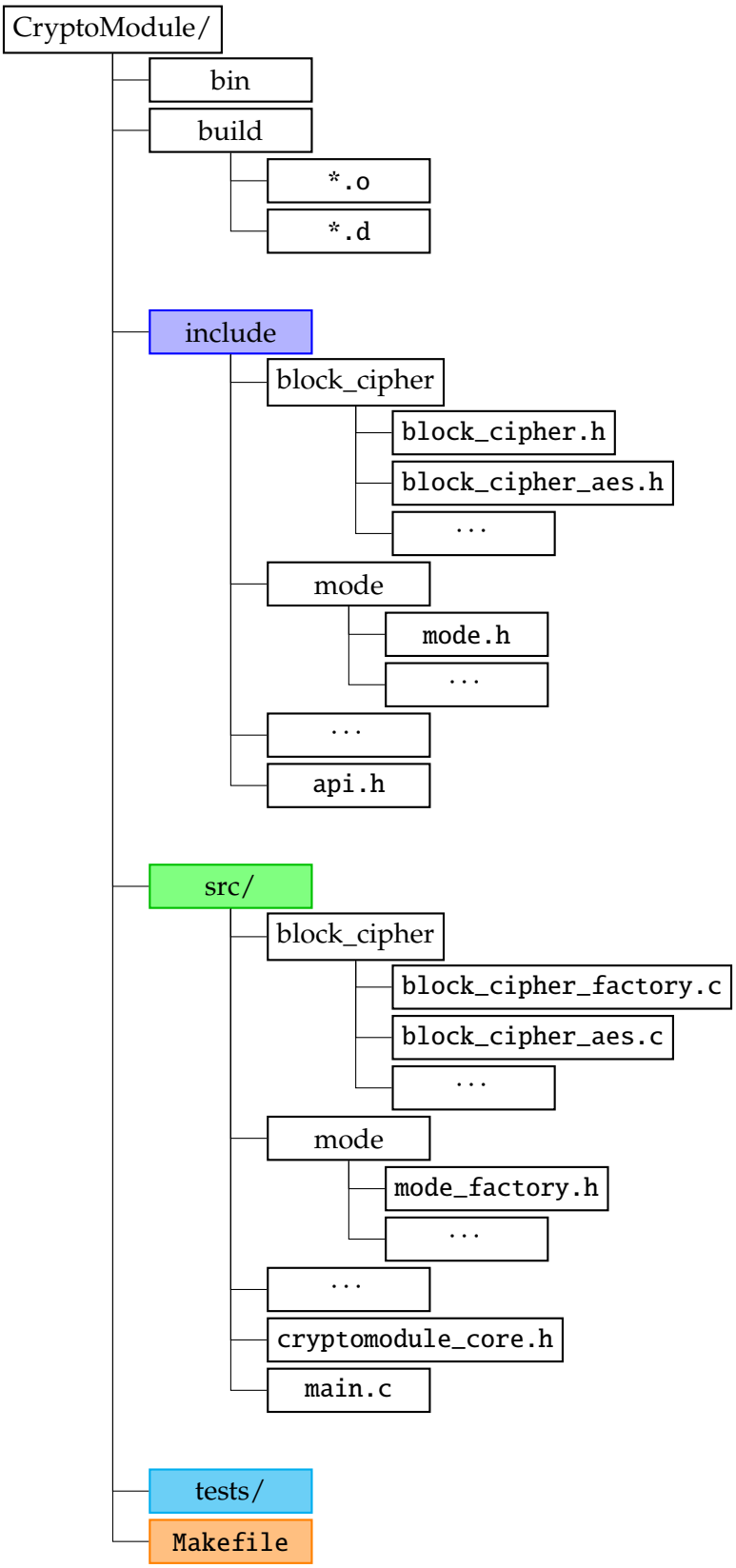
Project Overview

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 induced functions:

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

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

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

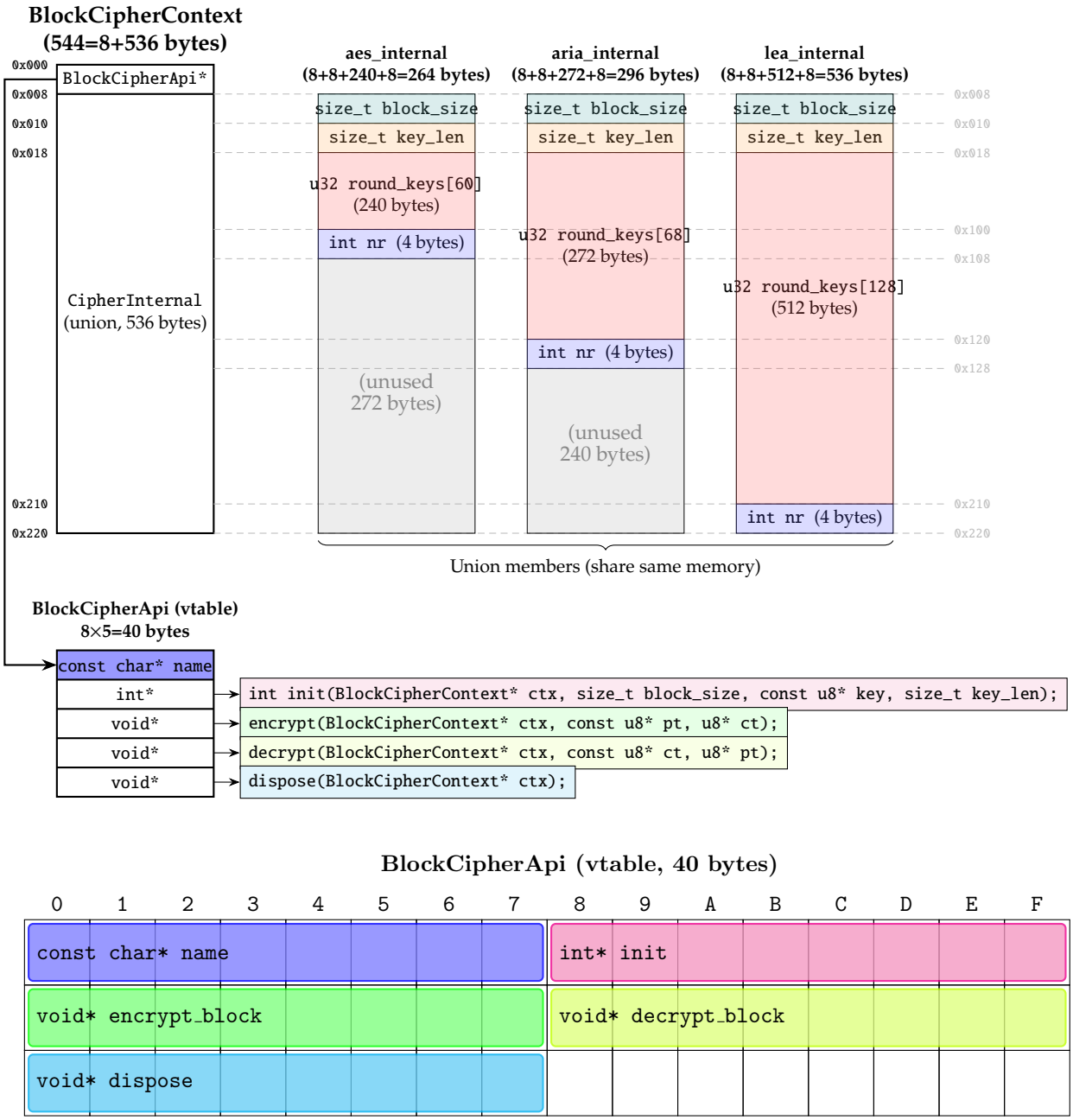
   In other words, for every key k, there is a unique inverse $D_k(\cdot) = D(k,\cdot) : \mathcal{C} \to \mathcal{M}$ s.t.

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

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)	**Rounds** (bit)	**RK Size** (bit)	**# of RKs** (bit)	**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	128 (4-word)	24	3072 (96-word)
LEA-192	128	192	28	128 (4-word)	28	3584 (112-word)
LEA-256	128	256	32	128 (4-word)	32	4096 (128-word)

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



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

```c
/* Forward declaration for the context. */
typedef struct BlockCipherContext BlockCipherContext;

/* The vtable or function pointer set describing any block cipher. */
typedef struct BlockCipherApi {
	const char *name; /* e.g. "AES" or "MyCipher" */

	/* Initialize the cipher with the chosen block size and key. */
	int (*init)(
		BlockCipherContext* ctx,
		size_t block_size,
		const u8* key,
		size_t key_len
	);
	/* Encrypt exactly one block. */
	void (*encrypt_block)(
		BlockCipherContext* ctx,
		const u8* plaintext,
		u8* ciphertext
	);
	/* Decrypt exactly one block. */
		void (*decrypt_block)(
		BlockCipherContext* ctx,
		const u8* ciphertext,
		u8* plaintext
	);
	/* Clean up resources, if needed. */
	void (*dispose)(
		BlockCipherContext* ctx
	);

} BlockCipherApi;

/* The context structure storing state. */
struct BlockCipherContext {
	const BlockCipherApi *api;
	u8 internal_data[256]; /* Example placeholder for key schedule, etc. */
};
```

Code 2.2: include/block_cipher/block_cipher_aes.h

```c
const BlockCipherApi* get_aes_api(void);
```

Code 2.3: src/block_cipher/block_cipher_aes.c

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

Chapter 3

Build and Integration

Chapter 4

Testing

Appendices