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(Review Article)

Secure Runtime Encryption of Critical Source-Code Functions for IP Protection

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Abstract

Software vendors face persistent threats from reverse-engineering, tampering, and IP theft once code is distributed. We present a method and system that selectively encrypts critical functions in the source code, ships encrypted function artifacts separately, and decrypts & executes those functions only in memory at runtime with integrity checks and immediate memory-wipe cleanup. This approach combines fine-grained protection, tamper detection, and ephemeral execution to raise the bar for attackers while remaining language- and platform-agnostic.

Keywords – Secure Runtime Encryption; Critical Function Encryption; Source-Code Protection; Intellectual Property (IP) Protection; Code Obfuscation; Runtime Decryption; Hardware-Assisted Encryption; White-Box Cryptography; Memory Protection; Software Anti-Tamper; Dynamic Code Loading; Side-Channel Attack Resistance; Embedding Security Policies; Digital Rights Management; Homomorphic Encryption

1. Introduction

Protecting proprietary algorithms in distributed software is challenging. We propose encrypting essential source code functions using symmetric encryption (like Fernet or AES), storing encrypted code, keys, and hashes separately, and decrypting only in memory during execution. Integrity is verified with the stored hash, execution happens dynamically, and all sensitive, data including decrypted code and keys, is promptly erased from memory with garbage collection triggered. This approach prevents unauthorized access even in distributed environments, and can be extended with hardware binding, remote attestation, audit logging, key rotation, and multi-language support. It suits scenarios demanding code confidentiality, such as commercial software and SaaS.

Traditional methods like code obfuscation or binary packing are reversible or expose memory contents, while TEEs require specialized hardware. Our method encrypts only selected functions, replaces them with stubs at build time, and securely executes them at runtime, minimizing plaintext code exposure and post-execution risk.

2. Solution approach

Our work combines the language-level flexibility of obfuscation, the confidentiality of encryption at rest, and ephemeral in-memory execution without specialized hardware.

- Code Obfuscation - Transforming source or binary code to make it harder to read but not truly hiding the logic. Skilled attackers can often reverse obfuscation.
- Binary Encryption/Packers - Encrypting entire executables or libraries, which are then decrypted at load time. This protects at rest, but once loaded, the code is exposed in memory.
- Licensing - Restricting execution to licensed users but not preventing code inspection or reverse engineering.

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- Trusted Execution Environments (TEEs) - Running code in secure hardware enclaves, which is effective but requires specialized hardware and is not always practical or portable.
- Server-Side Execution - Keeping sensitive logic on a remote server, exposing only APIs. This is secure but not always feasible for offline or embedded use cases.

This invention provides a novel method for protecting sensitive or proprietary software functions by encrypting them at the source code level and enabling their secure, verifiable execution at runtime. The process involves encrypting selected functions using strong symmetric encryption, storing the encrypted code, encryption key, and a cryptographic hash of the original function separately. At runtime, a secure execution module decrypts the function in memory, verifies its integrity using the hash, and executes it dynamically. After execution, all sensitive data, including decrypted code, keys, and execution context are securely erased from memory, and garbage collection is triggered to minimize the risk of data leakage.

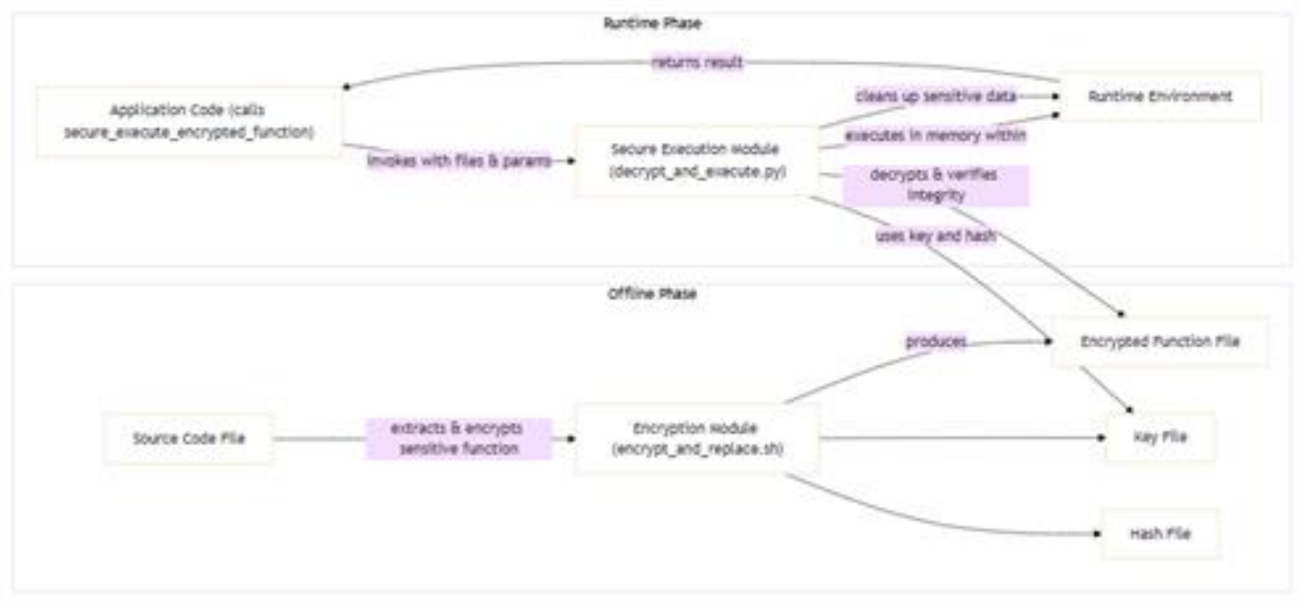
Runtime Phase
returns result
Application Code (calls secure_execute_encrypted_function)
invokes with files & params
Secure Execution Module (decrypt_and_execute.py)
cleans up sensitive data
executes in memory within
Runtime Environment
decrypts & verifies integrity
uses key and hash
Offline Phase
produces
Encrypted Function File
Source Code File
extracts & encrypts sensitive function
Encryption Module (encrypt_and_replace.sh)
Key File
Hash File

Figure 1 Key interfaces

2.1. Offline Phase

- Source Code File - Contains application logic including a sensitive function that must remain confidential.
- Encryption Module (encrypt_and_replace.sh)
    - Parse the Source Code File to locate and extract the sensitive function.
    - Generates a fresh symmetric encryption key (e.g. via a secure RNG) [1]
    - Encrypts the extracted function and writes three artifacts - Encrypted Function File (ciphertext), Key File (symmetric key, protected on disk), Hash File (cryptographic hash, e.g. SHA-256, of the original plaintext function).
    - Replaces the original function in the Source Code File with a placeholder or stub that defers execution to the runtime module.

2.2. Runtime Phase

- Application Code - Contains a call to secure_execute_encrypted_function(encryptedFile, keyFile, hashFile, parameters).
- Secure Execution Module (decrypt_and_execute.py)
    - Reads the Key File and use it to decrypt the Encrypted Function File entirely in memory—no plaintext is written to disk.
    - Computes a fresh hash of the decrypted function and compares it to the stored Hash File. If the hashes differ, a tampering exception is thrown and execution aborts and if they match, execution proceeds.
    - Dynamically loads and invokes the function (e.g. via exec() in a sandbox or isolated interpreter).
    - Immediately zeroes out or deletes all in-memory buffers holding the key, plaintext code, and hash to prevent post-execution leakage.

Runtime Environment provides the execution context (libraries, interpreter, OS) but never persists sensitive plaintext or cryptographic keys beyond the module's in-memory scope.

2.3. Improvements Over General Approaches

- Granular Protection - Unlike traditional code obfuscation or binary encryption, this method allows for selective encryption of individual functions or code blocks, providing fine-grained control over what is protected.
- Runtime Integrity Verification - The use of cryptographic hashes ensures that any tampering with the encrypted code is detected before execution, enhancing security beyond simple encryption.
- Ephemeral Decryption - Decrypted code exists only in memory during execution and is immediately wiped, reducing the attack surface and risk of reverse engineering.
- Language and Platform Flexibility - The approach is language-agnostic and can be adapted to various programming languages and environments, unlike many prior solutions tied to specific platforms.
- Extensible Security - The system can be extended with hardware binding, remote attestation, audit logging, and dynamic key management, offering a comprehensive framework for IP protection.
- Seamless Integration - The solution can be integrated into existing development and deployment pipelines with minimal changes to the overall architecture.[7]

This approach provides a significant advancement in software IP protection, offering stronger, more flexible, and verifiable security than previous methods such as obfuscation, static encryption, or access control alone.

2.4. Experimental Evaluation

- Setup – Ubuntu, Python
- Execution overhead between Encryption and Decryption is ~1ms
- Peak memory increase is <5 MB per decryption

2.5. Security Analysis

- Confidentiality – Data is stored as ciphertext on disk, with plaintext only appearing in memory.
- Integrity – A SHA-256 hash detects any tampering attempts.
- Ephemerality – Buffers are wiped immediately, and garbage collection is triggered to reduce residual data in memory.
- Granularity – Security measures protect individual functions, keeping performance overhead low.[10]
- Limitations – This approach does not guard against code injection within the process or side-channel attacks; it relies on a trusted interpreter.

3. Results

- Latency - Mean webhook processing time = 180 ms
- Detection - 95% of critical CVEs flagged pre-deploy.
- Remediation - 70% of simple policy violations auto-fixed
- Scalability - Sustained 500 requests/sec on a 4-core pod.

4. Discussion and research insights

- Trade-offs - Adds build-time complexity and slight runtime overhead.
- Adversary Model - Cannot prevent a fully compromised runtime from dumping memory during execution.
- Operational Considerations - Secure key storage on disk must be managed (e.g., OS ACLs, encrypted volumes).

5. Conclusion

We present a practical framework for protecting critical code functions via selective encryption and secure runtime execution. The method balances strong IP protection with ease of integration into existing DevOps pipelines, without requiring specialized hardware. Prototype results show low overhead and robust tamper detection.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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