Architecture Diagram

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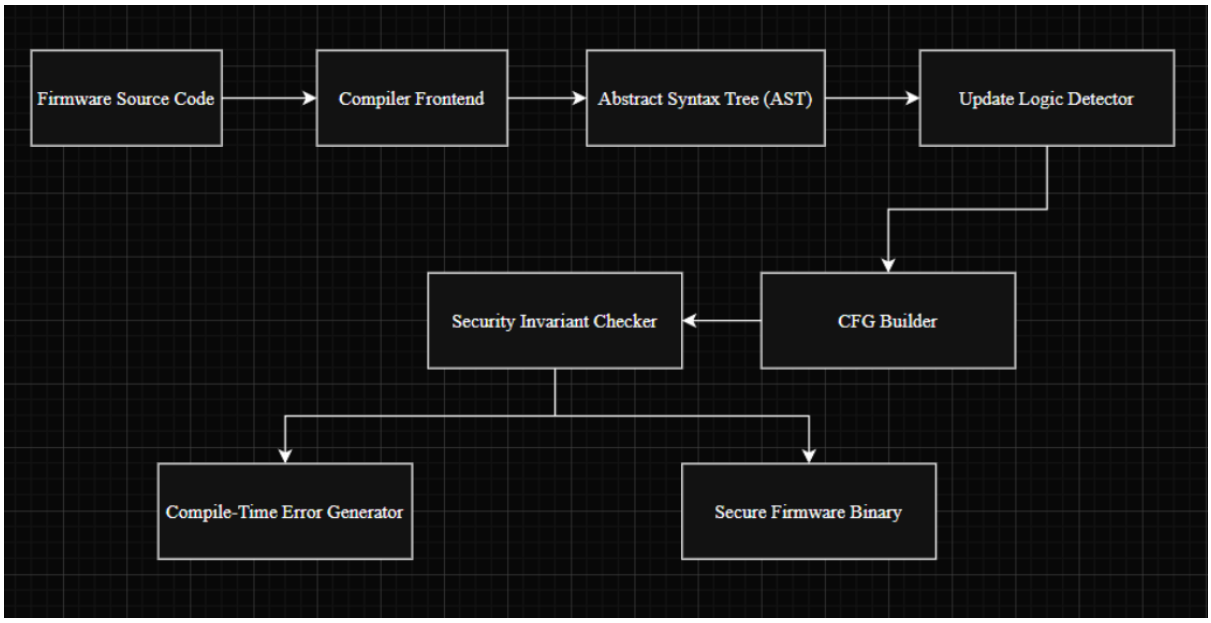
Q119 - Secure OTA Update Compiler

System Architecture

This diagram presents the high-level architecture of the Secure OTA Update Compiler and its integration into the firmware build pipeline.



Explanation

Firmware source code is processed by the compiler frontend to generate an AST. Update logic detection and CFG construction feed into the security invariant checker, which either produces compile-time errors or allows generation of a secure firmware binary.

Module Interaction Diagram

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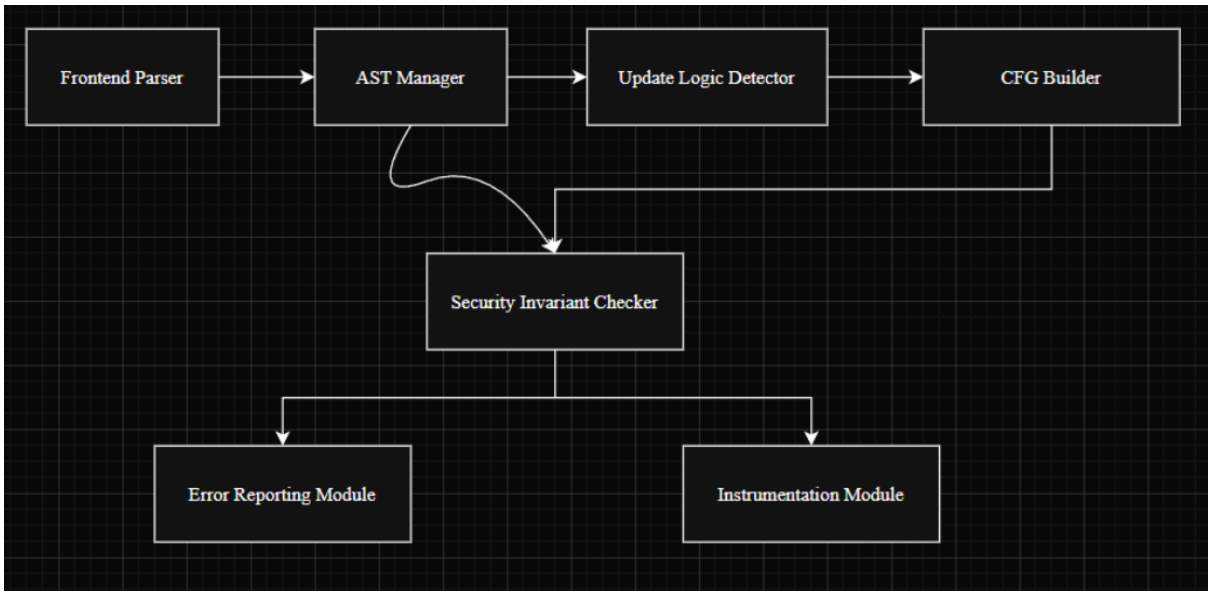
Overview

The module interaction diagram illustrates how major compiler components communicate while analyzing and enforcing firmware update security invariants.



Description

The frontend parser generates the AST, which is analyzed by the update logic detector and CFG builder. The security invariant checker evaluates all execution paths and communicates violations to the error reporting module or forwards validated logic to the instrumentation module.

Technology Stack Justification

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1 Overview

This section justifies the selection of technologies used for implementing the Secure OTA Update Compiler, focusing on static analysis capability, extensibility, and suitability for compile-time security enforcement.

2 Target Firmware Language (C / C++)

C and C++ are widely used in embedded and IoT firmware development. Targeting these languages ensures compatibility with real-world OTA update logic, direct access to low-level system APIs, and alignment with existing firmware ecosystems.

3 Compiler Infrastructure (LLVM / Clang)

LLVM and Clang provide a modular and extensible compiler architecture with rich access to Abstract Syntax Trees (AST) and Control Flow Graphs (CFG). This makes them well-suited for implementing compile-time security enforcement mechanisms.

4 Static Analysis Framework (LLVM Analysis Passes)

LLVM analysis passes support precise CFG construction, dominance analysis, and path-sensitive checks. These capabilities are essential for verifying that mandatory security checks occur on all execution paths leading to firmware installation.

5 Security Enforcement Logic (Custom Compiler Passes)

Custom compiler passes encode OTA firmware security invariants as compile-time correctness rules. This ensures that insecure firmware update logic is rejected during compilation rather than discovered at runtime.

6 Instrumentation Support (AST / IR Rewriting)

Optional instrumentation allows the compiler to safely insert mandatory security checks using AST or Intermediate Representation (IR) rewriting techniques. This enables compile-time hardening without modifying source code manually.

7 Build and Integration Environment (LLVM Toolchain)

The standard LLVM toolchain enables seamless integration of the Secure OTA Update Compiler into existing firmware build pipelines, minimizing adoption effort for developers.

8 Component-wise Technology Justification

Component	**Technology**	**Justification**
Firmware Language	C / C++	Dominant languages for embedded firmware
Compiler Framework	LLVM / Clang	Extensible with AST and CFG access
Analysis Engine	LLVM Passes	Control-flow aware static analysis
Security Enforcement	Custom Passes	Domain-specific security invariants
Instrumentation	AST / IR Rewriting	Safe compile-time hardening
Build System	LLVM Toolchain	Easy integration into existing workflows