

# **Smart contract audit**

## **rain.extrospection**

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## Project description

The `rain.extrospection` repository implements a set of interfaces, libraries, and a concrete contract designed to expose low-level bytecode analysis logic to off-chain tooling. Unlike typical on-chain logic, this project focuses on "extrospection"—analyzing the bytecode of other contracts directly.

## Executive summary

<b>Type</b>	Library
<b>Languages</b>	Solidity
<b>Methods</b>	Architecture Review, Manual Review, Unit Testing, Functional Testing, Automated Review
<b>Documentation</b>	README.md
<b>Repositories</b>	<a href="https://github.com/rainlanguage/rain.extrospection">https://github.com/rainlanguage/rain.extrospection</a>

## Reviews

Date	Repository	Commit
30/01/26	rain.extrospection	60f35a0fc7e38fe6879c638ee25b46e88bfc9892
05/02/26	rain.extrospection	4c0aed6fa250d22c42b62dedaba20429a30609a9
10/02/26	rain.extrospection	ab33ddb8b64d7566edfb15a775d86c536c977181

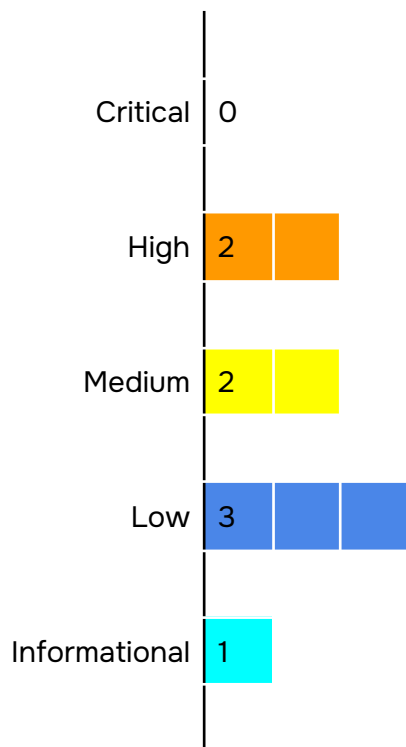
## Scope

<b>Contracts</b>
<code>src/concrete/Extrospection.sol</code>
<code>src/interface/deprecated/IExtrospectBytecodeV1.sol</code>
<code>src/interface/IExtrospectBytecodeV2.sol</code>
<code>src/interface/IExtrospectERC1167ProxyV1.sol</code>
<code>src/interface/IExtrospectInterpreterV1.sol</code>



src/lib/EVMOpCodes.sol
src/lib/LibExtrospectBytecode.sol
src/lib/LibExtrospectERC1167Proxy.sol

## Technical analysis and findings



# Security findings

## \*\*\*\* Critical

No critical severity issue found.

## \*\*\* High

### H01 - Incorrect Instruction Boundary Parsing in Reachability Scanner

The `scanEVMOpCodesReachableInBytecode()` function in `LibExtrospectBytecode.sol` contains a logic error when scanning "unreachable" (dead) code regions.

According to the Ethereum Yellow Paper (Section 9.4.3, Jump Destination Validity), a valid jump destination (JUMPDEST) must strictly appear as an opcode. It cannot be part of the immediate data of a PUSH instruction. During execution, the EVM program counter advances past the data bytes of a PUSH instruction, ensuring they are never executed.

However, the current scanner implementation fails to respect these boundaries when in a "halted" state. When the scanner encounters a halting opcode (e.g. STOP, RETURN), it pauses execution analysis and linearly scans for a JUMPDEST (0x5B) byte to resume. In this state, it ignores PUSH opcodes. Consequently, if the immediate data of a PUSH instruction contains the byte 0x5B, the scanner incorrectly identifies it as a valid JUMPDEST.

This causes the scanner to resume execution analysis mid-instruction, misinterpreting the remaining PUSH data and subsequent bytes as executable opcodes. This leads to an incorrect reachability map, potentially flagging safe contracts as unsafe or failing to detect dangerous opcodes in what is actually reachable code.

**Path:** `src/lib/LibExtrospectBytecode.sol`

**Recommendation:** Update the scanning logic within the halted state (specifically inside the case 1 block) to recognize PUSH opcodes (0x60 - 0x7F) and advance the cursor past their immediate data. This ensures that 0x5B is only recognized as a JUMPDEST when it appears at a valid instruction boundary.

#### Example Scenario:

Data: `hex"00605b"`

Expected: Scanner halts at 00. It sees 60 (PUSH1), skips 5B (data). No JUMPDEST found. Code remains unreachable.

Actual (Bug): Scanner halts at 00. It sees 60, ignores it. It sees 5B, interprets it as JUMPDEST. Scanner resumes, marking 5B as reachable.



**Found in:** 60f35a0f

**Status:** Fixed at 4c0aed6f

## H02 - Interpreter Safety Check Bypassed by Transient Storage

### Modification

The `IExtrospectInterpreterV1` interface implements a safety check via `scanOnlyAllowedInterpreterEVMOpCodes()` to ensure that candidate interpreter contracts do not perform state-modifying operations. This is enforced by the `NON_STATIC_OPS` bitmask, which identifies forbidden opcodes such as `SSTORE`, `CREATE`, and `CALL`.

However, the current implementation fails to include the `TSTORE` (Transient Storage Store) opcode in the `NON_STATIC_OPS` list. `TSTORE` performs a write operation to the transient storage, thereby violating the requirement that the interpreter be immutable and free of state changes during execution.

As a result, a malicious or buggy interpreter contract utilizing `TSTORE` would be incorrectly flagged as "safe," allowing it to mutate state unexpectedly.

**Path:** `src/interface/IExtrospectInterpreterV1.sol`

**Recommendation:** Update `src/interface/IExtrospectInterpreterV1.sol` to include `EVM_OP_TSTORE` in the `NON_STATIC_OPS` constant. This ensures that any contract using transient storage modification is correctly rejected by the safety scan. (Note: This requires `EVM_OP_TSTORE` to be defined in `EVMOpCodes.sol` first).

**Found in:** 60f35a0f

**Status:** Fixed at 4c0aed6f

## \*\* Medium

### M01 - Unconditional JUMP Treated as Non-Halting

The `HALTING_BITMAP` definition in `EVMOpCodes.sol` missed the unconditional `JUMP` opcode (0x56). In the EVM, an unconditional `JUMP` does not allow execution to fall through to the next instruction. The instruction immediately following a `JUMP` is unreachable unless it is a valid `JUMPDEST` that is targeted by a jump from elsewhere.

By treating `JUMP` as non-halting, the scanner continued to mark the subsequent bytes as "reachable" via sequential flow. This incorrectly flags dead code (which often contains metadata or invalid opcodes) as reachable.



Code following a JUMP that should be ignored (until the next JUMPDEST) is included in the reachability analysis. This can cause the scanner to detect "dangerous" opcodes in dead code regions, flagging safe contracts as unsafe.

**Path:** src/lib/EVMOpCodes.sol

**Recommendation:** Update the *HALTING\_BITMAP* constant in src/lib/EVMOpCodes.sol to include the EVM\_OP\_JUMP (0x56) opcode.

**Found in:** 60f35a0f

**Status:** Fixed at 4c0aed6f

## M02 - Lack of Support for EVM Object Format (EOF)

The current bytecode analysis implementation in LibExtrospectBytecode is designed exclusively for legacy EVM bytecode. It assumes a linear sequence of instructions and relies on legacy control flow mechanisms (like JUMP and JUMPDEST) to determine opcode reachability.

The EVM Object Format (EOF) introduces a structured container format that separates code and data sections and introduces new control flow instructions (e.g., RJUMP, CALLF). The current scanner does not recognize the EOF container structure (starting with the 0xEF00 magic bytes) or its specific validation rules.

Running the existing scanner on an EOF contract will lead to undefined behavior, such as misinterpreting headers as executable opcodes, failing to trace execution paths correctly, or incorrectly flagging safe code as unsafe due to the inability to parse the new format.

**Path:** src/\*

**Recommendation:** Update the library to detect EOF contracts by checking for the 0xEF00 prefix. Upon detection, the library should either:

1. Gracefully revert or return an error indicating that EOF analysis is not yet supported.
2. Implement specific parsing logic to handle the EOF container format, respecting its section boundaries and new control flow opcodes.

**Found in:** 60f35a0f

**Status:** Fixed at 4c0aed6f



## \* Low

### L01 - Incomplete EVM Opcode Definitions

The `src/lib/EVMOpCodes.sol` library defines a list of EVM opcode constants but fails to include several instructions present in the current EVM version. Specifically, the following opcodes are undefined:

1. 0x49: BLOHASH
2. 0x4A: BLOBBASEFEE
3. 0x5C: TLOAD
4. 0x5D: TSTORE
5. 0x5E: MCOPY

While the lack of definitions does not immediately break the compilation, it creates a blind spot for any logic relying on this library to be an exhaustive reference of executable or state-changing opcodes.

**Path:** `src/lib/EVMOpCodes.sol`

**Recommendation:** Update `src/lib/EVMOpCodes.sol` to include constants for `EVM_OP_BLOHASH`, `EVM_OP_BLOBBASEFEE`, `EVM_OP_TLOAD`, `EVM_OP_TSTORE`, and `EVM_OP_MCOPY`.

**Found in:** 60f35a0f

**Status:** Fixed at 99e20bf

### L02 - Hardcoded Solidity Metadata Assumptions

The `trimSolidityCBORMetadata()` function in `LibExtrospectBytecode.sol` relies on a very specific, hardcoded pattern to detect and trim Solidity CBOR metadata. It explicitly checks for:

1. A specific length (53 bytes).
2. Specific leading bytes (0xa264697066735822...).
3. A specific hardcoded hash of the "static" parts of the metadata structure.

The Solidity documentation states that:

1. The metadata hash is CBOR-encoded.
2. The last two bytes of the bytecode indicate the length of the CBOR encoded information.
3. The metadata format can vary (e.g., using Swarm instead of IPFS, or different solc versions encoding versions differently).
4. The documentation explicitly warns: "The CBOR mapping can also contain other keys... Do not rely on it starting with 0xa264..."



The current implementation violates this warning by relying on a rigid byte pattern. If a future Solidity version changes the order of keys in the CBOR map, adds a new key, or if a user configures their compiler to use Swarm (bzzr1) instead of IPFS, this function will fail to detect and trim the metadata. This makes the `checkCBORTrimmedBytecodeHash` function brittle and likely to revert unexpectedly for valid contracts compiled with slightly different settings or versions.

**Path:** `src/lib/LibExtrospectBytecode.sol`

**Recommendation:** Refactor `trimSolidityCBORMetadata()` to follow the standard metadata decoding process described in the documentation:

1. Read the last two bytes of the bytecode to determine the CBOR data length.
2. Verify that this length is reasonable and within the bytecode bounds.
3. Use this dynamic length to identify the metadata region rather than assuming a fixed 53-byte structure.
4. Ideally, verify that the data at that tail is indeed valid CBOR (though a length check might be sufficient for simple trimming purposes).

This change would make the library robust across different compiler versions and configurations (IPFS vs. Swarm).

**Found in:** 60f35a0f

**Status:** Acknowledged

### L03 - Inconsistent Interpreter Isolation (TLOAD Allowed)

The `IExtrospectInterpreterV1` interface defines a set of `INTERPRETER_DISALLOWED_OPS` to ensure that an interpreter contract is "safe" and isolated. It explicitly bans `SLOAD` (Storage Load) with the rationale that "Interpreter cannot store so it has no reason to load from storage." However, while `TSTORE` (Transient Storage Store) is banned, `TLOAD` (Transient Storage Load, 0x5C) is currently allowed.

This is inconsistent with the isolation philosophy. If an interpreter is not allowed to write to transient storage (`TSTORE`), it generally should not need to read from it (`TLOAD`), unless there is a specific use case for reading transient data set by the caller (which implies a lack of isolation). Allowing `TLOAD` could allow the interpreter to access state from the surrounding transaction context, violating the "pure" execution model implied by the other bans.

**Path:** `src/interface/IExtrospectInterpreterV1.sol`



**Recommendation:** Add `EVM_OP_TLOAD` to the `INTERPRETER_DISALLOWED_OPS` bitmask in `src/interface/ExtrospectInterpreterV1.sol`.

**Found in:** 4c0aed6f

**Status:** Fixed at f2c4f5ad

## Informational

### I01 - Potential Hash Literal Truncation

The hex literal has 63 characters instead of 64. Solidity will left-pad with a zero, resulting in `0x0e55864b....`. This may be intentional (if the hash happens to start with `0x0e`) or a typo (if a digit was accidentally omitted).

**Path:** `src/lib/LibExtrospectBytecode.sol`

**Recommendation:** Verify the expected hash value is correct. If intentional, add a leading 0 for clarity.

**Found in:** 60f35a0f

**Status:** Fixed at d9416b4



## General Risks




- **EVM Hard Fork Sensitivity:** The `scanEVMOpCodesReachableInAccount` function relies on a specific model of EVM execution, including the set of opcodes that halt execution (e.g., `STOP`, `RETURN`, `REVERT`). Future EVM hard forks that introduce new control flow mechanisms or halting opcodes could render the reachability analysis incomplete or incorrect, requiring a contract upgrade.
- **Compiler Metadata Assumptions:** The `trimSolidityCBORMetadata` function relies on the specific CBOR encoding pattern used by current versions of the Solidity compiler. Changes to this format in future solc versions, or the use of different compilers (e.g., Vyper), may cause metadata trimming to fail or result in hash mismatches.
- **Gas Intensity:** The opcode scanning algorithms iterate over the entire bytecode of a target contract. While optimized, these operations are  $O(n)$  relative to bytecode size and are computationally expensive. They are primarily intended for off-chain execution (via `eth_call`); using them in on-chain transactions may result in significant gas costs or exceed block gas limits for large contracts.



## Approach and methodology




To establish a uniform evaluation, we define the following terminology in accordance with the OWASP Risk Rating

Methodology:

	<b>Likelihood</b> Indicates the probability of a specific vulnerability being discovered and exploited in real-world scenarios
	<b>Impact</b> Measures the technical loss and business repercussions resulting from a successful attack
	<b>Severity</b> Reflects the comprehensive magnitude of the risk, combining both the probability of occurrence (likelihood) and the extent of potential consequences (impact)

Likelihood and impact are divided into three levels: High H, Medium M, and Low L. The severity of a risk is a blend of these two factors, leading to its classification into one of four tiers: Critical, High, Medium, or Low.

When we identify an issue, our approach may include deploying contracts on our private testnet for validation through testing. Where necessary, we might also create a Proof of Concept PoC to demonstrate potential exploitability. In particular, we perform the audit according to the following procedure:

	<b>Advanced DeFi Scrutiny</b> We further review business logics, examine system operations, and place DeFi-related aspects under scrutiny to uncover possible pitfalls and/or bugs
	<b>Semantic Consistency Checks</b> We then manually check the logic of implemented smart contracts and compare with the description in the white paper.
	<b>Security Analysis</b> The process begins with a comprehensive examination of the system to gain a deep understanding of its internal mechanisms, identifying any irregularities and potential weak spots.

