Audit Process and Reporting

The audit process varies greatly from company to company, and between individuals as there is, as yet, no generally-accepted industry standard process.

Smart contract auditing is a niche information security service. It arose out of necessity.

Smart contracts audits aim to prevent the pain entrepreneurs, developers and users experience when Ethereum contracts are hacked or otherwise fail.
Immutability implies that repair may be difficult and costly, or impossible.
Immutability implies a requirement for debut production releases to be free of defects, but errors and oversights are likely to remain commonplace as new developers enter the space.
The EVM is an unfamiliar platform, blockchain is, at first, an unfamiliar paradigm, and Solidity is, at first, an unfamiliar language. It is not reasonable to expect perfection from new developers.

Observing projects getting killed by preventable problems increased general awareness of the importance of preventative quality-assurance.
Two approaches shaped the formative Ethereum code security industry.

1. Bug Bounties

The first of these is Bug Bounties. Bug bounties are a time-tested approach to reinforcing information security. Organizations such as HackerOne , organize bug bounties for corporate clients. Bug Bounties are a way of reaching out to large numbers of qualified developers, to possibly discover critical issues.

2. Formal Verification

Formal verification is the process by which one proves properties of a system mathematically. In order to do that one writes a formal specification of the application behavior. The formal specification is analogous to our Statement of Intended Behavior, but it is written in a machine-readable language. The formal specification is later proved (or not) using one of the available tools.

The Audit Process

> *Auditing a smart contract entails a methodical review of the in-scope source code, in order to provide reasonable assurance that the code behaves as expected, and contains no vulnerabilities.*

Reasonable assurance is important because it is impossible to ensure a piece of code contains no bugs. Beware of this when wording reports. Declaring a code base is bug free

is irresponsible, and can lead to liability problems.

> *The company receives a defense against possible liability. The auditor accepts reputational risk.*

For emphasis, auditors should apply care to all forms of communication to avoid a situation in which the auditor appears to take on, perhaps unwittingly, liability for the project.

How Will They all Fit Together?

The best processes will mix and layer a number of approaches, increasing the probability of finding a bug, if one exists.

A recent example is MakerDAO's Multi Collateral DAI set of smart contracts. Most of the smart contracts were formally verified and an audit was conducted. This was the start of an excellent process. Even so, a USD $50,000 critical bug was awarded by their Bug Bounty program, demonstrating the value of a Bug Bounty even after audits and formal verification.

The process we recommend is an audit, or audits, followed by a well-funded bug bounty that is open for sufficient time to build confidence in the project and with significant rewards for finding critical bugs.

Code freeze

From a software engineering perspective, a Freeze is a period when the rules that govern changes become more strict. Freezes are used for a variety of reasons. For example a team might implement a Feature Freeze to prevent any new features being added so they can focus on testing, issue resolution, even documentation and marketing collateral. A Specifications Freeze might block further design changes so that implementation of the specification can proceed.

In our case, a Code Freeze is a full code freeze - no changes of any kind while the audit is performed. Smart contract audits are normally performed on repository containing the code, so no commits are permitted during the audit.

This means development is finished. The developers made their best effort to create an application that behaves exactly as specified and contains no bugs.

This is very important. The main reason is obvious: Auditors should look at the version that is going to be deployed. Smart contracts are immutable (we'll get to upgradeability hacks shortly). The audit can be thought of as a dress rehearsal for actual deployment. After deployment, remediation of defects will be either extremely costly or completely impossible. An audit is always about a precise deployment candidate. Future versions of that candidate (if any) must be considered unaudited, since any change is potentially a source of new problems.

The business world applies tremendous pressure on this process. Deadline pressure will invariably push against the ideals of thoroughness and process integrity. As the auditor who accepts reputational risk and endorses the audit finding, your duty is to defend the integrity of the process.

Always request a commit and stick to that during the audit, while also documenting it in the report. Never try to audit a moving target. The effectiveness of your work will be impaired, as will your reputation.

Specifying intended behaviour

The auditor is tasked with ensuring the application behaves as specified. Where, exactly, is application behavior specified? This will vary greatly from project to project, but ideally there should exist a succinct document outlining the goal of the application, what is allowed and what is prevented. We call this a Statement of Intended Behavior. It should be precise and unambiguous so auditors can compare what the developers want to happen and the code that is intended to make it happen.

A Statement of Intended Behaviour will be presented as a separate document, sometimes as part of the repository's wiki or readme.md. Sometimes the document is simply non-existent. In such a case, request that the developer, along with the rest of his team create a document before the audit starts. Input from business-focused professionals is valuable. Sometimes, they will have a clearer view of how the system should behave.

The size of the specification will be proportional to the complexity of the application. To generalize for any application, the specs should include:

- Goal of the application
- Main flows
- The actors / roles and what they do
- Access restrictions
- Failure states to be avoided

One caveat: You will stumble upon specifications that seem to be wrong, and in fact are. If you notice that the owner of the contract can drain the contract of user's funds, it seems obvious that it needs to be reported. But what if the client has specified this as intended behavior?

This is always a tough call, and has been discussed many times such as in Adam Kolar's article and recently in the unsolicited audit of Compound Finance's contracts.

When in doubt, document the issue in the report. The whole purpose of our industry is to create systems where trust is not required, or its role is greatly minimized.

Estimating and price quotes

The goal of an estimate is to efficiently assess the key factors that tend to affect actual effort / hours. In this context, “efficiently” means to limit oneself to a superficial perusal of the code that won’t take too long. The key is to know what to look for.

Many companies quote based on lines of code. In our experience, line count (quantity) is a very poor indicator. Complexity is a better indicator of the actual time required for the audit process. A very large, monolithic smart contract will often be easier to audit than a handful of very small smart contracts that interact in multiple ways.

In our experience, good indicators to note include:

- **The count of external calls**: The number of external calls is a good indicator because they impact the code base complexity in a number of ways.
  Even simple implementations such as an ERC20 token can have an impact on a calling smart contract: USDT and OMG tokens do not return true for successful transfers, for example.
  Contracts can be maliciously altered too, so if you are calling untrusted contracts, this has to be accounted for. Recently SpankChain was hacked and the attacker used a rogue ERC20 token implementation. The rogue contract implemented the ERC20 standard interface, but when called for a transfer would re-enter SpankChain's contract.
- **The count of public / external functions**: These are the points of entry. Execution starts here. They will determine the number of paths possible during execution.
- **Use of Solidity Assembly**: Solidity Assembly takes a lot longer to audit. Code is harder to read, several opcodes that are not accessible via Solidity are at the developer’s disposal and none of Solidity’s usual safeguards apply.
- **[Code Smell**](program-analysis/#looking-for-code-smells)
- **Other signs of cleverness, novel solutions**: Anything not idiomatic

When the Client Proposes the Scope

- To audit only certain files in the overall project
- To audit an amended version of something that was audited before, possibly by someone else.

There are important considerations to keep in mind in these cases.

- **Treat all out-of-scope contracts as untrusted contracts**. This may be counter-intuitive to the client, because they trust them. Again, your duty is to safeguard the integrity of the process and your audit team’s reputation. If you do not review them, treat them (and most importantly, calls to them from the in-scope contracts) as interactions with untrusted contracts.
- **Treat all audits as full audits**. It is not uncommon that clients request a follow-up audit on code that has previously been audited and changed just a bit. If you were not the first auditor, make sure to quote a full audit of the code.

> Lastly, if you notice important parts of the code base are out of scope, take time to guide your client to understand the risks involved. Remember, clients and readers of your report are depending on you to identify and raise concerns.

The Process

Extropy uses a very particular process, that we feel is ideal for auditing smart contracts. All audits include three auditors in the team, with the exception of some very low complexity audits, in which case we allow teams of two.

We schedule a debrief meeting close to the delivery day.
Iit's not uncommon that a vulnerability will be found by say only two out of three.
This is, itself, an advantage of layering independent audits, diverse sets of experience, and uniquely personal work processes.

We do not require the auditors to follow a prescribed process. Auditors are encouraged to audit using the tools they know and trust, inspecting code in the ways that best suit them. In that debrief meeting, the reports are merged into the final Extropy report that is delivered to the client.

Remediation Period

After the report is delivered the project enters a phase in which the client can report fixes that will be verified and documented by the team. The effectiveness of the fixes is verified by the audit team. This is to confirm that the fixes actually work and, importantly, do not create new issues.

The commits in which each issue was fixed are included, as well as a last-reviewed version both in the summary and in the conclusion of the report.

Our reports can be public, at the discretion of the client.

After the Audit

We encourage clients to proceed to a bug bounty with significant rewards, as another way to layer mitigation of the risk of bugs and their impact.

In bug bounties, the hunters tend to look for critical bugs, but report whatever they see along the way. They tend to not look over the whole codebase, but they spend time in areas that appear to be high-risk. In combination with an audit, the entire code base is secured by an audit, and the high risk areas are further secured by more eyes and more imagination focused on the code. That’s more experts applying their experience, their imagination and their skills to mitigate the risk that something subtle has gone unnoticed.

Audit Report

The Audit Report
The Audit Report is the deliverable of the engagement. As such, it's important that it includes defined sections and communicates the project completely. These are the normalized section headings of an audit report:

- Identification of the client
- Date
- Scope (list all files)
- Commit hash and repository address
- Bugs
- Audit Methodology
- Conclusion

Document who requested the audit. It’s acceptable if the client requested anonymity. Your report should indicate this explicitly. Also document the date the audit was published, the files reviewed, bugs and concerns discovered and an overall conclusion about the health of the application.

Be aware of the audience, for example, the client might be a Venture Capitalist with limited understanding of the technical details.

Not all Audit Reports are prepared for such diverse audiences. If delivering to developers on a confidential basis, it may be acceptable to be less didactic while ensuring that bugs are clearly and concisely described and that the introduction and conclusion can be understood by the average ethereum user (a technically literate user).

In particular, be sure to describe the potential impact (why it matters) in terms that are understandable by the widest possible audience, and explanations in terms a developer can parse to comprehend the precise nature of the bug without further explanation.

Reporting Bugs

Bug reports are the main product of both audits and bug hunts. A bug report is only as good as the understanding it provokes in the mind of the receiver. The central task of a bug report is to make the issue crystal clear to other people.

Also keep in mind that the audience of a bug report is often the very people who either wrote the code or audited it. They have looked at it from many angles and your task is to change their minds about something they thought was correct.
Explain in a matter-of-fact, non-accusatory tone and include sufficient information to support your claims.

Clearly describe the problem, the consequences, steps to get there, impact, severity and optionally a suggested direction for the fix.

Keep in mind that bugs are subjective. Indeed, considerable controversy can swirl around exactly what is and what is not a bug. For example, under certain conditions that probably cannot possibly exist, something terrible could happen. Or, under everyday conditions, something odd can happen but it is of no serious consequence.

Some good examples:

The ERC20 Approval Attack:

This is how the original ERC20 approval attack was described. Although the format is unusual, it has everything that a well-described bug should have: the context, the steps to the exploit, a brief analysis and a possible workaround.

CryptoKitties empty fallback:

This was found by Nick Johnson during the initial crypto kitties bug bounty. It follows a format more likely to be found in bug bounty and audit reports with concise explanation and consequences.

Categorization of Severity

Risk ratings, as well as the processes we've just seen, vary greatly between organizations. Each company will have its own way to classify bugs. Even when the familiar categories of critical, major, and minor are used, the definitions of what's included are inconsistent between firms.

This is another example of organizations in the space working independently on their own processes in a standards-free setting. When one finds a bug, it's important to categorize it properly, according to the local customs of the audit team or bug bounty program.

> *You need to be prepared to defend your classification of the bug as well as your description of the bug.*

Several industry standards (in the wider security industry, not smart contract audits) address the topic. The most prominent of these is the OWASP (Open Web Application Security Project) risk classification standard, which is used by the Ethereum Foundation and many others. Another is the CVSS (Common Vulnerability Scoring System).

OWASP

Risk = Likelihood * Impact

Risk equals the Likelihood of something materializing (or, in our case, the likelihood of the bug being exploited) times the Impact caused when it happens. This formulation is pervasive. It applies to everyone assessing risk across all domains.

With this understanding in mind, let's look at how OWASP breaks down likelihood and impact, making a previously purely interpretative assessment more objective.

Likelihood

OWASP breaks likelihood into two sub-dimensions. The final score is usually a simple average of all the values. The factors are:

Threat Agent Factors

Threat agent is the possible attacker. The goal here is to estimate the likelihood of a successful attack by this group of threat agents. Use the worst-case threat agent.

- **Skills**: How technically skilled is this group of threat agents?
- **Motive**: How motivated is this group of threat agents to find and exploit this vulnerability?
- **Opportunity**: What resources and opportunities are required for this group of threat agents to find and exploit this vulnerability?
- **Size**: How large is this group of threat agents?

Vulnerability Factors

The next set of factors are related to the vulnerability involved. The goal here is to estimate the likelihood of the particular vulnerability involved being discovered and exploited. Assume the threat agent selected above.

- Ease of discovery: How easy is it for this group of threat agents to discover this vulnerability?
- Ease of exploit: How easy is it for this group of threat agents to actually exploit this
- Awareness: How well-known is this vulnerability to this group of threat agents?
- Intrusion detection: How likely is an exploit to be detected?

Impact

Impact is usually measured in financial terms, in OWASP's case it also derives from a number of factors:

Technical Impact Factors

Technical impact can be broken down into factors aligned with the traditional security areas of concern: confidentiality, integrity, availability, and accountability. The goal is to estimate the magnitude of the impact on the system if the vulnerability were to be exploited.

- Loss of confidentiality
- Loss of integrity
- Loss of availability

- Loss of accountability

Business Impact Factors

The business impact stems from the technical impact, but requires a deep understanding of what is important to the company running the application. In general, you should be aiming to support your risks with business impact. The business risk is what justifies investment in fixing security problems.

The factors below are common areas for many businesses, but this area is even more unique to a company than the factors related to threat agent, vulnerability, and technical impact.

- **Financial damage**
- **Reputation damage**
- **Non-compliance**
- **Privacy violation**

OWASP provides a nice spreadsheet so we don't have to reinvent the wheel.

Although OWASP's model is the industry standard, when we look at our niche (Ethereum smart contracts), we'll find simpler models.
The model below is very simple, but can be applied to most smart-contract-only bug bounties:

- Critical: Stealing user funds, freezing funds in the smart contracts.
- Major: A user obtains advantage over others in an unintended way.
- Minor: Bugs that can cause friction to users, but put no funds at risk and create no unfair advantages for particular users.

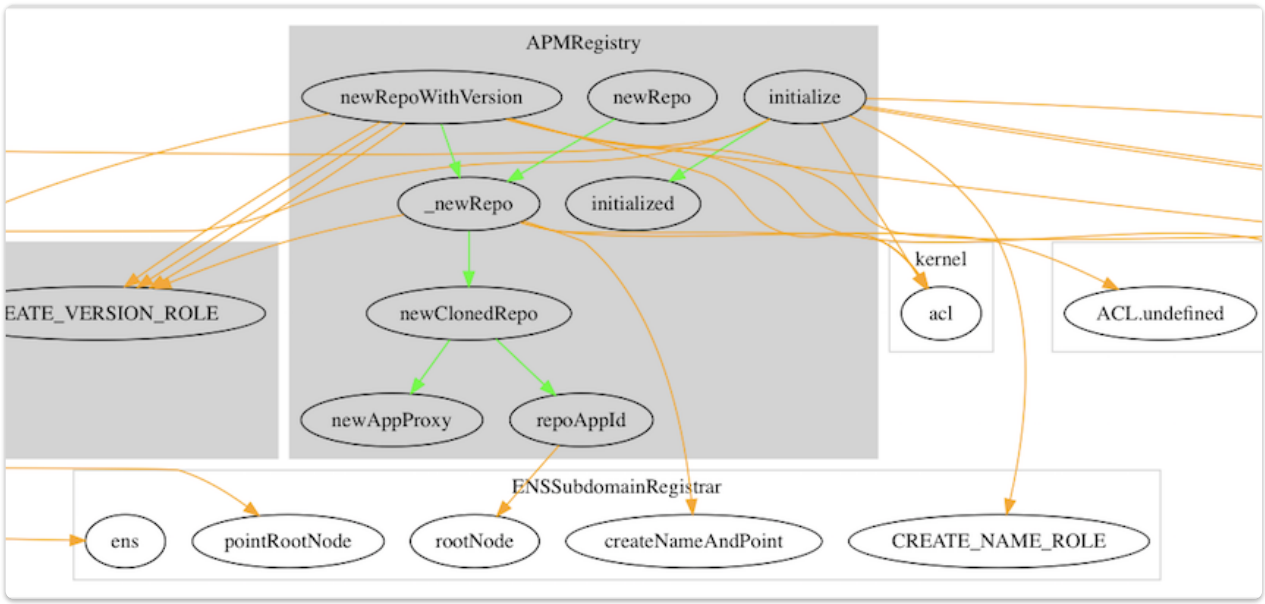
- Informational : A suggested better approach or optimisation

Static Analysis and Visualisation Tools

Visualisation

- EVM Lab

- Surya



- Piet
- Solidity Metrics

Static and Dynamic Analysis

- [Mythx] (https://mythx.io/) - also available as a remix plugin
- Slither
  - List of Detectors
- Echidna
  -Vertigo - Mutation testing framework
  -Manticore
  - Program Exploration
  - Input Generation
  - Error Discovery
  - Instrumentation
  - Programmatic Interface

Checklists

SWC Registry
SCSVS
Smart Contract Security Verification Standard 14-part checklist created to standardize the security of smart contracts.

CONSENSYS KNOWN ATTACKS

- Reentrancy
- Oracle Manipulation
- Frontrunning
- Timestamp Dependence
- Insecure Arithmetic
- Denial of Service