L43: Smart Contract Security

Module F: Advanced Topics

Blockchain & Cryptocurrency Course

December 2025

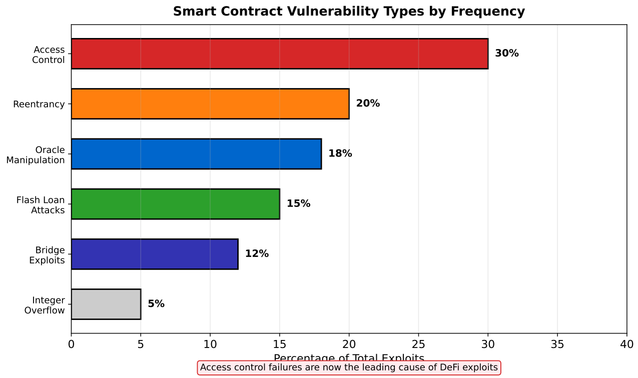
Learning Objectives

- Understand the stakes of smart contract security
- Identify top vulnerability types (reentrancy, access control, oracle manipulation)
- Analyze real-world exploits (The DAO, Parity, bridge hacks)
- Apply security tools (Slither, Mythril, formal verification)
- Implement defense in depth strategies

The Stakes of Smart Contract Security

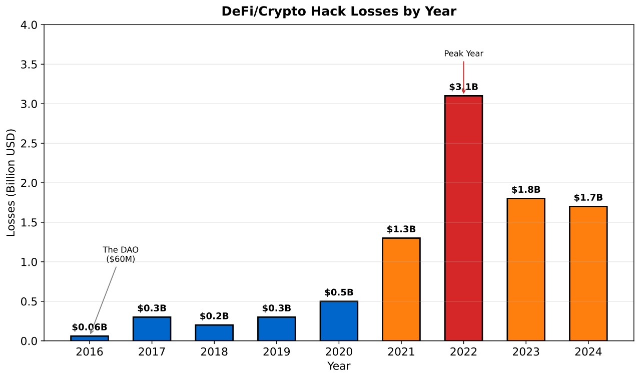
- **Code is Law**: Smart contracts are immutable and self-executing
- **High-Value Targets**: DeFi protocols hold billions in assets
- **Irreversibility**: Bugs cannot be patched without upgradeable contracts
- **Losses to Date**: \$8B+ stolen from smart contract exploits (2016-2024)
- **Asymmetry**: One vulnerability can drain entire protocol
- **Composability Risk**: Vulnerabilities cascade across protocols

Top Vulnerability Types



Access control failures have become the leading cause of DeFi exploits

Historical Losses



2022 was peak year ($3.1B); losses decreasing but still significant

Reentrancy: The DAO Hack (2016)

- **The DAO**: Decentralized organization, $150M raised
- **Vulnerability**: External call before state update
- **Attack Mechanism**:
  1. Attacker deposits 1 ETH
  2. Calls withdraw(1), contract sends 1 ETH
  3. Attacker's fallback recursively calls withdraw()
  4. Balance not yet updated, sends another 1 ETH
  5. Loop continues until contract drained
- **Result**: $60M drained
- **Aftermath**: Ethereum hard fork (ETH vs ETC split)

Reentrancy: Defense

Checks-Effects-Interactions Pattern:

1. **Check**: Verify conditions (require statements)
2. **Effect**: Update state variables FIRST
3. **Interaction**: Make external calls LAST

Reentrancy Guard (Mutex):

- Lock flag prevents recursive calls
- OpenZeppelin ReentrancyGuard is industry standard

Root Cause: State updated after external call
Prevention: Always update state before external calls

Access Control Vulnerabilities

Common Mistakes

- Missing onlyOwner modifier
- Default function visibility (public)
- Unprotected selfdestruct
- Constructor typo (pre-0.5.0)

Parity Wallet Hack (2017)

- initWallet() unprotected
- Attacker became owner
- Called selfdestruct
- $300M frozen forever

Best Practices

- Use OpenZeppelin Ownable
- Explicit visibility modifiers
- Role-based access control
- Multi-sig for critical functions

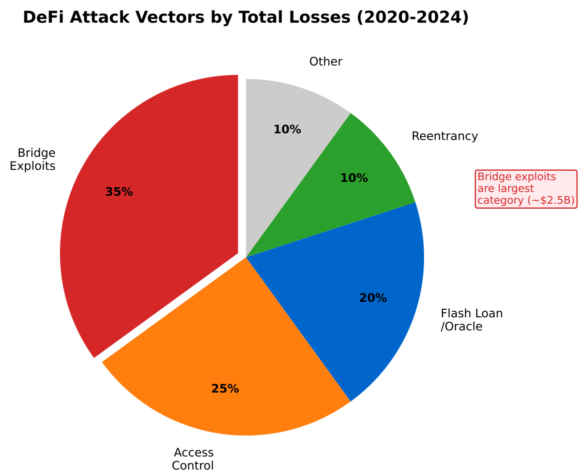
2024 Reality

- Access control is now top attack vector
- Private key compromises
- Admin privilege escalation

Oracle Manipulation

- **Problem**: DeFi relies on external price data (oracles)
- **Vulnerable Pattern**: Using single DEX price as oracle
- **Attack Vector**:
  1. Flash loan borrow massive funds
  2. Manipulate DEX pool price (10x increase)
  3. Protocol reads manipulated price
  4. Exploit (borrow, liquidate, mint at wrong price)
  5. Restore pool, repay flash loan, keep profit
- **Real Examples**: Harvest Finance ($34M), Cream ($130M)
- **Defense**: Chainlink oracles, TWAP, multiple sources

Attack Vectors by Loss Amount

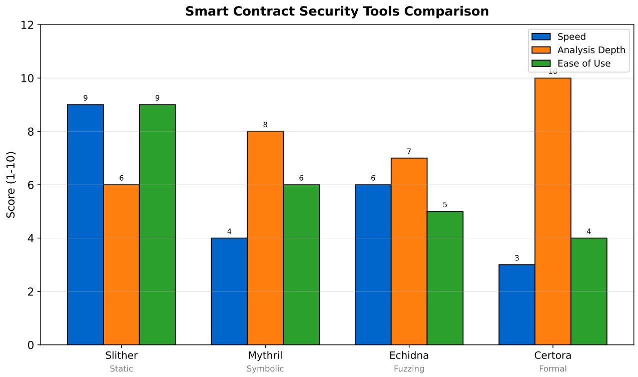


Bridge exploits account for largest share of total losses

Bridge Exploits: The New Frontier

- **Why Bridges?**: Cross-chain transfers require lock-and-mint
- **Attack Surface**: Validators, smart contracts, key management
- **Notable Exploits**:
  - Ronin Bridge (2022): $625M - validator key compromise
  - Wormhole (2022): $320M - signature verification bug
  - Nomad (2022): $190M - initialization vulnerability
- **Key Issues**:
  - Centralized validator sets
  - Complex multi-chain logic
  - High-value targets ($10B+ locked in bridges)
- **Trend**: Bridge security is top priority for 2024-2025

Security Tools Comparison



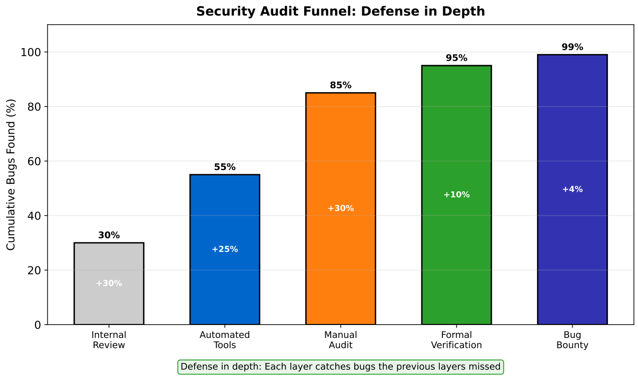
Combine fast tools (Slither) with deep analysis (Mythril, Certora)

Security Tools Overview

Tool	Type	Detects
Slither	Static analyzer	Reentrancy, overflow, access
Mythril	Symbolic execution	Integer bugs, unchecked calls
Echidna	Fuzzer	Invariant violations
Certora	Formal verifier	Specification violations

- **Slither**: Fast, easy CI/CD integration
- **Mythril**: Deep analysis, finds complex bugs
- **Echidna**: Property-based testing
- **Certora**: Mathematical proofs

Defense in Depth



Each security layer catches bugs that previous layers missed

Audit Process

1. **Internal Review**: Developer self-audit, peer review
2. **Automated Tools**: Slither, Mythril in CI/CD
3. **Manual Audit**: Security firm (2-4 weeks, $50k-$500k)
   - Trail of Bits, OpenZeppelin, Quantstamp
4. **Formal Verification**: High-value contracts (Certora)
5. **Bug Bounty**: Community testing (Immunefi)
6. **Monitoring**: Real-time detection (Forta, OpenZeppelin Defender)
7. **Insurance**: Coverage for exploits (Nexus Mutual)

Bug Bounty Programs

- **Purpose**: Incentivize white-hat hackers
- **Platforms**: Immunefi, HackerOne, Code4rena
- **Payouts**: $1k (low) to $10M+ (critical)
- **Record**: Wormhole $10M bounty (2022)
- **Notable Programs**:
  - MakerDAO: Up to $10M
  - Ethereum Foundation: Up to $250k
  - Compound: Up to $500k
- **ROI**: $1 in bounties prevents $100+ in losses
- **Best Practice**: Continuous bounty, not just pre-launch

Upgradeable Contracts

- **Problem**: Immutable contracts cannot be patched
- **Solution**: Proxy pattern (separate storage and logic)
- **Transparent Proxy**:
  - Proxy holds storage, delegates to implementation
  - Admin can upgrade implementation address
- **UUPS (Universal Upgradeable Proxy)**:
  - Upgrade logic in implementation (smaller proxy)
- **Risk**: Admin key compromise $\rightarrow$ malicious upgrade
- **Mitigation**: Multi-sig, timelock delays, immutable after maturity

Security Best Practices

1. Use latest Solidity (0.8.0+ for overflow protection)
2. Follow Checks-Effects-Interactions pattern
3. Apply reentrancy guards (OpenZeppelin)
4. Explicit visibility for all functions
5. Decentralized oracles (Chainlink) or TWAP
6. Pull over push for payments
7. Avoid loops over unbounded arrays
8. Run Slither + Mythril in CI/CD
9. Professional audit before mainnet
10. Bug bounty program
11. Real-time monitoring (Forta)

Summary

Key Takeaways:

- Smart contract security is critical: \$8B+ cumulative losses
- Top vulnerabilities: Access control, reentrancy, oracle manipulation, bridges
- The DAO hack (\$60M) led to Ethereum hard fork
- Bridge exploits are now largest loss category
- Defense in depth: Automated tools + audits + formal verification + bounties
- Tools: Slither (fast), Mythril (deep), Certora (formal proofs)
- Upgradeable contracts: Allow patches but introduce admin key risk
- 2024 trend: Real-time monitoring and “Security as a Service”

Questions for Reflection

1. Why is the Checks-Effects-Interactions pattern important?
2. How do oracle manipulation attacks exploit DeFi protocols?
3. What makes bridge security particularly challenging?
4. Should audited protocols still have bug bounties?
5. What are the trade-offs of upgradeable contracts?