L15: Solidity Fundamentals

Module B: Ethereum & Smart Contracts

Blockchain & Cryptocurrency Course

December 2025

Learning Objectives

By the end of this lesson, you will be able to:

- Describe Solidity's role as a smart contract language
- Declare and use fundamental data types (uint, address, bool, string, bytes)
- Write functions with appropriate visibility and state mutability modifiers
- Implement events for logging and monitoring
- Use mappings and arrays for data storage
- Apply inheritance and interfaces

The Problem: How do we write bug-free financial code?

The Challenge
Smart contracts handle billions of dollars in value, yet bugs are irreversible once deployed. Unlike traditional software, there's no "update" button—a single logic error can drain funds permanently.

Why It Matters

- Smart contract bugs are publicly exploitable by anyone monitoring the blockchain
- Historical losses: The DAO ($60M, 2016), Parity multisig freeze ($280M, 2017), Poly Network ($611M, 2021)

Today's lesson: How Solidity Fundamentals addresses this challenge

What We Need

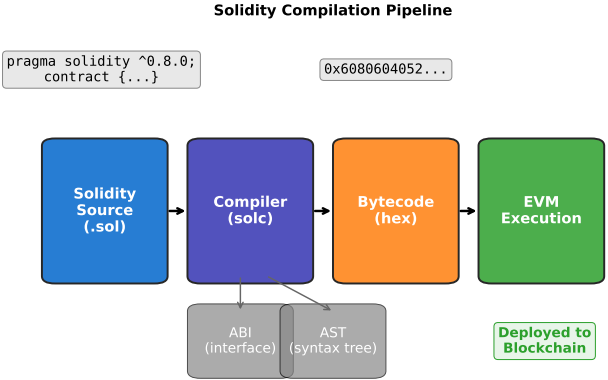
- Risk management and mitigation
- Language features that prevent common vulnerability patterns (reentrancy, integer overflow, access control failures)

The Cryptoeconomics Question
Managing systemic and idiosyncratic risks

What is Solidity?

Solidity is a statically-typed, contract-oriented programming language:

- Created specifically for Ethereum smart contracts
- Syntax similar to JavaScript/C++, compiles to EVM bytecode
- Current stable version: 0.8.x (as of 2025)



Basic Contract Structure

Every Solidity file starts with a version pragma:

```
// SPDX-License-Identifier: MIT
pragma solidity ^0.8.0;

contract HelloWorld {
    string public message;

    constructor(string memory initialMessage) {
        message = initialMessage;
    }

    function setMessage(string memory newMessage) public {
        message = newMessage;
    }

    function getMessage() public view returns (string memory) {
        return message;
    }
}
```

Key Elements: License identifier, pragma, contract declaration, state variables, constructor, functions

SPDX License and Version Pragma

Required at top of every Solidity file:
Common Licenses:

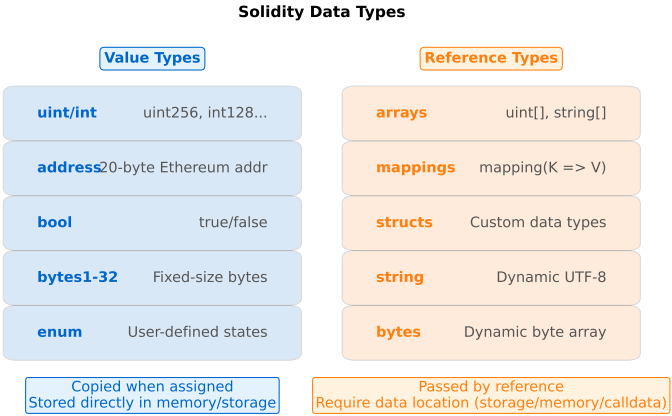
- **MIT:** Permissive open-source license
- **GPL-3.0:** Copyleft license (derivatives must be open-source)
- **UNLICENSED:** Proprietary code

Version Pragma:

- `pragma solidity ^0.8.0;` - Compatible with 0.8.0 to 0.8.x
- `pragma solidity >=0.8.0 <0.9.0;` - Range specification
- `pragma solidity 0.8.20;` - Exact version

Data Types Overview

Solidity has two categories of data types:



Value Types: Integers and Booleans

Integers:

- `uint` (unsigned): 0 to $2^{256} - 1$ (alias for `uint256`)
- `int` (signed): -2^{255} to $2^{255} - 1$ (alias for `int256`)
- Sized variants: `uint8, uint16, ..., uint256`

Booleans:

- `bool`: `true` or `false`
- Operators: `!` (not), `&&` (and), `||` (or)

```
contract Types {
    uint256 public largeNumber = 1000000000000000000;  // 1e18
    uint8 public smallNumber = 255;  // Max value for uint8
    int256 public signedNumber = -42;
    bool public isActive = true;
}
```

Value Types: Address

Address type holds 20-byte Ethereum addresses:

- `address`: Basic address type
- `address payable`: Can receive Ether via `transfer()` or `send()`

Address Members:

- `<address>.balance`: Returns Ether balance (in Wei)
- `<address payable>.transfer(uint amount)`: Send Ether, reverts on failure

```
contract AddressExample {
    address public owner;
    address payable public recipient;

    constructor() {
        owner = msg.sender;  // Address of contract deployer
        recipient = payable(msg.sender);  // Convert to payable
    }

    function checkBalance() public view returns (uint) {
        return owner.balance;  // Balance in Wei
    }
}
```

Reference Types: Arrays

Fixed-Size Arrays:

```
uint[5] public fixedArray;  // Array of 5 uints
```

Dynamic Arrays:

```
uint[] public dynamicArray;
string[] public names;

function addElement(uint value) public {
    dynamicArray.push(value);  // Append to array
}

function getLength() public view returns (uint) {
    return dynamicArray.length;
}

function removeLastElement() public {
    dynamicArray.pop();  // Remove last element
}
```

Reference Types: Mappings

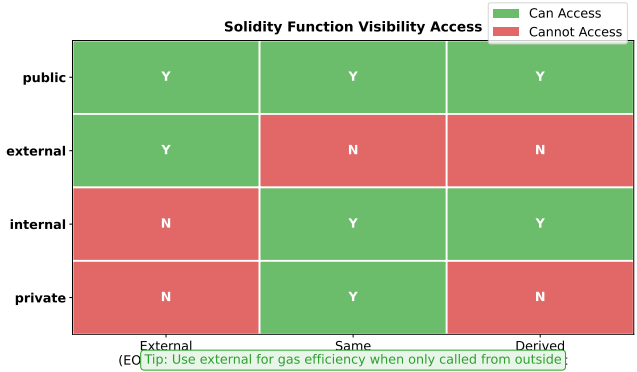
Key-value storage (like hash tables):

```
contract MappingExample {
    // Mapping from address to balance
    mapping(address => uint256) public balances;

    // Nested mapping (address to address to allowance)
    mapping(address => mapping(address => uint256)) public allowances;

    function updateBalance(address account, uint256 amount) public {
        balances[account] = amount;
    }

    function getBalance(address account) public view returns (uint256) {
        return balances[account];  // Returns 0 if key doesn't exist
    }
}
```

Key Properties: All keys exist with default value, cannot iterate, only in storage

Functions: Visibility Modifiers

Four visibility levels determine who can call a function:



Functions: State Mutability

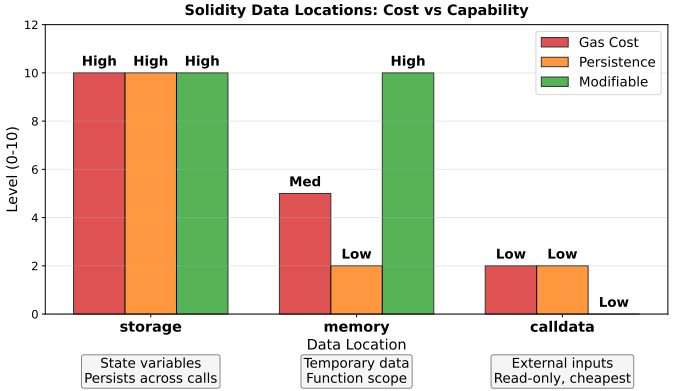
Three state mutability levels:

1. **view:** Reads state but doesn't modify it (no gas when called off-chain)
2. **pure:** Doesn't read or modify state
3. **(none):** Can read and modify state (always costs gas)

```
contract Mutability {
    uint public value = 10;

    function getValue() public view returns (uint) {
        return value;  // Reads state (view)
    }

    function add(uint a, uint b) public pure returns (uint) {
        return a + b;  // No state access (pure)
    }

    function setValue(uint newValue) public {
        value = newValue;  // Modifies state (no modifier)
    }
}
```

Data Locations: storage vs memory vs calldata

Reference types require explicit data location:



Events

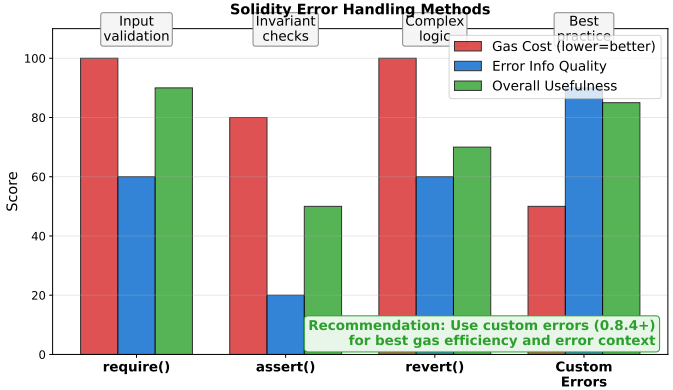
Events enable logging for off-chain monitoring:

```
contract EventExample {
    event Transfer(address indexed from, address indexed to, uint256 amount);
    event Approval(address indexed owner, address indexed spender, uint256 amount);

    mapping(address => uint256) public balances;

    function transfer(address to, uint256 amount) public {
        require(balances[msg.sender] >= amount, "Insufficient balance");
        balances[msg.sender] -= amount;
        balances[to] += amount;
        emit Transfer(msg.sender, to, amount);  // Emit event
    }
}
```

Indexed Parameters: Up to 3 parameters can be `indexed` for efficient filtering

Error Handling Methods

Solidity provides multiple error handling mechanisms:



Error Handling: require, assert, revert

1. **require(condition, message):** Validate inputs/conditions, refunds gas
2. **assert(condition):** Check invariants (should never fail)
3. **revert(message):** Unconditional revert with message

```
function transfer(address to, uint amount) public {
    require(to != address(0), "Cannot transfer to zero address");
    require(balances[msg.sender] >= amount, "Insufficient balance");

    balances[msg.sender] -= amount;
    balances[to] += amount;

    assert(balances[msg.sender] + balances[to] == totalSupply);  // Invariant
}
```

Custom Errors (Solidity 0.8.4+)

More gas-efficient than string error messages:

```
contract CustomErrors {
    error InsufficientBalance(uint requested, uint available);
    error Unauthorized(address caller);

    address public owner;

    function withdraw(uint amount) public {
        if (msg.sender != owner) {
            revert Unauthorized(msg.sender);
        }
        if (balances[msg.sender] < amount) {
            revert InsufficientBalance(amount, balances[msg.sender]);
        }
        // ... transfer logic
    }
}
```

Benefits: Lower gas cost, typed parameters, better error context

Modifiers

Reusable code for function preconditions:

```
contract ModifierExample {
    address public owner;
    bool public paused = false;

    constructor() { owner = msg.sender; }

    modifier onlyOwner() {
        require(msg.sender == owner, "Not the owner");
        _;  // Placeholder for function body
    }

    modifier whenNotPaused() {
        require(!paused, "Contract is paused");
        _;
    }

    function pause() public onlyOwner { paused = true; }
    function unpause() public onlyOwner { paused = false; }

    function criticalFunction() public onlyOwner whenNotPaused {
        // Only owner can call, and only when not paused
    }
}
```

Inheritance

Solidity supports multiple inheritance:

```
contract Ownable {
    address public owner;
    constructor() { owner = msg.sender; }
    modifier onlyOwner() {
        require(msg.sender == owner, "Not owner");
        _;
    }
}

contract Pausable is Ownable {
    bool public paused;
    function pause() public onlyOwner { paused = true; }
}

contract MyContract is Pausable {
    function doSomething() public onlyOwner {
        // Inherits owner, onlyOwner, paused, pause()
    }
}
```

Key: `is` for inheritance, `virtual`/`override` for polymorphism

Interfaces

Define contract structure without implementation:

```
interface IERC20 {
    function totalSupply() external view returns (uint256);
    function balanceOf(address account) external view returns (uint256);
    function transfer(address to, uint256 amount) external returns (bool);
    event Transfer(address indexed from, address indexed to, uint256 value);
}

contract MyToken is IERC20 {
    mapping(address => uint256) private _balances;
    uint256 private _totalSupply;

    function totalSupply() public view override returns (uint256) {
        return _totalSupply;
    }
    // ... implement other functions
}
```

Problem Solved? Solidity Fundamentals

The Original Problem

How do we write bug-free financial code?

How Solidity Fundamentals Solves It

- Static typing catches type mismatches at compile time (e.g., can't send ETH to non-payable address)
- Visibility modifiers enforce access control patterns (onlyOwner prevents unauthorized actions)
- State mutability (view/pure) prevents accidental state changes in read-only functions

Remaining Limitations

- No formal verification by default—compiler doesn't prove absence of logic bugs
- Tooling maturity lags traditional languages (limited IDE support, debuggers)

Open Questions

- Will formal verification tools (Certora, K Framework) become standard for high-value contracts?
- Risk: Black swan events (0-day compiler bugs), cascading failures (reentrancy across protocols)

Solidity Fundamentals partially solves "we write bug-free financial code" but introduces new trade-offs

Key Takeaways

1. **Solidity Basics:** Statically-typed language compiling to EVM bytecode
2. **Data Types:** Value types (uint, address, bool) vs reference types (arrays, mappings)
3. **Visibility:** public, external, internal, private determine access
4. **State Mutability:** view (read-only), pure (no state), default (modify)
5. **Data Locations:** storage (persistent), memory (temp), calldata (cheapest)
6. **Error Handling:** Use custom errors (0.8.4+) for gas efficiency

Discussion Questions

1. Why is `string` more expensive than `bytes32` for storing short text?
2. When should you use `external` vs `public` for function visibility?
3. Why can't you iterate over a mapping's keys in Solidity?
4. What are the tradeoffs between events vs state variables for historical records?
5. How does the `indexed` keyword in events affect gas costs and queryability?

Next Lesson Preview: L16 - Lab: Contract Interaction

Coming up next (hands-on lab):

- Introduction to Remix IDE
- Deploying SimpleStorage contract
- Interacting with deployed contracts
- Using MetaMask with test networks
- Deploying to Sepolia testnet

Preparation:

- Install MetaMask browser extension
- Create Ethereum account and save recovery phrase
- Get Sepolia testnet ETH from faucet

Quiz: Questions 1-5

Q1. What is the maximum value that can be stored in a uint8 variable?
A) 128 B) 255 C) 256 D) 65535
Answer: B – uint8 is an 8-bit unsigned integer with range 0 to $2^8 - 1 = 255$.

Q2. Which data type should be used for an Ethereum address that needs to receive Ether?
A) address B) address payable C) bytes20 D) uint160
Answer: B – address payable can receive Ether via transfer() or send().

Q3. What does the "view" state mutability modifier indicate?
A) Function can modify state B) Function cannot read or modify state
C) Function reads state but cannot modify it D) Function is only visible internally
Answer: C – view functions read state without modifying it, consuming no gas when called off-chain.

Q4. Which visibility modifier allows a function to be called ONLY from within the same contract?
A) public B) external C) internal D) private
Answer: D – private functions can only be called from within the same contract, not from derived contracts.

Q5. What is the default value for an uninitialized mapping entry?
A) null B) undefined C) Zero/default value of the value type D) Throws an error
Answer: C – All keys in a mapping exist with their type's default value (0 for uint, false for bool, etc.).

Quiz: Questions 6-10

Q6. Which error handling method should be used to check invariants that should never fail?
A) require() B) assert() C) revert() D) throw
Answer: B – assert() is for internal errors and invariant checking; it should never fail in correct code.

Q7. What is the purpose of the constructor in a Solidity contract?
A) To destroy the contract B) To initialize state variables when contract is deployed
C) To create new instances of the contract D) To define contract visibility
Answer: B – The constructor runs once during deployment to initialize state variables.

Q8. Which data location is the cheapest for function parameters in terms of gas?
A) storage B) memory C) calldata D) stack
Answer: C – calldata is read-only and cheapest because data is not copied into memory.

Q9. How many parameters in an event can be marked as "indexed" for efficient filtering?
A) 1 B) 2 C) 3 D) Unlimited
Answer: C – Up to 3 parameters can be indexed in an event for efficient off-chain filtering.

Q10. What does the underscore (_) represent in a modifier?
A) A comment marker B) A private variable prefix
C) Placeholder for the function body D) An unused parameter
Answer: C – The underscore is replaced by the modified function's body during execution.

Quiz: Questions 11-15

Q11. Which keyword is used to inherit from another contract?
A) extends B) implements C) is D) inherits
Answer: C – Solidity uses "is" for inheritance (e.g., contract MyToken is ERC20).

Q12. What is the difference between "pure" and "view" functions?
A) pure is faster than view B) pure cannot read state, view can read but not modify
C) pure is for external calls only D) No difference, they are aliases
Answer: B – pure functions access no state variables; view functions read but don't modify state.

Q13. Which of the following is TRUE about mappings in Solidity?
A) They can be iterated like arrays B) They are stored in memory
C) All possible keys exist with default values D) They have a length property
Answer: C – Mappings have no concept of undefined keys; all keys map to their type's default value.

Q14. What is the recommended error handling method in Solidity 0.8.4+ for gas efficiency?
A) String-based require() B) Custom errors with revert
C) assert() for all checks D) try-catch blocks
Answer: B – Custom errors are more gas-efficient than string error messages in require().

Q15. Which visibility modifier allows external contracts to call a function but NOT internal calls?
A) public B) external C) internal D) private
Answer: B – external functions can only be called from outside the contract, saving gas for calldata.

Quiz: Questions 16-20

Q16. What is the size of the address type in Solidity?
A) 16 bytes B) 20 bytes C) 32 bytes D) 40 bytes
Answer: B – Ethereum addresses are 20 bytes (160 bits) long.

Q17. Which method is used to add an element to a dynamic array?
A) append() B) add() C) push() D) insert()
Answer: C – push() appends an element to the end of a dynamic array.

Q18. What happens when a function marked "view" attempts to modify state?
A) Compilation warning B) Compilation error
C) Runtime error D) State modification is ignored
Answer: B – Solidity compiler will reject code where view functions attempt state modifications.

Q19. Which of the following can be declared in an interface?
A) State variables B) Function implementations
C) Function signatures only D) Constructors
Answer: C – Interfaces can only declare function signatures, events, and errors, not implementations or state.

Q20. What is the purpose of the "memory" keyword for reference types?
A) Optimize for low memory usage B) Indicate temporary storage during function execution
C) Enable garbage collection D) Allow dynamic resizing
Answer: B – memory indicates data is stored temporarily during function execution, not persisted to blockchain.