Lesson 19: Ethereum and Smart Contracts

Module 2: Blockchain Fundamentals

Digital Finance

Bitcoin's Limitations: Why Ethereum?

Bitcoin Script:

- Not Turing-complete (no loops)
- Limited expressiveness
- Designed for simple transfers
- No complex state

Ethereum Vision (Vitalik Buterin, 2013):

- Turing-complete programming
- Decentralized applications (dApps)
- "World Computer"
- Programmable money and agreements

charts/lesson_19/bitcoin_vs_ethereum.pdf

Smart Contracts: Code as Law

charts/lesson_19/smart_contract_concept.pdf

Account Model: Ethereum's Design

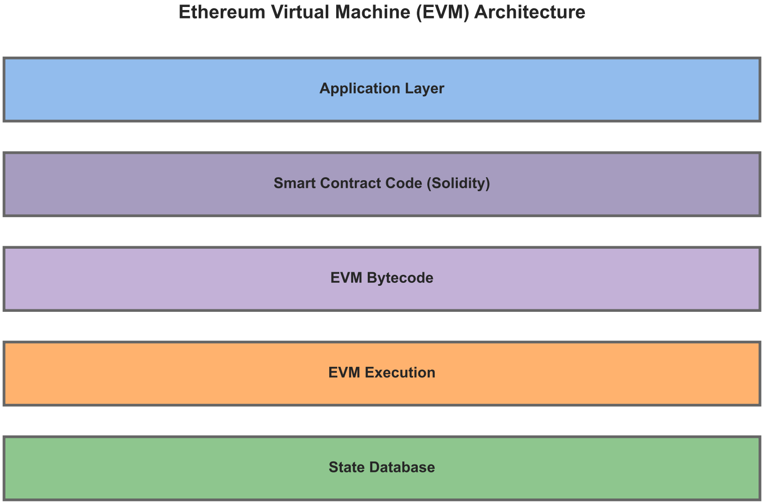
Two Account Types:

1. **Externally Owned Accounts (EOAs):**
   - Controlled by private key
   - Can send transactions
   - No code
2. **Contract Accounts:**
   - Controlled by code
   - Triggered by transactions
   - Store state

charts/lesson_19/account_types.pdf

State: Each account has balance, nonce, code (contracts only), storage

Ethereum Virtual Machine (EVM)



Ethereum Virtual Machine (EVM) Architecture

Application Layer

Smart Contract Code (Solidity)

EVM Bytecode

EVM Execution

State Database

Gas: Metering Computation

Why Gas?

- Prevent infinite loops (halting problem)
- Prioritize transactions
- Compensate miners/validators
- Align incentives

Gas Mechanics:

- Each operation costs gas
- User sets gas limit + gas price
- Unused gas refunded
- Out of gas → revert (but gas consumed)

charts/lesson_19/gas_mechanism.pdf

Gas Costs: Operation Examples

Operation	Gas Cost	Rationale
ADD (arithmetic)	3	Simple computation
MUL (multiplication)	5	Slightly more complex
SSTORE (write storage)	20,000	Permanent state change
SLOAD (read storage)	2,100	Storage access
CREATE (deploy contract)	32,000	Base cost + code size
Transaction (base)	21,000	Minimum for any transaction

Design: Expensive operations (storage, deployment) cost more to prevent spam

Transaction Cost Calculation

Example: Simple ETH Transfer

- Gas limit: 21,000
- Gas price: 50 gwei (1 gwei $= 10^{-9}$ ETH)
- Total fee: $21,000 \times 50 \times 10^{-9} = 0.00105$ ETH

Example: Token Transfer (ERC-20)

- Gas limit: 65,000 (contract interaction)
- Gas price: 50 gwei
- Total fee: $65,000 \times 50 \times 10^{-9} = 0.00325$ ETH

Example: Complex DeFi Swap

- Gas limit: 300,000 (multiple contract calls)
- Gas price: 100 gwei (priority)
- Total fee: $300,000 \times 100 \times 10^{-9} = 0.03$ ETH ($\sim$\$60 at \$2000/ETH)

Legacy Fee Market: First-Price Auction

Pre-EIP-1559 (before Aug 2021):

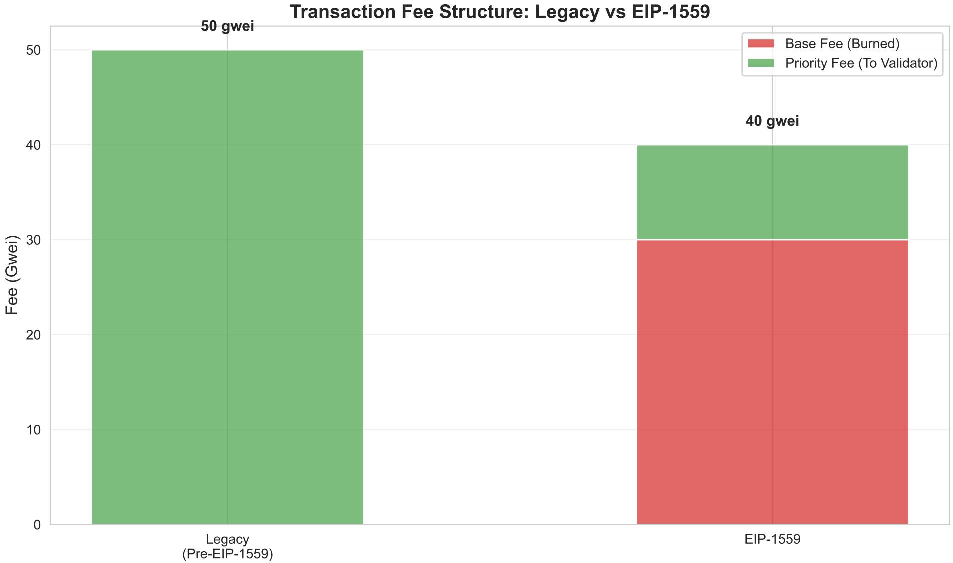
- Users bid gas price
- Miners select highest bids
- First-price auction
- Overpay or get stuck

Problems:

- Fee estimation difficult
- High volatility
- Miner extractable value (MEV)

charts/lesson_19/legacy_fee_market.pdf

EIP-1559: Fee Market Reform (August 2021)



New Fee Structure:

EIP-1559 Base Fee Dynamics

Base Fee Adjustment:

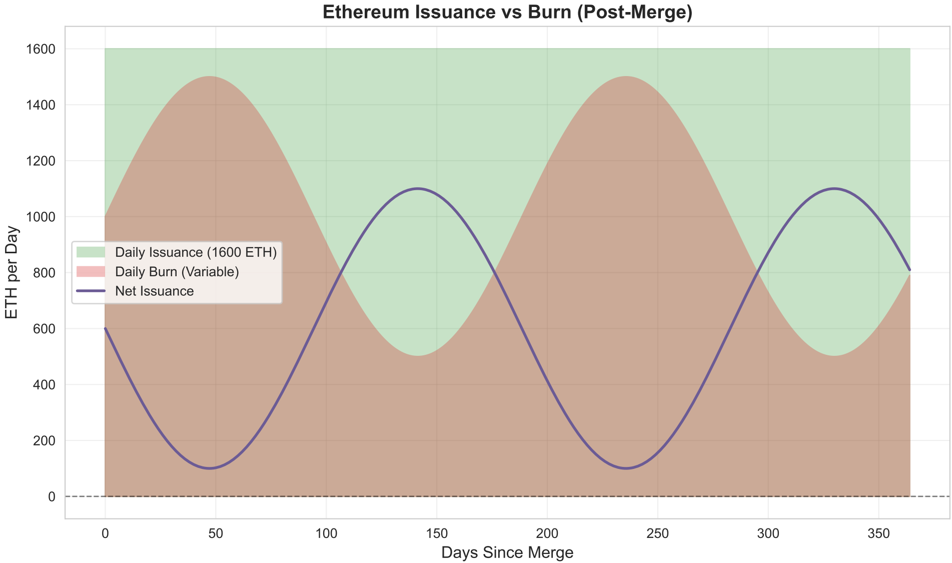
- Target: 15M gas per block
- If block $>$ 15M: base fee ↑ 12.5%
- If block $<$ 15M: base fee ↓ 12.5%
- Max block size: 30M gas

Formula:

$$\Delta_{\text{base}} = \frac{\text{Gas Used} - 15M}{15M} \times \frac{\text{Base Fee}}{8}$$

charts/lesson_19/base_fee_adjustment.pdf

Fee Burning: Deflationary Pressure



Issuance: ∼1,600 ETH/day (PoS rewards)

Solidity: High-Level Smart Contract Language

Example: Simple Token Contract

charts/lesson_19/solidity_example.pdf

Smart Contract Lifecycle

charts/lesson_19/contract_lifecycle.pdf

Contract Storage: Persistent State

Storage Layout:

- Key-value store (256-bit slots)
- Permanent (persists between calls)
- Expensive (SSTORE = 20,000 gas)
- Optimizations: packing, mappings

Memory vs Storage:

- **Storage:** Permanent, expensive
- **Memory:** Temporary, cheap, cleared after execution

charts/lesson_19/storage_vs_memory.pdf

Events and Logs

Purpose:

- Emit structured data from contracts
- Stored in transaction receipts
- Indexed for efficient querying
- Off-chain applications listen to events

Use Cases:

- Token transfers (Transfer event)
- Price updates (oracles)
- Audit trails
- UI updates (wallets, dApps)

charts/lesson_19/events_architecture.pdf

External Calls: Composability and Risks

Contract Interactions:

- Contracts can call other contracts
- Enables composability (“money legos”)
- DeFi protocols build on each other

Risks:

- Reentrancy attacks
- Uncontrolled gas consumption
- Malicious contract logic
- Dependency vulnerabilities

charts/lesson_19/external_call_flow.pdf

Reentrancy: The DAO Hack (2016)

charts/lesson_19/reentrancy_attack.pdf

Oracles: Bridging On-Chain and Off-Chain

Problem:

- Smart contracts cannot access external data
- No internet, APIs, randomness
- Determinism requirement

Oracle Solution:

- Third-party data feeds
- Price feeds (ETH/USD)
- Weather data
- Sports scores

`charts/lesson_19/oracle_architecture.pdf`

Chainlink: Decentralized oracle network, aggregates multiple data sources

Gas Optimization Strategies

- **Storage Packing:** Use uint128 instead of uint256 where possible (fit in one slot)
- **Avoid Storage Writes:** Use memory for temporary data
- **Short-Circuit Logic:** `require` checks early, minimize wasted gas
- **Batch Operations:** Aggregate multiple actions in one transaction
- **Events over Storage:** Emit events instead of storing historical data
- **Minimal Contract Size:** Lower deployment costs
- **Use Libraries:** Reusable code via DELEGATECALL

Example: Storing 100 values individually: $\sim$2M gas. Packed into single array: $\sim$500K gas

Upgradeable Contracts: Proxy Pattern

charts/lesson_19/proxy_pattern.pdf

Summary

- **Ethereum:** World computer, Turing-complete smart contracts, account model
- **EVM:** Stack-based VM, executes bytecode, deterministic, replicated
- **Gas:** Meters computation, prevents infinite loops, aligns incentives
- **EIP-1559:** Base fee (burned) + priority fee, deflationary pressure
- **Solidity:** High-level language, compiles to bytecode
- **Risks:** Reentrancy, oracles, immutability challenges

Next Lesson: Tokens – ERC-20, ERC-721 (NFTs), and token economics