Brief Introduction to Smart Contracts and Solidity

CS 731: Blockchain Technology and Applications

Instructor : Chavhan Sujeet Yashavant

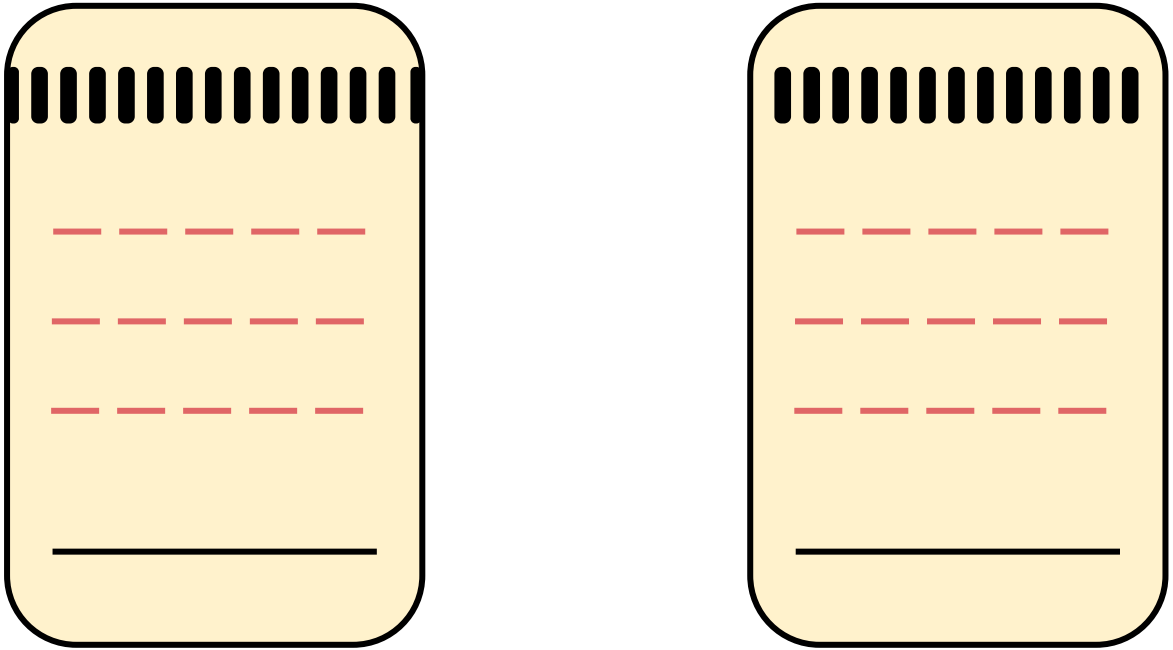
What is Ethereum?

It’s a Blockchain, With following additions

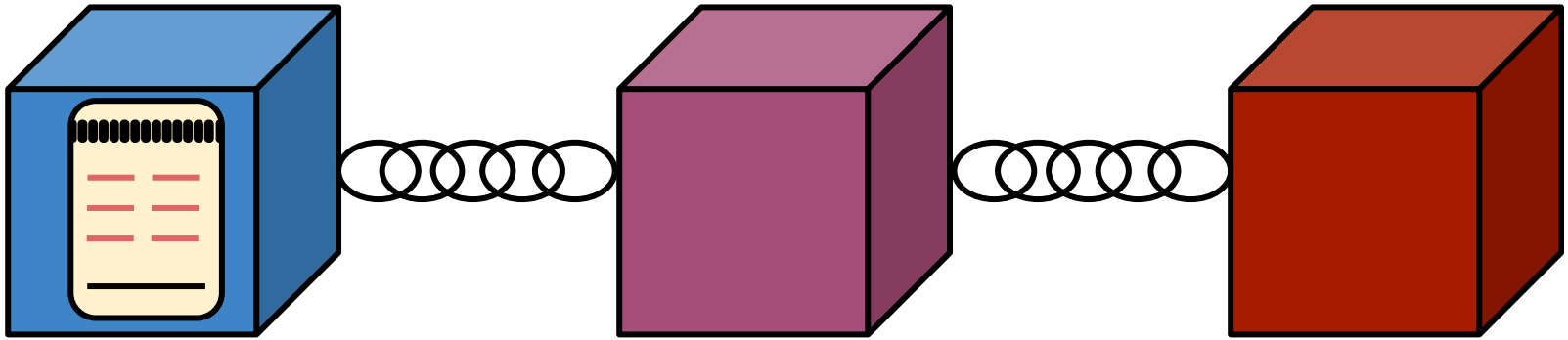
- A built-in programming Language
- Two types of accounts
  - User Accounts (Controlled by Private Keys)
  - Contract Accounts (Controlled by Code)
- Anyone can create an app by defining it as a Contract

Ref: DEVCON1: Understanding the Ethereum Blockchain Protocol - Vitalik Buterin

Smart Contracts



Smart contracts



- Tiny computer programs
- Stored inside a blockchain

Ref: https://savjee.be/videos/simply-explained/smart-contracts/

Smart Contract

- A code that resides on blockchain
- Executes when certain predetermined conditions are satisfied

Smart Contract

- agreement between mutually distrusting participants
- automatically enforced by the consensus mechanism of the blockchain
- without relying on a trusted authority.

Ref: Atzei, Nicola, Massimo Bartoletti, and Tiziana Cimoli. "A survey of attacks on ethereum smart contracts (sok)." *International conference on principles of security and trust*. Springer, Berlin, Heidelberg, 2017.

What a Contract can Do?

- Send ETH to other contracts

Ref: DEVCON1: Understanding the Ethereum Blockchain Protocol - Vitalik Buterin

What a Contract can Do?

- Send ETH to other contracts
- Read/write Storage

Ref: DEVCON1: Understanding the Ethereum Blockchain Protocol - Vitalik Buterin

What a Contract can Do?

- Send ETH to other contracts
- Read/write Storage
- Call (i.e. start execution in) other Contracts

Ref: DEVCON1: Understanding the Ethereum Blockchain Protocol - Vitalik Buterin

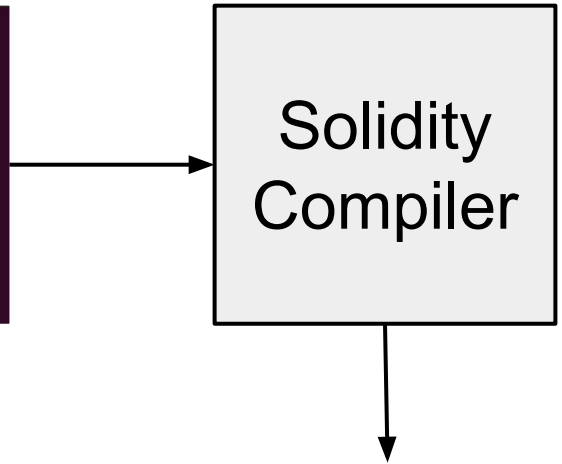
Smart Contract Execution

- Every (full) node on Ethereum network processes every transaction

Ref: DEVCON1: Understanding the Ethereum Blockchain Protocol - Vitalik Buterin

Smart Contract Execution

```
pragma solidity ^0.4.17;
contract Inbox
{
        string public message;
        function Inbox(string initialMessage) public {
                message = initialMessage;
        }
        function SetMessage (string newMessage) public {
                message = newMessage;
        }
}
```



bytecode:

'6060604052341561000f57600080fd5b60405161038e38038061038e8339810160405280805190910190506000818051610003d9291602001906100445565b50506100df565b828054600181600116156101000203166002900480601f0160208091040260200160405190810160405280929190818152602001828054600181600116156101000203166002900480156101d15780601f106101a6576101008083540402835291602001916101d1565b820191906000526020600020905b8154815290600101906020018083116101b457829003601f168201915b505050505081565b828054600181600116156101000203166002900490600052602060002090601f016020900481019282601f1061021a57805160ff1916838001178555610247565b828001600101855582156102475791820158281111561024757825182559160200191906001019061022c565b5061025392915061025756509056b6102739291506102575650905600a165627a7a723058208f0f3e57d60457b58d09389d0da7d2d5375adecd20cfdb52a65ef21ee981d1440029',

Smart Contract Execution

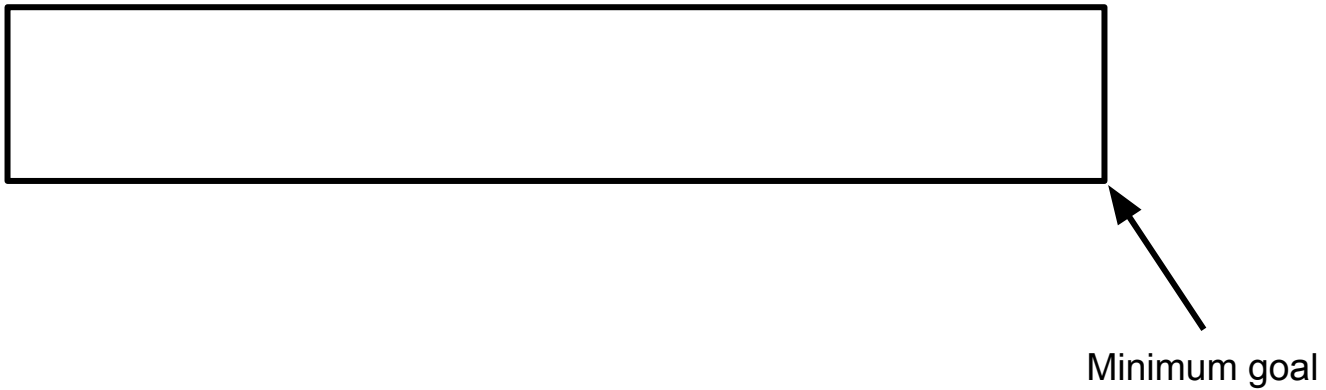
```
bytecode:
  '6060604052341561000f57600080fd5b60405161038e38038061038e83398101604052808051909101905060008180516100 3d9291602001906100445 65b50506100df565b828054600181600116156101000203166002900480601f0160208091040260200160405190810160405280929190818152602001828054600181600116156101000203166002900480156101d15780601f106101a657610100808354040283529160200191610 1d1565b820191906000526020600020905b81548152906001019060200180831161 01b457829003601f168201915b505050505081565b828054600181600116156101000203166002900490600052602060002090601f016020900481019282601f1061021a57805160ff1916838001178555610247565b828001600101855582156102475792182015b8281115610247578251825591602001919060010190610 1c565b506102539291506102575 65b5090565b61027191905b8082111561025357600081556001016102 5d565b905600a165627a7a723058208f0f3e57d60457b58d09389d0da7d2d5375adecd20cfdb52a65ef21ee981d1440029',
```

EVM (Ethereum Virtual Machine)

Ethereum Virtual Machine (EVM)

- Global Singleton Computing Machine with a shared ledger of data

Crowdfunding platform



Ref: https://savjee.be/videos/simply-explained/smart-contracts/

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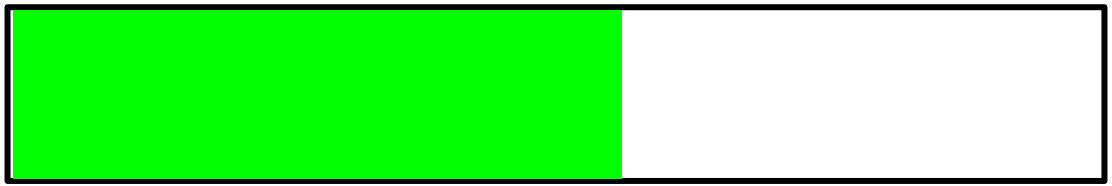
Crowdfunding platform



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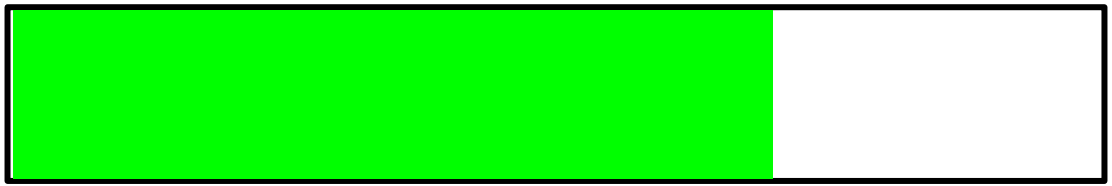
Crowdfunding platform



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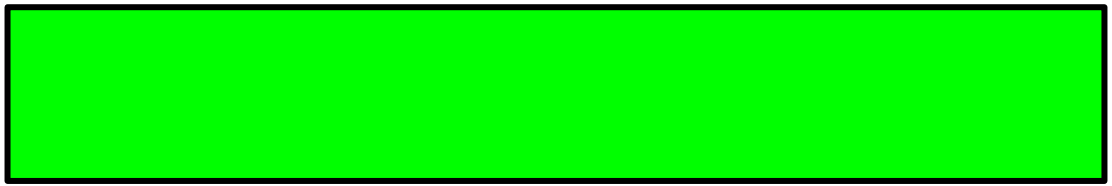
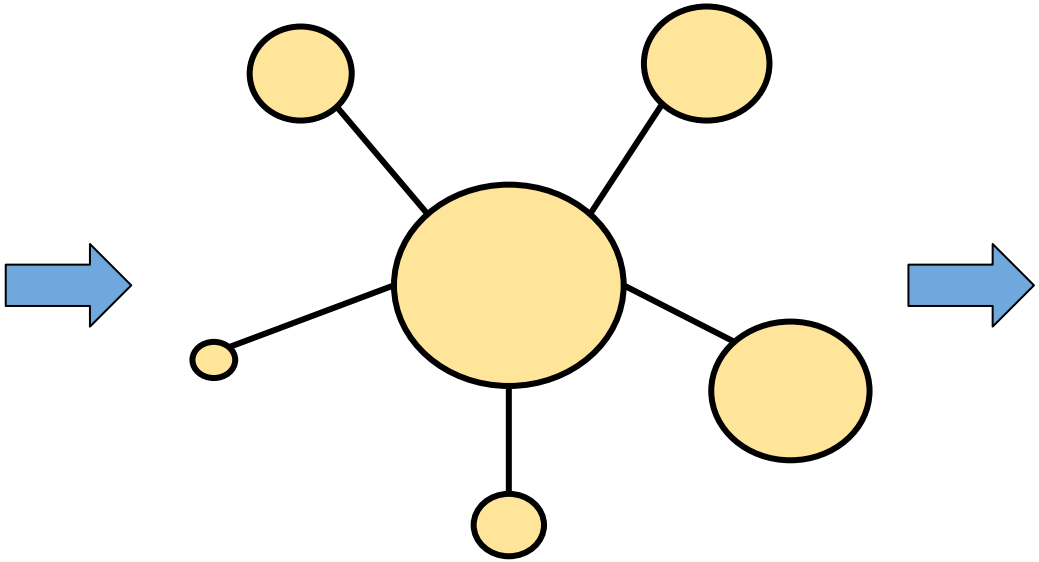
Crowdfunding platform



Funded!

Ref: https://savjee.be/videos/simply-explained/smart-contracts/

Kickstarter for Crowdfunding platform



Supporters

Product team

Ref: https://savjee.be/videos/simply-explained/smart-contracts/

Kickstarter for Crowdfunding platform

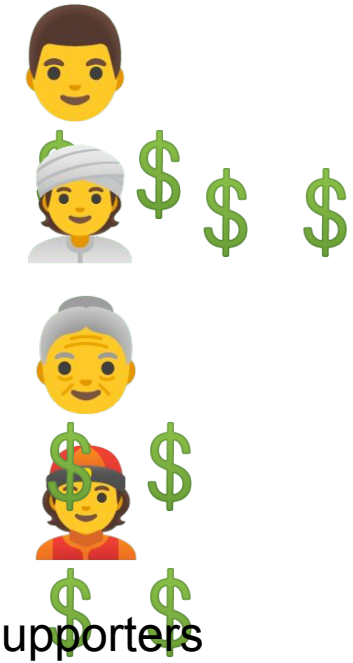
Trusting a third-party is required

Ref: https://savjee.be/videos/simply-explained/smart-contracts, https://pngimg.com

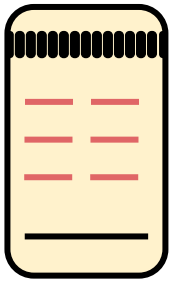
Smart contracts

We can build a similar system with a Smart Contracts without the requirement of any third party

Kickstarter with Smart Contract



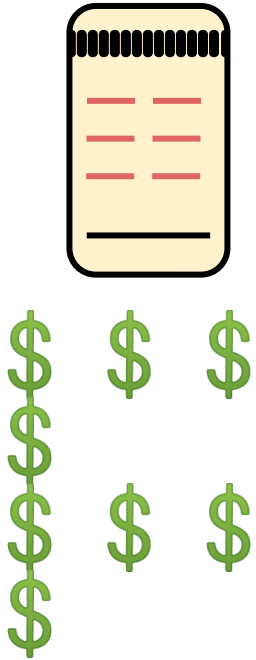
Supporters



Product team

Kickstarter with Smart Contract

Supporters

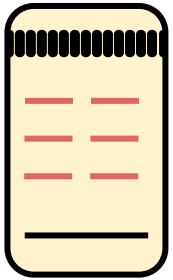


Product team

Kickstarter with Smart Contract

Supporters

Funded!



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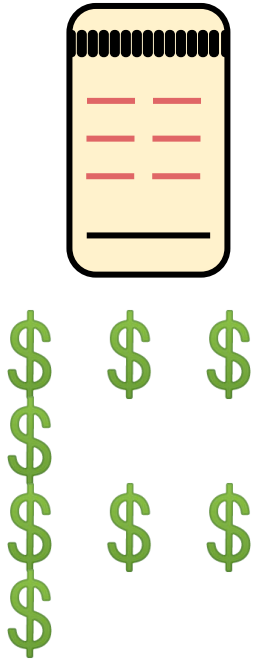
Kickstarter with Smart Contract

Supporters



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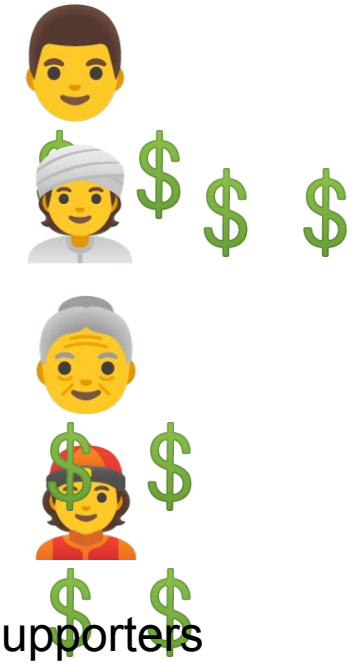
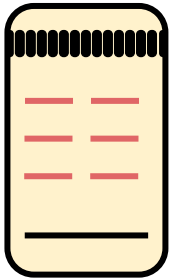
Kickstarter with Smart Contract



Supporters

Failed!



Product team

Introduction to Solidity

```
1  pragma solidity ^0.4.17;
2  contract Inbox {
3      string public message;
4      function Inbox(string initialMessage) public {
5          message = initialMessage;
6      }
7      function setMessage(string newMessage) public {
8          message = newMessage;
9      }
10     function getMessage(
11     ) public view returns (string) {
12         return message;
13     }
14 }
```

Introduction to Solidity: Version Pragma

```
1 pragma solidity ^0.4.17;
```

- Instructions to the compiler on how to treat the code.
- All solidity source code should start with a “version pragma” which is a declaration of the version of the solidity compiler this code should use.
- This helps the code from being incompatible with the future versions of the compiler which may bring changes.

Ref: https://www.geeksforgeeks.org/introduction-to-solidity

Introduction to Solidity: Contract keyword

```
1  pragma solidity ^0.4.17;
2  contract Inbox {
3      string public message;
4      function Inbox(string initialMessage) public {
5          message = initialMessage;
6      }
7      function setMessage(string newMessage) public {
8          message = newMessage;
9      }
10     function getMessage(
11     ) public view returns (string) {
12         return message;
13     }
14 }
```

It declares a contract under which is the code encapsulated.

Ref: https://www.geeksforgeeks.org/introduction-to-solidity

Introduction to Solidity: State Variables

```
1  pragma solidity ^0.4.17;
2  contract Inbox {
3      string public message;
4      function Inbox(string initialMessage) public {
5          message = initialMessage;
6      }
7      function setMessage(string newMessage) public {
8          message = newMessage;
9      }
10     function getMessage(
11     ) public view returns (string) {
12         return message;
13     }
14 }
```

Permanently stored in contract storage → written to Ethereum Blockchain.

Ref: https://www.geeksforgeeks.org/introduction-to-solidity

Introduction to Solidity: Function declaration

```
1  pragma solidity ^0.4.17;
2  contract Inbox {
3      string public message;
4      function Inbox(string initialMessage) public {
5          message = initialMessage;
6      }
7      function setMessage(string newMessage) public {
8          message = newMessage;
9      }
10     function getMessage(
11     ) public view returns (string) {
12         return message;
13     }
14 }
```

Constructor

Ref: https://www.geeksforgeeks.org/introduction-to-solidity

Introduction to Solidity: Function Visibility

Introduction to Solidity: Function Visibility

- Public - any contract and account can call
- Private - only inside the contract that defines the function
- External - only other contracts and accounts can call
- Internal - only inside contract that inherits an internal function

Ref: https://solidity-by-example.org/visibility/

Introduction to Solidity: View and Pure functions

- View function declares that no state will be changed.
- Pure function declares that no state variable will be changed or read.

Ref: https://solidity-by-example.org/visibility/

Introduction to Solidity: Code Execution on Real Blockchain (Try this after success on Local Blockchain)

- Testnet (most of the course projects will do it):
  - Can use **Remix** and **Metamask**
  - Can use **hardhat** to deploy on **Goerli Testnet**
- Mainnet
  - Require real money
  - Do not try unless you become expert

Ref: https://www.geeksforgeeks.org/introduction-to-solidity

Introduction to Solidity: Code Execution on Local Blockchain (Try this first)

- Offline (Blockchain inside local machine): I will post a video link on Discord about how to do it. It takes time.
  - Can use **Remix** and **Ganache**
- Online (Blockchain inside browser): Remix IDE
  - Simple one, first try this
  - Let’s see a Demo

Ref: https://www.geeksforgeeks.org/introduction-to-solidity

Crowdfunding Smart Contract

```
pragma solidity ^0.4.19;
contract Crowdfunding {
    address owner;
    uint256 deadline;
    uint256 goal;
    mapping(address => uint256) public pledgeOf;
    function Crowdfunding(uint256 numberOfDays, uint256 _goal) public {
        owner = msg.sender;
        deadline = now + (numberOfDays * 1 days);
        goal = _goal;
    }
    function pledge(uint256 amount) public payable {
        require(now < deadline);                // in the fundraising period
        require(msg.value == amount);
        pledgeOf[msg.sender] += amount;
    }
    function claimFunds() public {
        require(address(this).balance >= goal); // funding goal met
        require(now >= deadline);               // in the withdrawal period
        require(msg.sender == owner);

        msg.sender.transfer(address(this).balance);
    }
    function getRefund() public {
        require(address(this).balance < goal);  // funding goal not met
        require(now >= deadline);               // in the withdrawal period
        uint256 amount = pledgeOf[msg.sender];
        pledgeOf[msg.sender] = 0;
        msg.sender.transfer(amount);
    }
}
```

Currency Example

```
pragma solidity ^0.8.4;
contract Coin {
    // The keyword "public" makes variables
    // accessible from other contracts
    address public minter;
    mapping(address => uint) public balances;
    // Events allow clients to react to specific
    // contract changes you declare
    event Sent(address from, address to, uint amount);
    // Constructor code is only run when the contract
    // is created
    constructor() {
        minter = msg.sender;
    }
    // Sends an amount of newly created coins to an address
    // Can only be called by the contract creator
    function mint(address receiver, uint amount) public {
        require(msg.sender == minter);
        balances[receiver] += amount;
    }
    // Errors allow you to provide information about
    // why an operation failed. They are returned
    // to the caller of the function.
    error InsufficientBalance(uint requested, uint available);
    // Sends an amount of existing coins
    // from any caller to an address
    function send(address receiver, uint amount) public {
        if (amount > balances[msg.sender])
            revert InsufficientBalance({
                requested: amount,
                available: balances[msg.sender]
            });
        balances[msg.sender] -= amount;
        balances[receiver] += amount;
        emit Sent(msg.sender, receiver, amount);
    }
}
```

Gas

- Halting problem
  - Can’t tell whether a program will halt or run infinitely

Ref: DEVCON1: Understanding the Ethereum Blockchain Protocol - Vitalik Buterin

Gas

- Halting problem
  - Can’t tell whether a program will halt or run infinitely
- Solution: Gas Limit

Ref: DEVCON1: Understanding the Ethereum Blockchain Protocol - Vitalik Buterin

Gas Limit

- Each opcode has a fixed amount of gas assigned and is a measure of computational effort
- Gas is the execution fee, paid by the sender of the transaction that triggered the computation

Ref: DEVCON1: Understanding the Ethereum Blockchain Protocol - Vitalik Buterin

Gas Limit

- User sets max amount of Gas for a transaction
- Gas is lost if a user run out of Gas Limit, all changes are reversed
- If a transaction uses less gas than gas limit, then user gets remaining Gas

Ref: DEVCON1: Understanding the Ethereum Blockchain Protocol - Vitalik Buterin

Gas Limit

- Total fees = Total amount of Gas used ❌ gas Price
- The gas price is not fixed

Ref: DEVCON1: Understanding the Ethereum Blockchain Protocol - Vitalik Buterin

Why Optimization?

- Caller needs to pay Gas according to Computational Steps

Ref: Brandstätter, Tamara, et al. "Characterizing Efficiency Optimizations in Solidity Smart Contracts." *2020 IEEE International Conference on Blockchain (Blockchain)*. IEEE, 2020.

Why Optimization?

- Caller needs to pay Gas according to Computational Steps
- Optimization ⇒ Gas Saving ⇒ Money Saving

Ref: Brandstätter, Tamara, et al. "Characterizing Efficiency Optimizations in Solidity Smart Contracts." *2020 IEEE International Conference on Blockchain (Blockchain)*. IEEE, 2020.

Why Optimization?

- Caller needs to pay Gas according to Computational Steps
- Optimization ⇒ Gas Saving ⇒ Money Saving
- A smart contract gets invoked many times, a small optimization can result in huge saving

Ref: Brandstätter, Tamara, et al. "Characterizing Efficiency Optimizations in Solidity Smart Contracts." *2020 IEEE International Conference on Blockchain (Blockchain)*. IEEE, 2020.

Gas Costly Pattern 1: Dead Code

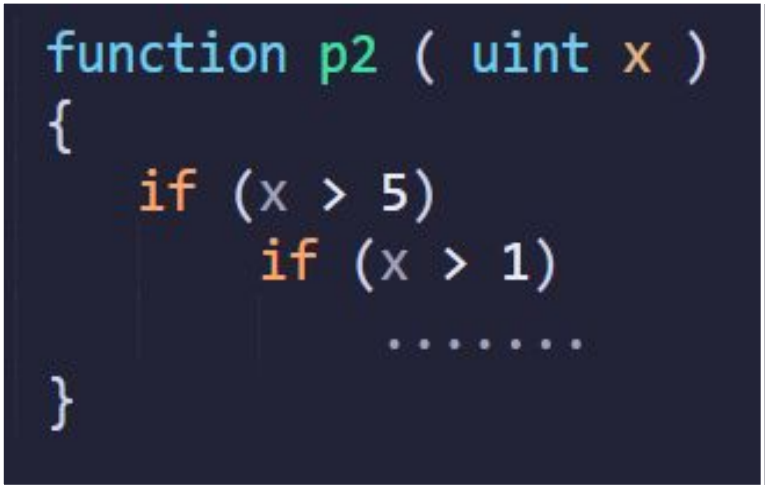
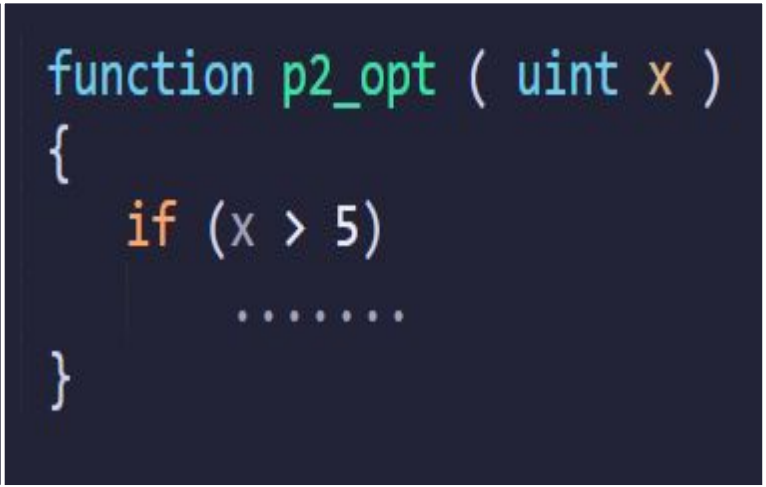
Unoptimized Code	Optimized Code

```
function p1 ( uint x )
{
    if (x > 5)
    {
        if (x*x < 20)
            Statement 1
        Statement 2
    }
    Statement 3
}
```

```
function p1_opt ( uint x )
{
    if (x > 5)
    {
        Statement 2
    }
    Statement 3
}
```

Ref: Chen, Ting, et al. "Under-optimized smart contracts devour your money." *2017 IEEE 24th International Conference on Software Analysis, Evolution and Reengineering (SANER)*. IEEE, 2017.

Gas Costly Pattern 2: Opaque Predicate

Unoptimized Code	Optimized Code
	

Ref: Chen, Ting, et al. "Under-optimized smart contracts devour your money." *2017 IEEE 24th International Conference on Software Analysis, Evolution and Reengineering (SANER)*. IEEE, 2017.

Gas Costly Pattern 3: Constant outcome of a Loop

```
1 function p4 returns (uint) {
2         uint sum = 0;
3         for (uint i = 1; i <= 100; i++)
4                 sum += i;
5         return sum;
6 }
```

```
1 function p4_opt returns (uint) {
2         return 5050;
3 }
```

Ref: Chen, Ting, et al. "Under-optimized smart contracts devour your money." *2017 IEEE 24th International Conference on Software Analysis, Evolution and Reengineering (SANER)*. IEEE, 2017.

Gas Costly Pattern 4: Comparison with Unilateral Outcome in a Loop

```
1 function p7 (uint x, uint y) returns (uint)
2 {
3         for (int i = 0; i < 100; i++)
4                 if (x > 0)
5                         y += x;
6         return y;
7 }
```

```
1 function p7_opt (uint x, uint y) returns (uint)
2 {
3         if (x > 0)
4                 for (int i = 0; i < 100; i++)
5                         y += x;
6         return y;
7 }
```

Ref: Chen, Ting, et al. "Under-optimized smart contracts devour your money." *2017 IEEE 24th International Conference on Software Analysis, Evolution and Reengineering (SANER)*. IEEE, 2017.

Smart Contract Security

- Correctness is ensured by the consensus mechanism
- Unfortunately, correctness is not sufficient to make Smart Contracts secure.

Ref: Atzei, Nicola, Massimo Bartoletti, and Tiziana Cimoli. "A survey of attacks on ethereum smart contracts (sok)." *International conference on principles of security and trust*. Springer, Berlin, Heidelberg, 2017.

Smart Contract Vuln 1: Overflow and Underflow

```
1  mapping (address => uint256) public balanceOf;
2
3  // INSECURE
4  function transfer(address _to, uint256 _value) {
5      /* Check if sender has balance */
6      require(balanceOf[msg.sender] >= _value);
7      /* Add and subtract new balances */
8      balanceOf[msg.sender] -= _value;
9      balanceOf[_to] += _value;
10 }
11
12 // SECURE
13 function transfer(address _to, uint256 _value) {
14     /* Check if sender has balance and for overflows */
15     require(balanceOf[msg.sender] >= _value &&
16       balanceOf[_to] + _value >= balanceOf[_to]);
17     /* Add and subtract new balances */
18     balanceOf[msg.sender] -= _value;
19     balanceOf[_to] += _value;
20 }
```

Ref: Sayeed, Sarwar, Hector Marco-Gisbert, and Tom Caira. "Smart contract: Attacks and protections." IEEE Access 8 (2020): 24416-24427.

Smart Contract Vuln 2: Default Visibilities

```
1  contract Puzzle {
2    uint256 amount = 0.5; //0.5 ethers
3    function submit_answer (string answer) {
4      //Logic to check submitted answer
5      if (/*answer is correct*/)
6        _sendEther();
7    }
8    function _sendEther(){
9      msg.sender.tranfer(amount);
10   }
11 }
```

Ref: Sayeed, Sarwar, Hector Marco-Gisbert, and Tom Caira. "Smart contract: Attacks and protections." IEEE Access 8 (2020): 24416-24427.

Smart Contract Vuln 3: Timestamp Dependence

- A smart contract that utilizes a current timestamp to produce random numbers in order to determine lottery results
- Miners can put a timestamp within 30 seconds of block validation
- Miners can alter outcome of random number generator

Ref: Sayeed, Sarwar, Hector Marco-Gisbert, and Tom Caira. "Smart contract: Attacks and protections." IEEE Access 8 (2020): 24416-24427.

Smart Contract Vuln 3: Timestamp Dependence

```
1  pragma solidity ^0.5.0;
2  contract TimedCrowdsale {
3    event Finished();
4    event notFinished();
5    // Sale should finish exactly at January 1, 2019
6    function isSaleFinished() private returns (bool) {
7      return block.timestamp >= 1546300800;
8    }
9    function run() public {
10     if (isSaleFinished()) {
11         emit Finished();
12     } else {
13         emit notFinished();
14     }
15   }
16 }
```

Ref: https://swcregistry.io/docs/SWC-116

THE END

Backup Slides

Gas assigned per Opcode

Operation	Gas	Description
ADD/SUB	3	Arithmetic Operation
MUL/DIV	5	
ADDMOD/MULMOD	8	
AND/OR/XOR	3	Comparison Operation
LT/GT/SLT/SGT/EQ	2	Stack Operation
POP	3	

Ref: Wood, Gavin. "Ethereum: A secure decentralised generalised transaction ledger." *Ethereum project yellow paper* (2014)

Gas assigned per Opcode

Operation	Gas	Description
BALANCE	400	Get balance of an account
CREATE	32000	Create a new account using CREATE
CALL	25000	Message-call into an account

Ref: Wood, Gavin. "Ethereum: A secure decentralised generalised transaction ledger." *Ethereum project yellow paper* (2014)

Gas assigned per Opcode

Operation	Gas	Description
MLOAD/MSTORE	3	Memory Operation
JUMP	8	Unconditional Jump
JUMPI	10	Conditional Jump
SLOAD	200	Storage Operation
SSTORE	5000/20000	

Ref: Wood, Gavin. "Ethereum: A secure decentralised generalised transaction ledger." *Ethereum project yellow paper* (2014)