Blockchains & Distributed Ledgers

Lecture 03

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Contracts

“A contract is a legally binding agreement which recognises and governs the rights and duties of the parties to the agreement”

What is a smart contract?

- Computer programs
- Contract code is executed by all full nodes
- The outcome of a smart contract is the same for everyone
- Context: Internal storage, transaction context, most recent blocks
- The code of a smart contract cannot change

Recent adage: “smart contracts are neither smart nor contracts”
In many ways a misnomer .. but a persistent one.

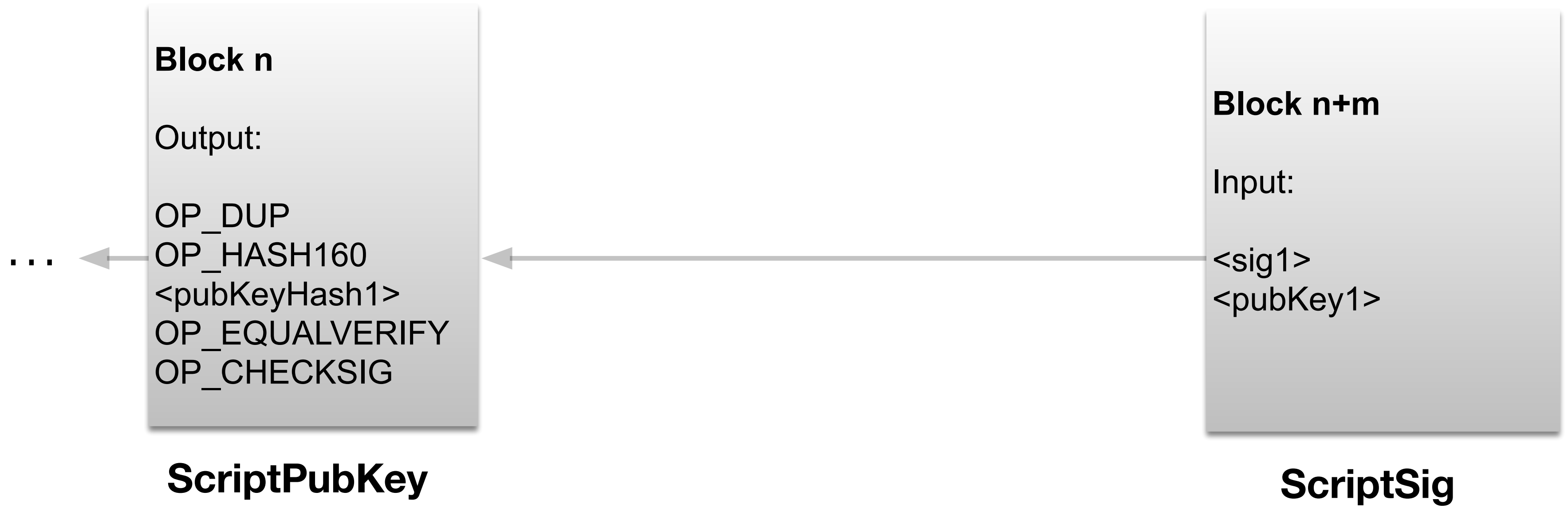
Bitcoin programs

- **Transaction:** a transfer of value in the Bitcoin network
- Each transaction consists of the following main fields:
    - **input**: a transaction output from which it spends bitcoins:
        i. previous transaction address
        ii. index
        iii. ScriptSig
    - **output**: instructions for spending the sent bitcoins:
        i. value: amount of bitcoins to send
        ii. ScriptPubKey: instructions on how to spend the sent bitcoins
- To validate a transaction:
    - concatenate ScriptSig of the current transaction with ScriptPubKey of the referenced transaction
    - check if it successfully compiles with no errors

Bitcoin Script

- Stack-based
- Data in the script is enclosed in <>: <sig>, <pubKey>, etc
- Opcodes: commands or functions
    - Arithmetic, e.g. OP_ABS, OP_ADD
    - Stack, e.g. OP_DROP, OP_SWAP
    - Flow control, e.g. OP_IF, OP_ELSE
    - Bitwise logic, e.g. OP_EQUAL, OP_EQUALVERIFY
    - Hashing, e.g. OP_SHA1, OP_SHA256
    - (Multiple) Signature Verification, e.g. OP_CHECKSIG, OP_CHECKMULTISIG
    - Locktime, e.g. OP_CHECKLOCKTIMEVERIFY, OP_CHECKSEQUENCEVERIFY

Bitcoin Script example



Block n

Output:

```
OP_DUP
OP_HASH160
<pubKeyHash1>
OP_EQUALVERIFY
OP_CHECKSIG
```

ScriptPubKey

Block n+m

Input:

```
<sig1>
<pubKey1>
```

ScriptSig

Stack	Script	Description
Empty	<sig1> <pubKey1> OP_DUP OP_HASH160 <pubKeyHash1> OP_EQUALVERIFY OP_CHECKSIG	
<sig1> <pubKey1>	OP_DUP OP_HASH160 <pubKeyHash1> OP_EQUALVERIFY OP_CHECKSIG	Add constant values from left to right to the stack until we reach an opcode.
<sig1> <pubKey1> <pubKey1>	OP_HASH160 <pubKeyHash1> OP_EQUALVERIFY OP_CHECKSIG	Duplicate top stack item
<sig1> <pubKey1> <pub1Hash>	<pubKeyHash1> OP_EQUALVERIFY OP_CHECKSIG	Hash at the top of the stack
<sig1><pubKey1> <pub1Hash><pubKeyHash1>	OP_EQUALVERIFY OP_CHECKSIG	Push the hashvalue to the stack
<sig1> <pubKey1>	OP_CHECKSIG	Check if top two items are equal
Empty	TRUE	Verify the signature.

Bitcoin’s scripting language limitations

- Lack of Turing-completeness: No loops
- Lack of state: Cannot keep internal state.
- Value-blindness: Cannot denominate the amount being sent
- Blockchain-blindness: Cannot access block header values such as nonce, timestamp and previous hash block.

Extending Bitcoin functionality: add new opcodes

- Building a protocol on top of Bitcoin:
  - Pros:
    - Take advantage of the underlying network and mining power.
    - Very low development cost
  - Cons:
    - No flexibility.
- Build an independent network:
  - Pros:
    - Easy to add and extend new opcodes.
    - Flexibility.
  - Cons:
    - Need to attract miners to sustain the network.
    - Difficult to implement.

Alternative blockchain applications

- Namecoin:
  - Bitcoin fork: Currency NMC
  - Decentralized name registration database: DNS, identities etc
- Colored coins:
  - On top of Bitcoin
  - Allows people to create their own digital currencies
- OmniLayer (formerly Mastercoin)
  - On top of Bitcoin
  - Distributed exchange, smart property, distributed e-commerce, etc
- OpenBazaar
  - On top of Bitcoin
  - Decentralized marketplace

Ethereum

Same principles as Bitcoin

- **A peer-to-peer network:** connects the participants
- **A consensus algorithm**: Proof of Work (will move to PoS)
- **A digital currency:** ether
- **A global ledger**: the blockchain
    - Addresses: key pair
    - Wallets
    - Transactions: digital signatures
    - Blocks

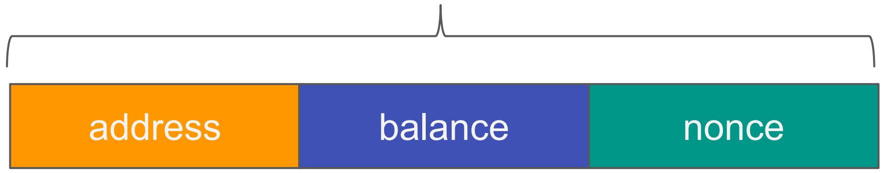
Ethereum: A universal Replicated State Machine

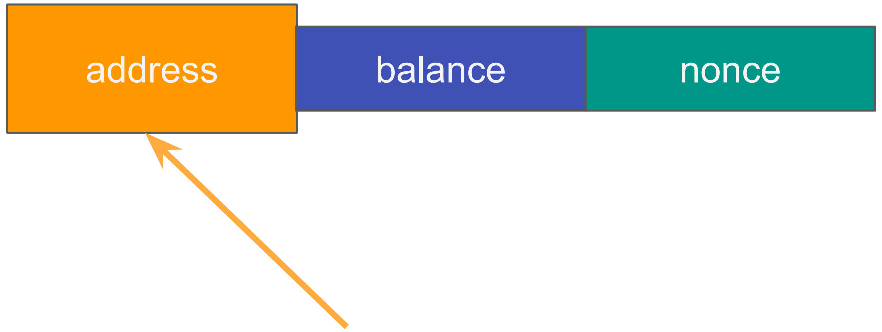
- Transaction-based deterministic state machine
  - Global singleton state
  - A virtual machine that applies changes to global state
- A global decentralized computing infrastructure
- Anyone can create their own state transition functions
- Stack-based bytecode language
- Turing-completeness
- Smart contracts
- Decentralized applications

Ethereum accounts

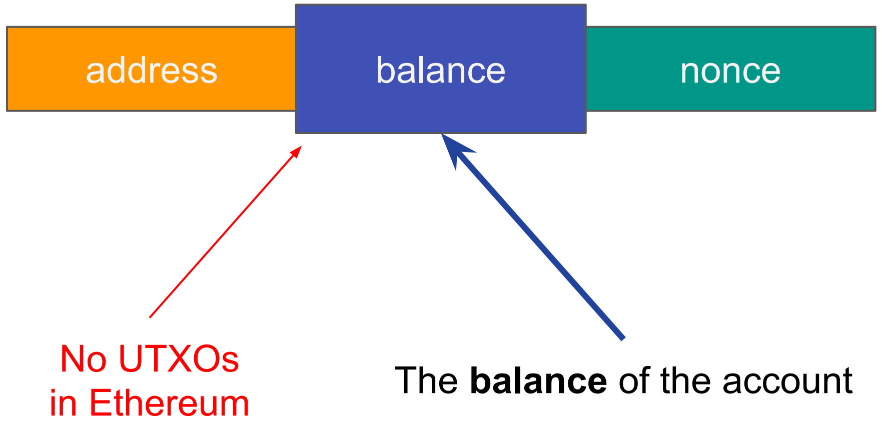
- Global state of Ethereum: **accounts**
- They **interact** to each other **through transactions** (messages)
- A **state associated** with it and a 20-byte **address** (160-bit identifier)

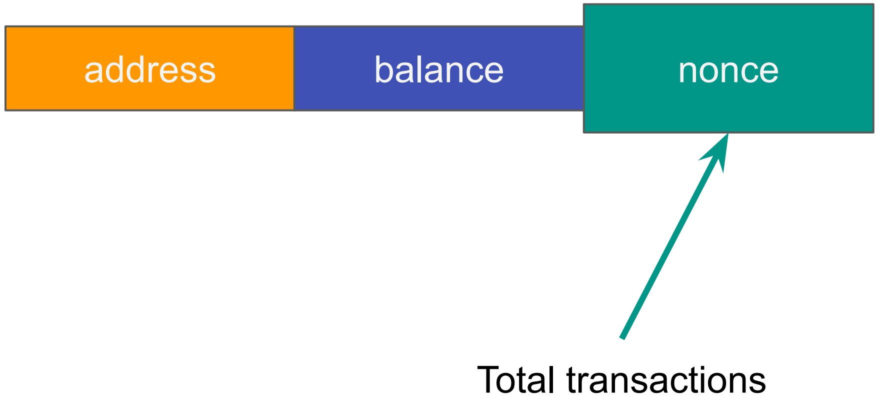
Ethereum account





The **address** of the account


address
balance
nonce
No UTXOs in Ethereum
The **balance** of the account


address
balance
nonce
Total transactions

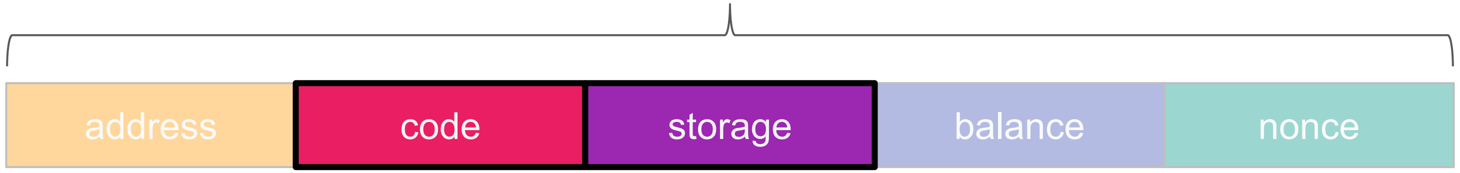
UTXO vs Accounts

- UTXOs pros:
  - Higher degree of privacy
  - Scalability (parallelism, sharding)
- Accounts pros:
  - Space saving
  - Conceptual Simplicity

Two types of accounts

- Personal accounts (what we’ve seen)
- **Contract accounts**

Ethereum contract account

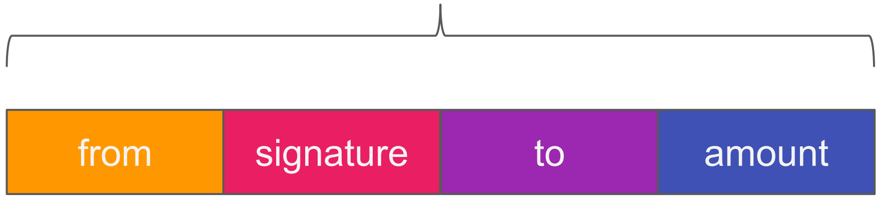


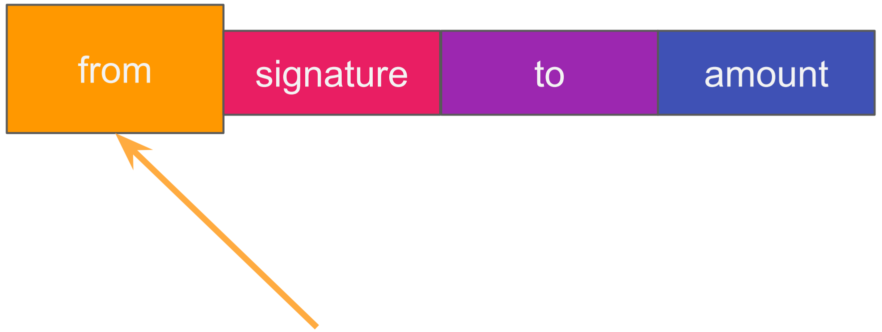
Ethereum accounts

	Personal account	Contract account
address	H(pub_key)	H(addr + nonce of creator)
code	∅	Code to be executed
storage	∅	Data of the contract
balance	ETH balance (in Wei)	ETH balance (in Wei)
nonce	# transaction sent	# transaction sent

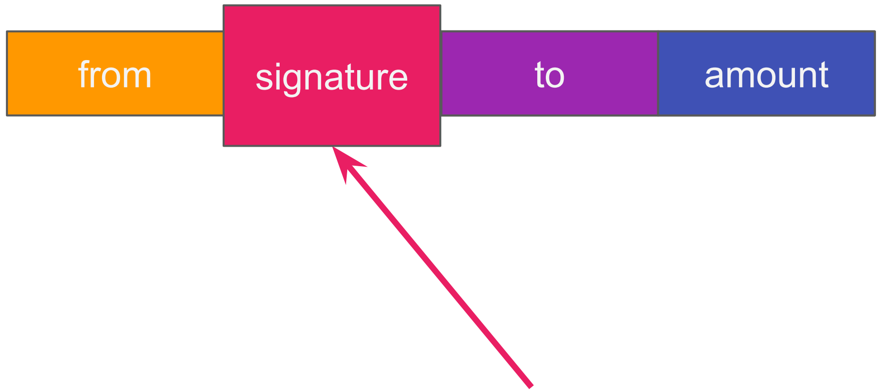
address
code
storage
balance
nonce

Ethereum transaction

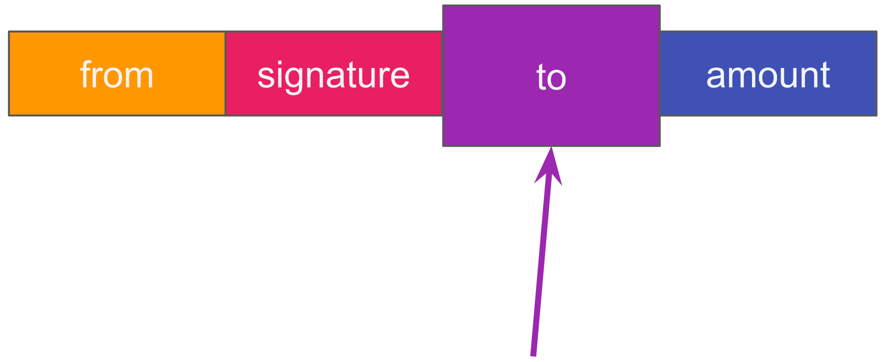




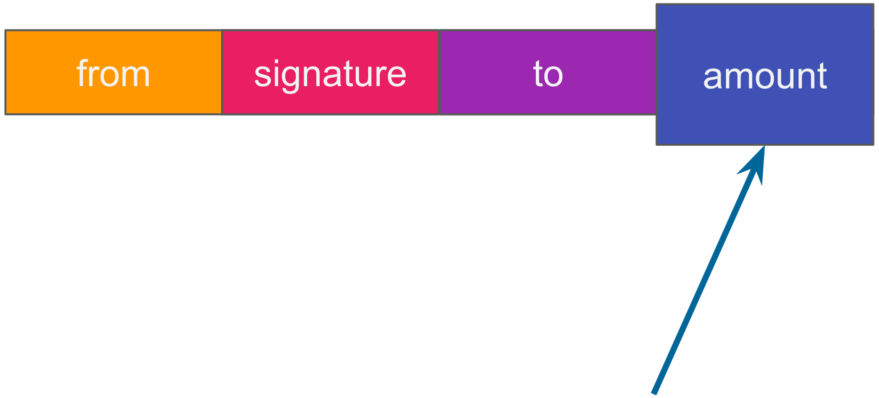
The **sender** of the transaction



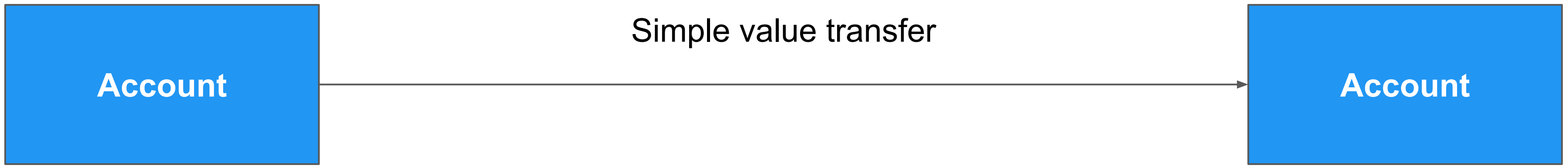
Digital signature on the **new transaction** created by **the sender’s private key**



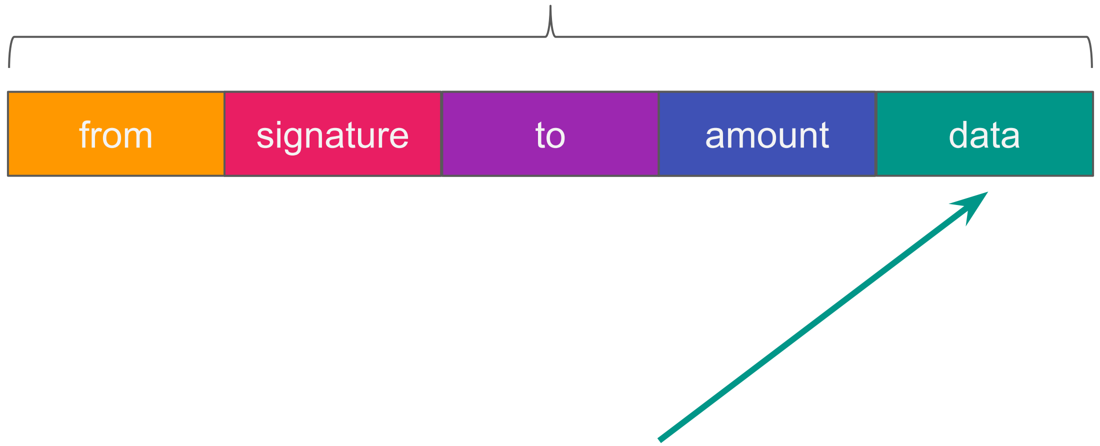
Receiver of the transaction



Amount transferred by transaction
Given in Wei


Account
Simple value transfer
Account

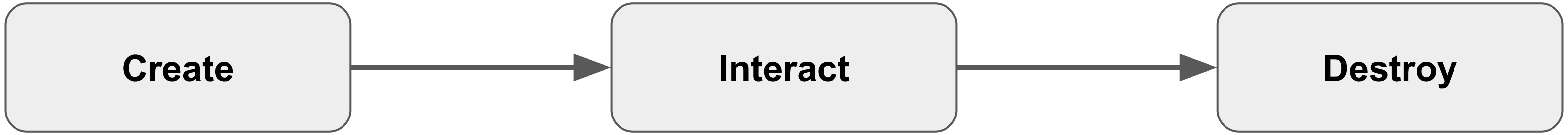
a transaction about a contract

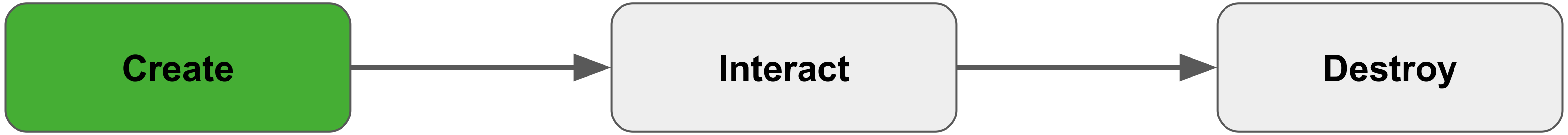


Transaction **about personal accounts**:
Field is unused

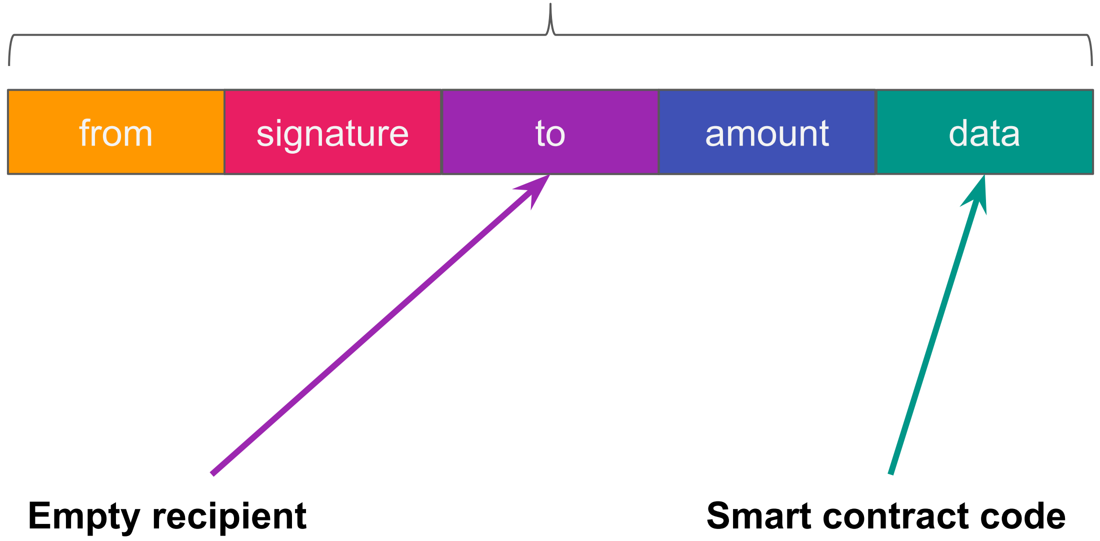
Transaction **about contracts**:
Will contain **data about the contract**

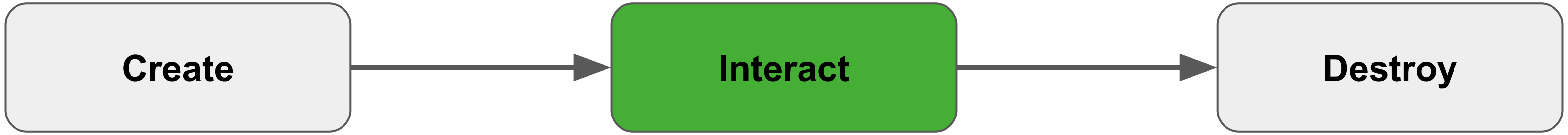
Smart contract lifecycle



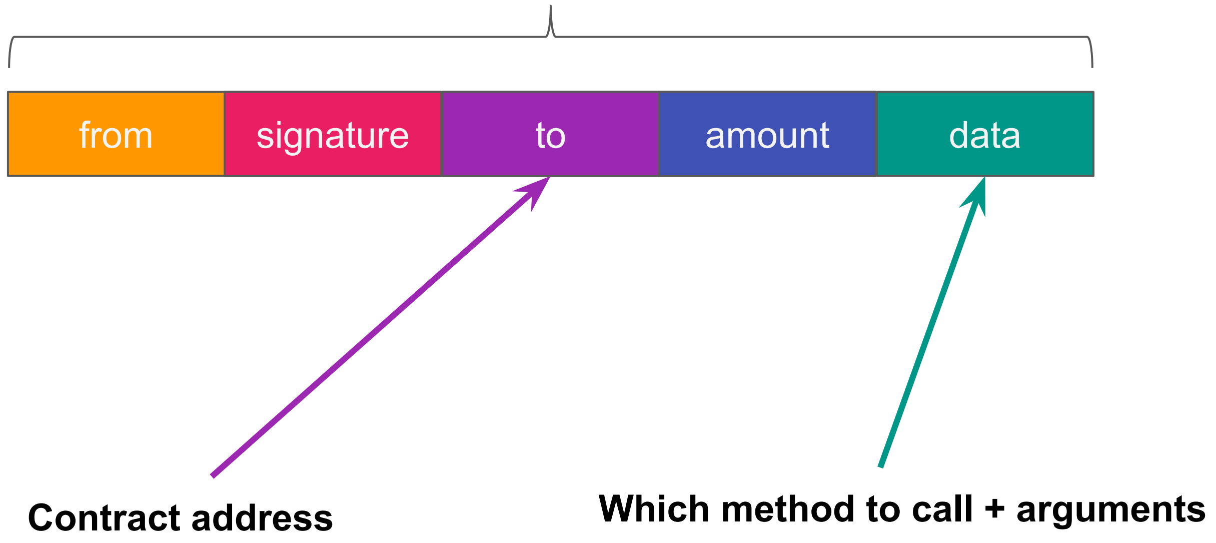

Create
Interact
Destroy

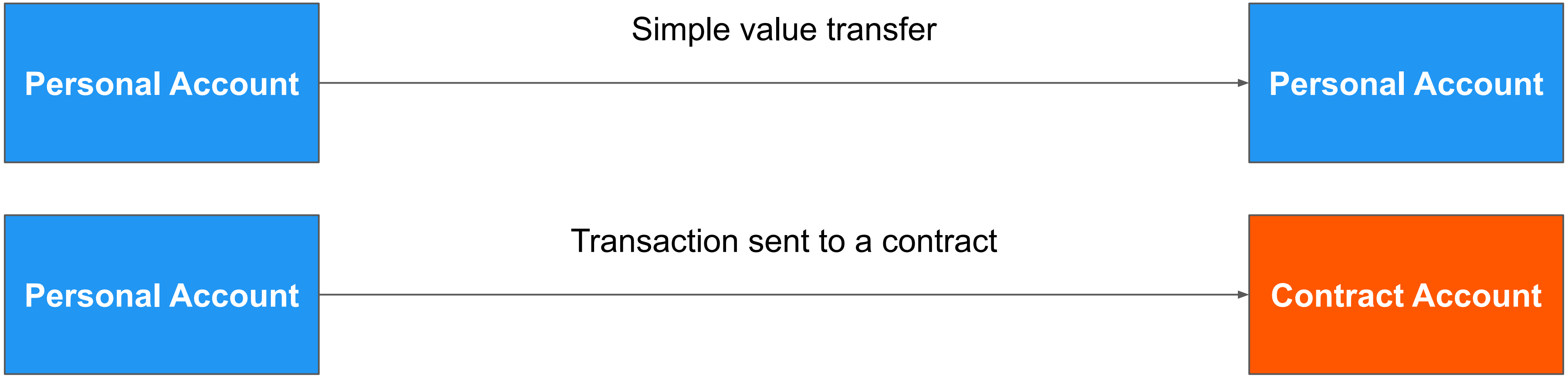
Transaction for contract creation




Create
Interact
Destroy

Transaction for contract interaction



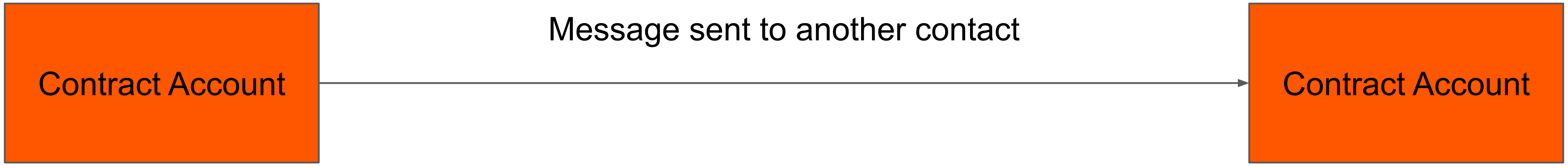

Personal Account
Simple value transfer
Personal Account
Personal Account
Transaction sent to a contract
Contract Account

Contract method call

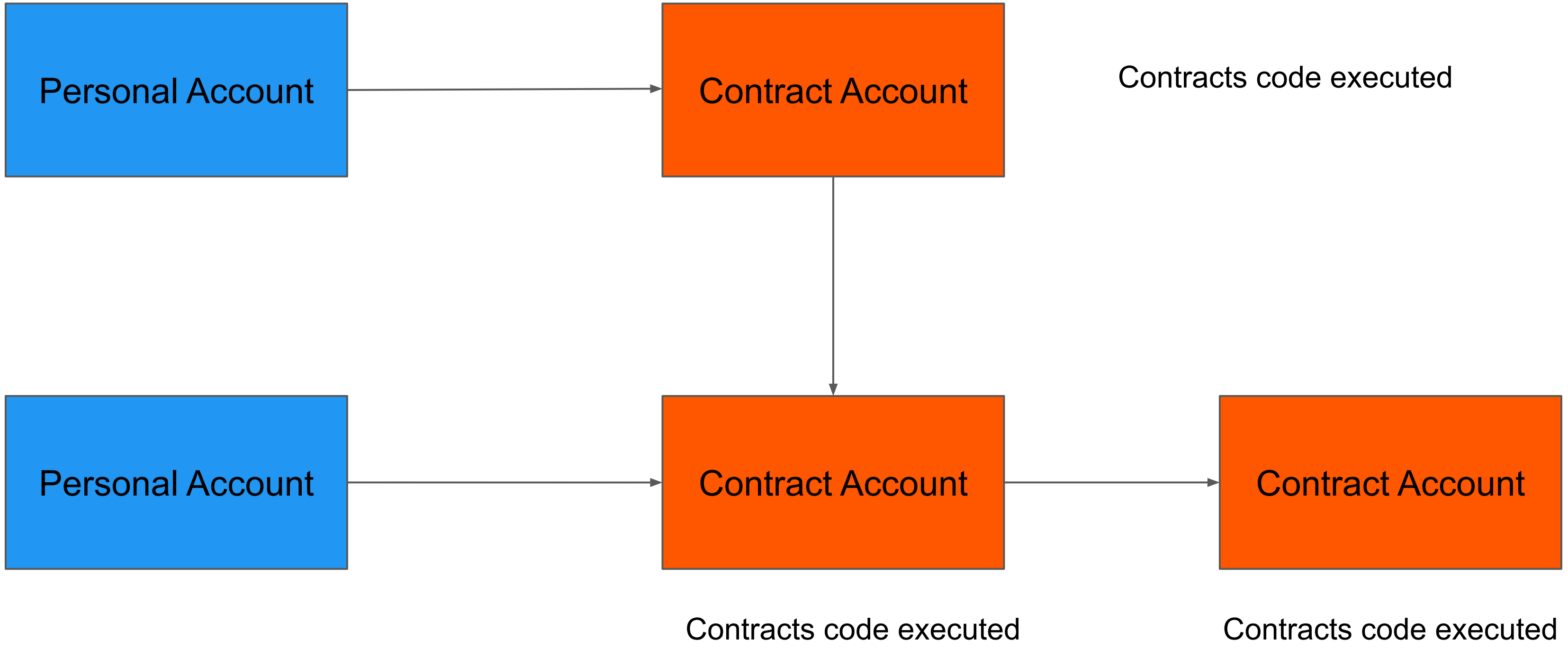
- When contract account is activated:
    a. Contract **code** runs
    b. It can read / write to **internal storage**
    c. It can **send other transactions** or **call other contracts**
- Can’t initiate new transactions on their own
- Can only fire transactions in response to other transactions received

Messages

- Like a **transaction** except it is **produced by a contract**
- Virtual objects
- Exist **only** in the **Ethereum execution environment**
- A message leads to the recipient account running its code
- **Contracts** can have **relationships** with **other contracts**

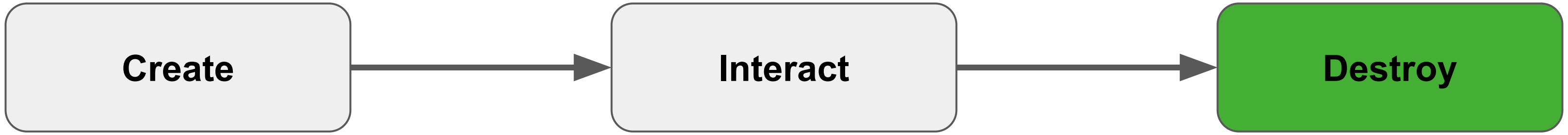

Contract Account
Message sent to another contact
Contract Account

Transactions & messages

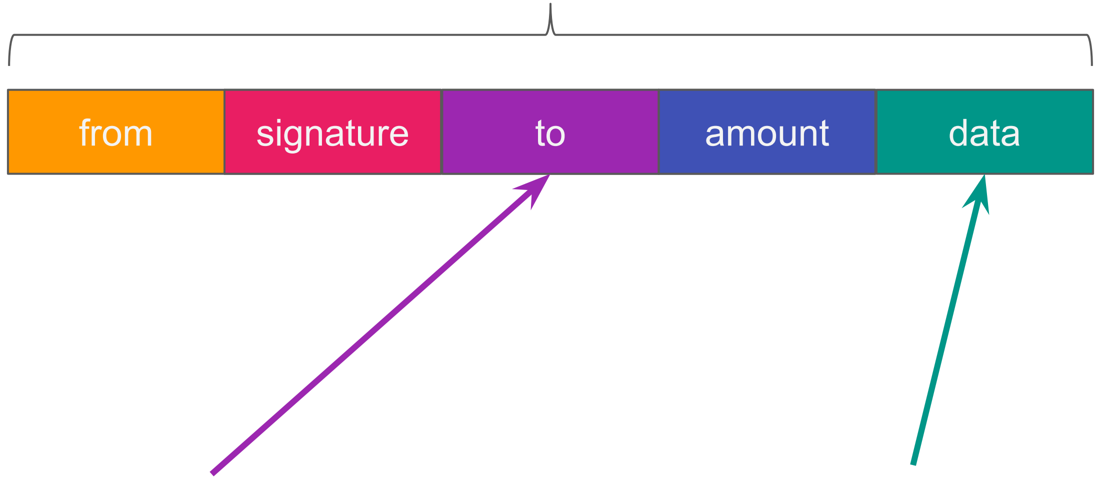


Types of transactions

	create	send	call
from	creator	sender	caller
signature	sig	sig	sig
to	∅	receiver	contract
amount	ETH	ETH	ETH
data	code	∅	f, args


Create
Interact
Destroy

a transaction for contract destruction



Contract address

The name of a method that calls the `selfdestruct` **opcode**

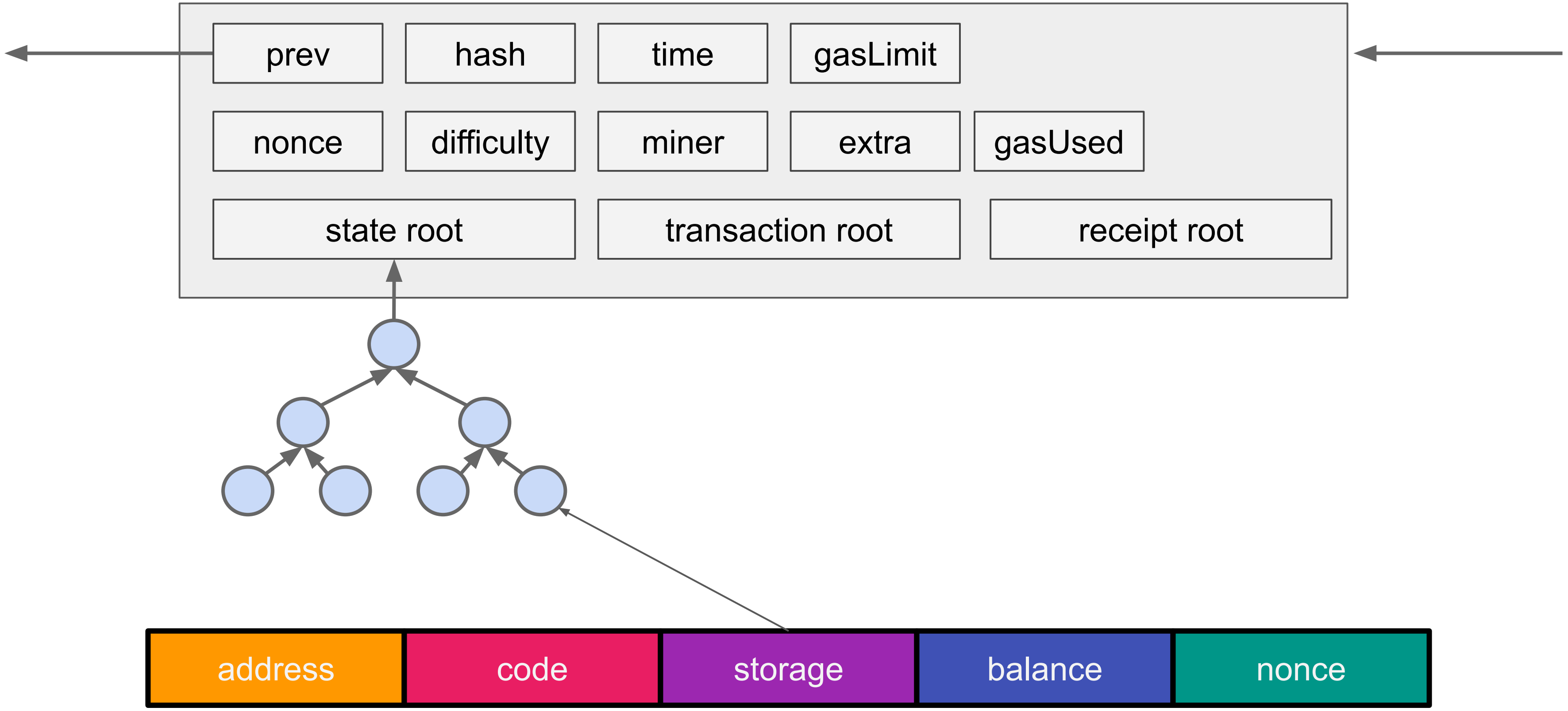
Ethereum Virtual Machine

- Series of **bytecode** instructions (EVM code)
- Each **bytecode** represents an **operation** (opcode)
- A quasi **Turing complete** machine
- **Stack-based** architecture (1024-depth)
- **32-byte** words (256-bit words)
- **Crypto** primitives

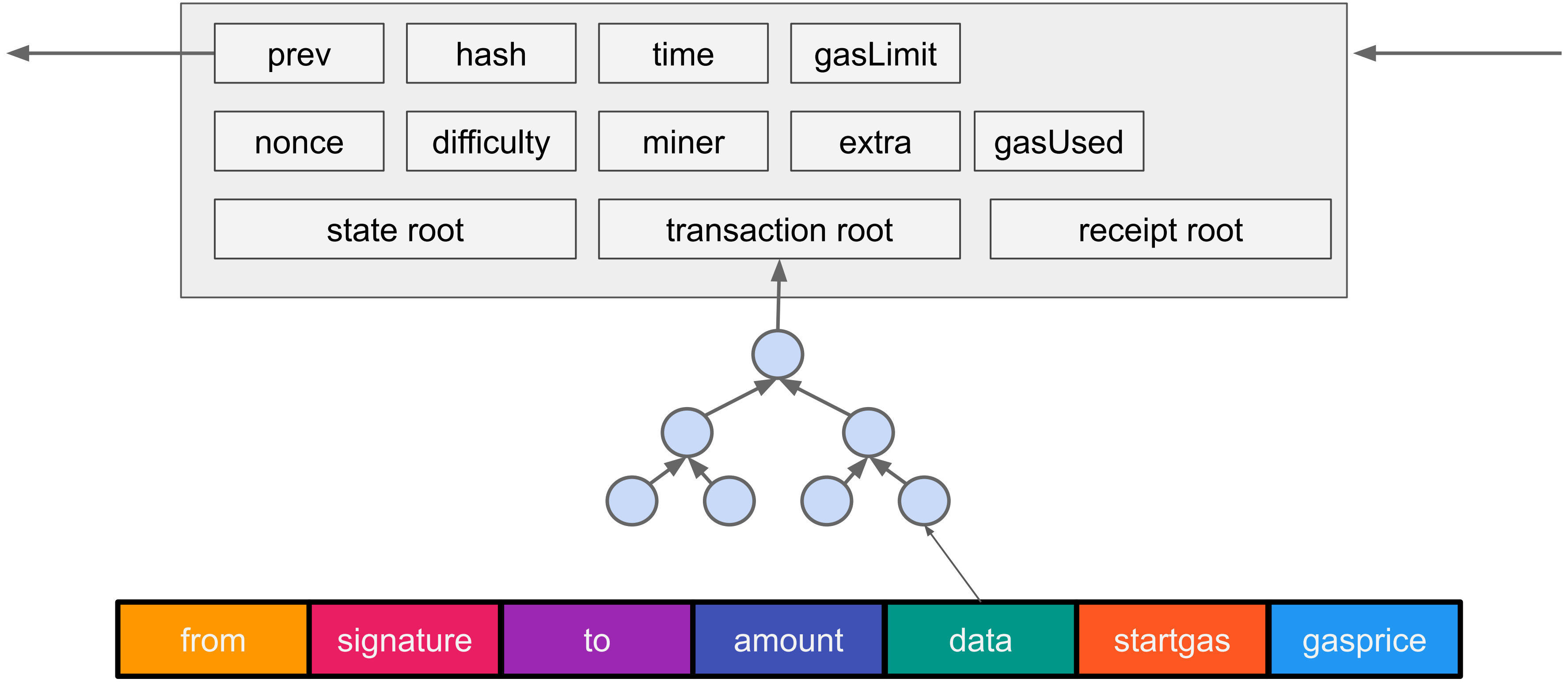
EVM: contract execution

- Three types of storage:
  - **Stack**
  - **Memory** (expandable byte array)
  - **Storage** (key/value store)
- All memory is **zero-initialized**
- Access: **value**, **sender**, **data**, **gas** limit and **block header** data (depth, timestamp, miner, hash)

Ethereum block



Ethereum block



Ethereum Mining

- **Similar** to **Bitcoin**
- **Blocks** contain: **transaction** list and most **recent state**
- Block **time**: ~12 - 15 **seconds**
- **Proof-of-work**: Ethash (designed to be **memory-hard**)
- Casper: Future transition to **proof-of-stake**
- **Winner** of the block: **2 ETH**

Ethereum fees: the phone booth model

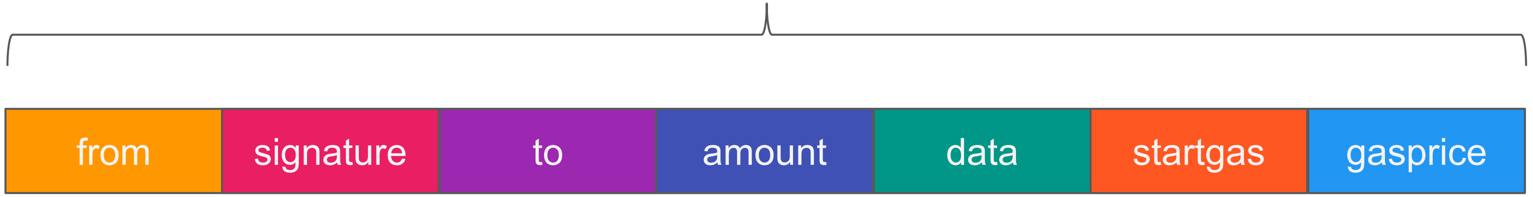
Gas: a necessary evil

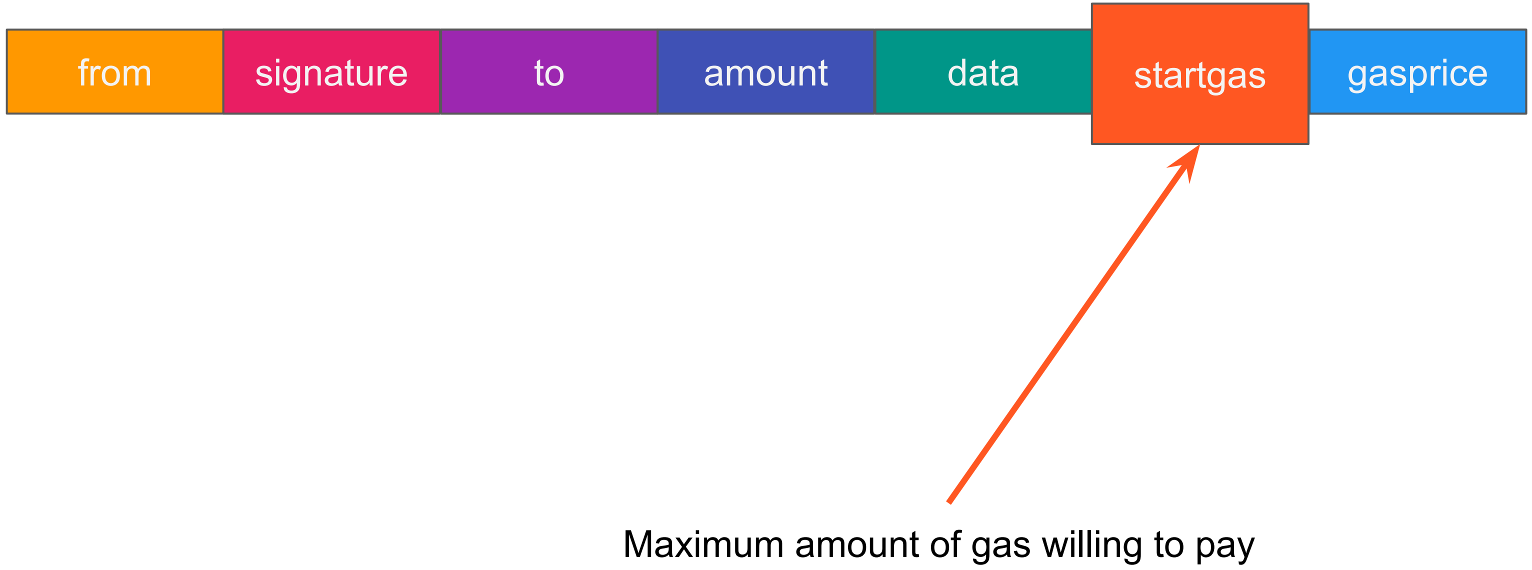
- Every node on the network:
  - evaluate all **transactions**
  - store all **state**
- The *halting problem*

Gas: a necessary evil

- Every **computation step** has a **fee**
- Is **paid** in **gas**
- **Gas** is the **unit** used to **measure computations**

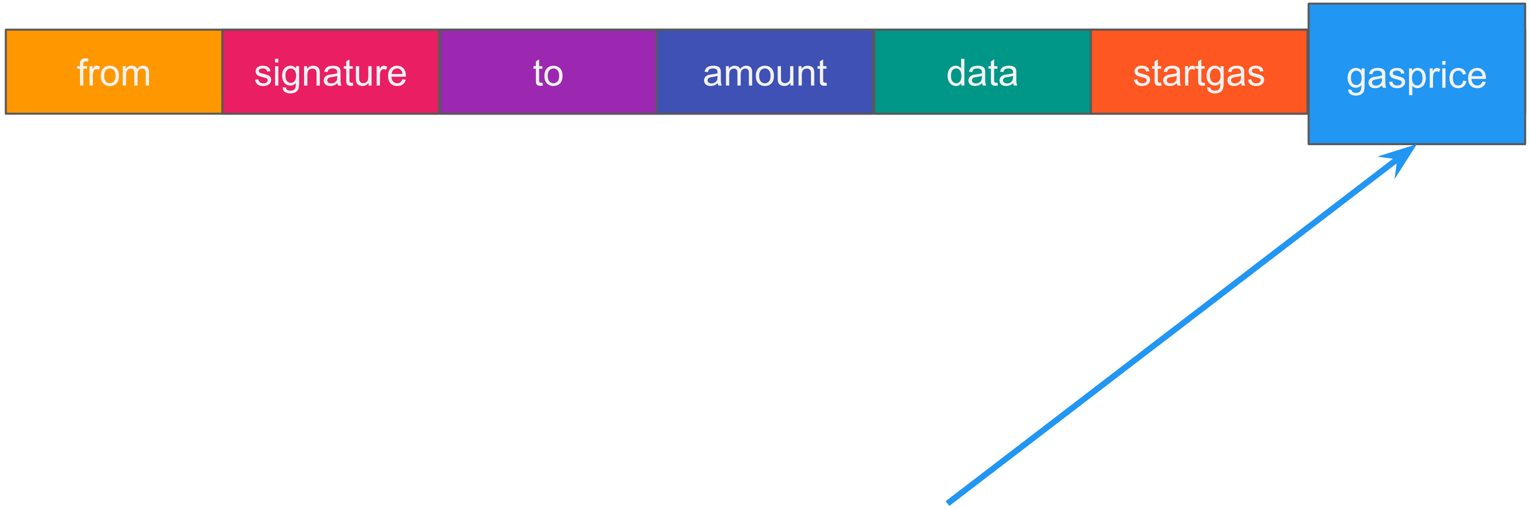
Ethereum transaction




from
signature
to
amount
data
startgas
gasprice
Maximum amount of gas willing to pay

Gas Limit

- Equals to startgas
- All **unused gas** is **refunded** at the end of a transaction
- **Out of gas** transaction are **not refundable**
- Blocks also have a gas limit



Price to pay per gas unit

Gas Price

- Measured in **gwei** (1 × 10^9 Wei)
- Determines how **quickly** a transaction will be **mined**

Transaction Fees

Gas Limit

50.000

×

Gas Price

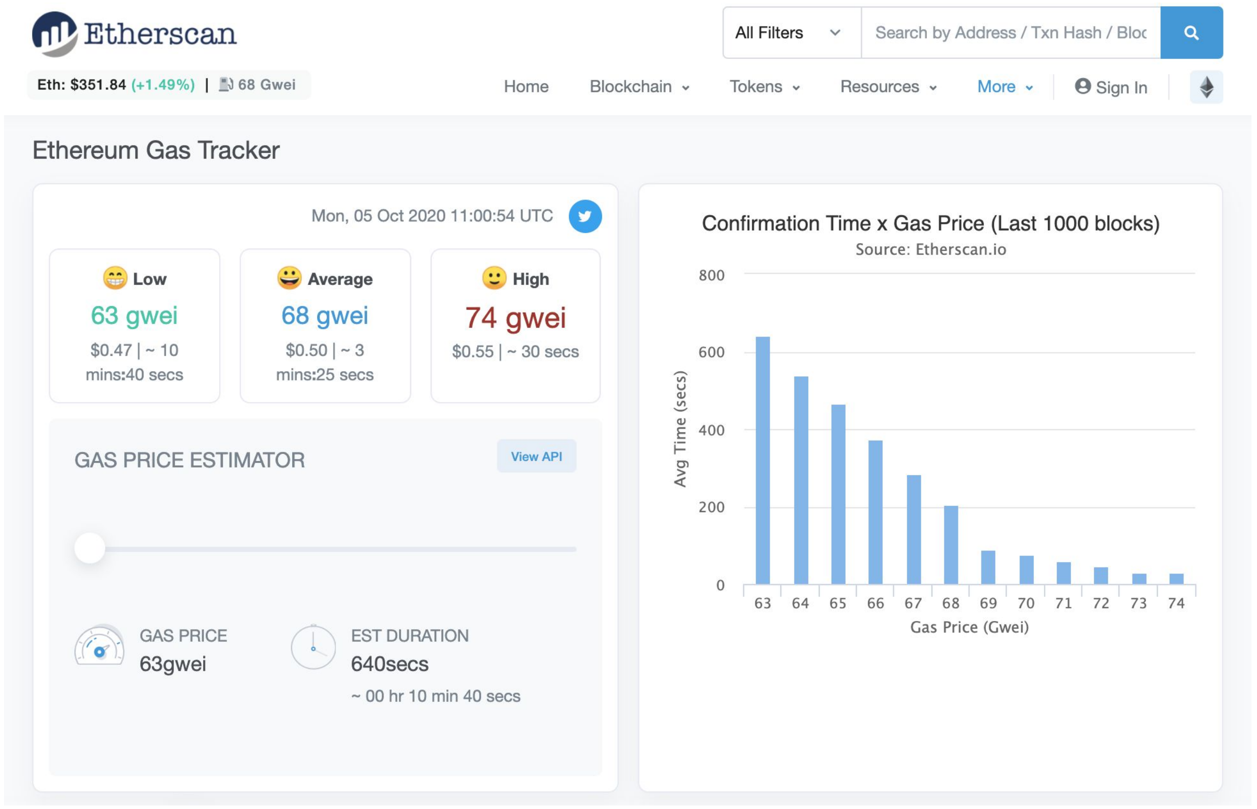
20 Gwei

=

Max transaction fee

0.001 ETH

Confirmation vs. Gas price


Etherscan

All Filters | Search by Address / Txn Hash / Bloc

Eth: $351.84 (+1.49%) | 68 Gwei

Home | Blockchain | Tokens | Resources | More | Sign In

Ethereum Gas Tracker

Mon, 05 Oct 2020 11:00:54 UTC

Low	Average	High
63 gwei	68 gwei	74 gwei
$0.47 | ~ 10 mins:40 secs	$0.50 | ~ 3 mins:25 secs	$0.55 | ~ 30 secs

GAS PRICE ESTIMATOR — View API

GAS PRICE 63gwei

EST DURATION 640secs ~ 00 hr 10 min 40 secs

Confirmation Time x Gas Price (Last 1000 blocks)

Source: Etherscan.io

https://etherscan.io/gastracker

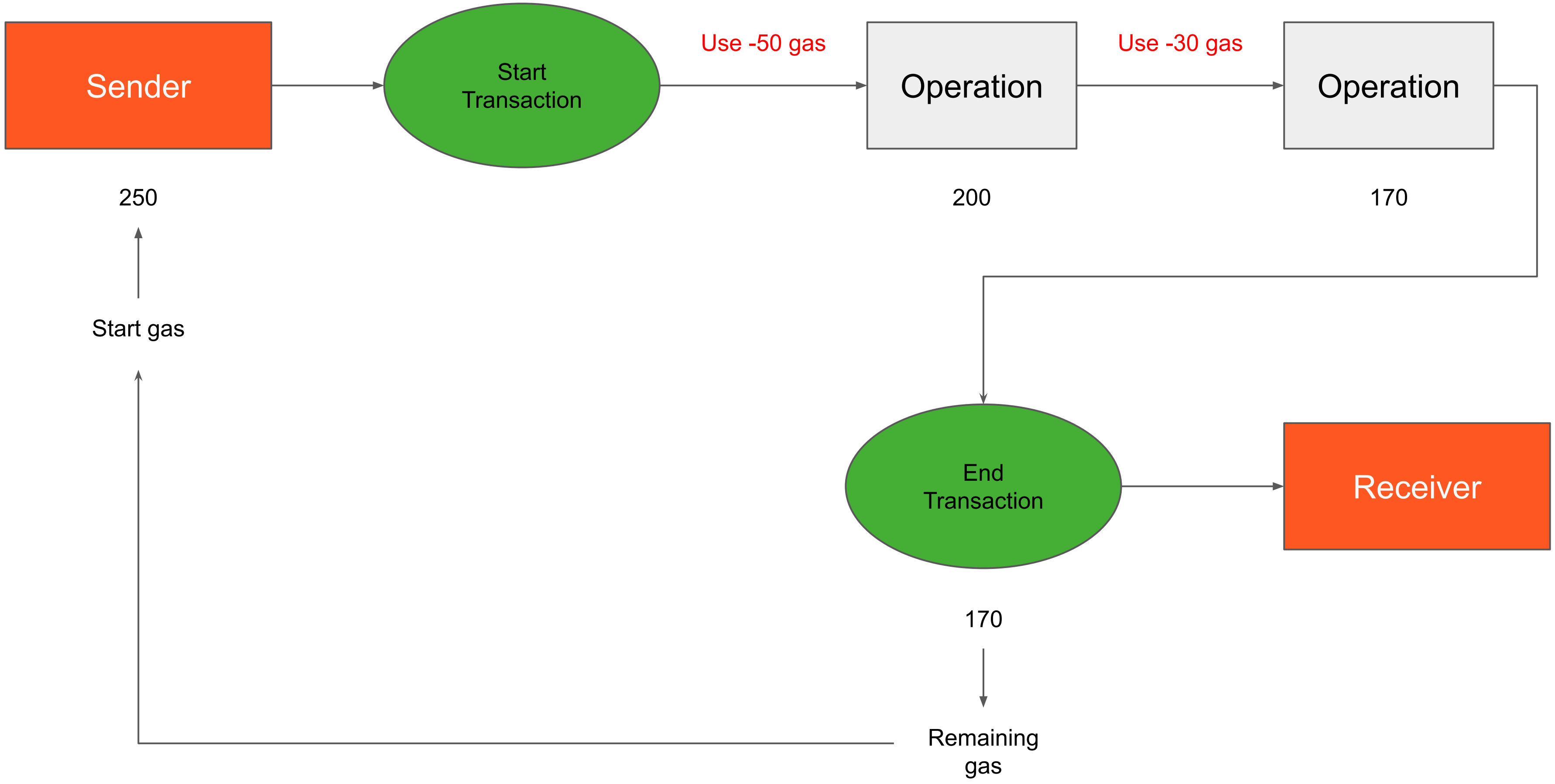
Storage in Ethereum

ETH Price: $166.41 (Apr 17, 2019) - Gas Price: 3 Gwei

Size	Gas	Cost (ETH)	Cost ($)
32 bytes	21.000	0.000063	$0.36088
1KB	724.664	0.002174	$0.01046
1MB	~697.325.562	2.09198	$347.268
10MB	~7.000.000.000	~21	$3,486
100MB	~70.000.000.000	~210	$34,860
1GB	~700.000.000.000	~2100	$348,600

Computation steps

1. If **gas_limit * gas_price** > **balance** then **halt**
2. **Deduct** gas_limit * gas_price from **balance**
3. Set gas = gas_limit
4. **Run code** deducting from gas
5. After termination **return remaining gas** to **balance**


Sender
Start Transaction
Use -50 gas
Operation
Use -30 gas
Operation
250
200
170
Start gas
End Transaction
Receiver
170
Remaining gas

Out of gas exceptions

- State **reverts** to **previous state**
- gas_limit * gas_price is **still deducted** from **balance**

Introduction to Solidity

Solidity

- A **high level programming** language for **writing** smart **contracts** on **Ethereum**
- **Compile** code for the **Ethereum Virtual Machine**
- **Syntax** looks like **JavaScript**

Solidity

- **Contracts** look like **classes** / **objects**
- **Static** Type (Most types can be cast, e.g bool(x))
- Most of the control structures from **JavaScript** are available in **Solidity** **except** for **`switch`**

```
pragma solidity ^0.5.1;

contract HelloWorld {

    function print () public pure returns (string memory) {

        return 'Hello World!';

    }

}
```

Pragmas

```
pragma solidity 0.5.0;

pragma solidity ^0.5.1;

pragma solidity >=0.5.0 < 0.6.0;
```

The pragma keyword is used to enable certain compiler (version) features or checks. Follows the same syntax used by npm.

Contract

```
contract <contract-name> { ... }
```

Constructors

```
contract HelloWorld {

    constructor () public { … }

}


contract HelloWorld {

    constructor (uint x, string y) public { … }

}
```

Solidity: Variables

- State variables:
    - Contract variables
    - **Permanently stored** in contract **storage**
    - **Must declare** at compilation time

- Local variables
    - Within a **function**: **cannot** be **accessed** outside
    - **Complex** types: at **storage** by default
    - **Value** types: in the **stack**
    - Function **arguments**: in **memory** by default

Types

- The **type** of each variable **needs to be specified** (Solidity is a statically typed language)
- **Two** types:
    - **Value** types
    - **Reference** types
- “**undefined**” or “**null**” values **does not exist** in Solidity
- **Variables** without a value **always** have a **default value** (zero-state) dependent on its type.
- Solidity follows the scoping rules of C99 (variables are visible until the end of the smallest `{}`-block)

Value types

Types: booleans

```
contract Booleans {
    bool p = true;
    bool q = false;
}
```

Operators: `!`, `&&`, `||`, `!=`, `==`

Types: integers

```
contract Integers {

    uint256 x = 5;

    int8 y = -5;

}
```

- Two types:
  - `int` (signed)
  - `uint` (unsigned)
- Keywords: `uint8` / `int8` to `uint256` / `int256` in step of 8.
- `uint` / `int` are alias for `uint256` / `int256`.
- Operators as usual:
  - Comparisons: `<=, <, ==, !=, >=, >`
  - Arithmetic operators: `+, -, *, /, %, **`
  - Bitwise operators: `&, |, ^`
  - Shift operators: `>>, <<`
- Range: $2^b - 1$ where $b \in \{ 8, 16, 24, 32, \ldots, 256 \}$
- Division always results in an integer and round towards zero (5 / 2 = 2).
- No floats!

Types: address

```
contract Address {

    address owner;

    address payable anotherAddress;

}
```

Address type holds an Ethereum address (20 byte value).
Payable address is an address you can send Ether to (you cannot send to plain addresses).

Types: fixed-size byte arrays

```
contract ByteArrays {

    bytes32 y = 0xa5b9...;

    // y.length == 32

}
```

- `bytes1`, `bytes2`, `bytes3`, ..., `bytes32`
- `byte` is alias for `byte1`
- `length`: fixed length of the byte array. You cannot change the length of a fixed byte array.

Types: Enum

```
contract Purchase {

    enum State { Created, Locked, Inactive }

}
```

Solidity: enum

```
pragma solidity ^0.4.24;

contract Enum {
    enum ActionChoices { GoLeft, GoRight, GoStraight, SitStill }
    ActionChoices choice;
    ActionChoices constant defaultChoice = ActionChoices.GoStraight;

    function setGoStraight() public {
        choice = ActionChoices.GoStraight;
    }

    function getChoice() public view returns (ActionChoices) {
        return choice;
    }
}
```

Reference types

Types: arrays, static and dynamic

```
contract Arrays {
      uint256[2] x;
      uint8[] y;
      bytes z;
      string name;
      // 2D: dynamic rows, 2 columns!
      uint [2][] flags;

      function create () public {
            uint[] memory a = new uint[](7);
            flags.push([0, 1]);
      }
}
```

- The **notation** of declaring **2D** arrays is **reversed** when compared to **other languages**!
  - **Declaration**: `uint[columns][rows] z;`
  - **Access**: `z[row][column]`
- `bytes` and `string` are **special** arrays.
- `bytes` is similar to `byte[]` but is **cheaper** (gas).
- `string` is a **UTF-8-encoded**.
- Members:
  - push: push an element at the end of array.
  - length: return or set the size of array.
- `string` does **not** have **length** member.
- **Allocate** memory **arrays** by using the **keyword** `new`. The size of memory arrays has to be known at compilation (in this case 7). You **cannot** resize a memory array.

Types: Struct

```
contract Vote {
    struct Voter {
        bool voted;
        address voter;
        uint vote;
    }
}
```

- A struct cannot contain a struct of its own type (the size of the struct has to be finite).
- A struct can contain mappings.

Solidity: structs

```
pragma solidity ^0.4.24;

contract Ballot {
   struct Voter {
      uint weight;
      bool voted;
      address delegate;
      uint vote;
   }
}
```

```
contract CrowdFunding {
   struct Funder {
      address addr;
      uint amount;
   }

   struct Campaign {
      address beneficiary;
      uint fundingGoal;
      uint numFunders;
      uint amount;
      mapping (uint => Funder) funders;
   }
}
```

Types: Mappings

```
contract Mappings {

    mapping(address => uint256) balances;

}
```

key

value

Visibility

Visibility

- **public**: Public functions can be called from other contracts, internally and personal accounts. For public state variables an automatic getter function is being created.
- **external**: External functions cannot be called internally. Variables cannot be declared as external.
- **Internal**: Internal function and variables can be called only internally. Contracts that inherit another contract can access the parent’s internal variables and functions.
- **private**: Private functions and variables can be called only by the contract in which they are defined and not by a derived contract. **Warning:** private variables are visible to all observers external to the blockchain.

Data location

Data location: areas

- Every complex type (arrays, structs, mappings) has a data location.
- Two types of location: storage and memory.
- As of Solidity version **5.0.0** you must **always declare** the data **location** of complex types inside functions’ body, arguments and returned values.

Data location: areas

- Storage:
    - Persistent.
    - All state variables are saved to storage.
    - Function's complex local values are saved to storage by default. (Solidity versions >= 5.0.0 force you to declare the data location).
- Memory:
    - Non-persistent.
    - Function's arguments and returned values are stored to memory by default. (Solidity versions >= 5.0.0 force you to declare the data location for complex types).

Data location: assignment copy/reference rules

Assignment of the form “variable <- variable”

- storage <-> memory: copy
- state (global storage) variable <- state variable, storage and memory: copy
- memory <-> memory : reference
- local storage variable <- storage: reference

Fallback function

Fallback function

```
contract Fallback {

    function () external {

        ...

    }

}
```

Unnamed function

- No arguments (`msg.*` is accessible, contains all data about incoming transaction, incl. sender and value).
- No returned values.
- Mandatory visibility: external.
- Executed if no data (transaction field) is supplied or if the function that a user tries to call does not exist.
- Executed whenever the contract receives plain Ether (without data).
- To receive Ether the fallback function must be marked as `payable`.
- In the absence of fallback function a contract cannot receive Ether and an exception is thrown.
- Should be simple - without consuming too much gas.

Solidity: Functions

- Can return multiple values
- Access
  - Public: Accessed by **anyone**
  - Private: Accessed **only** from the **contract**
  - Internal: Accessed **only internally**
  - External: Accessed **only externally**
- Declarations
  - View: They promise **not** to **modify** the **state**
  - Pure: They promise **not** to **read** from or **modify** the **state**.
  - Payable: Must be used to **accept Ether**

Remember that on-chain data is public despite access declaration!!

```
pragma solidity ^0.4.24;


contract Jedi {

    function computeForce() internal pure returns (uint){
            return 50;
    }

   function getExtraForce() private pure returns (uint) {
            return 100;
   }

}


contract Ewok {
    Jedi j = new Jedi();
    uint force =  j.computeForce(); // error private method
}
```

```
pragma solidity ^0.4.24;


contract Human is Jedi {
    uint age = 70;
    string name = “Luke”;
    string lastName = “Skywalker”;
    bool isMaster = false;
    uint force = 0;

    function setMaster(bool _master) external {
            isMaster = _master;
            force = computeForce(); // internal call
            force = force + getExtraForce(); // error private
method
    }

    function getJedi() public view returns (uint, string, string,
bool){
            return (age, name, lastName, isMaster) //
multi-values
    }

}
```

Solidity: events

- EVM logging mechanism
- Arguments are stored in the transaction log
- An alternative to store data cheaply
- Client software can create “listeners” to events (eg. in Python/JS)

Solidity: events

```
pragma solidity ^0.4.24;

contract ClientReceipt {
   event Deposit(
      address indexed _from,
      bytes32 indexed _id,
      uint _value
   );

   function deposit(bytes32 _id) public payable {
      emit Deposit(msg.sender, _id, msg.value);
   }
}
```

Contract - Solidity

```
var abi = /* abi as generated by the compiler */;
var web3 = /* http/ws connection to Eth full node */;
var contractObject = web3.eth.contract(abi);
var contractInstance = contractObject.at("0x1234...ab67");
/* address */

var event = contractInstance.Deposit();

// watch for changes
event.watch(function(error, result){
   if (!error)
      console.log(result);
   ....
   /* use result to access event data .. */
});
```

Client - Javascript

Solidity: Inheritance

- Multiple inheritance
- **One contract** is created on the **blockchain** for all derived contracts: codes concatenate
- The general **inheritance** system is very **similar** to **Python’s**

Solidity: Inheritance

- Use `` `**is**` `` keyword to **extend** a contract
- **Derived** contracts: **access** all non-private members, internal functions and state variables
- **Abstract** contracts can be used as **interfaces**
- **Functions** can be **overridden**
- **Interfaces**: functions are not implemented

Solidity: Inheritance

```
pragma solidity ^0.4.24;

interface Regulator {
   function checkValue(uint amount)  external returns (bool);
   function loan() external returns (bool);
}
contract LocalBank is Bank(10) {
   string private name;
   uint private age;

   function setName(string newName) public {
      name = newName;
   }
   function getName() public view returns (string) {
      return name;
   }
   function setAge(uint newAge) public {
      age = newAge;
   }
   function getAge() public view returns (uint) {
      return age;
   }
}
```

```
contract Bank is Regulator {
   uint private value;
   constructor(uint amount) public {
      value = amount;
   }
   function deposit(uint amount) public {
      value += amount;
   }
   function withdraw(uint amount) public {
      if (checkValue(amount)) {
         value -= amount;
      }
   }
   function balance() public view returns (uint) {
      return value;
   }
   function checkValue(uint amount) public view returns (bool) {
      return value >= amount;
   }
   function loan() public view returns (bool) {
      return value > 0;
   }
}
```

Solidity: Modifiers

```
pragma solidity ^0.4.24;

contract owned {

   address owner;


   constructor() public { owner = msg.sender; }


   modifier onlyOwner {
      require(msg.sender == owner);
      _;
   }
}
```

```
contract mortal is owned {
   function close() public onlyOwner {
      selfdestruct(owner);
   }
}
```

Solidity: units and globally available variables

- Ether Units
  - A literal number can take a suffix of wei, finney, szabo or ether (2 ether == 2000 finney evaluates to true)
- Time Units
  - Suffixes like seconds, minutes, hours, days, weeks and years (1 hours == 60 minutes)

Solidity: units and globally available variables

- Block and Transaction Properties
  - block.blockhash
  - block.coinbase
  - msg.data
  - msg.gas
  - msg.value
  - msg.sender
  - now
  - tx.origin

Solidity: units and globally available variables

- Error Handling
  - Via error objects (see: https://solidity.readthedocs.io/en/v0.6.0/control-structures.html)
  - assert
  - require
  - revert
- Mathematical and Cryptographic Functions
  - addmod, mulmod
  - Keccak256 (SHA-3), sha256, ripemd160

Solidity: units and globally available variables

- Address Related
  - <address>.balance
  - <address>.transfer
  - <address>.send
  - <address>.call, <address>.callcode, <address>.delegatecall
- Contract Related
  - this, selfdestruct

Send ether

Send ether

Function	Gas forwarded	Error handling	Notes
`transfer`	2300	throws on failure	**Safe** against re-entrancy
`send`	2300	`false` on failure	**Safe** against re-entrancy
`call`	all remaining gas	`false` on failure	**Not safe** against re-entrancy

Interacting with other contracts

Interacting with other contracts

```
contract Planet {
    string private name;
    constructor (string memory _name) public { name = _name; }
    function getName() public returns(string memory) { return name; }
}

contract Universe {
    address[] planets;
    event NewPlanet(address planet, string name);

    function createNewPlanet(string memory name) public {
        Planet p = new Planet(name);
        planets.push(address(p));
        emit NewPlanet(address(p), p.getName());
    }
}
```

Thank you!