Blockchain and Cryptocurrencies

Week 8 - Smart Contracts

Dr. Thi Thu Ha Doan   Prof. Dr. Peter Thiemann

Albert-Ludwigs-Universität Freiburg, Germany

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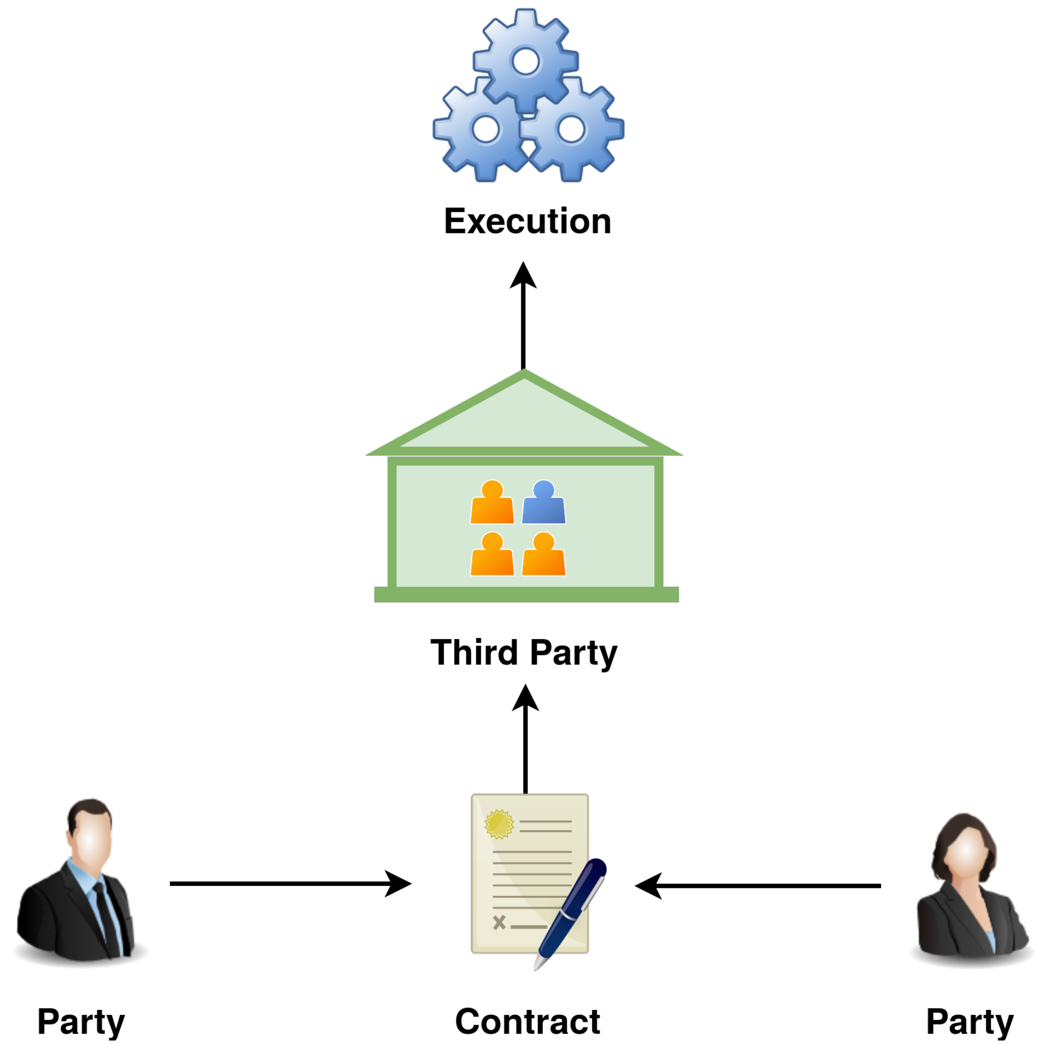
Traditional Contracts



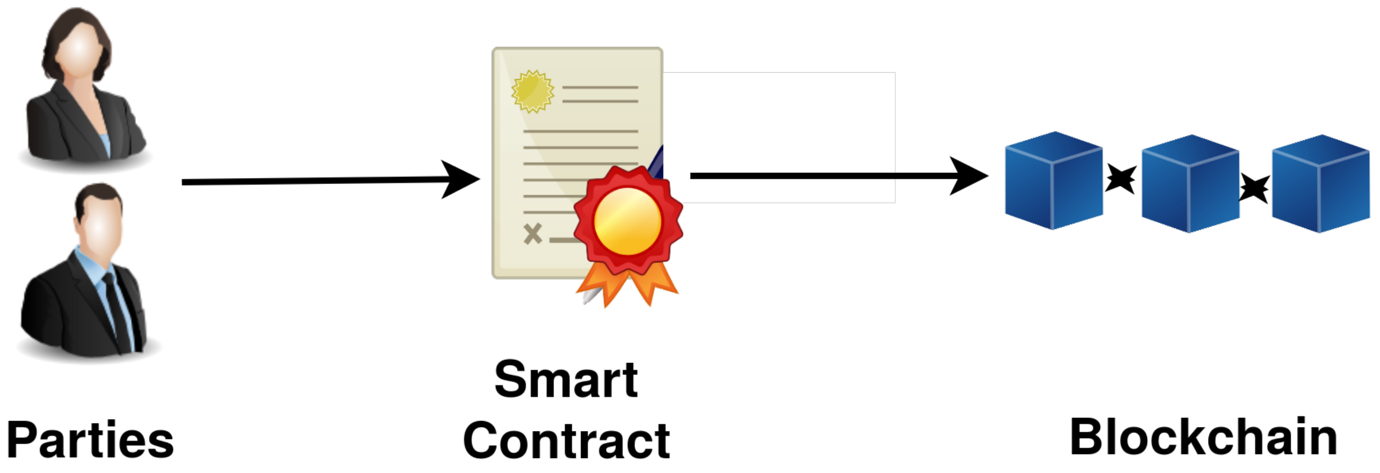
Definition

- contract parties
- common goal
- obligations of each party
- further contractual clauses
- declaration of will

Smart Contracts

A **smart contract** is a program that is stored and automatically executed on a blockchain.

- First mentioned 1997 by Nick Szabo
- Contract in form of code (Code is law)
- Self-executing and self-enforcing rules



Smart Contracts

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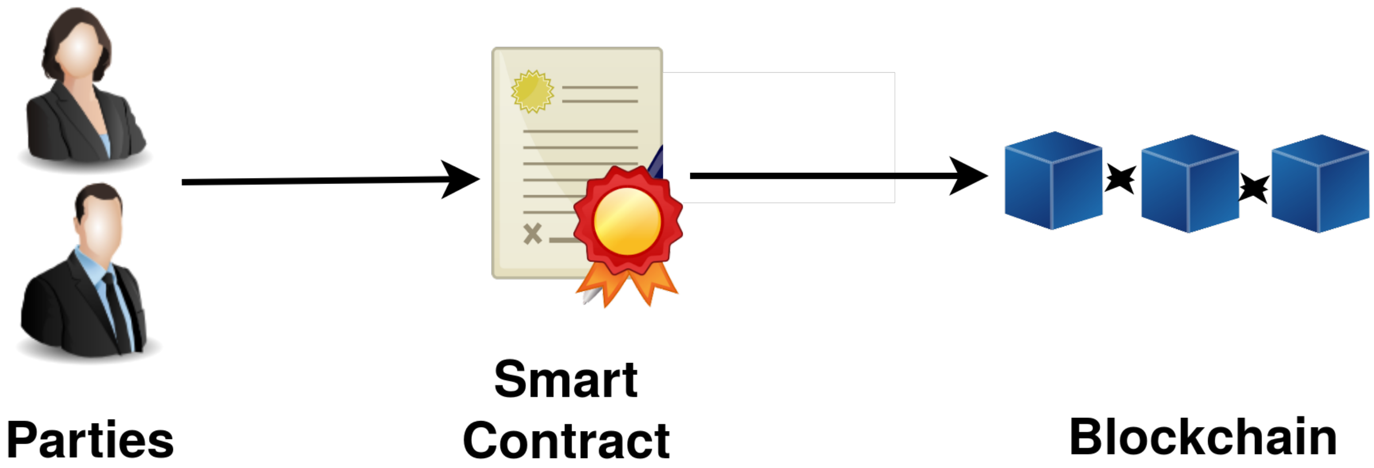
Goals:

- Trusted execution without third parties
- Security and low transaction costs



Smart Contracts

Properties

- Stored on a blockchain ⇒ **immutable**
- Executed and validated by the network ⇒ **distributed**
- transparent
  - access, interact and verify (everyone)
  - consensus about the result
  - maintain application state

Smart Contracts

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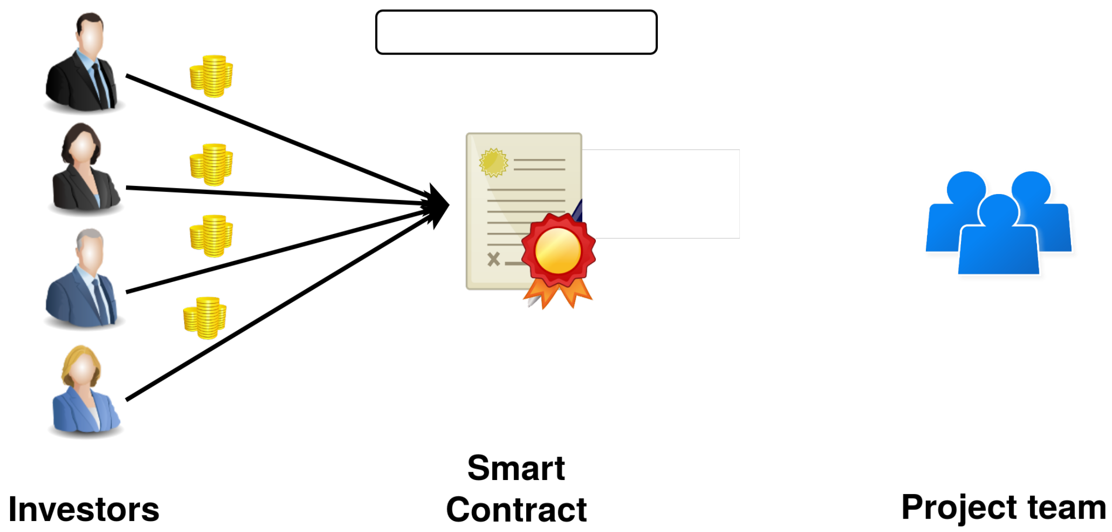
Functions

- send and receive coins
- interact with other smart contracts

Example: Crowdfunding

To raise money from a group of investors to fund a project

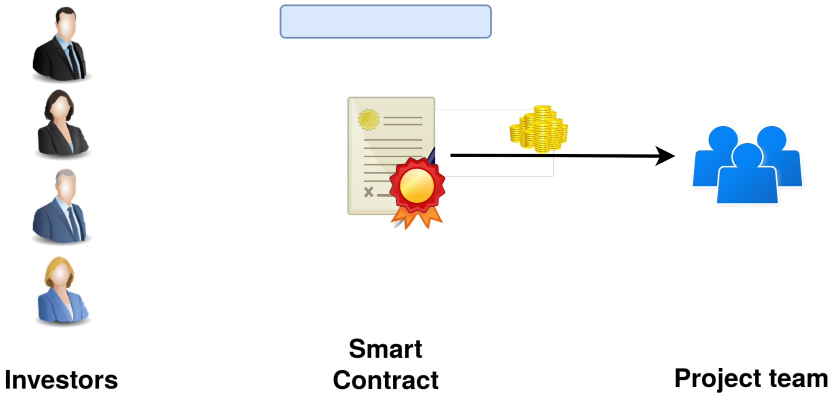
- set up a funding goal and a deadline
- start to collect money



Example: Crowdfunding

Terms and Conditions

1. if the funding goal is met, transfer the money to the project team



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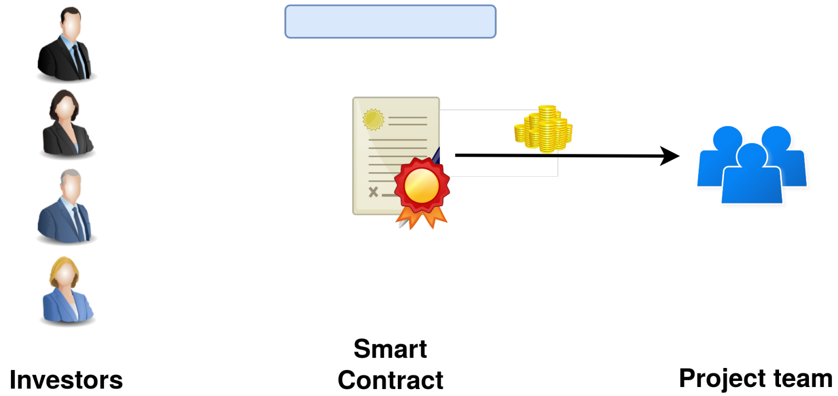
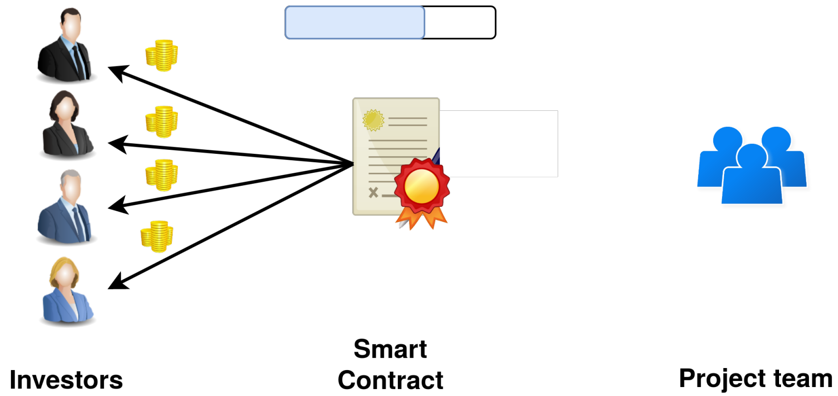


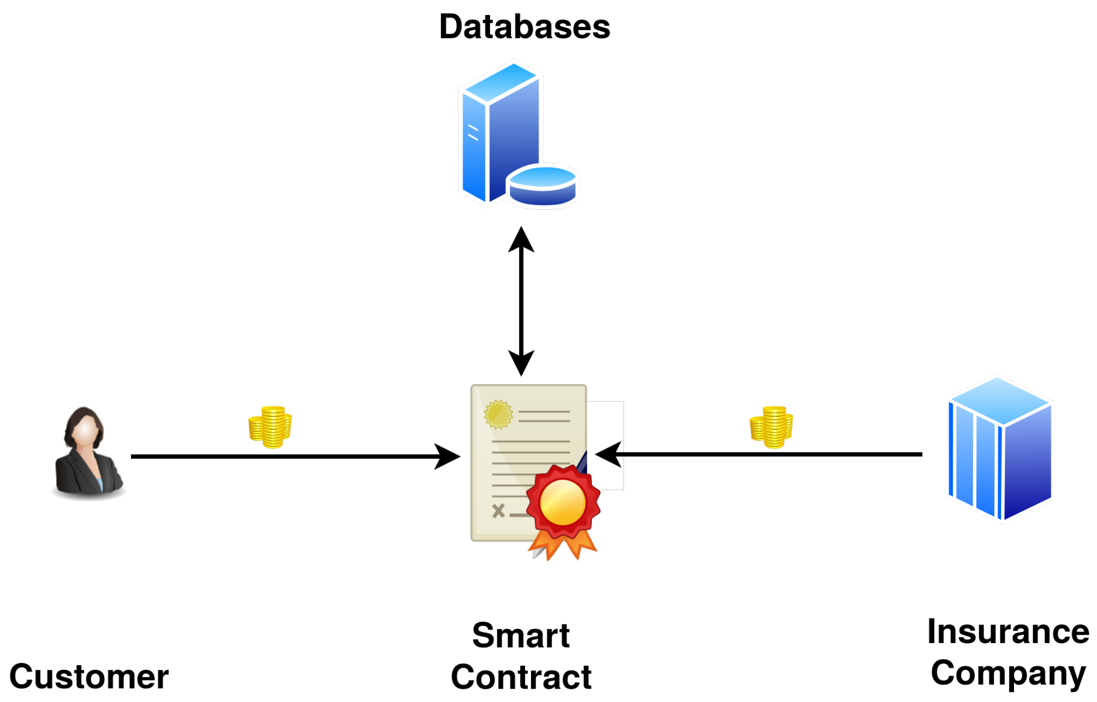
2. if the project fails to reach the funding goal, return the money to the investors



Example: Flight Delay Insurance

Ensure that a customer is compensated for a delayed flight

- compensation condition: flight delayed for more than two hours
- linked to the databases that record the flight status



https://www.axa.com/en/magazine/axa-goes-blockchain-with-fizzy

Example: Flight Delay Insurance

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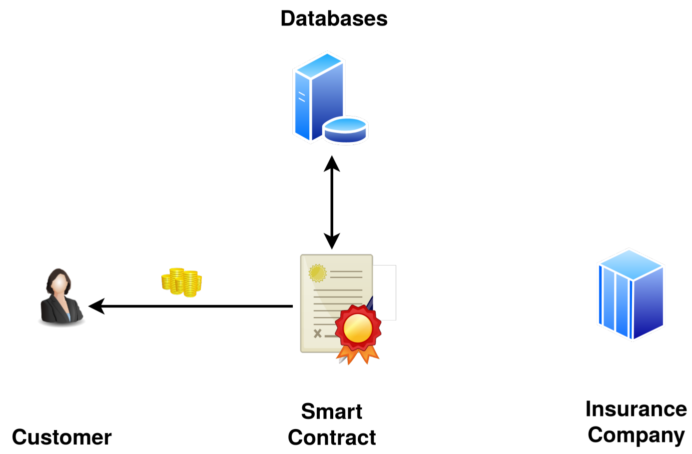

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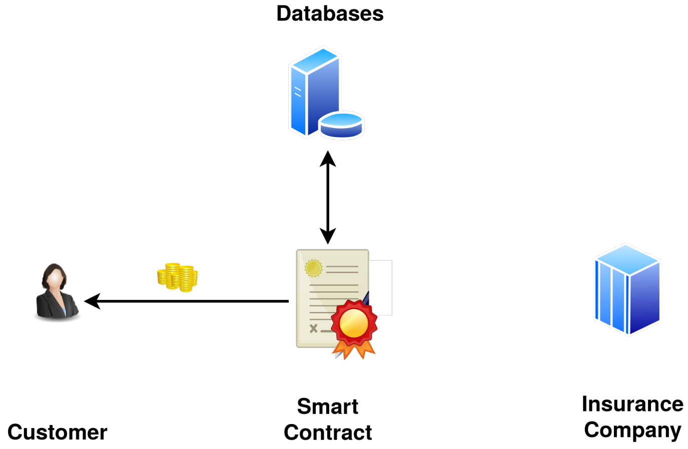
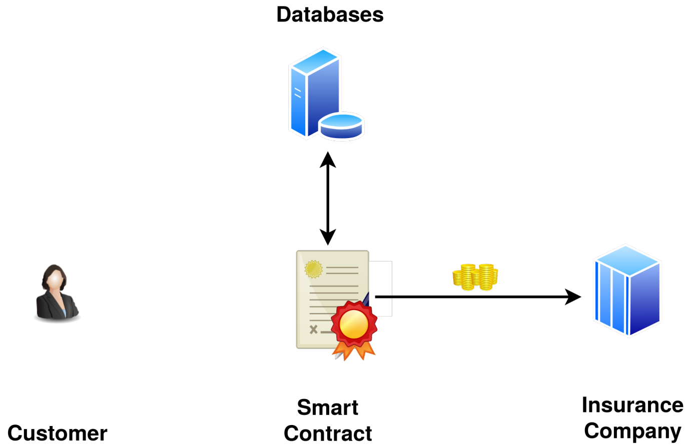


2. if less than two hours delay, transfer premium to the insurance company



Store

Smart contract's variables/states are stored on the blockchain

- storage space of a smart contract is limited by cost

Gas

Traditional transaction fees

- Fee to compensate the network
- Fixed for each kind of transaction
- Bitcoin: depending on the size of the transaction

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Transaction fees for smart contracts

Effort of the network:

- time to run (number of steps)
- storage needed

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Transaction fees for smart contracts

Effort of the network:

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Gas

- each operation and each storage allocation requires a certain amount of gas to be executed.
- fee is calculated from gas price **offered by the caller**
  Total fee = gas_Used * gas_Price

Gas

Example: Gas consumption

Add two numbers: ADD 3 4

- load or store a number: 10 gas
- adding two numbers: 20 gas

$$\text{Total gas} = 10 + 10 + 20 + 10$$

Gas

Gas Limit

Maximum amount of gas a caller is willing to pay (deposited like a prepayment)

- each operation has different gas cost
- reasonable gas limit is needed
- when the gas runs out
  - network stops executing the code,
  - **contract reverts back to its original state**

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Gas limit too high

- the block gas limit
- unused gas is returned

Contents

Ethereum Blockchain

- Distributed computing platform (blockchain 2.0)
- First and most well-known smart contract platform
- Released 2015, co-founded by Vitalik Buterin and Gavin Wood
- Goal: decentralized software development platform
- Native cryptocurrency: 1 Ether $= 10^{18}$ Wei $= 10^{9}$ Gwei

Ethereum's Features

Block time

About 15 seconds (compared to 10 minutes BTC)

Minting

New coins generated at a constant rate (unless hard forked)

Mining

- Proof-of-work, but different algorithm Ethash for which ASICs are less advantageous
- Migration to proof-of-stake planned

Transaction fees

Calculated by computational effort, bandwidth use, and storage needs

Account-based

Coins are represented by account balances (rather than UTxOs). Accounts can be controlled by a private key or a smart contract.

Pros and cons of account-based blockchains

Advantages

- More flexible transactions. Dependance on existing state and on external input allows for oracles and other logic to influence the outcome.
- Transactions do not explicitly refer to the resulting state $\Rightarrow$ smaller transaction sizes.

Disadvantages

- Transactions affecting the same account(s) will have to be scheduled.
- Account models encourage address reuse, which enables linking transactions to a single owner, thus compromising privacy.

Ethereum Fee Schedule

Appendix G. Fee Schedule

The fee schedule G is a tuple of 31 scalar values corresponding to the relative costs, in gas, of a number of abstract operations that a transaction may effect.

Name	Value	Description*
G_{zero}	0	Nothing paid for operations of the set W_{zero}.
G_{base}	2	Amount of gas to pay for operations of the set W_{base}.
$G_{verylow}$	3	Amount of gas to pay for operations of the set $W_{verylow}$.
G_{low}	5	Amount of gas to pay for operations of the set W_{low}.
G_{mid}	8	Amount of gas to pay for operations of the set W_{mid}.
G_{high}	10	Amount of gas to pay for operations of the set W_{high}.
$G_{extcode}$	700	Amount of gas to pay for an EXTCODESIZE operation.
$G_{extcodehash}$	400	Amount of gas to pay for an EXTCODEHASH operation.
$G_{balance}$	400	Amount of gas to pay for a BALANCE operation.
G_{sload}	200	Paid for a SLOAD operation.
$G_{jumpdest}$	1	Paid for a JUMPDEST operation.
G_{sset}	20000	Paid for an SSTORE operation when the storage value is set to non-zero from zero.
G_{sreset}	5000	Paid for an SSTORE operation when the storage value's zeroness remains unchanged or is set to zero.
R_{sclear}	15000	Refund given (added into refund counter) when the storage value is set to zero from non-zero.
$R_{selfdestruct}$	24000	Refund given (added into refund counter) for self-destructing an account.
$G_{selfdestruct}$	5000	Amount of gas to pay for a SELFDESTRUCT operation.
G_{create}	32000	Paid for a CREATE operation.
$G_{codedeposit}$	200	Paid per byte for a CREATE operation to succeed in placing code into state.
G_{call}	700	Paid for a CALL operation.
$G_{callvalue}$	9000	Paid for a non-zero value transfer as part of the CALL operation.
$G_{callstipend}$	2300	A stipend for the called contract subtracted from $G_{callvalue}$ for a non-zero value transfer.
$G_{newaccount}$	25000	Paid for a CALL or SELFDESTRUCT operation which creates an account.
G_{exp}	10	Partial payment for an EXP operation.
$G_{expbyte}$	50	Partial payment when multiplied by $\lceil \log_{256}(exponent) \rceil$ for the EXP operation.
G_{memory}	3	Paid for every additional word when expanding memory.
G_{txcreate}	32000	Paid by all contract-creating transactions after the *Homestead* transition.
$G_{txdatazero}$	4	Paid for every zero byte of data or code for a transaction.
$G_{txdatanonzero}$	68	Paid for every non-zero byte of data or code for a transaction.
$G_{transaction}$	21000	Paid for every transaction.
G_{log}	375	Partial payment for a LOG operation.
G_{logdata}	8	Paid for each byte in a LOG operation's data.
G_{logtopic}	375	Paid for each topic of a LOG operation.
G_{sha3}	30	Paid for each SHA3 operation.
$G_{sha3word}$	6	Paid for each word (rounded up) for input data to a SHA3 operation.
G_{copy}	3	Partial payment for *COPY operations, multiplied by words copied, rounded up.
$G_{blockhash}$	20	Payment for BLOCKHASH operation.
$G_{quaddivisor}$	20	The quadratic coefficient of the input sizes of the exponentiation-over-modulo precompiled contract.

https://ethereum.github.io/yellowpaper/paper.pdf

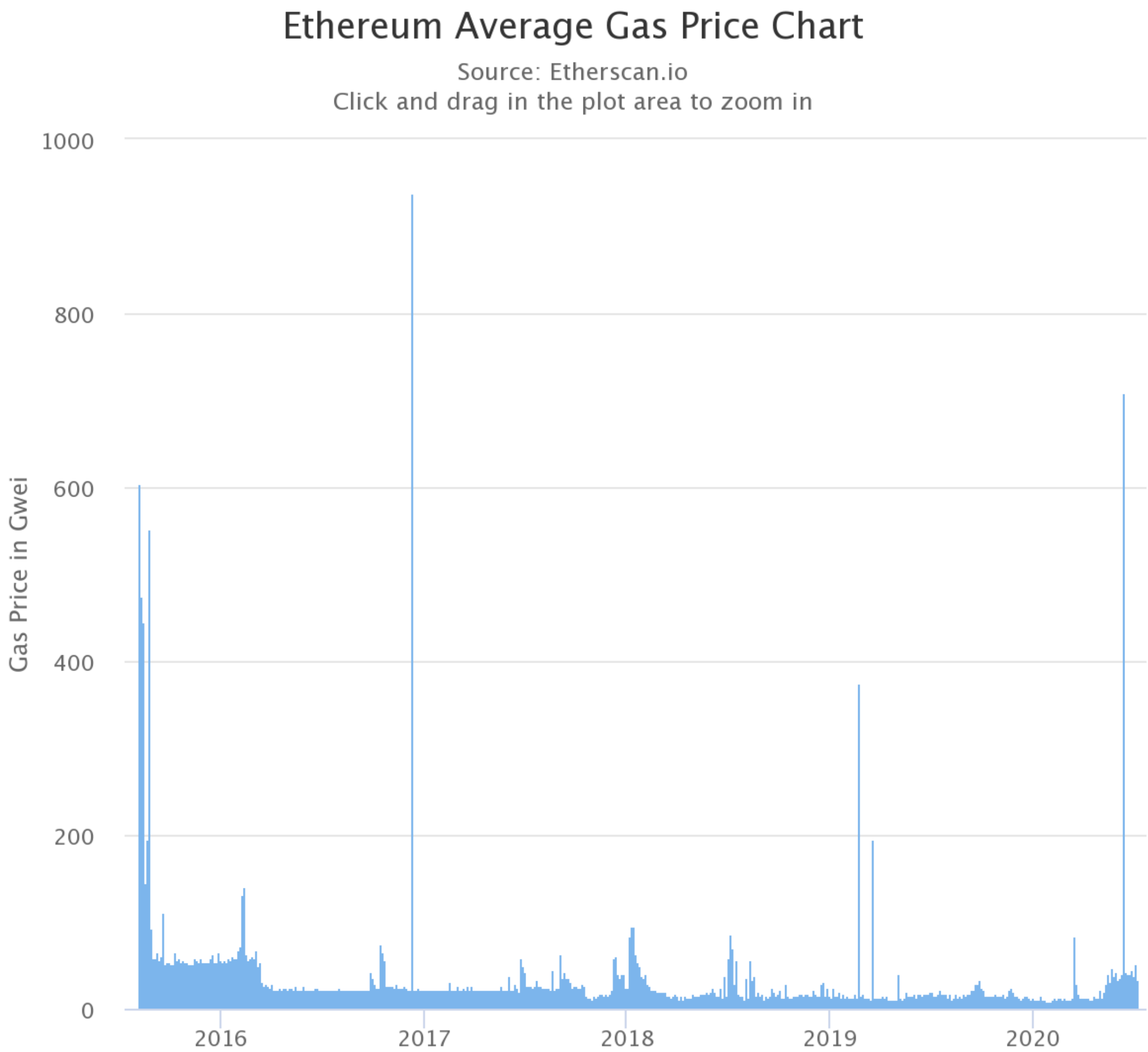
Gas Price

The gas price offered determines how quickly the network processes the contract.
It is up to the miner to accept an offer.
Some websites offer predictions:

Predictions for Gas Used = 21000	Gas Price 32 Gwei	Gas Price 66 Gwei
% of last 200 blocks accepting this gas price	48.1481481481	100
Transactions At or Above in Current Txpool	109	11
Mean Time to Confirm (Blocks)	41	2
Mean Time to Confirm (Seconds)	555	27
Transaction fee (ETH)	0.000672	0.001386
Transaction fee (Fiat)	$0.15926	$0.32848

https://ethgasstation.info/calculatorTxV.php

Ethereum Average Gas Price Chart



https://etherscan.io/chart/gasprice

Ethereum Virtual Machine (EVM)

- Execution platform of Ethereum smart contracts
- Stack-based (like BTC), but Turing-complete
- EVM bytecode: Special instructions for dealing with blockchain requirements (e.g., hashing, signing)
- State space components: account state, world state, storage state, block information, runtime environment information

EVM state space

Accounts

1. Externally owned accounts, controlled by private key
2. Contract accounts, associated with contract code

- Messages between external accounts: transfer of value
- Messages from external account $\rightarrow$ contract: invoke the contract's code

Components of account state

- Nonce
- Balance (in Wei)
- CodeHash

EVM state space (II)

World State

- mapping between 160-bit address $\rightarrow$ account state
- maintained in Modified Merkle Patricia Trie (a mix of a Merkle tree and a prefix tree)

Storage State

- account specific information at run time
- e.g., the runtime stack

EVM state space (III)

Block information — to support a transaction

- Blockhash – The hash of the most recently completed block
- Coinbase – The address of the recipient
- Timestamp – The current block's timestamp
- Number – The number of the current block
- Difficulty – The difficulty of the current block
- Gaslimit – The gas limit that is attached to the current block

Runtime Environment Information

- Gas price – Current gas price as specified by the initiator of the transaction
- Codesize – The size of the transaction codebase
- Caller – The address of the account that is executing the transaction
- Origin – The address of the transaction's original sender

High-Level Contract Languages

Several contract languages compile to EVM byte code

- Solidity (most common, some resemblance to JavaScript),
- Serpent (deprecated),
- LLL (low-level Lisp-like language),
- Vyper (derived from Python).

Solidity in a Nutshell

- Object-oriented, high-level language for implementing smart contracts.
- Design influenced by C++, Python and JavaScript
- Statically typed, supports inheritance, libraries and complex user-defined types.
- Compiles to EVM.

Example

```
pragma solidity >=0.4.0 <0.6.0;

contract SimpleStorage {
    uint storedData;

    function set(uint x) public {
        storedData = x;
    }

    function get() public view returns (uint) {
        return storedData;
    }
}
```

- keeps a single unsigned integer of persistent data
- get and **set** methods to retrieve and modify
- callable by anyone with the contract's address

Example Overlay Currency

```
contract Coin {
    address public minter;
    mapping (address => uint) public balances;

    event Sent(address from, address to, uint amount);

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

    function mint(address receiver, uint amount) public {
        require(msg.sender == minter);
        require(amount < 1e60);
        balances[receiver] += amount;
    }

    function send(address receiver, uint amount) public {
        require(amount <= balances[msg.sender], "Insufficient balance.");
        balances[msg.sender] -= amount;
        balances[receiver] += amount;
        emit Sent(msg.sender, receiver, amount);
} }
```

Example Overlay Currency (II)

- address data type: 160 bit addresses, no arithmetic
- public instructs the compiler to generate an access method (like a getter) for a state variable
- mapping (address => uint)public balances;
  another public state variable, initialized to all zero, lookup only—no iterator!
- event
  can be emitted from the contract
  UIs can listen to events without much cost
- the constructor remembers the creator of the contract msg.sender
- mint
  only the creator can mint, the amount should not be ridiculous, minting is on behalf of a single receiver
- send
  callable by anyone, provided sufficient funds available

Smart Contracts Benefits

- Transparency
- Automated
- Accuracy
- Security
- Speed
- Efficiency
- Trust
- Clear Communication
- Storage & Backup.
- Paper Free
- ...

Challenges of Smart Contracts

- privacy and security: no effective way to guarantee the security of smart contract code
- performance: gas and store limits, resource-constrained running environment, limited online resources
- programming languages and tools: basic, limitations

Smart Contract Applications

- Financial Services & Insurance
- Supply chain management
- Mortgage transactions
- Automated payments
- Real Estate
- Engagement contracts
- Transport & Logistics
- Supply Chain Transparency
- Medical Research
- Creating Smart Contracts
- ...

Smart Contract Platforms

- Ethereum
- EOS
- Tezos
- Cardano
- Stellar
- NEO
- ...