# RareSkills - Advanced Solidity

Meek Msaki (Meek#6464)

May 2023

Advanced solidity bootcamp with Dominik Teiml. Summary of the ethereum yellow paper.

# 1 Chapter 1

# 2 Chapter 2

# 3 Chapter 3

- $\boldsymbol{\sigma}$ - (sigma) World state
- $\boldsymbol{\mu}$ - (mu) Machine state
- $\boldsymbol{\Upsilon}$ - (upsilon) Ethereum state transition
- $C$ - General cost function
- $KEC$ - Keccak-256 hash function
- $KEC512$ - Keccak512 hash function
- $T$ - Ethereum transaction
- $\delta$ - (delta) the number of items required on a stack for a given operation
- $\mathbf{o}$ - the output data of a message call
- $\mathbb{N}$ - a set of scalar non-negative numbers e.g. set of integers smaller than $2^{256}$ denoted by $\mathbb{N}_{256}$
- $\mathbb{B}$ - a set of byte sequences, e.g. bytes 32 is denoted by $\mathbb{B}_{32}$
- $f$ - a function
- $\ell$ - a function which evaluates the last item in the given sequence

# 4 Chapter 4

## 4.1 The World State

- $\boldsymbol{\sigma}$ - represents world state or state. It is a mapping between addresses (160-bit) and account states, a data structure serialised as Recursive Length Prefix (RLP)
  - $\boldsymbol{\sigma}[a]$ = **Account state** - The state of ethereum accounts has four fields
    - $\boldsymbol{\sigma}[a]_n$ = account's **nounce state**
    - $\boldsymbol{\sigma}[a]_b$ = account's **balance state**
    - $\boldsymbol{\sigma}[a]_s$ = 256-bit hash **storageRoot** of merkle patricia trie root node that encodes storage contents (a mapping between 256-bit integer values)
      - For Eternally Owned Accounts, $\boldsymbol{\sigma}[a]_s = \varnothing$
      - For Contract accounts $\boldsymbol{\sigma}[a]_s \neq \varnothing$

      - It's not hash of the merkle trie root but for the key/value pairs stored within $\boldsymbol{\sigma}[a]_s \equiv TRIE(L_I^*((\boldsymbol{\sigma}[a]_s))$
    * $\boldsymbol{\sigma}[a]_c$ = **codeHash** - Keccak 256-bit hash of contract bytecode that gets executed when the account receives a message call
      - For Eternally Owned Accounts, $\boldsymbol{\sigma}[a]_c = \varnothing$
      - For contract accounts $\boldsymbol{\sigma}[a]_c \neq \varnothing$
        - $KEC(\mathbf{b}) = \boldsymbol{\sigma}[a]_c$, $\mathbf{b}$ to denote the contract's EVM bytecode
  - An account is *empty* if it has no code $\boldsymbol{\sigma}[a]_c = \varnothing$, zero nonce $\boldsymbol{\sigma}[a]_n = 0$ and zero balance $\boldsymbol{\sigma}[a]_b = 0$
    * $EMPTY(\boldsymbol{\sigma}, a) \equiv \boldsymbol{\sigma}[a]_c = KEC(()) \wedge \boldsymbol{\sigma}[a]_n = 0 \wedge \boldsymbol{\sigma}[a]_b = 0$
  - An account is *dead* if its account state is non-existent or empty
    * $DEAD(\boldsymbol{\sigma}, a) \equiv \boldsymbol{\sigma}[a] = \varnothing \vee EMPTY(\boldsymbol{\sigma}, a)$

## 4.2 The Transaction

- $T$ - a single cryptographically sigend instruction by an EOA.
- $S$ - maps transaction to the sender with ECDSA SECP-256k1 curve (hash of the transaction excepting three signature fields).
- Assert the sender of a transaction $T$ represents $S(T)$
- $L_T(T) \equiv \begin{cases} (T_n, T_p, T_g, T_t, T_v, T_i, T_w, T_r, T_s) \text{ if } T_t = \varnothing \\ (T_n, T_p, T_g, T_t, T_v, T_d, T_w, T_r, T_s) \textit{ otherwise} \end{cases}$ - Specifies how to serialize a transaction

  The sender of a transaction cannot be a contract

  There are two subtype of transactions

  - Those that result in message calls
  - Those that result in creation of new accounts with associated code ('contract creation')

  EIP-1559: Fee market change (type 2) transactions have:

  - $T_n$ - Transaction nounce for the sender, $T_n \in \mathbb{N}_{256}$
  - $T_g$ - Gas Price, $T_p \in \mathbb{N}_{256}$
  - $T_g$ - Gas Limit, $T_g \in \mathbb{N}_{256}$
  - $T_t$ - To (160-bit address), $T_t \in \begin{cases} \mathbb{B}_{20} \text{ if } T_t \neq \varnothing \\ \mathbb{B}_0 \text{ contract creation} \end{cases}$
  - $T_i$ - EVM-code for account initialization, $T_i \in \mathbb{B}$
  - $T_r, T_s$ - Signature of the transaction used to determine the sender of the transaction
  - $T_w$ - **ChainId** and **yParity** are combined to form single value $T_w = 2\beta + 35 + T_y$ (see EIP-155 by Buterin [2016b]), $T_w \in \mathbb{N}_{256}$
  - $T_x$ - EIP-2718 transaction type, $T_x \in \{1, 2\}$
  - $T_p$ - Gas Price, $T_p \in \mathbb{N}_{256}$
  - $T_g$ - Gas Limit, $T_g \in \mathbb{N}_{256}$
  - $T_v$ - Value, $T_v \in \mathbb{N}_{256}$
  - $T_r, T_s$ - Signature of the transaction used to determine the sender of the transaction, $T_r \in \mathbb{N}_{256}$, $T_s \in \mathbb{N}_{256}$
  - $T_{\boldsymbol{A}}$ - Access list (Legacy transactions don't have access list)
  - $T_c$ - Chain ID, $T_c = \beta$
  - $T_y$ - yParity signature, $T_y \in \mathbb{N}_1$ (bool)
  - $T_i$ - init is an unlimited size byte array specifying the EVM-code for contract initialization procedure, it is fragment that returns a **body**, $T_i \in \mathbb{B}$
  - $T_d$ - data byte array specifying input data of a message call, $T_d \in \mathbb{B}$

  EIP-2930 (type 1) transactions also have:

  - $T_{\boldsymbol{A}}$ - Access list (Legacy transactions don't have access list)
  - $T_c$ - Chain ID must equal chain ID $\beta$, $T_c = \beta$
  - $T_y$ - yParity signature

## 4.3 The Block

The Block, $B \equiv (B_H, B_T, B_U)$, is a collection of the following relevant pieces of information:

1. **T** - information corresponding to <u>transactions</u>
   - $B_T$ - A series of transactions from this block
2. **U** - A set of block headers, ($ommers^2$) or <u>uncles</u>
   - $B_U$ - A list of ommer block headers
3. $H$ - represents block <u>*header*</u>, which contains: $\mathbb{B} = \{B : B \in \mathbb{B} \vee \|B\| = n\}$
   (a) $H_p$ - **parentHash** - keccak256-bit hash of the parent's block header
   - $H_p \in \mathbb{B}_{32}$
   - $H_p \equiv KEC(P(B_H))$ where $P(B_H)$ is the parent block header of $B$
   - $TRIE(L_s(\sigma)) = P(B_H)_{H_r}$

   (b) $H_o$ - **ommersHash** - keccak256-bit hash of the ommers list of this block
   - $H_o \in \mathbb{B}_{32}$
   - $H_o \equiv KEC(RLP(L_H^*(B_U)))$

   (c) $H_c$ - **beneficiary** - 160-bit address that receives of all fees collected from successful mining this block
   - $H_c \in \mathbb{B}_{20}$

   (d) $H_r$ - **stateRoot** - keccak256 hash of the root node of the state trie after all transaction are executed on this block, $H_r \equiv KEC(TRIE(L_s(\Pi(\sigma, B))))$
   - $H_r \in \mathbb{B}_{32}$
   - $\Pi$ - transaction state's accummulation function

   (e) $H_t$ - **transactionRoot** - keccak26-Bit hash of trie's root node with this block's transactions
   - $H_t \in \mathbb{B}_{32}$
   - $H_t \equiv KEC(TRIE(\{\forall i < \|B_{\mathbf{T}}\|, i \in \mathbb{N} : p_T(i, B_{\mathbf{T}}[i])\}))$

   (f) $H_e$ - **receiptsRoot** - keccak256-bit hash of the trie's root node containing receipt's of each transaction from this block, $H_e \equiv KEC(TRIE(\{\forall i < \|B_R\|, i \in \mathbb{N} : p_R(i, B_R[i])\}))$
   - $H_e \in \mathbb{B}_{32}$
   - $B_R$ - values steming from the computation of transactions, specificaly transaction receipts

   (g) $H_b$ - **logsBloom** - Bloom filter from indexable info (logger addres and log topics) contained in each log entry from the receipt of each transaction in this block
   - $H_b \in \mathbb{B}_{256}$

   (h) $H_d$ - **difficulty** - a scalar value of the difficulty level of this block
   - $H_d \in \mathbb{N}$

   (i) $H_i$ - **number** - a scalar value equal to the number of ancestor blocks
   - $H_i \in \mathbb{N}$

   (j) $H_l$ - **gasLimit** - a scalar value equal to the current limit of gas expenditure per block
   - $H_l \in \mathbb{N}$

   (k) $H_g$ - **gasUsed** - a scalar value equal to the total gas used in transactions in this block
   - $H_g \in \mathbb{N}$

   (l) $H_s$ - **timestamp** - a scalar value equal to the output of Unix's time() at the block's inception
   - $H_s \in \mathbb{N}_{256}$

   (m) $H_x$ - **extraData** - arbitrary byte array data relevant to this block, must be 32 bytes or less
   - $H_x \in \mathbb{B}$

   (n) $H_m$ - **mixHash** - 256-bit hash which combined with nonce, proves a sufficient amount of computation has been carried out in this block
   - $H_m \in \mathbb{B}_{32}$

   (o) $H_n$ - **nonce** - 64-but value which combined with mix-hash proves sufficient computation has been carried out
   - $H_n \in \mathbb{B}_8$

### 4.3.1 Transaction Receipt

- $B_R[i]$ - receipt for the $i^{th}$ transaction in an index-keyed trie who's root is recorded in the header as $H_e$
- $R \equiv (R_x, R_z, R_u, R_b, R_l)$
- $L_R(R) \equiv (R_z, R_u, R_b, R_l)$ - the $L_R$ function prepares tx receipt to be transformed into an RLP-serialized bytes array

- $R$ - Transaction receipt (a tuple of 5 items):
  1. $R_x$ - equal to the corresponding transaction type
  2. $R_z$ - status code of the transaction, $R_z \in \mathbb{N}$ (non-negative integer)
  3. $R_u$ - cumulative gas used, $R_u \in \mathbb{N}$ (non-negative integer)
  4. $R_l$ - a series of logs entries $(O_0, O_1, ...)$ created through execution of the transaction:
     (a) A log entry, $O$, is a tuple of: $O \equiv (O_a, (O_{t0}, O_{t1}, ...), O_d)$
        i. $O_a$ - logger's address, $O_a \in \mathbb{B}_{20}$
        ii. $O_t$ - series of 32-byte log topics, $\forall x \in O_t : x \in \mathbb{B}_{32}$
        iii. $O_d$ - some number of bytes data, $O_d \in \mathbb{B}$
  5. $R_b$ - the Bloom filter composed from the information in the logs, $R_b \in \mathbb{B}_{256}$
     (a) $M$ - a function (bloom filter) to reduce a log entry into a single 256-byte hash:
        i. $M(O) \equiv \bigvee_{x \in O_a \cup O_t} (M_{3:2048}(x))$
           A. $M_{3:2048}$ - a specialized Bloom filter that sets three bits out of 2048, given an arbitrary byte sequence
           B. $M_{3:2048}$ - takes the low-order 11 bits of each of the first 3 pairs of bytes in a keccak-256 hash of the byte sequence
           C. $M_{3:2048}(\mathbf{x} : \mathbf{x} \in \mathbb{B}) \equiv \mathbf{y} : \mathbf{y} \in \mathbb{B}_{256}$ where:
              - $\mathbf{y} = (0, 0, 0, ..., 0)$ except:
              - $\forall i \in \{0, 2, 4\} : B_{2047-m(\mathbf{x},i)}(\mathbf{y}) = 1$
              - $B$ - a bit reference function
           D. $m(\mathbf{x}, i) \equiv KEC(\mathbf{x})[i, i+1] \mod 2048$

### 4.3.2 Holistic Validity

- identity of state when transactions executed in order on the base state
  - $H_r \equiv TRIE(L_s(\Pi(\sigma, B))) \land$
  - $H_o \equiv KEC(RLP(L_H^*(B_U))) \land$
  - $H_t \equiv TRIE(\{\forall i < \|B_{\mathbf{T}}\|, i \in \mathbb{N} : p_T(i, B_{\mathbf{T}}[i])\}) \land$
  - $H_e \equiv TRIE(\{\forall i < \|B_R\|, i \in \mathbb{N} : p_R(i, B_R[i])\}) \land$
  - $\bigvee_{r \in B_R} (\mathbf{r}_b)$

**(TODO: to be continued... pg 6/41)**

### 4.3.3 Serialization

- $L_H(H)$ - preparation function for block header
  - $L_H(H) \equiv (H_p, H_o, H_r, H_t, H_e, H_b, H_d, H_i, H_l, H_g, H_s, H_x, H_m, H_n)$
- $L_B(B)$ - preparation function for block
  - $L_B(B) \equiv (L_H(B_H), \tilde{L}_T^*(B_H), L_H^*(B_U))$
  - $\tilde{L}_T$ - takes special care of EIP-2718 transactions

#### 4.3.4 Block Header Validity

- $P(H) \equiv B' : KEC(RPL(B'_H)) = H_p$
- $H_i \equiv P(H)_{Hi} + 1$ - the block number is the parent's block number uncremented by one
- $D(H)$ - canonical difficulty fo a block header $H$
- $\varsigma_2$ - $Homestead$ diffuculty parameter
- $\epsilon$ - exponetial difficulty symbol

# 5 Chapter 5

# 6 Chapter 6 (Transaction Execution)

- $\Upsilon$ - state transition function
- $\boldsymbol{\sigma}'$ - the post-transactional state
- $\boldsymbol{\sigma}' = \Upsilon(\sigma, T)$ - $\Upsilon$ is the function, $T$ is the transaction and $\sigma$ the state
- $\Upsilon^g$ - evaluates amount of gas used in the transaction
- $\Upsilon^l$ - evaluates transaction's accrued log items
- $\Upsilon^z$ - evaluates the status code resulting from the transaction

## 6.1 Substate

*Accrued substate* ($A$) is the information that is acted upon immediately following the transaction execution

- $A \equiv (A_s, A_l, A_t, A_r, A_a, A_K)$
- $A_s$ - the self destruct set, a set of accounts that will be discarded following transaction completion
- $A_l$ - log series of archived and indexable 'checkpoints' in VM code execution
- $A_t$ - set of touched accounts, which the empty ones are deleted at the end of transaction
- $A_r$ - the refund balance, from SSTORE instruction when contract storage is reset to zero from non-zero
- $A_a$ - the set of accessed account addresses
- $A_K$ - a tuple of a 20-byte account address and a 32-byte storage slot (a set of storage keys)
- $A^0$ - an empty accrued substate
- $A^0 \equiv (\varnothing, (), \varnothing, 0, \pi, \varnothing)$, where: $\pi$ is a set of precompiled addresses
- $\pi$ - a set of all precompiled addresses

## 6.2 Execution

- $g_0$ - amount of gas this transaction requires to be paid prior to execution, intrinsic gas $g_0$

$$g_0 \equiv \sum_{i \in T_i, T_d} \begin{cases} G_{txdatazero} \text{ if } i = 0 \\ G_{txdatanonzero} \text{ otherwise} \end{cases} + \begin{cases} G_{txzero} \text{ if } T_t = \varnothing \\ 0 \text{ otherwise} \end{cases}$$

$$+G_{transaction} + \sum_{j=0}^{\|T_A\|-1} (G_{accesslistaddress} + \|T_A[j]_s\| G_{accessliststorage})$$

- $T_i, T_d$ is the series of bytes of the transaction's associated data and initialisation EVM-code

- $G_{txcreate}$ is added if the transaction is creating a contract, but not if a result of EVM-code
- $G_{accesslistaddress}$ and $G_{accessliststorage}$ are the cost of warming up account and storage access
- $G$ (defined in appendix G) - is a tuple of scalar values corresponding to relative costs in gas of operations
- $v_0$ - upfront cost is $v_0 \equiv T_g T_p + T_v$
- $S(T)$ - the sender of a transaction
- Validity of transaction is determine $S(T) \neq \varnothing \wedge \sigma[S(T)]_c = KEC(()) \wedge T_n = \sigma[S(T)]_n \wedge g_0 \leq T_g \wedge V_0 \leq \sigma[S(T)]_b \wedge T_g \leq B_{HI} - \ell(B_R)_u$
- $T_g - g_0$
- Before table

| Name | Value | Description |
|---|---|---|
| $G_{zero}$ | 0 | 0 gas operations of the set $W_{zero}$ = {STOP, RETURN, REVERT} |
| $G_{jumpdest}$ | 1 | gas paid for JUMPDEST operation |
| $G_{base}$ | 2 | gas paid for operations of set $W_{base}$ = {ADDRESS, ORIGIN, CALLER, CALLVALUE, CALLDATASIZE, CODESIZE, COINBASE, TIMESTAMP, NUMBER, DIFFICULTY, GASLIMIT, CAHINID, RETURNDATASIZE, POP, POP, MSIZE, Gas} |
| $G_{verylow}$ | 3 | gas paid for operations of set $W_{verylow}$ = {ADD, SUB, NOT, LT, GT, SLT, SGT, EQ, ISZERO, AND, OR, XOR, BYTE, SHL, SHR, SAR, CALLDATALOAD, MLOAD, MSTORE, MSTORE8, PUSH*, DUP*, SWAP*} |
| $G_{low}$ | 5 | gas paid for operations of set $W_{low}$ = {MUL, DIV, SDIV, MOD, SMOD, SIGNEXTEND, SELFBALANCE} |
| $G_{mid}$ | 8 | gas paid for operations of set $W_{mid}$ = {ADDMOD, MULMOD, JUMP} |
| $G_{high}$ | 10 | gas paid for operations of set $W_{high}$ = {JUMPI} |
| $G_{warmaccess}$ | 100 | cost for a warm account or storage |
| $G_{accesslistaddress}$ | 2400 | cost for warming up an account with the acess list |
| $G_{accessliststorage}$ | 1900 | cost for warming up a storage with the access list |
| $G_{coldaccountaccess}$ | 2600 | cost for a cold account access |
| $G_{coldload}$ | 2100 | cost for a cold account access |
| $G_{sset}$ | 20000 | cost for an SSTORE operation from non-zero to zero |
| $G_{sreset}$ | 2900 | cost for an SSTORE operation from zero to zero (unchanged) |
| $R_{sclear}$ | 15000 | refund when SSTORE operation on a storage is set from non-zero to zero |
| $R_{selfdestruct}$ | 24000 | refund for self-destructing and account |
| $G_{selfdescturct}$ | 5000 | gas paid for a SELFDESTRUCT operation |
| $G_{create}$ | 32000 | gas paid for a CREATE operation |
| $G_{codedeposit}$ | 200 | cost paid per byte for a CREATE operation to success in placing code to state |
| $G_{callvalue}$ | 9000 | gas paid for a non-zero value transfer as part of the CALL operation |
| $G_{callstipend}$ | 2300 | a stipend for the called contract subtracted from the $G_{callvalue}$ for a non-zero value |
| $G_{newaccount}$ | 25000 | gas paid for a CALL or SELFDESTRUCT operations which creates a new account |
| $G_{exp}$ | 10 | partial payment for an EXP operations |
| $G_{expbye}$ | 50 | partial payment when multiplied by the number of bytes in the exponent for EXP operation |
| $G_{memory}$ | 3 | gas paid for every additional word when expanding memory |
| $G_{txcreate}$ | 32000 | gas paid by all contract-creating transactions after *Honstead* transition |
| $G_{txdatazero}$ | 4 | gas paid for every zero bytes of data or code for a transaction |
| $G_{txdatanonzero}$ | 16 | gas paid for every non-zero bytes of data or code for a transaction |
| $G_{transaction}$ | 21000 | gas paid for every transaction |
| $G_{log}$ | 375 | partial payment for a LOG operation |
| $G_{logdata}$ | 8 | gas paid for each bytes in a LOG operation's data |
| $G_{logtopic}$ | 375 | gas paid for each topic of a LOF operation |
| $G_{keccak256}$ | 30 | gas paid for each KECCAK256 operation |
| $G_{keccak256word}$ | 60 | gas paid for each word (rounded up) for input data to a KECCAK256 operation |
| $G_{copy}$ | 3 | partial payment for set $W_{copy}$ = {CALLDATACOPY, CODECOPY, RETURNDATACOPY} operations, multiplied by words copied, rounded up |
| $G_{blockhash}$ | 20 | gas pid for each BLOCKHASH operation |

– After table