# Neon EVM

Ethereum Smart Contracts Scaled by Solana
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**Neon EVM** is an Ethereum virtual machine on Solana that enables dApp developers to use Ethereum tooling to scale and get access to liquidity on Solana.

## Abstract

Ethereum remains the dominant blockchain protocol linked to smart contract trading and settlement. Its infrastructure for dApp developers and end-users is the most advanced.

This paper introduces Neon EVM: a tool that allows for Ethereum-like transactions to be processed on Solana, taking full advantage of the functionality native to Solana, including parallel execution of transactions. As such, Neon EVM allows dApps to operate with the low gas fees, high transaction speed, and high throughput of Solana, as well as offering access to the growing Solana market.

The Ethereum state is represented by Merkle-Patricia Trie that stores key-value data for all smart contracts, and smart contracts written in Solidity do not have separate references to shared data and contracts' code. Therefore, these smart contracts have to be executed in sequence to ensure deterministic behavior. This limits a throughput: highly optimized blockchains with EVM are capable of processing up to a maximum of 1,500 TPS.

However, Solana is designed to support massive scaling of decentralized applications, with a maximum throughput of more than 50,000 TPS. To take full advantage of Solana's functionality, Neon EVM is built as a smart contract of Solana. This also ensures flexibility in terms of updates: Neon EVM can be updated easily when new Ethereum functionality appears.

In the case of Neon EVM, an intermediary proxy server that can be run by anybody wraps up Ethereum-like transactions into Solana transactions and sends them to Neon EVM that executes them in parallel. To ensure the parallel execution of smart contracts, Neon EVM implements several strategies. In particular, each contract keeps its data in its own Solana storage and account balances used to pay for Neon transactions are also separated.

The solution allows any Ethereum application to be run on Solana without any changes to its codebase, including UniSwap, SushiSwap, 0x, and MakerDAO. All key tools for Ethereum dApps can work on Solana, including Solidity, Metamask, Remix, Truffle, and others.

Neon EVM is best suited to developers that want to enjoy a first-mover advantage and reach new customers on Solana, or those who want to scale with the low gas fees and high throughput that Solana provides. It is also good for those developers who are looking to tap into liquidity on Solana.

# Introduction

Ethereum is set to remain among the booming blockchain ecosystems. The number of active dApps on Ethereum is hovering above 300 and the number of active users of these dApps is close to 6 million, with the number of transactions on the rise. Ethereum's popularity is not only down to its processing of smart contracts, but also thanks to its sophisticated infrastructure for application development.

Solana is one of the most technically advanced blockchains, offering low gas fees and high throughput of transactions due to its technological innovations. Among these innovations is its Proof-of-Stake consensus system that is reinforced via a Proof-of-History protocol, a transaction parallelization technology that optimizes resources and ensures that Solana can scale horizontally across GPUs and SSDs, along with an optimized mempool system that speeds up throughput.

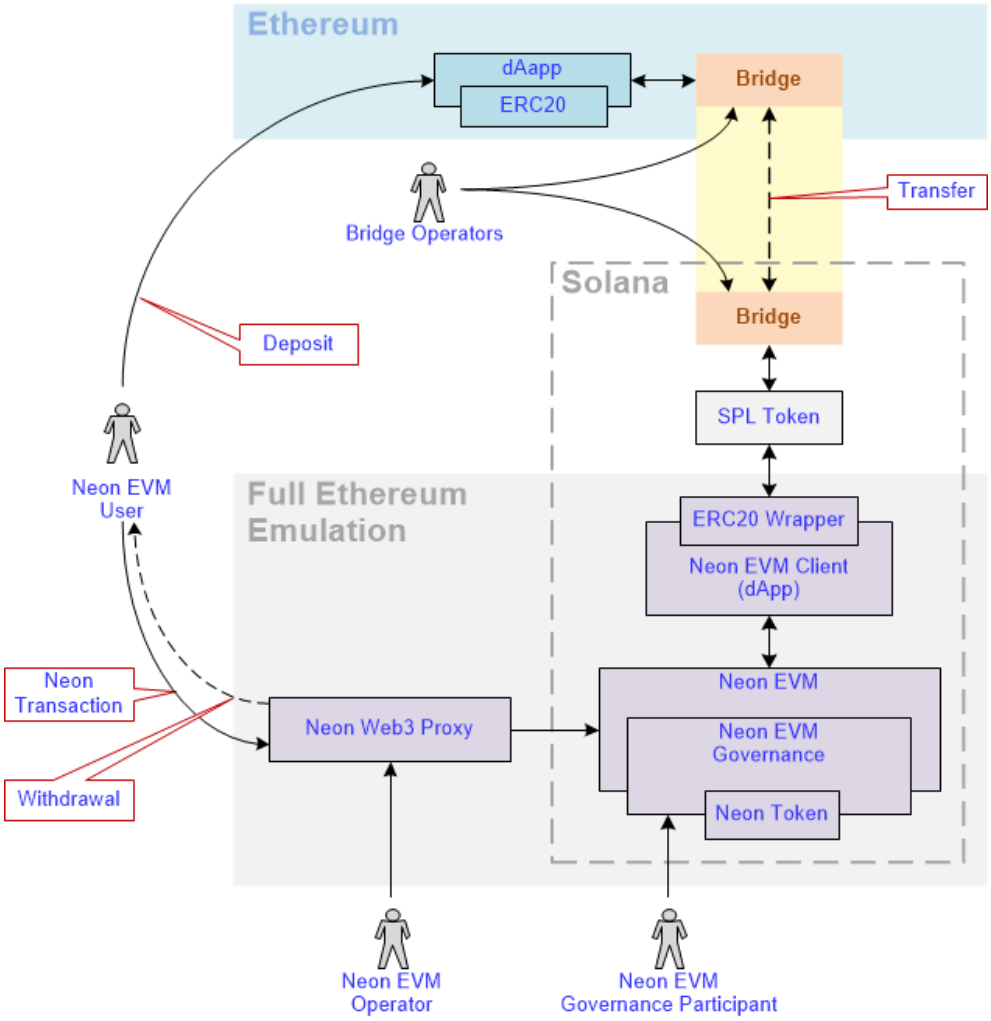
Neon EVM is a cross-chain solution that allows dApp developers to access the advantages of Solana and thus expand their services: to offer new products like arbitrage or high-frequency trading, grow their user base, and decrease costs where possible, including gas fees. It enables full compatibility with Ethereum on Solana.

# Neon EVM Fundamentals

Solana blockchain has its own Berkeley Packet Filter virtual machine (BPF virtual machine). This virtual machine is used in the Linux kernel and has already been tested through time. BPF bytecode was originally designed for fast execution. Solana supports just-in-time compilation for BPF bytecode, which significantly increases the speed of execution of BPF contracts. Neon EVM is written in Rust and compiled to BPF bytecode. This allows us to take full advantage of Solana functionality, including parallel execution of transactions. It also makes it easy to update Neon EVM regardless of Solana's hard forks.

Let's take a deeper look at the technical solution that Neon EVM offers.

# Neon EMV Architecture




Technical definitions:

- **Neon EVM** is an Ethereum Virtual Machine compiled into Berkeley Packet Filter bytecode of a virtual machine running on Solana.
- **Neon EVM user** is any user who has an account in Neon EVM with a balance in ETH, ERC20, and ERC721 tokens.
- **Neon EVM client** is any application that has an EVM (Solidity/Vyper/etc.) bytecode contract loaded into the Neon EVM on Solana.
- **Neon EVM operator** is any Solana account that pays for the execution of a Neon transaction in SOL tokens and receives payment for this work from the Neon EVM user in an arbitrary token specified by the user.

- **Neon EVM governance** is a decentralized Neon EVM governance that manages Neon EVM work by setting up Neon EVM parameters and updating Neon EVM software; it gets fees for its services.
- **Neon Web3 Proxy** is a tool that can be used by a Neon EVM operator to package a Neon transaction into a Solana transaction.
- **Neon Transaction** is a transaction formed according to Ethereum rules with a signature produced by Ethereum rules.
- **Bridge** is an EVM third-party (independent from Neon) solution with its own operators.

Neon EVM has the following functions:

- Uploading EVM contracts (built by Solidity/Vyper compilers) to individual Solana accounts.
- Checking signatures according to Ethereum rules on Solana.
- Executing Neon transactions, including, if necessary, in an iterative manner taking into account Solana resource constraints with the financial guarantees for completion of transactions.
- Calculating gas consumption according to Ethereum rules.
- Receiving a payment from the user to Neon EVM operator for the gas consumed and fees in any ETH or any ERC-20 token specified by the user.
- Calculating and withdrawing fees in SOL tokens to the governance pool of Neon EVM from the Neon EVM operator account for execution of Neon transactions.
- Storing EVM data of contracts in the form of a hash table using the Hash Array Mapped Trie algorithm (HAMT).

# Neon Web3 Proxy

Neon Web3 Proxy is a service that provides a Web3 API to access the Solana blockchain. It is an intermediary for communication between Neon EVM clients and Neon EVM and it can be run by Neon EVM operators. Neon Web3 Proxy is optional for any Neon EVM client. Its main functionality is to help Neon EVM clients start using Neon EVM without any changes to their codebase.

## ERC20 SPL-Wrapper

For each Solana token, an ERC20 SPL-Wrapper contract can be deployed. The task of the ERC20 SPL-Wrapper is to ensure the interaction of the Solana applications with EVM (Solidity/Vyper/etc.) bytecode contracts. ERC20 SPL-Wrapper can be also used to transfer funds in Solana tokens using Ethereum wallets such as Metamask.

## ERC20 SPL-Bridge

This contract is for ERC20 contracts. When it’s called, it generates a Solana token which represents the corresponding ERC20 token in the SPL-token contract. The Solana tokens registered in the SPL-token contract can be transferred to Solana contracts.

# Independence of Operations Within Neon EVM

Neon EVM ensures the independence of its operations by providing open access to its infrastructure to anybody who is willing and capable of running Neon Web3 Proxy. Moreover, Neon Web 3 Proxy can be replaced with a client library by any Neon EVM client. The transactions received by Neon EVM cannot be discriminated against because they do not have any attributes that determine their priority. The unchangeable nonce and user signature fields verified by Neon EVM guarantee the consistency of execution of Neon transactions and protect from re-execution.

# Parallel Execution of Neon Transactions on Solana

Most blockchains process transactions in a single thread. It means that one contract at a time modifies the blockchain state. In contrast, Solana can process tens of thousands of contracts in parallel, using as many cores as are available to its validator. This functionality is known as Sealevel and it greatly increases the throughput.

Parallel processing is possible because Solana transactions describe all the states a transaction will read or write while executing. This prevents transactions from overlapping, allowing independent transactions and those that are reading the same state to be executed concurrently.

Neon transactions are executed by Solana as native transactions: in parallel while restricting access to shared data from Solana state. However, in some cases, a Neon transaction requires more resources than Solana allocates for one transaction. In this case, the Neon EVM executes the transaction iteratively, and the extended mode of restricting access to shared data in Solana state is used (for details, see the section on iterative execution of Neon transactions).

To ensure the parallel execution of Solana transactions, Solana requires a list of all Solana accounts involved in a transaction. If there is a call to a Solana account that is not specified in the header of the Solana transaction, the algorithm aborts the execution with an error.

Parallel execution of Neon transactions by Neon EVM is carried out in the following manner:

- Each EVM (Solidity/Vyper/etc.) bytecode contract executed on Solana has its independent state.
- Neon Web3 Proxy has a built-in EVM similar to Neon EVM.
- When Neon Web3 Proxy receives a Neon transaction:
    - It performs a test launch of the Neon transaction, calling the Solana node for the current state.
    - As a result of the test performed, Neon Web3 Proxy receives a complete list of contracts and accounts involved in the Neon transaction.
    - It forms a Solana transaction, using a list of Neon contracts and Neon accounts, inside which the Neon transaction is packaged.

- Solana receives all of the necessary information to execute Solidity contracts using its tools, including parallel execution.

# Acceleration Neon Transaction Execution

As noted above, Neon Web3 Proxy performs a test run to obtain a complete list of Neon accounts that are used for the execution of Neon transactions. A test run takes time, and this time could be critical when a transaction needs to be executed fast.
Any Neon transaction can be executed without a test run in the following manner:

- The Solana transaction is built on the client side (web/mobile) with a Neon transaction packaged within it. The Solana transaction is sent directly to a Solana node without Neon Web3 Proxy. It's important to understand that, using this method, it's up to the sender to make sure that:
    - In cases when the Neon transaction is too big, it has to be executed iteratively (see more in the section on iterative execution of Neon transactions below).
    - A list of all Neon accounts and contracts corresponding to the Neon transaction has to be determined on the client-side.
- Additional methods in the Neon Web3 Proxy with a transfer of the list of Neon accounts involved can be used. It's important to understand that — using this method — it's up to the sender to make sure that a list of all Neon accounts and contracts corresponding to the Neon transaction has to be determined on the client side.

# Iterative Execution of Neon Transactions

Solana blockchain limits the resources allocated to the execution of a single transaction to ensure optimal usage of hardware. To perform the best service possible (taking into account the existing restrictions of Solana), Neon EVM introduces iterative execution of Neon transactions.
The main steps of iterative execution are the following:

- Neon EVM transfers the deposit in SOL tokens from the operator's account to a separate account.
- The size of the deposit is determined by the Neon EVM settings set by Neon EVM governance. The deposit consists of:
    - A reward to Solana validators for executing Solana transactions.
    - A fee to the Neon EVM governance that goes to the governance pool.
    - A fee for iterative execution of the Neon transaction that is blocked.
- Neon EVM blocks Solana accounts used in Neon transactions.
- If any Solana accounts are already blocked by another Neon transaction, then the new transaction is queued for execution by Neon Web3 Proxy.

Neon EVM settings set by Neon EVM governance:

- *The maximum number of iterations per Neon transaction*. Solana currently charges a fee to verify the signatures specified in a Solana transaction. Thus, in a Solana transaction, only the Solana signature of the Neon EVM operator in charge of the transaction is

specified. All Neon signatures are verified by the Neon EVM during the execution of Neon transactions. The number of iterations per Neon transaction is unknown in advance. It is necessary to limit the execution time of a transaction because all accounts and contracts involved in this transaction will be blocked for use in other Neon transactions. Therefore, Neon EVM governance sets the maximum number of iterations and the maximum number of waiting blocks (Mn). The size of the deposit directly depends on the maximum number of iterations.

- *A fee to the Neon EVM governance pool* (see the section on Neon EVM economy and governance).
- *A deposit for the iterative execution of a Neon transaction*:
    - Depends on the number of accounts involved in the transaction, as this affects the parallel execution of transactions in Solana.
    - Is paid to the operator who performs the last step of the Neon transaction and finalizes it.
- *The maximum number of waiting blocks (Mn) is determined by Neon EVM governance.* The operator is given a maximum of blocks (Mn) between two iterations when it can perform the next iteration. After Mn blocks, any other operator can continue the execution and receive the deposit.

The formula for calculating the deposit:

- **Mn**: maximum number of waiting for blocks between two iterations for one operator, after which the transaction can be continued by another operator.
- **Mi**: maximum number of iterations per Neon transaction.
- **Li**: number of SOL to check one Solana signature.
- **Na**: number of accounts used in Solana transaction.
- **Fa**: deposit in SOL for the iterative execution to be paid to each Solana account that is specified in a transaction.
- **Fg**: fee in SOL to the Neon EVM governance pool.
- **Rs**: resulting deposit in SOL.

$$Rs = Mi * Li + Fa * Na + Fg$$

The main steps for iterative execution of a Neon transaction are the following:

- If it's not the first iteration, then:
    - If more than Mn blocks have passed, the execution is passed to another operator.
    - Restore the state of the Neon EVM.
- Complete the maximum EVM steps specified in the Solana transaction.
- If it's not the end of execution:
    - Record the operator which completed a step in iterative execution.
    - Increase the number of completed iterations.
    - Save the state of the Neon EVM to the state of Solana.

The conditions to end the iterative execution of a Neon transaction:

- The Neon transaction is completed.
- Mi iterations of Neon transactions have been reached.
- The Neon transaction was canceled; in this case, the unspent deposit is burned. Neon transactions can be canceled:
    - By any Neon EVM operator if Mn blocks have not passed from the last iteration.
    - Otherwise, by the Neon EVM operator from the last iterative execution.

At the end of the iterative execution of a Neon transaction:

- The result of the Neon transaction is saved into the Solana receipt.
- The Neon EVM operator is paid the remaining deposit.

The formula for calculating the remaining deposit:

- **Mi**: maximum number of iterations per Neon transaction.
- **Md**: the number of iterations used to execute a Neon transaction.
- **Li**: the number of SOL to check one Solana signature.
- **Na**: the number of accounts in the Solana transaction.
- **Fa**: the amount of the deposit in SOL for iterative execution for one account in the Solana transaction.
- **Rd**: the resulting remaining deposit in SOL.

$$Rd = (Mi - Md) * Li + Fa * Na$$

# Payment for Neon Transactions

The calculation of the cost of transaction execution in Neon EVM is carried out according to Ethereum rules. It uses a tool for gas calculation available on Ethereum.

The cost of gas in Neon EVM is significantly lower than on Ethereum as it is based on Solana's gas price. It is to be determined taking into consideration:

- The cost of executing a Solana transaction, which depends on the number of signatures specified in the transaction — as mentioned earlier, in Solana transactions only one signature (that of the Neon EVM operator) is specified because Neon signatures are verified in Neon EVM (see the above section on iterative execution of transactions).
- A fee to be paid to Neon EVM governance that keeps Neon EVM running.
- A fee to the Neon EVM operator that executes the transaction.

The payment means is to be determined by the Neon EVM user:

- By default, the Neon EVM user pays the Neon EVM operator in ETH tokens.
- However, Neon EVM provides users with an option to choose any other ERC20 token to pay for Neon transactions.
- The payment preferences are stored in the Solana state.

There is an independent market for Neon EVM operators, and a user can choose an operator with reasonable prices for transactions. Neon EVM clients can enforce their payment policies based on their demands. Any Neon EVM user can independently deploy Neon Web3 Proxy and execute a Neon transaction using Neon EVM without help from Neon EVM operators. In this case, the user has to cover the transaction execution on Solana with SOL tokens.

# Neon EVM Economy and Governance

The Neon EVM economy is fee-based. The NEON token is a governance token. At the launch, the governance is to be handled by a decentralized protocol with a clear and user-friendly process for proposing and voting for protocol improvements, and a multisig contract whose keys are held by reputable individuals and entities with a vested interest in the success of Neon EVM.

# Summary

Neon EVM is a viable solution for anyone who is looking to scale Ethereum dApps on Solana in a developer-friendly manner. To take full advantage of Solana's functionality, Neon EVM is built as a smart contract of Solana. This also ensures flexibility in terms of updates. Neon EVM has a high level of decentralization as it is governed with a help of a decentralized protocol and any user can set up Neon Web3 Proxy and receive payments for executing transactions via Neon EVM.

Neon EVM is a full Ethereum emulation with gas consumption calculated by Ethereum rules, iterative execution of large Ethereum EVM contracts, and full compatibility with all existing Ethereum tools. It enables parallel execution of EVM (Solidity/Vyper/etc.) bytecode contracts on Solana. It also provides access to Solana infrastructure via Ethereum tools and access to native Solana tokens, registered in the SPL-token contract through the ERC20 token interface, native to contracts and tools made for Ethereum. Users can pay for the services of Neon EVM in ETH or any ERC20 tokens.

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