Neon EVM

Ethereum Smart Contracts Scaled by Solana
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Neon EVM is an Ethereum virtual machine on Solana that allows 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, with the most advanced infrastructure for dApp developers and end-users.

This paper introduces Neon EVM, a tool that allows Ethereum-like transactions to be processed on Solana and takes 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 while offering access to the growing Solana market.

The Ethereum state is represented by a 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 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 anyone wraps Ethereum-like transactions into Solana transactions and sends them to Solana for parallel execution of the Neon EVM contract. To ensure the parallel execution of smart contracts, Neon EVM implements several strategies. For example, each contract keeps its data in its own Solana storage, and account balances used to pay for Neon transactions are also separated.

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

Neon EVM is best suited to developers who want to enjoy a first-mover advantage and reach new customers on Solana, or who want to scale with the low gas fees and high throughput that Solana provides. It is also good for 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 due not only to its processing of smart contracts, but also 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, and an optimized mempool system that speeds up throughput.

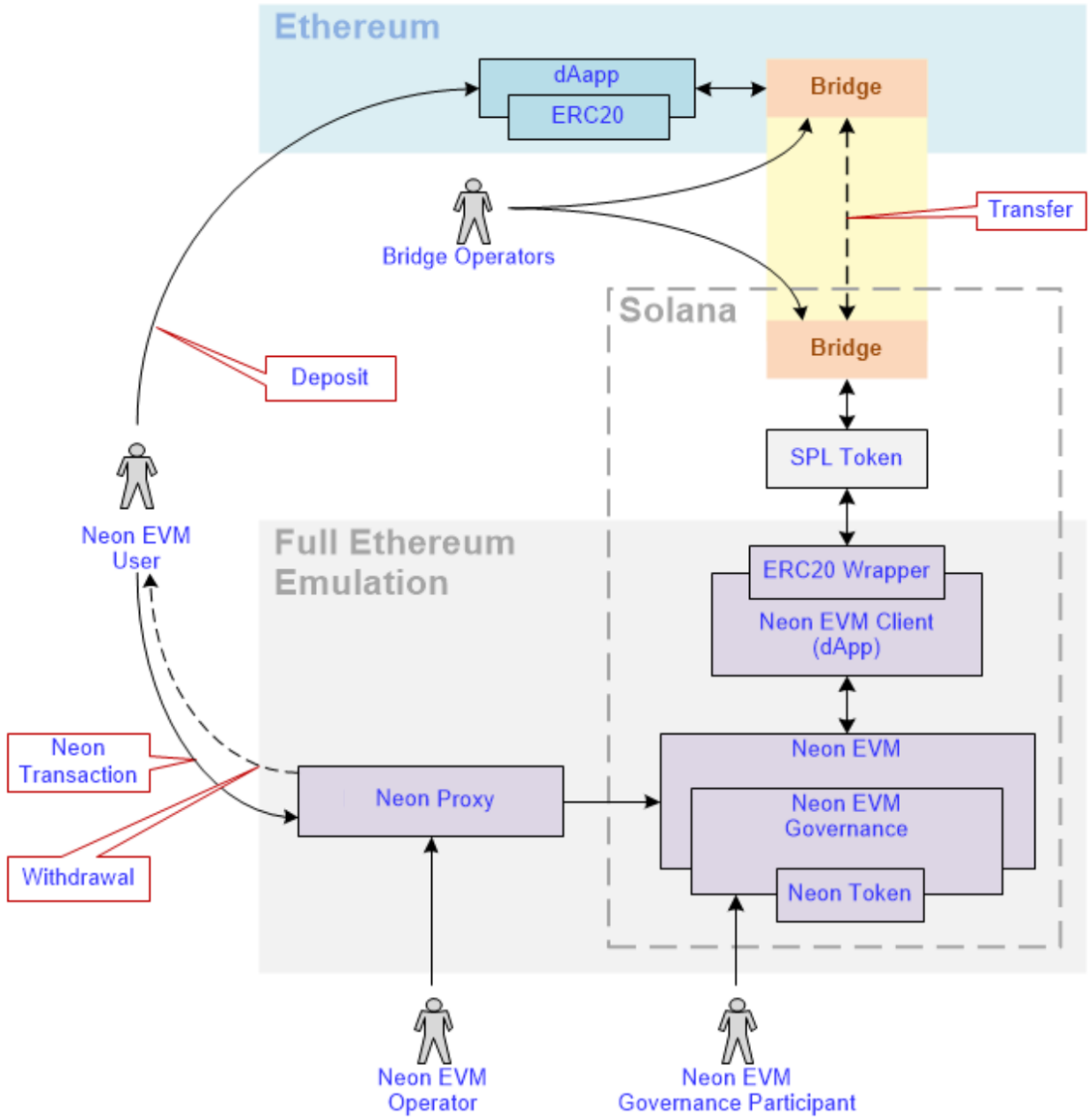
Neon EVM is an on-chain solution that allows dApp developers to access the advantages of Solana and expand their services, offer new products like arbitrage or high-frequency trading, grow their user base, and decrease costs where possible, including gas fees. Neon EVM enables full compatibility with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

Neon EVM Fundamentals

The Solana blockchain has its own Berkeley Packet Filter (BPF) virtual machine. This virtual machine is used in the Linux kernel and has already been tested. 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. The Neon EVM smart contract is written in Rust and compiled to BPF bytecode. This allows Neon EVM 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 EVM Architecture



Technical definitions:

- **Neon EVM** is an Ethereum Virtual Machine that represents a smart contract written in Rust and compiled into the 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 NEON, ERC-20, and ERC-721 tokens.

- **Neon EVM client** is any application that has an EVM (Solidity, Vyper, etc.) bytecode contract loaded into 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 NEON tokens.
- **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 receives fees for its services.
- **Neon 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 solution (independent from Neon) 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 based on LAMPORT transaction payments of Solana.
- Receiving a payment from the user to the Neon EVM operator for the gas consumed and fees in any NEON token.
- Calculating and withdrawing fees in SOL tokens to the governance pool of Neon EVM from the Neon EVM operator account for the execution of Neon transactions.

Neon Proxy

Neon Proxy is a service that provides an Ethereum-like 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 Proxy is optional for any Neon EVM client. Its main function is to help Neon EVM clients start using Neon EVM without any changes to their codebase.

ERC-20 SPL Wrapper

For each Solana token, an ERC-20 SPL wrapper contract can be deployed. The task of the ERC-20 SPL wrapper is to ensure the interaction of the Solana applications with EVM (Solidity, Vyper, etc.) bytecode contracts. The ERC-20 SPL wrapper can also be used to transfer funds in Solana tokens using Ethereum wallets such as MetaMask.

Independence of Operations Within Neon EVM

Neon EVM ensures the independence of its operations by providing open access to its infrastructure to anyone who is willing and capable of running Neon Proxy. Moreover, Neon 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 consistent execution of Neon transactions and protect from re-execution.

Preconditions for the Execution of Neon Transactions

As with other Solana-native dApps, in order to enable the execution of Neon transactions, the user must grant Neon EVM access to their accounts. Neon EVM then acts on behalf of the user for user transactions such as transfers, swaps, or other operations. It verifies the information received (the nonce field and the signature) and enables the operation that is asked for.

To prevent forgery and unlawful operations, the following fields are checked and verified:

- The nonce field: It has a unique transaction index, which is verified by the Neon EVM smart contract. This makes double-spend attacks impossible.
- The signature field: It is formed according to the Ethereum rules. The Neon transaction signature is verified by the Neon EVM smart contract. Note: the procedures for validating the Solana signature and the Neon signature are different, and are implemented using different algorithms.

Neon EVM access to user accounts is secured in the following ways:

- Neon EVM smart contract code is freely available for anyone to review. It was audited in October, 2022.
- Neon transactions are validated by independent Solana validators.
- Decentralized Neon EVM governance is responsible for the updates of the Neon EVM contract.

Parallel Execution of Neon Transactions on Solana

Most blockchains process transactions in a single thread, meaning that the blockchain state is modified by one contract at a time. In contrast, Solana can process tens of thousands of contracts in parallel using as many cores as are available on a Solana node. This functionality is known as Sealevel, and it greatly increases 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, which allows 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 the 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 the 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.

The procedure for the parallel execution of Neon transactions consists of the following steps:

1) Neon Proxy, which has a built-in EVM similar to Neon EVM, receives a Neon transaction from the user.
2) Neon Proxy performs a test launch of the Neon transaction, calling the public Solana cluster RPC endpoint or its own Solana node for the current state.
3) As a result of the test performed, Neon Proxy receives a complete list of contracts and accounts involved in the Neon transaction.
4) Neon Proxy forms a Solana transaction using a list of Neon contracts and Neon accounts, inside which the Neon transaction is wrapped.
5) Neon Proxy sends the Solana transaction for on-chain execution to the Solana cluster.
6) The Solana cluster gets the Solana transaction and sends it for execution to the leading Solana node.
7) The concurrent transaction processor of the Solana node executes the Solana transactions in parallel, checking the independence by verifying the Solana accounts in the header of the Solana transaction.
8) Solana transactions with the packed Neon transactions are executed in parallel, calling the Neon EVM smart contract in the following manner:
    a. Neon EVM smart contract is loaded.
    b. EVM (Solidity, Vyper, etc.) bytecode smart contract is loaded.
    c. Each EVM (Solidity, Vyper, etc.) bytecode smart contract executed on Solana has its own independent state.
    d. The Neon EVM smart contract executes any Neon transaction by calling the EVM smart contract method.
    e. When the Neon transaction is executed on-chain, data from the Solana state is used and changed.
    f. At the end of the execution of the Neon transaction, Neon EVM updates the Solana state.

Acceleration of Neon Transaction Execution

As noted above, Neon 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 quickly.
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 Proxy. Note: When using this method, it's up to the sender to make sure that:
    - In cases where the Neon transaction is too big, it has to be executed iteratively. (Learn more in the section on iterative execution of Neon transactions below.)
    - A list of all Neon accounts and contracts corresponding to the Neon transaction must be determined on the client side.
- Using additional methods in the Neon Proxy with a transfer of the list of Neon accounts involved. Note: it's up to the sender to make sure that a list of all Neon accounts and contracts corresponding to the Neon transaction has been determined on the client side.

Iterative Execution of Neon Transactions

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

- Neon EVM transfers the deposit in SOL tokens from the operator's account to a separate account.
    - The main role of the deposit is to motivate the operator to complete Neon transactions.
    - The size of the deposit is determined by the Neon EVM settings set by Neon EVM governance.
- Neon EVM blocks the 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 Proxy.

The Neon EVM settings set by Neon EVM governance are:

- *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 Neon EVM during the execution of Neon transactions. The number of iterations per Neon transaction is not known 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).

- *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*. This is paid to the operator who performs the last step of the Neon transaction and finalizes it.
- *The maximum number of waiting blocks (Mn), determined by Neon EVM governance.* The operator is given a maximum number 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 main steps for the iterative execution of a Neon transaction are as follows:

- 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 number of EVM steps specified in the Solana transaction.
- The Neon operator pays fees in SOL tokens for each iteration:
    - A fee to the Solana leader for executing the Solana transaction.
    - Transfer LAMPORTs to Solana accounts for rent exempt payments in the case of creating new Solana accounts. For example, a Neon transaction creates a new Solana account in the case of transferring NEON tokens to non-existent Neon users. In another example, a Neon transaction deploys a new Neon contract.
    - A fee to the Neon EVM treasury. (See Neon EVM governance below.)
- Neon EVM calculates gas based on the number of LAMPORTs spent by the Neon operator.
    - Neon EVM transfers NEON tokens from the Neon user to the Neon operator at the end of each iteration.
    - Gas price is calculated by Neon Proxy based on the ratio of cost for SOL and NEON tokens.
    - Each Neon operator sets a fee for Neon transaction execution. The fee should allow the Neon operator to cover hardware costs and transaction execution costs, and bring a profit.
- If it's not the end of execution:
    - Record the operator that 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 are:

- 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.

- 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.
- Data modified by the Neon transaction is saved into the Solana storage.
- The Neon EVM operator receives the deposit.
- Neon EVM unlocks accounts that were blocked at the start of the Neon transaction.

Payment for Neon Transactions

The cost of Neon transaction execution in Neon EVM is calculated according to Solana rules for Solana transaction execution.

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

- The cost of executing a Solana transaction, which depends on the number of signatures specified in the transaction. As previously mentioned, in Solana transactions only one signature is specified (that of the Neon EVM operator) because Neon signatures are verified in Neon EVM. (See the above section on iterative execution of transactions.)
- The transferring of LAMPORTs to Solana accounts for rent exempt payments in the case of creating new Solana accounts. Neon EVM creates a Solana account with a balance equivalent to two years of rent payments to exclude cases of losing accounts by Neon users.
- A fee to Neon EVM governance to keep Neon EVM running.
- A fee to the Neon EVM operator that executes the transaction.

A Neon transaction formed according to the Ethereum rules contains two groups of fields that are used in payment for Neon transactions:

- The first group consists of two fields: gas_price and gas_limit. These fields in the Ethereum network are used to pay for the gas spent on the transaction to the miner that produces a block. There are no miners in the case of Neon EVM, but the Neon operators are running proxies and sending Neon transactions to the Solana cluster and are rewarded for the work done. The Neon user pays for gas in NEON tokens.
- The second group consists of a field value. This field is used on Ethereum for two purposes: first, to enable the transfer of NEON tokens. Second, to enable payment to the Ethereum smart contracts according to the functionality that is used by a user. Neon users will be able to transfer only NEON tokens as a value token to prevent issues with the execution of Ethereum smart contracts deployed in Neon EVM.

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 a Neon Proxy and

execute a Neon transaction on–chain 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 utility token that is needed to pay for the execution of Neon transactions. This token will be used for governance purposes. At launch, Neon governance will be handled by an SPL governance program with add-ins.

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 by the decentralized protocol based on an SPL governance program with add-ins. And any user can set up Neon Proxy and receive payments for executing transactions via Neon EVM.

Neon EVM is a full Ethereum emulation with gas consumption calculated by Solana rules and iterative execution of large Ethereum EVM contracts. It is fully compatible with all existing Ethereum tools. It enables parallel execution of EVM bytecode (Solidity, Vyper, etc.) 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 ERC-20 token interface, which is native to contracts and tools made for Ethereum. Users can pay for the services of Neon EVM in NEON tokens.

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