The zkEVM Architecture

Part IV: Exchanging Asssets and Messages

Polygon zkEVM & Universitat Politècnica de Catalunya (UPC)

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Outline

Asset Exchange

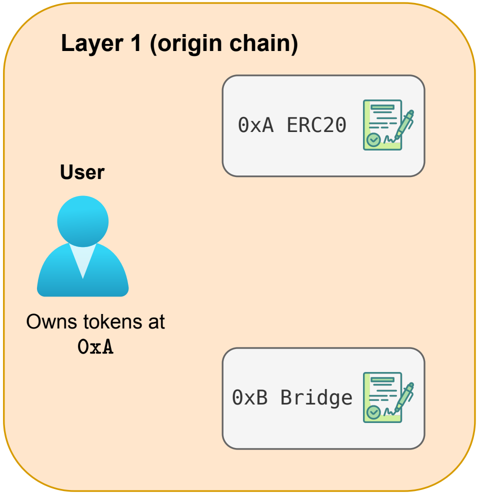
- The bridge allows transferring assets from one chain to another chain.
- Assets are tokens of some type, e.g. ERC20 or ERC721.
- The asset transferring is in fact an ”illusion”:

  Assets are not transferred, but temporarily locked on the origin chain while the same amount of equivalent assets/cryptocurrency are issued in the destination chain.

- If the assets go back to the origin chain, they are **unlocked** in the original chain and **burned** in the destination chain.

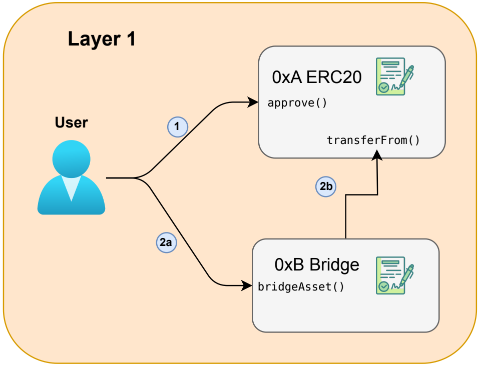
Bridging ERC20 Tokens

- Let's start describing an **ERC20 token exchange**.
- Let's consider that `0xA` is an instance of an ERC20 token originally in L1 and we want to transfer tokens to another chain.
- For this purpose, first, the tokens have to be transferred to the `Bridge` smart contract (at `0xB`).



ERC20 Token Transfer to Bridge (with approve)

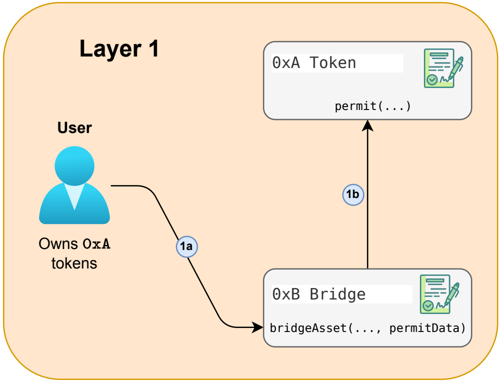
- To transfer the tokens to the bridge, the typical flow is to first send an approve transaction to the ERC20 contract.
- And then, the user sends a transaction to `bridgeAsset()` and the `Bridge` contract transfers the tokens to itself.



ERC20 Token Transfer to Bridge (with permit)

Alternatively, the `permit` function, if available in the token smart contract, allows users to grant permission and to spend their tokens in a **single transaction**, avoiding the need of `approve`+`transferFrom`.

- The standard arguments to call **`permit()`** are the following:
  - `owner`: The user (0xE).
  - `spender`: The bridge (0xB).
  - `value`: Amount of tokens.
  - `deadline`: Deadline to spend the tokens.
  - `signature`: Signature of the owner including antireplay attacks measures (that is, it contains a nonce and the `DOMAIN_SEPARATOR`)



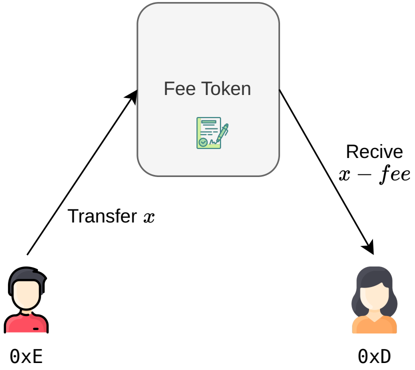
Fee Tokens

There are a certain kind of tokens (called **fee tokens**) that, upon receiving a transfer request from a user, deduct a fee from the transferred value before the receptor receives the remaining value.

- In our case, we must store the correct amount ($x - \texttt{fee}$) in the leaves of all our Exit Trees:

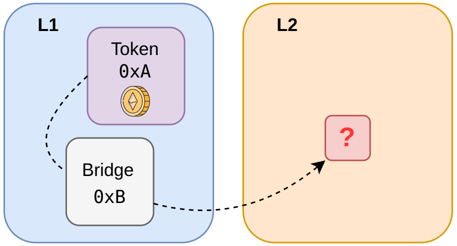
  $$\texttt{leafAmount} = \texttt{balanceAfter} - \texttt{balanceBefore}$$

- In the case of non-fee tokens, `leafAmount` should equal `amount`.



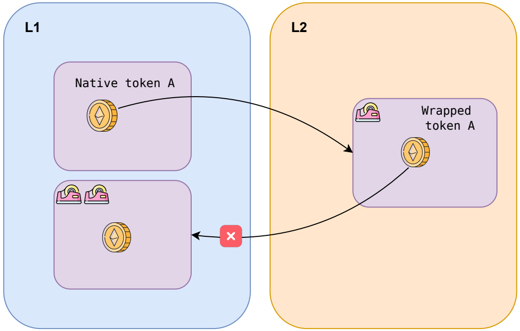
Transfer the Tokens to Destination Layer

- Recall that tokens live in a instance of a smart contract deployed in its corresponding Layer.
- Therefore, when transferring tokens from one layer to another one, we might need to create an instance of a token contract in the destination layer to hold the tokens (if this instance does not already exist).
- These contracts are called contracts of **wrapped tokens**.



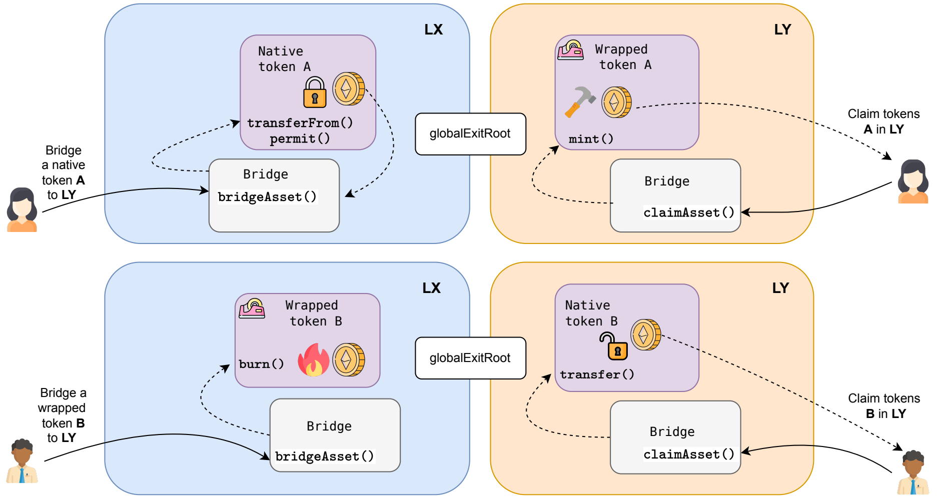
Avoiding Loops of Wrappings

- Another thing that we need to manage is the possible creation of *loops of wrappings*.
- That is to say, creating a new wrapped token smart contract in the origin Layer.

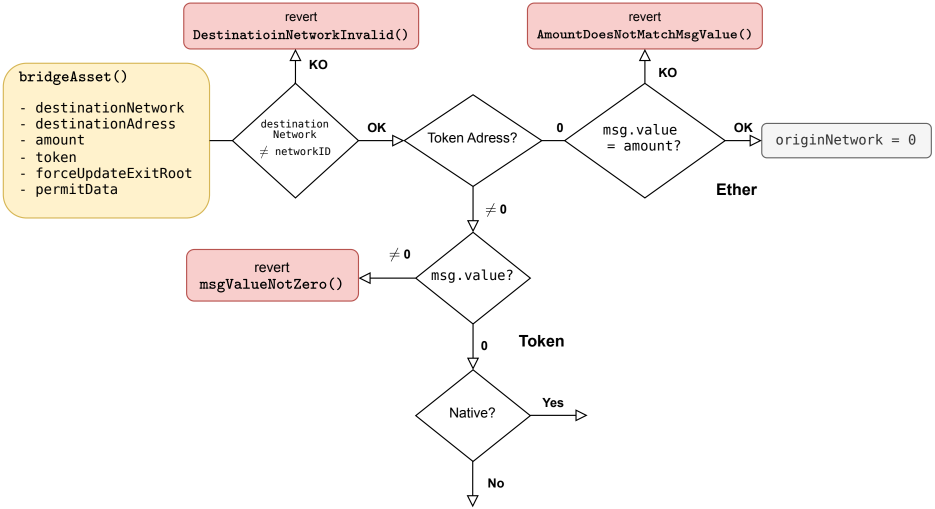


- To achieve that, we always set `originNetwork` to be the network of the native token.
- In the case of Ether, the origin network is L1.

Overview of Asset Transfer with Bridge-Claim



Flow of **bridgeAsset()**: Part I

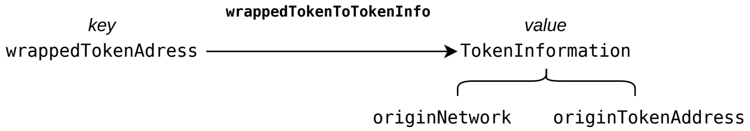


Native Tokens vs Wrapped Tokens i

- In the `Bridge` smart contract, we have a wrapped token information struct, which contains the following data:

```
struct TokenInformation{
  uint32 originNetwork;
  address originTokenAddress;
}
```

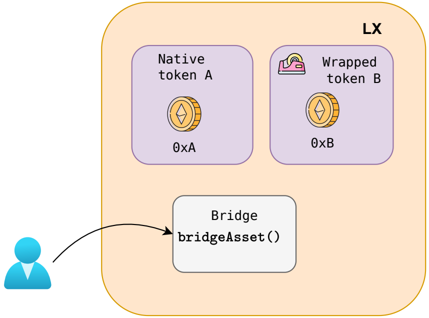
- We use `TokenInformation` as the value of the `wrappedTokenToTokenInfo` mapping, keyed by the `wrappedTokenAdress`.



Native Tokens vs Wrapped Tokens ii

Using the token address and the `wrappedTokenToTokenInfo` mapping, we check if the token is native or wrapped.

`TokenInformation.originTokenAdress` must be zero if it is native and non-zero if is wrapped.



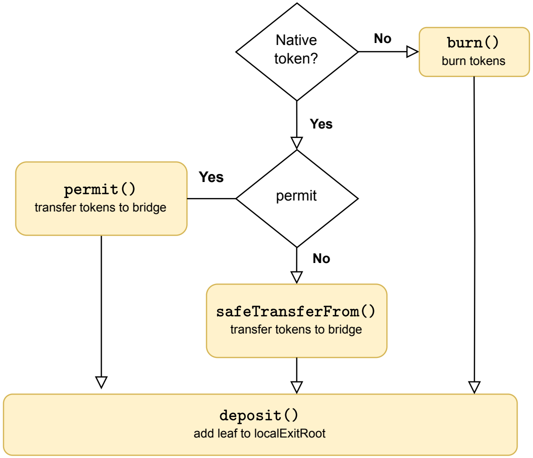
- If bridged token is `0xA` then

  `wrappedTokenToTokenInfo[0xA].originTokenAdress` $= 0$.

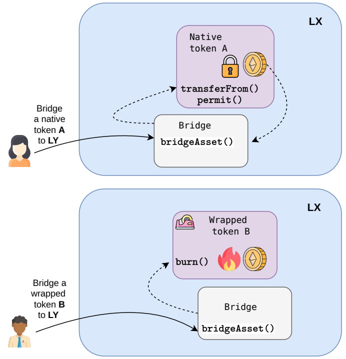
- If bridged token `0xB` then

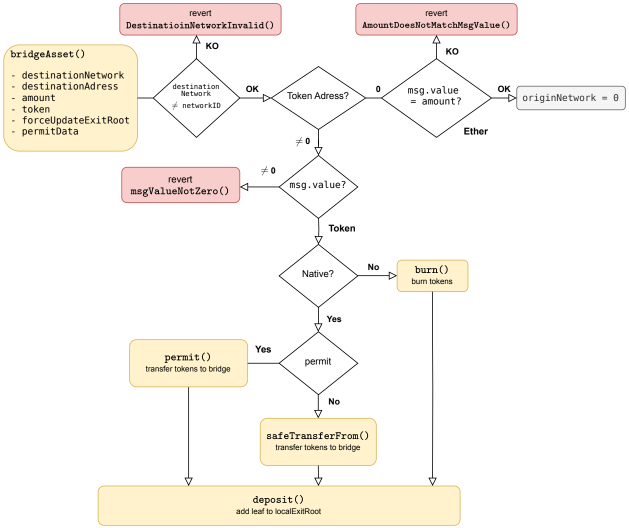
  `wrappedTokenToTokenInfo[0xB].originTokenAdress` $\neq 0$.

Flow of **`bridgeAsset()`**: Part II

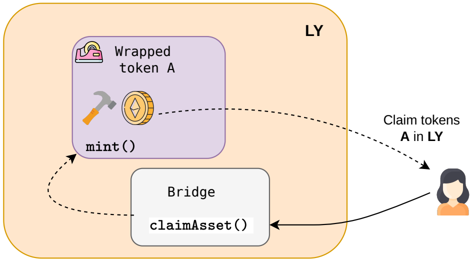


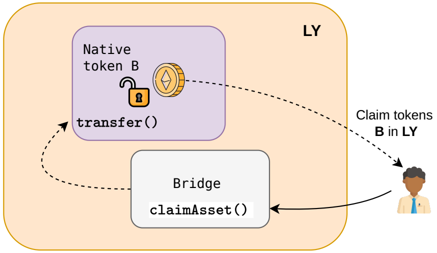
Complete Flow of **bridgeAsset()**



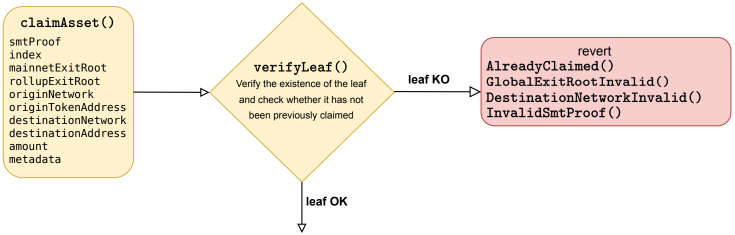


Claim Assets





Flow of **`claimAsset()`**: Part I



Storing binary-valued maps: **`BitMap`** Optimization i

- Recall that, when nullifying claims, we need to store an associative map `uint256` $\rightarrow$ `bool`.
- For example: `3` $\mapsto$ `true`, `7` $\mapsto$ `false`, etc.
- We want to do it in the most efficient way in Solidity.
- As a first try, we could use an `uint256` $\rightarrow$ `bool` mapping directly, but in Solidity this uses 256 bits for each value in the mapping (despite being a boolean!).
- An optimization would be using a bit map, which consists in grouping 256 indexes and use its bit-wise values to construct a `uint256`.
- For this purpose, the first step is to change the mapping definition to `uint256` $\rightarrow$ `uint256`.
- Then, each index is divided in a word position (`wordPos`) and a bit position (`bitPos`).

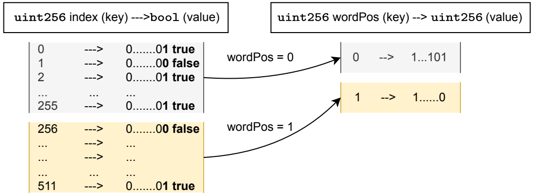
Storing binary-valued maps: **BitMap** Optimization ii

- **Word positions** of each index specifies which key of the new mapping contains the wanted value

$$\texttt{wordPos} = \lfloor \texttt{index}/256 \rfloor.$$

- On the other side, the **bit positions** specifies at which bit position of the corresponding **uint256** value (uniquely determined by **wordPos**) we can find the wanted value.

$$\texttt{bitPos} = \texttt{index} \mod 256.$$



`BitMap` Optimization Example

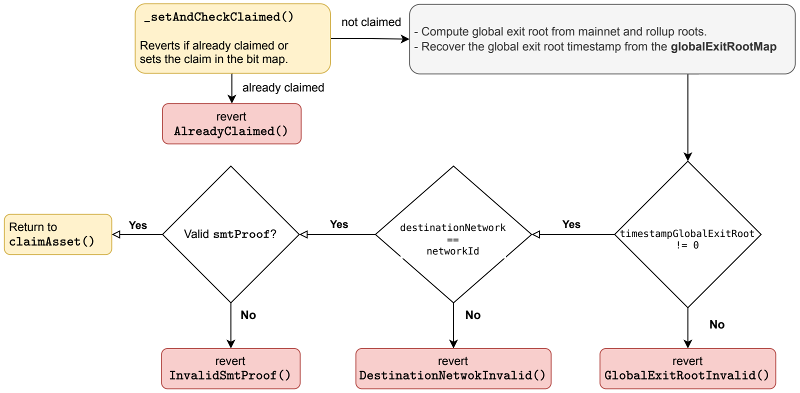
- For example, consider the mapping

$$0 \mapsto \texttt{false}, 1 \mapsto \texttt{true}, \ldots, 519 \mapsto \texttt{true}, 520 \mapsto \texttt{false}, 521 \mapsto \texttt{false}, \ldots$$

- We want to retrieve in the new mapping the value for the index 520, which is `false` in the original mapping.
- We compute `wordPos` and `bitPos` as specified:
  - `wordPos`: $\lfloor 520/256 \rfloor = 2$.
  - `bitPos`: $520 \mod 256 = 8$.
- Hence, in order to look for the corresponding boolean of index 520, we must use 2 as the key of the mapping and then get the 8th bit of the returned value (which will be 0, corresponding to `false`).

$$0 \mapsto 1\ldots110, 1 \mapsto 1\ldots000, 2 \mapsto 1\ldots10\mathbf{0}1011011.$$

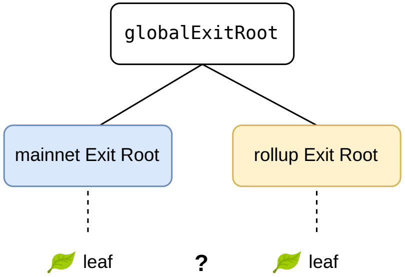
Flow of **verifyLeaf()**



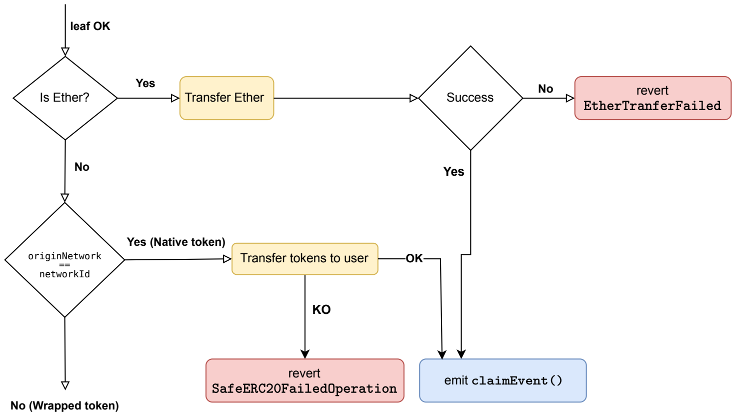
_setAndCheckClaimed()
Reverts if already claimed or sets the claim in the bit map.
not claimed
- Compute global exit root from mainnet and rollup roots.
- Recover the global exit root timestamp from the **globalExitRootMap**
already claimed
revert AlreadyClaimed()
timestampGlobalExitRoot != 0
Yes
No
revert GlobalExitRootInvalid()
destinationNetwork == networkId
Yes
No
revert DestinationNetwokInvalid()
Valid smtProof?
Yes
No
revert InvalidSmtProof()
Return to claimAsset()

Verifying Leaves of Exit Trees

With the Merkle proof (the `smtProof` parameter), we need to check that the leaf is included in the appropriate Exit Tree:



Flow of **`claimAsset()`**: Part II



Note. The bridge smart contract in L2 has a big amount of ETH to do the transfers.

Wrapped Tokens i

Let’s consider that we are in a situation in which claimed tokens must be transferred to a wrapped token smart contract.

In this case:

a) We need to check whether the corresponding contract instance exists or not.

b) If the instance for the wrapped token does not exist, we must create it.

Wrapped Tokens ii

- For a), we use a mapping to store the information of wrapped token instances:

$$\begin{tikzcd}\overset{\textit{key}}{\texttt{bytes32 tokenInfoHash}} \arrow[r, "\texttt{tokenInfoToWrappedToken}"] & \overset{\textit{value}}{\textit{Wrapped}\ \texttt{tokenAddress}}\end{tikzcd}$$

```
bytes32 tokenInfoHash = keccak256(
  abi.encodePacked(originNetwork, originTokenAddress)
);
```

- For b), creating the instances of tokens for wrapped tokens, we use `CREATE2` to be able to predict the deployment address.

CREATE vs. CREATE2

- With the CREATE opcode the address of the new smart contracts is calculated as follows:

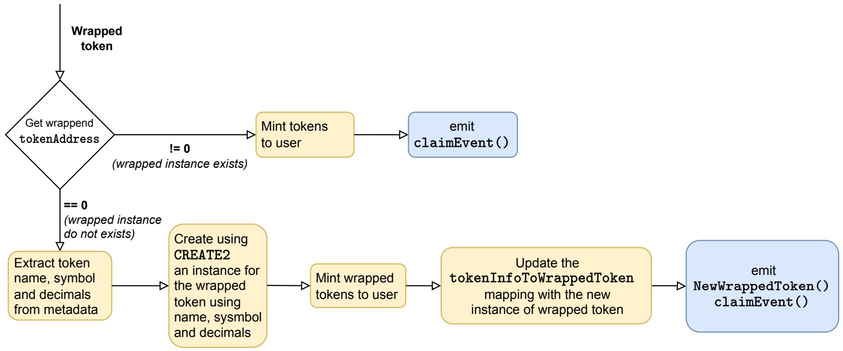
$$new\_address = hash(sender, nonce)$$

- With CREATE2, the address of the new smart contracts is calculated as follows:

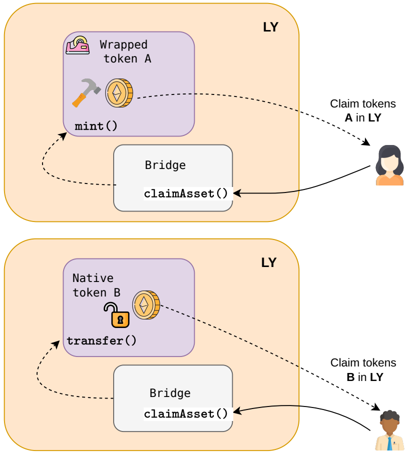
$$new\_address = hash(0xFF, sender, salt, creationBytecode, [args])$$

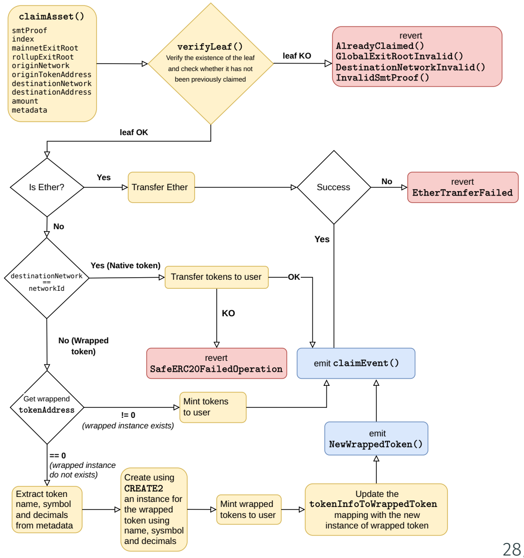
`https://docs.soliditylang.org/en/latest/control-structures.html#salted-contract-creations-create2`

Flow of `ClaimAsset()` Part III


Wrapped token
Get wrappend tokenAddress
!= 0
(wrapped instance exists)
Mint tokens to user
emit claimEvent()
== 0
(wrapped instance do not exists)
Extract token name, symbol and decimals from metadata
Create using CREATE2 an instance for the wrapped token using name, sysmbol and decimals
Mint wrapped tokens to user
Update the tokenInfoToWrappedToken mapping with the new instance of wrapped token
emit NewWrappedToken() claimEvent()

Complete Flow of `claimAsset()`




claimAsset()
smtProof
index
mainnetExitRoot
rollupExitRoot
originNetwork
originTokenAddress
destinationNetwork
destinationAddress
amount
metadata
verifyLeaf()
Verify the existence of the leaf and check whether it has not been previously claimed
leaf KO
revert
AlreadyClaimed()
GlobalExitRootInvalid()
DestinationNetworkInvalid()
InvalidSmtProof()
leaf OK
Is Ether?
Yes
Transfer Ether
Success
No
revert
EtherTranferFailed
Yes
No
destinationNetwork == networkId
Yes (Native token)
Transfer tokens to user
OK
KO
revert
SafeERC20FailedOperation
emit claimEvent()
No (Wrapped token)
Get wrappend tokenAddress
!= 0
(wrapped instance exists)
Mint tokens to user
emit NewWrappedToken()
== 0
(wrapped instance do not exists)
Extract token name, symbol and decimals from metadata
Create using CREATE2 an instance for the wrapped token using name, sysmbol and decimals
Mint wrapped tokens to user
Update the tokenInfoToWrappedToken mapping with the new instance of wrapped token

Related `view` Functions

- `preCalculateWrappedAddress()`: returns the precalculated address of a wrapper using the token information.

```
function precalculatedWrapperAddress(
  uint32 originNetwork,
  address originTokenAddress,
  string calldata name,
  string calldata symbol,
  uint8 decimals
) external view returns (address);
```

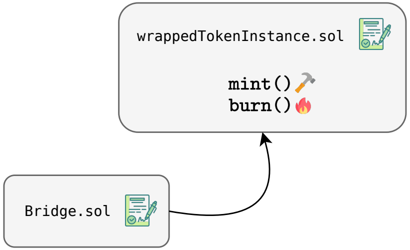
  Note. These addresses can be pre-calculated thanks to using `CREATE2`.

- `getTokenWrappedAddress()`: returns the address of a wrapper contract using the token information if already exists.

```
function getTokenWrappedAddress(
  uint32 originNetwork,
  address originTokenAddress
) external view returns (address);
```

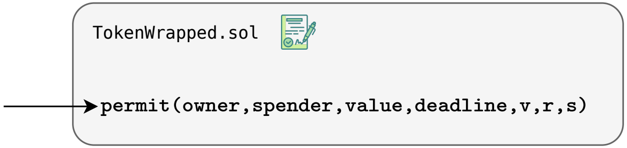
Wrapped Token Instances

- Our wrapped token contracts are ERC20 contracts.
- The code is in *lib/TokenWrapped.sol*.
- Mint and burn are only allowed to be called from the bridge contract.



Permit in TokenWrapped i

- The token contract implements the permit function of *EIP*2612, which performs a token approval with the provided permit data.
- In an **EIP2612** contract, we have to include:
  - The hash of the type of the domain used.
  - The hash of the signature of the permit function used.



Permit in TokenWrapped ii

- The signature $\sigma = (v, r, s)$ is performed over the hash of the following data:

$$\texttt{"\textbackslash x19\textbackslash x01"} + \texttt{DOMAIN\_SEPARATOR} + \texttt{dataHash}$$

```
bytes32 digest = keccak256(abi.encodePacked("\x19\x01", DOMAIN_SEPARATOR(), hashStruct));
```

- The first string `"\x19\x01"` is used to indicate that we **are not signing a transaction**.
- The `DOMAIN_SEPARATOR` is defined according EIP712 and it should be unique to the contract and chain to prevent replay attacks from other domains.

The EIP 712 Domain Separator

- The usual way to compute the `DOMAIN_SEPARATOR` is as a hash of a `name, version, chainId` and a `verifyingContract`:

```
// Domain typehash
bytes32 public constant DOMAIN_TYPEHASH = keccak256("EIP712Domain(string name,string version,uint256 chainId,address verifyingContract)");
```

- There exists a view function to retrieve the `DOMAIN_SEPARATOR` for the corresponding `chainID`:

```
function DOMAIN_SEPARATOR() public view returns (bytes32) {
  return  block.chainid == deploymentChainId ? _DEPLOYMENT_DOMAIN_SEPARATOR : _calculateDomainSeparator(block.chainid);
}
function _calculateDomainSeparator(uint256 chainId) private view returns (bytes32) {
  return keccak256(abi.encode(DOMAIN_TYPEHASH, keccak256(bytes(name())), keccak256(bytes(VERSION)), chainId, address(this)));
}
```

The Data Signed for the Permit Function

- The **hashStruct** is the hash of the arguments of the permit function together with a hash that identifies the signature of the permit function used:

```solidity
// Permit typehash
bytes32 public constant PERMIT_TYPEHASH = keccak256("Permit(address owner,address spender,uint256 value,uint256 nonce,uint256 deadline)");

bytes32 hashStruct = keccak256(abi.encode(
        PERMIT_TYPEHASH,
        owner,
        spender,
        value,
        nonces[owner]++,
        deadline
    )
);
```

- The **nonces** mapping is used to avoid attacks that try to replay the same permit message of the same owner.
- Finally, with an **ecrecover**, the permit function checks that the signature provided in the arguments corresponds to the signed hashed data.

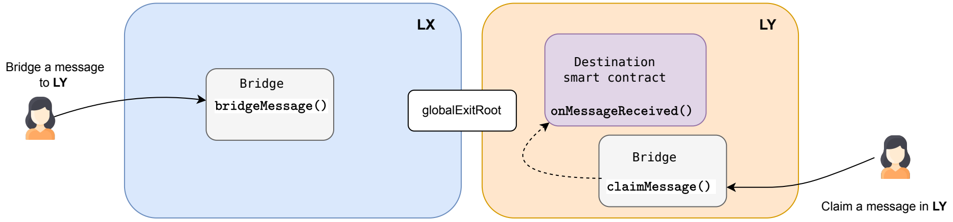
Outline

Leaves of Exit Trees (Review)

- `leafType` used to identify whether the leaf is an asset or a message:
  - Asset: value is 0.
  - Message: value is 1.
- `originNetwork`: the identifier (`chainId`) of origin layer of the exchange.
- `originAddress`: if it is an asset exchange, it is the address of the token contract.

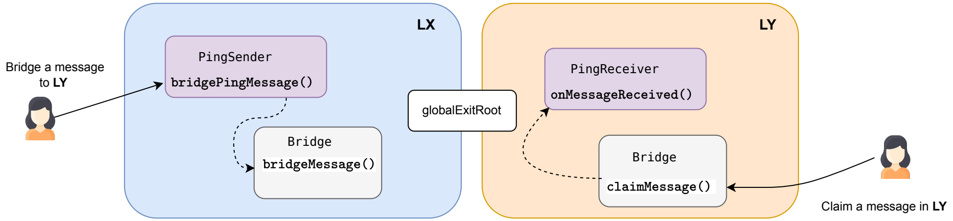
  If it is an message exchange, it is the source address of the bridge call.
- `destinationNetwork`: the identifier of the destination layer (`chainId`) of the exchange.
- `destinationAddress`: is the account receiving the asset or the address of the smart contract if it is a message exchange.
- `leafAmount`: amount of asset exchanged (Ether or Tokens).
- `bytes32 metadataHash`: the hash of the metadata.
  - Asset: the metadata is the name, symbol and decimals of the token.
  - Message: the metadata is the `calldata` for calling the `onMessageReceived()` function.

Bridge-Claim for Messages



Unlike bridging assets, which is closely managed by the `Bridge` smart contract, **messages** are a more low level primitive which you can use to **create any logic that you want**.

Example of Bridge-Claim for Messages: Ping/Pong



https://github.com/0xPolygonHermez/code-examples/tree/main/pingPongExample

More Examples of Bridge-Claim for Messages

- You can find more examples, e.g. an implementation for custom ERC20 or NFT bridging, at:

  `https://github.com/0xPolygonHermez/code-examples`

- The DAI project has a custom implementation for bridging ERC20:

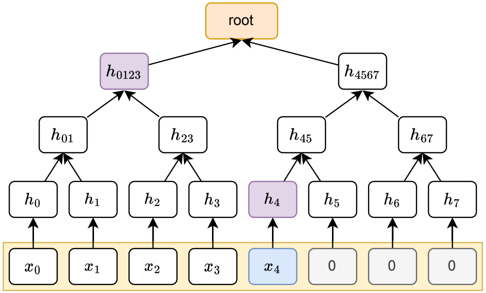
  `https://github.com/pyk/zkevm-dai`

- Also the USDC project has a custom implementation for bridging ERC20 in which the main idea is to be able to manage white/black lists of addresses.

Outline

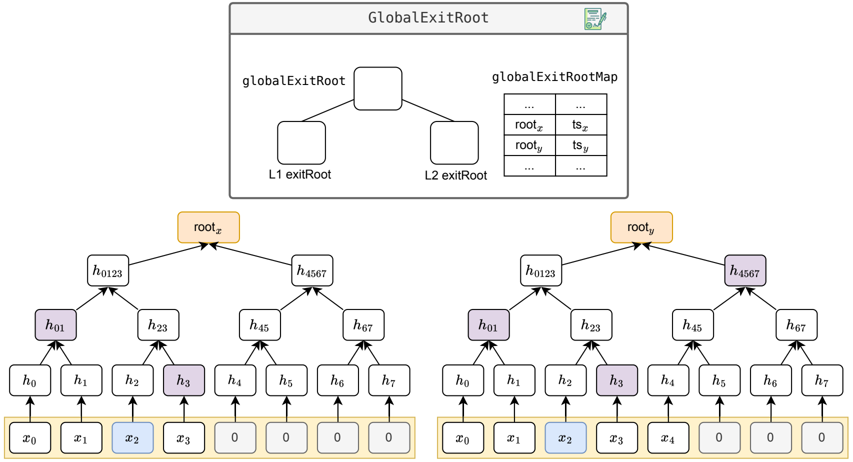
Providing Merkle Proofs i

- Merkle proofs of Exit Trees are validated using roots stored at the `GlobalExiRoot` contract.
- The `Bridge` contract only contains information to build the Merkle proof of the last inserted deposit.
- So, we need a way of obtaining Merkle proofs for past roots.



For obtaining Merkle proofs for past deposits, we use an external backend that is synchronized with all the historical global exit roots.

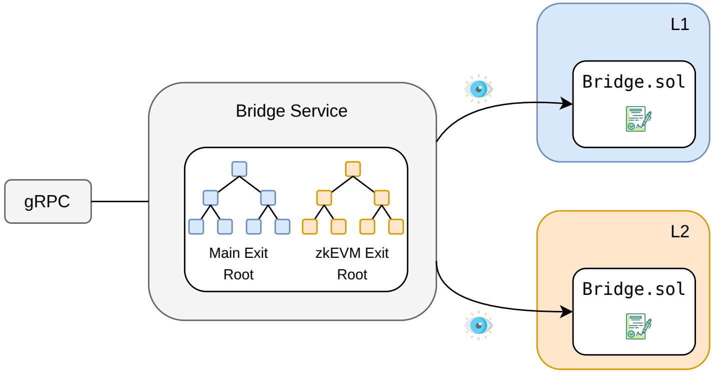
Providing Merkle Proofs ii



GlobalExitRoot
globalExitRoot
L1 exitRoot
L2 exitRoot
globalExitRootMap
... | ...
root_x | ts_x
root_y | ts_y
... | ...
root_x
h_{0123}
h_{4567}
h_{01}
h_{23}
h_{45}
h_{67}
h_0 h_1 h_2 h_3 h_4 h_5 h_6 h_7
x_0 x_1 x_2 x_3 0 0 0 0
root_y
h_{0123}
h_{4567}
h_{01}
h_{23}
h_{45}
h_{67}
h_0 h_1 h_2 h_3 h_4 h_5 h_6 h_7
x_0 x_1 x_2 x_3 x_4 0 0 0

ZkEVM Bridge Service i

The bridge service stores all the data of local exit trees in the different layers and provides Merkle proofs so that claim transactions can be easily created.



ZkEVM Bridge Service ii

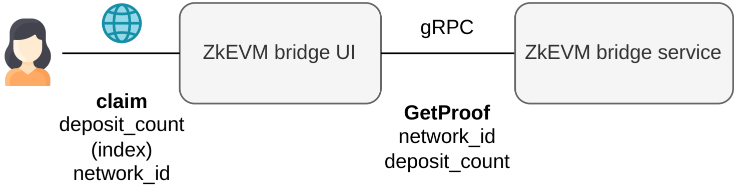
The bridge service makes its procedures available via a gRPC API.

The gRPC API provides proofs like the following:

```
message Proof {
    repeated string merkle_proof = 1; // hash values of the proof
    uint64 exit_root_num = 2; // mainnet exit tree root timestamp
    uint64 l2_exit_root_num = 3; // rollup exit tree root timestamp
    string main_exit_root = 4; // mainnet exit tree root hash
    string rollup_exit_root = 5; // rollup exit tree root hash
}
```

ZkEVM Bridge UI

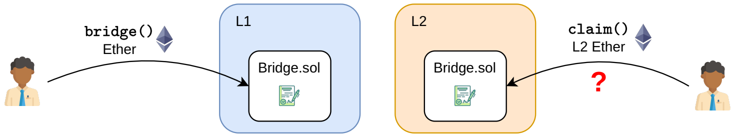
- The consumer of the bridge service is the zkEVM bridge UI.
- The zkEVM bridge UI is a web service that users can utilize to perform their claims in L1 and L2.



You can access the polygon bridge at `https://portal.polygon.technology/bridge`

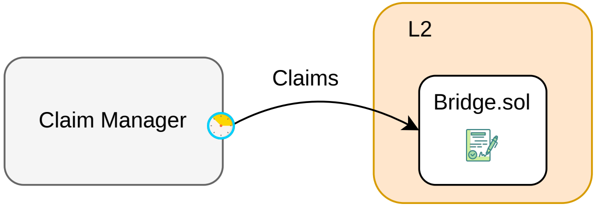
L2 ETH Deadlock

- Claim transactions in L1 are not problematic because there is publicly available L1 ETH supply.
- However, claim transactions in L2 is problematic because users need to first claim to obtain L2 ETH.
- But to claim its L2 ETH, the user needs L2 ETH (because it requires to send a transaction).
- This results in a **dead look**.



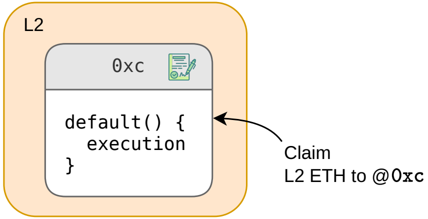
Claim Manager

- **Solution: sponsor L2 claim transactions**.
- We have a claim manager service that periodically (as a cron, without API) checks for unclaimed asset transactions and sends the L2 claim transactions for free.



Security Considerations for the Claim Service

- Being able to execute transactions for free, like sponsored claims, is always a vector of attacks, including DoS, so we must be sure that these sponsored transactions do not do anything beyond the claim processing.



- **Countermeasures:** Limit provided gas, check transactions and discard problematic ones, use OOC error, etc.
- **Note:** We currently sponsor asset claims (ETH or tokens) but **not message claims**.