

Cardano Smart Contracts



with Helios

Lawrence Ley, B.Sc

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This book would not have been possible without Christian Schmitz and the open source project called Helios.

Preface

With the invention of Bitcoin in 2008, Satoshi's [whitepaper](#) titled "Bitcoin: A Peer-to-Peer Electronic Cash System" ushered in an era of trustless decentralized digital currencies. [Ethereum](#) which launched in 2015, introduced the concepts of programmability into decentralized ledger technology. This allowed application developers to use a blockchain to store data and programs in a decentralized and permissionless way. Cardano launched in 2017 and leverages Bitcoin's secure UTXO architecture and created a deterministic, scalable and secure blockchain consensus and programmability model. Cardano can be considered a 3rd generation blockchain and builds upon both Bitcoin and Ethereum and aspires to be the world's financial operating system.

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Introduction

Developing smart contracts for Cardano required learning Haskell PlutusTx which is not easy to learn. An unfamiliar language, cpu and memory execution constraints and time spent on setup creates friction for new developers.

Fortunately, there are some new alternative plutus smart contract languages that eliminate this friction and allow developers to get started quickly. Greater focus can be spent on application and business logic and avoid reduced velocity caused by an uncommon language syntax, time consuming nix-shell/cabal configurations and compilation.

This book will focus on Helios which is a strongly typed, functional programming language whose compiler is written in javascript. One of the main advantages with Helios, is that it can be easily compiled on almost any target architecture that supports javascript. Additionally, there is an approximate 50% performance overhead improvement using Helios vs Haskell PlutusTx V2. Helios is also a transaction builder that can be used in off-chain code to build, sign and submit transactions.

Demeter Run

Demeter Run is an excellent platform for setting up a Cardano environment quickly. One of the most important aspects of a Cardano development environment is accessing the Cardano node. This would typically involve downloading the [Cardano Node](#) from source or a docker image and then setting it up with the correct configuration. When you are dealing with production, the cardano node needs to run a separate server with 16GB memory, 100GB+ SSD disk, 2 cpu cores and can take some time to sync even if using a Cardano node db [snapshot](#).

Thankfully, this is where Demeter Run comes in. It will create a workspace for you pre-configured and ready to go!

Setup

1. Go to <https://demeter.run/> and create an account
2. Select a cluster (US or Europe)
3. Select Discover Plan (free)
4. Select Network (Preview/Preprod/Mainnet)
5. Enter Project name and select Create Project
6. After project has been built select Open
7. Select Setup Dev Workspace
8. Select Clone an existing github repository
 - a. <https://github.com/lley154/helios-examples.git>
9. Select your coding stack as Typescript
10. Select workspace as small
11. Select network to connect to as Preprod
12. Scroll down and Select Create Workspace
13. After the workspace has been completed, select OPEN VS CODE top right on the screen
14. A popup window will appear and select the checkbox to trust the authors of the parent folder workspace. Then choose the button "Yes, I trust the authors"
15. Customize Web VS code as needed
16. Select the hamburger menu (top left) -> Terminal -> New Terminal

Now you have access to your workspace.

Query Tip

Try to run the following command.

```
$ cardano-cli query tip --testnet-magic 1
{
  "block": 526708,
  "epoch": 45,
  "era": "Babbage",
  "hash": "258c7fc2d52fce305720f9d8b3fb4376100f0914a63d77efb73c5098833a299f",
  "slot": 18213433,
  "syncProgress": "100.00"
}
```

The syncProgress is 100% so this means that the cardano node is fully synchronized with the blockchain for the Preprod testnet.

Workspaces

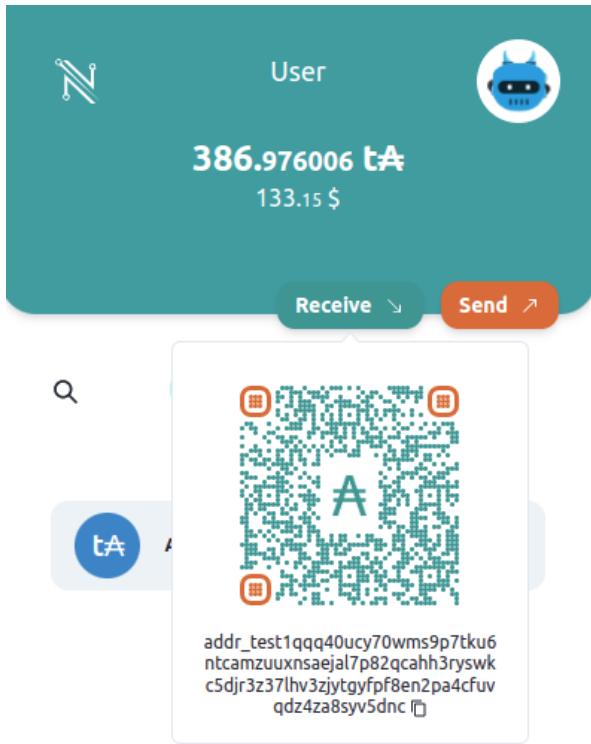
A workspace is temporary, so make sure you commit your work and push it to your online GitHub repository when you are done.

Addresses

A Cardano Address is at the heart of the Cardano blockchain. Every asset on Cardano needs to reside at an address. There are two types of address that you will typically interact with, a base address or an enterprise address.

Base Address

A base address is the address you see when receiving Ada from a browser wallet (eg. [Nami](#), [Eternl](#), [Flint](#), etc.)



ⓘ Preprod

In this case, we have the following address:

Addr_test1qqq40ucy70wms9p7tku6ntcamzuuxnsaejal7p82qcahh3ryswkc5djr3z371hv3zjtygyfpf8en2pa4cfuvqdz4za8syv5dnc

We can inspect the address with the following command:

```
$ echo
addr_test1qqq40ucy70wms9p7tku6ntcamzuuxnsaejal7p82qcahh3ryswkc5djr3z371hv3zjyt
gyfpf8en2pa4cfuvqdz4za8syv5dnc | ./utils/cardano-address address inspect
{
    "address_style": "Shelley",
    "address_type": 0,
    "network_tag": 0,
    "spending_key_hash":
    "0157f304f3ddb8143e5db9a9af1dd8b9c34e1dccbbff04ea063b7bc4",
    "spending_key_hash_bech32":
    "addr_vkh1q9t1xp8nmkupg0jahx5678wch8p5u8wvh0lsf6sx8daug8cyak6",
    "stake_key_hash":
    "6483ad8a364388a3efdd911488b4112149f33507b5c278c03455174f",
    "stake_key_hash_bech32":
    "stake_vkh1vp6mz3kgwy28m7ajy2g3dq3y9ylxdg8khp83sp525t57tzwkxk",
    "stake_reference": "by value"
}
```

This is a test address because the address_type is 0, but we also see the "addr_test" prefix which indicates that this is a testnet (eg. preprod) address. If an address_type is 1, then it is a production address and will have "addr" as the prefix.

An address is derived from both a spending_key_hash and a stake_key_hash. The spending_key_hash is more commonly known as the public key hash or PKH. The staking_key_hash is used when you stake your Ada from a wallet to a [stake pool](#) operator.

Enterprise Address

Another type of address commonly used is called an enterprise address.

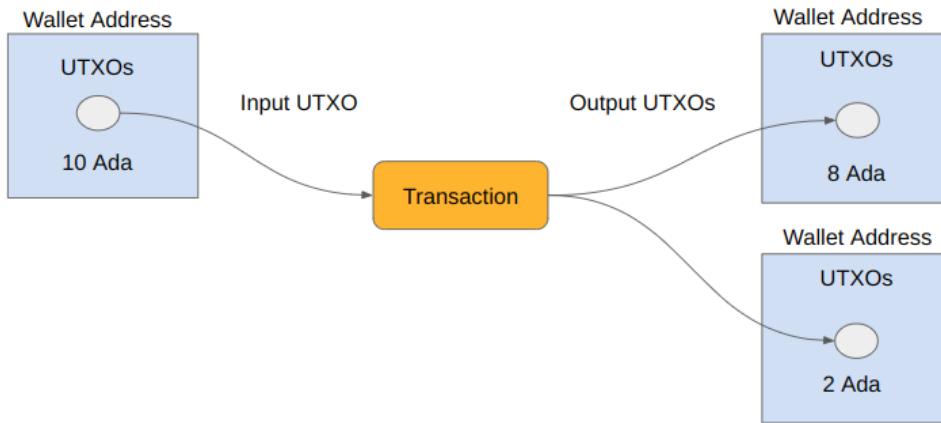
```
$ echo addr_test1vq5s7k4kwqz4rrfe8mm9jz9tpm7c5u93yfwwsaw708yxss5sm70qjg |  
./utils/cardano-address address inspect  
{  
    "address_style": "Shelley",  
    "address_type": 6,  
    "network_tag": 0,  
    "spending_key_hash":  
"290f5ab67005518d393ef65908ab0efd8a70b1225ce875de79c86852",  
    "spending_key_hash_bech32":  
"addr_vkh19y844dnsq4gc6wf77evs32cwlk98pvfztn58thneep59yhwpvvm",  
    "stake_reference": "none"  
}
```

Enterprise addresses do not have a `stake_key_hash` only a `spending_key_hash`.

For more info on how to install `cardano-address` and derive addresses from a passphrase, please see the appendix section on Address Key Derivation.

Transactions

Transactions are used to transfer assets from one address to another. Every transaction contains one or more inputs and one or more outputs. Here is a simplified diagram showing the transfer of Ada using a Cardano transaction.



A UTXO is an unspent transaction output. A Transaction consumes one or more UTXOs and then produces one or more UTXOs where each UTXO is locked at an address. When trying to determine the amount of assets at an address, we are actually counting the asset amounts in each UTXO locked at an address.

Here is an example of 2 UTXOs at an address *

```
$ cardano-cli query utxo --address addr_test1vzu...dxn7 --cardano-mode  
--testnet-magic 1  
TxHash TxIx Amount  
-----  
158...925 0 3551912116 lovelace + TxOutDatumNone  
b4e...0d2 0 5000000 lovelace + TxOutDatumNone
```

* Please note that the address and TxHash have been abbreviated so they can fit properly on this page.

Observations:

- In this example, there are 2 UTXOs
- Transaction hash 158...925 with index 0 has 3,551,912,116 lovelace
- Transaction hash b4e...0d2 with index 0 has 5,000,000 lovelace
- There is 1,000,000 lovelace in 1 Ada
- The amount of Ada locked at the address is

3,551.912116
+ 5.000000
3,556.912116

Datums

In the previous example you may have noticed TxOutDatumNone at the end of the UTXO output. This field is used to store persistent information in the UTXO and is called the datum. A datum is created when building and submitting a transaction.

TxOutDatumNone indicates that there is no datum information associated with this UTXO. Here is an example where an inline datum is present with a UTXO.

```
cardano-cli$ cardano-cli query utxo --address addr_test1wrm...hm3f
--cardano-mode --testnet-magic 1
TxHash TxIx Amount
-----
b07...91da 0 88270000 lovelace + TxOutDatumInline ... (ScriptDataConstructor 0
[ScriptDataNumber 87770000, ScriptDataBytes "4666620215361", ScriptDataBytes
"0.34180"])
b87...107e 1 20000000 lovelace + TxOutDatumNone
```

TxOutDatumInline indicates that there is an inline datum present. A datum can also be the hash value of the actual datum. Using a datum hash was the only way datums could be stored on-chain prior to the Vasil hard fork in Fall of 2022. Unless the datum size is large, inline datums are typically the preferred approach.

Redeemers

Redeemers are also included in a smart contract transaction and may be used to execute different conditions depending on the value of the redeemer. Additionally, Redeemers can be used to pass data to a smart contract at runtime during transaction construction.

Metadata

A transaction can also generate metadata that is stored on-chain. This can provide human readable information about a transaction and can also be leveraged by applications. Either technique (Datums and/or Metadata) both store persistent data on-chain. The decision on what technique to use depends on how the data will be accessed. If the data needs to be validated inside a smart contract, then use a datum. If you need to provide transaction details to an off-chain application, token minting or human verification, then use metadata.

Cardano Blockchain Architecture

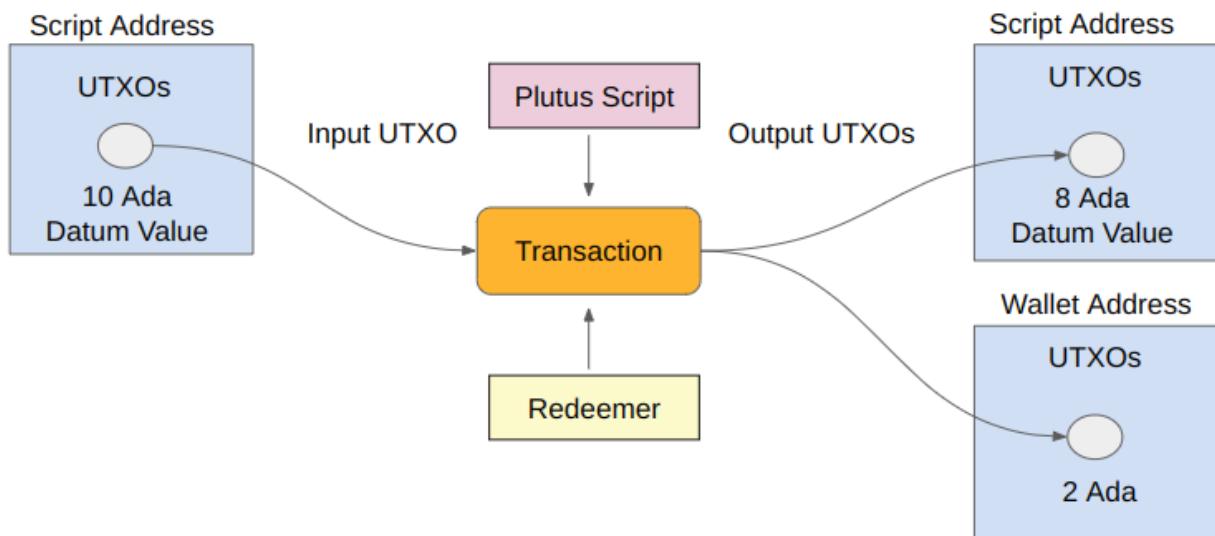
Cardano uses an *extended UTXO* blockchain architecture. What this means is that in addition to using UTXOs for assets, there is the capability to add a datum value to UTXOs as well.

UTXO Model

In a UTXO model (eg. Bitcoin), the owner of a private key(s) for an address is the only one that can spend a UTXO locked at that address.

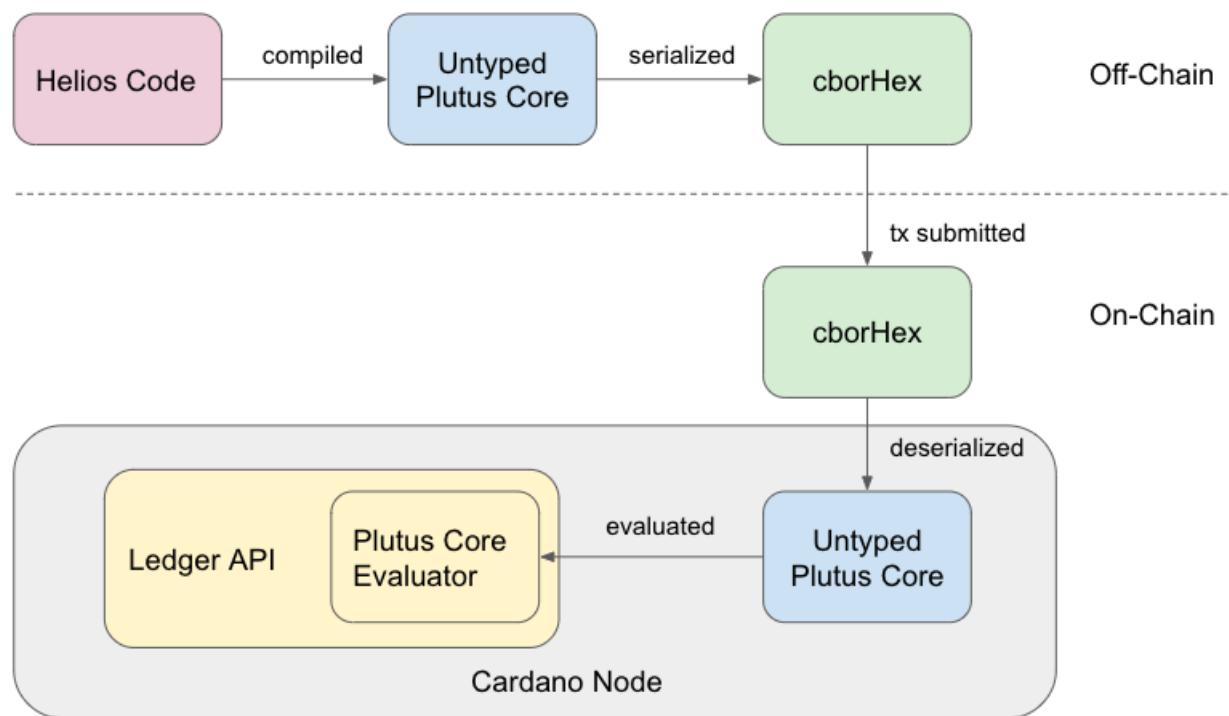
eUTXO Model

In a eUTXO model (eg. Cardano), a [Turing-complete](#) script can spend a UTXO locked at a script address. Below is a diagram showing a simplified smart contract transaction where 10 Ada is locked at a Plutus Script address.



Plutus Scripts

Helios code is compiled to Untyped Plutus Core which is the plutus script format needed by the Plutus Core Evaluator. When you compile and submit a transaction with Helios, the smart contract is first evaluated by a local Helios virtual machine. This leverages the [deterministic](#) nature of Cardano where you find out **before** you submit the transaction if it will succeed or fail and the transaction fee. Below is a simplified diagram showing the process of getting a plutus script to the Cardano node and evaluating it as part of a transaction.



Signing Transactions

In order for a transaction to be executed successfully on the Cardano blockchain, it must contain valid signatures that demonstrate that the owners of the UTXO(s) being spent have agreed to this. This agreement is done by signing the hash of the transaction body with the owner's private key. The signatures are then bundled into a group of transactions known as a transaction witness set. Once the signatures for each UTXO being spent has been included, the transaction can be sent to the blockchain for verification.

Cardano-cli

Cardano-cli is a widely used command line tool for querying and executing transactions on the Cardano blockchain. It is helpful to be familiar with this tool because by using it, you will have a better understanding on how transactions are constructed, signed and submitted. Cardano-cli is also used in backend servers and batch processing.

Bash Shell Scripts

Using the cardano-cli tool on the command line is awkward so it is more convenient to use it inside a bash shell script or Node.js. Here is a simple bash shell script for executing a simple cardano-cli transaction.

```
#!/usr/bin/env bash

source_addr=addr_test1vq5s7k4kwqz4rrfe8mm9jz9tpm7c5u93yfwssaw708yxss5sm70qjg
source_utxo=3188f0f28667f753f864b39475acb3d55cf27e146fa6414ac57f5c6c63c705c2#
destination_addr=addr_test1qqq967dwdp009smfeqtzhve89fyuqqjydkvwc9md5atyg2429gnmszjc7hyf
685vp7qxeffjd568s3p234fg5ryhrkvjsn7muqm
user_skey=/config/workspace/repo/.keys/user/key.skey
network="--testnet-magic 1"

# generate param file from cardano-cli tool
cardano-cli query protocol-parameters $network --out-file pparms.json

cardano-cli transaction build --babbage-era --cardano-mode \
$network \
--change-address "$source_addr" \
--tx-in "$source_utxo" \
--tx-out "$destination_addr+2000000" \
--protocol-params-file pparms.json \
--out-file transfer-tx-alonzo.body
echo "tx has been built"

cardano-cli transaction sign \
--tx-body-file transfer-tx-alonzo.body \
$network \
--signing-key-file "$user_skey" \
--out-file transfer-tx-alonzo.tx
echo "tx has been signed"

echo "Submit the tx with plutus script and wait 5 seconds..."
cardano-cli transaction submit --tx-file transfer-tx-alonzo.tx $network
```

Test Drive

Here is the **before** snapshot of the source and destination addresses.

Source Wallet Address

```
$ cardano-cli query utxo --address addr_test1vq5...qjg --cardano-mode  
--testnet-magic 1  
TxHash TxIx Amount  
-----  
db34...3ee 0 10000000 lovelace + TxOutDatumNone
```

Destination Wallet Address

```
$ cardano-cli query utxo --address addr_test1vq7k...pds --cardano-mode  
--testnet-magic 1  
TxHash TxIx Amount  
-----
```

Then we run the script

```
$ ./transfer-tx.sh preprod  
Estimated transaction fee: Lovelace 165721  
tx has been built  
tx has been signed  
Submit the tx with plutz script and wait 5 seconds...  
Transaction successfully submitted.
```

Here is the snapshot **after** the transaction of source and destination addresses

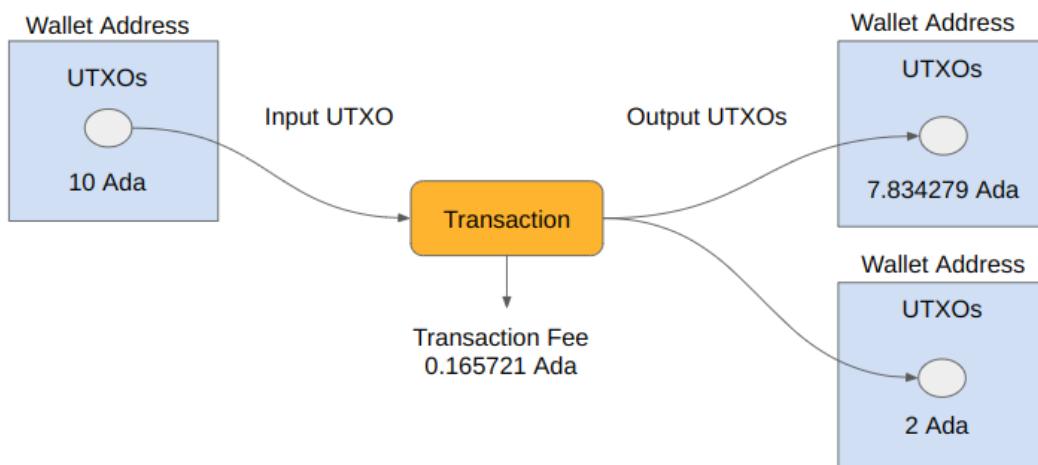
Source Wallet Address

```
$ cardano-cli query utxo --address addr_test1vq5s...qjg --cardano-mode  
--testnet-magic 1  
TxHash TxIx Amount  
-----  
996...95c 1 7834279 lovelace + TxOutDatumNone
```

Destination Wallet Address

```
$ cardano-cli query utxo --address addr_test1vq7...pds --cardano-mode  
--testnet-magic 1  
TxHash TxIx Amount  
-----  
996...95c 0 2000000 lovelace + TxOutDatumNone
```

So, when including the fees, the simple transaction diagram looks like the following.



Transfer Ada

Helios is both a language that compiles to plutus and an off-chain transaction builder. In this section we will review how to construct a transfer Ada transaction using Helios with a front-end web application.

Wallet

You will need a Chrome browser wallet extension installed in your browser. For the examples in this book, we will use [Nami wallet](#). After you have installed Nami wallet, please do the following to ensure your wallet is on the correct network.

1. Select the Extensions icon on your browser and select Nami wallet
2. Select the account icon image (top right)
3. Select Settings near the bottom of the popup window
4. Select Network
5. Select Preprod in the drop down menu
6. Go back to the main view and select the account icon image again
7. Now select New Account
8. Create another account name & password
9. You can switch between accounts by selecting the account icon image

Testnet Faucet

You will need to get some test Ada.

1. Go to the Nami account you want to receive some Ada with and select the Receive button
2. Copy the receiving address to your clipboard
3. Open a new browser tab and go to the [Cardano testnet faucet](#) page
4. In the Environment dropdown, select the Preprod Network
5. In the Address field, past the receiving address you copied in step 2
6. Select Request Funds
7. You may have to wait 10-60 seconds before the funds are in your wallet.

Note: you can only request test Ada once every 24 hours.

Expose Port

To be able to access a web app with Demeter, you will need to expose the port that the web app binds to. The default port is 3000, so we will expose this port and will be provided with a URL to access the web application.

1. Select your workspace on your Demeter Dashboard
2. Select the Exposed Ports tab
3. Select Expose Port+ button
4. Enter a port name (eg Next.js) and port number (eg 3000)

Running Next.js Application

In a VSCode Web Terminal window, execute the following commands to setup and then start the Next.js application

```
$ cd transfer-ada  
$ npm install  
$ npm run dev
```

Use the Exposed Port URL provided above to access the next.js application.

Test Drive

With the Next.js application now running, select the Nami selector to connect your wallet.

The screenshot shows a web browser window with the URL "3000-ruthless-language-wkwiq7.us1.demeter.run". The main title is "Helios Tx Builder". Below it is a "Connect to your wallet" section containing a radio button labeled "Nami" which is currently unselected (grayed out).

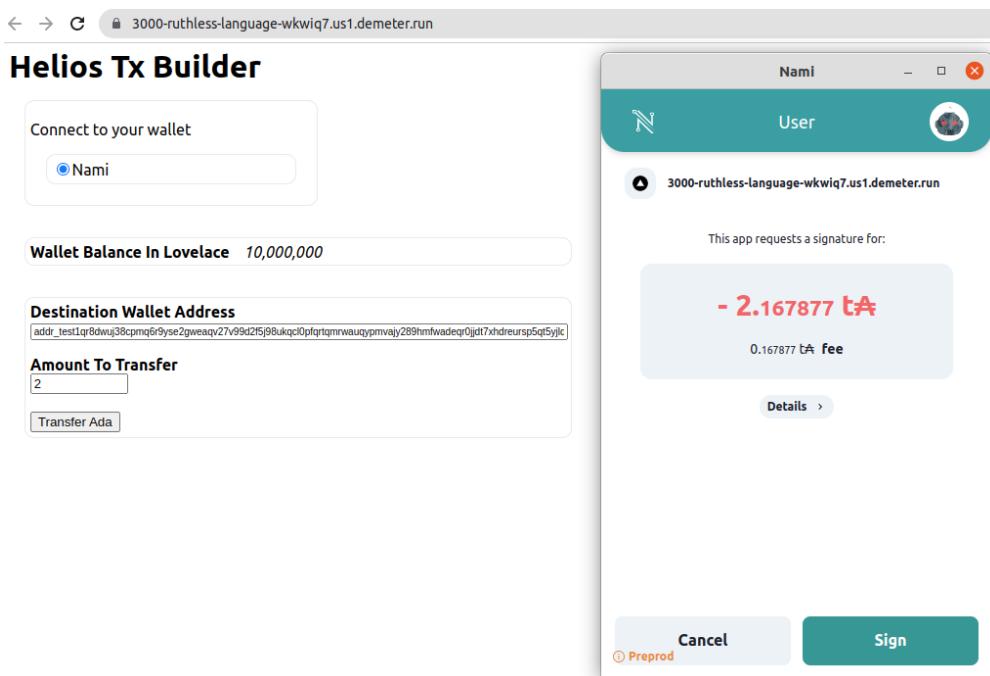
You will now see the following showing the available lovelace balance for the wallet currently selected.

The screenshot shows the "Helios Tx Builder" interface after selecting the "Nami" wallet. It displays the "Wallet Balance In Lovelace" as "10,000,000". Below that are sections for "Destination Wallet Address" (with a placeholder "Enter User Wallet Address") and "Amount To Transfer" (with a placeholder "Enter Amount"). At the bottom is a "Transfer Ada" button.

For the other Nami account that does not have any account balance, switch to that account and copy a receiving address. Make sure you **switch back** to the account that has funds available to transfer.

Enter the receiving address and the amount of Ada you want to transfer and select the Transfer Ada button.

The Nami wallet should appear for you to sign the transaction.



After you sign by entering your wallet password, you should see the following success message

The screenshot shows a web browser window with the URL `3000-ruthless-language-wkwiq7.us1.demeter.run`. The main title is "Helios Tx Builder". Below it, there's a button labeled "Connect to your wallet" with a dropdown menu showing "Nami" selected. A large callout box contains the text "Transaction Success!!!", the TxId [84225ba3e489d39b33676b675d0d8429e12bbc5ce770326474271123a6ee02f3](#), and a note: "Please wait until the transaction is confirmed on the blockchain and reload this page before doing another transaction".

You can select the TxId link to confirm the transaction using the blockchain explorer [cexplorer](#) or verify in your Nami wallet.

Under The Hood

The first step is detecting if the browser wallet exists.

```
const checkIfWalletFound = async () => {

  let walletFound = false;
  const walletChoice = whichWalletSelected;
  if (walletChoice === "nami") {
    walletFound = !!window?.cardano?.nami;
  }
  return walletFound;
}
```

The second step is creating an API object that the Tx builder will be able to use.

```
const enableWallet = async () => {

  try {
    const walletChoice = whichWalletSelected;
    if (walletChoice === "nami") {
      const handle: Cip30Handle
        = await window.cardano.nami.enable();
      const walletAPI = new Cip30Wallet(handle);
      return walletAPI;
    }
  } catch (err) {
    console.log('enableWallet error', err);
  }
}
```

Now the Helios Tx can be built using WalletHelper to get key information such as the wallet UTXOs and the change address of the wallet.

```
...
const adaAmountVal = new Value(BigInt((adaQty)*1000000));

// Get wallet UTXOs
const walletHelper = new WalletHelper(walletAPI);
const utxos = await walletHelper.pickUtxos(adaAmountVal);

// Get change address
const changeAddr = await walletHelper.changeAddress;

// Start building the transaction
const tx = new Tx();
tx.addInputs(utxos[0]);

// Add the destination address and the amount of Ada to send
tx.addOutput(new TxOutput(Address.fromBech32(address), adaAmountVal));

const networkParams = new NetworkParams(
  await fetch(networkParamsUrl)
  .then(response => response.json())
)

// Send any change back to the buyer
await tx.finalize(networkParams, changeAddr);

console.log("Verifying signature...");
const signatures = await walletAPI.signTx(tx);
tx.addSignatures(signatures);

console.log("Submitting transaction...");
const txHash = await walletAPI.submitTx(tx);

...
```

Minting

Minting is the on-chain process of creating new native tokens that are included in UTXO(s) and locked at an address. A native token has the same properties as Ada and is considered a first class citizen on the blockchain. A minting policy script is an efficient mechanism for creating/burning tokens and defines the rules for a minting or burning transaction.

NFT

A NFT is a non-fungible token that can't be divisible which means that there is only one in existence. So the best way to ensure you are only creating one unique token is to leverage the unique property of a UTXO. If we recall, a UTXO is an unspent transaction output. So once a UTXO is spent, it is no longer an ***unspent*** transaction output. So as long as we include a UTXO in our transaction input and spend it, no other transaction will be able to spend that UTXO.

Minting Smart Contract

Every Helios smart contract must contain a `func main` where the validation logic occurs. To specify the type of plutos script, we state on the first line `minting` and the name of the program NFT.

```
minting nft
```

Next we need to specify the UTXO that will be used as an input and hard code it as a parameter value. Therefore, create a `TxOutputId` object with both the transaction ID of "#6e1...996" and a transaction index of 0.

```
const TX_ID: ByteArray = #6e1...996
const txId: TxId = TxId::new(TX_ID)
const outputId: TxOutputId = TxOutputId::new(txId, 0)
```

Since we set a UTXO as a contract parameter, the minting policy hash will be different (unique) based on the value of this parameter.

The `func main` is a required function for all Helios plutos scripts. This is where you can get access to important objects such as the `ScriptContext`. The `ScriptContext` object has information about the current transaction (#1) which is used in the validation logic. We also get the minting policy hash (#2) of this minting policy script and use it to construct an `Asset Class` object (#3) for the token we are minting. Finally, we get the token that was actually minted (#4) as part of this transaction via the `ScriptContext` `Tx` object.

```
func main(ctx: ScriptContext) -> Bool {
    tx: Tx = ctx.tx; // #1
    mph: MintingPolicyHash = ctx.get_current_minting_policy_hash(); // #2
    assetclass: AssetClass = AssetClass::new(
        mph,
        "NTF Token Name".encode_utf8()
    ); // #3
    value_minted: Value = tx.minted; // #4
}
```

Now we are ready to do the actual validation. First we will check that the NFT has the correct minting policy hash, token name, quantity of 1 and has been minted as part of this transaction.

```
(value_minted == Value::new(assetclass, 1)).trace("NFT1: ")
```

Second, we check that the UTXO that we specified as a parameter to the smart contract is actually included as a transaction input.

```
tx.inputs.any((input: TxInput) -> Bool {  
    (input.output_id == outputId).trace("NFT2: ")  
}
```

The `.trace("NFT: ")` function will generate a trace error message with the evaluated value if the validator returns false. This is very helpful to isolate what conditions are true and which one is false.

So, all together, a complete NFT minting smart contract is as follows.

```
minting nft  
  
const TX_ID: ByteArray = #6e1...996  
const txId: TxId = TxId::new(TX_ID)  
const outputId: TxOutputId = TxOutputId::new(txId, 0)  
func main(ctx: ScriptContext) -> Bool {  
    tx: Tx = ctx.tx;  
    mph: MintingPolicyHash = ctx.get_current_minting_policy_hash();  
    assetclass: AssetClass = AssetClass::new(  
        mph,  
        "NTF Token Name".encode_utf8()  
    );  
    value_minted: Value = tx.minted;  
    // Validator logic starts  
    (value_minted == Value::new(assetclass, 1)).trace("NFT1: ") &&  
    tx.inputs.any((input: TxInput) -> Bool {  
        (input.output_id == outputId).trace("NFT2: ")  
    }  
}
```

Compiling The Script

We have a number of options to get smart contract code onto the blockchain.

- Store the script inside the Next.js app and compile it in the browser and then submit it as part of a transaction
- Pre-compile the script ahead of time and submit it as part of a transaction
- Pre-compile the script ahead of time and load it on-chain as a pl uterus reference script. Other transactions can simply use the on-chain reference script and do not need a copy of it.

For this simple contract, we will just include it in the Next.js app we built, compile it on the fly and submit the transaction. The fact that the Helios compiler is written in javascript gives us a lot of flexibility on when and where we compile to pl uterus code.

Below is the on-chain and off-chain code for the mintNFT function. It includes dynamic compiling of Helios code with runtime variables as contract parameters. Also note that there is a specific Metadata data type that needs to be created so it can be attached to a transaction.

```

const mintNFT = async (params : any) => {

    const address = params[0];
    const name = params[1];
    const description = params[2];
    const img = params[3];
    const minAda: number = 2000000; // minimum Ada for NFT
    const maxTxFee: number = 500000; // max estimated tx fee
    const minChangeAmt: number = 1000000; // min Ada for change
    const minAdaVal = new Value(BigInt(minAda));
    const minUTXOVal = new Value(BigInt(minAda + maxTxFee + minChangeAmt));

    // Get wallet UTXOs
    const walletHelper = new WalletHelper(walletAPI);
    const utxos = await walletHelper.pickUtxos(minUTXOVal);
    // Get change address
    const changeAddr = await walletHelper.changeAddress;
    // Determine the UTXO used for collateral
    const colatUtxo = await walletHelper.pickCollateral();
    // Start building the transaction
    const tx = new Tx();
    // Add the UTXOs as inputs
    tx.addInputs(utxos[0]);
}

```

```

const mintScript =`minting nft

const TX_ID: ByteArray = #` + utxos[0][0].txId.hex + `

const txId: TxId = TxId::new(TX_ID)
const outputId: TxOutputId =
    TxOutputId::new(txId, ` + utxos[0][0].utxoIdx + `)

func main(ctx: ScriptContext) -> Bool {
    tx: Tx = ctx.tx;
    mph: MintingPolicyHash = ctx.get_current_minting_policy_hash();

    assetclass: AssetClass = AssetClass::new(
        mph,
        "` + name + `".encode_utf8()
    );
    value_minted: Value = tx.minted;

    // Validator logic starts
    (value_minted == Value::new(assetclass, 1)).trace("NFT1: ") &&
    tx.inputs.any((input: TxInput) -> Bool {
        (input.output_id == outputId).trace("NFT2: ")
    }
)
}`

// Compile the helios minting script
const mintProgram = Program.new(mintScript).compile(optimize);
// Add the script as a witness to the transaction
tx.attachScript(mintProgram);
// Construct the NFT that we will want to send as an output
const nftTokenName = ByteArrayData.fromString(name).toHex();
const tokens: [number[], bigint][] = [[hexToBytes(nftTokenName),
                                         BigInt(1)]];

```

```

// Create an empty Redeemer because we must always send a Redeemer with
// a plutus script transaction even if we don't actually use it.
const mintRedeemer = new ConstrData(0, []);
// Indicate the minting we want to include as part of this transaction
tx.mintTokens(
    mintProgram.mintingPolicyHash,
    tokens,
    mintRedeemer
)
// Construct the output and include both the minimum Ada as
// well as the minted NFT
tx.addOutput(new TxOutput(
    Address.fromBech32(address),
    new Value(minAdaVal.lovelace, new Assets([[mintProgram.mintingPolicyHash,
        tokens]]))
));
// Add the collateral utxo
tx.addCollateral(colatUtxo);
const networkParams = new NetworkParams(
    await fetch(networkParamsUrl)
        .then(response => response.json())
)
// Attached the metadata for the minting transaction
tx.addMetadata(721, {"map":
    [[mintProgram.mintingPolicyHash.hex,
        {"map": [[name, { "map": [[[name, name],
            ["description", description],
            ["image", img]
        ]]]}
    ]]]}
})
);

```

```
// Send any change back to the buyer
await tx.finalize(networkParams, changeAddr);

console.log("Verifying signature..."); 
const signatures = await walletAPI.signTx(tx);
tx.addSignatures(signatures);

console.log("Submitting transaction..."); 
const txHash = await walletAPI.submitTx(tx);

console.log("txHash", txHash.hex );
setTx({ txId: txHash.hex });
}
```

Test Drive

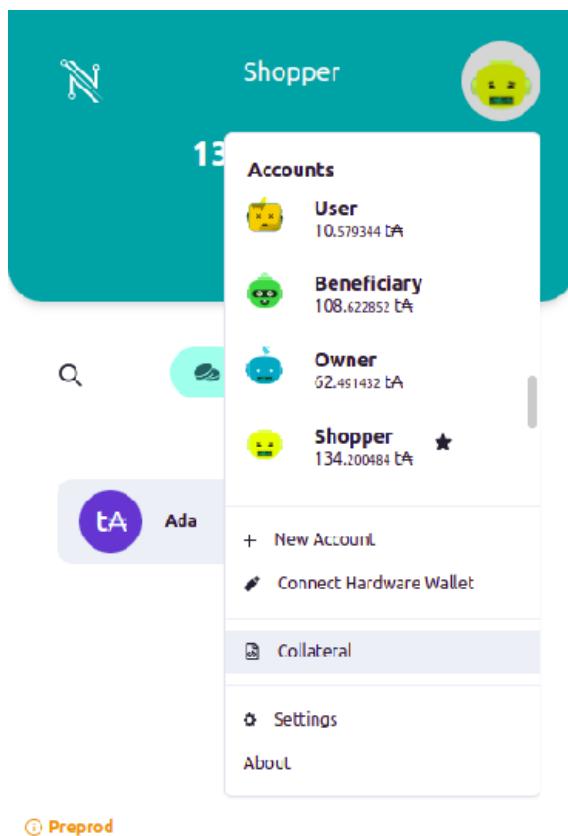
You can now mint your own NFT by starting up the Next.js application and submitting the transaction.

```
$ cd nft/app  
$ npm install  
$ npm run dev
```

Make sure you expose port 3000 for your workspace in Demeter Run, on the Exposed Ports tab. Then use the URL on the Exposed Ports tab to access the Next.js application.

Collateral

A small amount of Ada (~5 Ada) is used as collateral to help protect the network against spam attacks when executing smart contracts. Open up your Nami wallet and go to the account you want to mint the NFT from. Select the account icon and then select Collateral in the popup window.



Submit Tx

Select your wallet and then enter in the required information

The screenshot shows the Helios Tx Builder interface for minting an NFT. At the top, there's a browser header with back, forward, and refresh buttons, and the URL '3000-precious-baseball-lfkchu.us1.demeter.run'. Below the header, the title 'Helios Tx Builder' is displayed in a large, bold, black font. A 'Connect to your wallet' button is visible, with 'Nami' selected. A 'Wallet Balance In Lovelace' indicator shows 1,455,260,289. The main form area contains fields for 'Destination Wallet Address' (containing a long hex string), 'NFT Token Name' (Mad Dog), 'NFT Description' (Crazy dog that loves treats), and 'NFT Image' (containing a long hex string). A 'Mint NFT' button is at the bottom of the form.

Connect to your wallet

wallet Nami

Wallet Balance In Lovelace 1,455,260,289

Destination Wallet Address
addr_test1qz7gedd4dv6y57dxc0l2awp2uq08zt5yguyuzrs2qvncr5378p8rj3dgxkjg5knpa3uvtvwgqd48t666ad05eaxasgo5prv

NFT Token Name
Mad Dog

NFT Description
Crazy dog that loves treats

NFT Image
QmckPQPzthJkS9GRSxdw2SzSinAwdDW34xDZd26MrV5S

Mint NFT

When you select the Mint NFT button and are asked to sign the transaction, you can go to the Details tab in Nami wallet and see the NFT being minted including the metadata.

The screenshot shows two windows side-by-side. The left window is titled 'Helios Tx Builder' and contains fields for 'Destination Wallet Address' (addr_test1...asqq5orvx2), 'NFT Token Name' (Mad Dog), 'NFT Description' (Crazy dog that loves treats), and 'NFT Image' (QmckPQPzthJlS9GRSxw2SzSinAvdDW34xDZd26MvES). A button labeled 'Mint NFT' is at the bottom. The right window is titled 'Nami' and shows the transaction details: 'Recipients' (addr_test1...asqq5orvx2) and '2 tA + 1 Asset'. Below this is the 'Metadata' section, which displays the JSON data for the NFT:

```
{
  "721": {
    "5321f22eab892802c853ba09da2c4401ff6d7c60c8cc3f41adab50b1": {
      "Mad Dog": {
        "description": "Crazy dog that loves treats",
        "image": "QmckPQPzthJlS9GRSxw2SzSinAvdDW34xDZd26MvES",
        "name": "Mad Dog"
      }
    }
  }
}
```

The 'Signing keys' section shows 'payment' selected. A 'Back' button is at the bottom right.

After submitting the transaction and waiting 10-60 seconds, you should be able to see the NFT on the blockchain explorer.

The screenshot shows the 'Helios Tx Builder' interface with a success message: 'Transaction Success!!!'. It displays the TxId: 2160df0b392543cfa7d6b163c1df0be4584f867b3636b66feb7bf9b0ac3dc1d3. A note below says: 'Please wait until the transaction is confirmed on the blockchain and reload this page before doing another transaction'.

<https://preprod.cexplorer.io/tx/2160df0b392543cfa7d6b163c1df0be4584f867b3636b66feb7bf9b0ac3dc1d3>

Cexplorer

To see the NFT on Cexplorer, do the following steps:

1. Select the TxId link in the Transaction Success box
2. Scroll down and select the Mint Tab
3. Select that Asset (in this case Mad Dog)
4. And then you will see all the properties of this NFT

The screenshot shows the Cexplorer.io interface for viewing an NFT. The URL in the address bar is `preprod.cexplorer.io/asset/asset1urm04nzzj2qru43p08swg7rzztw9kl7ru73hdy/preview#data`. The left sidebar has sections for CARDANO EXPLORER (Dashboard, Watchlist, Pools, Assets, Blocks, Transactions, dApps, Metadata, More), EDUCATION (Articles, Videos, Wiki), and ANALYTICS (Decentralization, Network). The main content area shows the NFT details for 'Mad Dog'. The title is '★ Mad Dog > NFT preview'. It includes a 'Fingerprint' link, 'Name (onchain)' (Mad Dog, Encoded: 4d616420446f67), and an 'Onchain data (epoch snapshot)' section with 'Supply' (1) and 'Owner' (stake_test...7n4dr). Below this is a navigation bar with links for Preview, TXs, Mints, Metadata, Owners, and Embed. The 'Metadata' section displays the JSON object:

```
{  
  "name": "Mad Dog",  
  "image": "QmckPQPzthJjks9GRSxdw25zSinAwdDW34XXDZd26MrV5S",  
  "description": "Crazy dog that loves treats"  
}
```

Multisig NFT

The reason why you may want to have multi-signature (multisig) signing during an NFT mint is that you want the buyer to be able to confirm what he is getting before it is actually minted and submitted to the blockchain. By including the public key hashes of both the buyer and seller in the minting policy, we can ensure that only when both signatures have been obtained will we be able to mint the NFT.

Your application will typically need to store the transaction and witness updates. In this example, the Next.js application stores the transaction in memory for simplicity. This could also have been stored in a database, filesystem or even included in a message to the recipients who need to sign the transaction and then pass it along to the next witness.

We will use the NFT minting script from the previous section and simply add 2 signers that must include their signature in the transaction. Since we are able to dynamically compile the pl uterus script in the browser, we will be able to add the signers to the pl uterus script as we build it.

Code Changes

Here is what the updated off-chain and on-chain code and NFT minting script will look like.

```
const mintNFT = async (params : any) => {

    const address = params[0];
    const name = params[1];
    const description = params[2];
    const img = params[3];
    const sellerAddr = params[4];

    const buyerPkh = Address.fromBech32(address).pubKeyHash;
    const sellerPkh = Address.fromBech32(sellerAddr).pubKeyHash;
    const minAdaVal = new Value(BigInt(2000000)); // minimum Ada needed to send an NFT

    // Get wallet UTXOs
    const walletHelper = new WalletHelper(walletAPI);
    const utxos = await walletHelper.pickUtxos(minAdaVal);
    // Get change address
    const changeAddr = await walletHelper.changeAddress;
    // Determine the UTXO used for collateral
    const colatUtxo = await walletHelper.pickCollateral();
    // Start building the transaction
    const tx = new Tx();
    // Add the UTXO as inputs
    tx.addInputs(utxos[0]);

    const mintScript =`minting nft

    const TX_ID: ByteArray = #` + utxos[0][0].txId.hex + `

    const txId: TxId = TxId::new(TX_ID)
    const outputId: TxOutputId = TxOutputId::new(txId, ` + utxos[0][0].utxoIdx + `)

    const BUYER: PubKeyHash = PubKeyHash::new(#` + buyerPkh.hex + `)
    const SELLER: PubKeyHash = PubKeyHash::new(#` + sellerPkh.hex + `)
```

```

func main(ctx: ScriptContext) -> Bool {
    tx: Tx = ctx.tx;
    mph: MintingPolicyHash = ctx.get_current_minting_policy_hash();
    assetclass: AssetClass = AssetClass::new(
        mph,
        " ` + name + ` ".encode_utf8()
    );
    value_minted: Value = tx.minted;

    // Validator logic starts
    (value_minted == Value::new(assetclass, 1)).trace("NFT1: ") &&
    (tx.inputs.any((input: TxInput) -> Bool {
        (input.output_id == outputId).trace("NFT2: ")
    })) &&
    tx.is_signed_by(BUYER).trace("NFT3: ") &&
    tx.is_signed_by(SELLER).trace("NFT4: ")
)
}

// Compile the helios minting script
const mintProgram = Program.new(mintScript).compile(optimize);
// Add the script as a witness to the transaction
tx.attachScript(mintProgram);
// Construct the NFT that we will want to send as an output
const nftTokenName = ByteArrayData.fromString(name).toHex();
const tokens: [number[], bigint][] = [[hexToBytes(nftTokenName), BigInt(1)]];

// Create an empty Redeemer because we must always send a Redeemer with
// a plutus script transaction even if we don't actually use it.
const mintRedeemer = new ConstrData(0, []);
// Indicate the minting we want to include as part of this transaction
tx.mintTokens(
    mintProgram.mintingPolicyHash,
    tokens,
    mintRedeemer
)

```

```

// Construct the output and include both the minimum Ada as well as the minted NFT
tx.addOutput(new TxOutput(
    Address.fromBech32(address),
    new Value(minAdaVal.lovelace, new Assets([[mintProgram.mintingPolicyHash,
tokens]])))
));
// Add the collateral utxo
tx.addCollateral(colatUtxo);
// Add buyer and seller required PKHs for the tx
tx.addSigner(buyerPkh);
tx.addSigner(sellerPkh);

const networkParams = new NetworkParams(
    await fetch(networkParamsUrl)
        .then(response => response.json())
)
// Attached the metadata for the minting transaction
tx.addMetadata(721, {"map": [[mintProgram.mintingPolicyHash.hex, {"map": [[name,
{
    "map": [["name", name],
    ["description", description],
    ["image", img]
]
}
]]}
]]}
);
console.log("tx before final", tx.dump());
// Send any change back to the buyer
await tx.finalize(networkParams, changeAddr);
console.log("tx after final", tx.dump());
// Store the transaction so it can be signed by the buyer and the seller
setTxBodyBuyer(tx);
}

```

New Functions

Next, we need to add 2 new functions in the off-chain code to handle the signing of the buyer and the signing and submitting of the seller.

```
const buyerSign = async () => {

    console.log("Verifying buyer signature...");
    const signatures = await walletAPI.signTx(txBodyBuyer);
    txBodyBuyer.addSignatures(signatures);

    console.log("buyerSigned", txBodyBuyer);
    setTxBodySeller(txBodyBuyer);

}

const sellerSignSubmit = async () => {

    console.log("Verifying seller signature...");
    const signatures = await walletAPI.signTx(txBodySeller);
    txBodySeller.addSignatures(signatures);

    console.log("Submitting transaction...");
    const txHash = await walletAPI.submitTx(txBodySeller);

    console.log("txHash", txHash.hex);
    setTx({ txId: txHash.hex });
}
```

Test Drive

The first screen will require the seller address which will be converted into the seller public key hash (PKH). The buyer (destination) address will be converted into the buyer PKH as well.

The screenshot shows the Helios Tx Builder interface. At the top, it displays the date and time: "Jan 23 09:48". Below that is the title "Helios Tx Builder" and a URL: "3000-material-baseball-zwzft4.us1.demeter.run". A "Connect to your wallet" button is present, with "Nami" selected. The main area contains fields for NFT creation:

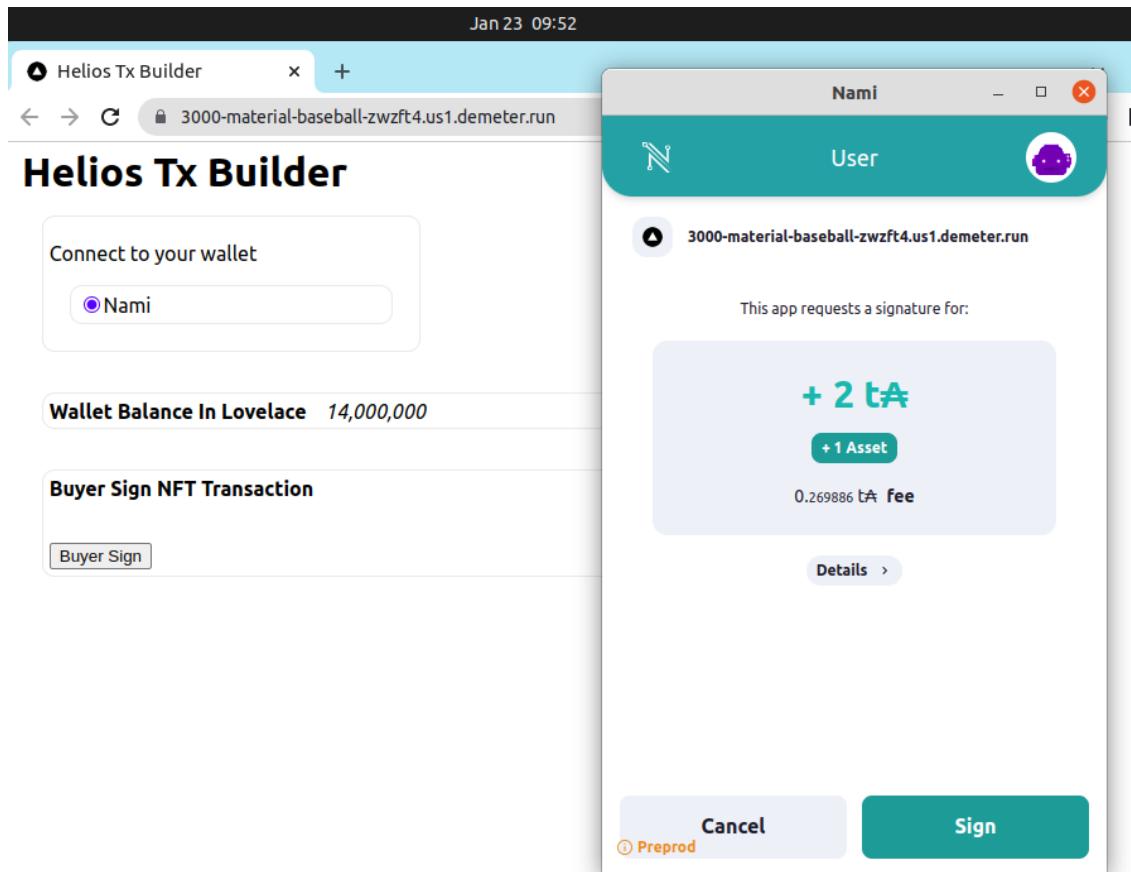
- Buyer Wallet Address:** addr_test1qq5vczw9q0tagsk5v8k5tr35kzd06ur3grdv7afmt3us5mdq56r869vgx0wnpw5cerwfgs5glfrnl9069dys57z0lgvq7vhg
- NFT Token Name:** Mad Dog
- NFT Description:** Crazy dog that loves treats
- NFT Image:** QmckPQPzthJjkS9GRSxdw2SzSinAwdDW34xDZd26MrV5S
- Seller Wallet Address:** addr_test1qrrkvmepf8lzh6mj4yn237f63tm4tzu7gchahvlmqnn2jkevlv9p983fmyphtfw2g6nlplq60pv4207lwwhqf97tj68s58rzv7

A "Mint NFT" button is located at the bottom left of the form.

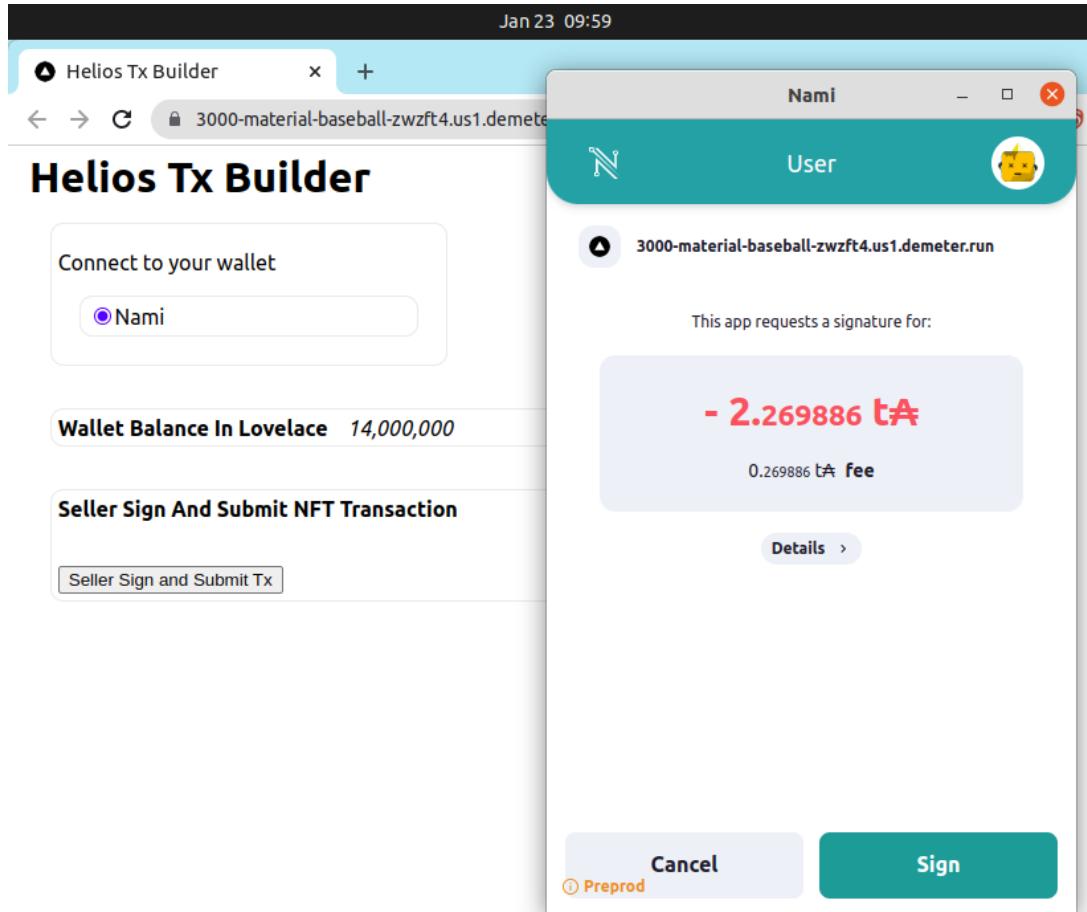
When the Mint NFT button is selected, the Buyer Sign button will show. As the transaction is being built, it will be stored as a state variable inside the Next.js application.

The screenshot shows the Helios Tx Builder interface. At the top, there is a header bar with the date "Jan 23 09:49" and a title "Helios Tx Builder". Below the header, there is a navigation bar with icons for back, forward, and refresh, followed by a URL "3000-material-baseball-zwzft4.us1.demeter.run". The main content area is titled "Helios Tx Builder". Inside this area, there is a section labeled "Connect to your wallet" with a dropdown menu showing "Nami" selected. Below this, there is a section labeled "Wallet Balance In Lovelace" with the value "14,000,000". At the bottom, there is a section labeled "Buyer Sign NFT Transaction" with a "Buyer Sign" button.

Now, we will switch the account in Nami wallet to the buyer account which is the same account that we used to provide the buyer address. Once that is done you will see the following request to sign the transaction.



If you selected an account that is not the correct buyer account, you will not be able to sign the transaction because the PKH will not match what is in the minting contract. Once you sign with the correct buyer wallet, you will now see the button for the seller to sign. Switch to the seller wallet account and select the sign and submit tx button.



Once you sign the transaction as the seller, you should now see that the transaction was submitted and the NFT has been minted.

The screenshot shows the Helios Tx Builder interface with the following details:

- Top bar: Jan 23 10:03
- Title bar: Helios Tx Builder
- Address bar: 3000-material-baseball-zwzft4.us1.demeter.run
- Main title: Helios Tx Builder
- Section: Connect to your wallet (selected wallet: Nami)
- Message: Transaction Success!!!
- Text: TxId [ed53f04ef8668c7208a94504aa5400640bc9d75a6aa3f927e0fb3b788d5d963d](#)
- Text: Please wait until the transaction is confirmed on the blockchain and reload this page before doing another transaction

The transaction is confirmed in cexplorer.io.

The screenshot shows the cexplorer.io transaction details page for the tx [ed53f04ef8668c7208a94504aa5400640bc9d75a6aa3f927e0fb3b788d5d963d](#).

Transaction Summary:

- Date: 2m38s ago
- Epoch: 47
- Block: 551,076
- Slot: 18,802,989 (epoch slot 140,589)
- Total Output: 9.73 ADA (0.30 LRC, 0.000018)
- Fee: 0.27 ADA
- Outputs: 2

Script Components:

- Assurance: 9/8
- Transaction Size: 1.91 kB (0.83 kB) - this tx 82%, other tx 18%
- Script Size: 1.08 kB
- Block Size (TX Count): 2.34 kB (2) - available 97%

Minted by: poolz063u...jwOe7

Content: ed53f04ef8...d963d

Contracts: addr...testl...8rzv7

Collateral: addr...testl...8rzv7

Mint: 773A

Metadata: addr...testl...vhgn8

Script: Mad Dog 1

Validators

A validator is used to confirm if a transaction is able to spend UTXOs locked at the validator script address. A Redeemer, Datum and UTXOs are all required as part of a transaction when executing a validator smart contract script.

Vesting

A vesting smart contract locks up assets for a specific period of time and then allows the beneficiary to access them once a deadline has passed. In this example from the Helios documentation, there is also the ability to cancel the vested tokens if the deadline has not already passed.

We will introduce the Datum and Redeemer which are key components of a smart contract transaction. The Datum is used to store persistent data on-chain. The Redeemer is used to tell the smart contract what type of transaction is occurring. In this case, the transaction is either a Cancel or Claim and processes the validation logic accordingly.

The Datum is a struct and looks like the following where Time is in POSIX second format.

```
struct Datum {  
    creator: PubKeyHash  
    beneficiary: PubKeyHash  
    deadline: Time  
}
```

The Redeemer is an enum datatype and is as follows.

```
enum Redeemer {  
    Cancel  
    Claim  
}
```

The complete validator Helios code is as follows. The Datum is passed into the main function along with the Redeemer and Script Context. We obtain the current time by pulling out the time range of this transaction using `tx.time_range.start`; We will see in the off-chain code later in this section on how to set the time range for this transaction.

```
spending vesting

struct Datum {
    creator: PubKeyHash
    beneficiary: PubKeyHash
    deadline: Time
}

enum Redeemer {
    Cancel
    Claim
}

func main(datum: Datum, redeemer: Redeemer, context: ScriptContext) -> Bool {
    tx: Tx = context.tx;
    now: Time = tx.time_range.start;
    redeemer.switch {
        Cancel => {
            // Check if deadline hasn't passed
            (now < datum.deadline).trace("VS1: ") &&

            // Check that the owner signed the transaction
            tx.is_signed_by(datum.creator).trace("VS2: ")
        },
        Claim => {
            // Check if the deadline has passed.
            (now > datum.deadline).trace("VS3: ") &&

            // Check that the beneficiary signed the transaction.
            tx.is_signed_by(datum.beneficiary).trace("VS4: ")
        }
    }
}
```

When dealing with more complex smart contracts, it is easier to work on it directly as a separate file where you can compile it beforehand. Additionally, there is a VS Code extension for Helios that you can use as well.

I would also recommend using deno to compile the smart contract to get the generated plutus code.

To setup deno, do the following using the VS Code Web terminal window.

```
$ cd ~/workspace/repo
```

Install deno testing a simple welcome typescript program.

```
$ npx deno-bin run https://deno.land/std/examples/welcome.ts
```

Next, go to the vesting directory and execute the following deno command to compile the Helios code.

```
$ cd vesting  
$ npx deno-bin run --allow-read --allow-write ./src/deploy-vesting.js
```

The compiler will give you errors if there are any syntax or type related errors. So you can fix those now and not later when you are running your code in the Next.js application. You can also see the resulting files located in the deploy directory

```
$ ls -l deploy/  
total 12  
-rw-rw-r-- 1 lawrence lawrence 63 Jan 19 10:58 vesting.addr  
-rw-rw-r-- 1 lawrence lawrence 56 Jan 19 10:58 vesting.hash  
-rw-rw-r-- 1 lawrence lawrence 788 Jan 19 10:58 vesting.plutus
```

Although we will not need these generated files for this example, there may be times when you need the generated plutus script, validator hash and/or validator address beforehand.

Once we confirm that the Helios source code compiles without errors, we will copy them over to the contracts directory.

```
$ cp src/vesting.hl contracts/
```

Next.js Setup

Now we need to set some environment variables that will be needed for this example. It is always best practice to control environment specific variables outside of the application code.

1. Using VS Code Web, select File -> Open
2. In the popup window enter the following path and filename /config/.bashrc
3. Authorize VS Code Web access if requested
4. Add the following lines to the bottom of the .bashrc file

```
export NEXT_PUBLIC_BLOCKFROST_API_KEY="get-your-blockfrost-api-key"
export NEXT_PUBLIC_BLOCKFROST_API="https://cardano-preprod.blockfrost.io/api/v0"
export NEXT_PUBLIC_NETWORK_PARAMS_URL="https://d1t0d7c2nekuk0.cloudfront.net/preprod.json"
```
5. Now, in the Terminal window type the following command to load these environment variables into your shell. These environment variables will automatically load next time you log in as well.
6. \$ source ~/.bashrc

Note: For step 4, you will need to set up and get your own [Blockfrost](#) account and api key.

Next.js Startup

Now we are ready to initialize and start up the Next.js application

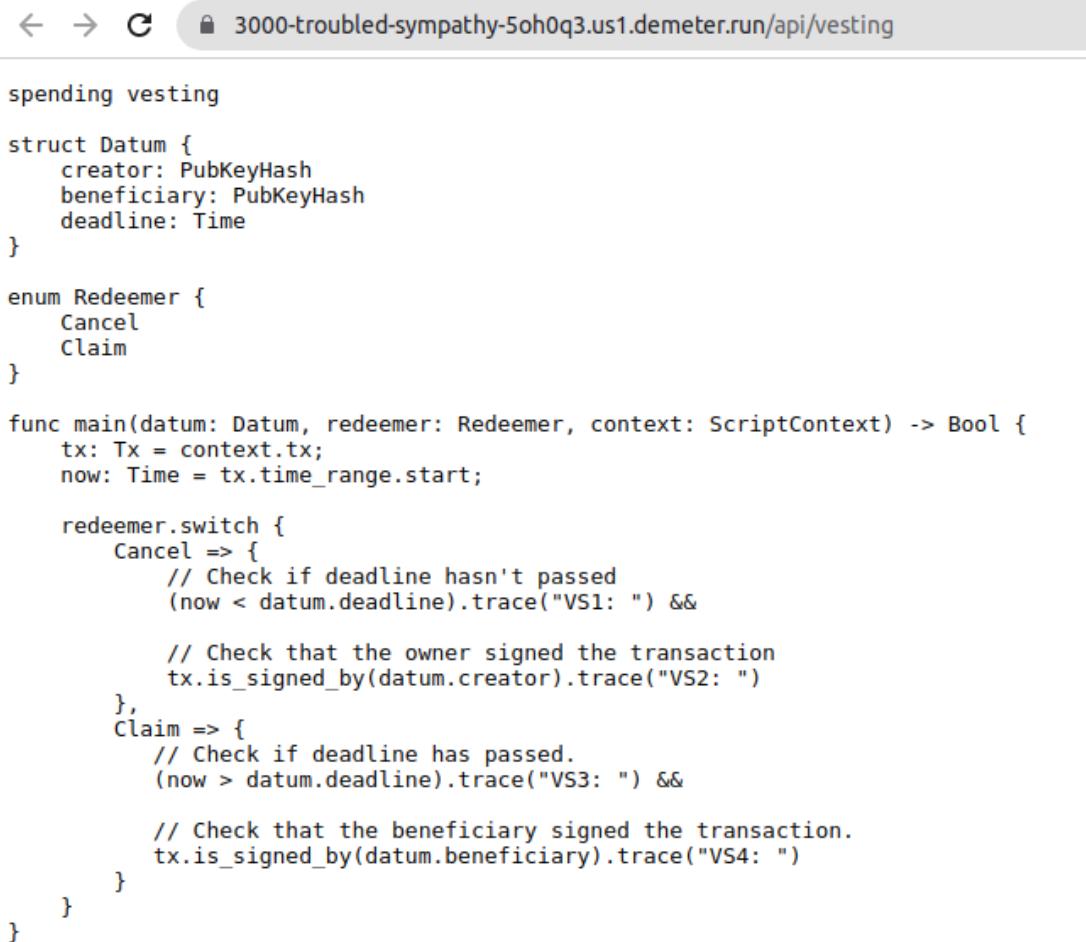
```
$ npm install  
$ npm run dev
```

Make sure you have exposed port 3000 on the Demeter Run workspace Exposed Port tab. Select the export port URL link to launch the application. Once you select your wallet, you should see.

The screenshot shows a web-based application titled "Helios Tx Builder". At the top, there's a header bar with back, forward, and refresh buttons, followed by a URL field containing "3000-troubled-sympathy-5oh0q3.us1.demeter.run". Below the header, the main title "Helios Tx Builder" is displayed in a large, bold font. A "Connect to your wallet" section contains a dropdown menu with "Nami" selected. Below this, a "View Smart Contract" button links to "vesting.hl". A "Wallet Balance In Lovelace" section shows a balance of "511,331,294". The interface is divided into several sections: "Beneficiary Wallet Address" (with an input field for "Enter Beneficiary Wallet Address"), "Amount Of Ada To Lock" (with an input field for "Enter Amount"), "Vesting Expiry Date" (with a date input field "mm/dd/yyyy" and a calendar icon), and a "Lock Ada" button. Another section for "Claim Funds" includes an input field for "Enter The Vesting Key" and a "Claim Funds" button. Finally, a "Cancel Vesting" section has an input field for "Enter The Vesting Key" and a "Cancel Vesting" button.

Smart Contract Viewer

We can verify the smart contract within the application by selecting the View Smart Contract link. This links to an API that reads the same file on the filesystem that is used during Helios Tx transaction builder construction.



The screenshot shows a browser window with the URL `3000-troubled-sympathy-5oh0q3.us1.demeter.run/api/vesting`. The page displays the source code of a Cardano smart contract. The code defines a struct `Datum` with fields `creator`, `beneficiary`, and `deadline`. It also defines an enum `Redeemer` with values `Cancel` and `Claim`. The `main` function takes a `Datum` and a `Redeemer` as parameters, along with a `ScriptContext`. It checks if the deadline hasn't passed (for `Cancel`) or if it has passed (for `Claim`). In both cases, it checks if the owner or beneficiary signed the transaction.

```
spending vesting

struct Datum {
    creator: PubKeyHash
    beneficiary: PubKeyHash
    deadline: Time
}

enum Redeemer {
    Cancel
    Claim
}

func main(datum: Datum, redeemer: Redeemer, context: ScriptContext) -> Bool {
    tx: Tx = context.tx;
    now: Time = tx.time_range.start;

    redeemer.switch {
        Cancel => {
            // Check if deadline hasn't passed
            (now < datum.deadline).trace("VS1: ") &&

            // Check that the owner signed the transaction
            tx.is_signed_by(datum.creator).trace("VS2: ")
        },
        Claim => {
            // Check if deadline has passed.
            (now > datum.deadline).trace("VS3: ") &&

            // Check that the beneficiary signed the transaction.
            tx.is_signed_by(datum.beneficiary).trace("VS4: ")
        }
    }
}
```

Lock Ada

Now, let's look at the off-chain Helios TX builder code. We will focus on some of the key new areas of code that have been added for this example. The lockAda function creates a datum and populates it with form values and the PKH of the owner wallet.

```
const lockAda = async (params : any) => {
  const benAddr = params[0] as string;
  const adaQty = params[1] as number;
  const dueDate = params[2] as string;
  const deadline = new Date(dueDate + "T00:00");
  const benPkh = Address.fromBech32(benAddr).pubKeyHash;
  const adaAmountVal = new Value(BigInt((adaQty)*1000000));

  ...
  // Construct the datum
  const datum = new ListData([new ByteArrayData(ownerPkh.bytes),
    new ByteArrayData(benPkh.bytes),
    new IntData(BigInt(deadline.getTime()))]);

  const inlineDatum = Datum.inline(datum);
  ...
```

The last change is to create a Tx Output to include both the Ada and the vesting key token.

```
...
// Construct the NFT that we will want to send as an output
const nftTokenName = ByteArrayData.fromString("Vesting Key").toHex();
const tokens: [number[], bigint][] = [[hexToBytes(nftTokenName), BigInt(1)]];

...
const lockedVal = new Value(adaAmountVal.lovelace,
  new Assets([[mintProgram.mintingPolicyHash, tokens]]));

// Add the destination address and the amount of Ada to lock & datum
tx.addOutput(new TxOutput(valAddr, lockedVal, inlineDatum));
...
```

Vesting Key Minting Policy

We also include an inline minting policy to create the vesting key token. This leverages the same technique that we used to mint a unique NFT and will be used to help locate the locked UTXO.

```
...
const mintScript =`minting nft

const TX_ID: ByteArray = #` + utxos[0][0].txId.hex + `
const txId: TxId = TxId::new(TX_ID)
const outputId: TxOutputId =
    TxOutputId::new(txId, ` + utxos[0][0].utxoIdx + `)

func main(ctx: ScriptContext) -> Bool {
    tx: Tx = ctx.tx;
    mph: MintingPolicyHash = ctx.get_current_minting_policy_hash();

    assetclass: AssetClass = AssetClass::new(
        mph,
        "Vesting Key".encode_utf8()
    );
    value_minted: Value = tx.minted;

    // Validator logic starts
    (value_minted == Value::new(assetclass, 1)).trace("NFT1: ") &&
    tx.inputs.any((input: TxInput) -> Bool {
        (input.output_id == outputId).trace("NFT2: ")
    }
)
}`

...
```

Claim Funds or Cancel Vesting

To claim or cancel from the vesting contract, the user must supply the vesting key token. We use this key to find the correct UTXO locked at the smart contract script address. The getKeyUtxo function does the lookup and returns a Helio UTXO Object.

```
// Get the utxo with the vesting key token at the script address
const getKeyUtxo = async (scriptAddress : string,
                           keyMPH : string, keyName : string ) => {

  const blockfrostUrl : string = blockfrostAPI + "/addresses/" +
    scriptAddress + "/utxos/" + keyMPH + keyName;

  let resp = await fetch(blockfrostUrl, {
    method: "GET",
    headers: {
      accept: "application/json",
      project_id: apiKey,
    },
  });

  if (resp?.status > 299) {
    throw console.error("vesting key token not found", resp);
  }
  const payload = await resp.json();

  if (payload.length == 0) {
    throw console.error("vesting key token not found");
  }
  const lovelaceAmount = payload[0].amount[0].quantity;
  const mph = MintingPolicyHash.fromHex(keyMPH);
  const tokenName = hexToBytes(keyName);

  const value = new Value(BigInt(lovelaceAmount),
    new Assets([[mph,
      [[tokenName, BigInt(1)]]]
    ]])
  );
}
```

```
return new UTxO(
    TxId.fromHex(payload[0].tx_hash),
    BigInt(payload[0].output_index),
    new TxOutput(
        Address.fromBech32(scriptAddress),
        value,
        Datum.inline(ListData.fromCbor(hexToBytes(payload[0].inline_datum)))
    )
);
}
```

Both claimFunds or cancelVesting functions are very similar. The code is almost identical to create a redeemer, get the UTXOs locked at the script address and confirm if the deadline has been reached.

```
...
// Create the Claim redeemer to spend the UTXO locked
// at the script address
const valRedeemer = new ConstrData(1, []);

// Get the UTXO that has the vesting key token in it
const valUtxo = await getKeyUtxo(valAddr.toBech32(), keyMPH,
        ByteArrayData.fromString("Vesting Key").toHex());

// Must include a redeemer to spend a UTXO at a script address
tx.addInput(valUtxo, valRedeemer);

// Send the value of the of the valUTXO to the recipient
tx.addOutput(new TxOutput(claimAddress, valUtxo.value));

// Specify when this transaction is valid from. This is needed so
// time is included in the transaction which will be used by the
// script. Add two hours for time to live and offset the current time
// by 5 mins.
const currentTime = new Date().getTime();
const earlierTime = new Date(currentTime - 5 * 60 * 1000);
const laterTime = new Date(currentTime + 2 * 60 * 60 * 1000);

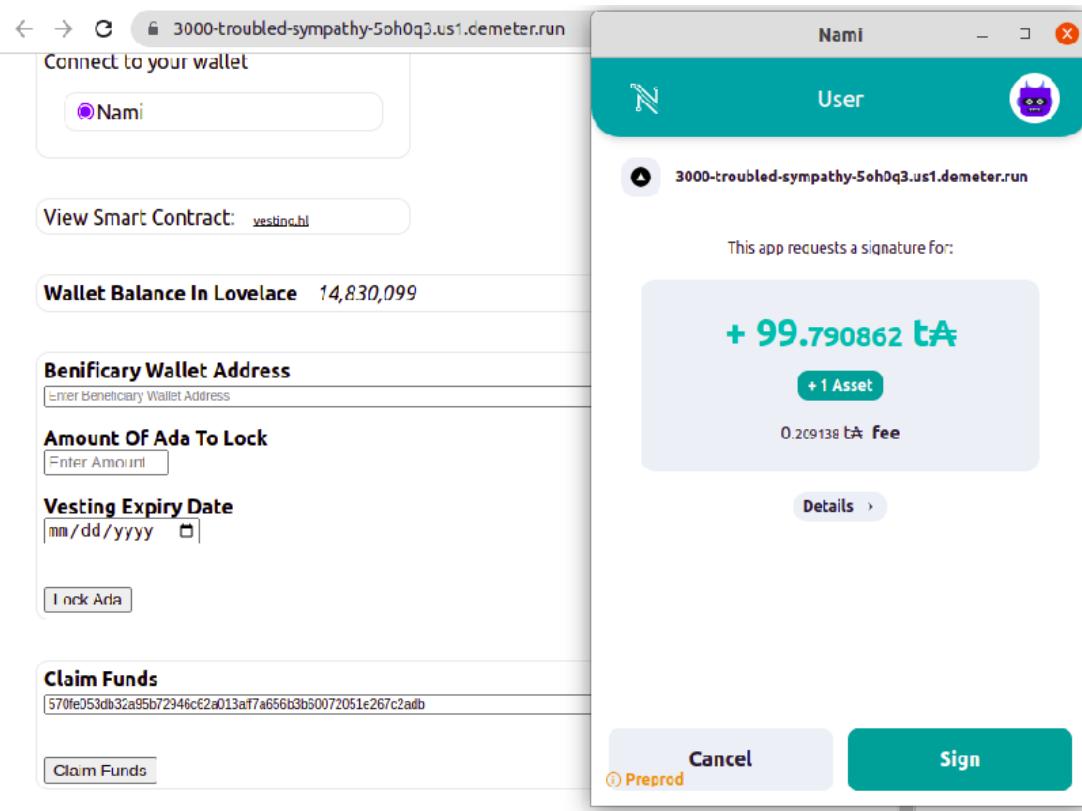
tx.validFrom(earlierTime);
tx.validTo(laterTime);
...
```

Test Drive

When the owner submits the transaction to lock up their funds at the smart contract, they are shown the vesting key which is used to unlock the funds afterwards.

The screenshot shows a web browser window with the URL `3000-troubled-sympathy-5oh0q3.us1.demeter.run`. The page title is "Helios Tx Builder".
A "Connect to your wallet" section shows a selected option "Nam".
A "View Smart Contract:" button links to `vesting.hl`.
A "Transaction Success!!!" box displays the TxId: `36ae88746977376c8f12d34a96a195d7d0d06929b4533e3eaa134b8259bf89c5`. It also contains the instruction: "Please wait until the transaction is confirmed on the blockchain and reload this page before doing another transaction".
A separate box at the bottom instructs: "Please copy and save your vesting key" followed by the key itself: **570fe053db32a95b72946c62a013aff7a656b3b60072051e267c2adb**, and "You will need this key to unlock your funds".

After entering the vesting key and selecting Claim Funds, the beneficiary needs to then sign and submit the transaction. As can be seen in this example, the beneficiary will be receiving 99.790862 tAda



On preprod explorer, both the Ada locked and the vesting key token has been transferred to the beneficiary. The smart contract allowed this transaction to succeed because the deadline was set in the past and the beneficiary wallet used had the correct PKH.

The screenshot shows the Cexplorer.io preprod interface. The URL in the address bar is `preprod.cexplorer.io/tx/f527d6db27bbcd9ac8bcf4d4b4f37f5764d20ed278355e2fb8af9ac8c193dd9`. The page displays a transaction details page for a Cardano transaction. The transaction was made 1m54s ago and is identified by hash `# f527d6db27...93dd9`. The total amount is `109.62A`. The transaction details show three outputs:

- 100A to `addr_test1...qekxy` (Vesting Key -1)
- 9.83A to `addr_test1...zcsuy` (Vesting Key 1)
- 9.62A to `addr_test1...zcsuy` (Vesting Key 1)

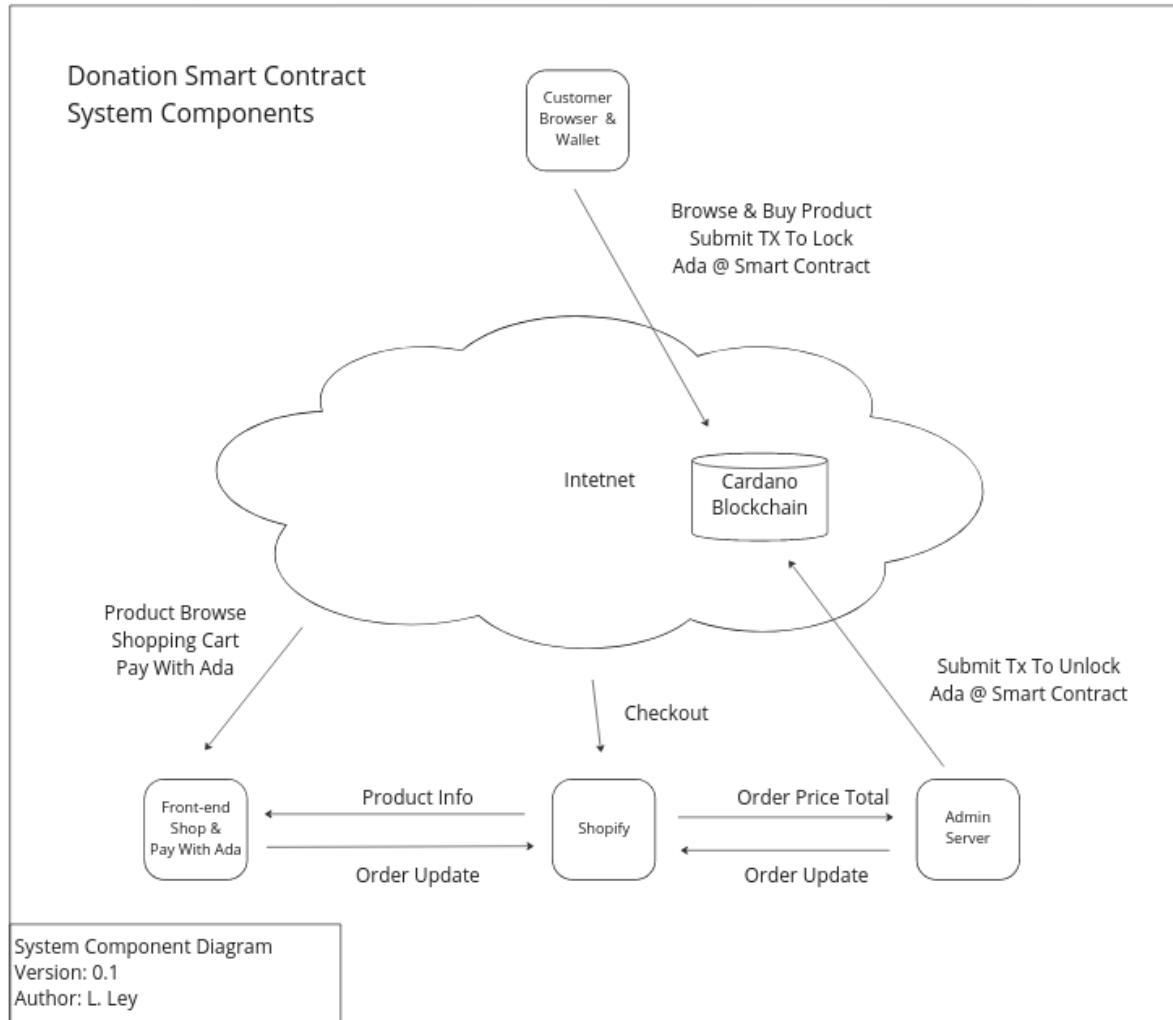
The left sidebar includes links for Dashboard, Watchlist, Pools, and Assets. The top right features a search bar and a button labeled `+ your b`.

Donation Traceability (Lock Ada)

In this final example we will review a donation traceability smart contract. It provides transparency and auditability on the percentage of an eCommerce order that is being donated.

System Components

The following diagrams show the systems involved interacting with the smart contract.



The main systems involved in this architecture are:

- Customer Browser
- Next.js Front-end Application
- Shopify
- Admin Server for batch processing
- Cardano Blockchain

When users purchase a product with Ada, the order amount will be locked into a smart contract. The smart contract has very specific rules on the percentage allocation and what wallet addresses the Ada can go to. This allows for traceability of the donation so everyone can see distribution of Ada to the merchant and charity accordingly.

Smart Contract Code

Here is the code for the smart contract for donation verification. Notice that the wallet addresses and the donation split allocation is hard coded as contract parameters. This means that they cannot change once the smart contract is compiled and loaded on-chain. We also want to lock down the script so only the admin can run it for added security, but this is an optional design choice.

```
spending vesting

struct Datum {
    orderAmount: Int
    orderId: ByteArray
    adaUsdPrce: ByteArray
}

enum Redeemer {
    Spend
    Refund
}

// Define the pkh of the merchant
const MERCHANT_PKH: ByteArray = #3d6...38c
const merchantPkh: PubKeyHash = PubKeyHash::new(MERCHANT_PKH)

// Define the pkh of the Donation
const DONOR_PKH: ByteArray = #b2b...7a9f
const donorPkh: PubKeyHash = PubKeyHash::new(DONOR_PKH)

// Define the pkh of the Refund
const REFUND_PKH: ByteArray = #a0a...9a9
const refundPkh: PubKeyHash = PubKeyHash::new(REFUND_PKH)

// Define the pkh of the Admin
const ADMIN_PKH: ByteArray = #b9a...7682
const adminPkh: PubKeyHash = PubKeyHash::new(ADMIN_PKH)

const SPLIT: Int = 90 // Define the split merchant to donor
const minAda = 1000000 // Define minimum Ada for a donation
const version = 2 // Increment version number for the contract if needed
```

```

func getDonationAmt (orderAmt: Int) -> Int {
    donationAmt: Int = (orderAmt * (100 - SPLIT)) / 100;
    if (donationAmt < minAda) {
        minAda
    } else {
        donationAmt
    }
}

func main(datum: Datum, redeemer: Redeemer, context: ScriptContext) -> Bool {
    tx: Tx = context.tx;
    redeemer.switch {
        Spend => {
            orderAmt: Int = datum.orderAmount;
            donationAmt: Int = getDonationAmt(orderAmt);
            merchantAmt: Int = orderAmt - donationAmt;
            donationAmtVal: Value = Value::lovelace(donationAmt);
            merchantAmtVal: Value = Value::lovelace(merchantAmt);
            merchOutTxs : []TxOutput = tx.outputs_sent_to(merchantPkh);
            donorOutTxs : []TxOutput = tx.outputs_sent_to(donorPkh);
            tx.is_signed_by(adminPkh).trace("DN1: ") &&
            (merchOutTxs.head.value == merchantAmtVal).trace("DN2: ") &&
            (donorOutTxs.head.value == donationAmtVal).trace("DN3: ")
        },
        Refund => {
            orderAmt: Int = datum.orderAmount;
            returnAmtVal: Value = Value::lovelace(orderAmt);
            refundOutTxs : []TxOutput = tx.outputs_sent_to(refundPkh);
            tx.is_signed_by(adminPkh).trace("DN4: ") &&
            (refundOutTxs.head.value == returnAmtVal).trace("DN5: ")
        }
    }
}

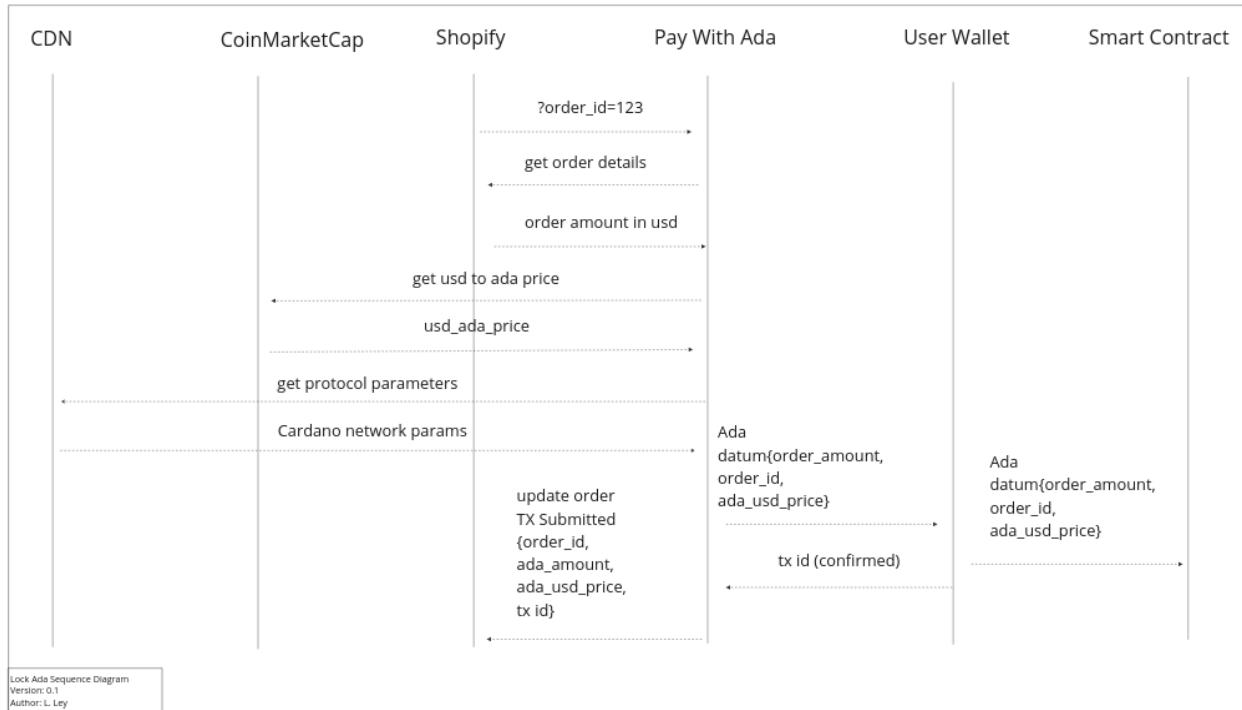
```

We will use hard coded contract parameters for the merchant, donor, refund and admin PKH. This will allow us to validate that the correct percentage of the order amount is actually getting locked at the merchant, donor or refund wallets. We also want to lock down the script so only the admin can run it for added security, but this is an optional design choice.

Pay With Ada

The following sequence diagram shows the logic for the pay with Ada component. This is needed so a customer can pay with Ada when completing their eCommerce order.

Locking Ada At The Smart Contract



The Pay With Ada component will get an order id from Shopify via a query string parameter in the browser URL. The Next.js app will then do a Shopify Admin API lookup to get the amount for the order. Once it has the amount of the order, it will do another lookup to get the ADA/USD conversion so we know how much Ada is required. Finally, when the user selects the Pay With Ada Button, a spend transaction is constructed with a datum for the user to sign and submit.

Compile & Deploy

Open the Terminal window in VS Code Web.

```
$ cd donation
```

Update the `src/donation.hl` smart contract with any changes in the parameters such as the merchant, donor, refund and admin PKH. After the changes are done, compile the Helios code in the donation directory.

If deno is not installed, run the following

```
$ npx deno-bin run https://deno.land/std/examples/welcome.ts
```

Now run the following command to compile the Helios smart contract to a plutus script.

```
$ npx deno-bin run --allow-read --allow-write ./src/deploy-donation.js
```

Then copy the generated file(s) to the scripts data directory and Next.js contracts directory respectively.

```
$ cp deploy/* scripts/cardano-cli/preprod/data  
$ cp src/donation.hl contracts
```

Next we need to add/update the following environment variables by editing the .bashrc file. You can access this via VS Code Web -> Open File and paste /config/.bashrc in the popup window.

Note, you may need to go to [Shopify](#) and [CoinMarketCap](#) and create accounts so you can get the required API keys.

```
export NEXT_PUBLIC_NETWORK="preprod"
export NEXT_PUBLIC_BLOCKFROST_API_KEY="blockfrost api key"
export NEXT_PUBLIC_BLOCKFROST_API="https://cardano-preprod.blockfrost.io/api/v0"
export NEXT_PUBLIC_NETWORK_PARAMS_URL="https://d1t0d7c2nekuk0.cloudfront.net/preprod.json"
export NEXT_PUBLIC_MIN_ADA=2000000
export NEXT_PUBLIC_SHOP="https://shopify-store-url"
export NEXT_PUBLIC_ACCESS_TOKEN="shopify access token"
export NEXT_PUBLIC_COIN_API_KEY="coin market cap api key"
export NEXT_PUBLIC_SERVICE_FEE=500000
export NEXT_PUBLIC_ORDER_API_KEY="create a unique base64 hash key"
```

Load in the environment variables to your current shell. These will get loaded automatically every time you log in if they exist in your .bashrc file

Next.js Setup

Now install the npm modules and start Next.js. Remember to expose port 3000 in the Demeter Run workspace Exposed Ports tab.

```
$ source ~/.bashrc  
$ npm install  
$ npm run dev
```

You should see the following which is correct when no order id is passed via the query string. Copy the Next.js app web URL which you will need in the next step.

The screenshot shows the Helios Tx Builder application running in a browser. The title bar indicates the window is titled "Helios Tx Builder". The address bar shows the URL "3000-material-baseball-zwzft4.us1.demeter.run". The main content area displays the "Helios Tx Builder" logo and a "Connect to your wallet" section with a dropdown menu showing "Nami" selected. Below this, there is a "View Smart Contract" button with a link to "donation.hl". A "Wallet Balance In Lovelace" section shows a balance of "68,659,442". At the bottom, a "Buy Product" section displays "Order ID 0", "Order Total \$0", and "ADA Amount Estimate 0", followed by a "Pay With Ada" button.

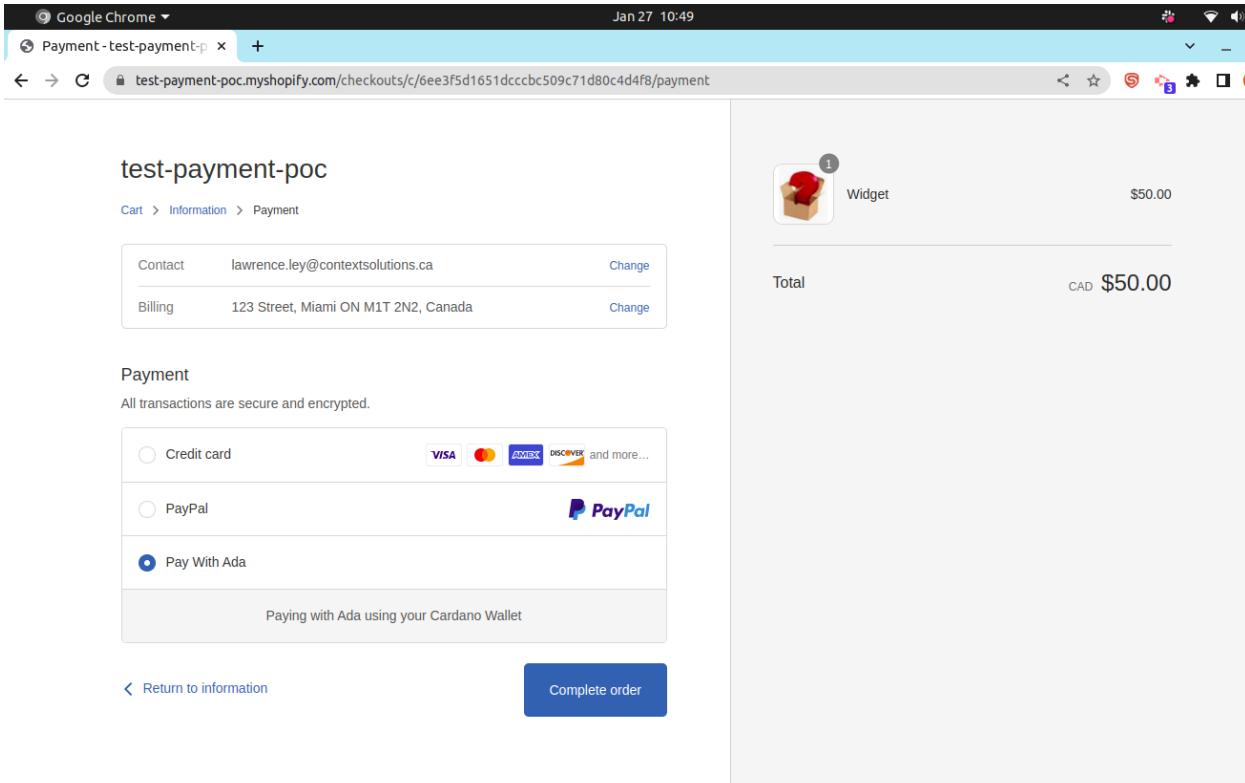
Shopify Settings

We will need to update the URL that is used to pay for Ada. Please see Shopify Ada Payments in the Appendix if you need help configuring a Shopify store for Ada payments.

1. Go to your shopify store admin section
2. Select Settings
3. Select Checkout
4. Scroll to the bottom and update the variable in the Additional Scripts dialog box with the URL you copied in the last step. For example:
`var urlStr = "https://3000-material-baseball-zwzft4.us1.demeter.run/";`
5. Select Save and close the Settings Window

Test Drive

Now go to your shopify store and proceed to checkout with a product and Select the Pay With Ada as a payment option.



The screenshot shows a Shopify payment page for a product named "Widget" priced at \$50.00 CAD. The payment method "Pay With Ada" is selected. The page includes fields for contact information (name and email) and billing address (street address). The payment section shows options for Credit card, PayPal, and Pay With Ada. A note at the bottom says "Paying with Ada using your Cardano Wallet". Navigation buttons at the bottom are "Return to information" and "Complete order".

Select Complete order and the user will be taken to the order status page.

The screenshot shows a Shopify payment confirmation page in a Google Chrome browser window. The URL in the address bar is test-payment-poc.myshopify.com/checkouts/c/51399cc5f7a9dba3ce62879b4e741b2c/thank_you. The page title is "test-payment-poc".

Order Summary:

Item	Quantity	Price
Widget	1	\$50.00
Total		CAD \$50.00

Customer Information:

Contact information	Payment method
lawrence.ley@contextssolutions.ca	Pay With Ada - \$50.00

Billing Address:

Test
123 Street
Miami ON M1T 2N2
Canada

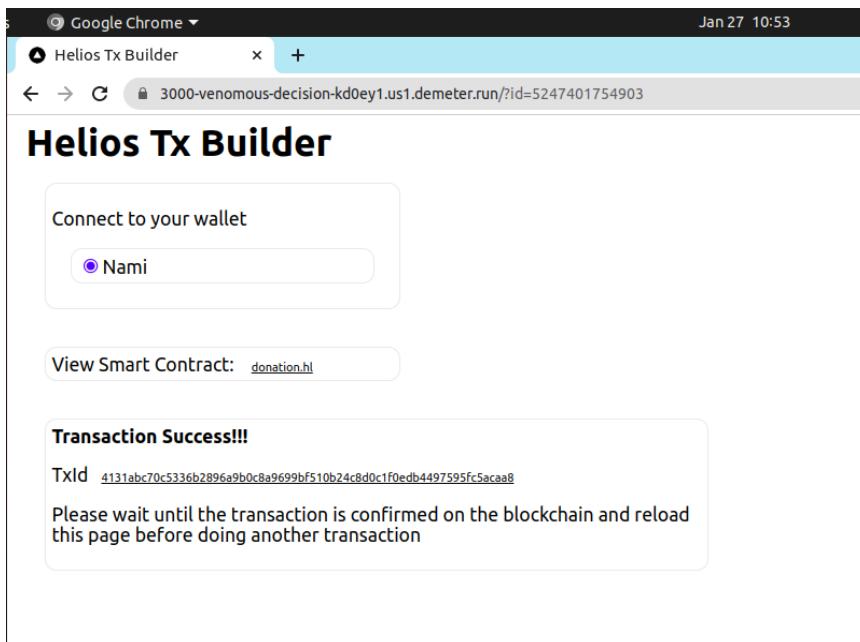
Buttons:

- Checkmark icon: Thank you!
- Email me with news and offers:
- Pay To Complete Your Order
- Pay Now In Ada
- Need help? Contact us
- Continue shopping

Select the Pay Now in Ada link and you will be directed to the Next.js web application. The URL will contain a query string which allows the application to retrieve the order dollar amount and then a ADA/USD conversion for the amount of Ada due.

The screenshot shows a Google Chrome browser window with the title "Helios Tx Builder". The URL in the address bar is "3000-venomous-decision-kd0ey1.us1.demeter.run/?id=5247401754903". The main content area displays the "Helios Tx Builder" logo and a "Connect to your wallet" section. A dropdown menu shows "Nami" selected. Below this, a button labeled "View Smart Contract: [donation.hl](#)" is visible. A "Wallet Balance In Lovelace" section shows a balance of "361,762,455". The "Buy Product" section displays the following details:
Order ID: 5247401754903
Order Total: \$50.00
ADA Amount Estimate: 132.28
A "Pay With Ada" button is present at the bottom of this section.

Select the Pay With Ada button and then sign and submit the transaction using your wallet. You have now paid for the order and locked the Ada into the donation smart contract address. You may also notice that no collateral was needed. We are simply locking the Ada (with a datum) at an address and not executing a smart contract yet. This design choice helps reduce friction during the shopping experience for users that have never used a Cardano dapp before.



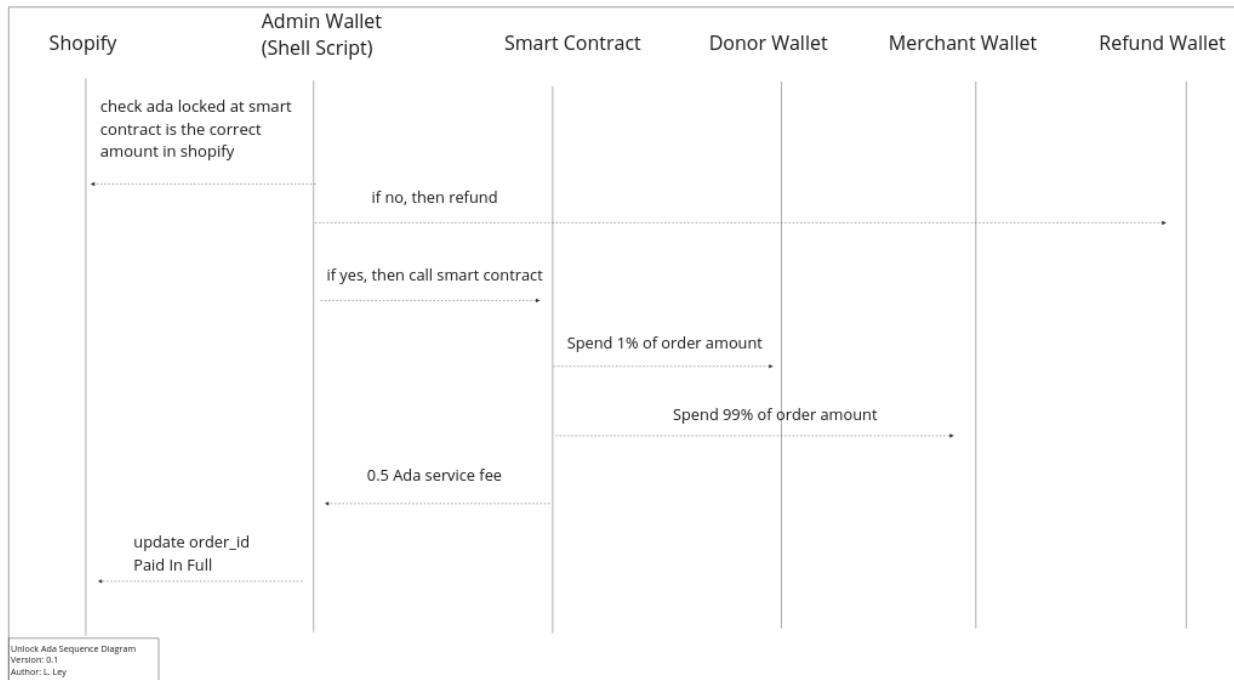
The transaction of locking the Ada and a datum can be seen on cexplorer.io..

The screenshot shows the 'Transaction detail' page for transaction hash 4131abc70c5336b2896a9b0c8a9699bf510b24c8d0c1f0edb4497595fc5aca8. The page is displayed in Google Chrome, with the title 'Transaction 4131abc70c5'. The transaction was created 41s ago and is part of epoch 48, block 564,494, slot 19,151,018. The total output is 361.59 Ada, with a fee of 0.17 Ada. There are 2 outputs. The transaction is minted by poolz063u...jw0e7. The page also shows a summary of the transaction size (0.29 kB) and block size (0.29 kB). The right side of the page includes social sharing options and a user profile for 'SleepingCharles'.

Donation Traceability (Unlock Ada)

In the previous section, we locked Ada to the donation traceability smart contract while purchasing an eCommerce order. This section will walk through how we unlock that Ada and send it to the Merchant and Charity accordingly.

Unlocking Ada At The Smart Contract



The unlocking of Ada involves executing a bash shell script by an administrator. If we recall, spending of Ada locked at the donation smart contract will only succeed if:

1. The transaction is signed by the admin PKH
2. The output goes to the merchant and donor addresses accordingly
3. The amount of Ada sent to the merchant and donor matches the donation split defined in the smart contract.

There are some additional checks during processing to confirm that the order amount in the datum matches the order amount in Shopify. This is needed because anyone can lock Ada with a datum value at the smart contract script address. We need additional off-chain logic that can confirm the locked UTXO is valid. Finally, if the transaction is successful, we update Shopify that the order has been paid in full.

Bash Shell Scripts

Using the Terminal window in VS Code Web, cd donation/scripts directory to see the bash shell scripts and the files needed to run them.

```
Bash shell scripts  
./cardano-cli/init-tx.sh  
./cardano-cli/refund-tx.sh  
./cardano-cli/spend-tx.sh
```

```
Environment specific settings  
.cardano-cli/preprod/global-export-variables.sh
```

```
Environment specific data files  
.cardano-cli/preprod/data/donation.plutus  
.cardano-cli/preprod/data/donation.addr  
.cardano-cli/preprod/data/redeemer-spend.json  
.cardano-cli/preprod/data/black-list-utxo.txt  
.cardano-cli/preprod/data/donation.hash  
.cardano-cli/preprod/data/redeemer-refund.json  
.cardano-cli/preprod/data/donation-spend-metadata.json
```

We will need to load the smart contract onto the blockchain as a reference script by running the init-tx.sh shell script. But before we can do that we must ensure there are 2 UTXO at the admin wallet address with 5 Ada of collateral and over 25 Ada to pay for uploading the script and transaction fees.

Something like the following would work.

```
$ cardano-cli query utxo --address addr_test1vzu6...dxn7 --cardano-mode
--testnet-magic 1
TxHash TxIx Amount
-----
9f0...d82 1 79759567 lovelace + TxOutDatumNone
e06...8d6 0 5000000 lovelace + TxOutDatumNone
```

Update the scripts/cardano-cli/preprod/global-export-variables.sh for the environment you are targeting (preprod). Most of the values should work out of the box for initial setup, but the addresses and keys need to change to addresses and keys you control.

```
# Define export variables
export BASE=/config/workspace/repo/donation
export WORK=$BASE/work
export TESTNET_MAGIC=1
export ADMIN_VKEY=/config/workspace/repo/.keys/admin/key.vkey
export ADMIN_SKEY=/config/workspace/repo/.keys/admin/key.skey
export ADMIN_PKH=/config/workspace/repo/.keys/admin/key.pkh
export MIN_ADA_OUTPUT_TX=2000000
export MIN_ADA_OUTPUT_TX_REF=25000000
export COLLATERAL_ADA=5000000
export
MERCHANT_ADDR=addr_test1vq7k907l7e59t52skm8e0ezsnmmc7h4xy30kg2klwc5n8rqug2pds
export
DONOR_ADDR=addr_test1vzetpfww4aaunft0ucvcrxugj8nt4lhltksktya0rx0uh48cqghjfg
export
REFUND_ADDR=addr_test1vzs24vjh8salzqt5pahgvr34ewfwagxaxr5pz7eswugzn2gmw4f5w
export
VAL_REF_SCRIPT=b8a3af2835b5f2789b1f9e1d53c953a26db9a7dfab0e204e8629d85772c9fc3
0#1
export SPLIT=90
export MIN_ADA_DONATION=1000000
```

Reference Scripts

Reference scripts are read only UTXOs that can be included as inputs into a transaction, but cannot be spent. This way, a reference script UTXO can be reused by more than one transaction either in parallel or sequentially.

Upload the plutus script onto the block chain by running the init-tx.sh shell script.

```
$ cd scripts/cardano-cli  
$ ./init-tx.sh preprod
```

After the transaction has been successfully submitted, you should be able to see the reference UTXO with 25 Ada locked at the script address. You will also see the UTXO with the Ada locked from the order in the previous section. It has an inline datum with an order total amount, order Id and ADA/USD price conversion.

```
$ cardano-cli query utxo --address addr_test1wr...kk0k --cardano-mode  
--testnet-magic 1
```

Amount	TxHash	TxIx
413...aa8 0	132280000 lovelace + TxOutDatumInline ReferenceTxInsScriptsInlineDatumsInBabbageEra (ScriptDataList [ScriptDataNumber 131780000, ScriptDataBytes "5247401754903", ScriptDataBytes "0.37941"])	
d6c...2ce 0	25000000 lovelace + TxOutDatumNone	

Next we need to update the `preprod/global-environment-variables.sh` file with the reference script UTXO TxHash and TxIdx.

```
export VAL_REF_SCRIPT=d6c...2ce3#0
```

Spend Script

Now we can run the spend-tx.sh shell script.

```
./spend-tx.sh preprod
```

And this is what the spend-tx.sh bash shell script looks like.

```
#!/usr/bin/env bash
set -e
set -o pipefail

# enabled debug flag for bash shell
set -x

# check if command line argument is empty or not present
if [ -z $1 ];
then
    echo "process-tx.sh: Invalid script arguments"
    echo "Usage: process-tx.sh [devnet|preview|preprod|mainnet]"
    exit 1
fi
ENV=$1

# Pull in global export variables
MY_DIR=$(dirname $(readlink -f $0))
source ${MY_DIR}/${ENV}/global-export-variables.sh
if [ "$ENV" == "mainnet" ];
then
    network="--mainnet"
else
    network="--testnet-magic $TESTNET_MAGIC"
fi
mkdir -p $WORK
mkdir -p $WORK-backup
rm -f $WORK/*
rm -f $WORK-backup/*

# generate values from cardano-cli tool
cardano-cli query protocol-parameters $network --out-file $WORK/pparms.json

# load in local variable values
validator_script="$BASE/scripts/cardano-cli/$ENV/data/donation.plutus"
validator_script_addr=$(cardano-cli address build --payment-script-file
"$validator_script" $network)
redeemer_file_path="$BASE/scripts/cardano-cli/$ENV/data/redeemer-spend.json"
admin_pkh=$(cat $ADMIN_PKH)
```

```

#####
# Spend the donation UTXO
#####
# Step 1: Get UTXOs from admin
#####
# There needs to be at least 2 utxos that can be consumed.
# One for spending of the token and one utxo for collateral
#####

admin_utxo_addr=$(cardano-cli address build $network
--payment-verification-key-file "$ADMIN_VKEY")
cardano-cli query utxo --address "$admin_utxo_addr" --cardano-mode $network
--out-file $WORK/admin-utxo.json

cat $WORK/admin-utxo.json | jq -r 'to_entries[] | select(.value.value.lovelace
> '$COLLATERAL_ADA' ) | .key' > $WORK/admin-utxo-valid.json

readarray admin_utxo_valid_array < $WORK/admin-utxo-valid.json

admin_utxo_in=$(echo $admin_utxo_valid_array | tr -d '\n')

cat $WORK/admin-utxo.json | jq -r 'to_entries[] | select(.value.value.lovelace
== '$COLLATERAL_ADA' ) | .key' > $WORK/admin-utxo-collateral-valid.json

readarray admin_utxo_valid_array < $WORK/admin-utxo-collateral-valid.json

admin_utxo_collateral_in=$(echo $admin_utxo_valid_array | tr -d '\n')

readarray black_list_utxo_array <
$BASE/scripts/cardano-cli/$ENV/data/black-list-utxo.txt

#####
# Step 2: Get the donation smart contract utxos
#####
cardano-cli query utxo --address $validator_script_addr $network --out-file
$WORK/validator-utxo.json

cat $WORK/validator-utxo.json | jq -r 'to_entries[] |
select(.value.inlineDatum | length > 0) | .key' > $WORK/order_utxo_in.txt
readarray order_utxo_in_array < $WORK/order_utxo_in.txt

order_array_length="${#order_utxo_in_array[@]}"

order_utxo_in=""
# Find a utxo that is not in the blacklist
for (( c=0; c<$order_array_length; c++ ))
do
    if printf '%s' "${black_list_utxo_array[@]}" | grep -q -x
    "${order_utxo_in_array[$c]}";

```

```

    then
        echo "UTXO on blacklist: ${order_utxo_in_array[$c]}"
    else
        order_utxo_in=$(echo ${order_utxo_in_array[$c]} | tr -d '\n')
        break
    fi
Done

# Check if there are any utxos at the validator that we can
# use, if not, then exit
if [ -z $order_utxo_in ];
then
exit 0
Fi

# Get the correct datum UTXO
order_datum_in=$(jq -r 'to_entries[]
| select(.key == "'$order_utxo_in'")
| .value.inlineDatum' $WORK/validator-utxo.json)

echo -n "$order_datum_in" > $WORK/datum-in.json

# Get the order details from the datum
order_ada=$(jq -r '.list[0].int' $WORK/datum-in.json)

order_id_encoded=$(jq -r '.list[1].bytes' $WORK/datum-in.json)
echo -n "$order_id_encoded" > $WORK/order_id.encoded
order_id=$(python3 hexdump.py -r $WORK/order_id.encoded)

ada_usd_price_encoded=$(jq -r '.list[2].bytes' $WORK/datum-in.json)
echo -n "$ada_usd_price_encoded" > $WORK/ada_usd_price.encoded
ada_usd_price=$(python3 hexdump.py -r $WORK/ada_usd_price.encoded)

merchant_split=$SPLIT
donor_split=$((100 - $SPLIT))
donor_ada_amount=$($order_ada * $donor_split / 100)

if (($donor_ada_amount < $MIN_ADA_DONATION ));
Then
    donor_ada=$MIN_ADA_DONATION
else
    donor_ada=$donor_ada_amount
Fi

merchant_ada=$($order_ada - $donor_ada))

now=$(date '+%Y/%m/%d-%H:%M:%S')

# verify that the amount paid of the order is the same

```

```

# as the order amount in shopify
shopify_order_amount=$(curl -H "X-Shopify-Access-Token:
$NEXT_PUBLIC_ACCESS_TOKEN"
"$NEXT_PUBLIC_SHOP/admin/api/2022-10/orders/"$order_id".json" | jq -r
'.order.total_price')

shopify_order_ada=$(python3 -c "print(round(($shopify_order_amount /
$ada_usd_price), 3))")

shopify_order_lovelace=$(python3 -c "print($shopify_order_ada * 1000000)")
shopify_order_ada_truncated=${shopify_order_lovelace%.*}

difference=$((order_ada - $shopify_order_ada_truncated))
difference_abs=$(echo ${difference#-})

if (( $difference_abs > 10000 )); then
    echo "Order amount mismatch between order amount in datum vs order amount
in shopify for $order_id"
    exit -1
fi

metadata={
  "1": {
    "order_detail": {
      "date": "$now",
      "donation_ada_amount": "$donor_ada",
      "donation_split": "$donor_split%",
      "order_id": "$order_id",
      "order_ada_amount": "$order_ada",
      "ada_usd_price": "$ada_usd_price",
      "version": "0.1"
    }
  }
}

echo $metadata >
$BASE/scripts/cardano-cli/$ENV/data/donation-spend-metadata.json
metadata_file_path="$BASE/scripts/cardano-cli/$ENV/data/donation-spend-metadata.json"

#####
# Step 3: Build and submit the transaction
#####
cardano-cli transaction build \
--babbage-era \
--cardano-mode \
$network \
--change-address "$admin_utxo_addr" \

```

```

--tx-in-collateral "$admin_utxo_collateral_in" \
--tx-in "$admin_utxo_in" \
--tx-in "$order_utxo_in" \
--spending-tx-in-reference "$VAL_REF_SCRIPT" \
--spending-plutus-script-v2 \
--spending-reference-tx-in-inline-datum-present \
--spending-reference-tx-in-redeemer-file "$redeemer_file_path" \
--tx-out "$MERCHANT_ADDR+$merchant_ada" \
--tx-out "$DONOR_ADDR+$donor_ada" \
--required-signer-hash "$admin_pkh" \
--protocol-params-file "$WORK/pparms.json" \
--metadata-json-file "$metadata_file_path" \
--out-file $WORK/spend-tx-alonzo.body

echo "tx has been built"

cardano-cli transaction sign \
--tx-body-file $WORK/spend-tx-alonzo.body \
$network \
--signing-key-file "${ADMIN_SKEY}" \
--out-file $WORK/spend-tx-alonzo.tx

echo "tx has been signed"

echo "Submit the tx with plutus script and wait 5 seconds..."
cardano-cli transaction submit --tx-file $WORK/spend-tx-alonzo.tx $network

# Update shopify that the order is paid in full
curl -s -d '{"order":{"id":"'${order_id}'","tags":"PAID IN FULL"}}' \
-X PUT "${NEXT_PUBLIC_SHOP}admin/api/2022-10/orders/${order_id}.json" \
-H "X-Shopify-Access-Token: ${NEXT_PUBLIC_ACCESS_TOKEN}" \
-H "Content-Type: application/json" > /dev/null

```

Test Drive

Before tx-spend.sh is executed

```
$ cardano-cli query utxo --address
addr_test1wr3m0vrrccxygtmexw7ur7vujjz5gqg4fjn0k2sjsjn04sdckk0k --cardano-mode --testnet-magic 1
                                         TxHash          TxIx      Amount
-----
4131abc70c5336b2896a9b0c8a9699bf510b24c8d0c1f0edb4497595fc5acaa8    0      132280000 lovelace
+ TxOutDatumInline ReferenceTxInsScriptsInlineDatumsInBabbageEra (ScriptDataList
[ScriptDataNumber 131780000, ScriptDataBytes "5247401754903", ScriptDataBytes "0.37941"])
d6c4a585ffbdcc371a3472e829133643c9dfa4f1b61a4ccb8e75fd4480c22ce    0      250000000 lovelace +
TxOutDatumNone
```

After tx-spend.sh is executed

```
$ cardano-cli query utxo --address
addr_test1wr3m0vrrccxygtmexw7ur7vujjz5gqg4fjn0k2sjsjn04sdckk0k --cardano-mode --testnet-magic 1
                                         TxHash          TxIx      Amount
-----
d6c4a585ffbdcc371a3472e829133643c9dfa4f1b61a4ccb8e75fd4480c22ce    0      250000000 lovelace +
TxOutDatumNone
```

We can see the successful transaction on explorer.io

The screenshot shows a Google Chrome browser window with the title "Transaction c3b2f3721139c7d38885f012bab6cae0cff96a405c14a228fe382f6b7b21f074". The page is from the "preprod.explorer.io" domain. The main content is titled "Transaction detail" and displays the following information:

Date	6m20s ago
Epoch	48
Block	504,597
Slot	19,153,936 (epoch slot: 59,536)
Total Output	634.07 A (\$ 241) (B 001048)
Fee	0.23 A (\$ 0)
Outputs	3

On the right side, there are several summary boxes:

- Assurance:** 22
- 0.7kB (0.7kB)** Transaction Size (this tx 99%)
- 0.7kB (1)** Block Size (TX Count) available 99%
- Minted by [BLADE] BLADE Pool - bladepool.com

At the bottom, there is a "Metadata" section showing three outputs:

Time	Address	Value
502.02A	addr_test1.gdxn7	502.29A
132.28A	addr_test1.ekk0k	118.6A
133.18A	addr_test1.ghjfg	133.0A

Blockchain Monitoring

In this chapter we will focus on how to monitor the blockchain for changes that our application needs to react to. The most basic type of monitoring is polling which we will describe first. Then we will look at event based monitoring which is more advanced and has more capabilities for error handling and event filtering.

Polling

Referring to the previous donation example, we need to monitor when Ada is locked at the smart contract. When this occurs, a script will execute a transaction to spend the UTXOs accordingly.

Cron

One approach is to simply set up a cron job to kick off the spend-tx.sh bash script at regular intervals. This script could also be written with Node.js, but in this case we will re-use the bash shell script as is.

A simple cron job to run the script every minute is as follows.

```
* * * * * (cd /absolute-path-to-script-directory/; ./spend-tx.sh preprod >> /absolute-path-to-log-directory/preprod.out)
```

Valid UTXOs

When the bash shell script runs, it pulls all the UTXOs currently locked at the smart contract script address. For a valid UTXO entry, the bash script builds a transaction, signs and submits it. Because anyone can lock anything to the script address, a mechanism was created to black list certain UTXOs if required. A UTXO that can't be spent could be the result of an incorrect or missing datum value.

Monitoring

Below is a simple monitoring script that if the count of the UTXOs at the script address is beyond 1, then manual investigation is required. If a UTXO can't be spent, then it can be added to the blacklist so the script will skip that particular UTXO. When there is more than 1 UTXO locked to the script address, a message will be sent to a Telegram group for a call to action.

Here is the bash shell monitoring script

```
#!/usr/bin/bash
count=$(./usr/local/bin/cardano-cli query utxo --address
addr_test1wzk3ds3t470srqhayn9mmxnmrnw5qsz5u0pd1zstjvrnsjq8t2haf --cardano-mode
--testnet-magic 1 | wc -l)
if (( $count > 3 ));
then
/usr/bin/curl -X POST \
-H 'Content-Type: application/json' \
-d '{"chat_id": "XXXXXXXXXX", "text": "Prod utxo count: '"$count"'",
"disable_notification": true}' \
https://api.telegram.org/botYYYYYY:ZZZZZZZZ\_xtc/sendMessage
fi
```

Events

Event based monitoring involves monitoring the blockchain activity typically in real-time. For example, a transaction locking Ada at a smart contract address could generate an event and the application responds with some type of action. If needed, an event could be triggered only after a number of [block confirmations](#) has occurred. Additionally, an event could be triggered if a blockchain [rollback](#) has occurred and the application needs to handle this accordingly.

Oura

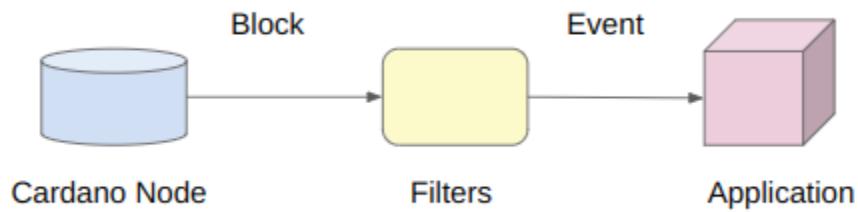
There are now service providers that you can subscribe to who have all of the infrastructure and connectivity to the Cardano blockchain set up and ready to go. All you need to do is select the blockchain event you want to define an action for. In our case we will use Oura and select a TxOutput event and watch the donation smart contract script address. The action will then call our webhook with a transaction hash and index and our Next.js application will process it.

The screenshot shows a web-based interface for managing smart contracts on the Cardano blockchain. The URL in the browser bar is `console.us1.demeter.run/smart-contract-book-e626a0/cardano-webhooks/new`. The main title is "demeter.run > Smart Contracts". A section titled "TxOutput" is displayed, with the sub-instruction "Data on a transaction output (UTXO)". Below this, there is a field labeled "address_equals" containing the value "addr_test1wzk3ds3t470srqhayn9mmxnmrnw5qsz5u0pd1zstjvrnsjq8t2haf". Underneath, an "Example Payload" is shown as a JSON object:

```
{  
  "context": {  
    "block_hash": "3f2669d3e70f7649e698cf8f0db2312b09c3619d23632c3069b850c4ad5e7f88",  
    "block_number": 276506,  
    "slot": 5767422,  
    "timestamp": 1665745362,  
    "tx_idx": 9,  
    "tx_hash": "6a3d1dc9d825ec8ff56b785c79bf0a78c6d0fa2dd01bdd9dad122e4a61dc6545",  
    "input_idx": null,  
    "output_idx": 1,  
    "output_address": null,  
    "certificate_idx": null  
}
```

Event Flow

The following high level diagram illustrates the way events are created and handed. Filters are set up on incoming blocks from the Cardano Node. If there is a filter match, then an event is triggered and an application webhook is called.



For more information about Oura can be found at <https://txpipe.github.io/oura/>

WebHook

Select an event we want to monitor and the URL of the webhook that we want Oura to call when such an event occurs. The webhook is created by setting up an API in our Next.js application. This API will execute the spend-tx.sh script with a specific transaction hash and index.

Here is what the events.ts code looks like for the new API created to handle an incoming webhook from Oura.

```
import path from 'path';
import type { NextApiRequest, NextApiResponse } from 'next'
import initMiddleware from '../lib/init-middleware'
import validateMiddleware from '../lib/validate-middleware'
import { check, validationResult } from 'express-validator'

const validateBody = initMiddleware(
  validateMiddleware([
    check('context.tx_idx').isInt({ min: 0, max: 255}),
    check('context.tx_hash').isBase64(),
  ], validationResult)
)

export default async function handler(
  req: NextApiRequest,
  res: NextApiResponse ) {
  const network = process.env.NEXT_PUBLIC_NETWORK as string;
  const eventAPIKey =
    process.env.NEXT_PUBLIC_EVENT_API_KEY as string;
  if (req.method == 'POST') {
    // Check for basic auth header
    if (!req.headers.authorization || 
        req.headers.authorization.indexOf('Basic ') === -1) {
      throw { status: 401,
              message: 'Missing Authorization Header'};
    }
    // Verify auth credentials
    const apiKey = req.headers.authorization.split(' ')[1];
    if (eventAPIKey != apiKey) {
      throw { status: 401,
              message: 'Invalid Authentication Credentials'};
    }
  }
}
```

```

// Sanitize body inputs
await validateBody(req, res)
const errors = validationResult(req)
if (!errors.isEmpty()) {
    return res.status(422).json({ errors: errors.array() })
}

const txId = req.body.context.tx_hash + ` ` +
            req.body.context.tx_idx;
const shell = require('shelljs');
const scriptsDirectory = path.join(process.cwd(),
                                    'scripts/cardano-cli');
const cmd = `(cd ${scriptsDirectory}; ./spend-tx.sh ${network} ${txId})`;

if (shell.exec(cmd).code !== 0) {
    res.setHeader('Tx-Status', 'Tx Failed');
    // Return 200 status because we don't want Oura to retry
    res.status(200).json(`Tx Failed: ${txId}`);
} else {
    res.setHeader('Tx-Status', 'Tx Submitted');
    res.status(200).json(`Tx Submitted: ${txId}`);
}
else {
    res.status(400);
    res.send(`Invalid API Request`);
}
}

```

The spend-tx.sh script is changed to accept a transaction hash (tx_hash) and index (tx_idx) via the command line arguments.

Smart Contract & Next.js Setup

Make sure that everything is set up correctly.

1. Increment the donation.hl version number (if required)
2. \$ npx deno-bin run --allow-read --allow-write ./src/deploy-donation.js
3. \$ cp deploy/* scripts/cardano-cli/preprod/data/
4. \$ cp src/donation.hl contracts/
5. \$ cd scripts/cardano-cli/
6. \$./init-tx.sh preprod
7. Query the new script address and make sure the reference script is there.

```
$ cardano-cli query utxo --address addr_test1wpg...42k --cardano-mode --testnet-magic
1
-----
```

TxHash	TxIx	Amount
78d...9ac	0	25000000 lovelace + TxOutDatumNone

8. Update the global-export-variables.sh file with scripts reference UTXO from the previous step
9. Ensure the correct env variables are set (see Donation section)
10. Start the Next.js application
\$ npm install
\$ npm run dev
11. Create a webhook for the new smart contract address in Oura

Oura Setup

The following steps are required to set up a Demeter Run webhook using the Oura hosted solution.

1. Go to Demeter Run and log in
2. Open or create a project
3. Select the Features tab
4. Select Cardano Webhooks
5. Select Create Webhook button
6. Enter the URL of your webhook (<https://some-url/api/events>)
7. Select Headers -> Add
 - a. Authorization
 - b. Basic YOUR-API-KEY
8. Toggle TxOutput Event on

Test Drive

An order is submitted on-chain and locked at the smart contract address.

The screenshot shows a Google Chrome browser window displaying the Cardano Explorer.io transaction detail page. The URL is <https://preprod.explorerio.io/tx/704b195961b0c4c72cb496971d81e57f0344e3edb1030d81d6239d2d7e0654b9>. The page header shows "Jan 27 13:59". The left sidebar contains navigation links for CARDANO EXPLORER (Dashboard, Watchlist, Pools, Assets, Transactions, dApps, Metadata, More), EDUCATION (Articles, Videos, Wiki), and ANALYTICS (Decentralization, Network). The main content area displays the "Transaction detail" for the specified hash. Key details include:

- Date: 4m20s ago
- Epoch: 48
- Block: 564,953
- Slot: 19,162,514 (epoch slot 68,114)
- Total Output: 203.43 A (\$ 77.4) (B 0.00336)
- Fee: 0.17 A (\$ 0)
- Outputs: 2

On the right side, there are several cards providing additional information:

- Assurance:** 16
- Transaction Size:** 0.29kB (0.29kb)
- Block Size (TX Count):** 0.29kB (1)
- Minted by:** [BGR] BURGER STAKE POOL

Below the transaction detail, under the "Content" section, are three transaction outputs:

- 203.59A → addr_test1.pmr54
- 130.97A → addr_test1.f842k
- 72.46A → addr_test1.pmr54

A transaction event at the smart contract script address is detected and an action is triggered in Oura.

Google Chrome ▾ Jan 27 13:56

TxPipe Console x +

console.us1.demeter.run/smart-contract-book-e626a0/cardano-webhooks/pathetic-accident-wa8s4n/logs

demeter.run > Smart Contracts PREPROD L

```
[2023-01-27T18:55:04Z DEBUG pallas_miniprotocols::chainsync::agents] rolling forward
[2023-01-27T18:55:04Z INFO oura::sources::n2c::run] rolling forward to point (19162504, 81aeeecdb93ccdd99340d7e5ea1cf994c8c73bd0b6599b6608cc7d10)
[2023-01-27T18:55:04Z DEBUG oura::sources::n2c::run] found 1 points with required min depth
[2023-01-27T18:55:04Z INFO oura::sources::n2c::run] rollback buffer state, size: 0, oldest: None, latest: None
[2023-01-27T18:55:04Z DEBUG pallas_multiplexer::bearers] parsed inbound msg, protocol id: 5, ts: 2506582375, payload length: 2
[2023-01-27T18:55:04Z DEBUG pallas_miniprotocols::chainsync::agents] reached tip, await reply
[2023-01-27T18:55:04Z DEBUG pallas_miniprotocols::chainsync::agents] tip was reached
[2023-01-27T18:55:14Z DEBUG pallas_multiplexer::bearers] parsed inbound msg, protocol id: 5, ts: 2516990944, payload length: 1209
[2023-01-27T18:55:14Z DEBUG pallas_miniprotocols::chainsync::agents] rolling forward
[2023-01-27T18:55:14Z INFO oura::sources::n2c::run] rolling forward to point (19162514, fff5be46240cbb59cb5ab166eabf0347105681de03164eaa27ec00a)
[2023-01-27T18:55:14Z DEBUG oura::sources::n2c::run] found 1 points with required min depth
[2023-01-27T18:55:14Z INFO oura::sources::n2c::run] rollback buffer state, size: 0, oldest: None, latest: None
[2023-01-27T18:55:14Z DEBUG request::connect] starting new connection: https://3000-venomous-decision-kd0ey1.us1.demeter.run/
[2023-01-27T18:55:14Z DEBUG hyper::client::connect::dns] resolving host="3000-venomous-decision-kd0ey1.us1.demeter.run"
[2023-01-27T18:55:14Z DEBUG pallas_multiplexer::bearers] parsed inbound msg, protocol id: 5, ts: 2516991852, payload length: 2
[2023-01-27T18:55:14Z DEBUG pallas_miniprotocols::chainsync::agents] reached tip, await reply
[2023-01-27T18:55:14Z DEBUG pallas_miniprotocols::chainsync::agents] tip was reached
[2023-01-27T18:55:14Z DEBUG hyper::client::connect::http] connecting to 34.213.123.117:443
[2023-01-27T18:55:14Z DEBUG hyper::client::connect::http] connected to 34.213.123.117:443
[2023-01-27T18:55:14Z DEBUG hyper::proto::h1::io] flushed 828 bytes
[2023-01-27T18:55:17Z DEBUG hyper::proto::h1::io] parsed 8 headers
[2023-01-27T18:55:17Z DEBUG hyper::proto::h1::conn] incoming body is content-length (82 bytes)
[2023-01-27T18:55:17Z DEBUG hyper::proto::h1::conn] incoming body completed
[2023-01-27T18:55:17Z DEBUG hyper::client::pool] pooling idle connection for ("https", 3000-venomous-decision-kd0ey1.us1.demeter.run)
[2023-01-27T18:55:21Z DEBUG pallas_multiplexer::bearers] parsed inbound msg, protocol id: 5, ts: 2524020673, payload length: 1645
[2023-01-27T18:55:21Z DEBUG pallas_miniprotocols::chainsync::agents] rolling forward
[2023-01-27T18:55:21Z INFO oura::sources::n2c::run] rolling forward to point (19162521, f1468ce03cd540d885bd76d0bbb9cab1472dba6ed3fbbae6ec2e8d6)
[2023-01-27T18:55:21Z DEBUG oura::sources::n2c::run] found 1 points with required min depth
[2023-01-27T18:55:21Z INFO oura::sources::n2c::run] rollback buffer state, size: 0, oldest: None, latest: None
[2023-01-27T18:55:21Z DEBUG pallas_multiplexer::bearers] parsed inbound msg, protocol id: 5, ts: 2524021518, payload length: 2
[2023-01-27T18:55:21Z DEBUG pallas_miniprotocols::chainsync::agents] reached tip, await reply
[2023-01-27T18:55:21Z DEBUG pallas_miniprotocols::chainsync::agents] tip was reached
```

The webhook API is called and successfully submits the transaction.

Address Detail > TXs

Time Ago	Hash	Total	Outputs
7s ago	# e090402724..e720f	55784A	-130.97A (\$ 499) B 0.00216 addr_test1...gdxn7 130.97A addr_test1...f842k 13.05A addr_test1...ghifg
14s ago	# 704b195961..654b9	203.43A	+130.97A (\$ 499) B 0.00216 addr_test1...pmr54 72.46A addr_test1...pmr54

The metadata for the transaction has also been recorded on-chain.

The screenshot shows a Google Chrome browser window displaying the Explorer.io Cardano Explorer. The URL in the address bar is `preprod.explorer.io/tx/e0904207245ed7b3c1e8ee7d23b28bdb9667e6635ca096309b0a8378663e720f/metadata#data`. The page header shows the date and time as Jan 27 14:01. The main content area displays transaction details:

Date	6m13s ago
Epoch	48
Block	564,954
Slot	19,162,521 (epoch slot 68,121)
Total Output	557.84 ADA (\$ 212) 0.000922
Fee	0.23 ADA (\$ 0)
Outputs	3

On the right side, there are several cards providing additional information:

- Assurance**: 19 items.
- Transaction Size**: 0.71kB (0.71kB), this tx 99%.
- Block Size (TX Count)**: 0.71kB (1) Block Size (TX Count), available 99%.
- Minted by**: [BGR] BURGER STAKE POOL.

At the bottom, there is a table titled "Content" showing transaction metadata:

Label	Data
1	{ "order_detail": { "date": "2023/01/27-18:55:15", "version": "0.1", "order_id": "5247520448599", "ada_usd_price": "0.38324", "donation_split": "10%", "order_ada_amount": "138470000", "donation_ada_amount": "138470000" } }

Troubleshooting

The following section describes some tips and tricks to help debug issues that may occur when developing Cardano smart contracts.

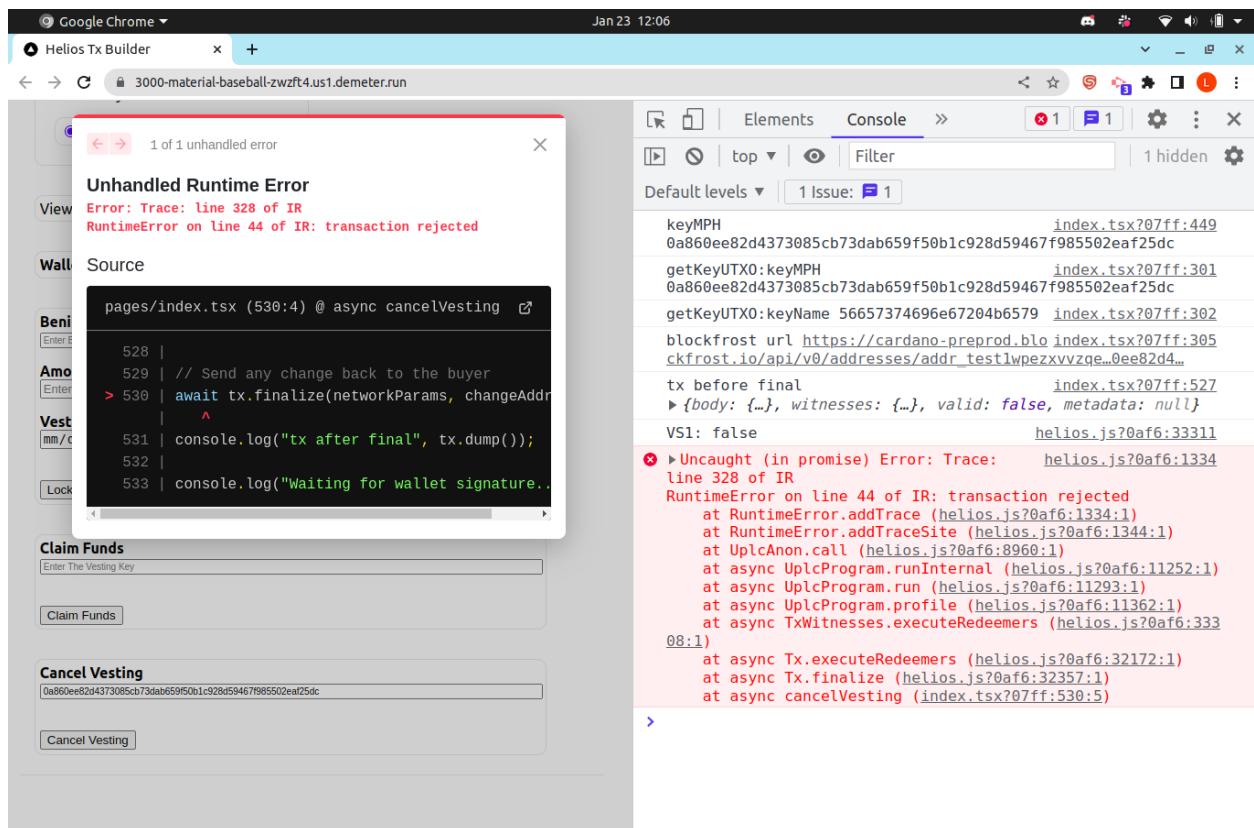
Trace()

A trace is added to the Helios code by using `.trace()` for an evaluation. The `.trace()` function is actually a wrapper for the `.print()` function and is used for convenience.

For example:

```
// Check if deadline hasn't passed
(now < datum.deadline).trace("VS1: ")
```

The trace can then be seen in the console logs where the platus script fails.



Show()

To add more information when debugging, you can add `.show()` to basic types which can then be included in the `.trace()` or `.print()` statements. For example:

```
func main(datum: Datum, redeemer: Redeemer, context: ScriptContext) -> Bool {  
    tx: Tx = context.tx;  
    now: Time = tx.time_range.start;  
    redeemer.switch {  
        Cancel => {  
            // Check if deadline hasn't passed  
            (now < datum.deadline).trace("now: " + now.show() + " VS1: ")  
        }  
    }  
}
```

Print()

You can also use the `print()` function to print out variables in the execution stack which will show in the browser console when the smart contract transaction fails:

```
func main(datum: Datum, redeemer: Redeemer, context: ScriptContext) -> Bool {  
    tx: Tx = context.tx;  
    now: Time = tx.time_range.start;  
    print(now.show());  
    redeemer.switch {  
        Cancel => {  
            // Check if deadline hasn't passed  
            (now < datum.deadline).trace("VS1: ")  
    }  
}
```

Common Sources Of Errors

Here is a list of common sources of errors and how to address them.

Issue	Fix
Plutus script exceeds cpu/mem units	Set optimize=true when calling Program.new(script).compile(optimize) Avoid unnecessary logic or transactions
Invalid reference UTXO	Make sure you update the global-export-variables file has the correct reference UTXO
Wrong script address	Make sure that the helio.js used in src directory and the helios npm node module are the same version.
Collateral not set	Make sure the wallet has collateral set which is needed to execute smart contracts
Insufficient funds	Make sure the wallet has sufficient funds for the transaction and that you are on the correct network.
Wallet account not set correctly	For Nami, make sure that when you are selecting between accounts that the current account select is the active one. You may also need to refresh the browser page as well.
Bash shell environment variables not set	Make sure you run source ~/ .bashrc to load the environment variables into your current shell.

Cardano-cli

To measure the amount of cpu and memory units the plutus script will use, for cardano-cli you just need to replace the output line in the bash shell scripts with the following.

```
--calculate-plutus-script-cost "$BASE/scripts/$ENV/data/mint-tx.costs"
```

So the end of the script will look like:

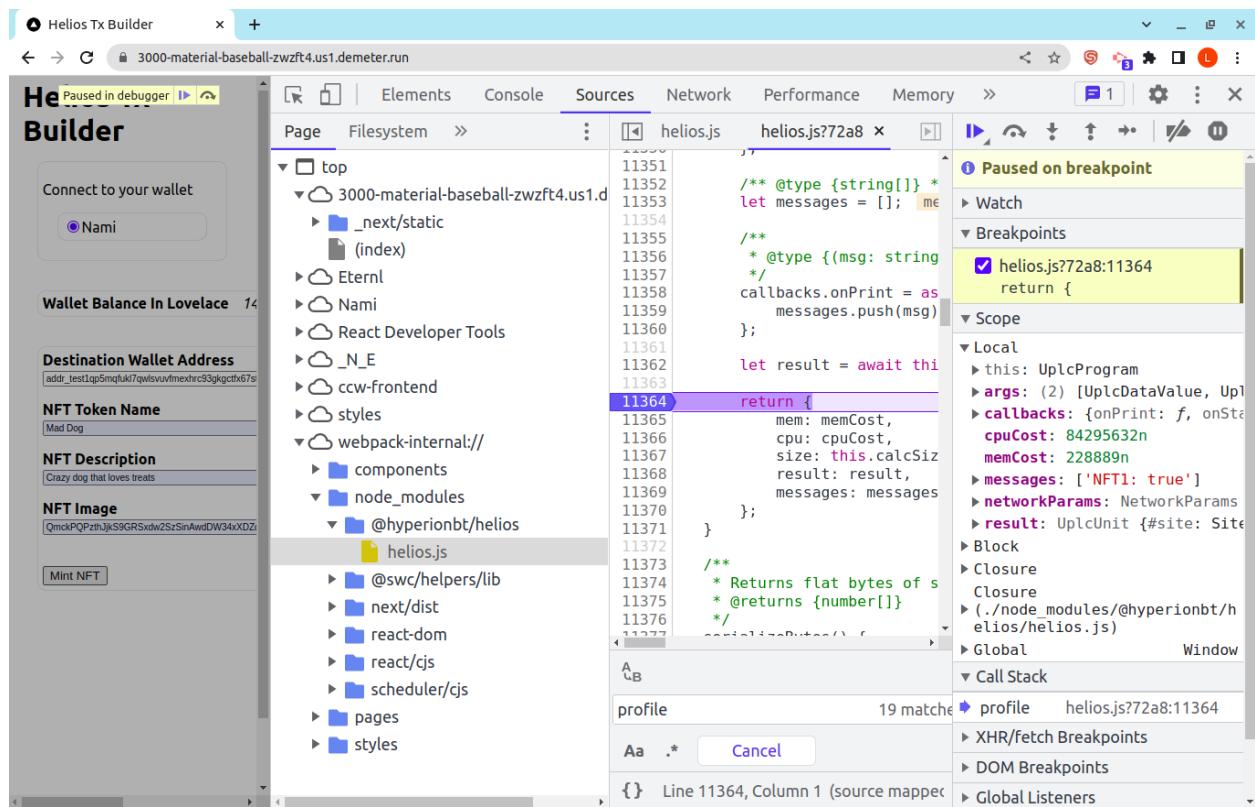
```
...
# Step 3: Build and submit the transaction
cardano-cli transaction build \
--babbage-era \
--cardano-mode \
$network \
--change-address "$admin_utxo_addr" \
--tx-in-collateral "$admin_utxo_collateral_in" \
--tx-in "$admin_utxo_in" \
--tx-in "$event_utxo" \
--spending-tx-in-reference "$VAL_REF_SCRIPT" \
--spending-plutus-script-v2 \
--spending-reference-tx-in-inline-datum-present \
--spending-reference-tx-in-redeemer-file "$redeemer_file_path" \
--tx-out "$MERCHANT_ADDR+$merchant_ada" \
--tx-out "$DONOR_ADDR+$donor_ada" \
--required-signer-hash "$admin_pkh" \
--protocol-params-file "$WORK/pparms.json" \
--metadata-json-file "$metadata_file_path" \
--calculate-plutus-script-cost "$BASE/scripts/$ENV/data/spend-tx.costs"
```

Which produces results in the spend-tx.costs file.

```
$ more spend-tx.costs
[
  {
    "executionUnits": {
      "memory": 417629,
      "steps": 153838242
    },
    "lovelaceCost": 35189,
    "scriptHash": "4734d1f1927b26089874c6b3b369c860d450189f6c1844352623ede6"
  }
]
```

Helios Tx Builder

1. Start up the Next.js application and fill in input fields
2. Right click to inspect the page
3. Select sources -> Webpack internals -> @hyberionbt/helios
4. In the helio.js file search for the word profile
5. At the line with return for the profile function, set a breakpoint
6. Then select Mint in this case
7. The cpuCost and memCost are displayed in Scope -> Local as cpuCost and memCost variables.



Network Parameters

To find out the current [cost model parameters](#) and the transaction max script size, cpu and mem units on the network, issue the following command:

```
cardano-cli query protocol-parameters --testnet-magic 1
```

Then look for the following values in the output.

```
...
"maxTxExecutionUnits": {
    "memory": 14000000,
    "steps": 10000000000
},
"maxTxSize": 16384,
...
```

Baseline Comparison

Here are the details of a comparison between a plutus validator script written in Haskell PlutusTx V2 and then again in Helios.

Metric	Haskell Plutus V2	Helios Plutus V2	Reduction
executionUnits Memory	1,899,564	805,465	~42.4 %
executionUnits Steps	528,441,393	297,796,866	~56.4 %
lovelaceCost	147,706	67,947	~46.0 %
Script size	8,125 KB	4,106 KB	~50.5 %

Helios Plutus V2 baseline testing log:

<https://github.com/lley154/littercoin/blob/preprod-5.0/testing/baseline.log>

Haskell Plutus V2 baseline testing log:

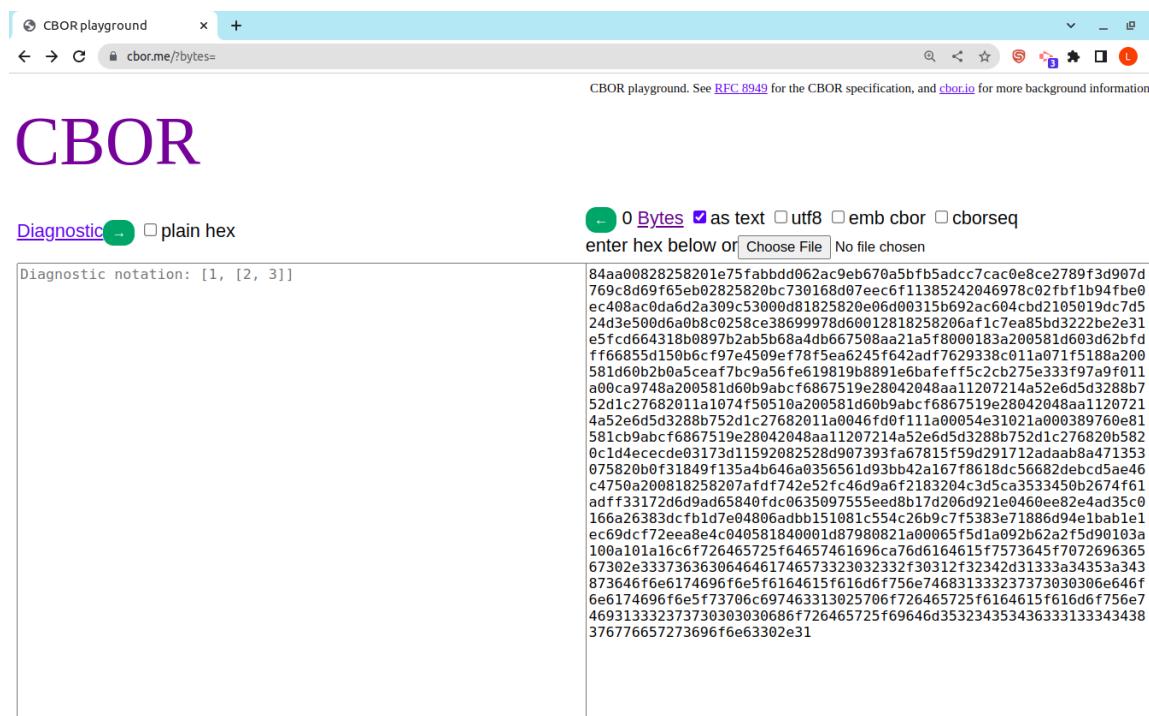
<https://github.com/lley154/littercoin/blob/baseline/testing/baseline.log>

CBOR.me

For advanced troubleshooting, you may need to inspect the transaction on-chain. It is stored in CBOR format and it can be decoded using the following web tool
<https://cbor.me/>

Copy the cborHex and paste it into cbor.me and make sure you select the “as text” option. For example:

```
$ cat work/spend-tx-alonzo.tx
{
  "type": "Witnessed Tx BabbageEra",
  "description": "Ledger Cddl Format",
  "cborHex": "84aa00828...63302e31"
}
```



The screenshot shows the CBOR playground interface. At the top, there's a header bar with tabs for 'CBOR playground' and 'cbor.me/?bytes='.

The main area has two sections:

- Diagnostic:** A button labeled 'Diagnostic' with a green circle icon, followed by a checkbox labeled 'plain hex'.
- Input/Output:** A text input field with a placeholder 'enter hex below or Choose File' and a note 'No file chosen'. To its left is a '0 Bytes' counter and a checkbox labeled 'as text' which is checked. Other unchecked options include 'utf8', 'emb cbor', and 'cborseq'.

The bottom section displays the decoded CBOR data as JSON:

```
Diagnostic notation: [1, [2, 3]]  
84aa00828258201e75fabbdd062ac9eb670a5bfb5adcc7cac0e8ce2789f3d907d  
769c8d69765eb02825820bcb730168d07/ee61f11385242046978c02fb1b94fbe0  
ec408ac0da6d2a309c53000d81825820e06d00315b692ac604cbd2105019dc7d5  
24d3e500d6a0b8c0258ce38699978d60012818258206af1c7ea85bd3222be2e31  
e5fcfd664318b0897b2ab5b68a4db667508aa21a5f8000183a200581d603d62b2fd  
ff66855d150b6cf97e4509eef78f5ea6245f642adff7629338c01la071f5188a200  
581d60b2b0a5ceaf7bc9a5fe6198198891e6bafeff5c2cb275e333f97a9f011  
a00ca9748a200581d60b9abc1f6867519e28042048aa11207214a52e6d5d3288b7  
52d1c2768201la1074f50510a200581d60b9abc1f6867519e28042048aa1120721  
4a52e6d5d3288b752d1c2768201la0046fd0f11la00054e31021a000389760e81  
581cb9abc1f6867519e28042048aa11207214a52e6d5d3288b752d1c276820b582  
0cl4eccede03173d11592082528d907393fa67815f59d291712adaabb8a471353  
075820b0f31849f135a4b646a0356561d93bb42a167f8618dc56682debcdfae46  
c4750a200818258207afdf742e52fc46d9a6f2183204c3d5ca3533450b2674f61  
adff33172d6d9ad65840fdc0635097555eedb17d206d921e0460ee82e4ad35c0  
166a26383dcfb1d7e04806adb151081c554c26b9c7f5383e71886d94e1bab1e1  
ec69dcf72eae84c040581840001d87980821a00065f5d1a092b62a2f5d90103a  
100a101a16c6f726465725f64657461696ca76d6164615f7573645f7072696365  
67302e333736363064646174657323032332f30312f32342d31333a34353a343  
873646f16e6174696f16e5f6164615f616d6f756e746831333237373030306e646f  
6e6174696f6e5f73706c697463313025706f726465725f6164615f616d6f756e7  
469313332373730303030686f726465725f69646d353234353436333133343438  
376776657273696f6e63302e31
```

Then select the very small arrow in green pointing to the left and you will get the transaction details on the left side.

CBOR playground

← → C cbor.me/?bytes=

CBOR playground. See [RFC 8949](#) for the CBOR specification, and [cbor.io](#) for more background information.

CBOR

Diagnostic plain hex

728 Bytes as text utf8 emb cbor cborseq
enter hex below or Choose File No file chosen

```
[{: [[{"h": "1E75FABBD062AC9EB670A5BFB5ADCC7CAC0E8CE2789F3D907D769C8D69F65EB", 2}, [{"h": "BC730168D07EEC6F11385242046978C02FBF1B94FBE0EC408AC0DA6D2A309C53", 0}], 13, [{"h": "E06D00315B692AC604CBD2105019DC7D524D3E500D6A0B8C0258CE38699978D6", 0}], 18, [{"h": "6AF1C7EA85BD3222BE2E31E5FCD664318B0897B2AB5B68A4DB667508AA215F8", 0}], 1, [{"h": "603D28DFBFD66855D150B6CF97E4509EF78F5PEA6245F642ADF7629338C", 1}, 119493000], 0, [{"h": "60B2B0A5CEF7BC9A56F619819B8891E6BAFFFC52CB275E333F97A9F", 1}, 13277000], 0, [{"h": "60B9ABC6867519E28042048A11207214A5E6D5D3288B752D1C27682", 1}, 276100357], 16, [{"h": "60B9ABC6867519E28042048A11207214A5E6D5D3288B752D1C27682", 1}, 4652303], 17, [{"h": "346797, 21, [{"h": "9BABC6867519E28842048A11207214A5E6D5D3288B752D1C27682"}], 11, [{"h": "C1D4ECECDE03173D11592082528D907393FA67815F59D291712ADAAB8A471353", 7}, {"h": "B0F31849F135A4B646A0356561D93BB42A167F8618DC56682DEBCD5AE46C4750}], 0, [{"h": "7AFDF742E52FC46D9A6F2183204C3D5CA3533450B2674F61ADFF33172D6D9AD6", 1}, {"h": "FDC0635097555SEED8817D206D921E0460E8E2F4AD35C0166A26383DCFB1D7E04806ADBA151801C554C26B8C7F5383E71886D94E1BABA1E1EC69DCF72EEA8E4C04}], 5, [{"h": "0, 1, 121([{}], [417629, 153838242])}], true, 259, [{"h": "1, {"order_detail": {"ada_usd_price": "0.37660", "date": "2023/01/24-13:45:48", "donation_ada_amount": "13277000"}, 0}], 0, [{"h": "00001[1*x6\u0004*xB\u0020\u00010P\u00019*xDC]RM=P\rj\\v\x8C\u0002X\xCE8i\x999\xD6", 0}], 0, [{"h": "00", 0}]]
```

```
84 AA # array(4)
      00 # map(10)
      82 # unsigned(0)
      82 # array(2)
      58 20 # array(2)
      # bytes(32)

1E75FABBD062AC9EB670A5BFB5ADCC7CAC0E8CE2789F3D907D769C8D69F65EB
#
"\u0001Eu\xFA\xBB\xDD\u0006*\u009\xEBg\n(\u00FBZ\xDC\xC7\xCA\xC0\xE8
\xCE"\u009\xF3\xD9\xA\xD7i\xC8e\xEB"
      02 # unsigned(2)
      82 # array(2)
      58 20 # bytes(32)

BC730168D07EEC6F11385242046978C02FBF1B94FBE0EC408AC0DA6D2A309C53
#
"\u00Bcs\u0001h\xD0-\u00ECo\u0011RB\u0004i\xC0\xBF\le\x94\xFB\xE0\xEC@
\xC0\xDAm*0\x9CS"
      00 # unsigned(0)
      0D # unsigned(13)
      81 # array(1)
      82 # array(2)
      58 20 # bytes(32)

E06D00315B692AC604CBD2105019DC7D524D3E500D6A0B8C0258CE38699978D6
#
"\u00E0m\u00001[i*\u006\xC6\u0004\xCB\xD2\u00010P\u00019*xDC]RM=P\rj\\v\x8
C\u0002X\xCE8i\x999\xD6"
      00 # unsigned(0)
```

Since we are currently in the [Babbage era](#), the CDDL spec is located [here](#).

Production

This final section will review some of the considerations that should be taken into account when deploying a smart contract into production.

Legal Notice

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Audit

Hiring an [independent auditor](#) to review smart contract development for production is strongly recommended for any projects involving customer funds. Please also be aware that Helios is a very new language and currently does not have the same level of audit and production verification as Haskell PlutusTx. That said, as more developers and project teams take advantage of the benefits of using Helios, this risk will diminish over time.

Test, Test, Test

Once a smart contract has been deployed, it cannot be rolled back or undone. This is the point of the blockchain to be immutable so developers must be aware of this fact when building blockchain applications.

To mitigate the risk of anything unexpected on mainnet, testing must be a key part of the development lifecycle. Helios has a unit testing framework called [Fuzzy Test](#) that can be used in addition to integration, functional and user acceptance testing.

All of the code examples have completed integration and functional testing with documented results located in the GitHub project [testing folder](#). Remember, it is important to test both the positive and negative scenarios.

Smart Contract Lifecycle

It is important to understand the smart contract lifecycle prior to deploying to production.

- What does an upgrade path look like and can it be done?
- Can the front-end application point to a new smart contract or does it involve coordination with end users?
- How will you remediate issues identified with a smart contract after a mainnet launch?
- How will you retire a smart contract?
- Monitoring [Cardano CIPs](#) for any changes to the plutus core evaluator that may impact smart contract functionality.

Sources and Acknowledgements

Open Source

The complete source code for all examples in this book are open source and located at <https://github.com/lley154/helios-examples>. There may be minor differences between the code samples in this book and the repository and this is mainly due to formatting to fit the page layout and for readability.

Without open source projects, this book and countless projects in our ecosystem would not have been possible. Please consider donating to one of your favorite open source projects so they can continue to build great things!

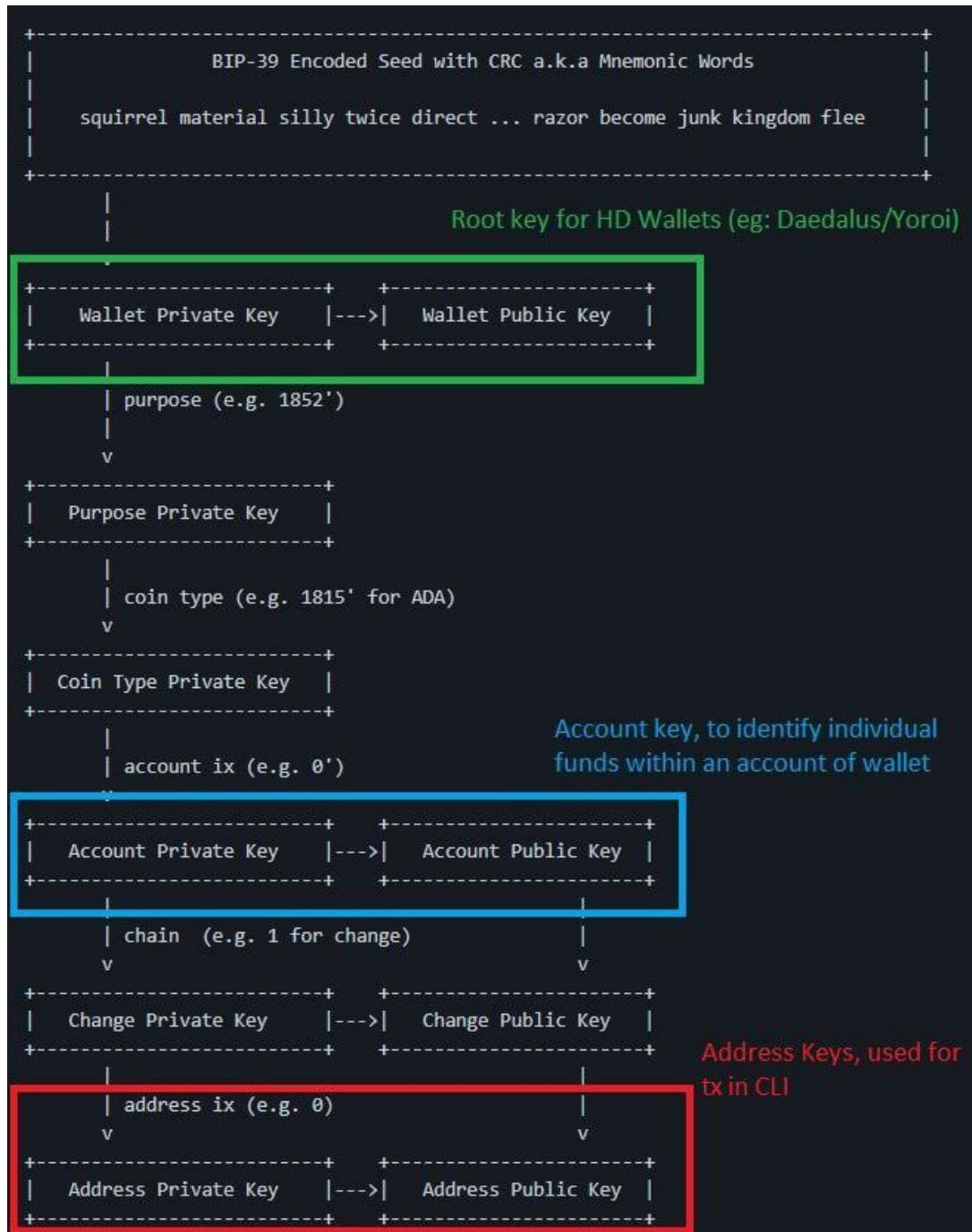
References

- <https://github.com/Hyperion-BT/helios>
- <https://www.hyperion-bt.org/helios-book/>
- <https://txpipe.github.io/oura/>
- <https://github.com/berry-pool/nami>
- <https://developers.cardano.org/>
- <https://docs.cardano.org/plutus/plutus-resources>
- <https://github.com/input-output-hk/cardano-addresses>
- <https://github.com/input-output-hk/cardano-node>
- <https://github.com/dendorferpatrick/nami-wallet-examples/blob/multi-wallets/Multi-Signature.md#4-hash-metadata-for-transaction>
- <https://www.youtube.com/@AndrewWestberg/videos>
- <https://www.essentialcardano.io/>
- <https://github.com/input-output-hk/plutus-pioneer-program>

Appendix

Address Key Derivation

Key derivation is a complex subject and the main idea behind it is that a private and public key is used to derive different types of keys that are used for different purposes. The starting point for a private key in blockchain cryptography is the BIP-39 encoded seed phrase. The following diagram¹ illustrates the steps involved in key derivation.



¹Source: <https://cardano.stackexchange.com/questions/4808/how-to-new-cardano-bip32privatekey-from-cborhex-in-file-skey-generate-by-cardan>

Here are the steps of obtaining a private key that can be used with cardano-cli from a newly generated passphrase.

1. Go to your Web VS Code in your browser
2. Select the hamburger menu (top left) and Terminal -> New Terminal
3. mkdir ~/.local/keys
4. cd ~/workspace
5. wget
 <https://github.com/input-output-hk/cardano-wallet/releases/download/v2022-12-14/cardano-wallet-v2022-12-14-linux64.tar.gz>
6. tar -xvzf cardano-wallet-v2022-12-14-linux64.tar.gz
7. cd cardano-wallet-v2022-12-14-linux64
8. ./cardano-address recovery-phrase generate --size 24 > ~/.local/keys/key.prv
9. ./cardano-address key from-recovery-phrase Shelley < ~/.local/keys/key.prv > ~/.local/keys/key.xprv
10. ./cardano-address key child 1852H/1815H/0H/0/0 < ~/.local/keys/key.xprv > ~/.local/keys/key.xsk
11. ./cardano-cli key convert-cardano-address-key --shelley-payment-key
 --signing-key-file ~/.local/keys/key.xsk --out-file ~/.local/keys/key.skey
12. ./cardano-cli key verification-key --signing-key-file ~/.local/keys/key.skey
 --verification-key-file ~/.local/keys/key.vkey
13. ./cardano-cli address key-hash --payment-verification-key-file
 ~/.local/keys/key.vkey --out-file ~/.local/keys/key.pkh
14. ./cardano-cli address build --payment-verification-key-file ~/.local/keys/key.vkey
 --out-file ~/.local/keys/key.addr --testnet-magic 1

You can then see the address created by your passphrase with a usable private & public key for cardano-cli.

```
$ more ~/.local/keys/key.addr
addr_test1v83ynr979e4xpjj28922y4t3sh84d0n08juy58am7jxmp4g6cgxr4
```

Installing Next.js

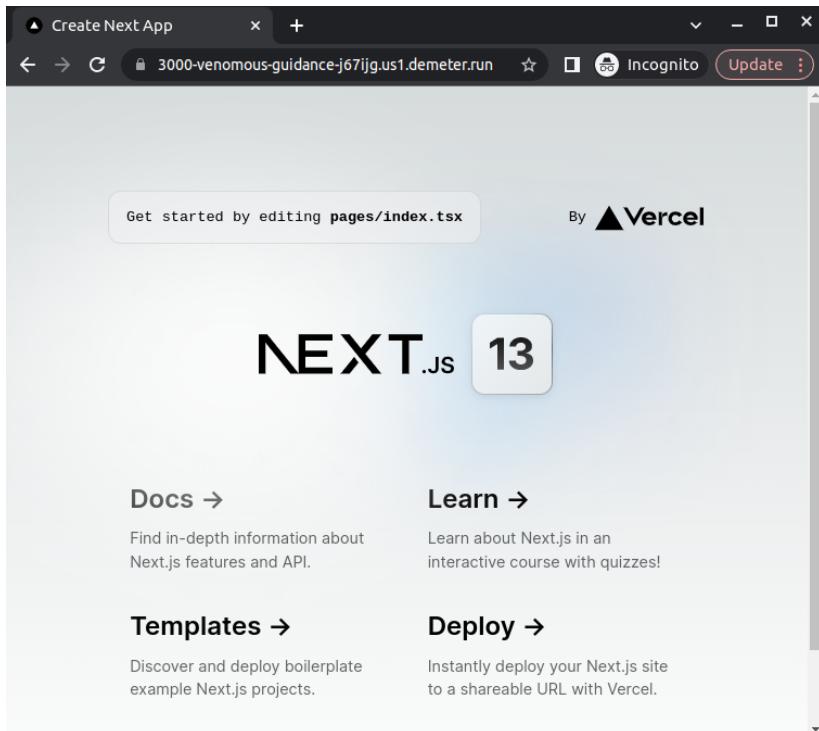
Go to your workspace using the terminal window in the Visual Studio Web.

```
$ npx create-next-app@latest --typescript .
Need to install the following packages:
create-next-app@13.1.2
Ok to proceed? (y) y
✓ Would you like to use ESLint with this project? ... Yes
✓ Would you like to use `src/` directory with this project? ... No
✓ Would you like to use experimental `app/` directory with this project? ... No
Creating a new Next.js app in /config/workspace/repo/helios-builder/app.
Using npm.
Installing dependencies:
- react
- react-dom
- next
- @next/font
- typescript
- @types/react
- @types/node
- @types/react-dom
- eslint
- eslint-config-next
added 271 packages, and audited 272 packages in 28s
102 packages are looking for funding
run `npm fund` for details
found 0 vulnerabilities
Initializing project with template: default
Success! Created app at /config/workspace/repo/helios-builder/app
npm notice
npm notice New major version of npm available! 8.19.3 -> 9.3.0
npm notice Changelog: https://github.com/npm/cli/releases/tag/v9.3.0
npm notice Run npm install -g npm@9.3.0 to update!
npm notice
abc@venomous-guidance-j67ijg-0:~/workspace/repo/helios-builder/app$
```

Startup Next.js

```
$ npm run dev
```

Then select the URL on the Exposed Ports tab for your workstation to launch the application. You should see the default Next.js page like this.



To use Helios, you will need to install the Helios npm module

```
$ npm install @hyperionbt/helios
```

Also install the express-validator module to sanitize inputs when required.

```
$ npm install express-validator
```

You will also need to replace the next.config.js file with the following

```
/** @type {import('next').NextConfig} */
const nextConfig = {
  reactStrictMode: true,
  webpack: function (config, options) {
    config.experiments = {
      asyncWebAssembly: true,
      topLevelAwait: true,
    };
    return config;
  },
};
module.exports = nextConfig;
```

IPFS (NFT Images)

The InterPlanetary File System (IPFS) is typically used to store NFT images and other media files. IPFS is a peer-to-peer file sharing network where uploaded content gets a unique key so it can be accessed.

There are a large number of service providers that can help get your images on to IPFS. An easy and free option is thirdweb.

<https://blog.thirdweb.com/guides/how-to-upload-and-pin-files-to-ipfs-using-storage/>

```
$ npx thirdweb@latest upload path/to/file.extension
```

Shopify Ada Payments

At the time of writing, there is no Ada Shopify payment plugin. The following Shopify integration is for merchants who have a basic plan and cannot customize their checkout page. For merchants who have higher priced plans, they can do more front-end and checkout customizations which can streamline a pay with Ada process.

Shopify Configuration

We need to update the Shopify store so when an order is placed, there is a link to pay with Ada.

1. In Settings, select Apps and sales channels
2. Select Develop apps for your store
3. Select Allow custom app development
4. Select Allow customer app development again
5. Create an app
6. Enter the name of the app, eg. "Pay With Ada"
7. Select Create app
8. Select Configure Admin API scopes
9. Scroll down and enable in the Order section, write_orders and read_orders
10. Scroll down and enable in the Products section, read_products
11. Go to the bottom of the page and press Save
12. Now select the API credentials tab
13. In the Access tokens box, select Install app
14. A prompt will ask you if you want to install your app, select Install
15. Go back to the main settings menu and select Payments
16. Select Add manual payment method
17. In the dialog box, enter the name of the payment method. eg "Pay With Ada"
18. Add additional details if required. eg "Paying with Ada using your Cardano Wallet"
19. Add payment instructions. eg. "Please select to the Pay Now With Ada link below to pay using your Cardano Wallet"
20. Go back to the main settings menu and Select Checkout
21. Scroll to the bottom of the page and add the following to the Additional scripts

```
window
<script>
  Shopify.Checkout.OrderStatus.addContentBox(
    '<h2 style="color:red;">Pay To Complete Your Order</h2>',
    '<a href="#" id="paynow">Pay Now In Ada</a>'
  );
  var urlStr =
  "https://3000-venomous-decision-kd0ey1.us1.demeter.run/";
  var url = new URL(urlStr);
  var params = url.searchParams;
  var orderId = Shopify.checkout.order_id
  params.append("id", orderId);

  function updatePayNow () {
    document.getElementById("paynow").href=url
  }
}
```

```
function updateOrderNum () {
    document.querySelector("body > div > div > div > main >
div.step > div.step_sections > div:nth-child(1) > div > div >
span").innerHTML=orderId
}

document.addEventListener("DOMContentLoaded", function() {
    updatePayNow()
}) ;
document.addEventListener("DOMContentLoaded", function() {
    updateOrderNum()
}) ;
</script>
```

22. Select Save
23. In the Setting menu, select Apps and sales channels
24. Select Develop Apps
25. Select Pay With Ada App
26. Select Manage Credentials
27. Show the Access Token and copy it to your clipboard
28. Paste the Access Token into your ~/.bashrc file for
NEXT_PUBLIC_ACCESS_TOKEN value

About Helios



A DSL for writing smart contracts on the Cardano blockchain.

Twitter: [@helios_lang](https://twitter.com/helios_lang)

Github: <https://github.com/Hyperion-BT/helios>

Discord: <http://discord.gg/XTwPrvB25q>

Web: <https://hyperion-bt.org>

About The Author



Lawrence Ley is passionate about learning new technologies and how they can make a positive impact. His Cardano journey started out in the Plutus pioneers program 2nd cohort and has worked on a number open source impact projects. He discovered Helios and was thoroughly impressed how easy it was to pick up due to its familiar language, syntax and structure. Since onboarding new developers to Cardano is not easy, he decided to write this book.

Twitter: [@lley154](https://twitter.com/lley154)

YouTube: <https://www.youtube.com/channel/UC5R8HrDUms8XqZVWszbA7A>

GitHub: <https://github.com/lley154>