

Ethereum Blockchain Developer Guide

The Guide for Learning Ethereum Blockchain Development with Labs and
Explanations

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1. Practical Ethereum Development

Heyo! So, you thought "Blockchains" are a cool thing? You have no idea where to start? This whole thing is too hard to figure out with weird YouTube tutorials and outdated sites?

Guess what!?

You're at the right place! And with my help you're developing your own Smart Contracts in no time!



1.1 Why This Guide Exists

When I started with Blockchain development back in 2016, the landscape for tutorials was very very *very* scarce. There were many tools, almost all only half-working. And no real guides. There was no Remix, no MetaMask, no Infura, no Truffle, no Academies, no ConsenSys. No nothing back then. My start was AlethZero. It crashed every few minutes or so and some whacky guides on how to compile Smart Contracts.

And for the entirety of 2016 the price of Ether was between \$1 and \$7.

AlethZero in Action

AlethZero in Action from this [YouTube Video](#)

What I was looking for was a *practical* guide that takes me through typical steps as a Smart Contract and DApp developer. Something that takes me through the pitfalls. Something I can relate to as a developer.

I'm not trying to do something shady. I'm not trying to build another Silk Road. This guide is not about Libertarianism. I'm not a cryptography researcher.

I am a CTO with a strong development background trying to do *practical* stuff with that technology. I am not trying to make anyone geek out on how much it will f*ck up our traditional world of finance.

I didn't have any of those guides. And I set out to change that. Already in 2016. But my first attempts were not great. In fact, they were very bad. Now, 15 video courses later, hundreds of hours spent on creating tutorials and video materials (if not thousands of hours!), I believe it reached a point where I have a framework for learning this *stuff*. And showing it to others. And I want to keep going.

When you're a traditional (web-)dev, then it's quite a bit of new material to learn and dig through. The traditional trust-model changed: the underlaying flow of registration/authentication is almost reversed. Tools are different. Language is different. Boundaries of what's possible are narrower. The business goals may be the same, but the way to reach them is *skewed*, for the lack of a better word.

And this guide shall be your new best friend.

1.2 Are You The Right Audience

It's certainly not a *complete reference* or covers the Solidity documentation front2back. You won't get a PhD after working through my code examples. But it gives you a deep understanding of the technologies behind famous DeFi-projects like Uniswap, ERC20 and ERC721 Tokens, Blockchain Supply Chain Solutions, and many more things. Scalable things. Trustable things. Enterprise'ey workflows. Stuff that I would expect a developer would bring when he wants to be hired.

Not me

That's not me. That's a foto I blatantly copied from unsplash. If you made it this far, why not just go and do your first transaction in the next chapter?! Photo by [Campaign Creators](#) on [Unsplash](#)

How hard will it be to go through the guide? That depends on your prior knowledge about web development. If you're a total beginner: never written a single line of JavaScript, never heard of RESTful APIs? Then better look somewhere else. Blockchains are not the best way to get started with development, it's hard to access and many underlaying ideas require fundamental understanding of how the web works.

If you are a C, C#, C++, Java, etc programmer with 20 years on your shoulders, you'll probably have an easy time. If you come from PHP, some things will be new, some things might look easy.

One thing I can promise you: I'll try to show you "the right way"™ to do things in an ever changing and more-than-ever demanding environment and I hope it will be enough to spark your interest to learn more about selected topics.

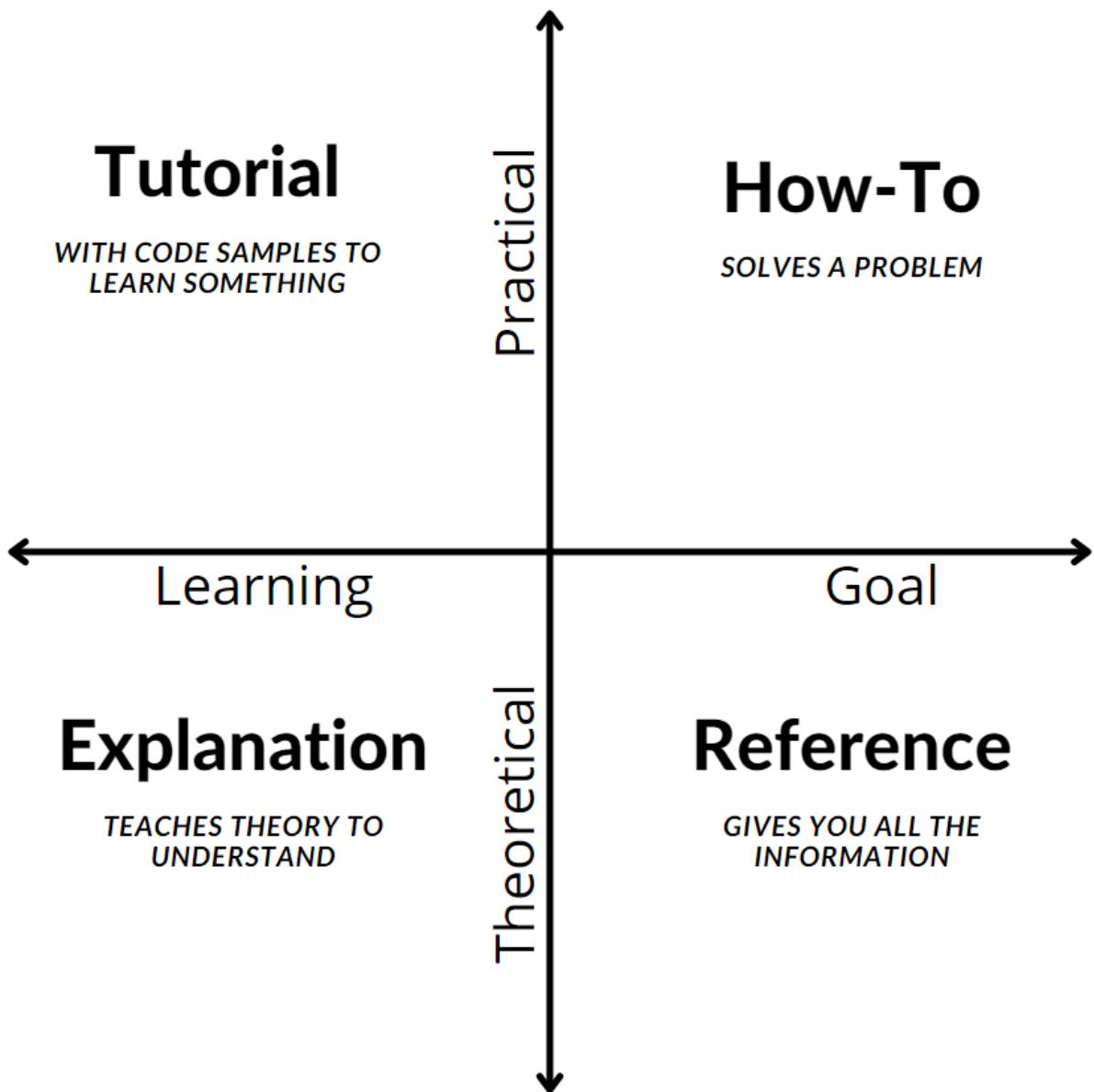
1.3 What You Will Learn

In these labs we're going through quite a bit and I'm not going to bullet-point every single tech and principle you're touching. Suffice to say, you'll have a workflow to develop your own projects. You'll have a fundamental understanding of Solidity. And you'll know the boundaries you're operating under (also called limitations).

At the end we'll run through a few full projects with Solidity on the Blockchain side and React on the Frontend side.

1.4 I saw you also do Video-Courses?

When you're looking to learn something, you can choose between with 4 different types of materials: Tutorials, How-To's, a full Reference and a theoretical explanation.



A school book about physics would be the classical "Theoretical Explanation". Yawn.

What's the difference between a Tutorial and a How-To?

A tutorial is learning oriented and a how-to is problem oriented. A tutorial is great for studying and a how-to is great to solve a specific problem when you're working. You wouldn't go to stackoverflow to learn a new skill, would you? And you would not take a 24h Udemy course to get that damn regex filter fixed, right?

The Solidity Documentation is a Reference, in my opinion. A pretty good one. Almost a Tutorial. What it lacks is teaching also about Blockchains and the tooling.

So, why an official (video) course on top of this guide?

This guide is a *tutorial* but it doesn't include a lot of theoretical knowledge. And it also doesn't include me directly showing, *on video*, how things are done.



This guide strips away most of the theoretical part and basically contains all the labs from of the video course [Ethereum Blockchain Development](#).

If videos are *your thing*, then check it out. I made it with my colleague and friend Ravinder Deol, who's just as much of a Blockchain enthusiast as I am.

Now a little self promo: We will take you from beginner to master. Here's why:

- This course is taught by the Co-Creator Of The Industry Standard Ethereum Certification.
- This course been updated to be 2021 Ready, so you'll be learning with all the latest tools.
- This course does not cut any corners, you will learn by building Real-World Projects in our labs.
- We've taught over 100,000 students in the cryptocurrency & blockchain ecosystem.
- Save Yourself Over \$10K, but still get access to the same materials as live bootcamps.
- This course is Constantly Updated with new content, projects and modules.

It's also a best-seller on Udemy and was picked up and transformed into corporate trainings and a book and instructor-led trainings, translated to chinese, probably pirated a few times, and more.

1.5 Work in Progress

Currently this written guide is a work in progress. I will update the following list as more and more chapters are being converted:

- Your First Transaction With MetaMask
- Your First Smart Contract with Remix
- Using different Blockchain Networks
- Solidity Basics: Integers, Boolean, Addresses, Strings
- LAB: Escrow - Deposit and Withdrawals
- Smart Contracts Life-Cycle: Starting, Pausing, Destroying Smart Contracts
- Understanding Mappings and Structs
- Exception Handling
- Constructor and Fallback Functions
- Solidity Advanced: Modifier, Inheritance, Constructors, Fallback
- Events and Return Variables
- LAB: Create a Shared Wallet
- LAB: Event Triggers / Supply Chain Example with Truffle 5 and Unit Tests
- Understand and Use Go-Ethereum Private Networks
- LAB: Asset Tokenization using OpenZeppelin and Truffle

Work in Progress

Please note, this site is a "work in progress" for the course "Ethereum Blockchain Developer Bootcamp With Solidity (2021)"

2. License and Re-Use

All my materials are *original* materials and it took several hundred hours to put them together. I didn't do it to earn money in the first place, but I am also not doing it solely for someone else to make money off my back.

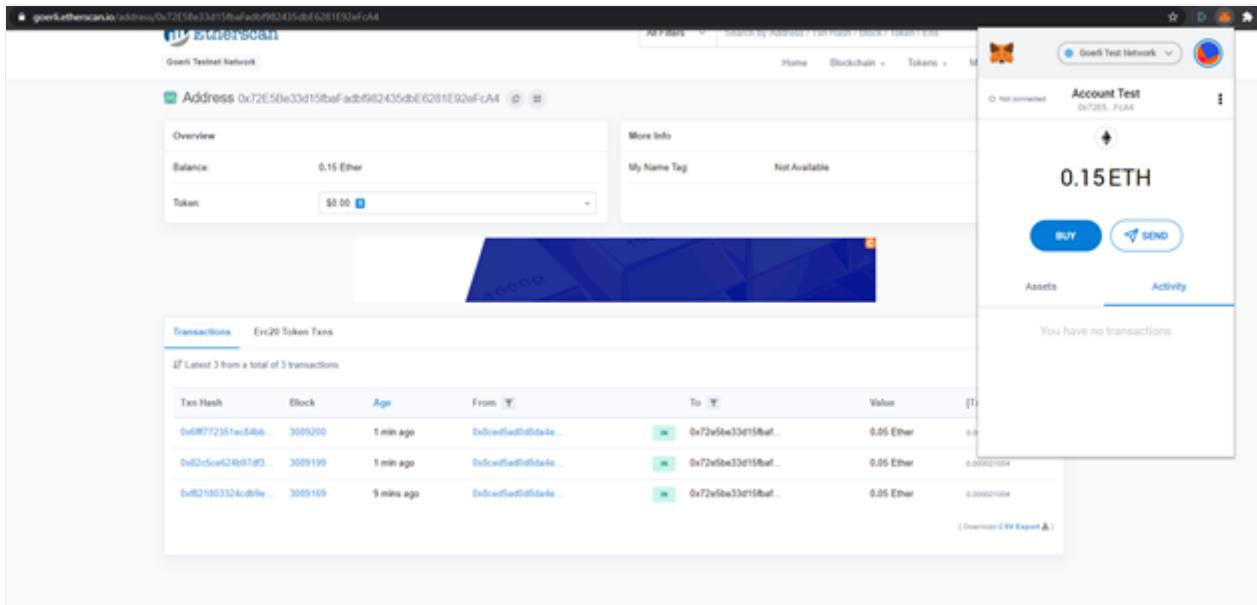
I offer sub-license agreements for commercial use and educational use. Reach out to me at thomas at vomtom dot at.

Last update: April 17, 2021

3. Your First Transaction

3.1 Lab: Download, Install and Use a Wallet to Create a Transaction

In this lab we are going to install MetaMask and create our first transaction.



3.1.1 What You Know At The End Of The Lab

- How to Get Free Ether To Test Transactions
- How To Securely Store Your Funds With Your Own Wallet
- Interact With Different Blockchains
- Industry Standard Way To Connect To Blockchains
- Understand Public Information With Block Explorers

3.1.2 Prerequisites - You need:

1. Chrome or Firefox browser.
2. An Internet connection

Brave Browser

If you are using a Brave Browser and you run into problems, then try to use Chrome instead.

3.1.3 Videos

■ Full Video Walkthrough: <https://www.udemy.com/course/blockchain-developer/?referralCode=E8611DF99D7E491DFD96>

3.1.4 Get Started

■ ■ ■ Let's get started by [Installing MetaMask](#)

Last update: April 23, 2021

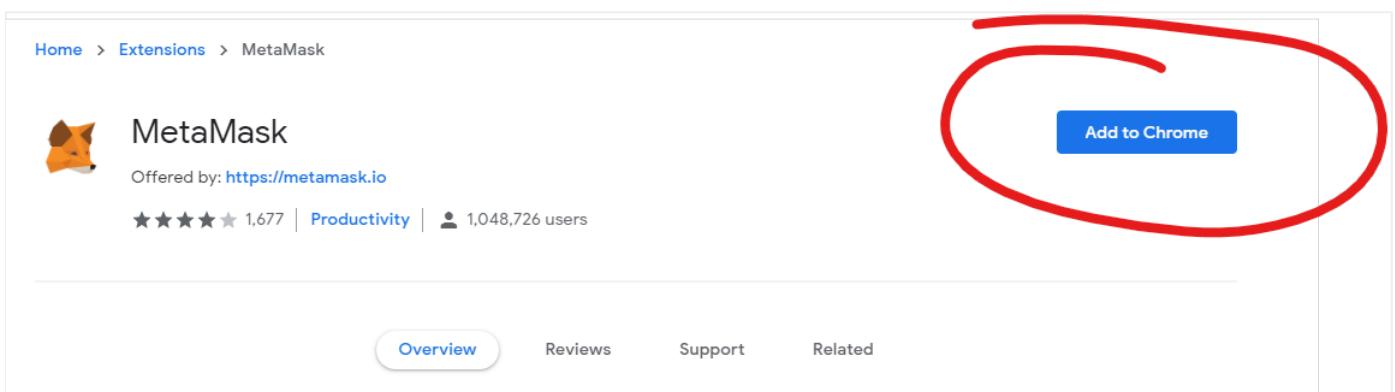
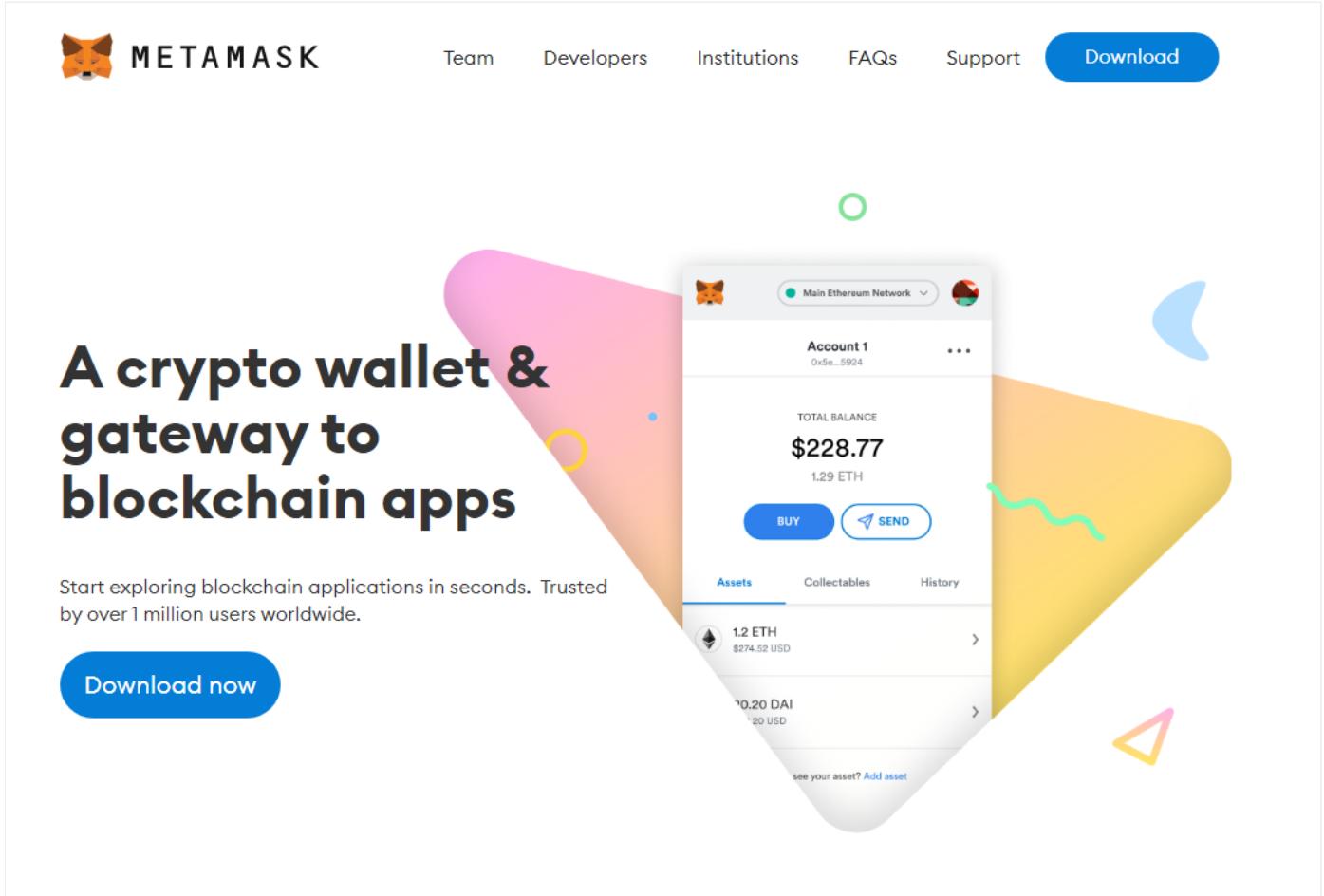
3.2 Installing MetaMask

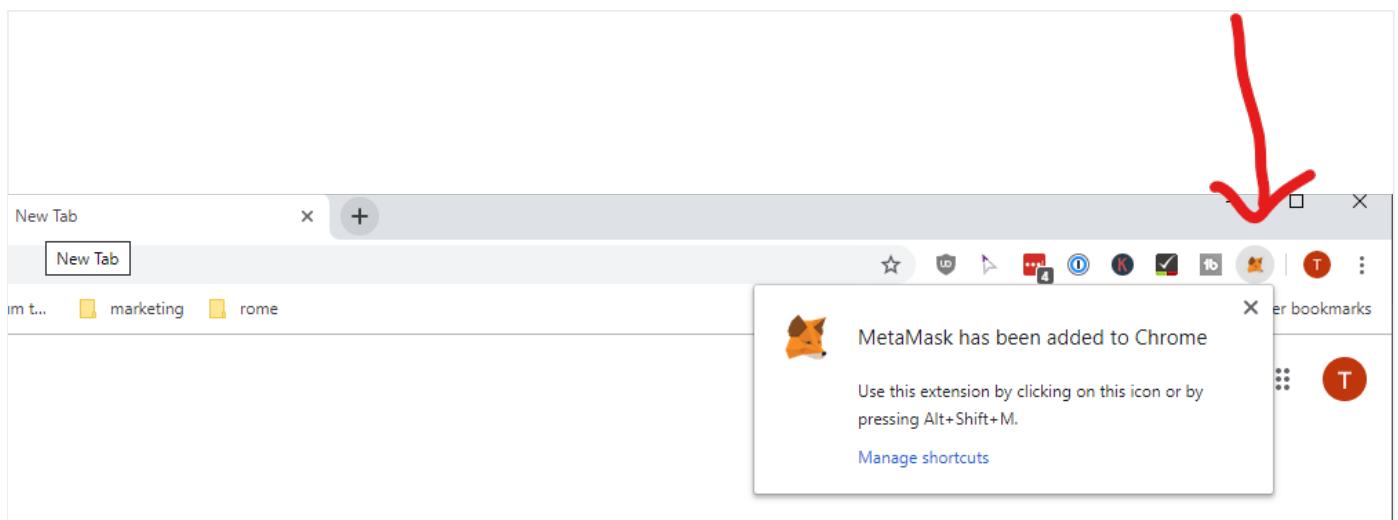
Firstly, we are going to install MetaMask. That is a browser plugin which can securely store private keys and connect to different blockchains.

How this exactly works is something we discuss later. For now we just play around.

3.2.1 Download MetaMask

Open <https://metamask.io> and download the plugin for your browser





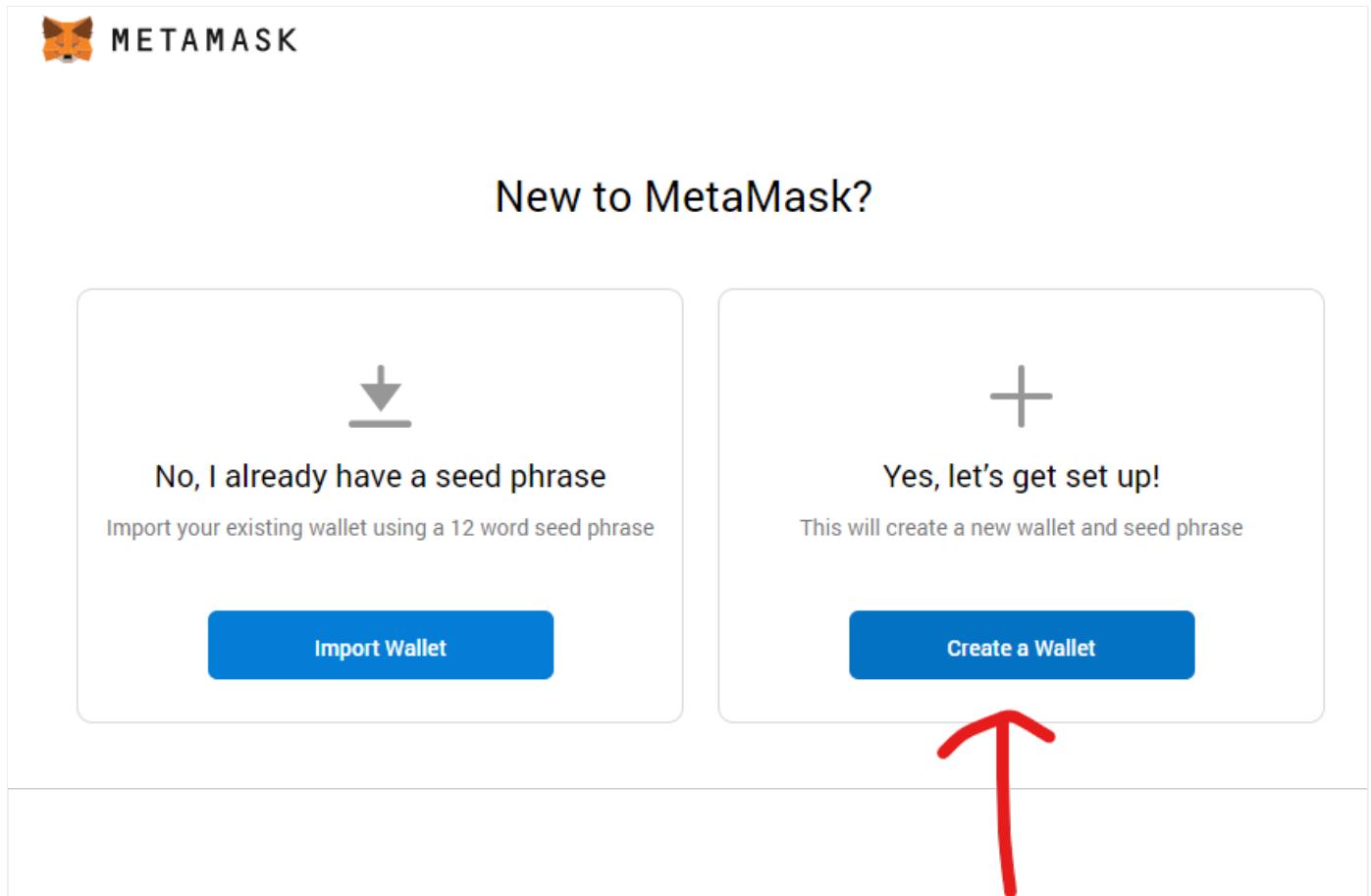
Perfect, that's it. Now, let's setup MetaMask and make it secure.

Last update: April 17, 2021

3.3 Setup MetaMask

When you install MetaMask, then it will automatically open up a "setup" page.

Hit "Begin" and walk through the setup-wizard. Let's create a new Wallet!



3.3.1 Statistical Information

If you want to send statistical information, is totally up to you, both is fine:



Help Us Improve MetaMask

MetaMask would like to gather usage data to better understand how our users interact with the extension. This data will be used to continually improve the usability and user experience of our product and the Ethereum ecosystem.

MetaMask will..

- ✓ Always allow you to opt-out via Settings
- ✓ Send anonymized click & pageview events
- ✓ Maintain a public aggregate dashboard to educate the community

- ✗ **Never** collect keys, addresses, transactions, balances, hashes, or any personal information
- ✗ **Never** collect your full IP address
- ✗ **Never** collect your full Ethereum private key

No Thanks

I agree

This data is aggregated and is therefore anonymous for the purposes of General Data Protection Regulation (EU) 2016/679. For more information in relation to our privacy practices, please see our [Privacy Policy here](#).

3.3.2 Set a Password

Create a new *strong* password. This password is used to encrypt your private keys. What private keys are exactly is discussed in a later section of the course, suffice to say though, they give access to *all your Ether*. So, better have a strong password here:



METAMASK

< Back

Create Password

New Password (min 8 chars)

Confirm Password

I have read and agree to the [Terms of Use](#)[Create](#)

3.3.3 Backup Phrase

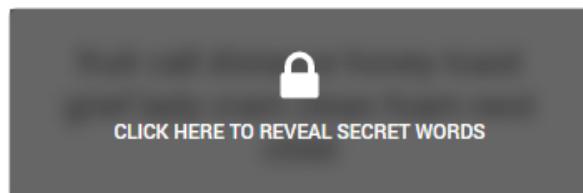
It would be better to safely store the secret phrase, but for sake of simplicity, let's just skip this for now:



Secret Backup Phrase

Your secret backup phrase makes it easy to back up and restore your account.

WARNING: Never disclose your backup phrase. Anyone with this phrase can take your Ether forever.



Remind me later

Next

Tips:

Store this phrase in a password manager like 1Password.

Write this phrase on a piece of paper and store in a secure location. If you want even more security, write it down on multiple pieces of paper and store each in 2 - 3 different locations.

Memorize this phrase.

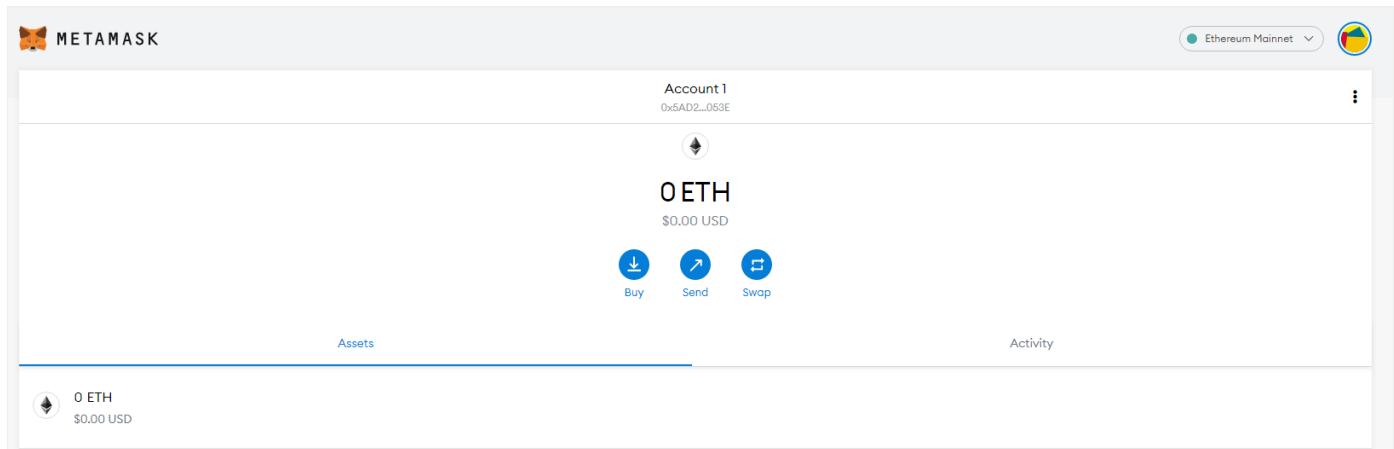
[Download this Secret Backup Phrase and keep it stored safely on an external encrypted hard drive or storage medium.](#)

Seed Phrase

A seed phrase (or here: Backup Phrase) is usually a number of human-readable words (e.g. 12 words). This represents the "master key" to regain access to all your accounts. It is a simple algorithm to create a number of private keys based on your backup phrase. Don't worry if you don't know yet what this means - just remember: Never (like **never ever**) give out your seed phrase!

3.3.4 Final Screen

And you should be greeted with this screen:



Let's see now how we can use MetaMask to transfer Ether...

Last update: April 17, 2021

3.4 Get Test-Net Ether

If you have never worked with blockchains before, then the first confusing this you will encounter is: There is not one blockchain, but *many* different blockchains. I am talking about Ethereum Blockchains.

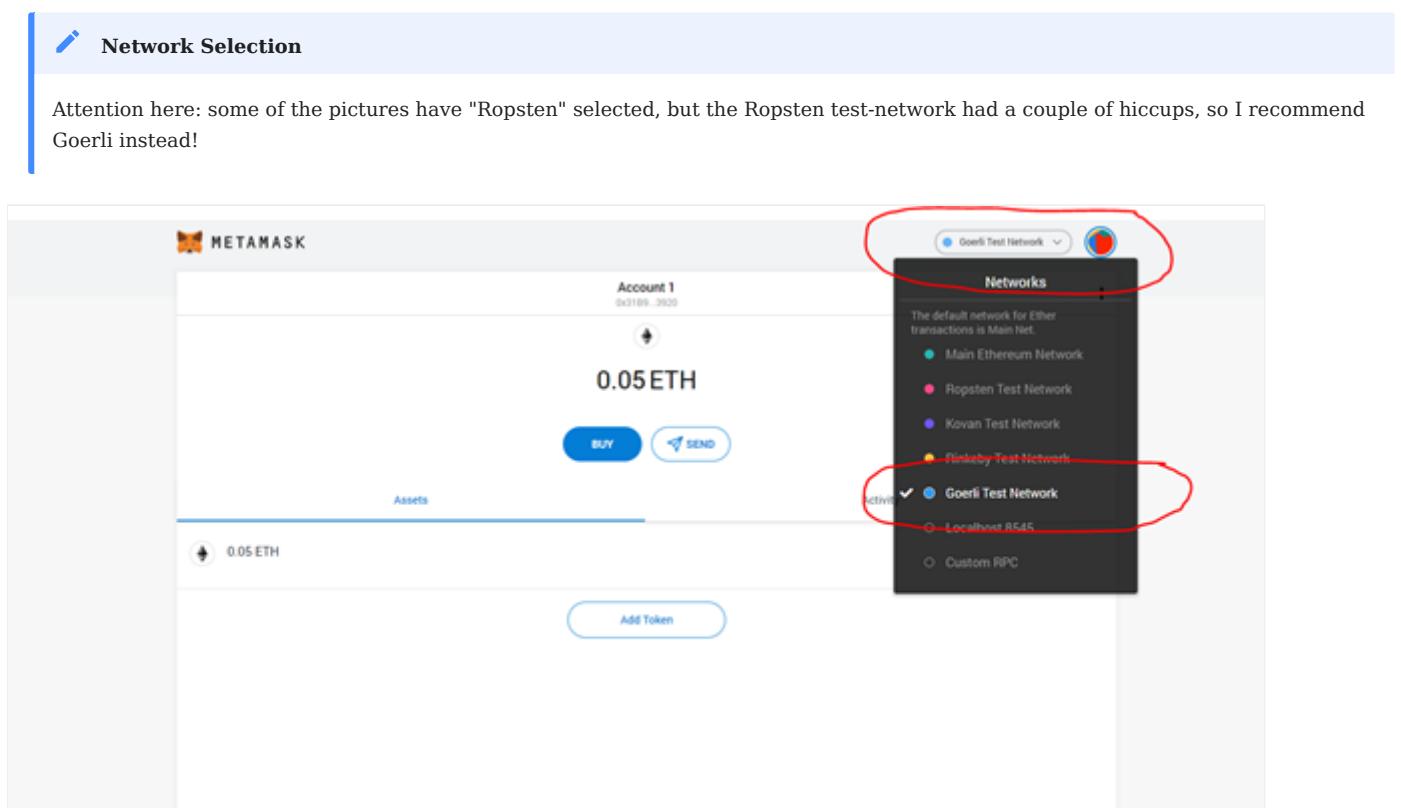
It's like having different databases. But only one is considered the "Main" Database, or "Mainnet".

There are also other blockchains, for testing different aspects. Each of those have usually a name and a specific network and chain id. There is no central list of them, because everyone can open their own blockchain, but here's a good [overview](#).

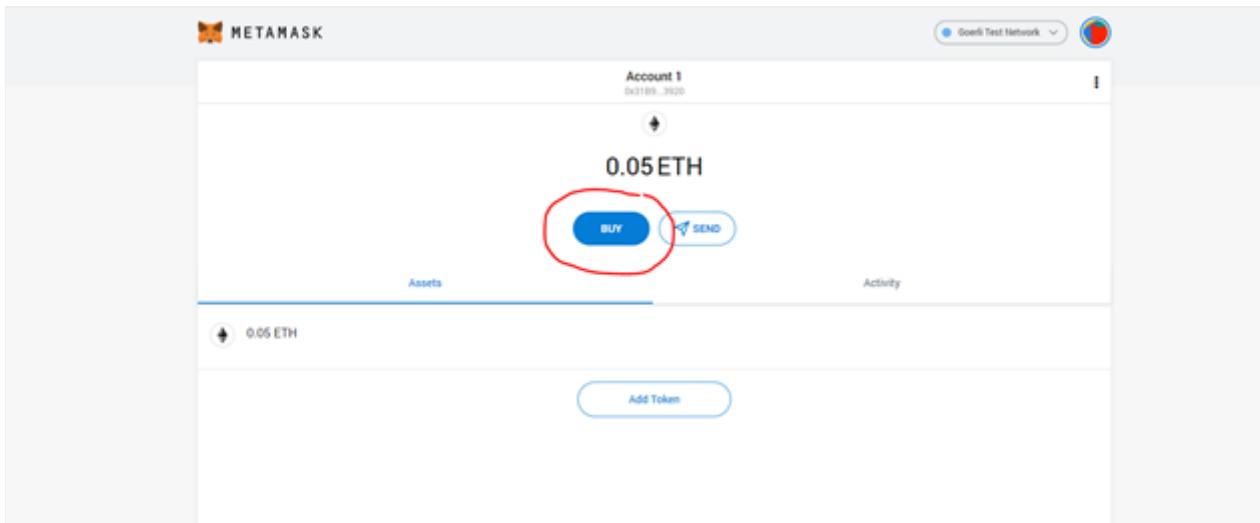
In this tutorial, we will use either Ropsten or Görli to get Test-Ether and start a transaction.

3.4.1 Get Görli Test-Ether

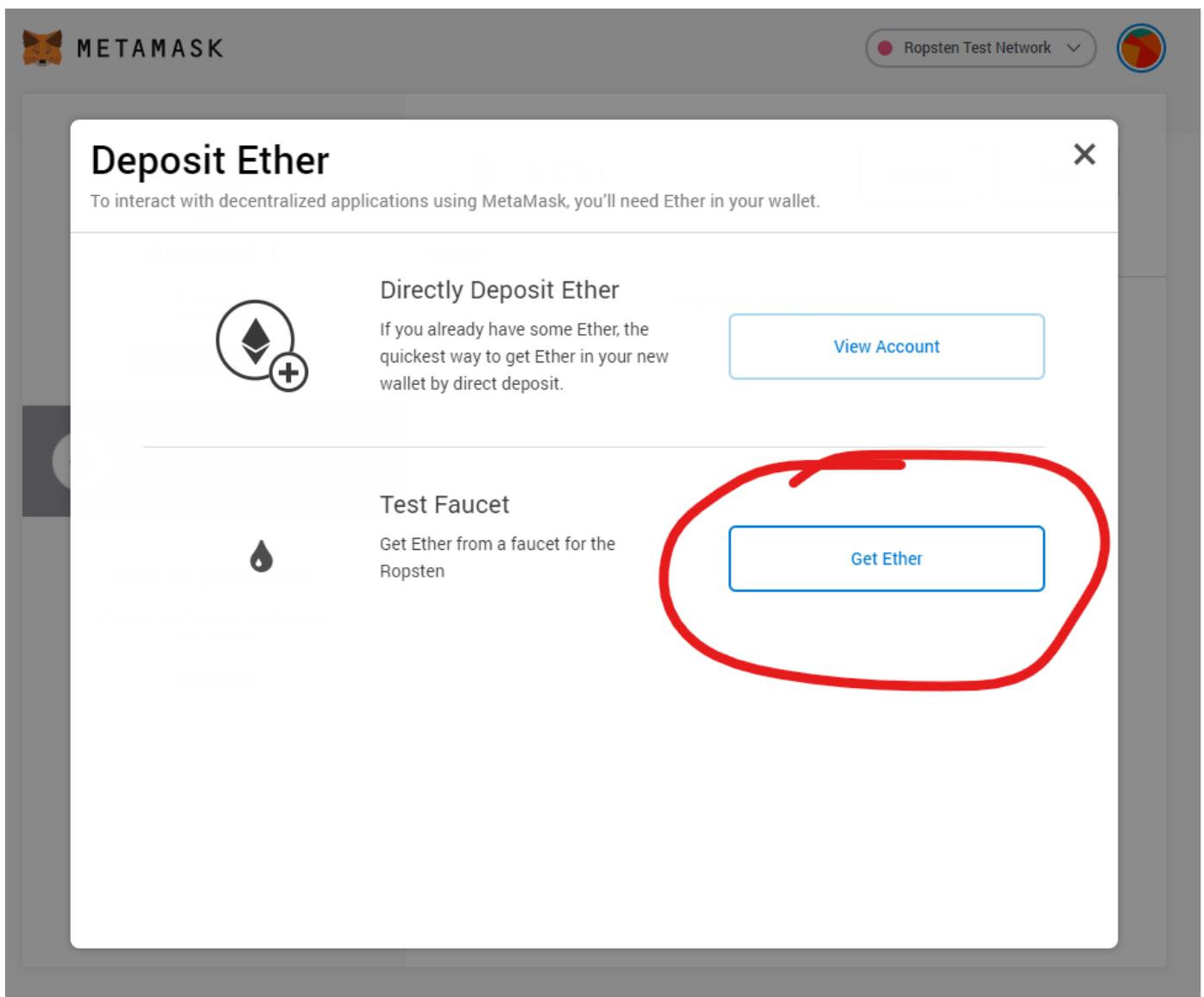
Switch the network to Goerli.



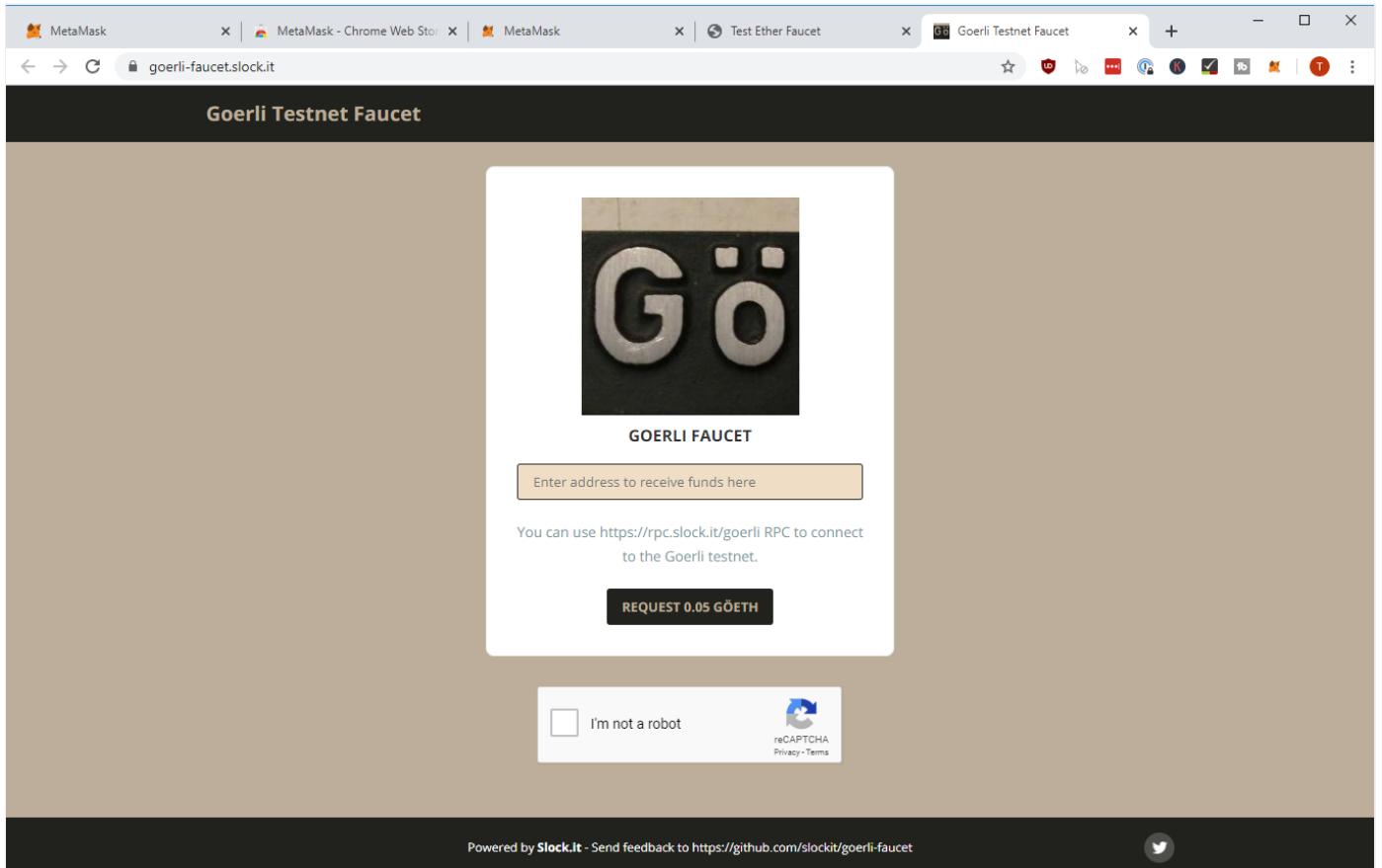
Hit "BUY"



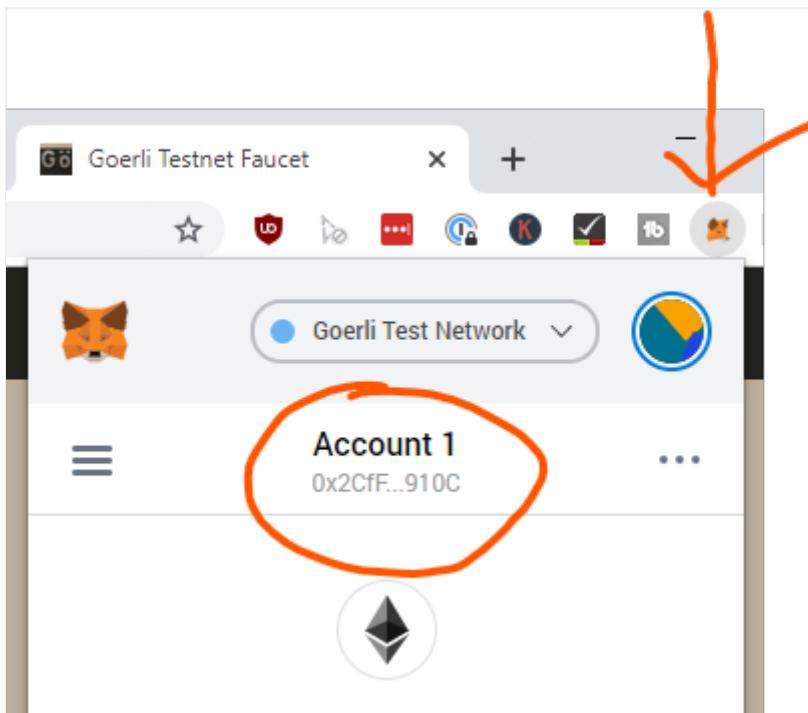
Click on "Get Ether"



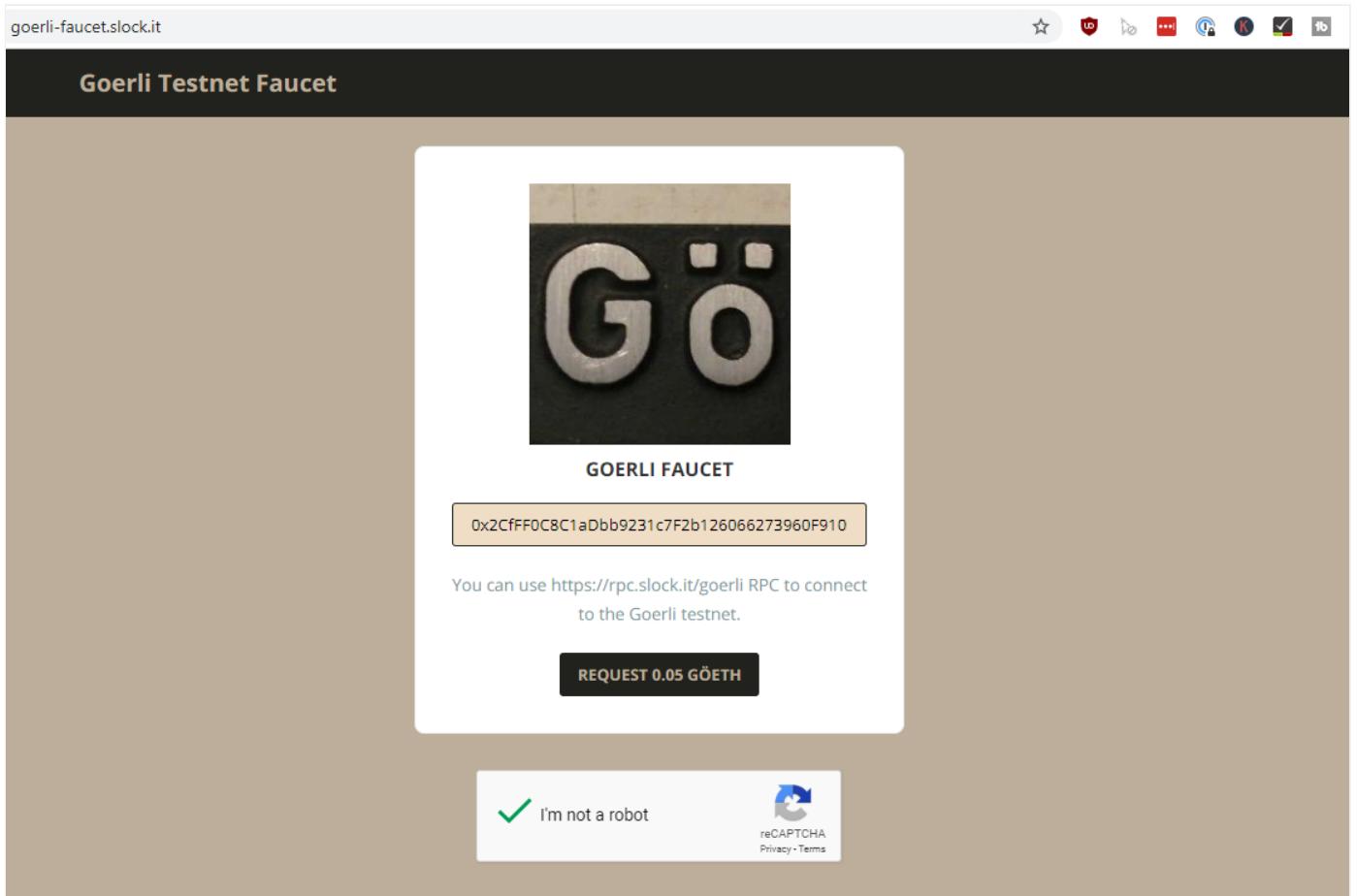
A new website should open up. That's the faucet to get Ether. A Faucet is like a "get free Ether" -- site. The Ethers are having no value, they are running under a "test" Blockchain, but they are great for getting your feet wet with transactions and how Wallets work.



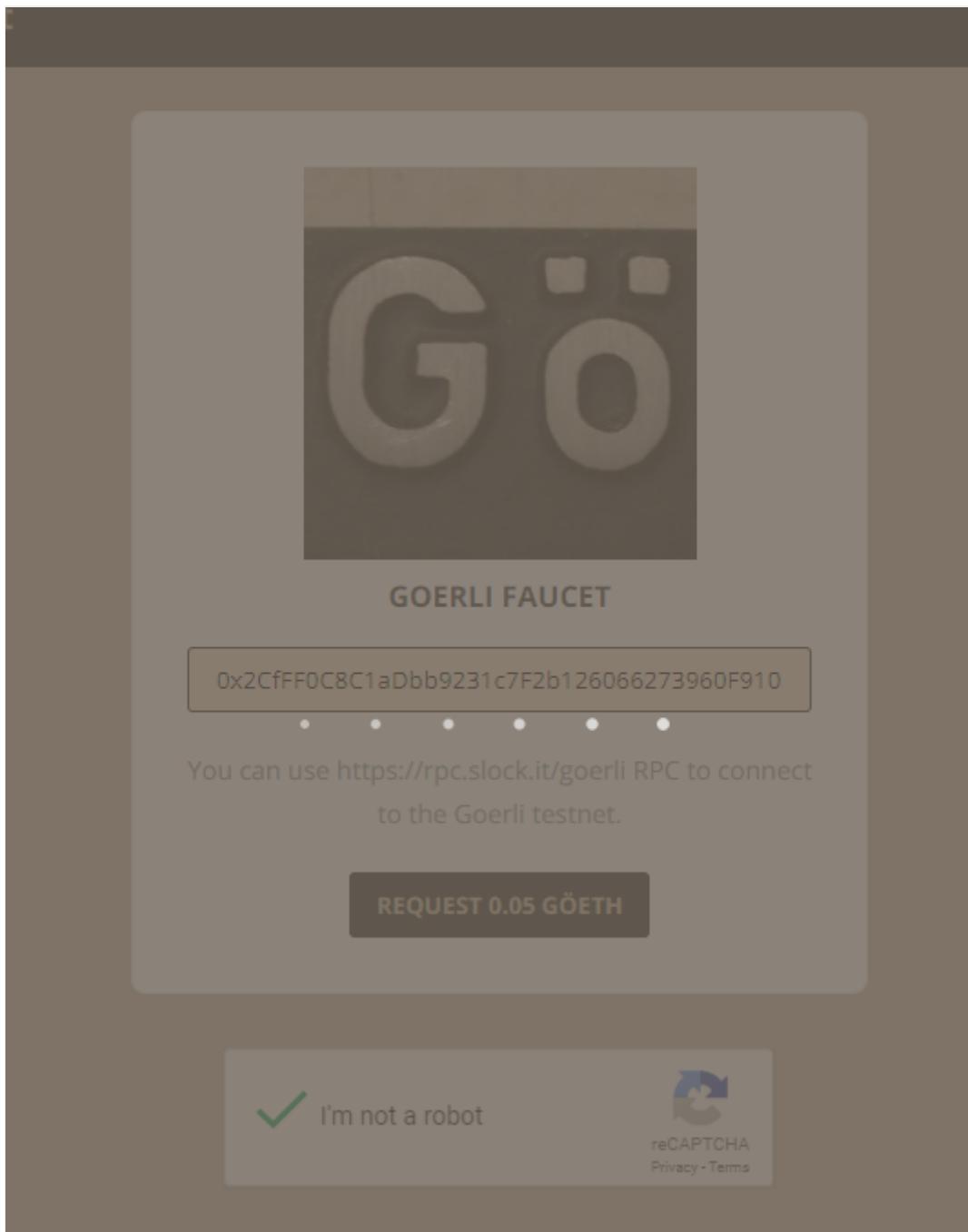
Copy your Address from MetaMask by clicking directly on the address:

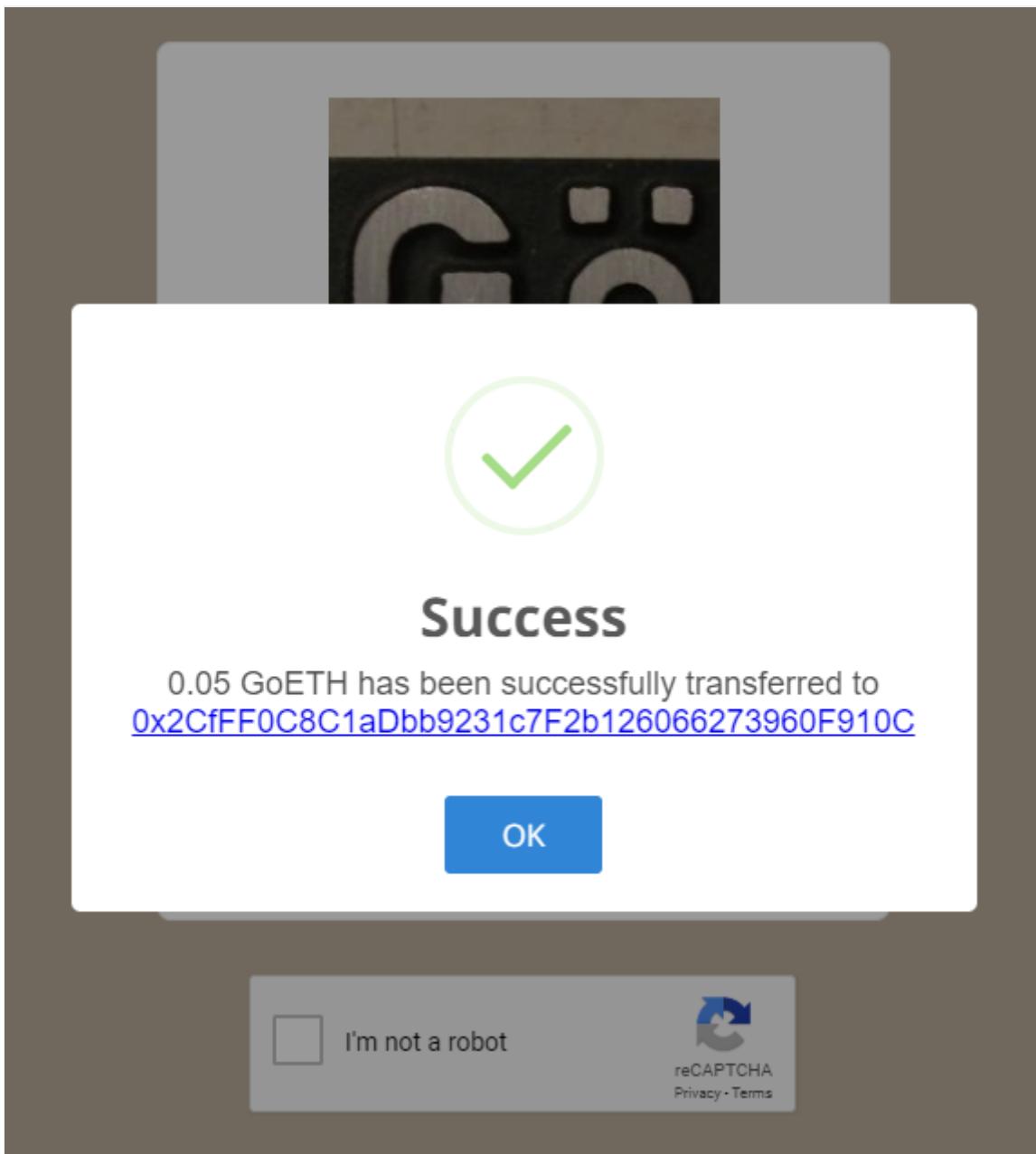


Paste it into the Goerli Faucet Value Field and hit "I'm not a robot" and "Request 0.05 GÖETH"



Wait until the popup appears...





Don't click the link of the transaction, most likely it will not really work anyways. Let's track our Incoming Transaction in the next step!

Last update: April 17, 2021

3.5 Track Ether

You might have heard it: all information on the Ethereum Blockchain is publicly visible information. So, if someone sends a transaction from A to B, then this is visible to all participants in the network.

There is specialized software to track those transactions, so called "Block explorers". One of them is [Etherscan](#).

Go to <https://etherscan.io/> and click the Ethereum logo at the top right and choose Goerli testnet.

The screenshot shows the Etherscan homepage with a dark blue header. In the top right corner, there is a dropdown menu with several network options: Ethereum Mainnet (selected), Ethereum Mainnet (CN), Ropsten Testnet, Kovan Testnet, Rinkeby Testnet, and Goerli Testnet. The 'Goerli Testnet' option is circled in red with an arrow pointing to it. The main content area displays various blockchain metrics like Ether price (\$1,227.37), market cap (\$140,296,512,928), and transaction counts (978.17 M). Below this, there are sections for 'Latest Blocks' and 'Latest Transactions'.

You should be at <https://goerli.etherscan.io/>. Copy and paste your address or copy the transaction hash from the previous step and paste it, either way, you should find a transaction that leads back to your wallet address:

The screenshot shows the Goerli Test Network wallet interface. At the top, there is a network selection dropdown set to 'Goerli Test Network'. Below it, there is a status message 'Not connected'. The main area shows 'Account 2' with the address '0x5797...5c1e'. At the bottom, there is a large 'Copy to clipboard' button with a downward arrow icon.

The screenshot shows the Etherscan interface for the Goerli Testnet Network. At the top, there's a search bar and navigation links for Home, Blockchain, Tokens, Misc, and Goerli. The main area displays a wallet address (0x5797B95C60Db61D3ed69b162733b2F008D695c1e) with a balance of 0.05 Ether. Below this, the 'Transactions' section shows one recent transaction: a withdrawal from the address to another (0x8ced5ad0d8da4ec21...) of 0.05 Ether in block 4128256, 3 mins ago. There's also a link to download CSV export.

This screenshot provides detailed transaction information for the transaction shown above. It includes fields for Transaction Hash (0x39f5a4dff7f12d2c5afed761934f059922e41963525b267a0e163de073aaa0a2), Status (Success), Block (4128256, 22 Block Confirmations), Timestamp (5 mins ago, Jan-18-2021 08:35:10 PM +UTC), From (0x8ced5ad0d8da4ec211c17355ed3dbfec4cf0e5b9), To (0x5797b95c60db61d3ed69b162733b2f008d695c1e), Value (0.05 Ether, \$0.00), Transaction Fee (0.000021004 Ether, \$0.000000), and Gas Price (0.000000001 Ether, 1 Gwei). A note at the top states "[This is a Goerli Testnet transaction only]".

You should see your transaction with the success message and all the details of the transaction.

Now open MetaMask from your browser and you should see some ETH in your wallet *on a test-net*.

Video / Screenshots difference

Note: I have 0.15ETH in my wallet, because I did this procedure 3 times for the screenshots.

The screenshot shows the Goerli Testnet Scan interface. At the top, it displays the address `0x72E5Be03d15baFadB982435dB6281E92eFcA4`. The main area shows an overview of the account, indicating a balance of **0.15 Ether**. Below this, there are sections for **Transactions** and **Erc20 Token Trans**, both showing 3 transactions. The transactions listed are:

Tx Hash	Block	Age	From	To	Value
<code>0x0f772361ec84b6...</code>	3009200	1 min ago	<code>0xdcaed5d0da4...</code>	<code>0x72E5Be03d15ba...</code>	0.05 Ether
<code>0x02c5ca624b97d0...</code>	3009199	1 min ago	<code>0xdcaed5d0da4...</code>	<code>0x72E5Be03d15ba...</code>	0.05 Ether
<code>0x821003324cd94...</code>	3009169	9 mins ago	<code>0xdcaed5d0da4...</code>	<code>0x72E5Be03d15ba...</code>	0.05 Ether

That's it. You have now installed a wallet and you have your first Ether ready. Let's carry on with the next steps!

Last update: April 17, 2021

3.6 Congratulations

Congratulations, LAB is completed

From the Course "Ethereum Blockchain Developer -- Build Projects in Solidity"

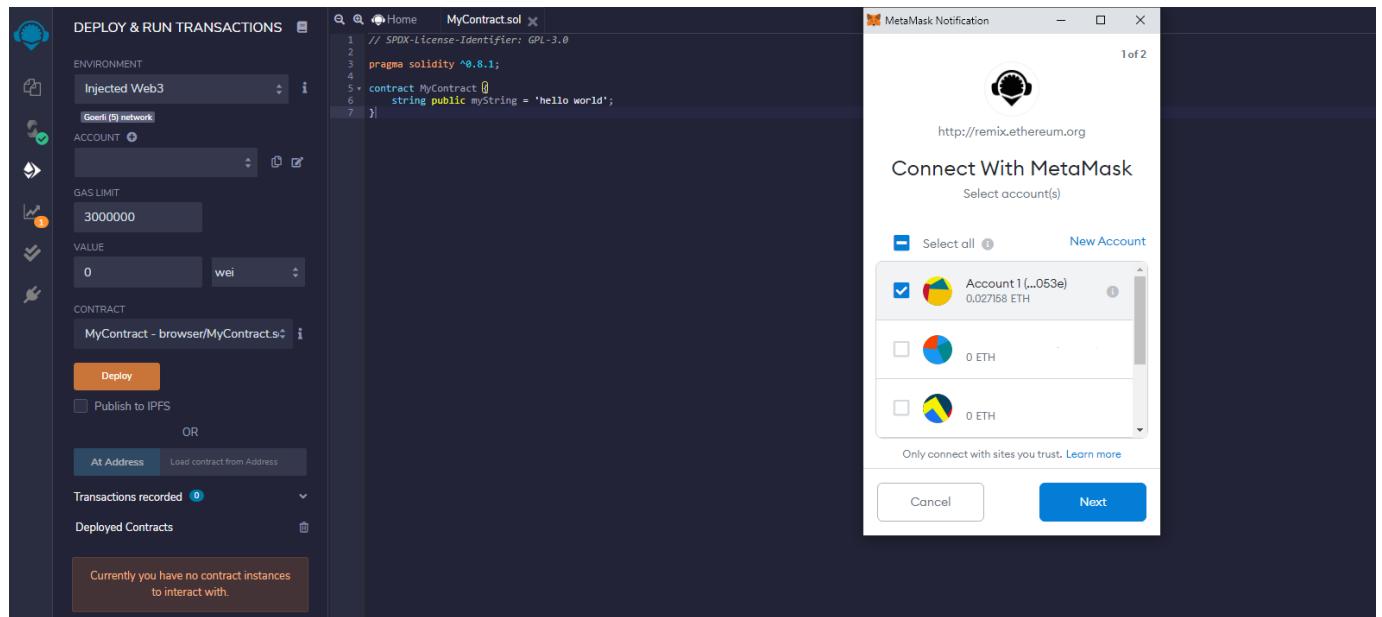
FULL COURSE: <https://www.udemy.com/course/blockchain-developer/?referralCode=E8611DF99D7E491DFD96>

Last update: April 17, 2021

4. Remix

4.1 Lab: Write your first Smart Contract

In this lab you are going to write your very first smart contract. We are also going to deploy it to a blockchain.



4.1.1 What You Know At The End Of The Lab

- ☒ Understand Remix IDE and the Tooling
- ☒ Get started with Smart Contract Development Fast and Easy
- ✿ Setup Remix the right way
- ✿ No matter if you want to write in Solidity 0.5.x, 0.6.x, 0.7.x or 0.8.x!
- ☒ Connect MetaMask and Remix to deploy to Görli

4.1.2 Prerequisites - You need:

1. Chrome or Firefox browser.
2. An Internet connection
3. Completed the Previous Lab with MetaMask and some Test-Ether

4.1.3 Videos

☒ Full Video Walkthrough: <https://www.udemy.com/course/blockchain-developer/?referralCode=E8611DF99D7E491DFD96>

4.1.4 Get Started

☒ ☒ ☒ Let's get started by [Setting up Remix](#)

Last update: April 23, 2021

4.2 Setup Remix

First we need to setup Remix to have the correct plugins installed, activated and configured. Before we do that, some general information!

What's Remix anyways?

Remix, previously known as Browser-Solidity, is a browser based development environment for Smart Contracts. It comes with compilers for different solidity versions and a blockchain simulation. It also has plenty of other plugins. It's a great way to get started!

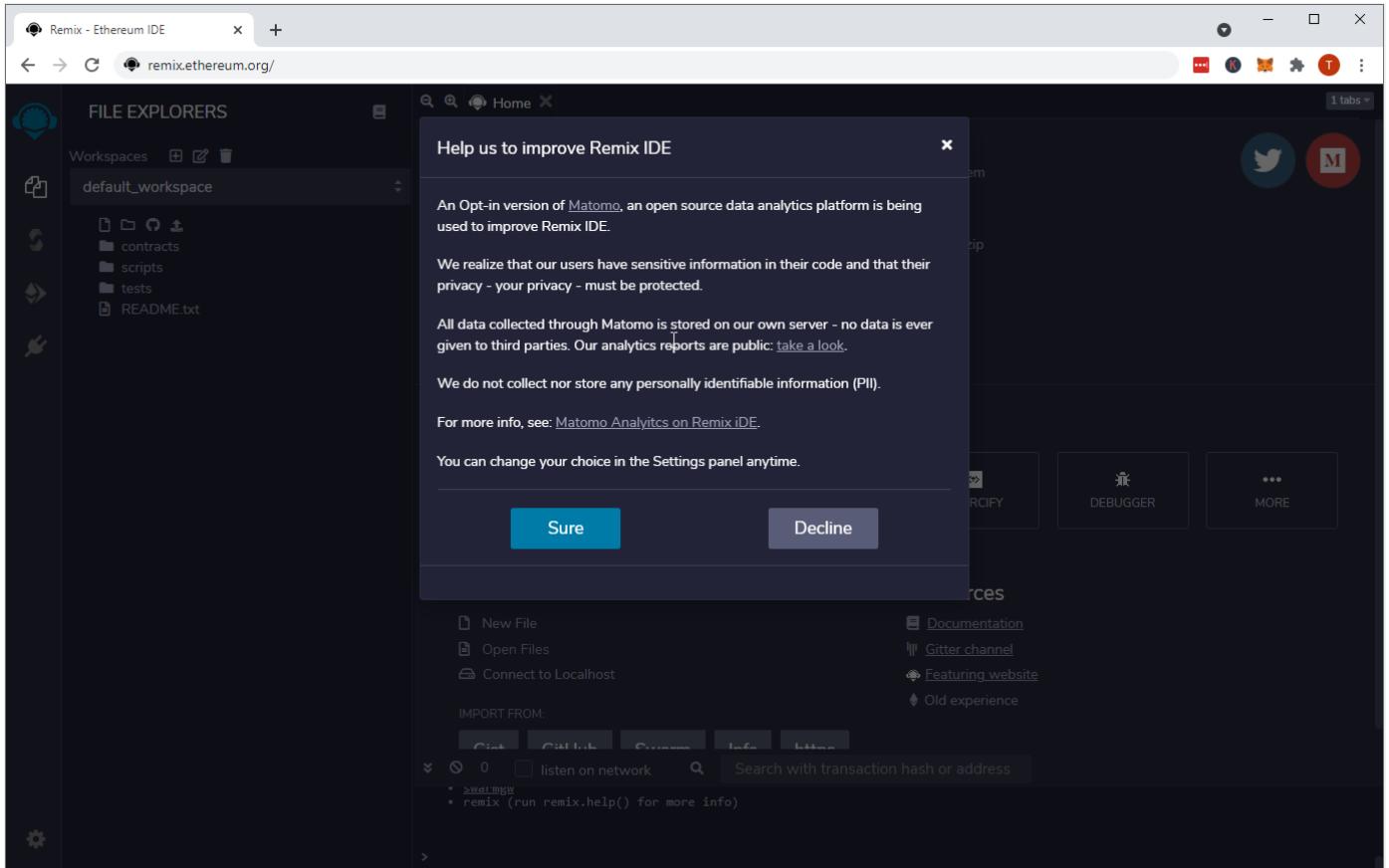
HTTP vs HTTPS

Be careful with the https vs http domain. Remix stores edited files in localstorage of the browser. If your smart contracts are suddenly gone, look at the protocol.

In this course we work with http, not https. This is especially important later when we do private blockchains which require CORS to be setup correctly.

4.2.1 Open Remix

Go to <http://remix.ethereum.org>. You should be greeted with the following page:



If the popup shows up for you, then feel free to accept if you have no concerns over privacy violations. For our course we can do that.

Updates from Video

In the video we are using an older version of Remix. Currently, by default, Remix starts with the dark theme. In the videos you see the light theme. You can change this in the settings: Bottom left, scroll down, theme light.

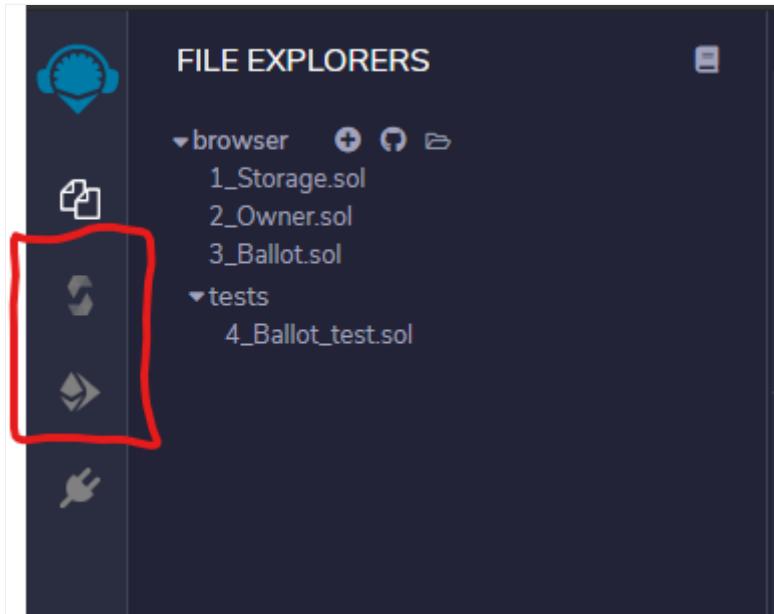
More importantly, in the videos we had to enable plugins. The most important plugins are now enabled *by default*. Below we're still making sure they are enabled, just in case.

4.2.2 Plugins

Remix is built with a pluggable architecture. All functions are done via plugins. The Compiler is a plugin, the blockchain connection is a plugin, the debugging functionality is a plugin and there are a lot of other plugins that might be useful.

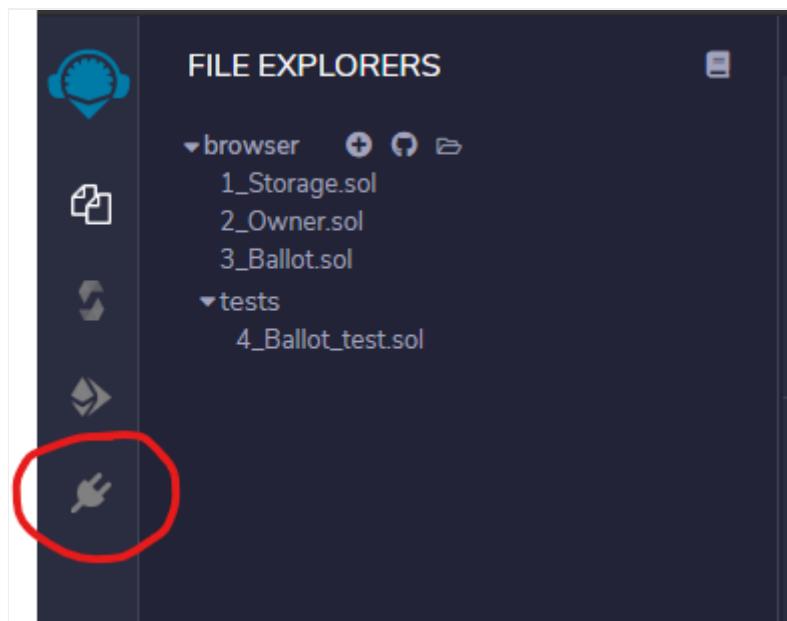
What you need in the next few chapters are

1. The Solidity compiler
2. The "Deploy & Run Transactions" Plugin

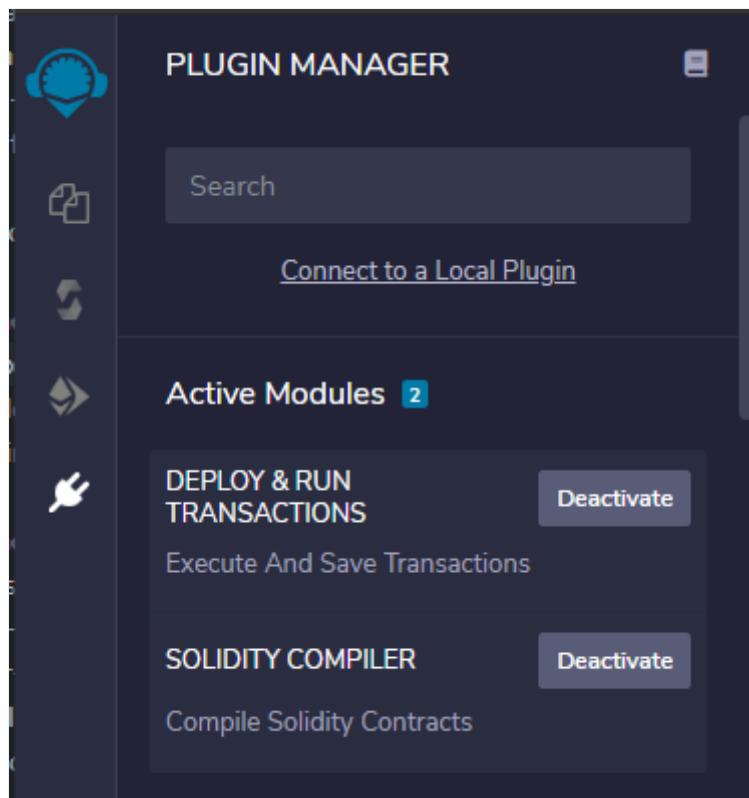


4.2.3 Enable Plugins

If the plugins are not showing up yet, then click on the plugin symbol and enable them:



And find the two plugins and activate them:



4.2.4 Configure the Compiler

In this chapter we are working with Solidity 0.8.1. The compiler will normally switch automatically based on the `pragma` line in your solidity files. But you can set a specific version, if necessary.

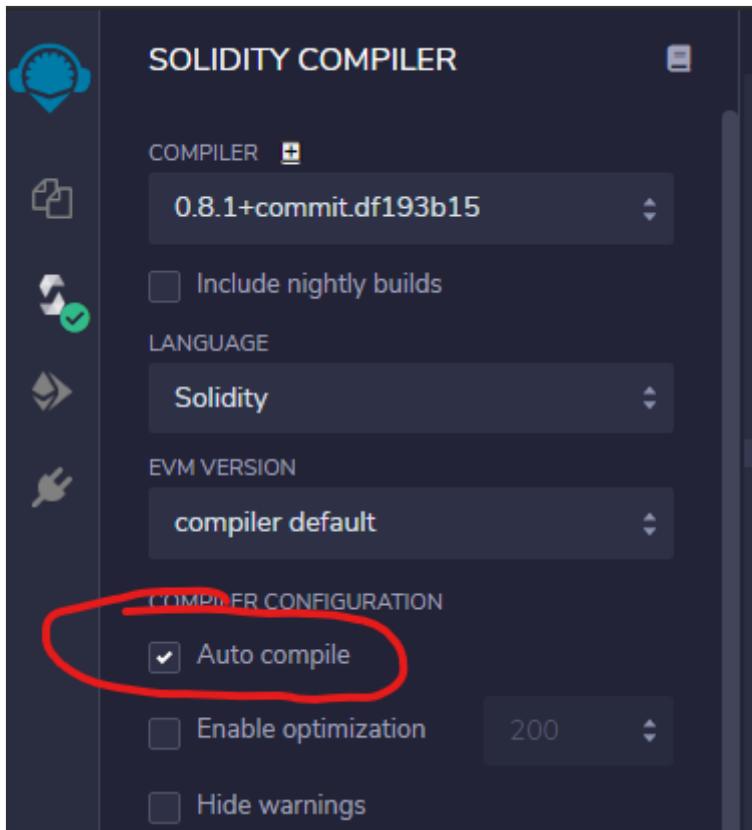
If you don't know what that is and don't want to wait several videos to understand what a pragma line is: In layman terms, it's here to configure your compiler. For example there's a version pragma, that tells the compiler "Hey, this source is made for compiler version XYZ". That's what we're going to use. Need more information? Either wait, or [read the official docs](#)

🔥 Switch Compiler Version

If it is necessary to switch compiler versions manually, you can always do this. You can either follow along in the videos, then use the compiler version the videos are using. Or you follow along this guide and use this solidity version.

New Compiler versions are published *very frequently*. It is very normal to find "outdated" solidity files around. Some very popular projects are using older solidity versions.

Make sure "auto-compile" is enabled:



Great! You're all set! Let's create your first file in the next section!

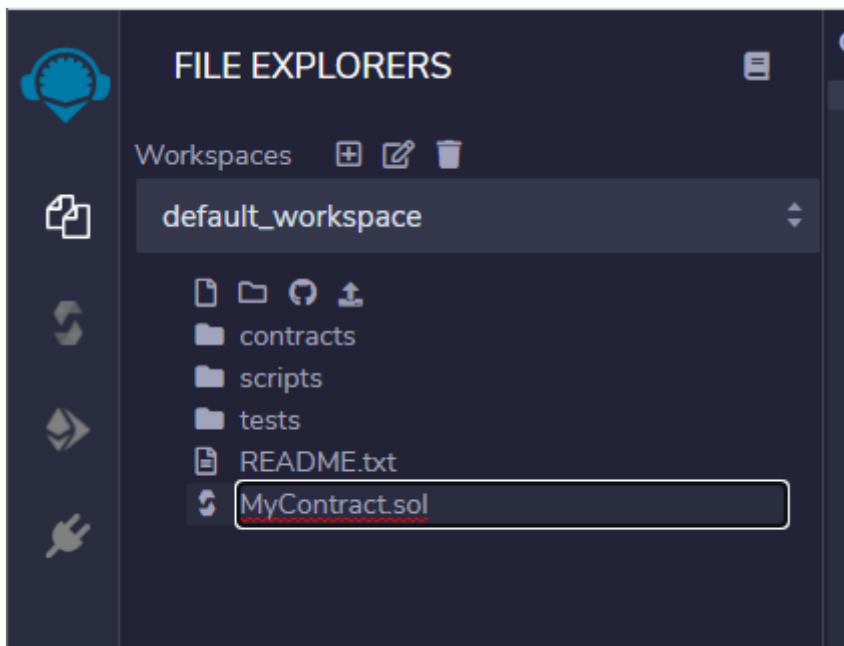
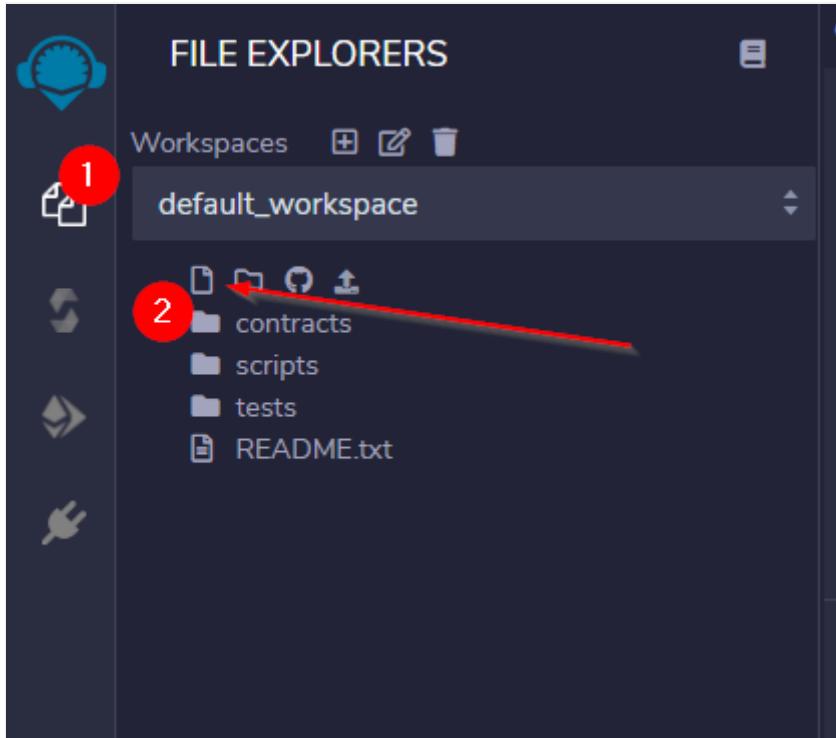
Last update: May 23, 2021

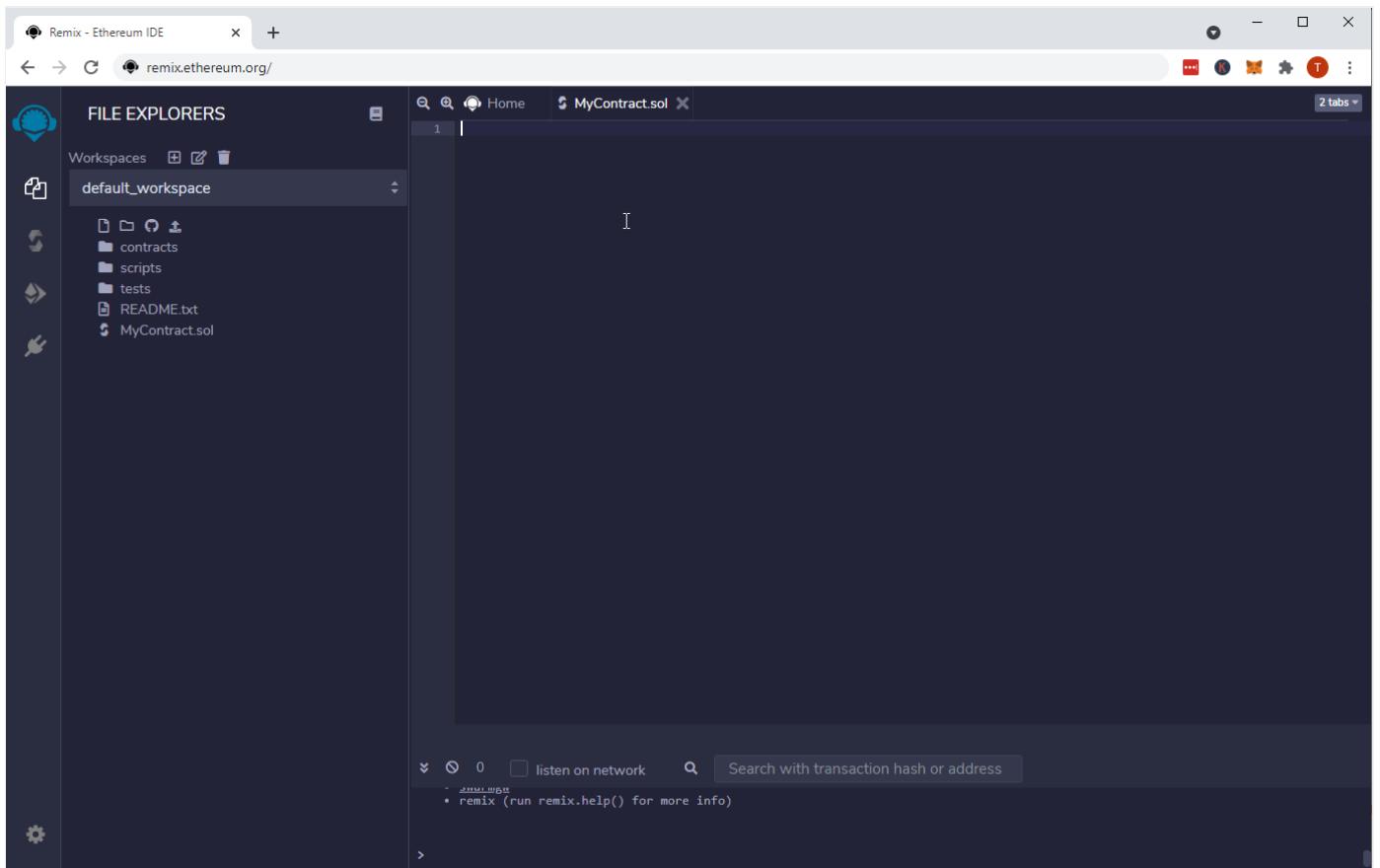
4.3 Create Your First Smart Contract

Now we are creating a new file and inserting some Solidity code. Don't worry if you don't fully understand everything - we have to start somewhere and we're here to play around. Just follow along, I promise everything will be clear later on!

4.3.1 Create A New File

Click on the plus icon in the code-editor and create a new file, name it "MyContract.sol". The sol-extension stands for Solidity.





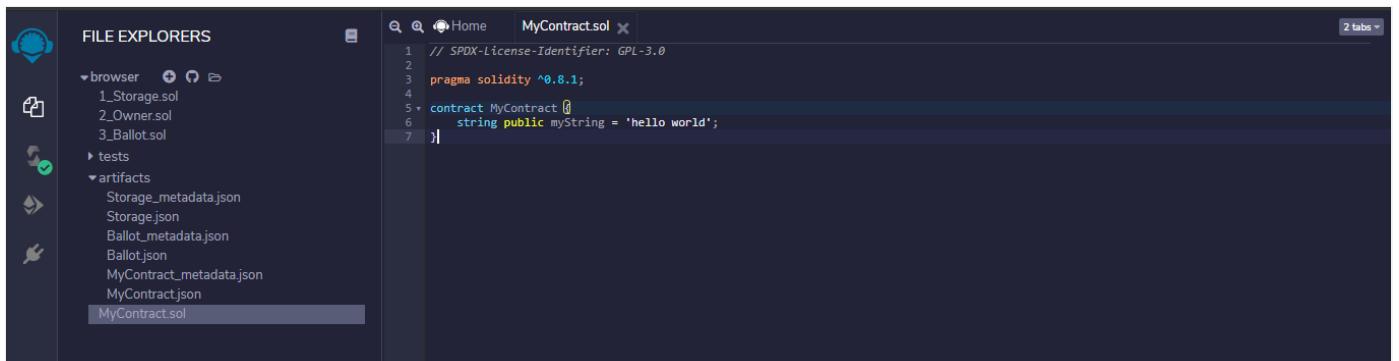
4.3.2 Add Solidity Hello World Code

Now add the following code to the file:

```
// SPDX-License-Identifier: GPL-3.0
pragma solidity ^0.8.1;

contract MyContract {
    string public myString = 'hello world';
}
```

It should look like this and the "Compiler" Plugin should have a green checkmark badge. That's the icon in the left side panel:



?

Wondering what that all means?

This is a very basic version of a Smart Contract. Let's go through it line by line:

```
// SPDX-License-Identifier: GPL-3.0 : The The Software Package Data Exchange® (SPDX®) identifier is there to clearly communicate the license under which the Solidity file will be made available. Well, if you make it available. But you should. Smart Contracts transparency and trust greatly benefit from the source being published and sometimes it's not 100% clear under which license the source is out in the wild. The SPDX identifier is optional, but recommended.
```

```
pragma solidity ^0.8.1 : The pragma keyword is for the compiler to enable certain features or check certain things. The version pragma is a safety measure, to let the compiler know for which compiler version the Solidity file was written for. It follows the SemVer versioning standard. ^0.8.1 means >=0.8.1 and <0.9.0.
```

```
contract MyContract : That's the actual beginning of the Smart Contract. Like a Class in almost any other programming language.
```

```
string public myString = 'hello world' : That is a storage variable. It's public and Solidity will automatically generate a getter function for it - you'll see that in a minute!
```

Perfect! Let's proceed to deploy this Smart Contract to a Blockchain!

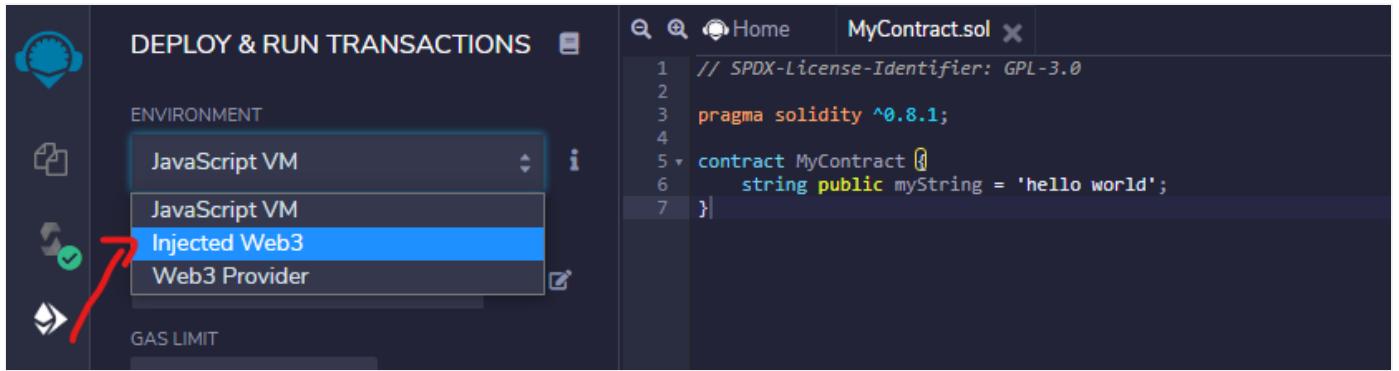
Last update: May 23, 2021

4.4 Deploy Smart Contract

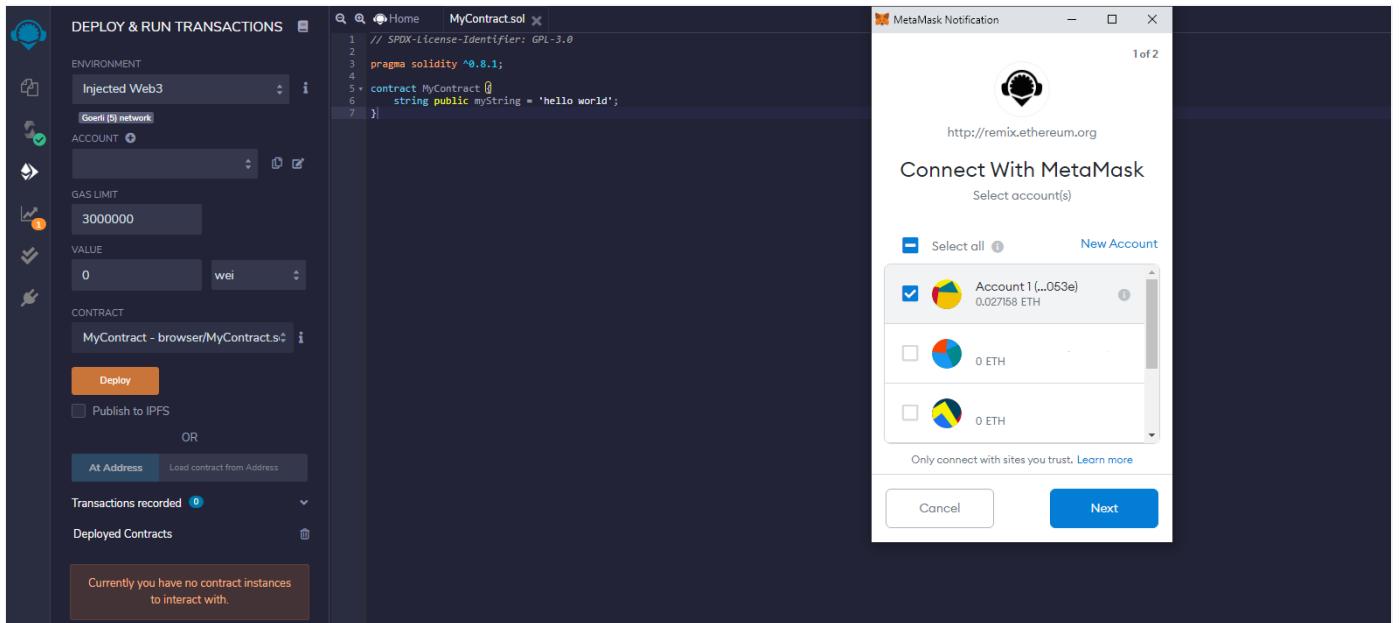
Now it's time to deploy our Smart Contract. We will do this to a real blockchain. In the previous video we got our first Ether on a Test-Network. We will use them now to deploy the smart contract.

4.4.1 Connect MetaMask to Remix

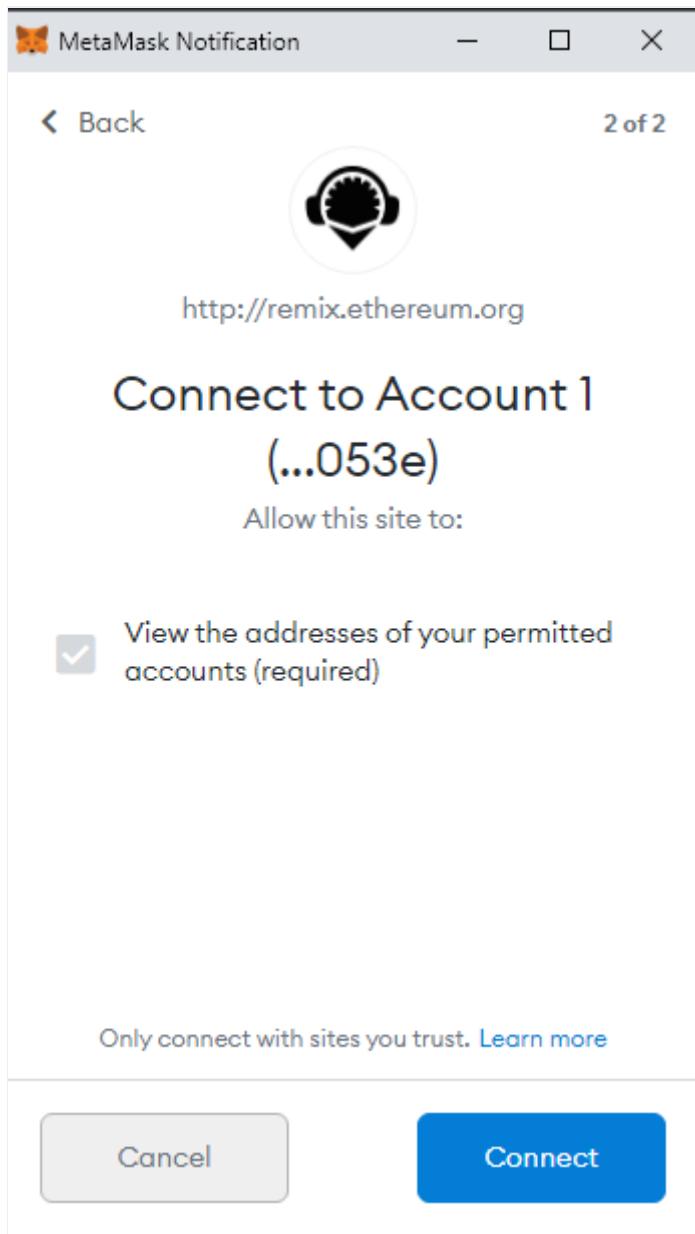
Switch over to the "Deploy & Run Transactions" Plugin. We need to configure it, so it uses our MetaMask Wallet to access the Blockchain.



As soon as you do this, MetaMask should pop up and ask you to connect your account to Remix.



Click "Next" and the "Connect":



Now your account should pop-up in the dropdown under the Environment Selection:

The screenshot shows the Remix IDE interface. On the left, there's a sidebar with "DEPLOY & RUN TRANSACTIONS" and "ENVIRONMENT". Under "ENVIRONMENT", "Injected Web3" is selected from a dropdown menu, and "Goerli (5) network" is listed below it. On the right, there's a code editor window titled "MyContract.sol" containing Solidity code. The code includes a SPDX license header, a pragma solidity statement, a contract definition named "MyContract" with a single public string variable "myString" initialized to "hello world", and a closing brace. Below the code editor, the "ACCOUNT" section shows a dropdown menu with "0x5AD...3053E (0.0271579..." and "0x5AD...3053E (0.027157936729999001 ether)" listed. The second option is highlighted with a blue background. At the bottom of the interface, there's a field with the value "3000000".

?

 Account not showing up?

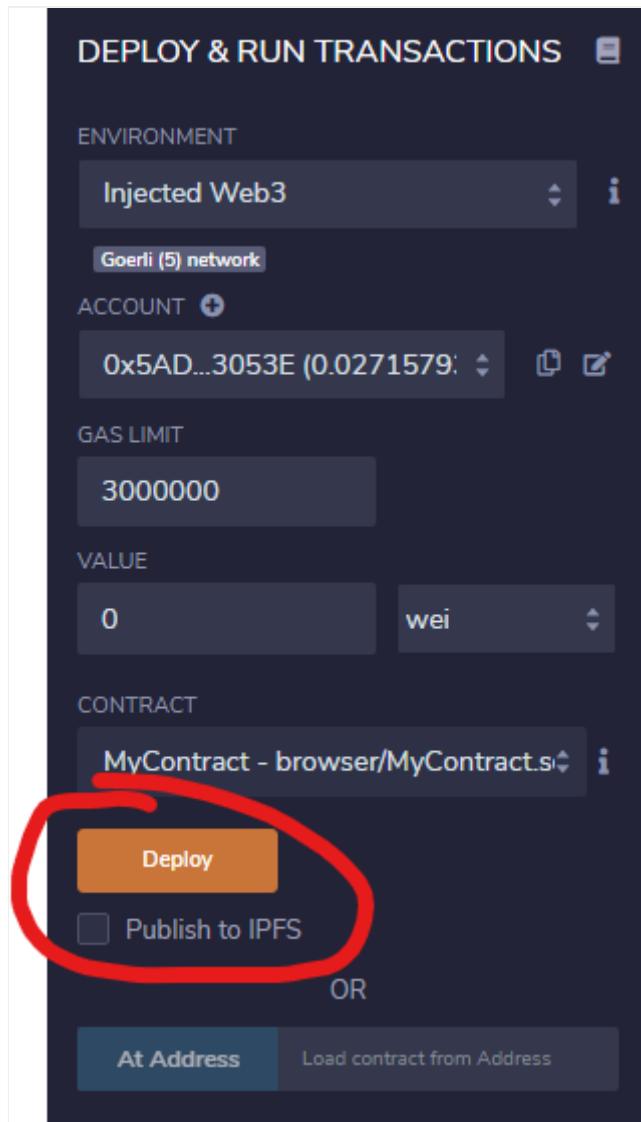
If your account doesn't show up, or MetaMask doesn't pop up, try to reload the page. There are sometimes caching issues.

4.4.2 Deploy the Smart Contract

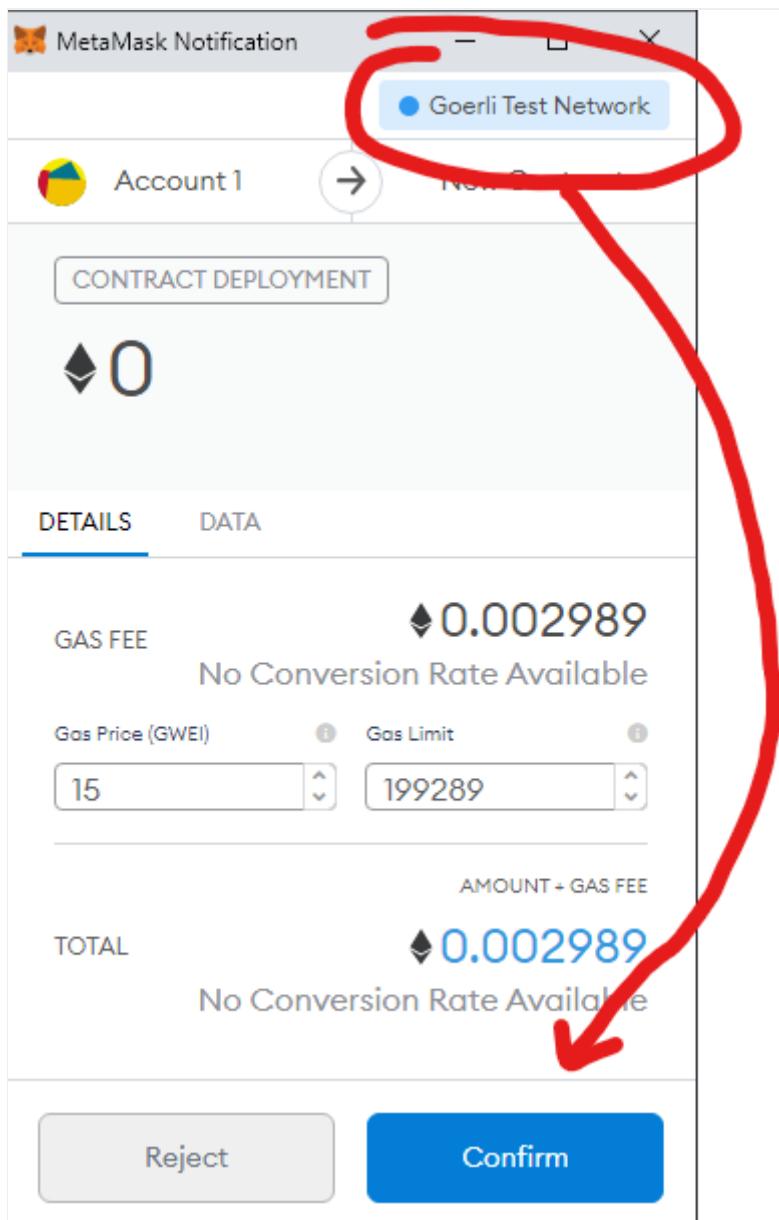
Let's deploy the Smart Contract now. First, make sure the correct Smart Contract is selected in the Dropdown:

The screenshot shows the 'DEPLOY & RUN TRANSACTIONS' interface. The 'ENVIRONMENT' dropdown is set to 'Injected Web3'. The 'ACCOUNT' dropdown shows '0x5AD...3053E (0.0271579)' with edit icons. The 'GAS LIMIT' input is set to '3000000'. The 'VALUE' section shows '0 wei'. Under 'CONTRACT', 'MyContract - browser/MyContract.sol' is selected. An orange 'Deploy' button is prominent. Below it is a checkbox for 'Publish to IPFS'. At the bottom, there are buttons for 'At Address' and 'Load contract from Address'.

Then simply hit "Deploy":



This should trigger MetaMask to ask you if you really want to send this transaction. Make sure the Görli Test-Network is selected and then simply hit "Confirm". If you selected the wrong network, then cancel the transaction, switch the network in MetaMask and hit "Deploy" again.



Perfect, now the transaction is on the way of getting mined. In the next section we will follow the transaction and interact with our smart contract!

Last update: April 17, 2021

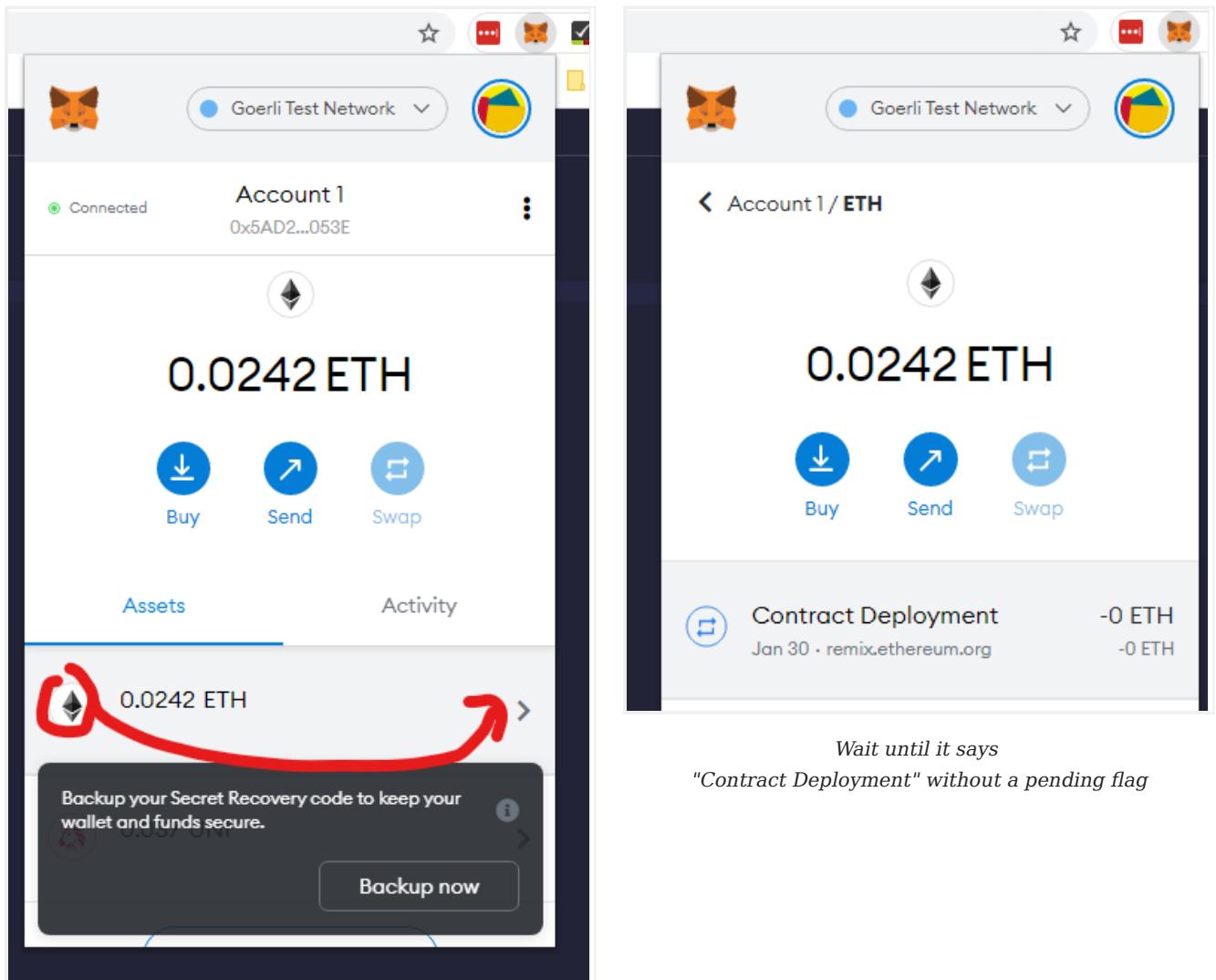
4.5 Interact with the Smart Contract

Now let's see if we can interact with the smart contract. Of course, at this point you have no idea what *interaction* actually means, so, let's just follow along.

4.5.1 Wait For Contract Readiness

First, we need to wait until the transaction is mined. We sent a transaction to the network, but before it's mined the contract won't be ready for any interaction. This can sometimes take a while, and sometimes it's really fast.

Wait until MetaMask says the Contract Deployment is complete. Open the MetaMask plugin in the top-right corner of Chrome, then check if the Smart Contract was already deployed:



Open MetaMask and go into the Ether Details

You will also see in Remix that the Contract is now ready:

The screenshot shows the Remix IDE interface. On the left, there's a sidebar with various icons for deploying and running transactions. The main area has tabs for "Home" and "MyContract.sol". The code editor contains the following Solidity code:

```

1 // SPDX-License-Identifier: GPL-3.0
2
3 pragma solidity ^0.8.1;
4
5 + contract MyContract {
6     string public myString = 'hello world';
7 }

```

Below the code, there are settings for the environment (Injected Web3, Goerli network), account (0x5AD...3053E), gas limit (300000), and value (0 wei). The "CONTRACT" section shows "MyContract - browser/MyContracts" and a "Deploy" button. There are also options to publish to IPFS or deploy at a specific address.

The right side of the interface shows deployment logs. It says "creation of MyContract pending..." and provides a link to Etherscan: <https://goerli.etherscan.io/tx/0xd7e479b675b966fa8e55de9257393831c1edfc756faeffd8784749f8b53a716a>. A red box highlights this section, which includes a green checkmark icon and the transaction details: [block:4197157 txIndex:0] from: 0x5AD...3053E to: MyContract.(constructor) value: 0 wei data: 0x608...10033 logs: 0 hash: 0xd7e...a716a. There is also a "Debug" button.

4.5.2 Interact With The Smart Contract

Now it's time to start our first interaction. In Remix we don't have to do any low-level things, it conveniently shows us buttons and input fields. You will later see how that works under the hood. We are covering it in the videos about the ABI Array.

Open the Dropdown on the left side:

The screenshot shows the Remix IDE interface. On the left, there's a sidebar with various icons for deploying, running, and interacting with contracts. The main area is divided into sections:

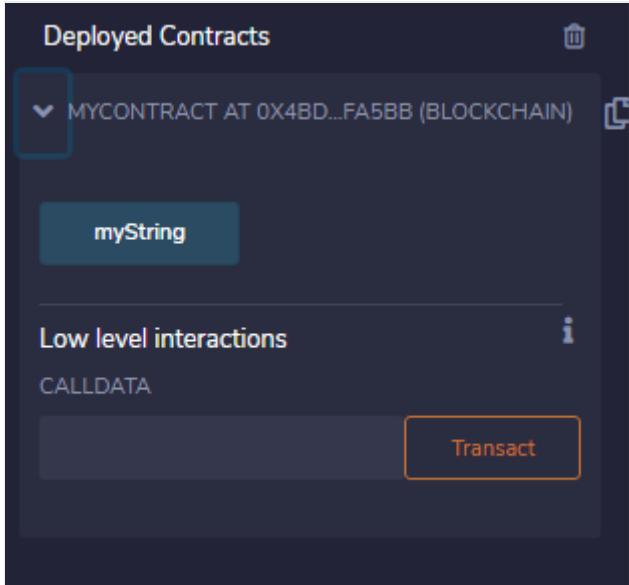
- DEPLOY & RUN TRANSACTIONS**: Contains fields for ENVIRONMENT (set to Injected Web3, Goerli network), ACCOUNT (set to 0x5AD...3053E), GAS LIMIT (3000000), and VALUE (0 wei).
- CONTRACT**: Shows "MyContract - browser/MyContract.sol" selected. Below it are buttons for "Deploy" (highlighted in orange) and "Publish to IPFS".
- Transactions recorded**: Shows 1 transaction.
- Deployed Contracts**: Shows a deployed contract at address 0x4BD...FA5BB (BLOCKCHAIN). A red oval highlights this section.
- Code Editor**: Displays the Solidity code for MyContract.sol:

```

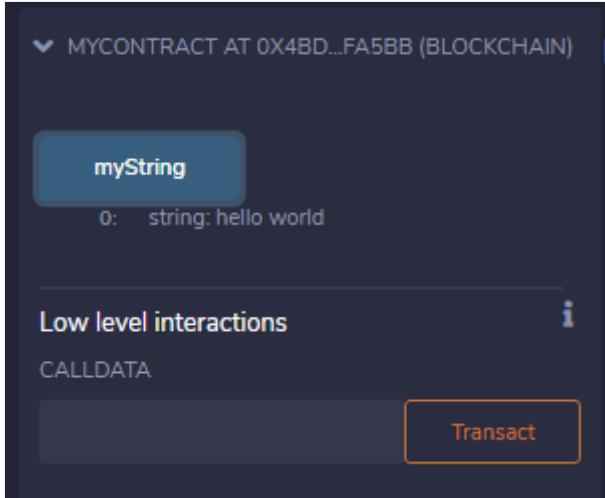
1 // SPDX-License-Identifier: GPL-3.0
2
3 pragma solidity ^0.8.1;
4
5 contract MyContract {
6     string public myString = 'hello world';
7 }

```
- Logs**: Shows a log entry for the deployment transaction:
 - Select a Javascript file in the file explorer and t
 - Right click on a JavaScript file in the file explor
 - The following libraries are accessible:
 - [web3_version 1.0.0](#)
 - [ethers.js](#)
 - [swarmgw](#)
 - [remix \(run remix.help\(\) for more info\)](#)
 - creation of MyContract pending...
 - <https://goerli.etherscan.io/tx/0xd7e479b675b966fa8e55de925>
 - [block:4197157 txIndex:0] from: 0x5AD...3053E to: MyContract (0x4BD...FA5BB) [0xd7e479b675b966fa8e55de925]

So that you can interact with the newly deployed Smart Contract:



Hit the "myString" Button and you will hopefully see that it returns "hello world" correctly.



This is it, your very first smart contract using Remix and the Görli Test-Network.

Last update: April 17, 2021

4.6 Congratulations

Congratulations, LAB is completed

From the Course "Ethereum Blockchain Developer -- Build Projects in Solidity"

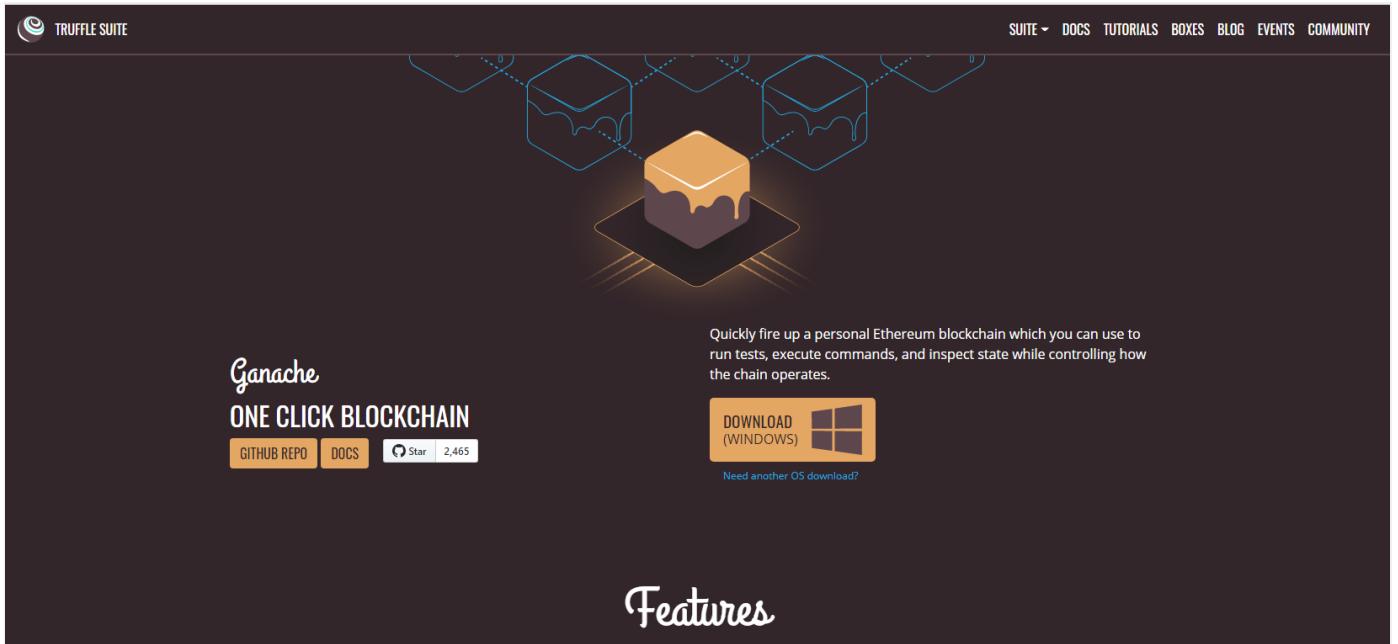
FULL COURSE: <https://www.udemy.com/course/blockchain-developer/?referralCode=E8611DF99D7E491DFD96>

Last update: April 17, 2021

5. Blockchain Networks

5.1 Lab: Use different Blockchain Networks

In this lab you are going to switch between different Blockchains. You are also setting up your own Development Blockchain.



It's a natural continuation from the previous Lab. We're going to deploy again to Görli, but we're also deploying to the JavaScript Virtual Machine. Then we're also directly connecting to a local Blockchain node, circumventing MetaMask and deploy our Smart Contract there in Ganache.

If all of that doesn't tell you anything - PERFECT! Follow along!

5.1.1 What You Know At The End Of The Lab

- ☒ Understand Different Connection Methods
- ☒ Download, Install and use Ganache
- ❖ Use JavaScript VM, Injected Web3 and Web3 Provider
- ☒ Understand why Ganache is useful

5.1.2 Prerequisites - You need:

1. Chrome or Firefox browser.
2. An Internet connection
3. About 15 Minutes of your precious time ☺

5.1.3 Videos

☒ Full Video Walkthrough: <https://www.udemy.com/course/blockchain-developer/?referralCode=E8611DF99D7E491DFD96>

5.1.4 Get Started

 Let's get started by [Starting With A Smart Contract](#)

Last update: April 23, 2021

5.2 Smart Contract Example

We have to start with *something*, so we're going to use the exact same Smart Contract as we used in our previous Lab.

5.2.1 Simple Smart Contract

If you still have Remix open from the previous Lab, then you can keep re-using that smart contract, otherwise create a new file and paste the following content:

MyContract.sol

```
// SPDX-License-Identifier: GPL-3.0
pragma solidity ^0.8.1;
contract MyContract {
    string public myString = 'hello world';
}
```

Alright, let's deploy to Görli via MetaMask.

🔥 Try yourself!

Before you go to the next Lesson, try yourself to deploy to Görli via MetaMask.

Last update: April 17, 2021

5.3 Injected Web3

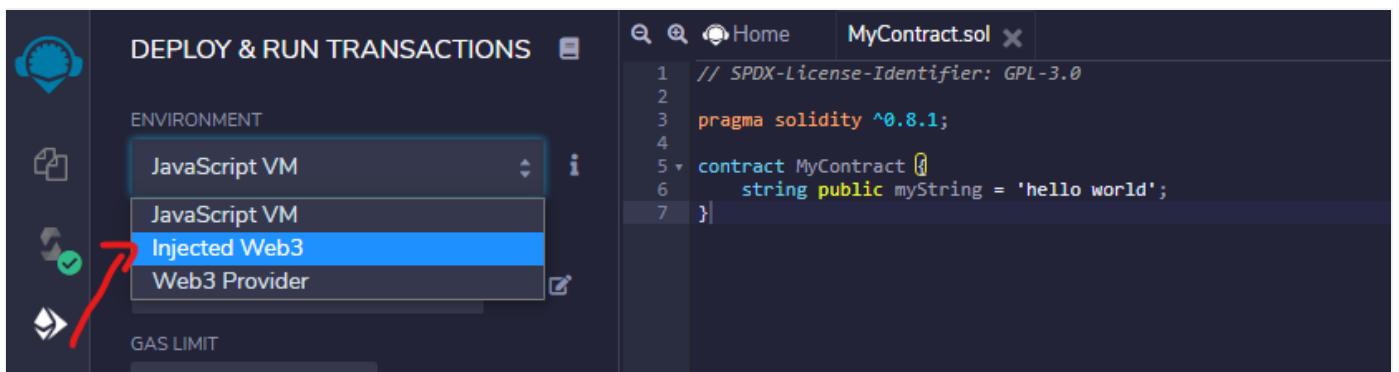
Tried yourself?

Did you try yourself before you opened this page? Did it work? Then directly try to see the difference when you deploy to the JavaScript VM and skip to the next page.

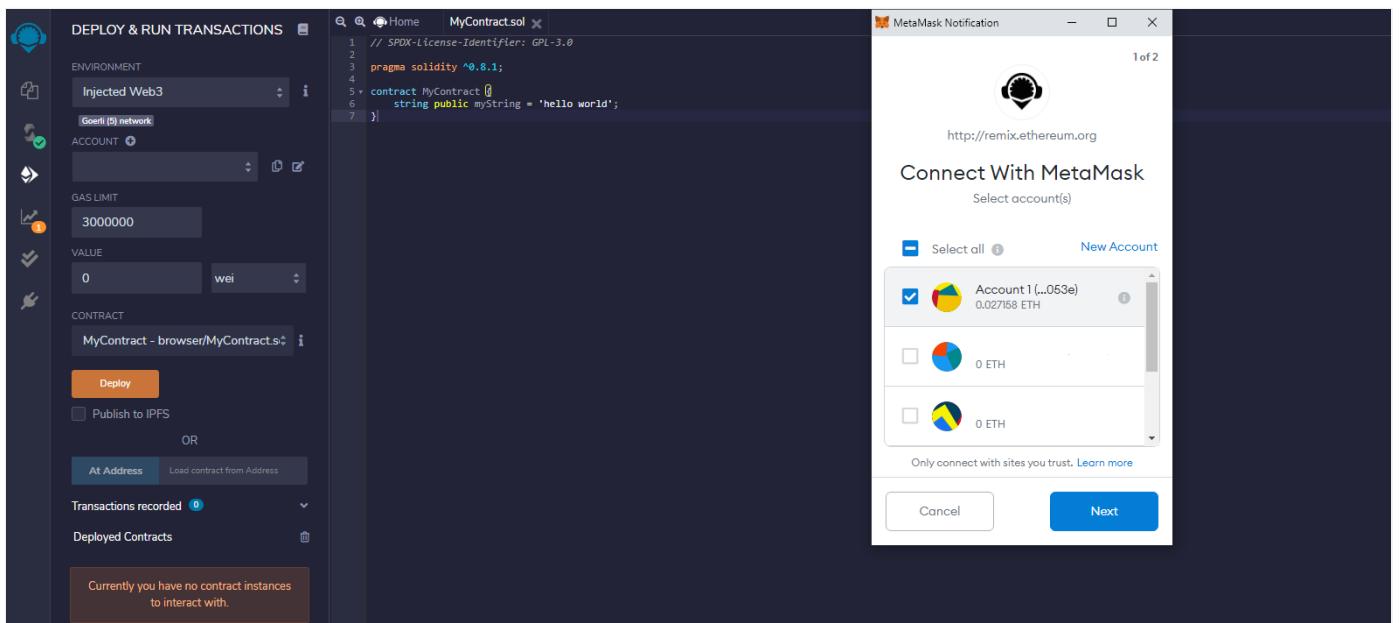
Alright, now we're going to deploy to Görli via MetaMask! This should look all too familiar from the previous Lab.

5.3.1 Connect MetaMask to Remix

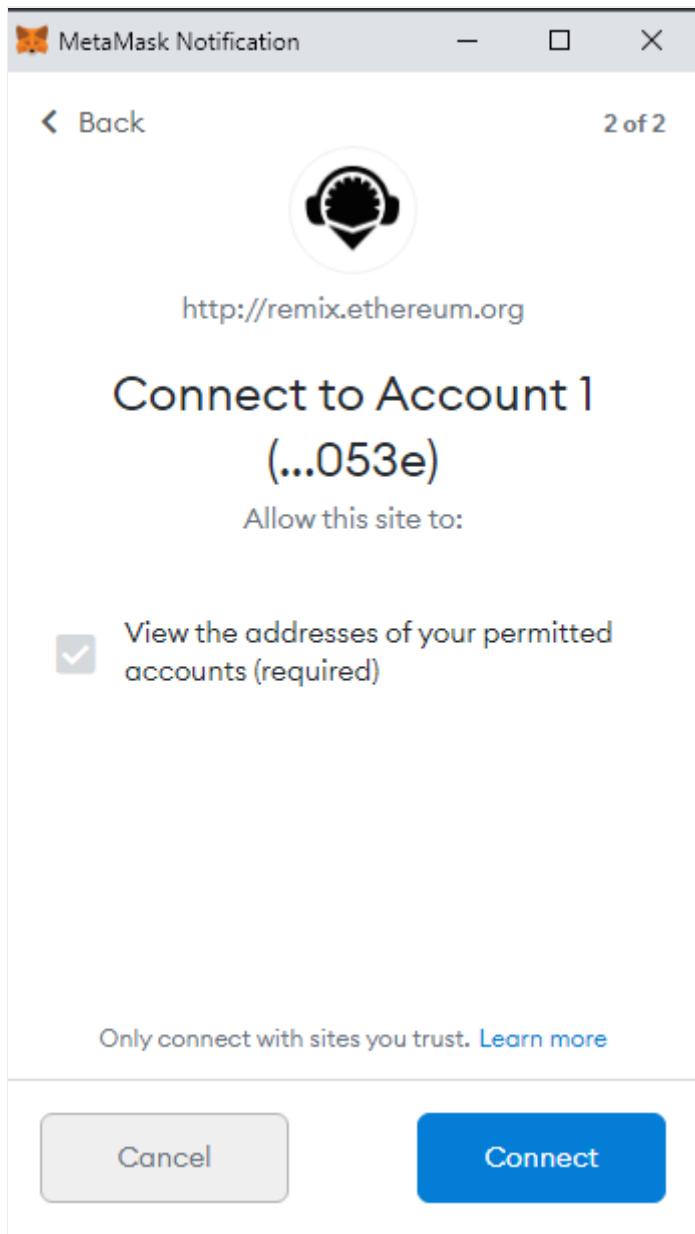
Switch over to the "Deploy & Run Transactions" Plugin. We need to configure it, so it uses our MetaMask Wallet to access the Blockchain.



As soon as you do this, MetaMask should pop up and ask you to connect your account to Remix.



Click "Next" and the "Connect":



Now your account should pop-up in the dropdown under the Environment Selection:

The screenshot shows the Remix IDE interface. On the left, the 'DEPLOY & RUN TRANSACTIONS' sidebar includes sections for 'ENVIRONMENT' (set to 'Injected Web3') and 'ACCOUNT' (set to '0x5AD...3053E (0.027157936729999001 ether)'). On the right, the code editor shows a Solidity contract named 'MyContract.sol' with the following code:

```
// SPDX-License-Identifier: GPL-3.0
pragma solidity ^0.8.1;
contract MyContract {
    string public myString = 'hello world';
}
```

?

Account not showing up?

If your account doesn't show up, or MetaMask doesn't pop up, try to reload the page. There are sometimes caching issues.

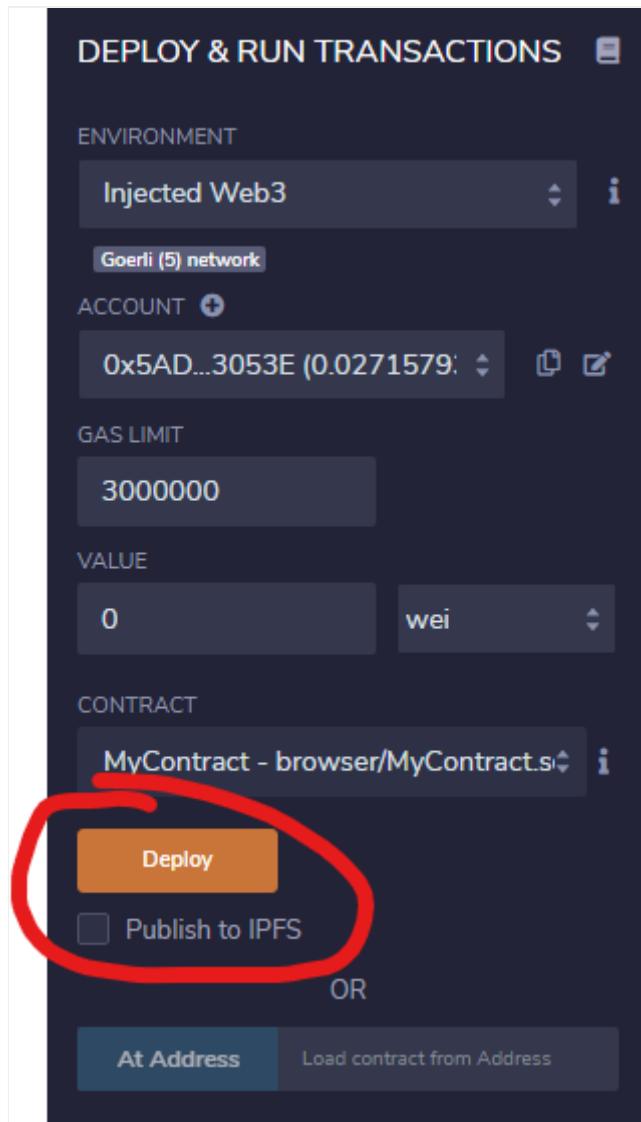
5.3.2 Deploy the Smart Contract

Let's deploy the Smart Contract now. First, make sure the correct Smart Contract is selected in the Dropdown:

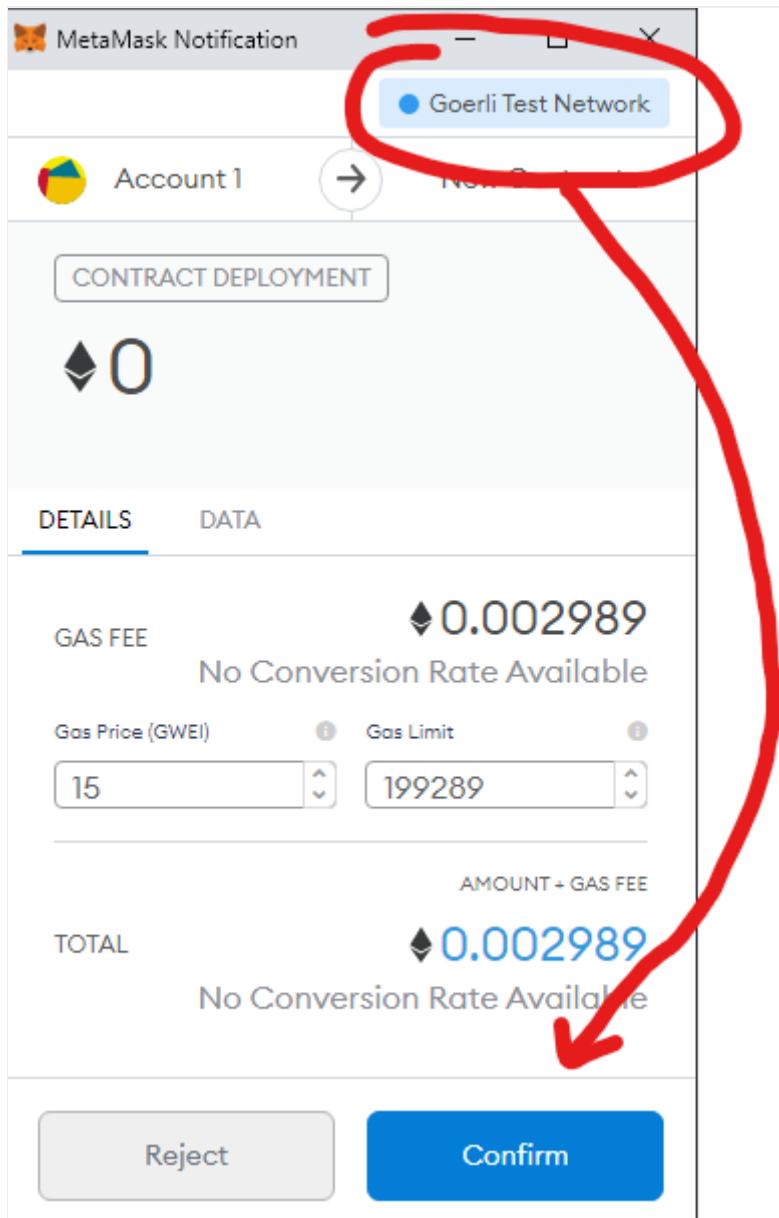
The screenshot shows the 'DEPLOY & RUN TRANSACTIONS' interface. It has the following fields set:

- ENVIRONMENT:** Injected Web3, Goerli (5) network
- ACCOUNT:** 0x5AD...3053E (0.0271579)
- GAS LIMIT:** 3000000
- VALUE:** 0 wei
- CONTRACT:** MyContract - browser/MyContract.sol
- Deploy** button (highlighted in orange)
- Publish to IPFS
- OR
- At Address / Load contract from Address buttons

Then simply hit "Deploy":



This should trigger MetaMask to ask you if you really want to send this transaction. Make sure the Görli Test-Network is selected and then simply hit "Confirm". If you selected the wrong network, then cancel the transaction, switch the network in MetaMask and hit "Deploy" again.



Perfect, now the transaction is on the way of getting mined.

5.3.3 Time until Smart Contract is ready

See how long that takes? Mining on real Blockchains, even test-networks, can take a while. It's not very convenient for Development.

This is why there are alternatives out there, especially for Development!

Let's checkout the most *basic* one, the JavaScript VM next!

Last update: April 17, 2021

5.4 The JavaScript VM in Remix

The JavaScript VM is a simulated Blockchain Environment that only exists in your browser. It also only exists as long as you keep the browser-tab open. Close it or reload it, you start from scratch.

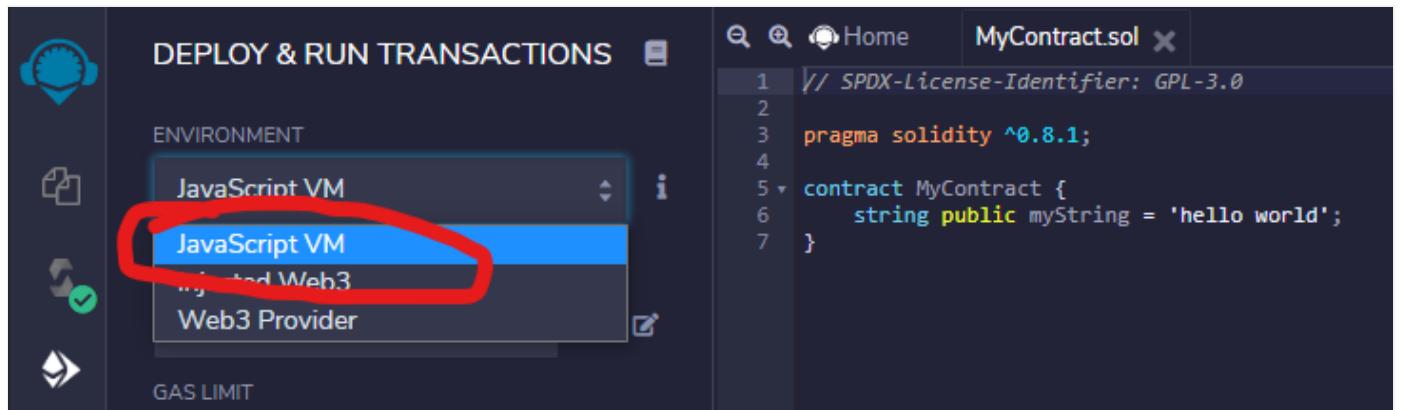
On the positive side: it's super fast! No waiting for Transactions to be mined. No complicated setup. It's just *there* and it *works out of the box*

On the negative side: There's only limited ways to connect to it. Once you reload everything is gone (non persistant). Sometimes things in the browser simulation work, which won't work on a real blockchain.

It's a great way to get started!

5.4.1 Deploy to JavaScript VM in Remix

Select the JavaScript VM from the Environment Dropdown in the "Deploy & Run Transactions" Plugin:



```
// SPDX-License-Identifier: GPL-3.0
pragma solidity ^0.8.1;
contract MyContract {
    string public myString = 'hello world';
}
```

Then simply hit "deploy":

The screenshot shows the Remix IDE's deployment interface. On the left, there are several icons for different environments and tools. The 'ENVIRONMENT' dropdown is set to 'JavaScript VM'. Below it are sections for 'ACCOUNT' (set to 0x5B3...eddC4 with 100 ether), 'GAS LIMIT' (set to 3000000), and 'VALUE' (set to 0 wei). The 'CONTRACT' section shows 'MyContract - browser/MyContract.sol'. A prominent red circle highlights the 'Deploy' button and the 'Publish to IPFS' checkbox below it. To the right, the code editor displays the following Solidity code:

```
// SPDX-License-Identifier: GPL-3.0
pragma solidity ^0.8.1;
contract MyContract {
    string public myString = 'hello world';
}
```

See how quickly that deployed? No MetaMask Popup. No wait time. It's just there. Bam! 🎉

The screenshot shows the deployment results in the Remix IDE. On the left, there are buttons for 'Deploy' and 'Publish to IPFS', and a dropdown for 'At Address' or 'Load contract from Address'. Below that, 'Transactions recorded' shows one entry. The main area displays the 'Deployed Contracts' section, which lists 'MYCONTRACT AT 0xD91...39138 (MEMORY)'. A red arrow points to the 'myString' function under this contract. To the right, the transaction history shows a pending creation of the contract and a successful constructor call. A large red circle highlights the transaction log for the constructor call, which includes the value (0 wei), data (0x608...10033), logs (0), and hash (0xf5c...21aac).

But it's also not perfect, because there's no way to connect other tools to this blockchain. It's gone when you close the browser. All in all it's not perfect.

Let's checkout Ganache!

Last update: April 17, 2021

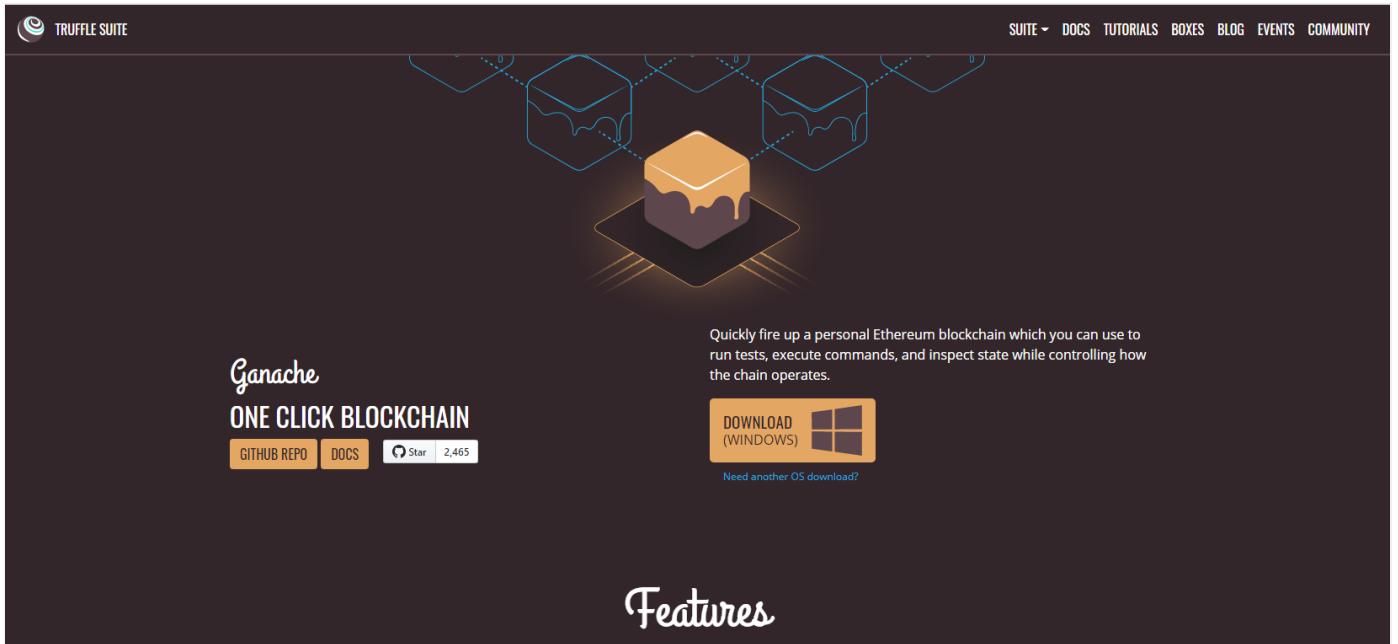
5.5 Web3 Provider

Connecting using a Web3 Provider actually establishes a connection to a software outside of the browser. Like you'd connect to a database. Or to any other API. It's either a RESTful interface or a WebSocket interface. And behind that interface sits a blockchain. This can be Go-Ethereum, Hyperledger Besu, Nethereum - or - Ganache for Development.

Let's start with Ganache!

5.5.1 Download and Install Ganache

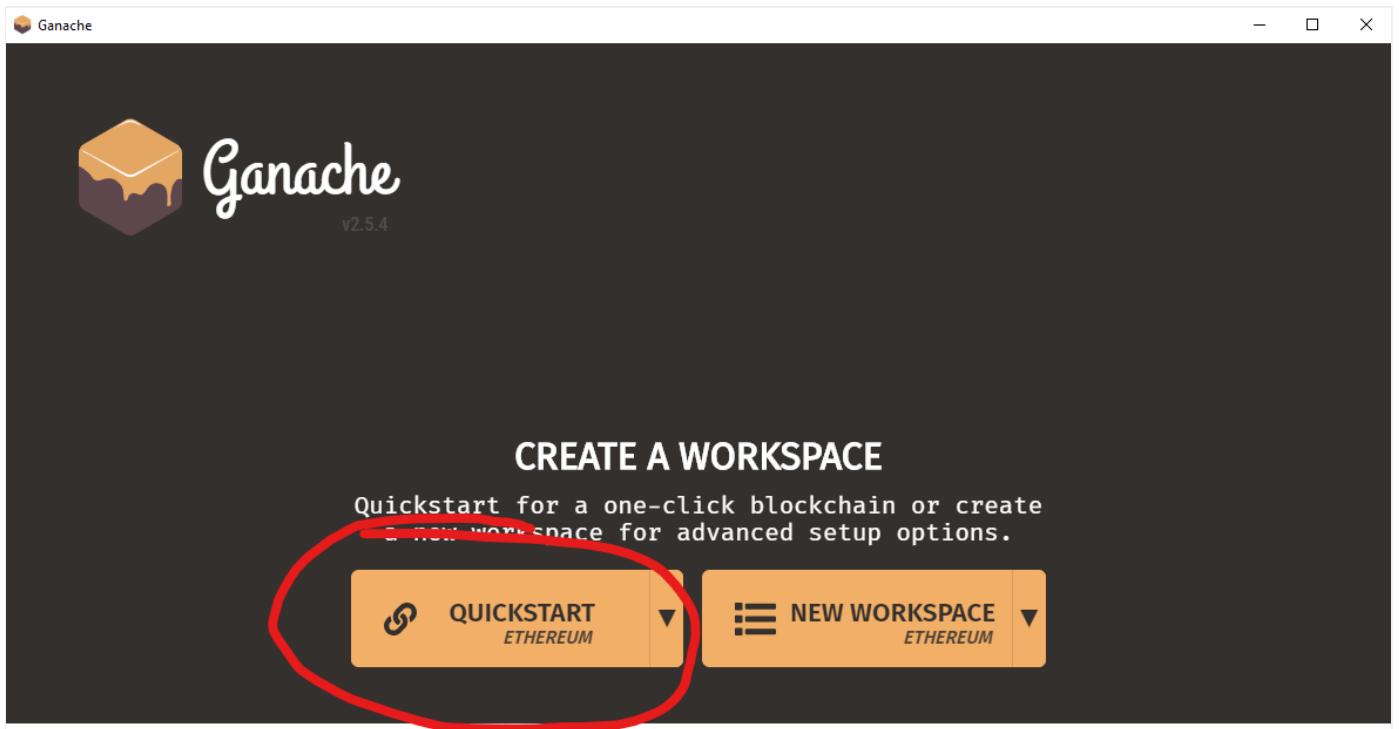
Go to <https://www.trufflesuite.com/ganache> and download Ganache for your Operating System. I am downloading it for Windows for this Lab. But there are also versions for MacOS and Linux. There's a UI Version and also a CLI (Command Line Interface) Version.



Run through the Setup Wizard and install it for your operating system.

5.5.2 Start Ganache

If you start ganache, it will ask you if you want to do a quickstart or actually start with a workspace. For now it's safe to say: We do a quickstart.

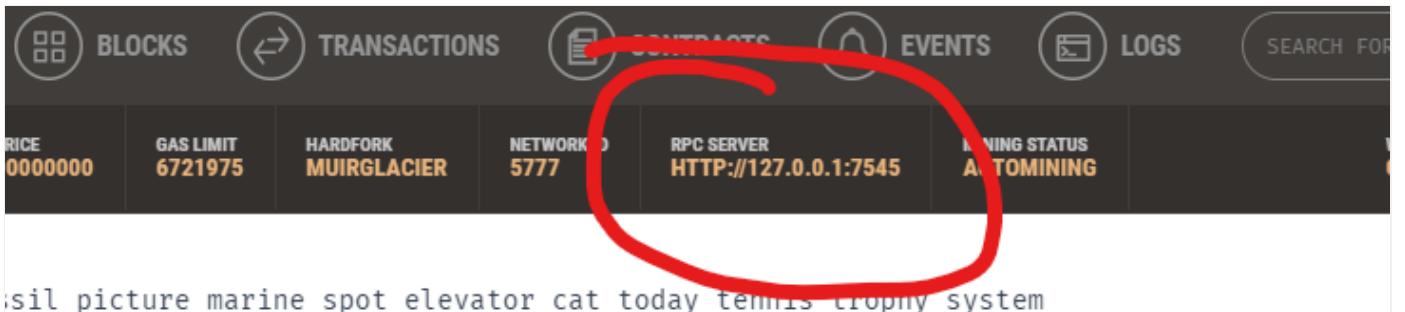


This will create 10 accounts and assign each 100 ether. The accounts are unlocked. All is ready!

GANACHE							SEARCH FOR BLOCK NUMBERS OR TX HASHES	LOGS			
ACCOUNTS	BLOCKS	TRANSACTIONS	CONTRACTS	EVENTS	LOGS	RPC SERVER	MINING STATUS	WORKSPACE	SAVE	SWITCH	SETTINGS
CURRENT BLOCK 0	GAS PRICE 20000000000	GAS LIMIT 6721975	HARDFORK MUIRGLEACIER	NETWORK ID 5777	RPC SERVER HTTP://127.0.0.1:7545	MINING STATUS AUTOMINING	WORKSPACE QUICKSTART				
MNEMONIC offer swamp fossil picture marine spot elevator cat today tennis trophy system										HD PATH m/44'/60'/0'/0/account_index	
ADDRESS 0x7dB0C4F167498781255A9b501802606a408ECC15	BALANCE 100.00 ETH						TX COUNT 0	INDEX 0			
ADDRESS 0xF3d4319e2866583bAb3eFc87B7882B72CF283B2c	BALANCE 100.00 ETH						TX COUNT 0	INDEX 1			
ADDRESS 0x12b00535C00F96A75bE99D61B5a4EB3BDc5d0219	BALANCE 100.00 ETH						TX COUNT 0	INDEX 2			
ADDRESS 0x4288d1c8fc2db1eBd9BEEA01cAEdA86913C9f858	BALANCE 100.00 ETH						TX COUNT 0	INDEX 3			
ADDRESS 0xC727AF1042DcEFd9411dE0FaF879fD551Ad41C33	BALANCE 100.00 ETH						TX COUNT 0	INDEX 4			
ADDRESS 0xd9Ab77AFe3854257690f288242f3c730258ac1a0	BALANCE 100.00 ETH						TX COUNT 0	INDEX 5			
ADDRESS 0xF259d60CB2192d86780c1392159f37709370A93F	BALANCE 100.00 ETH						TX COUNT 0	INDEX 6			

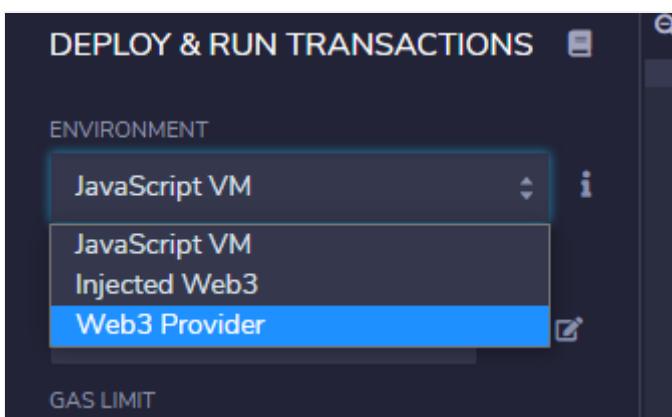
Ganache is now a Blockchain and a Wallet. Two in one. Anyone can connect to it using a Web3 Provider Method either via http RPC or WebSockets.

Pay attention to the RPC Endpoint:

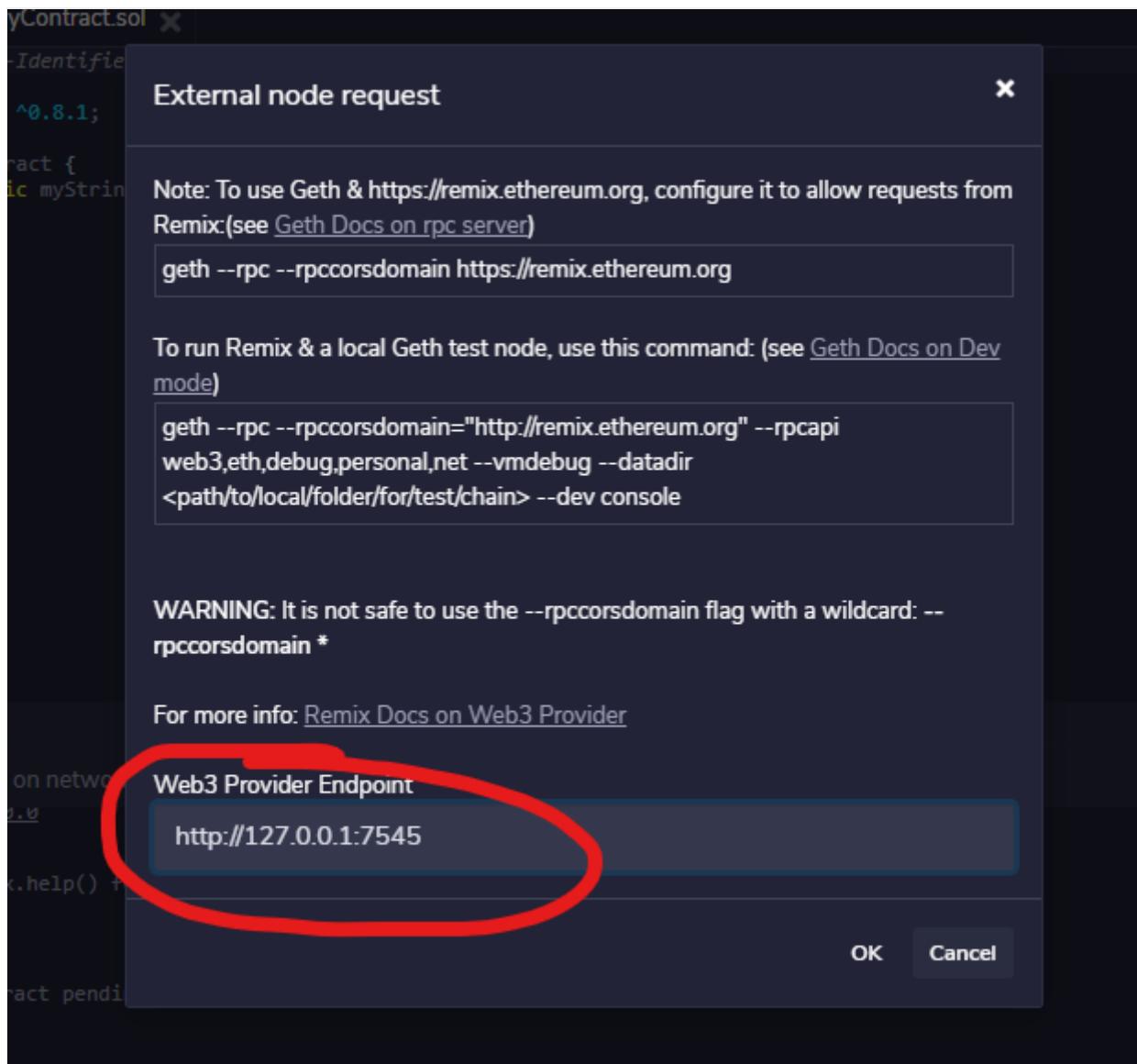


5.5.3 Connect Remix

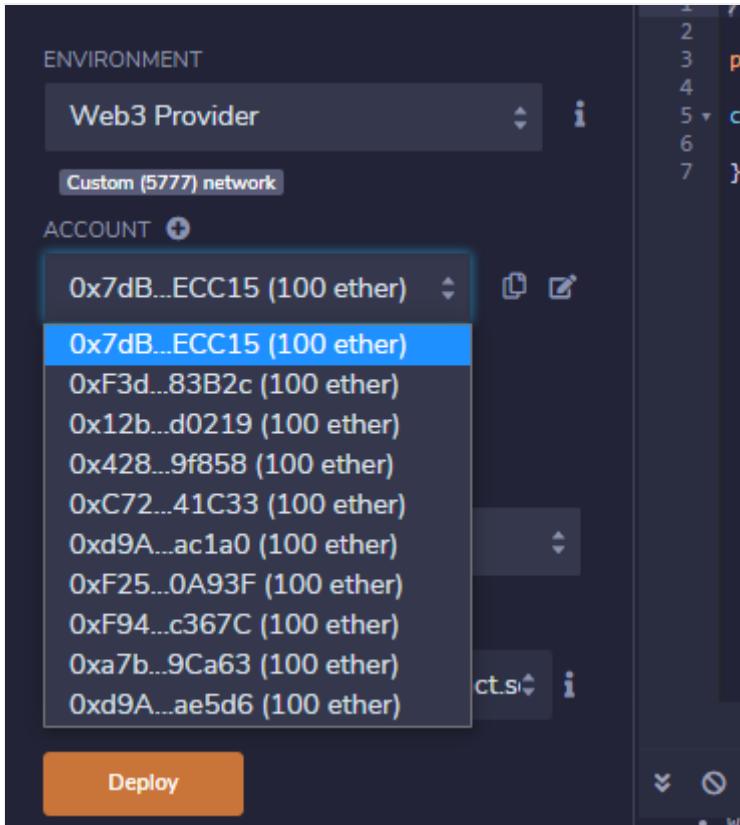
From the Environment Dropdown select now "Web3 Provider":



A new Popup will appear, and enter the RPC Server URL from Ganache. Pay attention to the Port number:

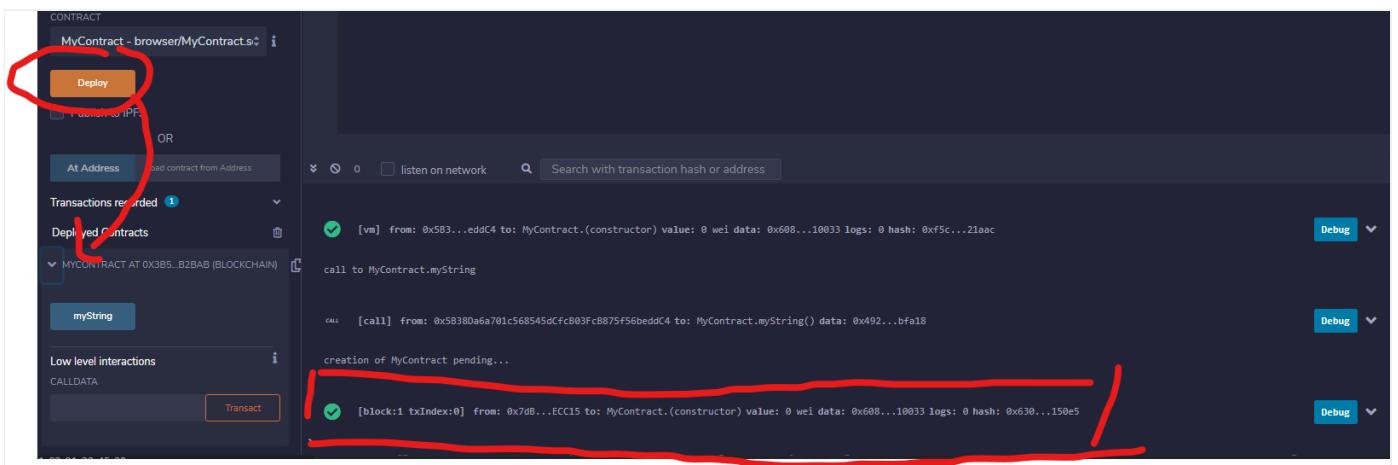


Your Accounts from Ganache should popup in the Accounts-Dropdown:



5.5.4 Deploy to Ganache

Now let's see what happens if we hit the Deploy Button:



Have you seen how fast that was?

Now you have the benefit of two things: An actual blockchain node, but fast like a development network.

Going forward it's probably best to use either the JavaScript VM or Web3 Provider with Ganache. The choice is yours, whatever you prefer. For ease of use, I'll use the JavaScript VM throughout the rest of the Solidity explanations.

Last update: April 17, 2021

5.6 Congratulations

Congratulations, LAB is completed

From the Course "Ethereum Blockchain Developer -- Build Projects in Solidity"

FULL COURSE: <https://www.udemy.com/course/blockchain-developer/?referralCode=E8611DF99D7E491DFD96>

Last update: April 17, 2021

6. Simple Variables

6.1 Lab: Solidity Basics

In this lab we're going to try different types of variables. You will get familiar with the very basic building blocks of a Smart Contract!

6.1.1 What You Know At The End Of The Lab

-  Familiarize yourself with Types of Variables
-  Get Insights into Solidity quirks and specials
-  Be able to bring your own ideas to life!

6.1.2 Prerequisites - You need:

1. Know how to use Remix

Solidity 0.8 Updates

The content has been updated for Solidity 0.8. If there are functional differences to the solidity files shown in the videos then they're highlighted.

In this guide a new smart contract is started every time we are doing a new type of variable. If you prefer to merge them together into one single file, feel free to do so.

6.1.3 Videos

 Full Video Walkthrough: <https://www.udemy.com/course/blockchain-developer/?referralCode=E8611DF99D7E491DFD96>

6.1.4 Get Started

-    Let's get started
-

Last update: April 23, 2021

6.2 Understanding (Unsigned) Integers

In case you don't know what *exactly* integers are, then let's define first what we're talking about:

An integer is [...] a number that can be written without a fractional component. For example, 21, 4, 0, and -2048 are integers, while 9.75, ... is not. <https://en.wikipedia.org/wiki/Integer>

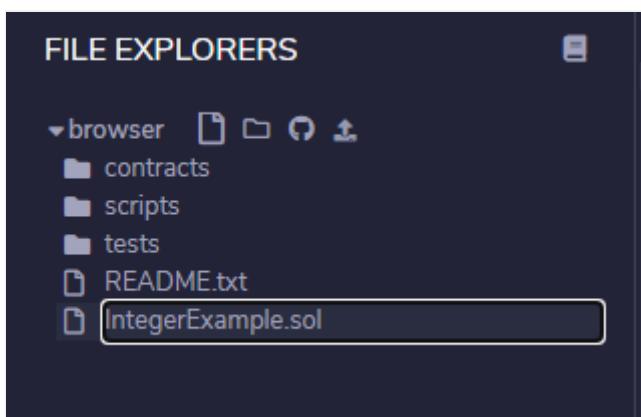
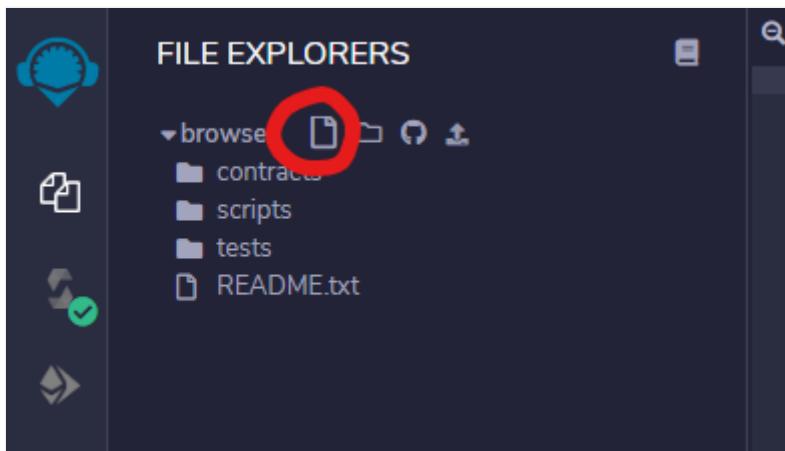
Integral types may be unsigned (capable of representing only non-negative integers) or signed (capable of representing negative integers as well) [https://en.wikipedia.org/wiki/Integer_\(computer_science\)](https://en.wikipedia.org/wiki/Integer_(computer_science))

In layman's terms: Integers are numbers without decimals. *Unsigned* integers cannot be negative.

Let's define a simple Smart Contract first so we can set an integer and then read the value again.

6.2.1 Smart Contract

Create a new file and name it IntegerExample.sol and fill in the following content:



```
IntegerExample.sol
// SPDX-License-Identifier: GPL-3.0
pragma solidity ^0.8.1;
contract IntegerExample {
    uint public myUint;
}
```

The screenshot shows the Truffle UI interface. On the left, there's a sidebar titled "FILE EXPLORERS" with various icons. Below it, the "browser" section shows a folder structure: contracts, scripts, tests, and artifacts. Inside "artifacts", there are files: IntegerExample_metadata.json, IntegerExample.json, README.txt, and IntegerExample.sol. The "IntegerExample.sol" file is currently selected, highlighted with a blue bar at the bottom. On the right, the main area displays the Solidity code for the "IntegerExample" contract:

```
// SPDX-License-Identifier: GPL-3.0
pragma solidity ^0.8.1;
contract IntegerExample {
    uint public myUint;
}
```

There are two important things to see here:

1. The variable is not initialized, but as we will see in a moment, still has a default value
2. A *public* variable automatically creates a getter function in solidity.

6.2.2 Deploy the Smart Contract

Open the "Deploy & Run Transactions" Plugin. Make sure the correct Smart Contract is selected from the dropdown. Then simply hit "Deploy":

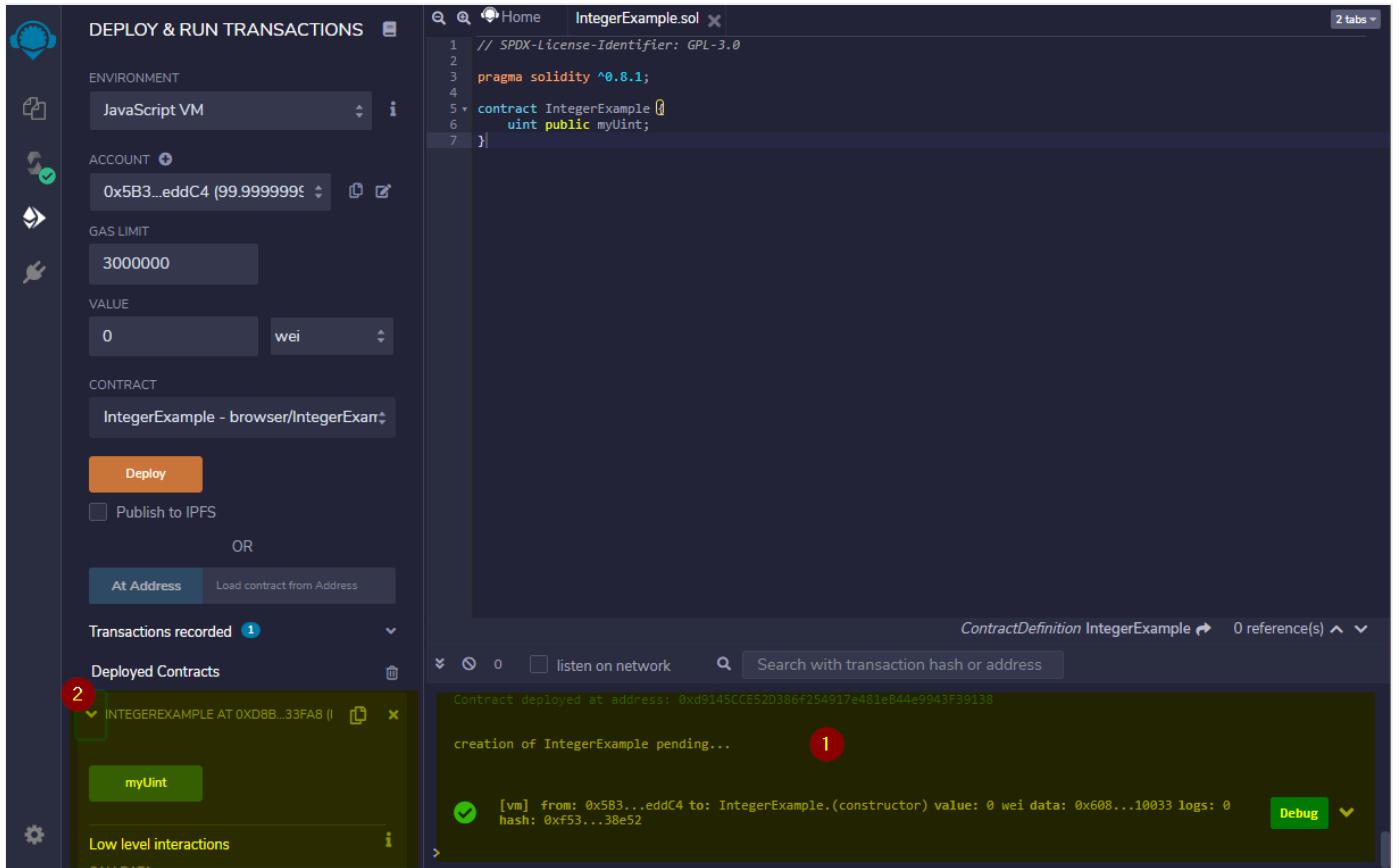
The screenshot shows the Truffle UI interface for deploying a Solidity contract named `IntegerExample`. The left sidebar contains environment settings like `JavaScript VM`, account `0x5B3...eddC4 (99.99999999999999)`, gas limit `3000000`, and value `0 wei`. The main area displays the Solidity code for `IntegerExample.sol`:

```
// SPDX-License-Identifier: GPL-3.0
pragma solidity ^0.8.1;
contract IntegerExample {
    uint public myUint;
}
```

Two red arrows point to the `Deploy` button and the `IntegerExample - browser/IntegerExan` dropdown menu. A red circle highlights the `Deploy` button.

You will be able to observe a few things:

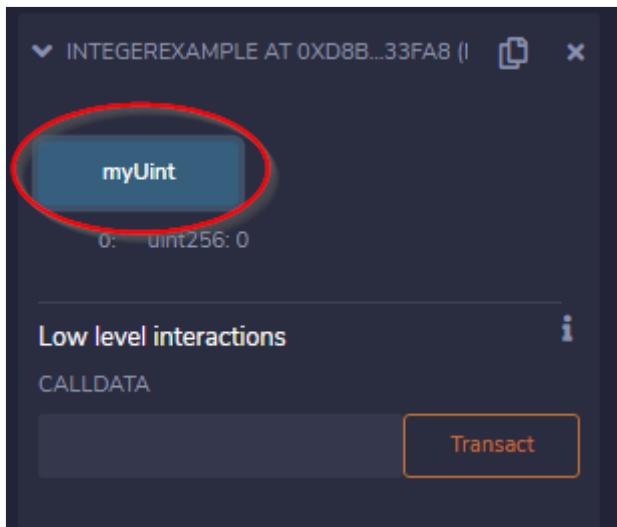
1. A new transaction will be sent and you can see that in the console of Remix (bottom right).
 2. Your Smart Contract is available in the "Deploy & Run Transactions" Plugin, at the bottom. You might need to uncollapse it.



You can now interact with your smart contract.

6.2.3 Interact with the Smart Contract

To interact with your Smart Contract, Remix is automatically generating buttons for every function. If you click on "myUint", you call the auto-generated getter function called "myUint".



Standard Workflow

This is a standard workflow, change the smart contract, redeploy. Currently, there are no in-place updates. For every change we do, we have to deploy a new version of the Smart Contract.

6.2.4 Write a Setter Function

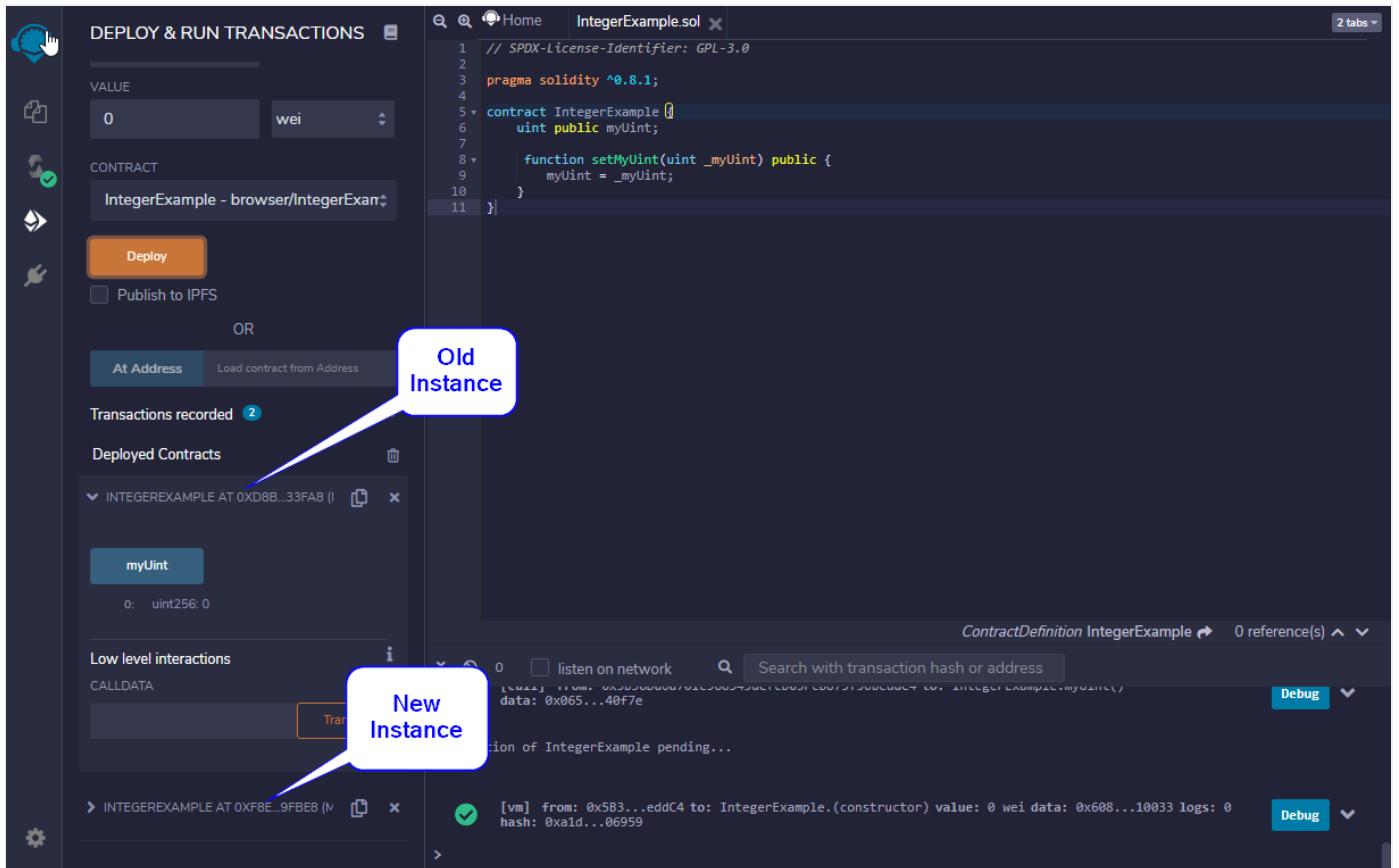
```
// SPDX-License-Identifier: GPL-3.0

pragma solidity ^0.8.1;

contract IntegerExample {
    uint public myUint;

    function setMyUint(uint _myUint) public {
        myUint = _myUint;
    }
}
```

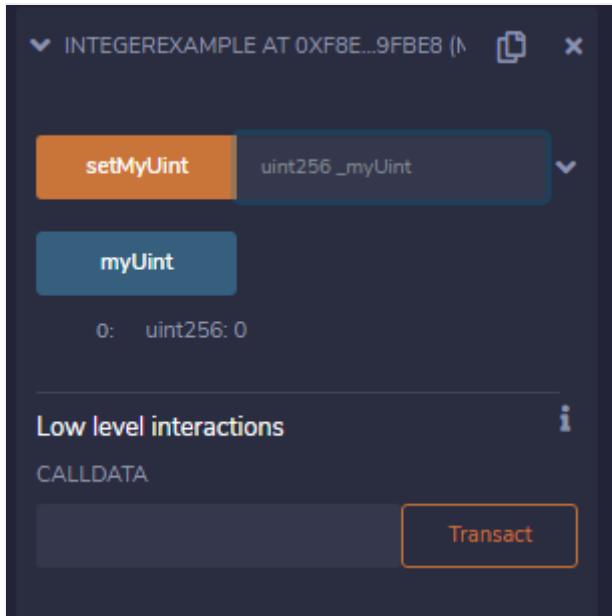
Deploy a new version of the Smart Contract - simply hit "Deploy" again. You will see that you have two *instances* of your Smart Contract on the bottom of the "Deploy & Run Transactions" Plugin. You can safely close the old version - the new version is on the bottom.



The screenshot shows the Truffle UI interface with two contracts displayed:

- myUint**: A contract with a single state variable `uint256 _myUint` initialized to 0. It has a "Low level interactions" section with a "Transact" button.
- setMyUint**: A contract with a function `setMyUint(uint256 _myUint)`. It also has a "Low level interactions" section with a "Transact" button.

If you click on "myUint" it will be initially 0 again.



Let's update it to 5. You can enter the number "5" into the input field next to "setMyUint", then click on "setMyUint":



If you do so, you can again observe the console of Remix on the bottom right that it sent a transaction.

The screenshot shows the Truffle UI interface. On the left, there's a sidebar with icons for file operations and a gear icon. The main area is titled "DEPLOY & RUN TRANSACTIONS". It shows a gas limit of 3000000 and a value of 0 wei. Below that, it says "CONTRACT" and lists "IntegerExample - browser/IntegerExample". There are "Deploy" and "Publish to IPFS" buttons, followed by an "OR" section with "At Address" and "Load contract from Address" options. Under "Transactions recorded", there's a section for "Deployed Contracts" with one entry: "INTEGEREXAMPLE AT 0xF8E...9FBE8". In this section, the "setMyUint" button is highlighted with a red arrow pointing to it. The "myUint" field shows a value of 0. Below this, under "Low level interactions", there's a "Transact" button. On the right side, the Solidity code for "IntegerExample.sol" is shown:

```
// SPDX-License-Identifier: GPL-3.0
pragma solidity ^0.8.1;
contract IntegerExample {
    uint public myUint;
    function setMyUint(uint _myUint) public {
        myUint = _myUint;
    }
}
```

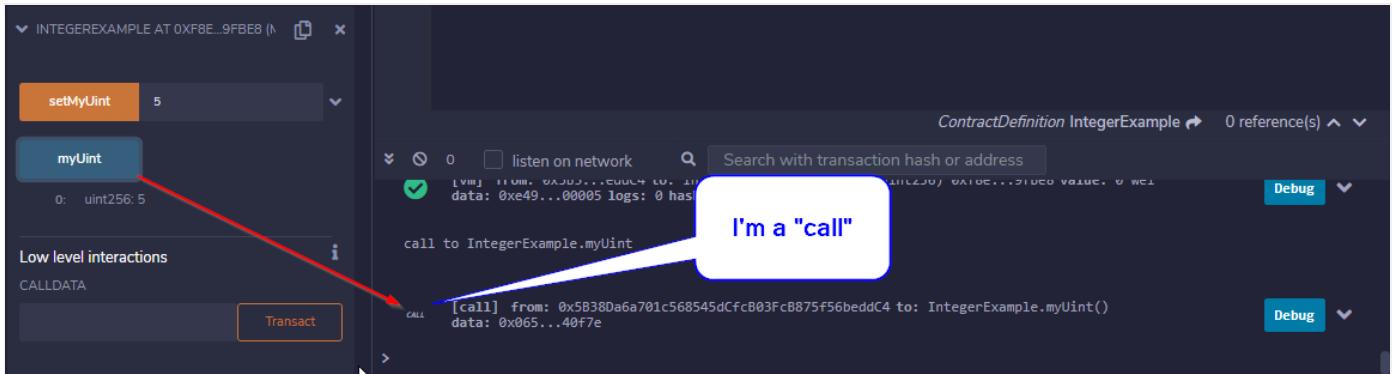
The bottom right corner of the UI shows a tooltip: "I am a transaction". The transaction details are also visible in the UI.

When you click on "myUint" now, it should show you "5" instead of "0".

This screenshot shows the state of the deployed contract. The "myUint" field now displays the value 5. The "Transact" button is still present. The transaction log at the bottom right shows a successful update:

[vm] from: 0x5B3...eddC4 to: IntegerExample.setMyUint(uint256) 0xf8e...9fBe8 value: 0 wei
data: 0xe49...00005 logs: 0 hash: 0xc03...933de

When you click on a function that only reads a value, then no transaction is sent to the network, but a *call*. You can see this in the console on the right side again.



Transaction vs Call

A transaction is necessary, if a value in a Smart Contract needs to be updated (writing to state). A call is done, if a value is read. Transactions cost Ether (gas), need to be mined and therefore take a while until the value is reflected, which you will see later. Calls are virtually free and instant.

Great! Now you know the basic workflow, how to deploy and how to update your code during development. But working only with Integers is a bit boring. Let's level up a bit and learn some more types before doing our first project.

Please note: In the next sections I will silently assume you are deploying a version of a Smart Contract and delete the old instance, whenever we do some changes. I recommend repeating this a few times so you don't forget it.

Last update: April 17, 2021

6.3 Boolean Types in Solidity

Boolean Types can be true or false. Let's define a simple Smart Contract to play around:

6.3.1 Boolean Smart Contract Example

Create a new Smart Contract in Remix, name it BooleanExample.sol and add the following content:

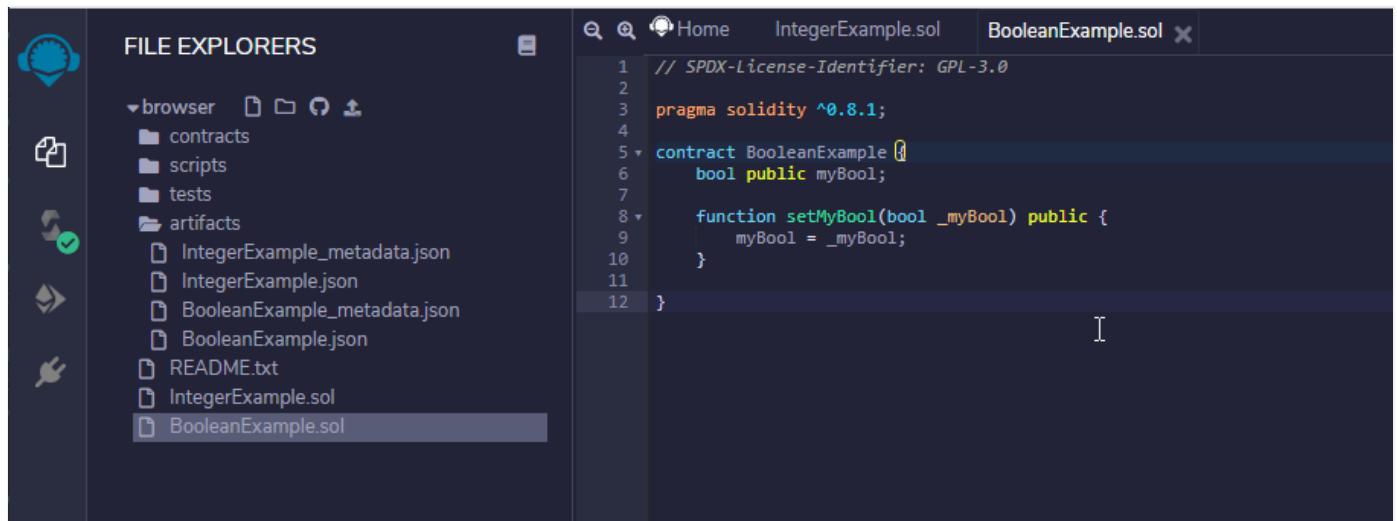
BooleanExample.sol

```
// SPDX-License-Identifier: GPL-3.0

pragma solidity ^0.8.1;

contract BooleanExample {
    bool public myBool;

    function setMyBool(bool _myBool) public {
        myBool = _myBool;
    }
}
```



6.3.2 Deploy the Smart Contract

Head over to "Run & Deploy Transactions" Plugin and deploy this Smart Contract.

When you click on "myBool" you will see that the variable is initialized with its default value, which is "false".

The screenshot shows the Truffle UI interface. On the left, there's a sidebar with icons for file operations like Open, Save, and Deploy. The main area has tabs for Home, IntegerExample.sol, and BooleanExample.sol. The BooleanExample.sol tab is active, displaying the following Solidity code:

```
// SPDX-License-Identifier: GPL-3.0
pragma solidity ^0.8.1;
contract BooleanExample {
    bool public myBool;
    function setMyBool(bool _myBool) public {
        myBool = _myBool;
    }
}
```

Below the code editor, there's a section for "Transactions recorded" showing one transaction: "setMyBool" with "bool _myBool". The value is listed as "0: bool: false".

On the right, the "ContractDefinition IntegerExample" pane shows a "Debug" button and a log entry for a call to "BooleanExample.myBool()". The log entry includes the hash: 0xed2...9aace and the data: 0x6de...ecde.

Now let's update the variable to "true":

1. enter "true" into the input field
2. hit the "setMyBool" button
3. see if the variable was updated by clicking on "myBool" again

This screenshot shows the same Truffle UI interface as before, but now the "myBool" value has been updated. The "myBool" button now displays "0: bool: true".

Boolean Operators

With boolean types you have the standard operators at your disposal. Operators: `!` (logical negation), `&&` (logical conjunction, "and"), `||` (logical disjunction, "or"), `==` (equality), `!=` (inequality).

We will use this in the upcoming projects.

Now you know two very basic types, and we could do already a *lot* with it, but before we head into our first project, let's see some more peculiarities which you only have in Solidity.

Last update: April 17, 2021

6.4 Integer Overflow and Underflow

6.4.1 What are Overflows or Underflows?

In previous versions of Solidity (prior Solidity 0.8.x) an integer would automatically roll-over to a lower or higher number. If you would decrement 0 by 1 (0-1) on an unsigned integer, the result would not be -1, or an error, the result would simple be: MAX(uint).

For this example I want to use uint8. We haven't used different types of uint yet. In our previous example worked with uint256, but bear with me for a moment. Uint8 is going from 0 to $2^8 - 1$. In other words: uint8 ranges from 0 to 255. If you increment 255 it will automatically be 0, if you decrement 0, it will become 255. No warnings, no errors. For example, this can become problematic, if you store a token-balance in a variable and decrement it without checking.

Let's do an actual example!

6.4.2 Sample Smart Contract

Create a new Smart Contrac with the name "RolloverExample.sol". We're going to use Solidity 0.7 for this example, as in Solidity 0.8 this behavior is different.

RolloverExample.sol

```
// SPDX-License-Identifier: GPL-3.0
pragma solidity 0.7.0;

contract RolloverExample {
    uint8 public myUint8;

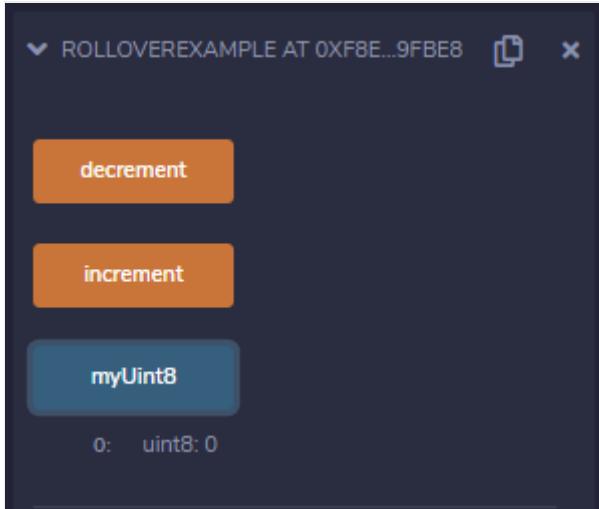
    function decrement() public {
        myUint8--;
    }

    function increment() public {
        myUint8++;
    }
}
```

The screenshot shows the Visual Studio Code interface. On the left, the 'FILE EXPLORERS' sidebar displays a file tree with folders for 'contracts', 'scripts', 'tests', and 'artifacts', along with JSON files like 'IntegerExample_metadata.json' and 'BooleanExample_metadata.json'. In the center, the main editor window shows the Solidity code for 'RolloverExample.sol'. The code includes a pragma directive for Solidity 0.7.0, a contract definition with a public uint8 variable 'myUint8', and two public functions: 'decrement()' and 'increment()'. The 'increment()' function increments the value of 'myUint8' using the post-increment operator ('myUint8++'). The 'decrement()' function decrements the value using the pre-decrement operator ('myUint8--').

Let's deploy the Smart Contract and see what happens if we call decrement.

Initially, myUint8 is 0:



If you press the "decrement" button, then the myUint8 is decremented by one. Let's see what happens, and also observe the Remix console:

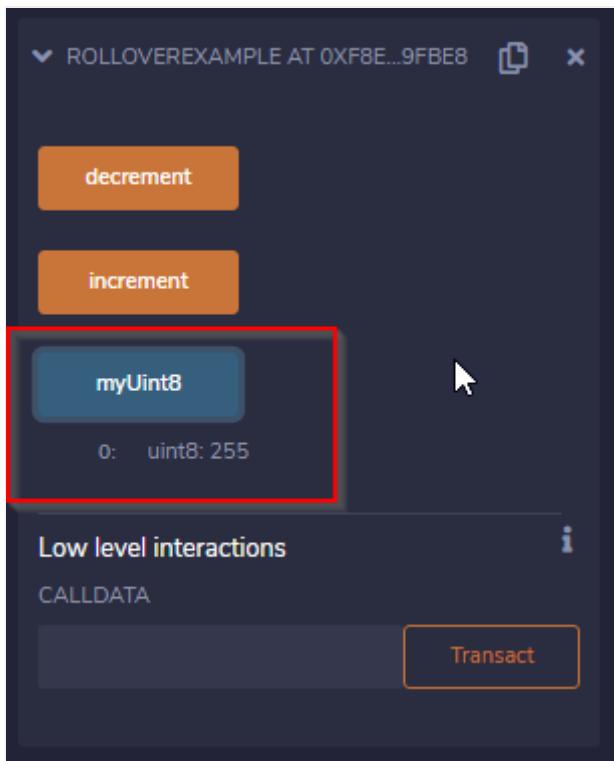
```
// SPDX-License-Identifier: GPL-3.0
pragma solidity 0.7.0;

contract RolloverExample {
    uint8 public myUint8;

    function decrement() public {
        myUint8--;
    }

    function increment() public {
        myUint8++;
    }
}
```

The transaction works perfectly. No errors occur. If you retrieve the value for myUint8 then you see it's 255:



🔥 Increment Example

Try yourself what happens when you increment again. Does it roll over again without a warning?

Now you see one of the quirks with Solidity. It's not completely unique to Solidity, but definitely something to be aware of. This is where Libraries like [SafeMath](#) were invented, which you will see later.

But what happened in Solidity 0.8?

6.4.3 Solidity 0.8 Difference

In Solidity 0.8, the compiler will automatically take care of checking for overflows and underflows. Let's run the same example with Solidity 0.8. Create a new file and fill in the following Smart Contract:

RolloverExampleSol08.sol

```
// SPDX-License-Identifier: GPL-3.0
pragma solidity 0.8.0;

contract RolloverExample2 {
    uint8 public myUint8;

    function decrement() public {
        myUint8--;
    }

    function increment() public {
        myUint8++;
    }
}
```

Deploy the new version and try to hit "decrement". Now you will get an error in the Remix console:

The screenshot shows the Truffle UI interface. On the left, there's a sidebar with icons for file operations like Deploy, Publish to IPFS, and At Address. The main area has tabs for Home, MorpherOracle.sol, and RolloverExample.sol. The RolloverExample.sol tab is active, displaying the following Solidity code:

```
// SPDX-License-Identifier: GPL-3.0
pragma solidity 0.8.0;

contract RolloverExample {
    uint8 public myUint8;

    function decrement() public {
        myUint8--;
    }

    function increment() public {
        myUint8++;
    }
}
```

Below the code, a transaction history pane shows a recent revert error for the decrement() function:

[vm] from: 0x5B3...eddC4 to: RolloverExample.decrement() 0x7EF...8CB47 value: 0 wei
data: 0x2ba...eceb7 logs: 0 hash: 0x466...d0eff

A note below explains the revert error: "transact to RolloverExample.decrement errored: VM error: revert. revert The transaction has been reverted to the initial state. Note: The called function should be payable if you send value and the value you send should be less than your current balance. Debug the transaction to get more information."

Your variable "myUint8" will remain 0, because it cannot roll over anymore:

The screenshot shows the Truffle UI interface for the RolloverExample contract. The myUint8 variable is highlighted with a red box. The value is shown as 0: uint8: 0. The increment button is also highlighted with a red box.

But what if you actually want to roll over? Then there is a new "unchecked" block you can wrap your variables around:

```
// SPDX-License-Identifier: GPL-3.0
pragma solidity 0.8.0;

contract RolloverExample2 {
    uint8 public myUint8;

    function decrement() public {
        unchecked {
            myUint8--;
        }
    }
}
```

```

}
function increment() public {
    unchecked {
        myUint8++;
    }
}

```

The screenshot shows the Truffle UI interface. On the left, there's a sidebar with icons for network selection, file management, and deployment. The main area is titled "DEPLOY & RUN TRANSACTIONS". It has tabs for "Deploy", "Publish to IPFS", and "At Address". Under "At Address", it says "Transactions recorded 8" and "Deployed Contracts" with a dropdown menu showing "ROLLOVEREXAMPLE AT 0x358...D5EE3". Below this, there are three buttons: "decrement", "increment", and "myUint8". The "myUint8" button is highlighted. To its right, it shows "0: uint8: 255". At the bottom, there's a "Low level interactions" section with a "Transact" button. On the right side of the screen, there's a code editor window titled "RolloverExample.sol" containing the Solidity code for the RolloverExample contract. Below the code editor, there's a transaction history section with a "call to RolloverExample.myUint8" entry and a "call [call] from: 0x5B38Da6a701c568545dCfcB03FcB875f56beddC4 to: RolloverExample.myUint8()" entry. There are also "Debug" buttons for each.

Then everything works again as you know it from previous Solidity versions. This is such an important quirks of Solidity that I wanted to bring it up early. Now, let's go back to some lighter topics.

Last update: April 17, 2021

6.5 Address Types

One type, which is very specific to Ethereum and Solidity, is the type "address".

Ethereum supports transfer of Ether and communication between Smart Contracts. Those reside on an *address*. Addresses can be stored in Smart Contracts and can be used to transfer Ether *from* the Smart Contract *to* an address stored in a variable.

That's where variables of the type *address* come in.

In general, a variable of the type *address* holds 20 bytes. That's all that happens internally. Let's see what we can do with Solidity and addresses.

6.5.1 Smart Contract Example

Let's create a new Smart Contract to have an example.

AddressExample.sol

```
// SPDX-License-Identifier: GPL-3.0
pragma solidity 0.8.1;

contract AddressExample {
    address public myAddress;

    function setAddress(address _address) public {
        myAddress = _address;
    }

    function getBalanceOfAccount() public view returns(uint) {
        return myAddress.balance;
    }
}
```

Deploy the Smart Contract with Remix to the JavaScript VM:

The screenshot shows the Remix IDE interface. On the left, there's a sidebar with icons for file operations, deployment, and settings. The main area is divided into two tabs: 'DEPLOY & RUN TRANSACTIONS' and 'AddressExample.sol'. The 'AddressExample.sol' tab contains the Solidity code for the smart contract. Below the code editor, there are sections for 'Deploy', 'Transactions recorded', and 'Deployed Contracts'. Under 'Deployed Contracts', it shows a deployed contract named 'ADDRESSEXAMPLE AT 0xD2A...FD005'. It lists three functions: 'setAddress', 'getBalanceOf...', and 'myAddress'. At the bottom, there's a 'Low level interactions' section with a 'Transact' button. The status bar at the bottom right shows deployment logs, including the transaction hash and logs.

⚠ Important Concepts

As you continue, please pay special attention to the following few concepts here which are *really* important and different than in any other programming language:

1. The Smart Contract is stored under its own address
2. The Smart Contract can store an address in the variable "myAddress", which can be its own address, but can be any other address as well.
3. All information on the blockchain is public, so we can retrieve the balance of the address stored in the variable "myAddress"
4. The Smart Contract can transfer funds *from* his own address *to* another address. But it cannot transfer the funds from another address.
5. Transferring Ether is fundamentally different than transferring ERC20 Tokens, as you will see later.

Before you continue, read the statements above and keep them in mind. These are the most mind-blowing facts for Ethereum newcomers.

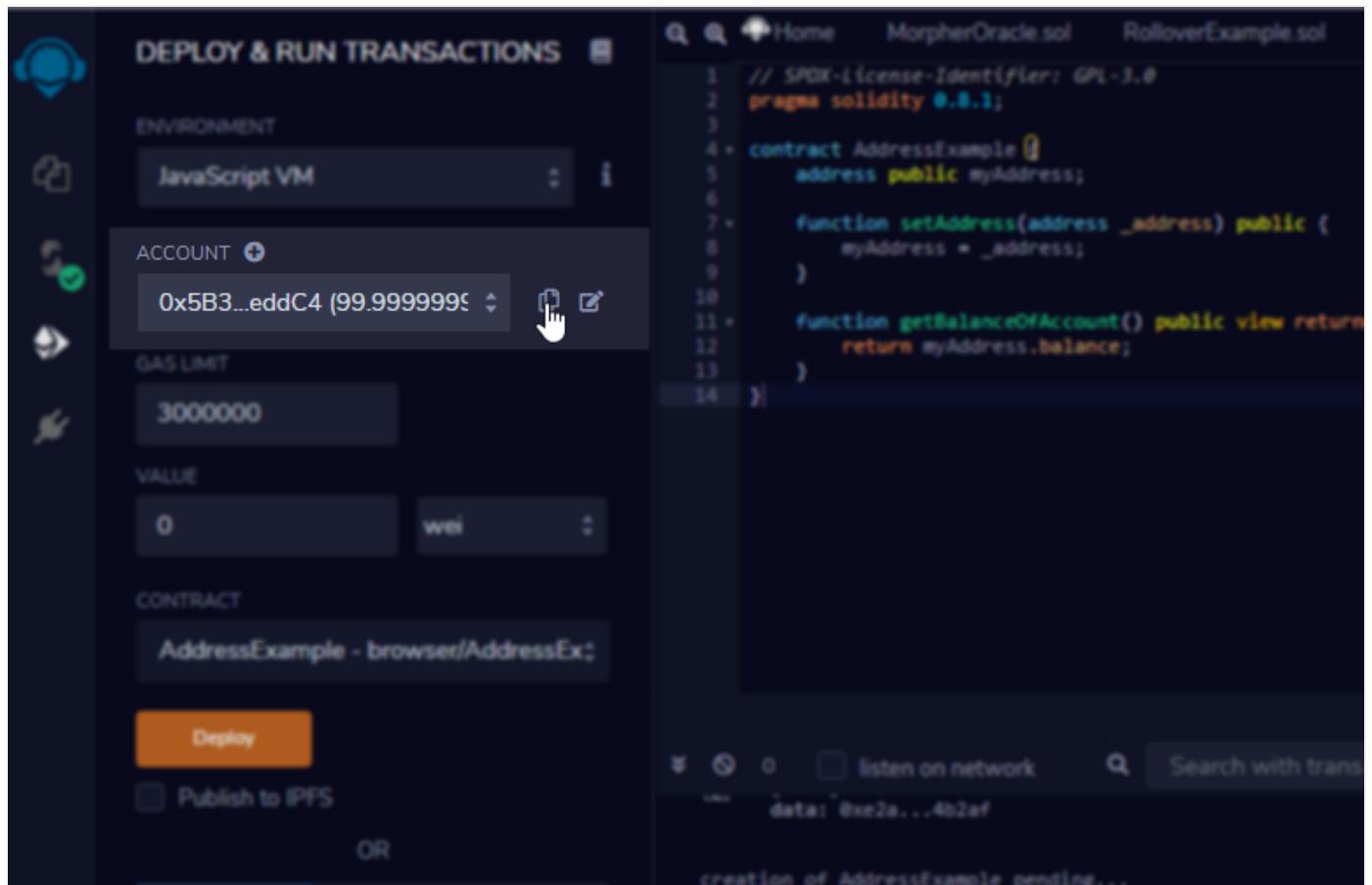
Let's run the Smart Contract and get the balance of addresses programmaticaly.

6.5.2 Run the Smart Contract

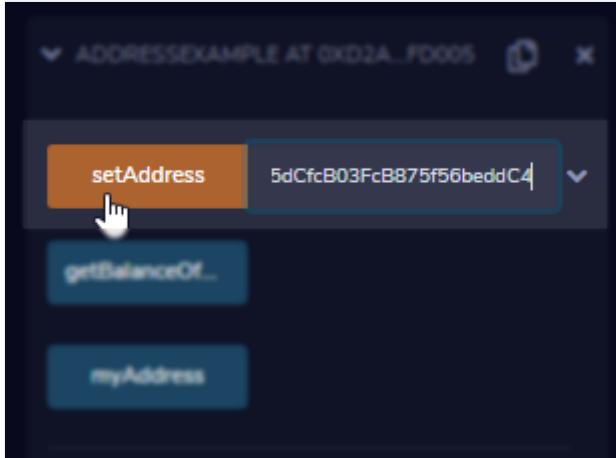
What we're going to do is to access the address in the accounts-list programmaticaly from within the Smart Contract. We will:

1. Copy the Address from the Accounts-List
2. Update the "myAddress" variable in the Smart Contract
3. Get the Balance of the address stored

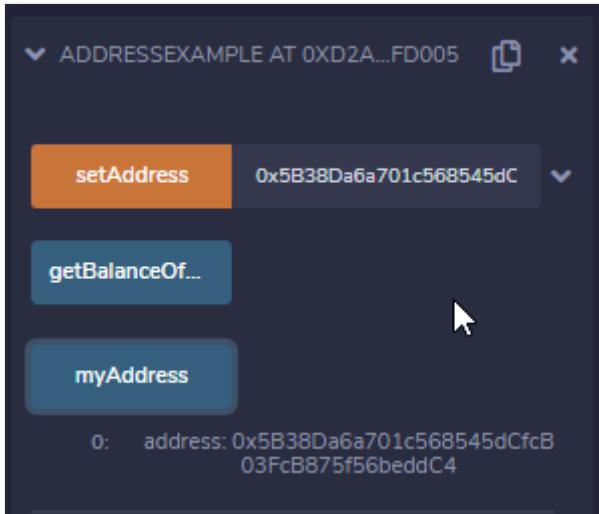
Let's copy your first address from the Accounts-List. Click the little "copy" icon next to your Account:



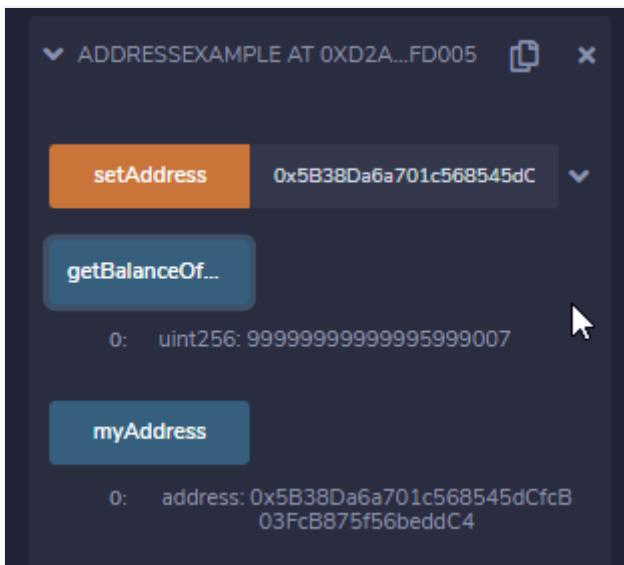
Then paste it into the input field next to "setAddress" and then click the "setAddress" button:



When you hit the "myAddress" button, it should show you *your* address:



Now, let's check the balance, click on "getBalanceOfAccount" button and it should show you the balance in Wei:



Ethereum Denominations

A short reminder on [Ethereum Denominations](#). Wei is the smallest, Ether = 10^{18} Wei.

Unit	Wei Exp	Wei
wei	1	1
Kwei	10^3	1,000
Mwei	10^6	1,000,000
Gwei	10^9	1,000,000,000
Ether	10^{18}	1,000,000,000,000,000,000

Your balance will be very similar to the one in the picture above, probably around 99.999999-some Ether. Why not 100 Ether, or where do the Ether come from? The JavaScript VM is a simulated environment that will "give" you 100 Ether to play. Every transaction costs a little bit of Ether in Gas-Costs, which we will cover later.

Later on you will see how a Smart Contract can manage Ether which are sent to the address of the Smart Contract. Let's discuss an example using Strings next!

Last update: April 17, 2021

6.6 String Types

Strings are actually Arrays, very similar to a bytes-array. If that sounds too complicated, let me break down some quirks for you that are somewhat unique to Solidity:

1. Natively, there are no String manipulation functions.
2. No even string comparison is natively possible
3. There are libraries to work with Strings
4. Strings are expensive to store and work with in Solidity (Gas costs, we talk about them later)
5. As a rule of thumb: try to avoid storing Strings, use Events instead (more on that later as well!)

If you still want to use Strings, then let's do an example!

6.6.1 Example Smart Contract

Let's create the following example Smart Contract, store a String and retrieve it again:

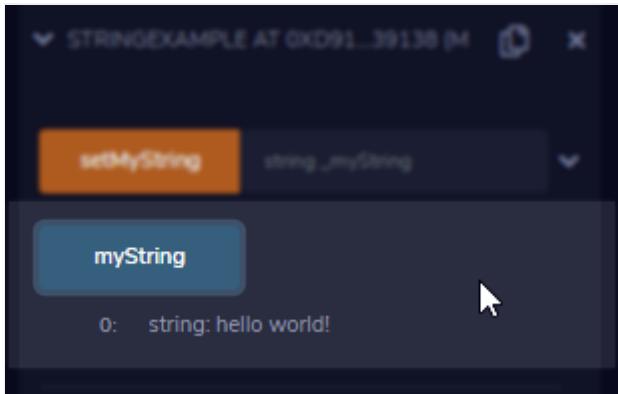
StringExample.sol

```
// SPDX-License-Identifier: GPL-3.0
pragma solidity 0.8.1;

contract StringExample {
    string public myString = 'hello world!';

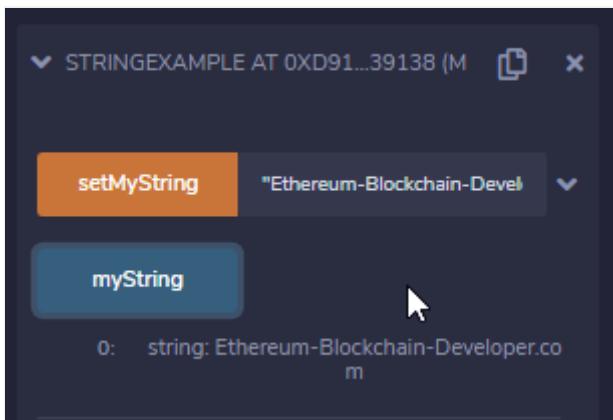
    function setMyString(string memory _myString) public {
        myString = _myString;
    }
}
```

Deploy the Smart Contract into the JavaScript VM and retrieve the String. It should output "hello world!", since it was initialized with this value:



Now we can overwrite the String with another String:

Write any String you want into the input box next to "setMyString" - for example "Ethereum-Blockchain-Developer.com". Then hit the "myString" button again:



Later, in the Gas-Cost section, you will see how inefficient it is to use Strings. I will also introduce some better ways storing Strings in a trustable way with Events on the Blockchain.

Last update: April 17, 2021

6.7 Congratulations

Congratulations, LAB is completed

From the Course "Ethereum Blockchain Developer -- Build Projects in Solidity"

FULL COURSE: <https://www.udemy.com/course/blockchain-developer/?referralCode=E8611DF99D7E491DFD96>

Last update: April 17, 2021

7. LAB: Deposit/Withdraw Ether

7.1 Lab: Smart Contract Self Managing Funds

In this lab you are going learn how a Smart Contract manages its own funds. You will send Ether to your Smart Contract. Then the Smart Contract will manage its own Ether and will be able to relay it to anyone else. It's like a bank account with programming code attached to it.

This can also be used to escrow Ether into a Smart Contract. First we'll do a very simple deposit/withdrawal example, then I'll show you how a Smart Contract can lock funds using a time-activated withdrawal functionality.

7.1.1 What You Know At The End Of The Lab

��识点 Understand Contract Addresses and the global msg-object

知识点 How Smart Contracts manage Funds

知识点 How to Send/Withdraw Ether to and from Smart Contracts

7.1.2 Prerequisites - You need:

1. Chrome or Firefox browser.
2. An Internet connection
3. About 30 Minutes of your precious time 知识点

7.1.3 Videos

视频 Full Video Walkthrough: <https://www.udemy.com/course/blockchain-developer/?referralCode=E8611DF99D7E491DFD96>

7.1.4 Get Started

知识点 Let's get started by [Starting With A Smart Contract](#)

Last update: April 23, 2021

7.2 Smart Contract

Let's start with a simple Smart Contract. Create a new file in Remix and paste the following code:

SendMoneyExample.sol

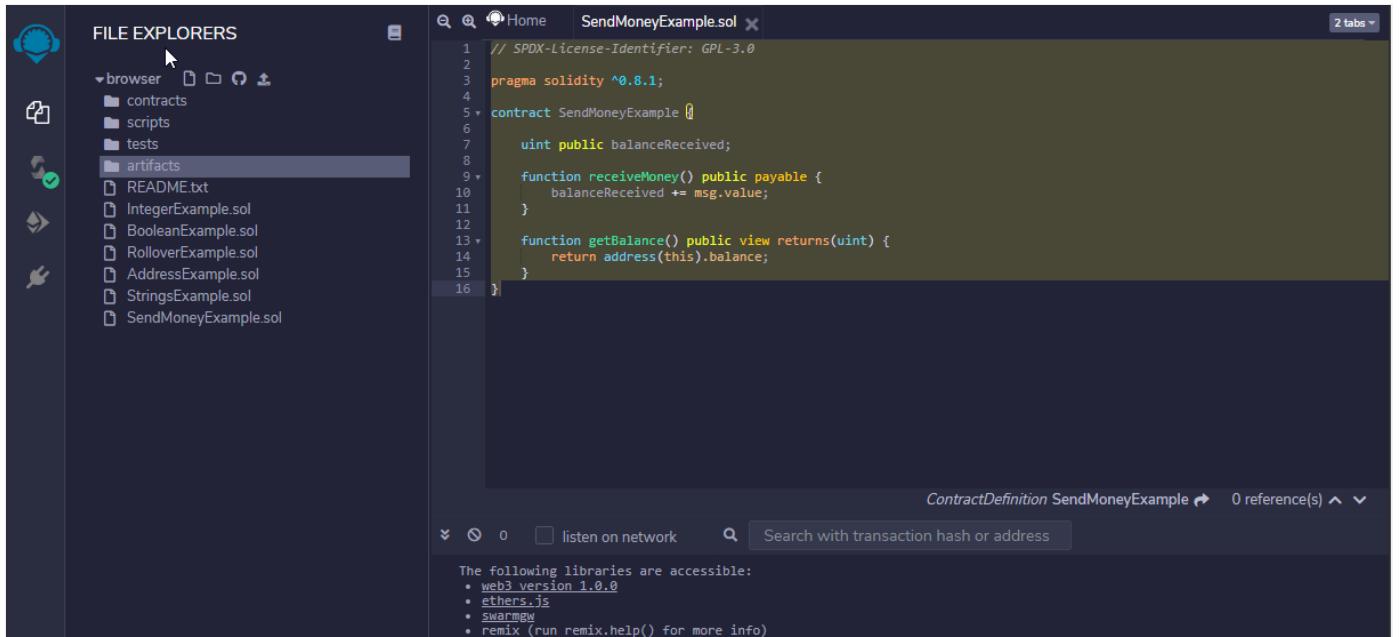
```
// SPDX-License-Identifier: GPL-3.0

pragma solidity ^0.8.1;

contract SendMoneyExample {
    uint public balanceReceived;

    function receiveMoney() public payable {
        balanceReceived += msg.value;
    }

    function getBalance() public view returns(uint) {
        return address(this).balance;
    }
}
```



A lot of new stuff in here. Don't worry, in a bit all of those things will be very familiar to you. I keep explaining them as we go along, but if you're interested right away then let's go through this one line at a time:

`uint public balanceReceived` : is a public storage variable. A public variable will create a getter function automatically in Solidity. So we can always query the current content of this variable.

`balanceReceived += msg.value` : The msg-object is a global always-existing object containing a few informations about the ongoing transaction. The two most important properties are `.value` and `.sender`. Former contains the amount of Wei that was sent to the smart contract. Latter contains the address that called the Smart Contract. We will use this extensively later on, so, just keep going for now.

`function getBalance() public view returns(uint)` : a view function is a function that doesn't alter the storage (read-only) and can return information. It doesn't need to be mined and it is virtually free of charge.

`address(this).balance` : A variable of the type address always has a property called `.balance` which gives you the amount of ether stored on that address. It doesn't mean you can access them, it just tells you how much is stored there. Remember, it's all public information. `address(this)` converts the Smart Contract instance to an address. So, this line essentially returns the amount of Ether that are stored on the Smart Contract itself.

Let's see if we can do something with it. Deploy the Smart Contract and play around a bit...

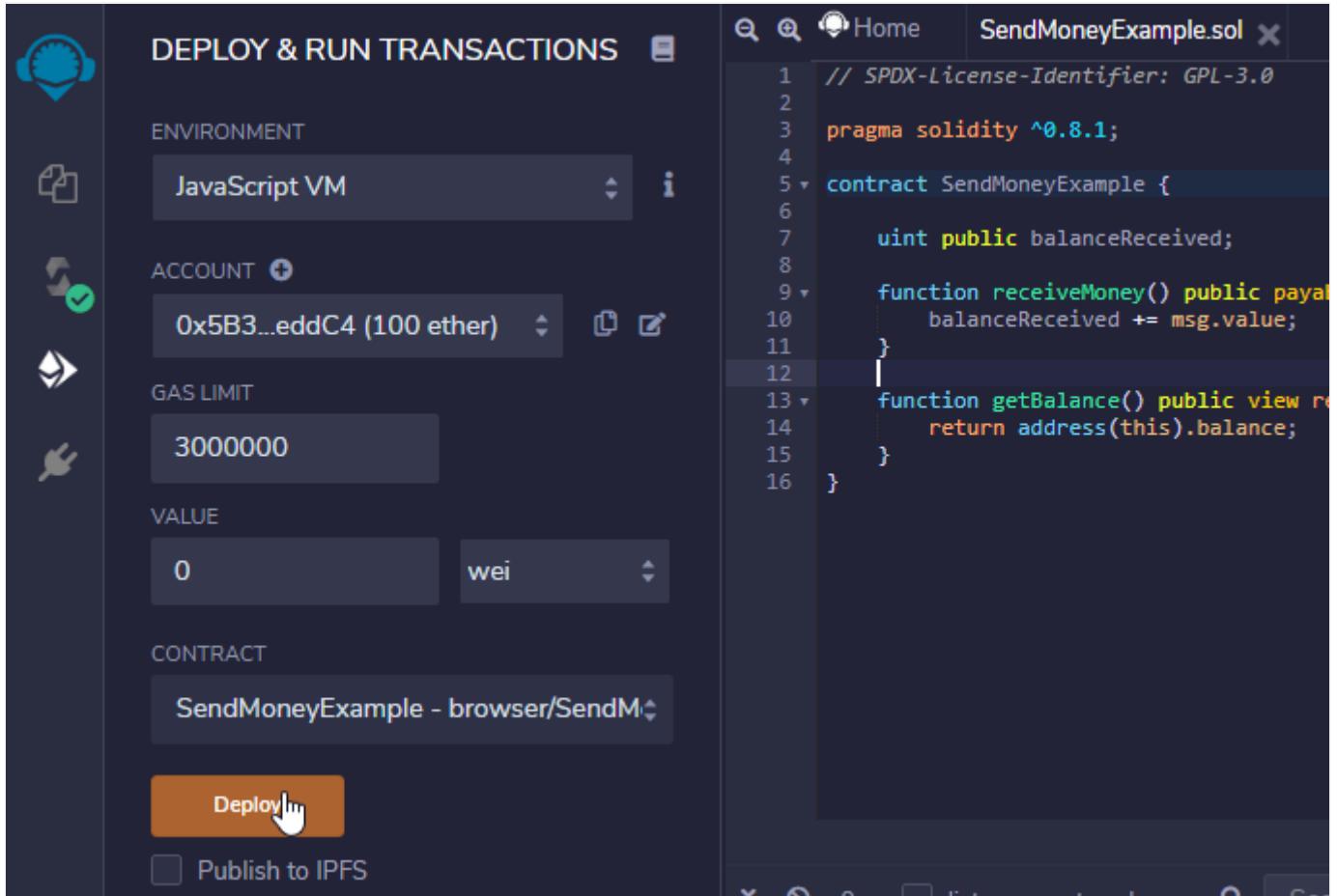
Last update: April 17, 2021

7.3 Deploy and Use the Smart Contract

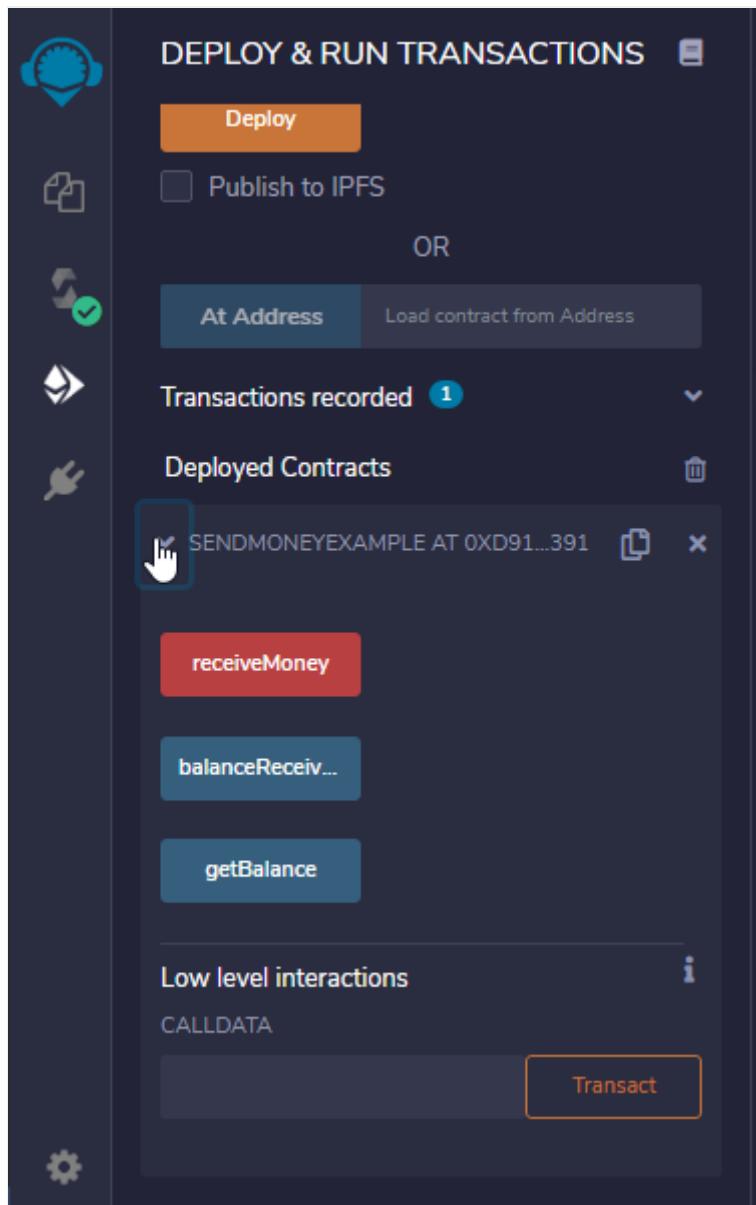
First thing is to deploy the Smart Contract. Then we'll see if we can deposit some Ether and get the balance from the Smart Contract.

7.3.1 Deploy the Smart Contract

Head over to the Deploy and Run Transactions Plugin and deploy the Smart Contract into the JavaScript VM:



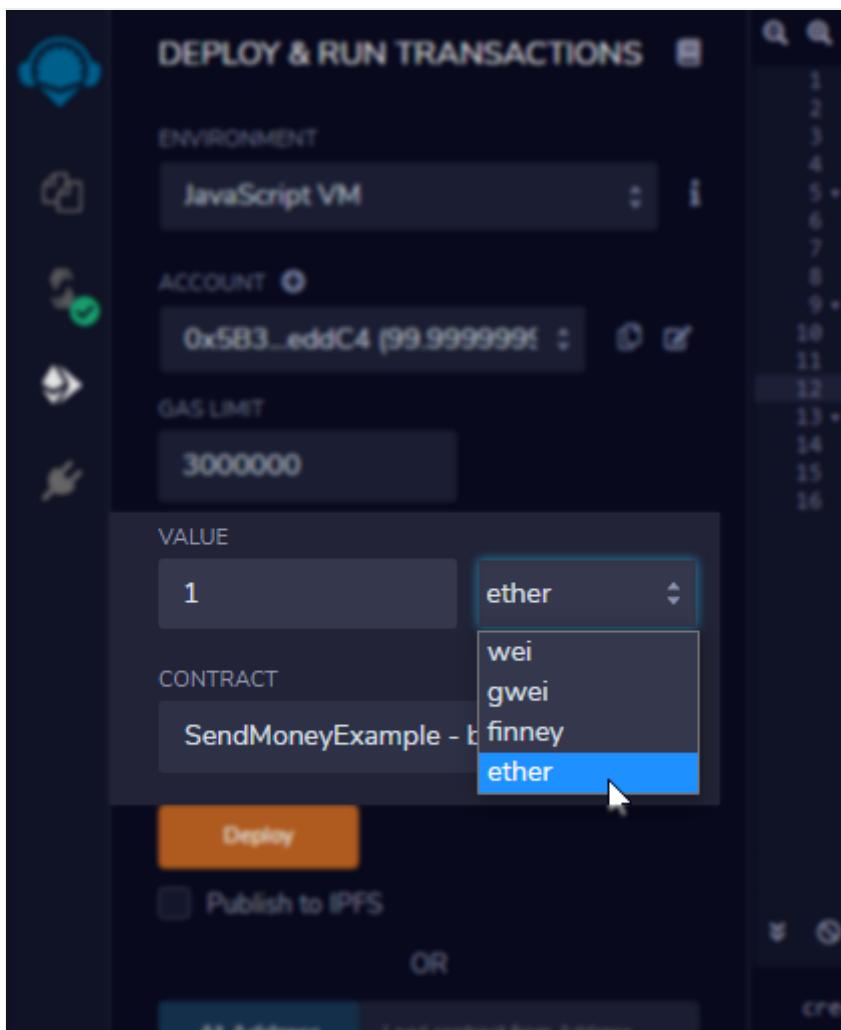
It should appear at the bottom of the Plugin - you probably need to expand the contract instance:



7.3.2 Send Ether To The Smart Contract

Now it is time to send some Ether to the Smart Contract!

Scroll up to the "value" field and put "1" into the value input field and select "ether" from the dropdown:



Then scroll down to the Smart Contract and hit the red "receiveMoney" button:

The screenshot shows the MetaMask extension's interface after deployment. On the left, there are icons for a blue headphones, a white square with a green checkmark, a white square with a red X, a white square with a green checkmark and a green arrow, a white square with a red X and a red arrow, and a white square with a green checkmark and a green arrow. The main area has the title "DEPLOY & RUN TRANSACTIONS". It shows a "Deploy" button, a checkbox for "Publish to IPFS", and a "Transactions recorded" section with a count of 2. Below that is a "Deployed Contracts" section showing "SENDMONEYEXAMPLE AT 0xD91...391". Under this, there are three buttons: a red "receiveMoney" button, a blue "balanceReceiv..." button, and a blue "getBalance" button. A red arrow points to the "receiveMoney" button. On the right, the code for the "SendMoneyExample" contract is displayed in a code editor:

```
// SPDX-License-Identifier: GPL-3.0
pragma solidity ^0.8.1;
contract SendMoneyExample {
    uint public balanceReceived;
    function receiveMoney() public payable {
        balanceReceived += msg.value;
    }
    function getBalance() public view returns(uint) {
        return address(this).balance;
    }
}
```

Below the code editor, there is a "ContractDefinition SendMoneyExample" section with "0 reference(s)". At the bottom, there is a "Transact" button and a "Debug" button. A message at the bottom indicates a transaction to "SendMoneyExample.receiveMoney" is pending.

Also observe the terminal , see that there was a new transaction sent to "the network" (although just a simulation in the browser, but it would be the same with a real blockchain).

7.3.3 Check the Balance

Now we sent 1 Ether, or 10^{18} Wei, to the Smart Contract. According to our code the variable `balanceReceived` and the function `getBalance()` should have the same value.

And, indeed, they do:

```

▼ SENDMONEYEXAMPLE AT 0xD91...391 ⌂ ✎

receiveMoney

balanceReceiv...
0: uint256: 10000000000000000000000000000000

getBalance
0: uint256: 10000000000000000000000000000000

```

But how can we get the Ether out again? Let's add a simple Withdrawal method.

Try it yourself first?

You want to try yourself first? Here are some hints:

We want a function that sends all Ether stored in the Smart Contract to the `msg.sender` (that's the address that calls the Smart Contract).

Since Solidity 0.8 that is non-payable, so you'd need to do something like `payable(msg.sender)` , which would give you an address that is capable of receiving Ether.

If you have no clue what the heck I'm talking about, don't worry - just head over to the next page.

Last update: April 17, 2021

7.4 Withdraw Ether From Smart Contract

So far we have sent Ether to our Smart Contract. But there is currently no way to get Ether back out again! So, what's next? Yes! A function to withdraw Ether would be good, ey!?

7.4.1 Add a Withdraw Function

Let's add the following function to the Smart Contract:

```
// SPDX-License-Identifier: GPL-3.0

pragma solidity ^0.8.1;

contract SendMoneyExample {
    uint public balanceReceived;

    function receiveMoney() public payable {
        balanceReceived += msg.value;
    }

    function getBalance() public view returns(uint) {
        return address(this).balance;
    }

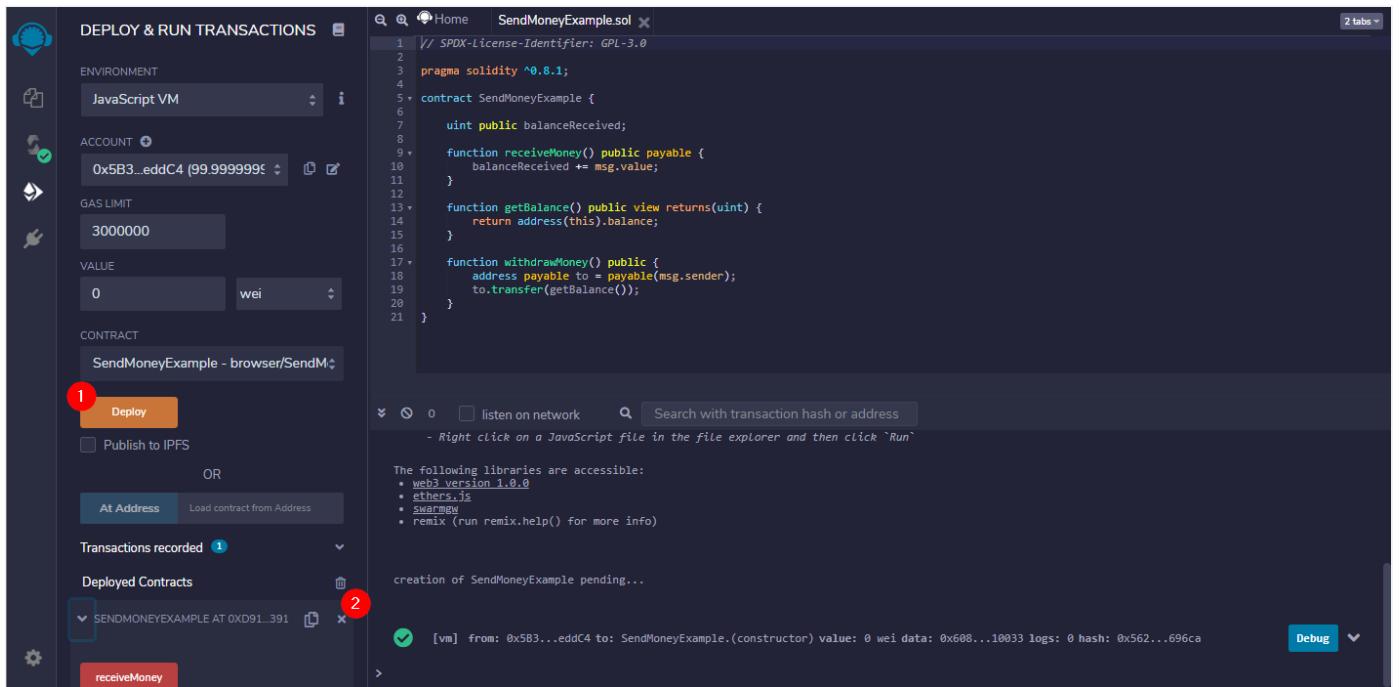
    function withdrawMoney() public {
        address payable to = payable(msg.sender);
        to.transfer(getBalance());
    }
}
```

This function will send all funds stored in the Smart Contract to the person who calls the "withdrawMoney()" function.

7.4.2 Deploy the new Smart Contract

Let's try this:

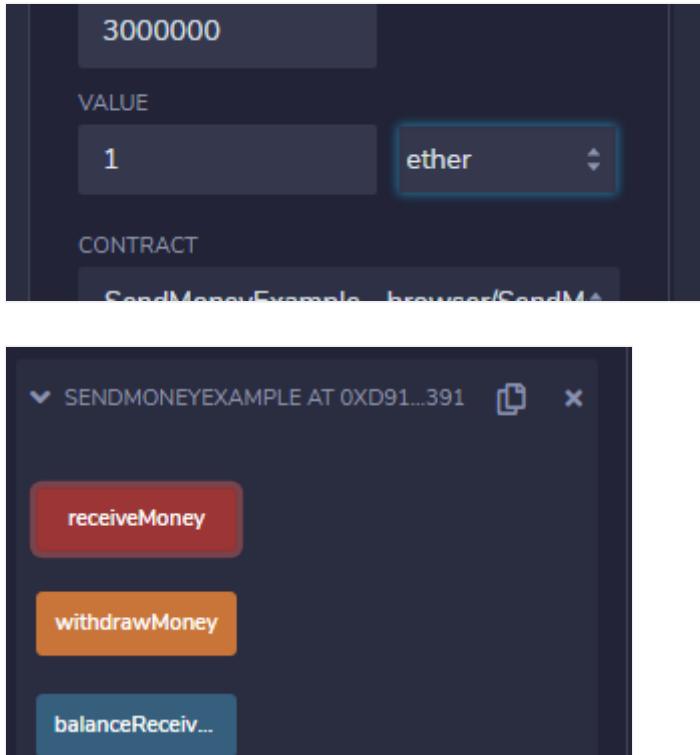
1. Deploy the new version and send again 1 Ether to the Smart Contract.
2. To avoid confusion I recommend you close the previous Instance, we won't need it anymore



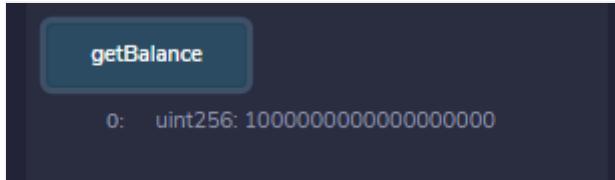
At the end you should end up with one active Instance of your Smart Contract.

The same procedure as before:

1. Put in "1 Ether" into the value input box
2. hit "receiveMoney" in your new contract Instance



Your balance should be 1 Ether again:



⚠ Not 1 Ether?

If your balance is 0, then double check the value field

If your balance is 2 Ether, then double check the contract Instance you are interacting with!

7.4.3 Withdraw Funds from the Smart Contract

Now it's time we use our new function! But to make things more exciting, we're going to withdraw to a different Account.

Select the second Account from the Accounts dropdown:

The screenshot shows the Truffle UI interface. On the left, there's a sidebar with icons for deploying, running, and monitoring. The main area has tabs for "DEPLOY & RUN TRANSACTIONS" and "SendMoneyExample.sol".

ENVIRONMENT: JavaScript VM

ACCOUNT: A dropdown menu lists several Ethereum addresses with their balances. One address, "0xAb8...35cb2 (100 ether)", is highlighted with a blue selection bar.

Smart Contract Code:

```
// SPDX-License-Identifier: GPL-3.0
pragma solidity ^0.8.1;

contract SendMoneyExample {
    uint public balanceReceived;

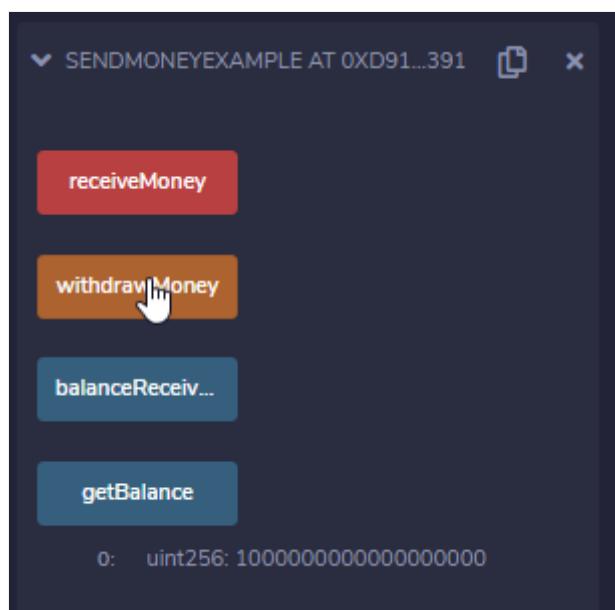
    function receiveMoney() public payable {
        balanceReceived += msg.value;
    }

    function getBalance() public view returns (uint) {
        return address(this).balance;
    }

    function withdrawMoney() public {
        address payable to = payable(msg.sender);
        to.transfer(getBalance());
    }
}
```

Logs: [vm] from: 0x5B3...eddC4 to: SendMoneyExample withdrawMoney logs: 0 hash: 0x0b0...227ae

Then hit the "withdrawMoney" button:



Observe the amount of Ether you have now in your Account:

The screenshot shows the Truffle UI interface. On the left, there's a sidebar with various icons. In the center, it says "DEPLOY & RUN TRANSACTIONS". Below that, "ENVIRONMENT" is set to "JavaScript VM". Under "ACCOUNT", there's a dropdown menu showing several accounts. One account, "0xAb8...35cb2", is highlighted with a blue background and shows two different balance values: "100.99999999999995 ether" and "100.999999999999970987 ether". The second value is also highlighted with a blue background and has a cursor icon over it, indicating it's being selected.

It's more than the previous 100 Ether! We got our 1 Ether through our Smart Contract into another Account! AWESOME!

Why not 101 Ether?

Are you wondering why you don't have 101 Ether in your Account? After all, you had 100 Ether before, and now you added 1 Ether, so, why is it not 101 Ether? Is the Math you learned in school worthless?

No, the Math you learned in School comes in handy actually.

What you can observe here is the concept of "Gas" on the Ethereum Blockchain. Every transaction on Ethereum costs a little bit. And it's not different here on a simulated chain. Same principles apply. How much is the Gas you paid, you're wondering? Well, you can open the transaction details and see for yourself. We're covering this - in depth - later on in the course. I also made a dedicated [video and blog post](#) about this if you want to deep dive right now.

While we can withdraw our funds now, the whole function itself is pretty useless, isn't it?! Anyone can withdraw funds to his Account. There are no fractions of the Amount - all in all, pretty insecure.

I still hope the concept is a bit clearer now!

Let's to another function, which allows us the send the full amount to a specific Address! It will still be insecure, but at least teaches a new concept - one at a time!

Try yourself first?

If you want to try yourself first, then do the following:

1. Create a new function that takes one address as argument
2. The full amount of Ether stored on the Smart Contract will be sent to this address

Alright, let's do this on the next page!

7.5 Withdraw To Specific Account

Previously we had our Smart Contract just blindly send the Ether to whoever called the Smart Contracts "withdrawMoney" function. Let's extend this a bit so that the Funds can be send to a specific Account.

It's still not secure, as basically anyone could interact with that function, but it's one step closer!

```
// SPDX-License-Identifier: GPL-3.0
pragma solidity ^0.8.1;

contract SendMoneyExample {
    uint public balanceReceived;

    function receiveMoney() public payable {
        balanceReceived += msg.value;
    }

    function getBalance() public view returns(uint) {
        return address(this).balance;
    }

    function withdrawMoney() public {
        address payable to = payable(msg.sender);
        to.transfer(getBalance());
    }

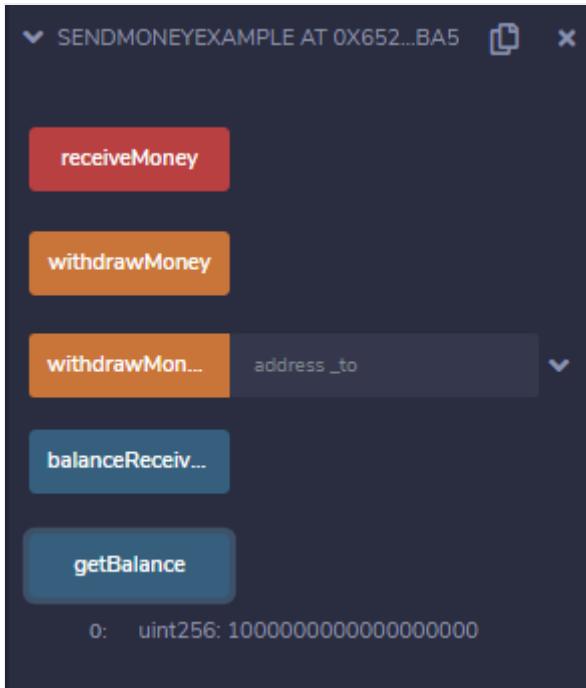
    function withdrawMoneyTo(address payable _to) public {
        _to.transfer(getBalance());
    }
}
```

As you can see, we can now specify an Address the money will be transferred to! Let's give this a try!

7.5.1 Redeploy our Smart Contract

Of course, we need to re-deploy our Smart Contract. There are no live-updates (yet?!). Same procedure as before:

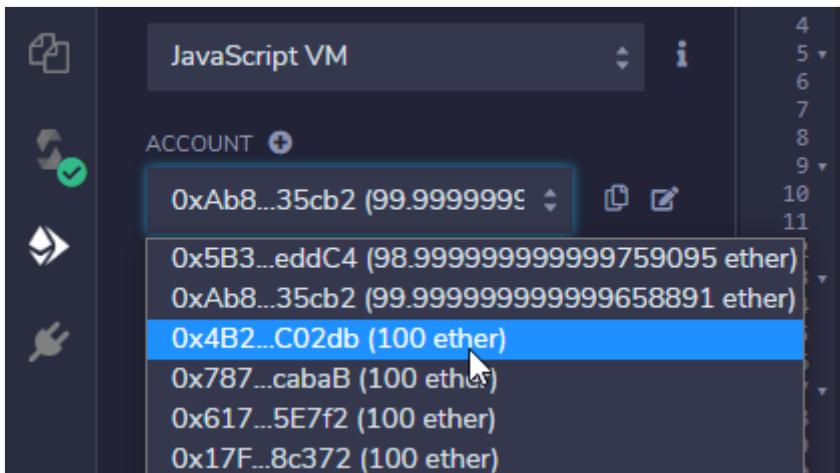
1. Deploy the Smart Contract
2. Close the old Instance
3. Send 1 Ether to the Smart Contract (don't forget the value input field!)
4. Make sure the Balance shows up correctly.



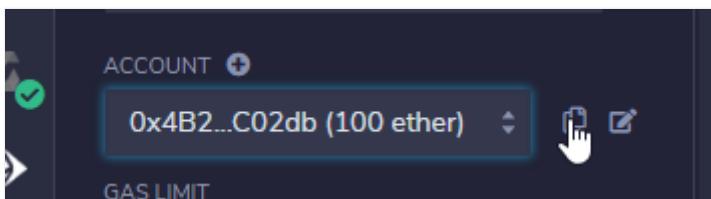
7.5.2 Test the "withdrawMoneyTo" function

Now it's time to test the new function. We're going to make things a bit more *exciting*: We're going to use our *first* account to send all funds to the *third* account. Why? Because we can . And because it's important to understand how gas fees are working - who is paying for the transaction.

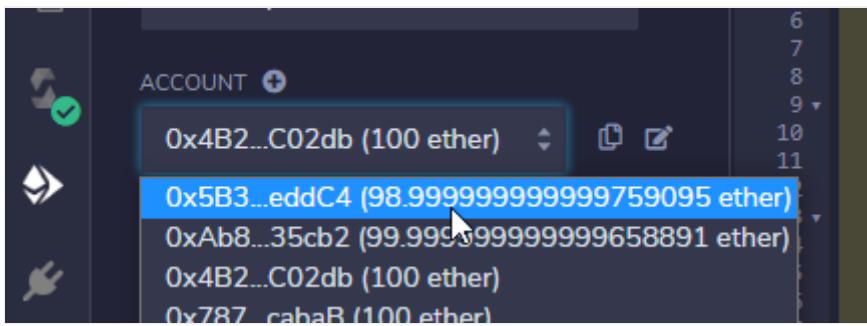
1. Select the *third* account from the dropdown



1. Hit the little "copy" icon:



1. Switch back to the first Account:



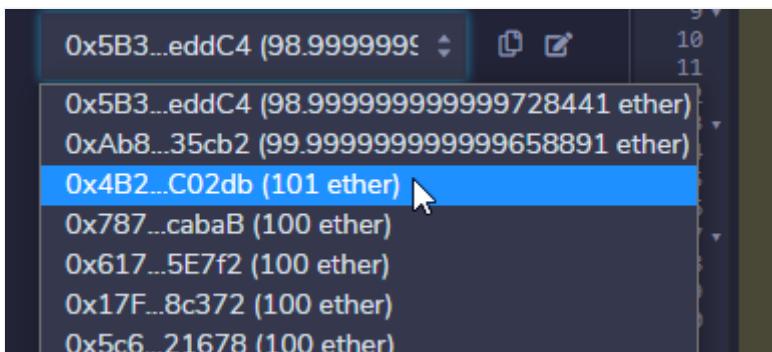
- Paste the Account you copied into the input field next to "withdrawMoneyTo":

The screenshot shows the Truffle UI interface for interacting with a smart contract. It includes a sidebar with buttons for 'receiveMoney', 'withdrawMoney', 'withdrawMon...', and 'balanceReceiv...'. Below these buttons is an input field containing the account address '0xE8f571ceCaE8A9e22...02db'. A tooltip message 'No function with that name?' is displayed above the input field, indicating that the function name does not exist.

i No function with that name?

If there's no function with that name, then you are most likely still interacting with the old Instance. Re-Deploy or even reload the whole page.

- Hit the "withdrawMoneyTo" button and see what happens! Wow, nothing happened. Well, only on the surface!
- Now open the Accounts dropdown. See the balance of your third Account? 101 Ether!!!



Why is there 101 Ether and not 100.999999999some? Because we sent a transaction from Account #1 to the Smart Contract, instructing the Smart Contract to send all funds stored on the Address of the Smart Contract to the third Account in your Account-List. Gas fees were paid by Account #1. Account #3 got 1 full Ether!

7.5.3 Time-Locked Withdrawals

That's all cool and fun so far, but let's go one step further and introduce `block.timestamp`. This global object contains the timestamp when a block was mined. It's not necessarily the *current timestamp* when the execution happens. It might be a few seconds off. But it's still enough to do some locking.

Next up I want to write a short Smart Contract that only allows withdrawal if the last deposit was more than 1 Minute ago.

☰ Try yourself first?

If you want to try yourself first, then we extend the Smart Contract and store the "block.timestamp" somewhere. Withdrawals can only happen if the "block.timestamp" during withdrawal is greater than the previously stored timestamp + 1 minutes (that is a globally available [constant in Solidity](#))

This is potentially not in the course videos. This exercise is optional.

Last update: April 17, 2021

7.6 Withdrawal Locking

Let's extend our Smart Contract to do some locking.

You will see that it is very easy to let our code take care of some specific logic to allow/disallow certain actions.

7.6.1 Extend the Smart Contract

What we need is to store the `block.timestamp` somewhere. There are several methods to go about this, I prefer to let the user know *how long* is it locked. So, instead of storing the deposit-timestamp, I will store the `lockedUntil` timestamp. Let's see what happens here:

```
// SPDX-License-Identifier: GPL-3.0

pragma solidity ^0.8.1;

contract SendMoneyExample {

    uint public balanceReceived;
    uint public lockedUntil;

    function receiveMoney() public payable {
        balanceReceived += msg.value;
        lockedUntil = block.timestamp + 1 minutes;
    }

    function getBalance() public view returns(uint) {
        return address(this).balance;
    }

    function withdrawMoney() public {
        if(lockedUntil < block.timestamp) {
            address payable to = payable(msg.sender);
            to.transfer(getBalance());
        }
    }

    function withdrawMoneyTo(address payable _to) public {
        if(lockedUntil < block.timestamp) {
            _to.transfer(getBalance());
        }
    }
}
```

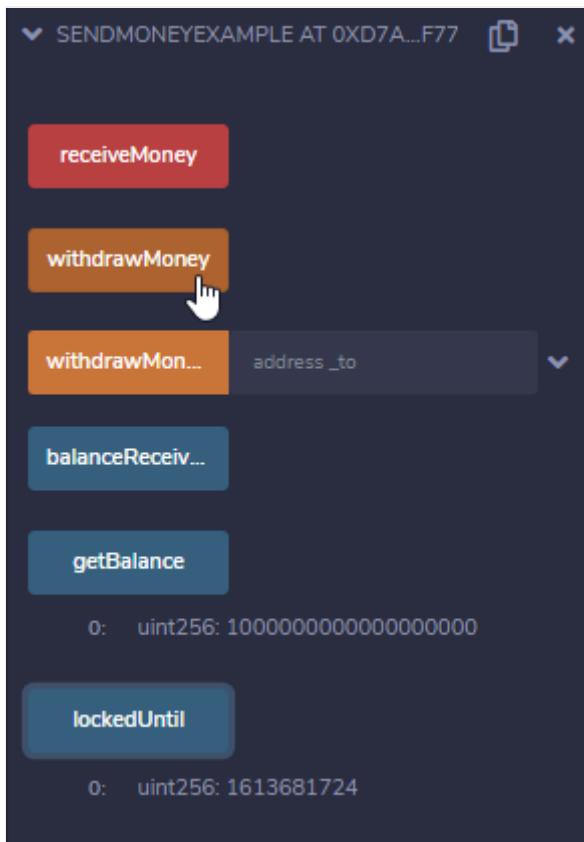
7.6.2 Deploy and Test the Smart Contract

Let's deploy the Smart Contract, same procedure as before:

1. Deploy a new Instance version
2. Remove the old Instance
3. Send 1 Ether to the Smart Contract (don't forget the value field) by clicking on "receiveMoney"
4. Check the Balance!

Alright, now what? Well, check the "lockedUntil" by clicking on the button. It will give you the timestamp until *nothing happens* when you click `withdrawMoney` or `withdrawMoneyTo`.

1. Click "withdrawMoney" - and nothing happens. The Balance stays the same until 1 Minute passed since you hit "receiveMoney".



Try it yourself!

But doing nothing, no feedback, that's not really user-friendly. You will learn later about [Exceptions: Require, Assert, Revert](#), how we can make this more user-friendly.

That's it for now, good job!

Last update: April 17, 2021

7.7 Congratulations

Congratulations, LAB is completed

From the Course "Ethereum Blockchain Developer -- Build Projects in Solidity"

FULL COURSE: <https://www.udemy.com/course/blockchain-developer/?referralCode=E8611DF99D7E491DFD96>

Last update: April 17, 2021

8. Smart Contract Life-Cycle

8.1 Lab: Starting, Pausing and Destroying/Stopping Smart Contracts

One things that is repeatedly asked: How can we stop Smart Contracts? What happens if we stop using Smart Contracts? How to destroy Smart Contracts? And many more questions are answered in these few exercises!

8.1.1 What You Know At The End Of The Lab

- 💡 How to destroy a Smart Contract for good using `selfdestruct`
- ❖ The Smart Contract life-cycle (can we actually *update*?)
- 💡 When we can interact with Smart Contracts and when not
- ✉ The Solidity Constructor

8.1.2 Prerequisites - You need:

1. Chrome or Firefox browser.
2. An Internet connection
3. Know how to use Remix a bit

8.1.3 Videos

💡 Full Video Walkthrough: <https://www.udemy.com/course/blockchain-developer/?referralCode=E8611DF99D7E491DFD96>

8.1.4 Get Started

💡 💡 💡 Let's get started!!! I know you can do it!

Last update: April 23, 2021

8.2 Sample Smart Contract

Before we begin, let's setup a sample Smart Contract. Just enough to get something working for us to have a simplistic example.

Create a new file in Remix. I've named mine "StartingStopping.sol", but obviously, you can name your file any way you'd like.

```
// SPDX-License-Identifier: GPL-3.0
pragma solidity ^0.8.1;

contract StartStopUpdateExample {
    function sendMoney() public payable {

    }

    function withdrawAllMoney(address payable _to) public {
        _to.transfer(address(this).balance);
    }
}
```

8.2.1 What does it do?

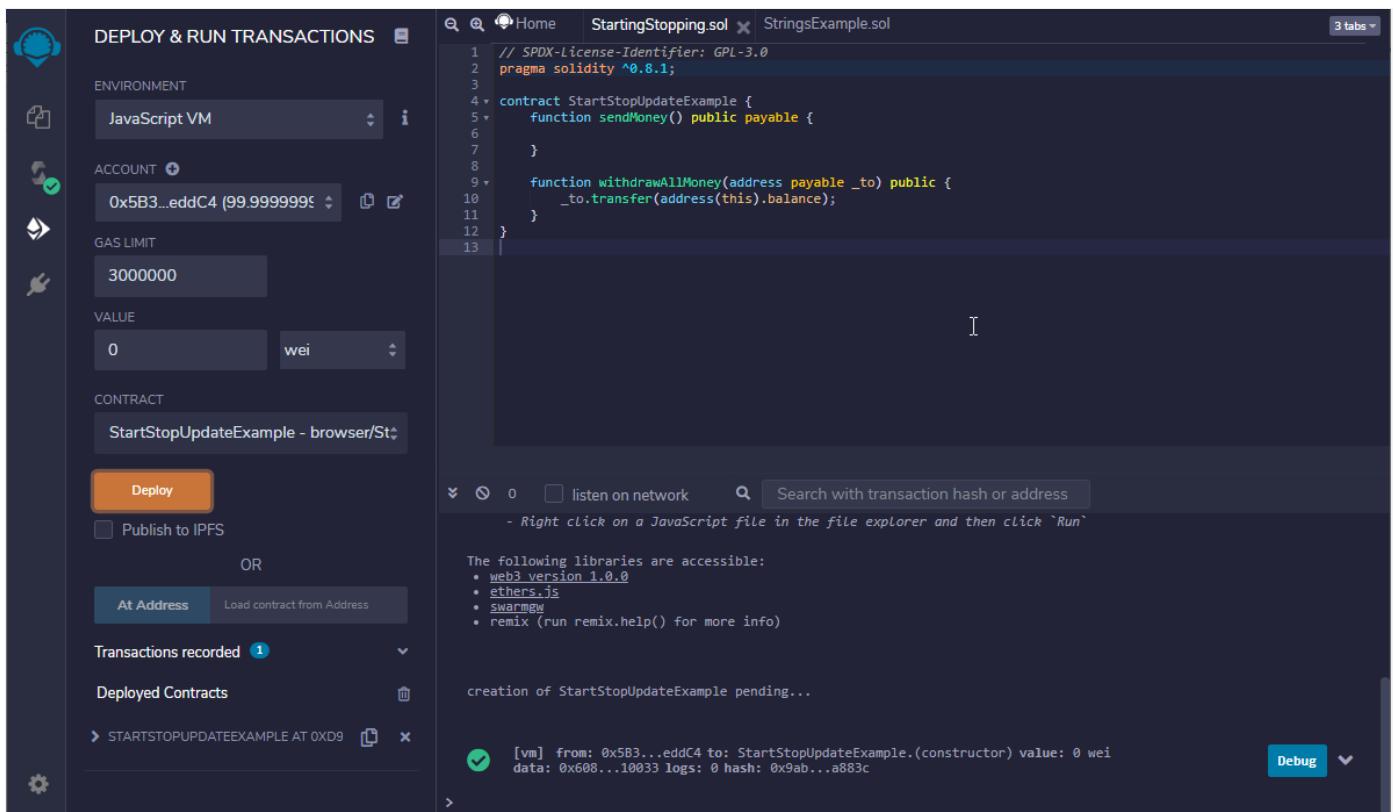
We have two functions:

`sendMoney()` : This function can receive Ether, it's a *payable* function.

`withdrawAllMoney(...)` : Very similar to our previous example, this function will automatically withdraw all available funds stored at the address of the Smart Contract to the variable in the `_to` function argument given address. What a sentence! In other words: It sends all Ether to the `_to` address.

8.2.2 Deploy the Smart Contract

Let's deploy the Smart Contract to the "JavaScript VM" in Remix. Head over to the "Deploy & Run Transactions" Plugin and hit Deploy:



Perfect! Let's try to send some Funds around!

8.2.3 Use the Smart Contract

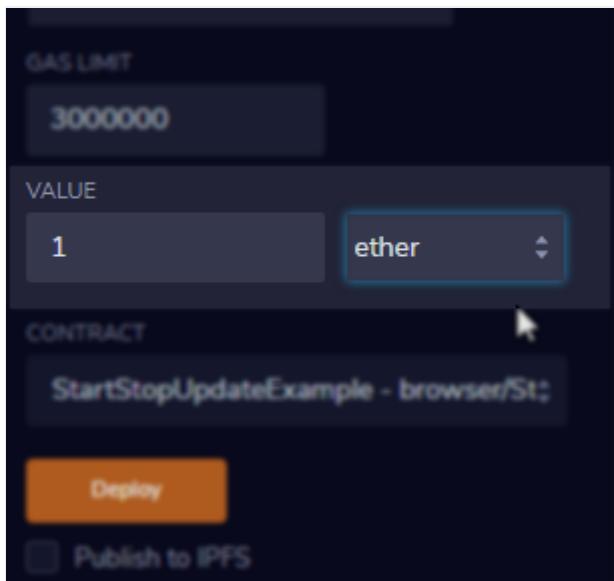
As before, we're going to:

1. Send Money to the Smart Contract using Account #1
2. Withdraw the Money using any other Account

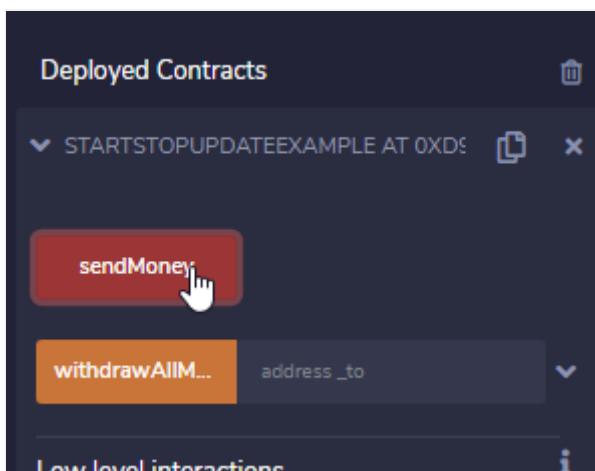
Already sounds scarily unsecure. If you come from traditional backend development, you should shiver now. But worry not, we'll get to safe heavens soon!

Alright, so, start by sending some funds to the Smart Contract...

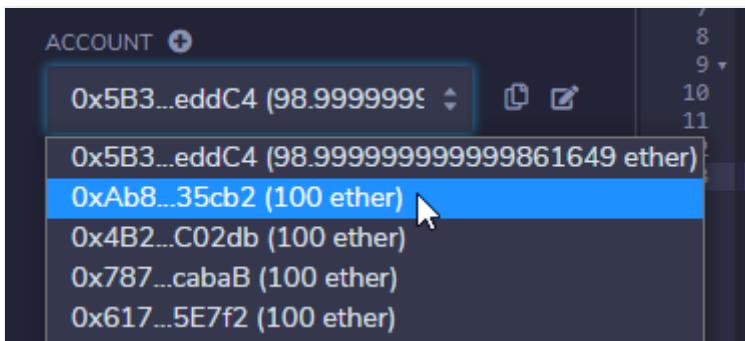
1. Enter 1 Ether into the value field:



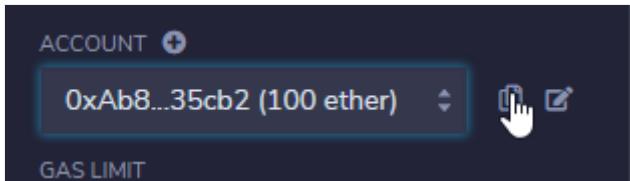
1. send it to the "sendMoney" function of your Smart Contract:



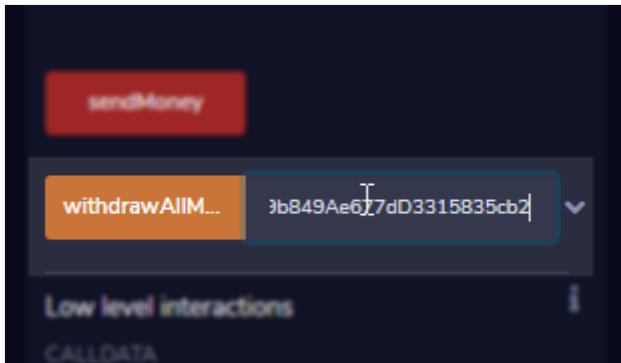
1. Select the second Account in the Accounts-Dropdown:



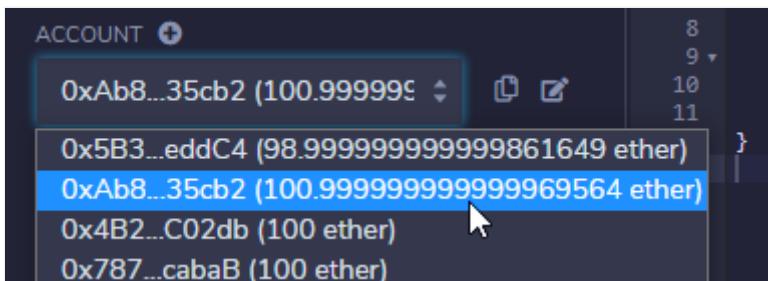
- ## 1. Copy the Address:



1. Paste the Address into the "withdrawAllMoney" input field:



1. Click the "withdrawAllMoney" button.
 2. Have a look if you have >100 eth in your Account #2 of the Accounts-Dropdown:



So, just to summarize how **insecure** that is:

1. Someone funded the Smart Contract
 2. But *everyone* can withdraw to any address of their choice?

That sounds pretty bad, right?

We can do better than that!!! In the next exercise we're going to restrict withdrawals to the person who *owns* the Smart Contract.

☰ Try yourself first?

Want to give it a try yourself? Great idea!

So, here's what you need:

1. A variable that stores the address of the person who deploys the Smart Contract.
2. a `constructor`. This gets called when the Smart Contract is deployed. It's named `constructor() { ... }`. Inside you set the address to the `msg.sender`.
3. a require in the `withdrawAllMoney` function. We're talking about Exceptions later in the course extensively, so don't worry too much about the internal workings. Make sure that the Address that calls the `withdrawAllMoney` function is the same as stored in the variable that is set by the constructor.

Alright, off to the solution: next page!

Last update: April 17, 2021

8.3 The Constructor

One thing we haven't really talked about yet is the constructor.

It's something you need to understand before we proceed!

The constructor is a *special* function. It is automatically called during Smart Contract deployment. And it can never be called again after that.

It also has a special name! It's simply called `constructor() { ... }`.

Let's see how that works to our advantage. Let's extend the Smart Contract we wrote before to make it a bit more secure.

8.3.1 Securing our Smart Contract using a simple Ownership-Model

We are going to set a storage variable to the address that deployed the Smart Contract. Then we will `require()` that the person interacting with `withdrawAllMoney` is the same as the one who deployed the Smart Contract.

Extend our Smart Contract:

```
// SPDX-License-Identifier: GPL-3.0
pragma solidity ^0.8.1;

contract StartStopUpdateExample {

    address public owner;

    constructor() {
        owner = msg.sender;
    }

    function sendMoney() public payable {

    }

    function withdrawAllMoney(address payable _to) public {
        require(owner == msg.sender, "You cannot withdraw.");
        _to.transfer(address(this).balance);
    }
}
```

So much new stuff in there! Let's dig through it line by line:

`constructor()` : is a *special* function that is called only once during contract deployment. It still has the same global objects available as in any other transaction. So in `msg.sender` is the address of the person who deployed the Smart Contract

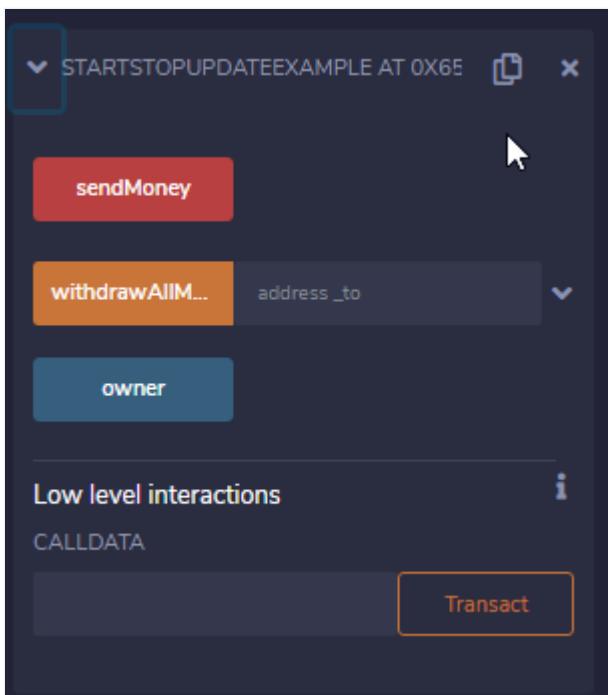
`require(owner == msg.sender, "You cannot withdraw.")` : That might be a bit early, but this is how you trigger Errors (or throw Exceptions) in Solidity. If the require evaluates to false it will stop the transaction, roll-back any changes made so far and emit the error message as String.

Everyone can send Ether to our Smart Contract. But only the person who deployed the Smart Contract can withdraw. Secure and Smart - Let's try this!

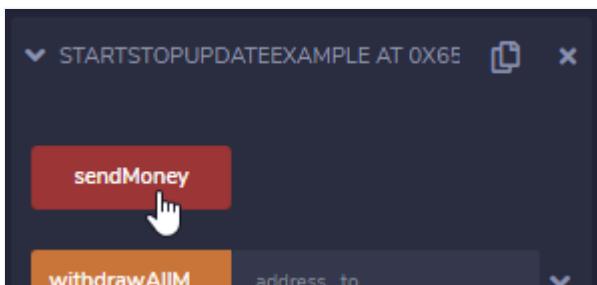
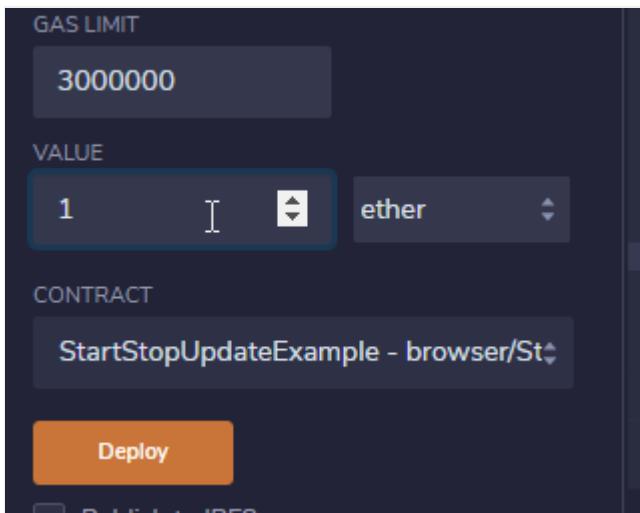
8.3.2 Testing our new Smart Contract

We're going to do the following:

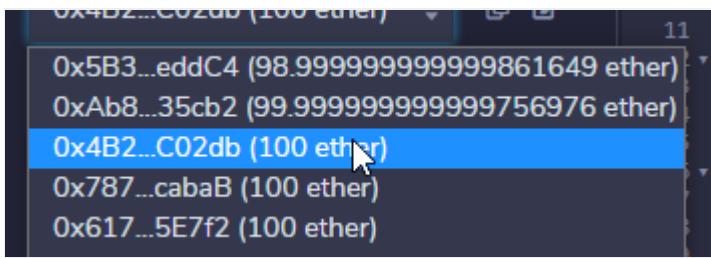
1. Deploy the new Smart Contract



2. Send Ether to the Smart Contract



3. Try to use another Account to withdraw

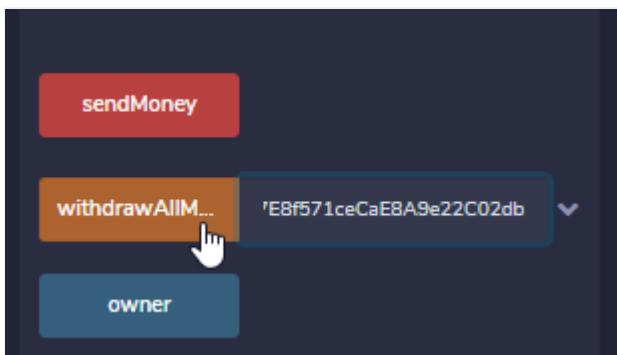


ACCOUNT +

0x4B2...C02db (100 ether)

GAS LIMIT

3000000



Note: Don't switch back, use the other Account to call withdrawAllMoney

4. Observe the Error Message

sendMoney

withdrawAllMoney 0xE8f571ceCaE8A9e22C02db

owner

Low level interactions

CALLDATA

Transact

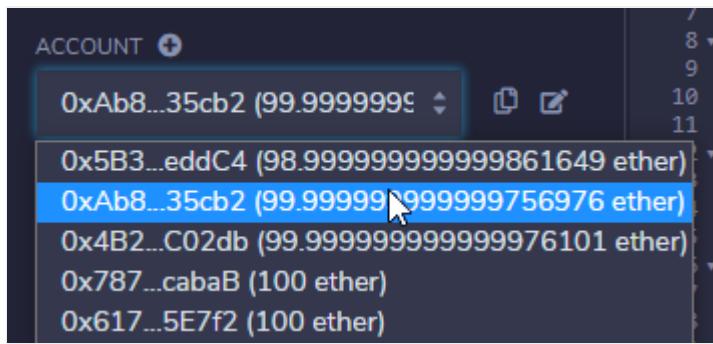
[vm] from: 0xAb8...35cb2 to: StartStopUpdateExample.sendMoney() 0x652...bA595 value: 10000000000000000000 wei data: 0x00...00 logs: 0 hash: 0xff8...468af

transact to StartStopUpdateExample.withdrawAllMoney pending ...

[vm] from: 0x4B2...C02db to: StartStopUpdateExample.withdrawAllMoney(address) 0x652...bA595 value: 0 wei data: 0x0ad...c02db logs: 0 hash: 0xf24...5d21a

transact to StartStopUpdateExample.withdrawAllMoney errored: VM error: revert. revert The transaction has been reverted to the initial state. Reason provided by the contract: "You cannot withdraw.". Debug the transaction to get more information.

5. Switch back to the original Account



Note: I used the second account in my account-dropdown to deploy the Smart Contract, so I am switching back to this one

6. Withdraw and see it works

The screenshot shows the Truffle UI interface. On the left, under 'Low level interactions', there is a red circle labeled '1' over the 'withdrawAllMoney' button. On the right, the transaction details are shown: step 1 shows the transaction being sent from the owner account to the contract, and step 2 shows the transaction pending with a note that it reverted due to the owner access rule.

Amazing, right! A very simplistic access rule that denies access to anyone except the one who deployed the Smart Contract.

Of course, you can spin that further. You can create a whole Access Model around this. [OpenZeppelin did this in their Ownable Models](#)

So, what's next? Let's see if we can pause our Smart Contract!

Can you think of a solution?

The Ethereum Virtual Machine has no functionality to pause Smart Contracts on a protocol-level. So, we need to think of a solution "in code".

Can you think of something? Maybe a boolean that pauses any deposits and withdrawals when it's true?

Give it a try!

Alright, off to Pausing Smart Contracts...

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8.4 Pausing Smart Contract

A Smart Contract cannot be "paused" on a protocol-level on the Ethereum Blockchain. But we can add some logic "in code" to pause it.

Let's try this!

8.4.1 Smart Contract Pausing Functionality

Let us update our Smart Contract and add a simple Boolean variable to see if the functionality is paused or not.

```
// SPDX-License-Identifier: GPL-3.0
pragma solidity ^0.8.1;

contract StartStopUpdateExample {
    address public owner;
    bool public paused;

    constructor() {
        owner = msg.sender;
    }

    function sendMoney() public payable {
    }

    function setPaused(bool _paused) public {
        require(msg.sender == owner, "You are not the owner");
        paused = _paused;
    }

    function withdrawAllMoney(address payable _to) public {
        require(owner == msg.sender, "You cannot withdraw.");
        require(paused == false, "Contract Paused");
        _to.transfer(address(this).balance);
    }
}
```

Content wise, there isn't much new. We have a function that can update the `paused` variable. That function can only be called by the owner. And `withdrawAllMoney` can only be called if the contract is not paused.

Of course, this doesn't make *much* sense, other than being some sort of academic example. BUT! It makes sense if you think of more complex functionality, like a Token Sale that can be paused. If you have `require(paused == false)` in all your customer-facing functions, then you can easily pause a Smart Contract.

8.4.2 Try the Smart Contract

Of course we're also trying if our functionality works!

1. Deploy a new Instance
2. Update `paused` to true
3. Try to `withdrawAllMoney` with any of your accounts, it won't work!

The screenshot shows the Truffle UI interface for a deployed Solidity contract named `StartStopUpdateExample`. The left sidebar displays the deployed contracts, and the main area shows the contract's source code, state variables, and transaction history.

Contract Source Code:

```
14
15
16
17 v     function setPaused(bool _paused) public {
18     require(msg.sender == owner, "You are not the owner");
19     paused = _paused;
20 }
21
22 v     function withdrawAllMoney(address payable _to) public {
23     require(owner == msg.sender, "You cannot withdraw.");
24     require(paused == false, "Contract Paused");
25     emit Transfer(_to, address(this), balance);
26 }
```

State Variables:

- `sendMoney`: Red button
- `setPaused`: Orange button, value: true
- `withdrawAllMoney`: Gray button, value: 0xAb8483F84d9C6d1Ef9b
- `owner`: Teal button
- `paused`: Blue button

Low level interactions:

- `CALLDATA`
- `Transact` button

Transaction History:

- A transaction to `withdrawAllMoney` failed with the error: `Error encoding arguments: Error: invalid address (argument="address", value="", code=INVALID_ARGUMENT, version=address/5.0.5) (argument=null, value="", code=INVALID_ARGUMENT, version=abi/5.0.7)`.
- A pending transaction to `withdrawAllMoney`.
- A revert message: `[vm] from: 0xAb8...35cb2 to: StartStopUpdateExample.withdrawAllMoney(address) 0xA83...5B10A value: 0 wei data: 0x0ad...35cb2 logs: 0 hash: 0xd57...632e9`.
- A revert message: `transact to StartStopUpdateExample.withdrawAllMoney errored: VM error: revert. revert The transaction has been reverted to the initial state. Reason provided by the contract: "Contract Paused". Debug the transaction to get more information.`.

In the next and last exercise for this Lab I want to destroy our Smart Contract.

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8.5 Destroy Smart Contracts using `selfdestruct`

We can not erase information from the Blockchain, but we can update the *current state* so that you can't interact with an address anymore *going forward*. Everyone can always go back in time and check what was the value on day X, but, once `selfdestruct` is called, you can't interact with a Smart Contract anymore.

Let's try this!

Potential Removal of SELFDESTRUCT

There might be an [Ethereum Protocol update](#) coming ahead which removes the SELFDESTRUCT functionality all-together. As writing this, it's not out there (yet), but might be soon, so take the following lab with this in mind.

8.5.1 Update our Smart Contract

Let's update our Smart Contract and add a `selfdestruct` function. This function takes one argument, an address. When `selfdestruct` is called, all remaining funds on the address of the Smart Contract are transferred to that address.

```
contract StartStopUpdateExample {
    address public owner;
    bool public paused;

    constructor() {
        owner = msg.sender;
    }

    function sendMoney() public payable {

    }

    function setPaused(bool _paused) public {
        require(msg.sender == owner, "You are not the owner");
        paused = _paused;
    }

    function withdrawAllMoney(address payable _to) public {
        require(owner == msg.sender, "You cannot withdraw.");
        require(paused == false, "Contract Paused");
        _to.transfer(address(this).balance);
    }

    function destroySmartContract(address payable _to) public {
        require(msg.sender == owner, "You are not the owner");
        selfdestruct(_to);
    }
}
```

On the surface it looks very similar to our `withdrawAllMoney` function, with one major difference: Once you call `destroySmartContract`, the address of the Smart Contract will contain no more code. You can still send transactions to the address and transfer Ether there, but there won't be any code that could send you the Ether back.

Let's try this!

8.5.2 Try our new Smart Contract

1. Deploy a new Instance
2. Send some Ether there by interacting with `sendMoney`
3. Try to call `destroySmartContract` and provide your own Account, so Ether are sent back.

A Transaction should go through smoothly!

```

16     require(msg.sender == owner, "You are not the owner");
17     paused = _paused;
18 }
19
20
21
22 function withdrawAllMoney(address payable _to) public {
23     require(owner == msg.sender, "You cannot withdraw.");
24     require(paused == false, "Contract Paused");
25     _to.transfer(address(this).balance);
26 }
27
28 function destroySmartContract(address payable _to) public {
29     require(msg.sender == owner, "You are not the owner");
30     selfdestruct(_to);
31 }
32 }
33

```

Low level interactions

CALLDATA

Transact

data: 0x608...10033 logs: 0 hash: 0xeb1...391c4

transact to StartStopUpdateExample.sendMoney pending ...

[vm] from: 0xAB8...35cb2 to: StartStopUpdateExample.sendMoney() 0x843...40406
value: 1000000000000000000 wei data: 0xcb...dbf5a logs: 0 hash: 0xb29...c8b82

transact to StartStopUpdateExample.destroySmartContract pending ...

[vm] from: 0xAB8...35cb2 to: StartStopUpdateExample.destroySmartContract(address) 0x843...40406
value: 0 wei data: 0x39d...35cb2 logs: 0 hash: 0x494...5de08

8.5.3 Interacting with Destroyed Smart Contracts

Now comes the part that is puzzling a lot of newcomers to Ethereum.

What happens if you try to send Ether again using the "sendMoney" function? Will there be an error or not?

There won't be an error! Internally you are sending Ether to an address. Nothing more.

Try it! Use the same contract instance, don't redeploy. Just enter 1 Ether and hit the `sendMoney` button.

The screenshot shows the Truffle UI interface. At the top, there's a 'VALUE' input field with the value '1' highlighted by a red circle with the number '1'. To the right of the input field is a dropdown menu set to 'ether'. Below this is a 'CONTRACT' dropdown menu containing the option 'StartStopUpdateExample - browser/St...'. A cursor arrow is positioned over the dropdown menu. Underneath the dropdown is an orange 'Deploy' button. To the left of the 'Deploy' button is a checkbox labeled 'Publish to IPFS'. Below these options is a section labeled 'OR' with two buttons: 'At Address' (selected) and 'Load contract from Address'. The main content area displays a list of contracts. The first contract listed is 'Transactions recorded' with 13 transactions, indicated by a red circle with the number '13'. Below it is a section titled 'Deployed Contracts' with a trash can icon. The first item in this section is 'STARTSTOPUPDATEEXAMPLE AT 0x84' with a copy icon and a delete icon. Below this item is a button labeled 'destroySmart...' and a text field containing the address '0xAb8483F64d9C6d1EcF9b'. At the bottom of the screen is a red button labeled 'sendMoney' with a red circle containing the number '2'.

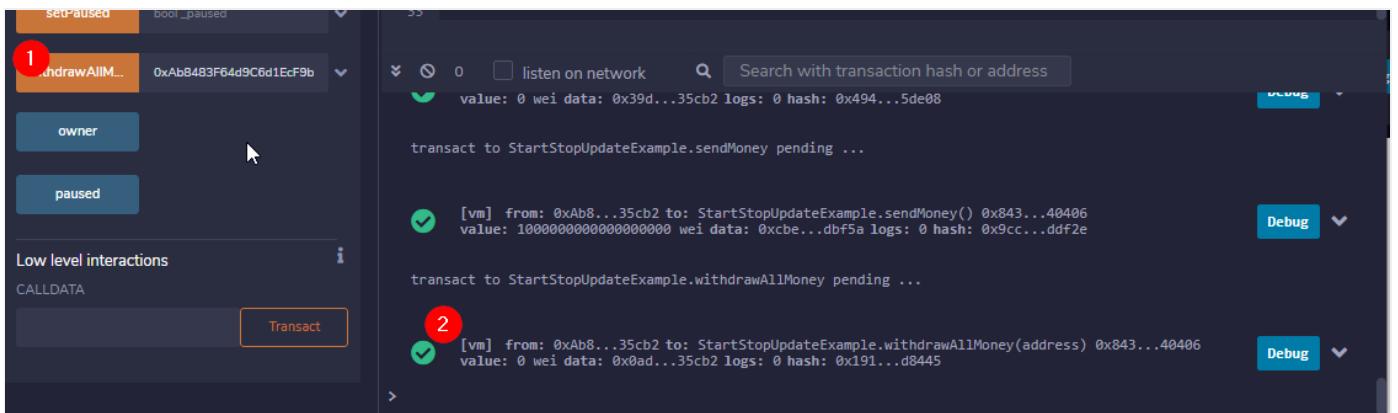
and see the log console:

The screenshot shows the Truffle UI interface with the following details:

- Contract:** STARTSTOPUPDATEEXAMPLE AT 0x84
- Transactions:**
 - destroySmart...**: 0xAaB4B3F84a9C8d11EcF9b
 - sendMoney**
 - setPaused**: bool _paused
 - withdrawAllH...**: address _to
- Logs:**
 - [vm] value: 10000000000000000000 wei data: 0xcbef...dbf5a logs: 0 hash: 0xb29...c8b82**
 - transact to StartStopUpdateExample.destroySmartContract pending ...**
 - [vm] from: 0xAb8...35cb2 to: StartStopUpdateExample.destroySmartContract(address) 0x843...40406 value: 0 wei data: 0x39d...35cb2 logs: 0 hash: 0x494...5de98**
 - transact to StartStopUpdateExample.sendMoney pending ...**
 - [vm] from: 0xAb8...35cb2 to: StartStopUpdateExample.sendMoney() 0x843...40406 value: 10000000000000000000 wei data: 0xcbef...dbf5a logs: 0 hash: 0x9cc...ddf2e**

Works perfectly fine!

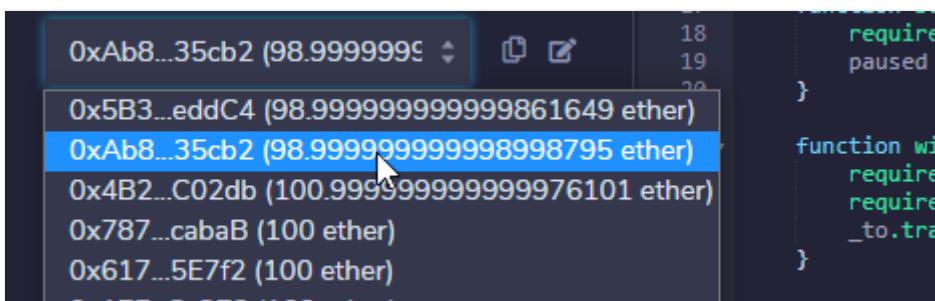
But try to get your Ether out again!



Also this transaction goes through smoothly! But wait!

Check your Balance!

It isn't updated...



You locked one Ether at the Smart Contract address for good. There's no more code running on that Address that could send you the Funds back.

So, be careful with the Contract life-cycle!

8.5.4 Re-Deployment of Smart Contracts to the Same Address

Once scenario, which is not in the course videos, is in-place upgrades. Since the **CREATE2** Op-Code was introduced, you can pre-compute a contract address.

Without CREATE2, a contract gets deployed to an address that is computed based on *your address + your nonce*. That way it was guaranteed that a Smart Contract cannot be re-deployed to the same address.

With the CREATE2 op-code you can *instruct* the EVM to place your Smart Contract on a specific address. Then you could call `selfdestruct()`, thus remove the source code. Then re-deploy a different Smart Contract to the same address.

This comes with several implications: when you see that a Smart Contract includes a `selfdestruct()` then simply be careful. Those implications will become more and more apparent as you progress through the course, especially when we talk about the ERC20 Token allowance. At this stage it is too early to discuss them all, but if you want to read on about it, checkout [this article](#).

Alright, that's enough of a detour into advanced topics.

Last update: April 17, 2021

8.6 Congratulations

Congratulations, LAB is completed

From the Course "Ethereum Blockchain Developer -- Build Projects in Solidity"

FULL COURSE: <https://www.udemy.com/course/blockchain-developer/?referralCode=E8611DF99D7E491DFD96>

Last update: April 17, 2021

9. Simple Mappings Introduction

9.1 Lab: Mappings and Structs

In this lab you are going learn how mappings work.

Mappings are a little bit like arrays or hash maps. You can store key/value pairs.

9.1.1 What You Know At The End Of The Lab

 You'll know how mappings work.

 You'll learn a new way to create account-white lists.

9.1.2 Prerequisites - You need:

1. Chrome or Firefox browser.
2. An Internet connection
3. About 30 Minutes of your precious time 

9.1.3 Videos

 Full Video Walkthrough: <https://www.udemy.com/course/blockchain-developer/?referralCode=E8611DF99D7E491DFD96>

9.1.4 Get Started

 Let's get started!

Last update: April 23, 2021

9.2 Smart Contract

We have to start with *something*, so we're going to start with the simplest of all examples possible. A simple mapping.

Create a new file in Remix and put in the following content:

```
// SPDX-License-Identifier: MIT

pragma solidity ^0.8.4;

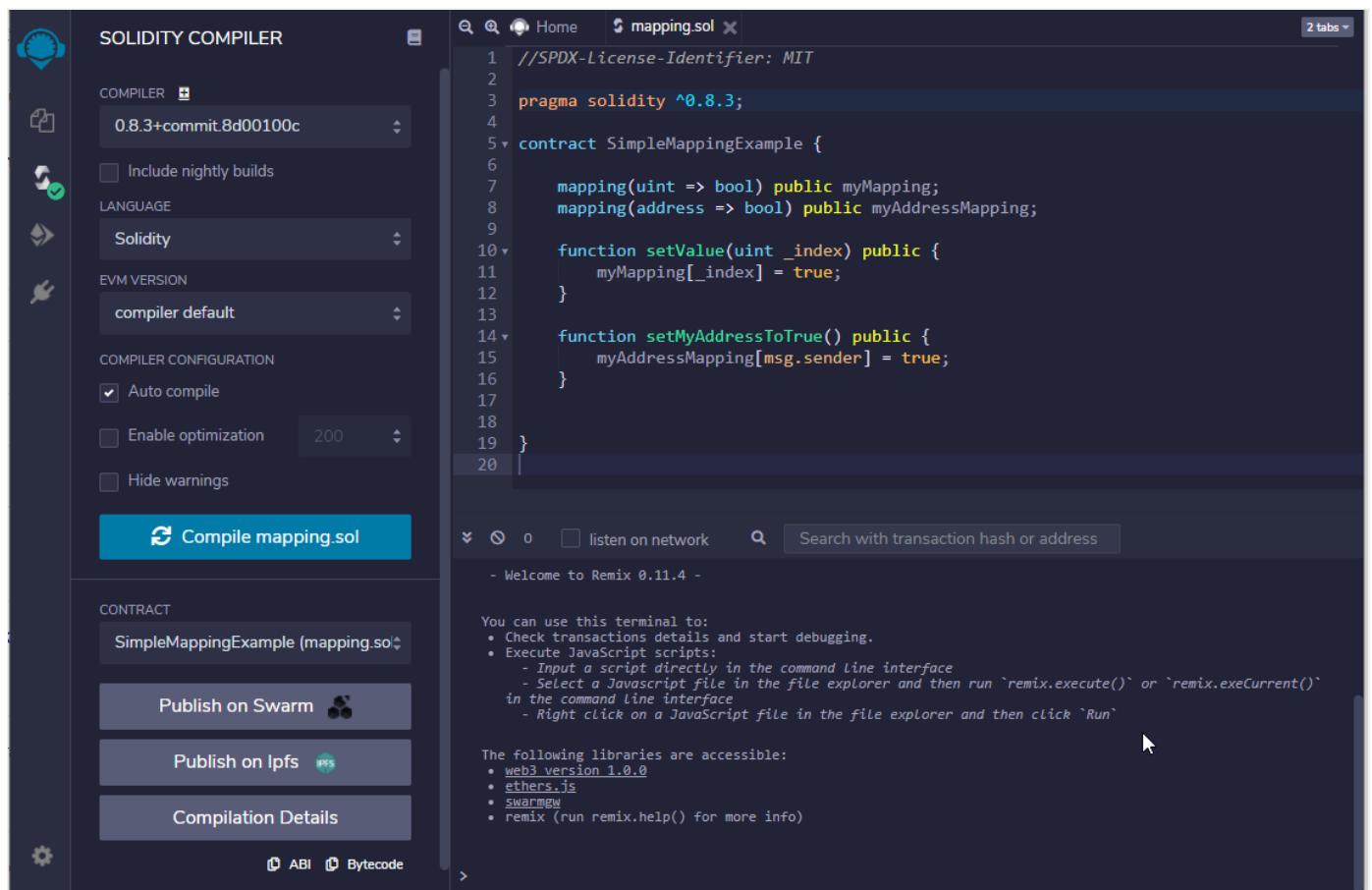
contract SimpleMappingExample {

    mapping(uint => bool) public myMapping;
    mapping(address => bool) public myAddressMapping;

    function setValue(uint _index) public {
        myMapping[_index] = true;
    }

    function setMyAddressToTrue() public {
        myAddressMapping[msg.sender] = true;
    }

}
```



9.2.1 Run the Smart Contract

Mappings are an interesting datatype in Solidity. They are accessed like arrays, but they have one major advantage: All key/value pairs are initialized with their default value.

If you have a look at the example Smart Contract, you'll see that we have two mappings.

One, that maps uint256 to booleans, that's called `myMapping`. Another one that maps addresses to booleans, that we called `myAddressMapping`.

We can access a mapping with the brackets `[]`. If we want to access the key "123" in our `myMapping`, then we'd simply write `myMapping[123]`.

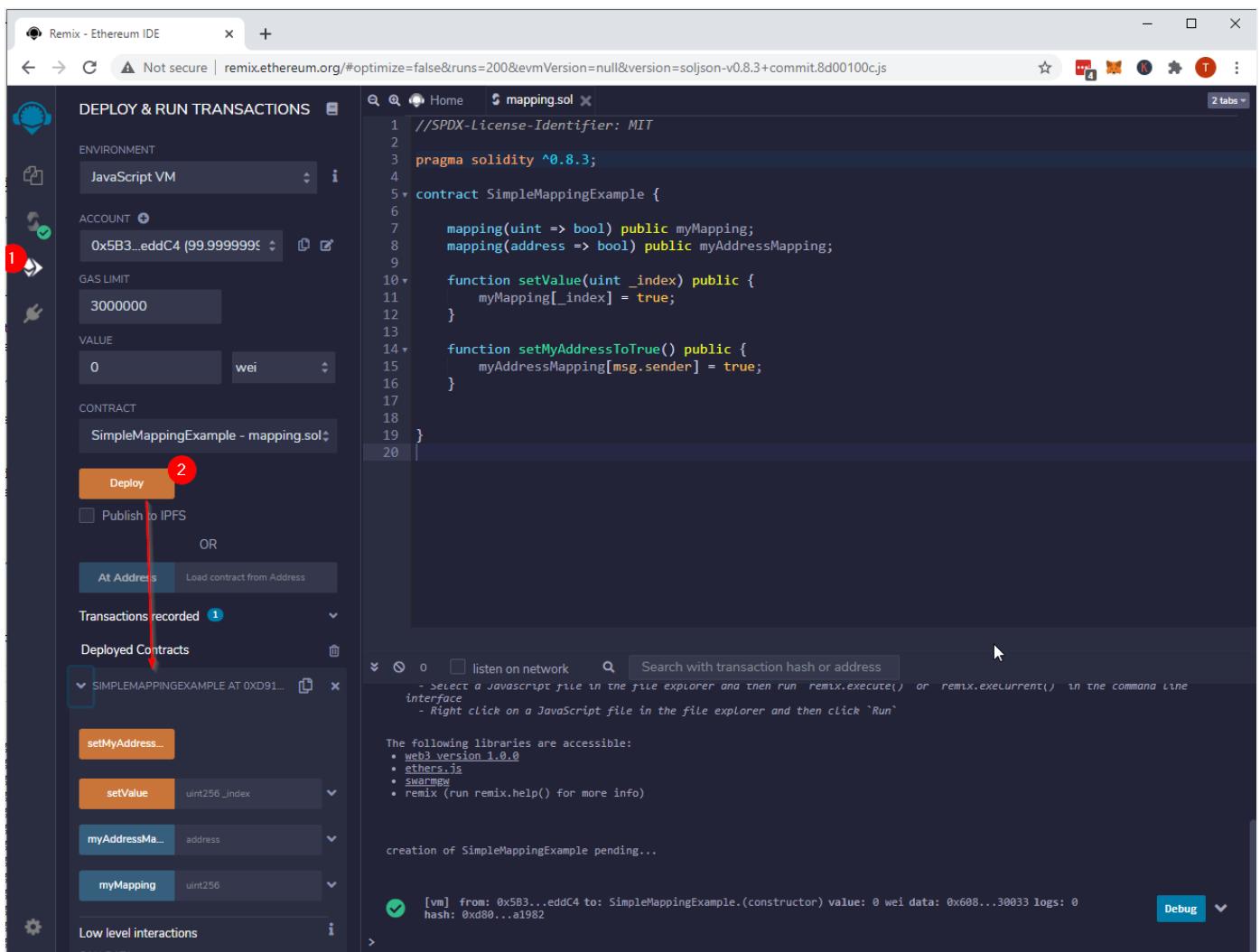
Our mappings here are public, so Solidity will automatically generate a getter-function for us. That means, if we deploy the Smart Contract, we will automatically have a function that looks technically like this:

```
function myMapping(uint index) returns (bool) {
    return myMapping[index];
}
```

We don't need to explicitly write the function. Also not for `myAddressMapping`. Since both are public variables, Solidity will add these auto_magic_ally.

Let's run the Smart Contract and see what happens!

Head over to the "Deploy and Run Transactions" Plugin and run the Smart Contract:



Perfect, let's read and write to the `uint => bool` mapping `myMapping` first.

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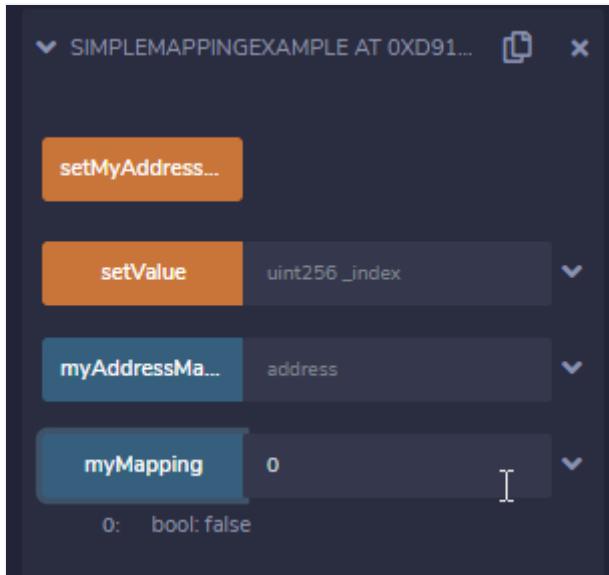
9.3 Access Mapping Variables

Mappings are accessed like arrays, but there are no index-out-of-bounds-exceptions. If you don't know what that means, don't worry, it was a joke for Java Developers.

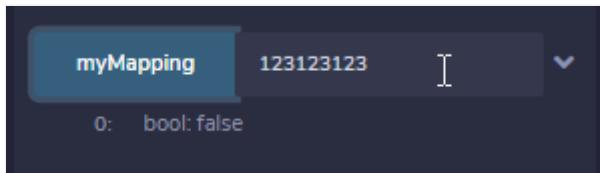
All possible key/value pairs are already initialized. You can simply access any key and get back "false", since that's the default boolean value.

Give it a try?

Enter "0" next to "myMapping" and hit the button. It will return false.



The same happens with "1", "2", or "123123123123123". Any index will return false, because we didn't write a value there yet.

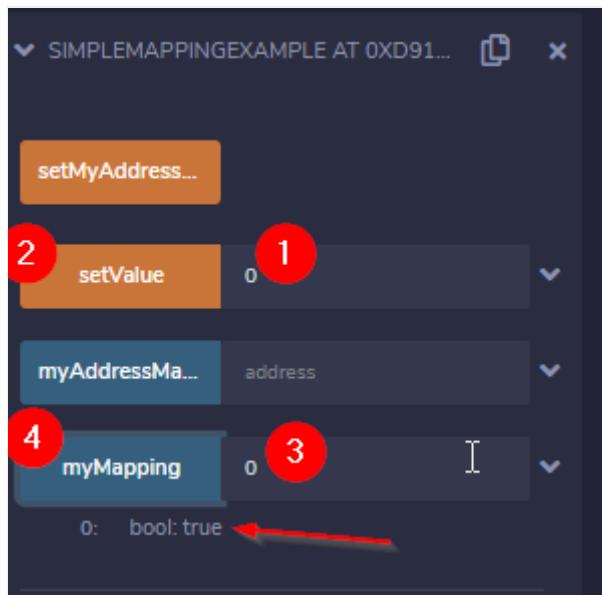


9.3.1 Write to a Mapping

If you have a look at our simple function `setValue(uint _index)`, then you will see you will write "true" to an `_index`. So, if the `_index = 0`, then `myMapping[0]` will be set to true. Again, no need to initialize anything here, it will just assign the value.

Give it a try!

1. Set the value of `myMapping[0]` to true, by entering "0" next to the "setValue" button
2. Hit the `setValue` button
3. retrieve the `myMapping[0]` value again, by entering "0" next to the "myMapping" button
4. It should return true



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9.4 Address Keys in Mappings

If you come from the traditional Development world, then integer keys are nothing particularly interesting probably. It's very much like using an array or a hash map or something similar.

Internal Storage of Mappings

Here's a little *advanced* detour to how mappings and arrays are stored internally in the EVM.

Array data is located starting at keccak256(p) and it is laid out in the same way as statically-sized array data would: One element after the other, potentially sharing storage slots if the elements are not longer than 16 bytes. Dynamic arrays of dynamic arrays apply this rule recursively.

The value corresponding to a mapping key k is located at keccak256(h(k) . p) where . is concatenation and h is a function that is applied to the key depending on its type:

1. for value types, h pads the value to 32 bytes in the same way as when storing the value in memory.
2. for strings and byte arrays, h computes the keccak256 hash of the unpadded data.

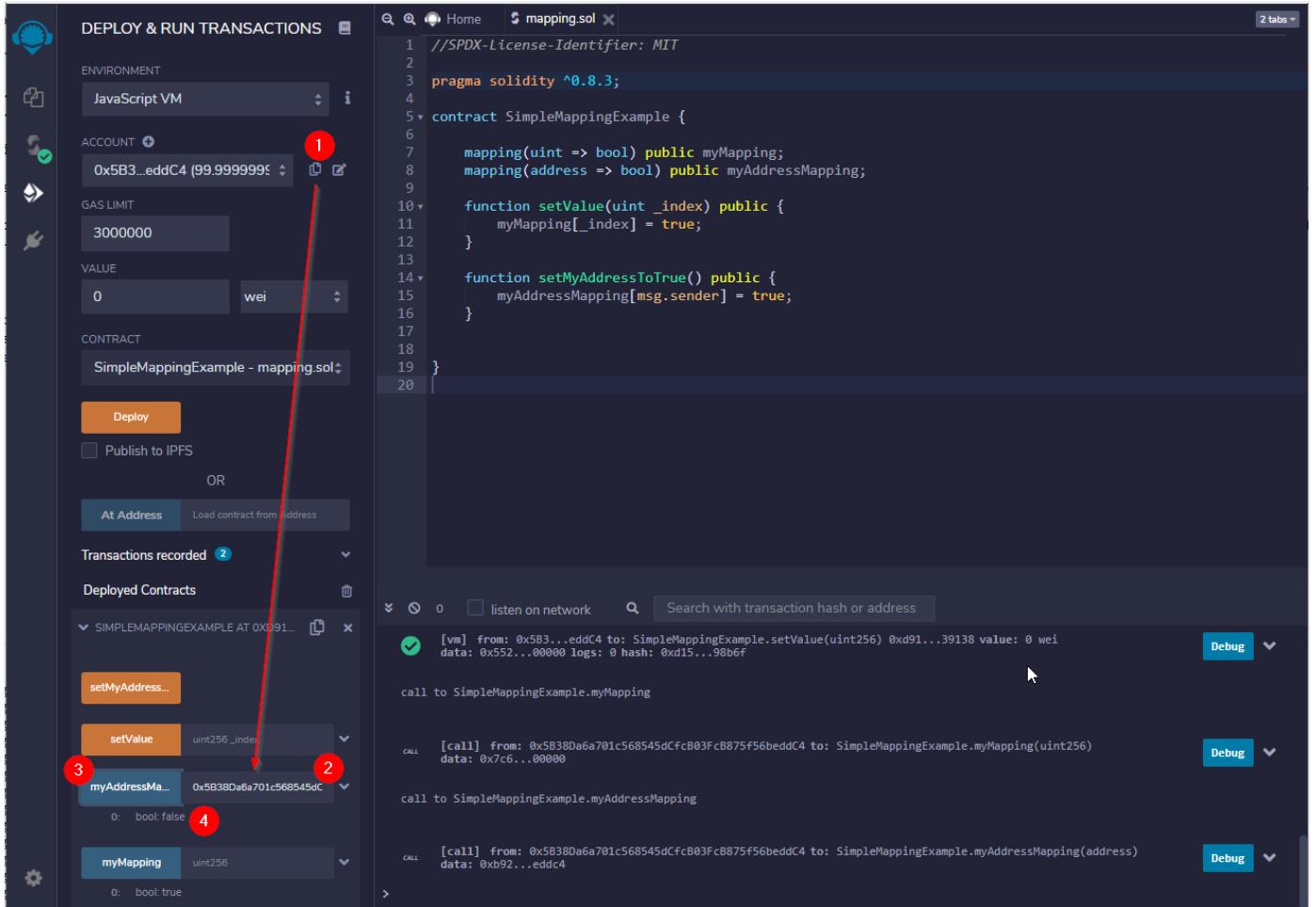
Find more information here on the Solidity page: https://docs.soliditylang.org/en/v0.8.3/internals/layout_in_storage.html?highlight=storage#mappings-and-dynamic-arrays

Addresses are a cool thing in Solidity. They are like a bank account number, an IBAN if you wish. You know who transacts with your Smart Contract and the Smart Contract knows who you are.

The cool thing is, addresses can be keys for arrays and mappings. And in our example we map addresses to boolean values. We could use this for white-listing for example. So, if an address is allowed to do a certain action in our Smart Contract then we can white-list it.

Let's see how that behaves. First, let's check the value for your own address:

1. Copy the Address from the Dropdown - there is a little copy icon next to the dropdown, press it
2. Paste the Address into the input field next to "myAddressMapping"
3. Press the Button
4. The value should be "false"



9.4.1 Set Address Keys in a Mapping

Let's have a closer look at the function `setMyAddressToTrue`:

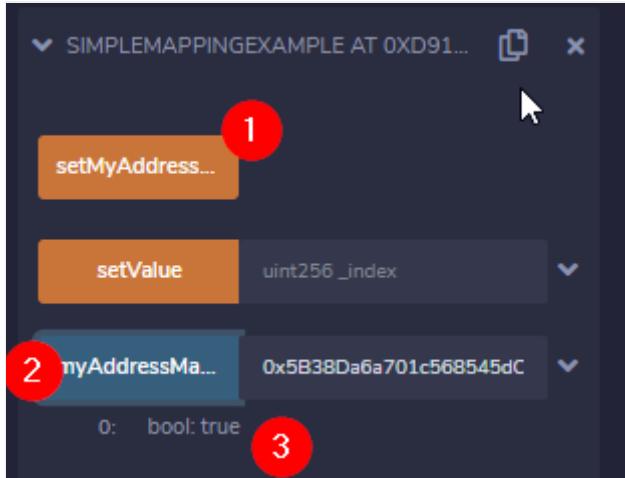
```
function setMyAddressToTrue() public {
    myAddressMapping[msg.sender] = true;
}
```

This function does several things:

1. it accesses the global `msg`-object and gets the senders address. So, if you are interacting with a specific address, then for the Smart Contract that address will be in `msg.sender`
2. It accesses the `myAddressMapping` mapping and sets the value "true" for the current address.

Let's give it a try!

1. simply click the "setMyAddressToTrue" button. There is no input field, because the address will automatically be the one you use to interact with the Smart Contract
2. Retrieve the value again
3. It should be true



9.4.2 Mappings of mappings

Because of the way mappings are stored within the EVM, it's possible to create mappings of mappings as well. For example:

```
mapping (uint => mapping(uint => bool)) uintUintBoolMapping;
```

Let's try a little coding exercise to get a feeling for mappings yourself!

Code Exercise

Try to use the mapping above, which is *not* public, and create both a getter and a setter function for it.

In case you get stuck, you can see the solution below.

Solution Code Exercise

```
mapping(uint => mapping(uint => bool)) uintUintBoolMapping;

function setUintUintBoolMapping(uint _index1, uint _index2, bool _value) public {
    uintUintBoolMapping[_index1][_index2] = _value;
}

function getUintUintBoolMapping(uint _index1, uint _index2) public view returns (bool) {
    return uintUintBoolMapping[_index1][_index2];
}
```

You might have seen, you can't name the getter function with the same name as the variable. But if you are making the variable public, then Solidity automatically creates a getter function with the same name as the variable. Peculiar detail to keep in mind here.

Alright, that's it for this lab. Congratulations, you created your first mapping and know how to access mappings.

The screenshot shows the Truffle UI interface for interacting with a Solidity contract. The left sidebar has icons for deploying, running transactions, and publishing to IPFS. The main area is divided into sections: **DEPLOY & RUN TRANSACTIONS**, **mapping.sol** (the contract source code), and **Transactions recorded**.

Contract Details:

- VALUE:** 0 wei
- CONTRACT:** SimpleMappingExample - mapping.sol
- Deploy:** Deploy button
- OR**: At Address or Load contract from Address

Transactions recorded: Shows 5 recorded transactions.

Deployed Contracts: Shows the deployed contract **SIMPLEMAPPINGEXAMPLE AT 0xD7A...** with the following interactions:

- setMyAddress...**
- setUintUIntBo...**: Value 0.0.true
- setValue**: Value uint256 _index
- getUintUIntBo...**: Value 0.0

Low level interactions:

- CALldata:** Transaction button

mapping.sol Contract Source Code:

```

1 // SPDX-License-Identifier: MIT
2
3 pragma solidity ^0.8.3;
4
5 contract SimpleMappingExample {
6
7     mapping(uint => bool) public myMapping;
8     mapping(address => bool) public myAddressMapping;
9     mapping(uint => mapping(uint => bool)) uintUIntBoolMapping;
10
11     function setUintUIntBoolMapping(uint _index1, uint _index2, bool _value) public {
12         uintUIntBoolMapping[_index1][_index2] = _value;
13     }
14
15     function getUintUIntBoolMapping(uint _index1, uint _index2) public view returns (bool) {
16         return uintUIntBoolMapping[_index1][_index2];
17     }
18
19     function setValue(uint _index) public {
20         myMapping[_index] = true;
21     }
22
23     function setMyAddressToTrue() public {
24         myAddressMapping[msg.sender] = true;
25     }
26
27 }
28
29 }
```

Transactions Recorded:

- [vm] from: 0x5B3...eddC4 to: SimpleMappingExample.(constructor) value: 0 wei data: 0x608...30033 logs: 0 hash: 0x190...2d4ce Debug
- [vm] from: 0x5B3...eddC4 to: SimpleMappingExample.setUintUIntBoolMapping(uint256,uint256,bool) 0xD7A...F7718 value: 0 wei data: 0xbc6...00001 logs: 0 hash: 0x960...11809 Debug
- call to SimpleMappingExample.getUintUIntBoolMapping
- call [call] from: 0x5B3...0a6a701c568545dCfcB03FcB875f56beddC4 to: SimpleMappingExample.getUintUIntBoolMapping(uint256,uint256) data: 0x637...00000 Debug

Last update: April 17, 2021

10. Mappings and Structs

10.1 Mappings and Structs

So far we have only used mappings and simple data types. So, we can now map addresses to booleans, or uint to addresses or any combination of that.

But what if you want to define something a bit more complex?

```

1 // SPDX-License-Identifier: MIT
2
3 pragma solidity ^0.8.4;
4
5 contract MappingsStructExample {
6
7     struct Payment {
8         uint amount;
9         uint timestamp;
10    }
11
12    struct Balance {
13        uint totalBalance;
14        uint numPayments;
15        mapping(uint => Payment) payments;
16    }
17
18    mapping(address => Balance) public balanceReceived;
19
20
21    function getBalance() public view returns(uint) {
22        return address(this).balance;
23    }
24
25    function sendMoney() public payable {
26        balanceReceived[msg.sender].totalBalance += msg.value;
27
28        Payment memory payment = Payment(msg.value, block.timestamp);

```

Let's say you work on the latest DeFi Project and your project does deposits and withdrawals. You not only want to save the amount that was deposited, but also by whom and possibly some more information.

You could define several mappings for this using simple data types. But there is also another way: Structs.

With structs you can define your own Datatype.

10.1.1 What You Know At The End Of The Lab

☒ How you can define your own datatypes using structs

☒ How to combine structs and mappings to get the most out of your Smart Contract functionality

10.1.2 Prerequisites - You need:

1. Chrome or Firefox browser.
2. An Internet connection
3. About 60 Minutes of your precious time ☺

10.1.3 Videos

☒ Full Video Walkthrough: <https://www.udemy.com/course/blockchain-developer/?referralCode=E8611DF99D7E491DFD96>

10.1.4 Get Started

018 018 018 Let's get started!

⚠ Updated to Solidity 0.8

The following Smart Contracts have been updated to Solidity 0.8 and might deviate slightly from the Videos. As always, all and everything will be explained so you don't need to worry to miss anything.

Last update: April 23, 2021

10.2 Basic Smart Contract

Let's create a Smart Contract we start with again. It's slightly different than in the previous Lab, because I actually want to do something with it. By the end of the lab we have some sort of Payment Smart Contract can keep track of deposits and withdrawals in an easy way using mappings and structs.

Create the following file in Remix:

```
// SPDX-License-Identifier: MIT

pragma solidity ^0.8.4;

contract MappingsStructExample {

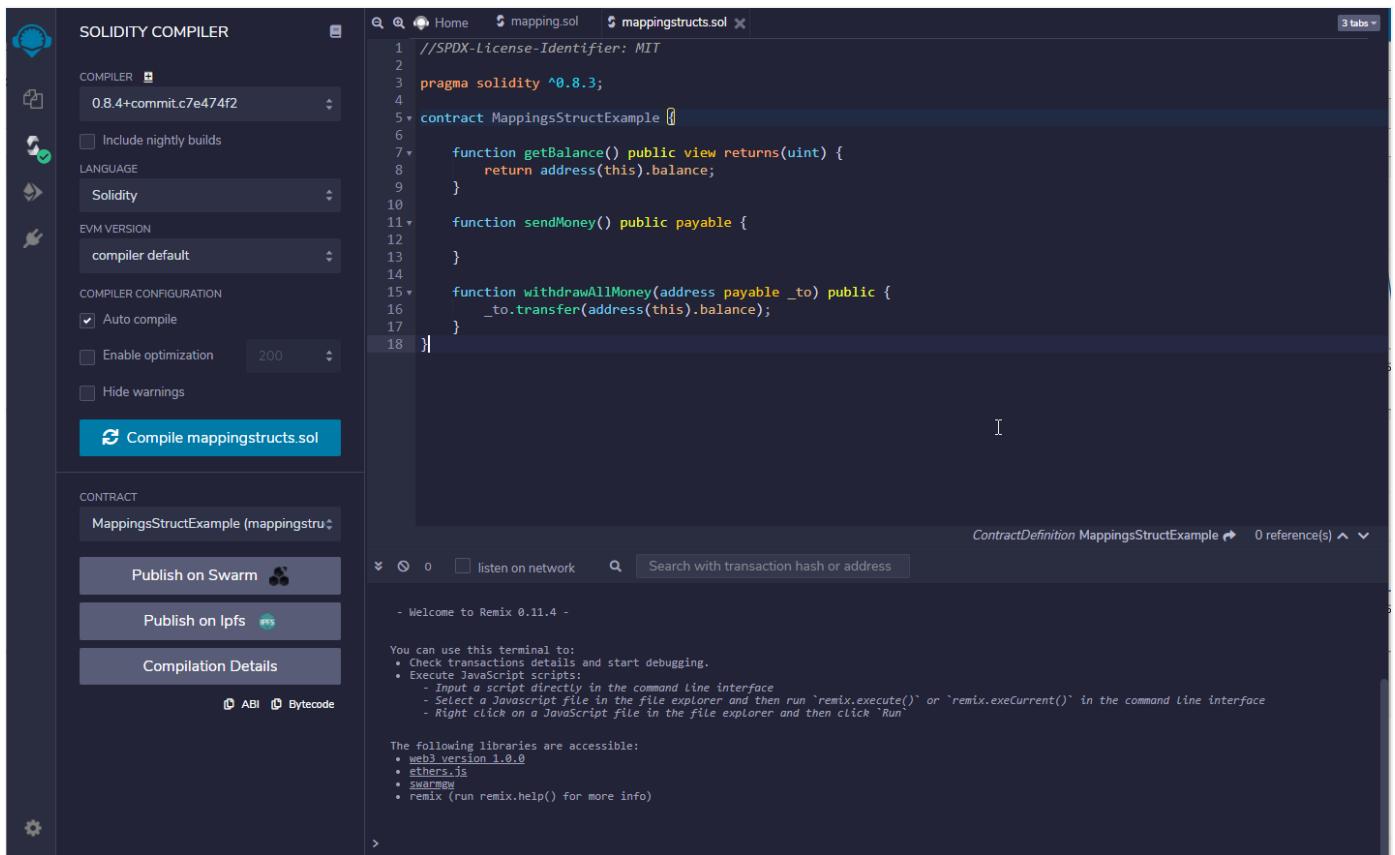
    function getBalance() public view returns(uint) {
        return address(this).balance;
    }

    function sendMoney() public payable {

    }

    function withdrawAllMoney(address payable _to) public {
        _to.transfer(address(this).balance);
    }
}
```

The Smart Contract is very simplistic. It allows everyone to send Ether to the Smart Contract. But it also allows everyone to transfer all funds from the Smart Contract to any address. Not very secure - yet.



The screenshot shows the Remix IDE interface. On the left, the 'SOLIDITY COMPILER' sidebar is open, showing the compiler version as 0.8.4+commit.c7e474f2, the language as Solidity, and the EVM version as compiler default. It also includes compiler configuration options like auto compile, enable optimization (set to 200), and hide warnings. A prominent blue button at the bottom of this sidebar says 'Compile mappingstructs.sol'. The main workspace displays the Solidity code for the 'MappingsStructExample' contract. Below the code, there's a terminal window with a welcome message for Remix 0.11.4, a list of accessible libraries (web3, ethers.js, SHARMDM, remix), and a note about using the command line interface. At the bottom of the workspace, there are tabs for 'ContractDefinition MappingsStructExample' and '0 reference(s)'.

```
// SPDX-License-Identifier: MIT

pragma solidity ^0.8.3;

contract MappingsStructExample {

    function getBalance() public view returns(uint) {
        return address(this).balance;
    }

    function sendMoney() public payable {

    }

    function withdrawAllMoney(address payable _to) public {
        _to.transfer(address(this).balance);
    }
}
```

Let's play around with this Smart Contract and see how it works with depositing and withdrawing money, and how we can make it more secure.

10.3 Understand the Limitations

In this step we basically execute the Smart Contract and see how it behaves, before we improve the Smart Contract with mapping and structs.

10.3.1 Deploy the Smart Contract

Head over to the "Deploy & Run Transactions" Plugin and Deploy the Smart Contract

The screenshot shows the Remix IDE interface for deploying a Solidity contract. The left sidebar has tabs for 'Deploy & Run Transactions' (selected), 'Environment' (JavaScript VM), 'Account' (0x5B3...eddC4), 'Gas Limit' (300000), and 'Value' (0 wei). The main area contains the Solidity code for 'MappingsStructExample':

```
// SPDX-License-Identifier: MIT
pragma solidity ^0.8.3;
contract MappingsStructExample {
    function getBalance() public view returns(uint) {
        return address(this).balance;
    }
    function sendMoney() public payable {
    }
    function withdrawAllMoney(address payable _to) public {
        _to.transfer(address(this).balance);
    }
}
```

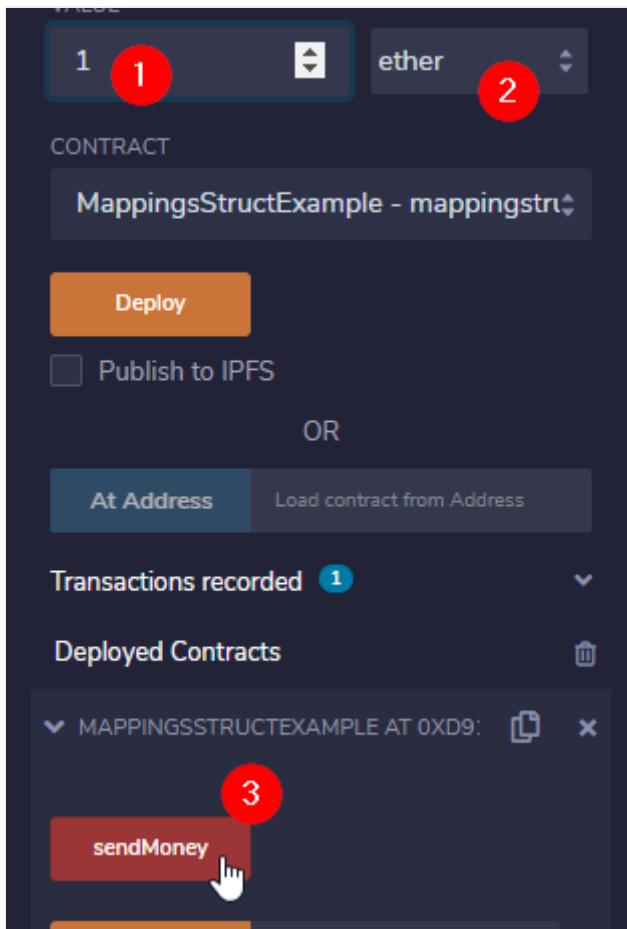
Below the code, there's a 'Deploy' button (labeled 2) and an 'At Address' dropdown. The 'Deployed Contracts' section shows the deployed contract at address 0x5B3...eddC4 with its constructor function 'sendMoney' (labeled 3) highlighted.

Now you should have your Smart Contract deployed and an instance under "Deployed Contracts"

10.3.2 Deposit some Funds

Let's send some Ether to the Smart Contract. The Contract will manage its own funds.

1. Enter "1" in the value field
2. Select "Ether" from the Dropdown
3. Hit the "sendMoney" Button



10.3.3 Withdraw Money

Our Smart Contract is extremely simple at this stage. It allows everyone to send money to the Smart Contract. It also allows everyone to withdraw everything. That's not very good obviously, unless you operate some sort of charity. Let's give it a try. Let's withdraw all money to our second account using our second account:

1. Select Account#2 from the Accounts Dropdown
2. Copy the Address
3. Paste the Address next to "withdrawAllMoney"
4. hit the "withdrawAllMoney" Button
5. Observe the increased Ether Amount for that Account

DEPLOY & RUN TRANSACTIONS

ENVIRONMENT

JavaScript VM

ACCOUNT

- 0x5B3...eddC4 (98.999999999999798581 ether)
- 0xAb8...35cb2 (100 ether)**
- 0x4B2...C02db (100 ether)
- 0x787...cabaB (100 ether)
- 0x617...5E7f2 (100 ether)
- 0x17F...8c372 (100 ether)
- 0x5c6...21678 (100 ether)
- 0x03C...D1Ff7 (100 ether)
- 0x1aE...E454C (100 ether)
- 0x0A0...C70DC (100 ether)
- 0xCA3...a733c (100 ether)
- 0x147...C160C (100 ether)
- 0x4B0...4D2dB (100 ether)
- 0x583...40225 (100 ether)
- 0xdD8...92148 (100 ether)

At Address Load contract from Address

DEPLOY & RUN TRANSACTIONS

ENVIRONMENT

JavaScript VM

ACCOUNT

0xAb8...35cb2 (100 ether)

GAS LIMIT

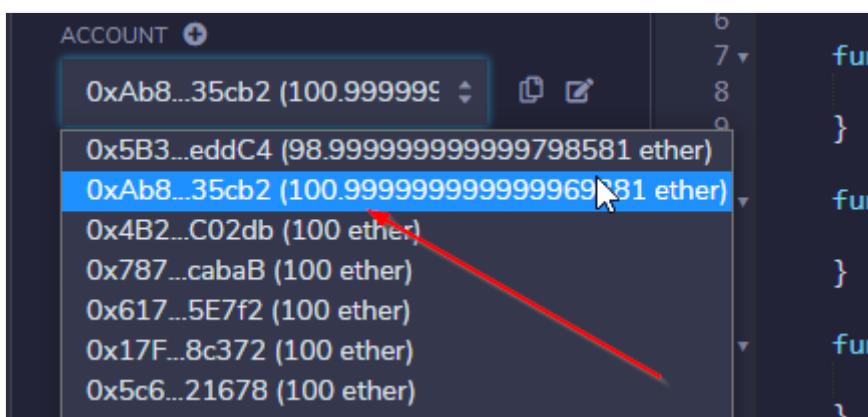
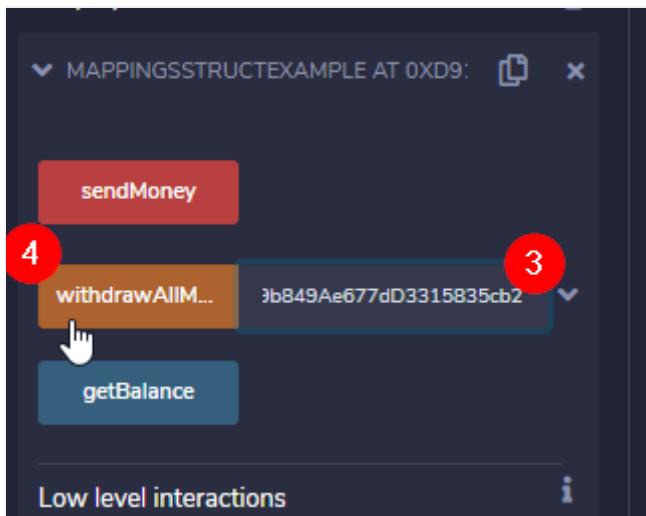
3000000

VALUE

Home

```

1 // SPDX-License-Identifier: MIT
2 pragma solidity ^0.8.0;
3
4 contract Mapping {
5     mapping(uint256 => string) public names;
6
7     function set(string memory _name, uint256 _id) public {
8         names[_id] = _name;
9     }
10
11    function get(uint256 _id) public view returns (string memory) {
12        return names[_id];
13    }
14 }
```



So, everyone can do everything with the Smart Contract. Let's make it a bit more secure!

Try yourself first

Want to give it a try yourself first before you proceed?

Extend the Smart Contract and use a Mapping to track who send how much to the Smart Contract.

Then only allow withdrawals for the amount deposited.

So, if address 0x123... deposits 1 Ether, then address 0x123... can withdraw 1 Ether again. Nobody else. And not more.

Use a mapping(address => uint) for this and track the funds with msg.value.

Last update: April 23, 2021

10.4 Add a Mapping

Let's make our Smart Contract inherently secure. We will allow only withdrawals for previously done deposits. It's the first step towards understanding Token Contracts, which you will see later!

Add the following things to the Smart Contract:

```
// SPDX-License-Identifier: MIT
pragma solidity ^0.8.4;
contract MappingsStructExample {
    mapping(address => uint) public balanceReceived;

    function getBalance() public view returns(uint) {
        return address(this).balance;
    }

    function sendMoney() public payable {
        balanceReceived[msg.sender] += msg.value;
    }

    function withdrawAllMoney(address payable _to) public {
        uint balanceToSend = balanceReceived[msg.sender];
        balanceReceived[msg.sender] = 0;
        _to.transfer(balanceToSend);
    }
}
```

To understand what's going on here:

When someone sends money using the "sendMoney" function, we track the msg.value (amount in Wei) with the balanceReceived mapping for the person who interacted with the Smart Contract.

If that same person tries to withdraw money again using "withdrawAllMoney", we look in that mapping how much he sent there previously, then reset the mapping and send the amount.

Re-Entrancy and Checks-Effects-Interaction Pattern

You are eventually wondering why we don't do the following:

```
function withdrawAllMoney(address payable _to) public {
    _to.transfer(balanceReceived[msg.sender]);
    balanceReceived[msg.sender] = 0;
}
```

This follows the so-called Checks-Effects-Interaction pattern. As a rule of thumb: You interact with outside addresses *last*, no matter what. Unless you have a trusted source. So, first set your Variables to the state you want, as if someone could call back to the Smart Contract before you can execute the next line after .transfer(...). Read more about this here: https://fravoll.github.io/solidity-patterns/checks_effects_interactions.html

10.4.1 Deploy the new Smart Contract

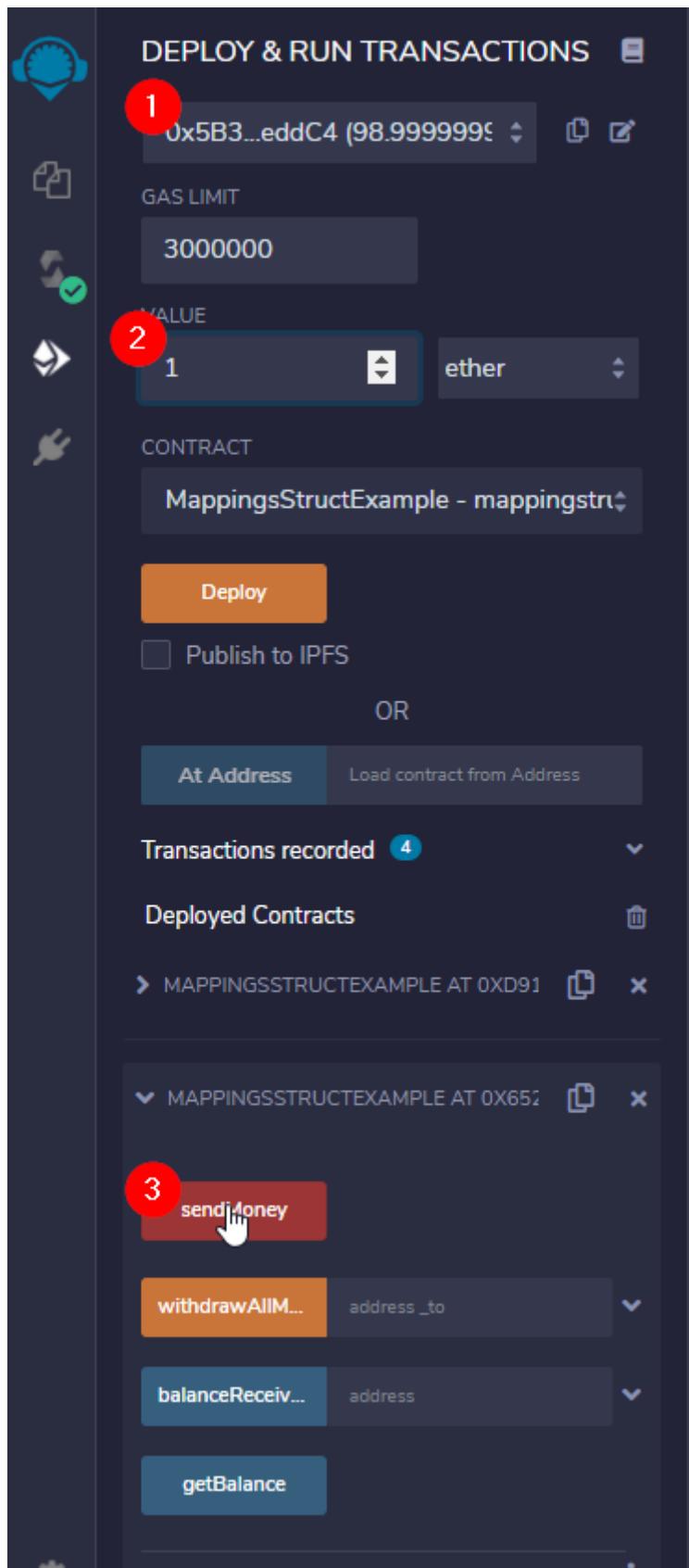
Head over to the "Deploy & Run Transactions" Plugin and deploy a new Instance.

The screenshot shows the Truffle UI interface. On the left, there's a sidebar with various icons and sections like 'DEPLOY & RUN TRANSACTIONS', 'GAS LIMIT', 'VALUE', 'CONTRACT', and 'Low level interactions'. A red arrow points from the 'Deploy' button in the sidebar to the 'Deploy' button in the main content area. The main content area has tabs for 'mapping.sol' and 'mappingstructs.sol'. It displays the Solidity code for the 'MappingsStructExample' contract. Below the code, there's a transaction history section titled 'Transactions recorded' with 4 items. One item is highlighted with a green checkmark: '[vm] from: 0x583...eddC4 to: MappingsStructExample.sendMoney() 0xd91...39138 value: 1000000000000000 wei data: 0xcbe...dbf5a'. There are also sections for 'Deployed Contracts' and 'Low level interactions'.

10.4.2 Deposit and Withdraw

We will deposit 1 Ether from two different accounts and then withdraw Ether again:

1. select **Account#1** from the Accounts Dropdown
2. Value: 1 Ether
3. Hit the "sendMoney" button
4. Select **Account#2** from the Accounts Dropdown
5. Value: 1 Ether
6. Hit the "sendMoney" button



DEPLOY & RUN TRANSACTIONS

4 0xAb8...35cb2 (100.999999)  

GAS LIMIT
3000000

5 Value
1 ether

CONTRACT
MappingsStructExample - mappingstr

Deploy

Publish to IPFS

OR

At Address Load contract from Address

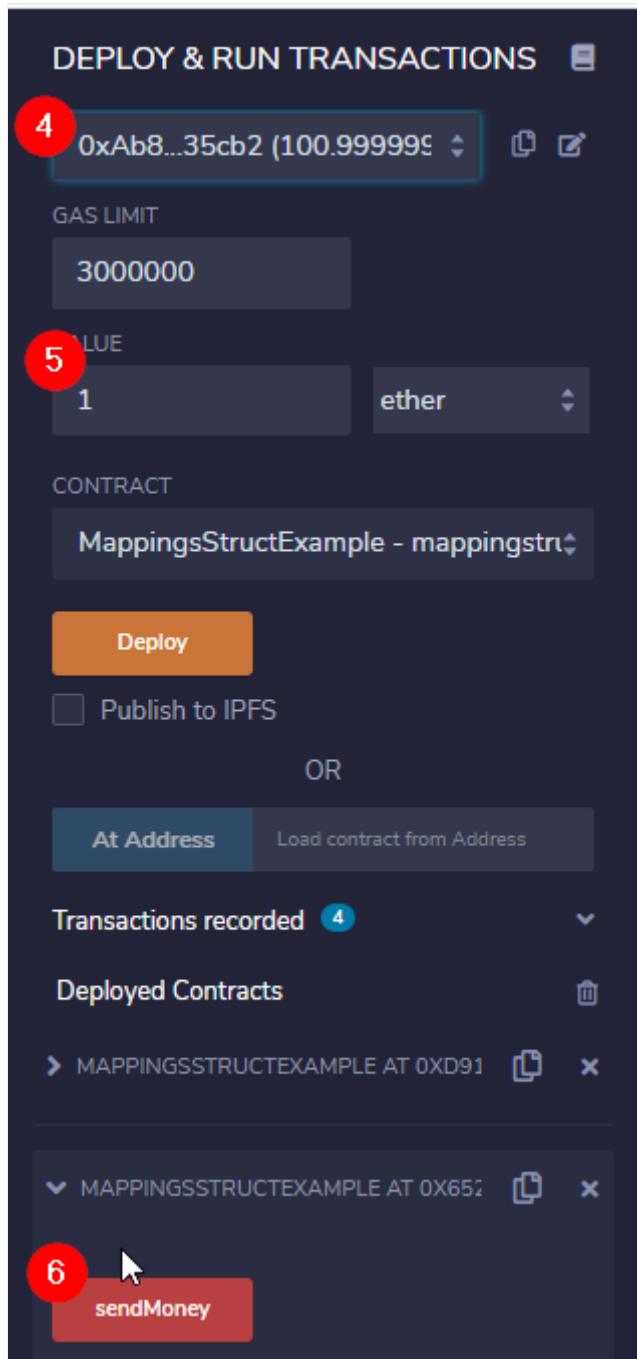
Transactions recorded 4

Deployed Contracts 

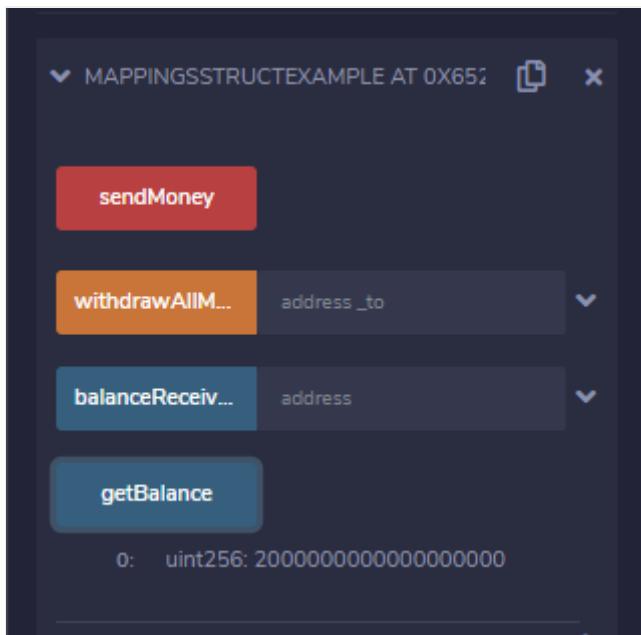
› MAPPINGSSTRUCTEXAMPLE AT 0XD91  

▼ MAPPINGSSTRUCTEXAMPLE AT 0X652  

6 



Now check the Balance of the *Smart Contract*:



You have 2 Ether ($2 * 10^{18}$ Wei) in the Smart Contract. But if you check the accounts individual amount from the mapping, then you see that each account can max withdraw 1 Ether:

DEPLOY & RUN TRANSACTIONS

0x5B3...eddC4 (97.99999999999999)

GAS LIMIT
3000000

VALUE
0 ether

CONTRACT
MappingsStructExample - mappingstruc

OR

At Address

Transactions recorded 6

Deployed Contracts

MAPPINGSSTRUCTEXAMPLE AT 0xD91

MAPPINGSSTRUCTEXAMPLE AT 0X652

address _to

0x5B38Da6a701c568545dC

0: uint256: 10000000000000000000000000000000

0: uint256: 20000000000000000000000000000000

0x5B38Da6a701c568545dC

10.4.3 Withdraw all Money to Account#3

Let's withdraw all the funds stored in the Smart Contract to Account#3 from the Accounts Dropdown:

1. Copy the address of Account#3 (select Account#3, copy)
2. Paste the Address into the withdrawAllMoney input field, but don't hit the button yet
3. Go back to Account#1
4. Hit the "withdrawAllMoney" button with Account#3-Address in the input field
5. Select Account#2 from the Accounts Dropdown
6. Hit the "withdrawAllMoney" button again with Account#3-Address in the input field
7. Check the Balance of the Smart Contract and of Account#3

The screenshot shows the MetaMask extension interface. On the left, there's a sidebar with various icons: a clock, a document, a gear, a checkmark, a diamond, and a hand. The main area has a title "DEPLOY & RUN TRANSACTIONS".
1. A dropdown menu lists several Ethereum addresses with their balances:

- 0x4B2...C02db (100 ether)
- 0x5B3...eddC4 (97.999999999999756058 ether)
- 0xAb8...35cb2 (99.999999999999601739 ether)
- 1 0x4B2...C02db (100 ether) **(highlighted)**
- 0x787...cabaB (100 ether)
- 0x617...5E7f2 (100 ether)
- 0x17F...8c372 (100 ether)
- 0x5c6...21678 (100 ether)
- 0x03C...D1Ff7 (100 ether)
- 0x1aE...E454C (100 ether)
- 0x0A0...C70DC (100 ether)
- 0xCA3...a733c (100 ether)
- 0x147...C160C (100 ether)
- 0x4B0...4D2dB (100 ether)
- 0x583...40225 (100 ether)
- 0xdD8...92148 (100 ether)

2. Below the dropdown is a section for "Transactions recorded" (6). It shows two entries:

- MAPPINGSSTRUCTEXAMPLE AT 0XD91
- MAPPINGSSTRUCTEXAMPLE AT 0X652

3. At the bottom, there are two buttons:

- sendMoney (red button)
- withdrawAllM... (orange button)

The "withdrawAllM..." button is highlighted with a red circle containing the number 2.

The screenshot shows the MetaMask extension's "Deploy & Run Transactions" interface. On the left, there is a sidebar with various icons: a blue gear, a document, a circular arrow with a checkmark, a diamond, and a hand. The main area has a dark background with white text.

Transactions Recorded: 7

Deployed Contracts:

- MAPPINGSSTRUCTEXAMPLE AT 0xD91
- MAPPINGSSTRUCTEXAMPLE AT 0X652

sendMoney

withdrawAllM... (4)

At Address Load contract from Address

0x5B3...eddC4 (97.9999999999999734436 eth) (highlighted with a red circle labeled 3)

0xA8...35cb2 (99.9999999999999601739 eth)

0x4B2...C02db (101 ether)

0x787...cabab (100 ether)

0x617...5E7f2 (100 ether)

0x17F...8c372 (100 ether)

0x5c6...21678 (100 ether)

0x03C...D1Ff7 (100 ether)

0x1aE...E454C (100 ether)

0x0A0...C70DC (100 ether)

0xCA3...a733c (100 ether)

0x147...C160C (100 ether)

0x4B0...4D2dB (100 ether)

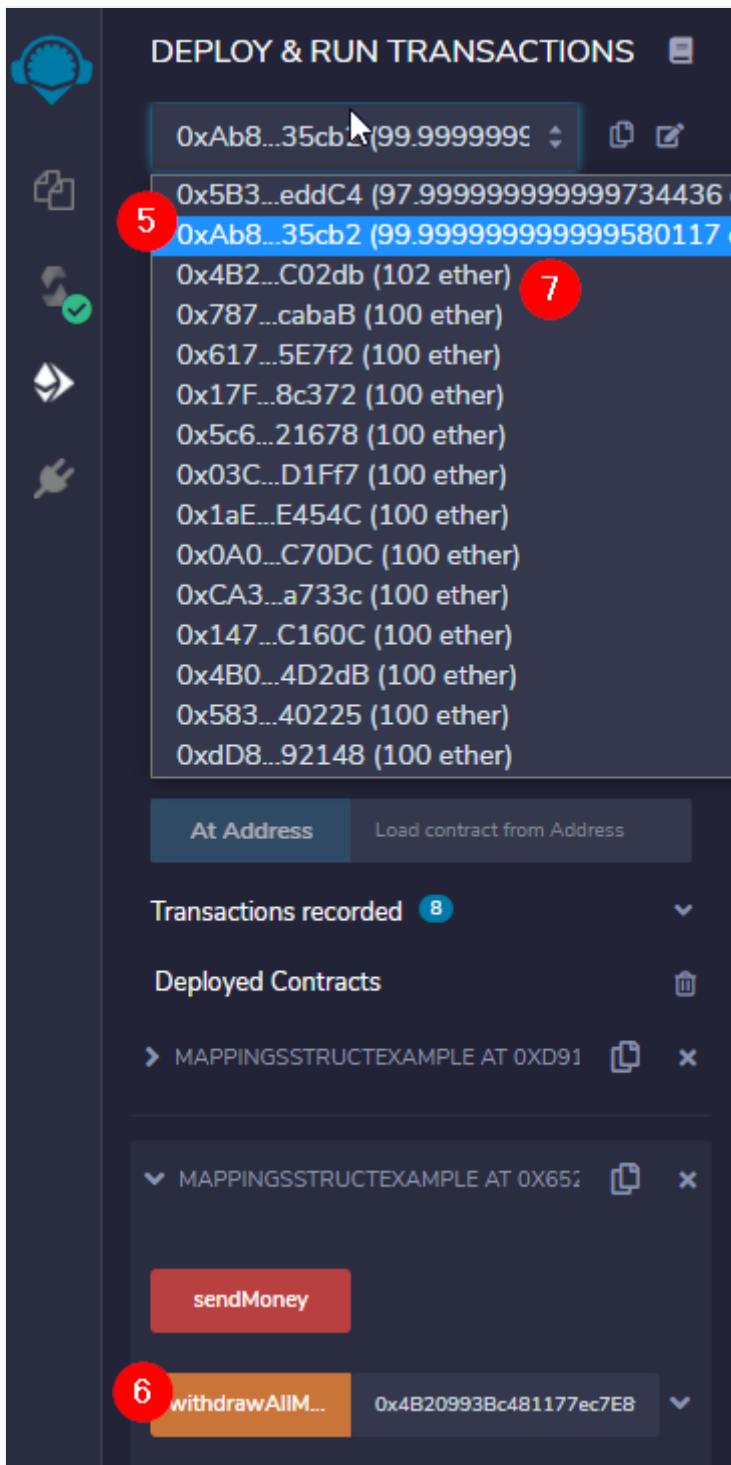
0x583...40225 (100 ether)

0xdD8...92148 (100 ether)

The screenshot shows the MetaMask wallet interface. On the left, there's a sidebar with icons for account management, a QR code, a green checkmark, a gear, and a power plug. The main area has a title "DEPLOY & RUN TRANSACTIONS".
A list of transactions is shown, with the last one highlighted in blue and circled in red with the number 5. This transaction is from address 0xAb8...35cb2 to itself with 99.9999999999999580117 ether.
Below the transaction list is a dropdown menu with "At Address" and "Load contract from Address".
Under "Transactions recorded", there are two entries:

- "Deployed Contracts" with a trash bin icon.
- "MAPPINGSSTRUCTEXAMPLE AT 0XD91" with a copy icon and a close button. This entry is circled in red with the number 6.

- "MAPPINGSSTRUCTEXAMPLE AT 0X652" with a copy icon and a close button. This entry is circled in red with the number 7.
- A red button labeled "sendMoney".
- A brown button labeled "withdrawAllMoney" which is circled in red with the number 6.
- A grey button labeled "0x4B20993Bc481177ec7E8".



Withdrawing all money is fun, but not very useful yet. Let's add another functionality to withdraw partial funds.

Try yourself first

Want to give it a try yourself first before you proceed?

Extend the Smart Contract and use the Mapping allow partial sending. That means, the user can specify an amount to send. The Smart Contract checks if the amount isn't larger than what the user previously deposited, deducts the amount from the users balance and sends it.

Last update: April 23, 2021

10.5 Add partial Withdrawals

Sending all funds is fun, but it isn't very useful. Sometimes, like with a Bank Account, you don't want to send out all the funds you have. You just want to send a little bit. We can do this quite easily with our new mapping.

Add the following things to the Smart Contract:

```
// SPDX-License-Identifier: MIT

pragma solidity ^0.8.4;

contract MappingsStructExample {

    mapping(address => uint) public balanceReceived;

    function getBalance() public view returns(uint) {
        return address(this).balance;
    }

    function sendMoney() public payable {
        balanceReceived[msg.sender] += msg.value;
    }

    function withdrawMoney(address payable _to, uint _amount) public {
        require(_amount <= balanceReceived[msg.sender], "not enough funds");
        balanceReceived[msg.sender] -= _amount;
        _to.transfer(_amount);
    }

    function withdrawAllMoney(address payable _to) public {
        uint balanceToSend = balanceReceived[msg.sender];
        balanceReceived[msg.sender] = 0;
        _to.transfer(balanceToSend);
    }
}
```

To understand what's going on here:

When someone withdraws funds, we check if the amount he wants to withdraw is smaller or equal than the amount he previously deposited. If yes, then we deduct the amount from his balance and send out the funds.

10.5.1 Deploy the new Smart Contract

Head over to the "Deploy & Run Transactions" Plugin and deploy a new Instance.

The screenshot shows the Truffle UI interface. On the left, there's a sidebar for "DEPLOY & RUN TRANSACTIONS" with fields for ACCOUNT (0xAb8...35cb2), GAS LIMIT (3000000), and VALUE (0 ether). Below these are sections for CONTRACT (MappingsStructExample) and DEPLOYED CONTRACTS (MappingsStructExample at 0xAb8...35cb2). A red arrow points from the "Deploy" button in the sidebar to the "sendMoney" button in the contract interaction section. The right side of the interface displays the Solidity code for the MappingsStructExample contract, which includes functions for sending and withdrawing money. The bottom right shows a transaction history with details like from, to, value, and logs.

```

1 // SPDX-License-Identifier: MIT
2
3 pragma solidity ^0.8.3;
4
5 contract MappingsStructExample {
6     mapping(address => uint) public balanceReceived;
7
8     function getBalance() public view returns(uint) {
9         return address(this).balance;
10    }
11
12    function sendMoney() public payable {
13        balanceReceived[msg.sender] += msg.value;
14    }
15
16    function withdrawMoney(address payable _to, uint _amount) public {
17        require(_amount <= balanceReceived[msg.sender], "not enough funds");
18        balanceReceived[msg.sender] -= _amount;
19        _to.transfer(_amount);
20    }
21
22    function withdrawAllMoney(address payable _to) public {
23        uint balanceToSend = balanceReceived[msg.sender];
24        balanceReceived[msg.sender] = 0;
25        _to.transfer(balanceToSend);
26    }
27 }
28

```

10.5.2 Deposit and Withdraw 50%

We will deposit 1 Ether from Account#1 and Withdraw 50% to Account#3. I won't provide Screenshots for the first few steps, since it's exactly the same as previously:

1. select **Account#1** from the Accounts Dropdown
2. Value: 1 Ether
3. Hit the "sendMoney" button
4. Select **Account#3** from the Accounts Dropdown
5. Copy the Address And Paste it in the "withdrawMoney" Input field
6. Add "50000000000000000000" as amount
7. Switch back to Account#1 and hit the "withdrawMoney" button.
8. Check the Balance of "Account#3"

```

// SPDX-License-Identifier: MIT
pragma solidity ^0.8.3;

contract MappingsStructExample {
    mapping(address => uint) public balanceReceived;

    function getBalance() public view returns(uint) {
        return address(this).balance;
    }

    function sendMoney() public payable {
        balanceReceived[msg.sender] += msg.value;
    }

    function withdrawMoney(address payable _to, uint _amount) public {
        require(_amount <= balanceReceived[msg.sender], "not enough funds");
        balanceReceived[msg.sender] -= _amount;
        _to.transfer(_amount);
    }

    function withdrawAllMoney(address payable _to) public {
        uint balanceToSend = balanceReceived[msg.sender];
        balanceReceived[msg.sender] = 0;
        _to.transfer(balanceToSend);
    }
}

```

If you are wondering why my input fields look like in the picture: There is a little down-arrow next to the input fields, so it will open an extended view.

If you followed along in this lab, then you have 102.5 Ether (102.5×10^{18} Wei) in the Account#3. If you just started with this step, then you have 100.5 Ether in Account#3.

Now, that's all good so far. Let's add another level of complexity to it by using Structs. We define our own Datatypes so we can track single payments from users.

Last update: April 23, 2021

10.6 Add Structs

So far we relied on simple Datatypes like addresses, uint or in previous labs also Booleans. But what if that's not enough? Maybe you want to track the timestamp when a deposit happened. You want to track every single deposit from every user. You want to track how many deposits happened, and many more details.

Of course, a rule of thumb is: Do only the most necessary functions on the blockchain, and everything else off-chain. But for sake of explaining Structs, we will track every single payment in the greatest detail possible with our Smart Contract.

If you have never worked with structs, objects or classes before, then think about it like this:

While you are tracking the current balance with a mapping that maps address to uint (`mapping(address=>uint) balanceReceived`) with something schematically like `balanceReceived[THE-ADDRESS] = THE-UINT`, with a struct you would access the children with a `.` (period).

Let's say you have a struct

```
MyStruct {
    uint abc;
}

mapping(address => MyStruct) someMapping;
```

Then you would write to the mapping like this `someMapping[THE-ADDRESS].abc = THE-UINT`. Why is this useful? Let's have a look into our Smart Contract!

Add the following things to the Smart Contract:

```
// SPDX-License-Identifier: MIT

pragma solidity ^0.8.4;

contract MappingsStructExample {

    struct Payment {
        uint amount;
        uint timestamp;
    }

    struct Balance {
        uint totalBalance;
        uint numPayments;
        mapping(uint => Payment) payments;
    }

    mapping(address => Balance) public balanceReceived;

    function getBalance() public view returns(uint) {
        return address(this).balance;
    }

    function sendMoney() public payable {
        balanceReceived[msg.sender].totalBalance += msg.value;

        Payment memory payment = Payment(msg.value, block.timestamp);
        balanceReceived[msg.sender].payments[balanceReceived[msg.sender].numPayments] = payment;
        balanceReceived[msg.sender].numPayments++;
    }

    function withdrawMoney(address payable _to, uint _amount) public {
        require(_amount <= balanceReceived[msg.sender].totalBalance, "not enough funds");
        balanceReceived[msg.sender].totalBalance -= _amount;
        _to.transfer(_amount);
    }

    function withdrawAllMoney(address payable _to) public {
        uint balanceToSend = balanceReceived[msg.sender].totalBalance;
        balanceReceived[msg.sender].totalBalance = 0;
        _to.transfer(balanceToSend);
    }
}
```

It's getting quite extensive here, bear with me. Let's go through the Smart Contract together to understand what's going on here!

We have one struct called `Payment`, which stores the amount and the timestamp of the payment. Then we have another struct called `Balance` which stores the total balance and a mapping of all payments done.

⚠️ Mapping has no Length

Mappings have no length. It's important to understand this. Arrays have a length, but, because how mappings are stored internally, they do not have a length.

Let's say you have a mapping `mapping(uint => uint) myMapping`, then all elements `myMapping[0]`, `myMapping[1]`, `myMapping[123123]`, ... are already initialized with the default value. If you map `uint` to `uint`, then you map key-type "uint" to value-type "uint".

⚠️ Structs are initialized with their default value

Similar to anything else in Solidity, structs are initialized with their default value as well.

If you have a struct

```
struct Payment {
    uint amount;
    uint timestamp;
}
```

and you have a mapping `mapping(uint => Payment) myMapping`, then you can access already all possible `uint` keys with the default values. This would produce **no** error:

```
myMapping[0].amount, or myMapping[123123].amount, or myMapping[5555].timestamp.
```

Similar, you can set any value for any mapping key:

```
myMapping[1].amount = 123 is perfectly fine.
```

So, with these two things in mind, structs allow you to define something similar like cheap class-variables.

Back to our Smart Contract.

10.6.1 Balance <-> Payment relationship

If you have a look at the two structs, then you see there is also a mapping inside:

```
struct Payment {
    uint amount;
    uint timestamp;
}

struct Balance {
    uint totalBalance;
    uint numPayments;
    mapping(uint => Payment) payments;
}

mapping(address => Balance) public balanceReceived;
```

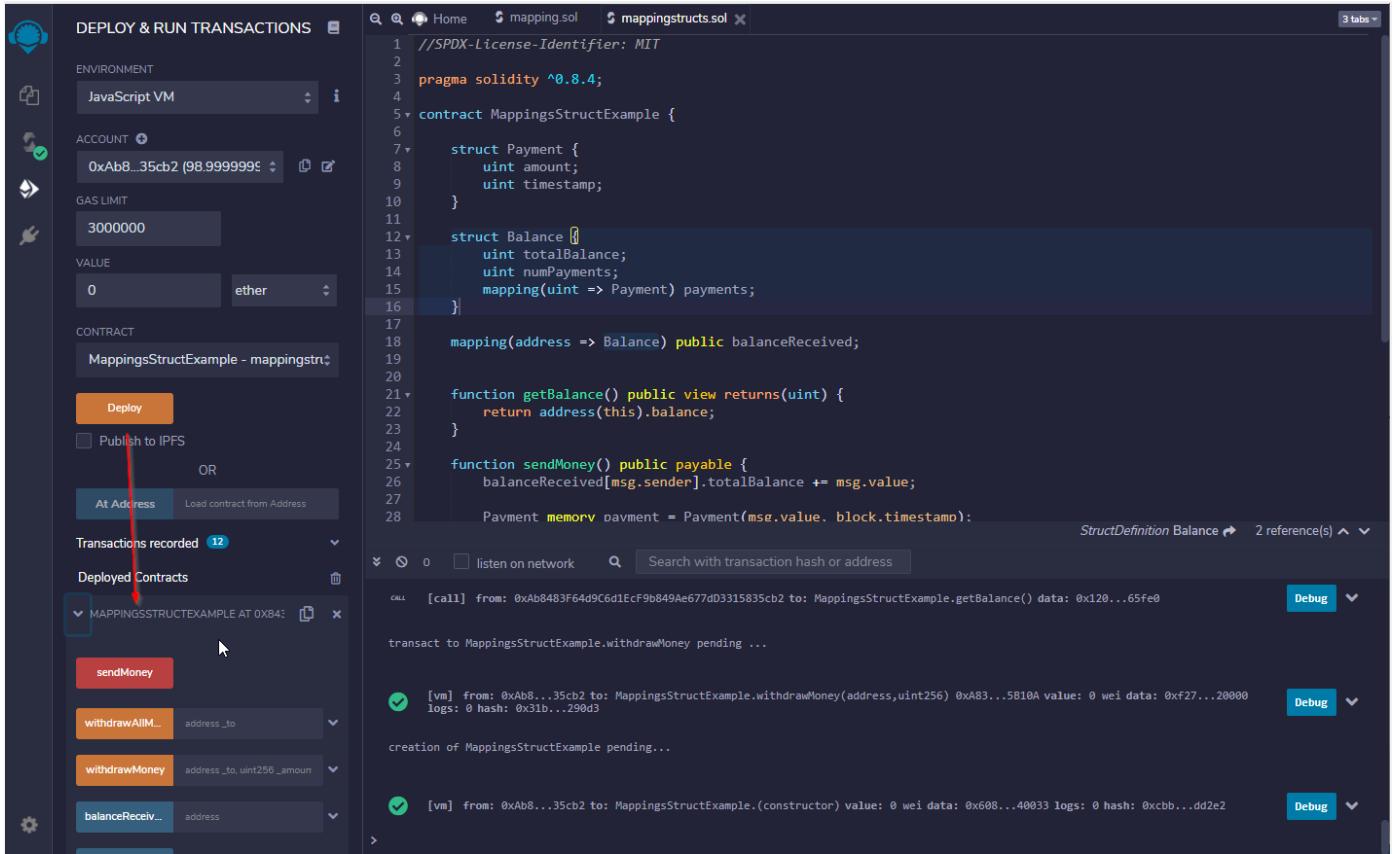
Because mappings have no length, we can't do something like `balanceReceived.length` or `payments.length`. It's technically not possible. In order to store the length of the payments mapping, we have an additional helper variable `numPayments`.

So, if you want to the first payment for address `0x123...` you could address it like this:

`balanceReceived[0x123...].payments[0].amount = ...`. But that would mean we have static keys for the payments mapping inside the `Balance` struct. We actually store the keys in `numPayments`, that would mean, the current payment is in `balanceReceived[0x123...].numPayments`. If we put this together, we can do
`balanceReceived[0x123...].payments[balanceReceived[0x123...].numPayments].amount = ...`.

Enough talking, let's give it a try!

10.6.2 Use the Smart Contract



The screenshot shows the Truffle UI interface for interacting with a Solidity smart contract named `MappingsStructExample`. The left sidebar contains settings for deployment: environment (JavaScript VM), account (0xAb8...35cb2), gas limit (300000), and value (0 ether). The right pane displays the Solidity code for the contract, which defines a struct `Payment` and a struct `Balance`, and includes functions for getting balance, sending money, and receiving money.

```

1 // SPDX-License-Identifier: MIT
2
3 pragma solidity ^0.8.4;
4
5 contract MappingsStructExample {
6
7     struct Payment {
8         uint amount;
9         uint timestamp;
10    }
11
12    struct Balance {
13        uint totalBalance;
14        uint numPayments;
15        mapping(uint => Payment) payments;
16    }
17
18    mapping(address => Balance) public balanceReceived;
19
20    function getBalance() public view returns(uint) {
21        return address(this).balance;
22    }
23
24    function sendMoney() public payable {
25        balanceReceived[msg.sender].totalBalance += msg.value;
26    }
27
28    Payment memory payment = Payment(msg.value, block.timestamp);
  
```

The bottom section shows transaction history and pending operations:

- Transactions recorded (12):**
 - [call] from: 0xAb8483F64d9C6d1EcF9b849Ae677d03315835cb2 to: MappingsStructExample.getBalance() data: 0x120...65fe0 Debug
 - transact to MappingsStructExample.withdrawMoney pending ...
- Deployed Contracts:**
 - MAPPINGSSTRUCTEXAMPLE AT 0x84: [copy]
 - sendMoney**
 - withdrawAll...** address _to
 - withdrawMoney** address _to, uint256 _amount
 - balanceReceiv...** address

1. Deploy a new Instance of the Smart Contract.
2. Then deposit 1 Ether with Account#1 (1 Ether -> sendMoney button)
3. Then check the Balance

```

// SPDX-License-Identifier: MIT
pragma solidity ^0.8.4;
contract MappingsStructExample {
    struct Payment {
        uint amount;
        uint timestamp;
    }
    struct Balance {
        uint totalBalance;
        uint numPayments;
        mapping(uint => Payment) payments;
    }
    mapping(address => Balance) public balanceReceived;
    function getBalance() public view returns(uint) {
        return address(this).balance;
    }
    function sendMoney() public payable {
        balanceReceived[msg.sender].totalBalance += msg.value;
        Payment memory payment = Payment(msg.value, block.timestamp);
        balanceReceived[msg.sender].payments[msg.value] = payment;
    }
    function withdrawAll() public {
        require(balanceReceived[msg.sender].totalBalance > 0);
        uint amount = balanceReceived[msg.sender].totalBalance;
        msg.sender.transfer(amount);
        balanceReceived[msg.sender].totalBalance = 0;
    }
    function withdrawMoney(uint _amount) public {
        require(_amount <= balanceReceived[msg.sender].totalBalance);
        msg.sender.transfer(_amount);
        balanceReceived[msg.sender].totalBalance -= _amount;
    }
    function getBalance() public view returns(Balance memory) {
        return balanceReceived[msg.sender];
    }
}

```

What you see is that you can retrieve the Balance easily, but you can't automatically get the "sub-mapping" (the mapping in the struct) value. You would have to write an extra getter-function, or you just use that mapping internally in your Smart Contract.

Of course, this is just an exemplary Smart Contract, but you will see later how we use mapping of mappings later in the Supply Chain Example.

On to the next Lab!

Last update: April 23, 2021

11. Exception Handling

11.1 Exception Handling: Require, Assert and Revert in Solidity

In this Lab you will learn more about Exception handling. At the end of the Lab I want you to be fully aware of when and how to use require, assert and revert.

How these behave with transactions and also between Smart Contracts.

11.1.1 What You Know At The End Of The Lab

💡 How to validate user input with require

💡 How to validate invariants with assert

💡 Observe Transactions and understand the reason why they are failing

11.1.2 Prerequisites - You need:

1. Chrome or Firefox browser.
2. An Internet connection
3. About 60 Minutes of your precious time 💡

11.1.3 Videos

💡 Full Video Walkthrough: <https://www.udemy.com/course/blockchain-developer/?referralCode=E8611DF99D7E491DFD96>

11.1.4 Get Started

💡 Let's get started!

⚠️ Using Solidity 0.6

In this lecture we deliberately using an older version of Solidity to demonstrate integer rollover assertion. This won't be necessary anymore with Solidity 0.8, but it is still a very common scenario in many recent DeFi Startups who are not yet using Solidity 0.8.

Last update: May 21, 2021

11.2 The Smart Contract

Let's start with this basic Smart Contract. As mentioned before, **it's written in Solidity 0.6**, not the latest version, because of the integer roll-over example that we will demonstrate.

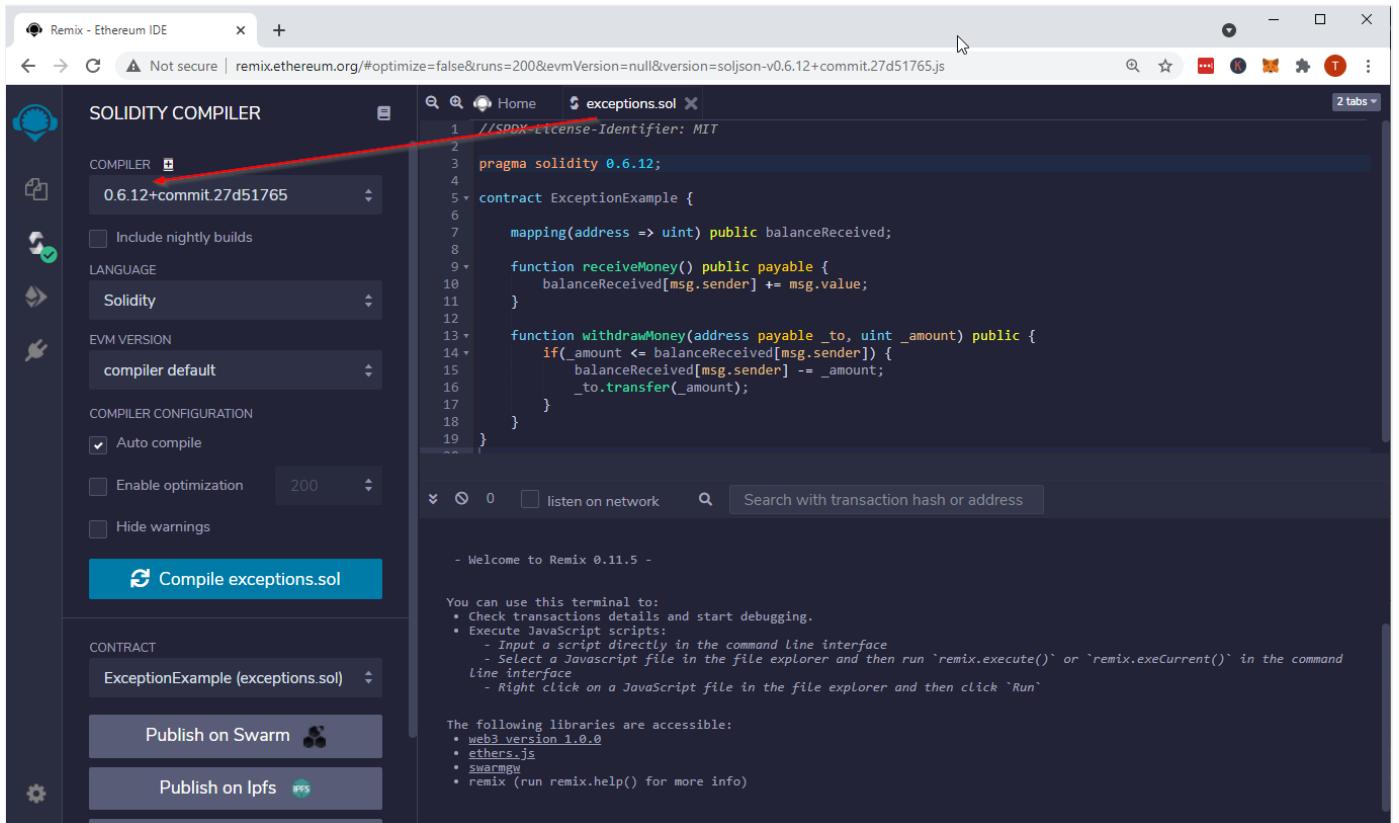
```
// SPDX-License-Identifier: MIT
pragma solidity 0.6.12;

contract ExceptionExample {
    mapping(address => uint) public balanceReceived;

    function receiveMoney() public payable {
        balanceReceived[msg.sender] += msg.value;
    }

    function withdrawMoney(address payable _to, uint _amount) public {
        if(_amount <= balanceReceived[msg.sender]) {
            balanceReceived[msg.sender] -= _amount;
            _to.transfer(_amount);
        }
    }
}
```

Add this Smart Contract to Remix. The correct Solidity Compiler Version should be selected automatically, but double check, to make sure everything is in order:



Okay, what does the Smart Contract do? It's a simplistic wallet contract.

1. You can send Ether to the Smart Contract (via `receiveMoney`).
2. You can withdraw Ether via `withdrawMoney`
3. The Balance of *your* account is stored in the `balanceReceived` mapping.

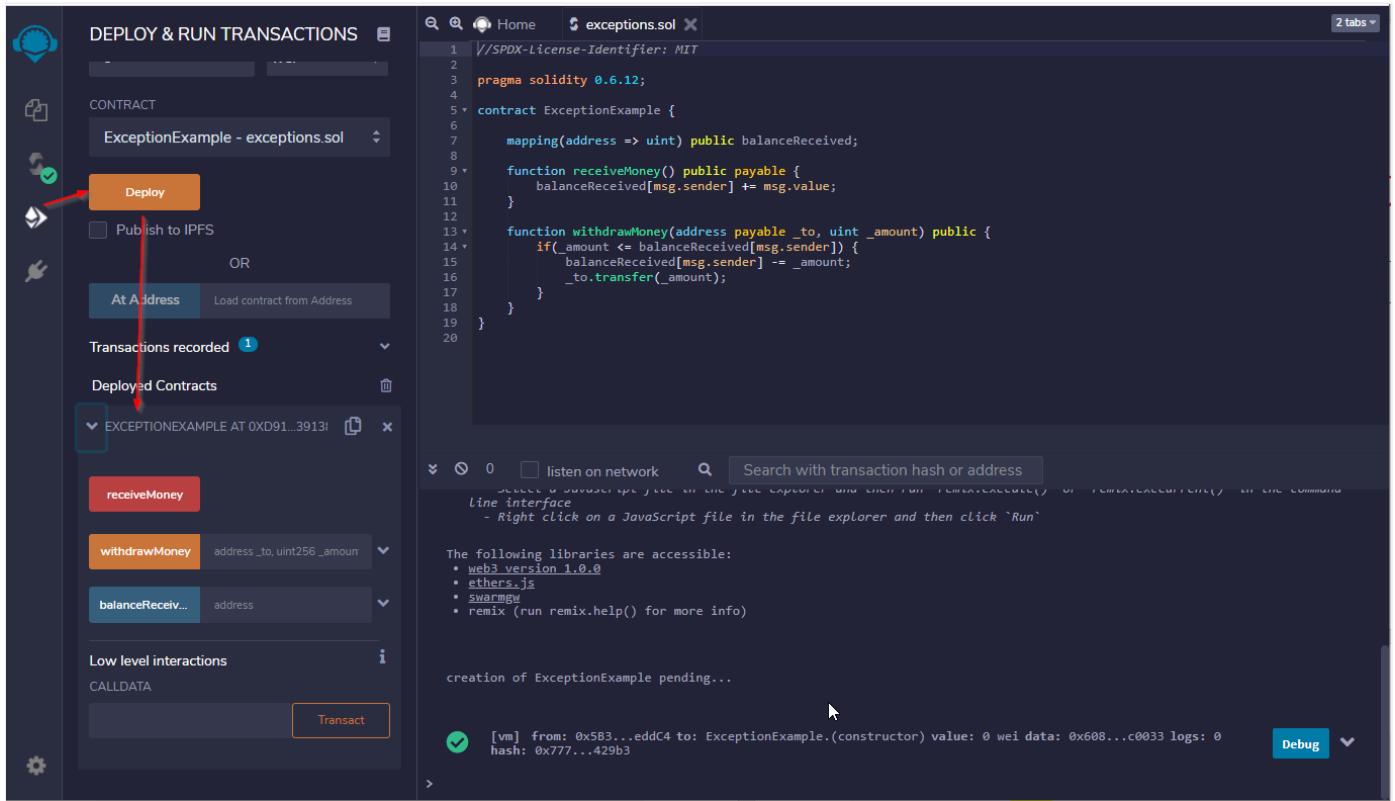
So far so good. Pay attention to the `withdrawMoney` function. There is a if-else control structure. If you don't have enough balance, then simply nothing happens. That is not ideal, there is no user-feedback.

Let's give it a try!

Last update: May 21, 2021

11.3 Try the Smart Contract

Deploy the Smart Contract. Head over to the "Deploy & Run Transactions" Plugin and Deploy it.



1. Copy your address into the withdraw money field.
2. Enter a number, like 1000, and
3. Hit withdrawMoney

You see, the transaction works without any problem. That's not good, because internally nothing happened and the user has the feedback that he just did a withdrawal for 1000 wei. Although nothing happened.

The screenshot shows the Truffle UI interface. On the left, there's a sidebar with deployment options like 'Deploy' and 'Publish to IPFS'. The main area displays a transaction record for a 'receiveMoney' call. A red arrow points from the sidebar's green checkmark icon to the transaction status field in the main panel, which shows 'true Transaction mined and execution succeed'.

Field	Value
status	true Transaction mined and execution succeed
transaction hash	0x1b974585a0da666a040f3a5126258633d6cd0e146807272ce680dd9ceb854d8b
from	0x5B38Da6a701c568545dCfcB03FcB875f56beddc4
to	ExceptionExample.receiveMoney() 0xd9145CCE52D386f254917e481e844e9943F39138
gas	3000000 gas
transaction cost	23091 gas
execution cost	1819 gas
hash	0x1b974585a0da666a040f3a5126258633d6cd0e146807272ce680dd9ceb854d8b
input	0x6d2...6ec18
decoded input	{}
decoded output	{}
logs	[]
value	0 wei

Try yourself first

Before heading to the next page, try yourself first to replace the if/else with a `require()`

Require is here for user-input validation and if it evaluates to false, it will throw an exception.

For example `require(false)` or `require(1 == 0)` will throw an exception. You can optionally add an error message `require(false, "Some Error Message")`

Last update: May 21, 2021

11.4 Add a Require

Alright, now it's time to add a require instead of the if/else control structure. Did you try? Let's compare our code:

```
// SPDX-License-Identifier: MIT

pragma solidity 0.6.12;

contract ExceptionExample {
    mapping(address => uint) public balanceReceived;

    function receiveMoney() public payable {
        balanceReceived[msg.sender] += msg.value;
    }

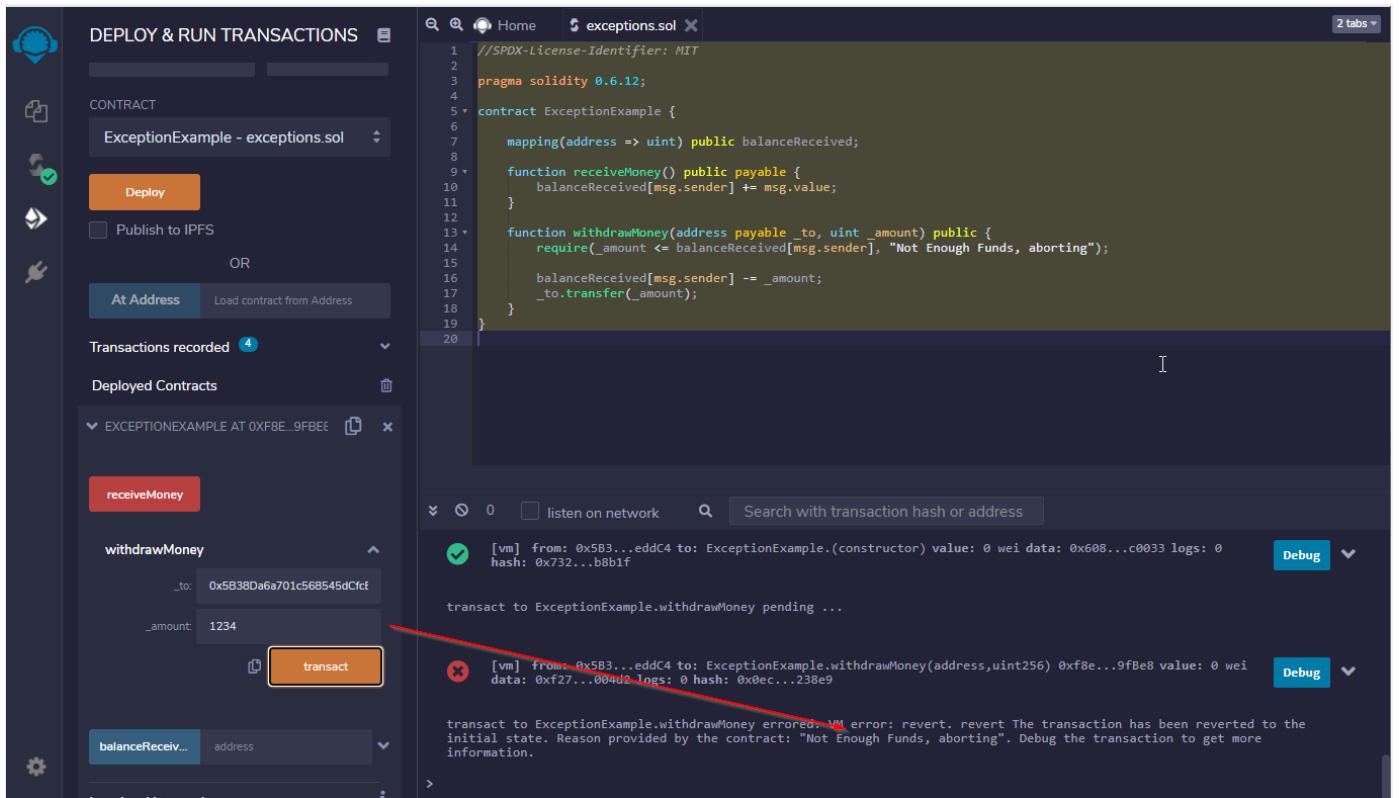
    function withdrawMoney(address payable _to, uint _amount) public {
        require(_amount <= balanceReceived[msg.sender], "Not Enough Funds, aborting");

        balanceReceived[msg.sender] -= _amount;
        _to.transfer(_amount);
    }
}
```

If you run this now and try to withdraw more Ether than you have, it will output an error. Repeat the steps from before:

1. Deploy a new Instance!
2. Copy your address
3. Enter an amount
4. Click on "withdrawMoney"

Observe the log window:



How cool is that! Not only your transaction fails, which is what we want, we also get proper feedback to the user. Great! But if we have require statements, what are assert for?

Let's check it out!

Last update: May 21, 2021

11.5 Assert to check Invariants

Assert is used to check invariants. Those are states our contract or variables should never reach, ever. For example, if we decrease a value then it should never get bigger, only smaller.

Let's change a few things in our Smart Contract to add an integer roll-over bug that we can easily trigger.

⚠ Bug

This contract has an intentional limitation, which we will use to trigger a bug. To subsequently fix it.

```
// SPDX-License-Identifier: MIT
pragma solidity 0.6.12;
contract ExceptionExample {
    mapping(address => uint64) public balanceReceived;

    function receiveMoney() public payable {
        balanceReceived[msg.sender] += uint64(msg.value);
    }

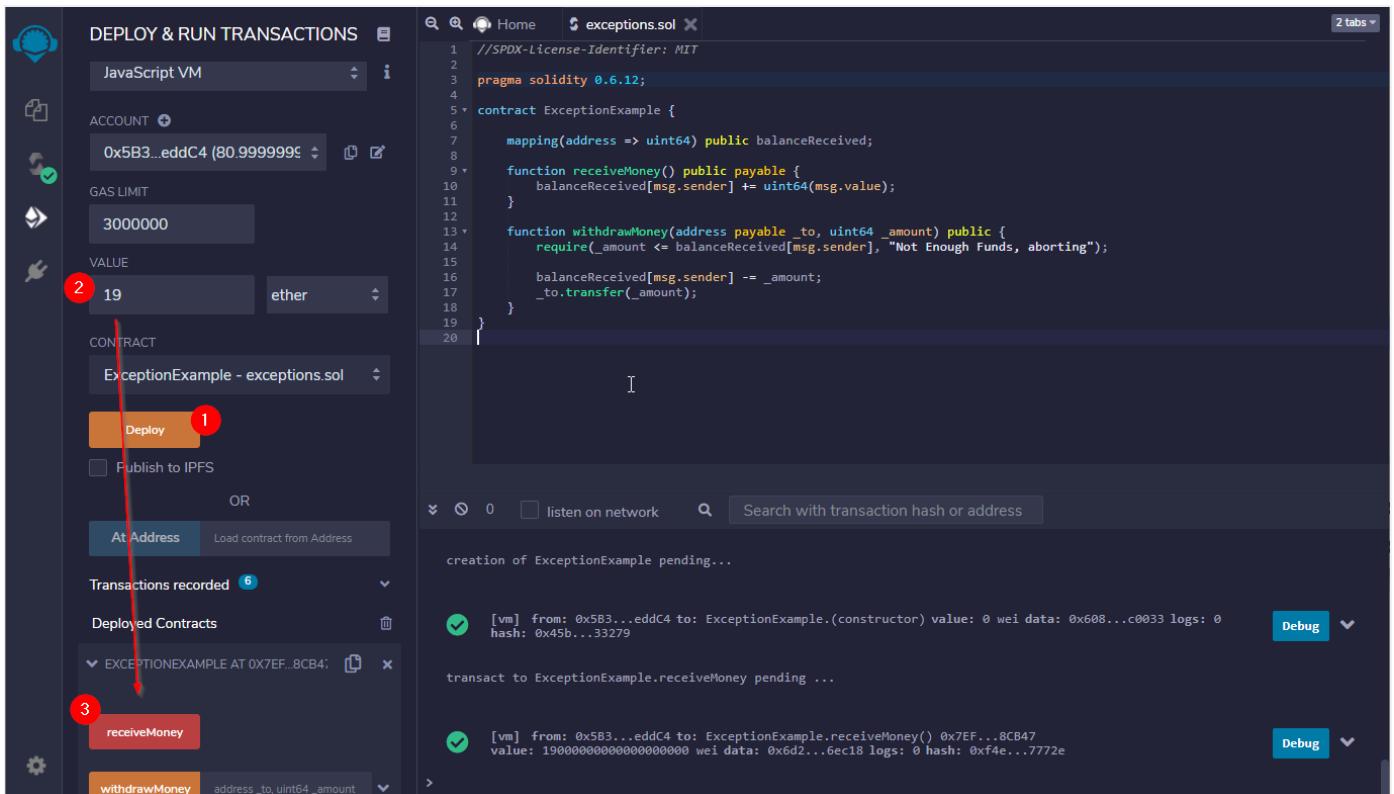
    function withdrawMoney(address payable _to, uint64 _amount) public {
        require(_amount <= balanceReceived[msg.sender], "Not Enough Funds, aborting");

        balanceReceived[msg.sender] -= _amount;
        _to.transfer(_amount);
    }
}
```

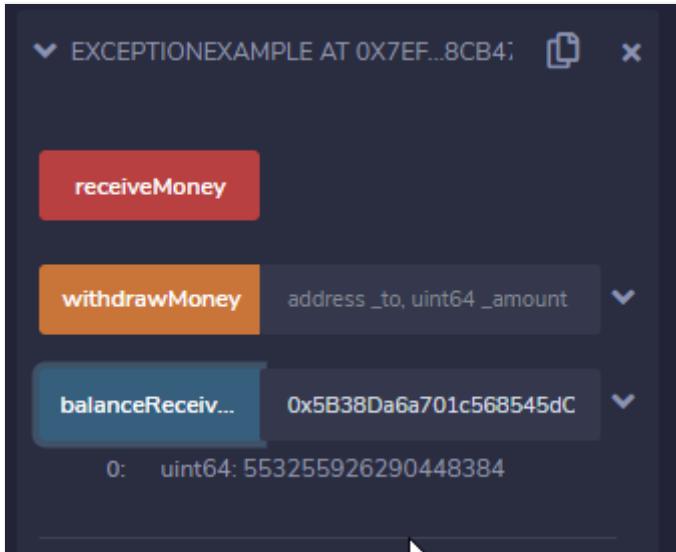
1. Deploy a new Contract Instance

2. Enter 19 **Ether** into the Value field

3. Hit "receiveMoney"



The Transaction goes through. Let's check our balance, we should have 190000000000000000000000 Wei, or?



That's only 553255926290448384 Wei, or around 0.553 Ether. Where is the rest? What happened?

We are storing the balance in an uint64. Unsigned integers go from 0 to 2^{n-1} , so that's $2^{64}-1$ or 18446744073709551615. So, it can store a max of 18.4467... Ether. We sent 19 Ether to the contract. It automatically rolls over to 0. So, we end up with $190000000000000000000000 - 18446744073709551615 - 1$ (the 0 value) = 553255926290448384.

How can we fix it?

11.5.1 Add an Assert to check invariants

Asserts are here to check states of your Smart Contract that should never be violated. For example: a balance can only get *bigger* if we *add* values or get smaller if we *reduce* values.

```
// SPDX-License-Identifier: MIT
pragma solidity 0.6.12;
contract ExceptionExample {
    mapping(address => uint64) public balanceReceived;

    function receiveMoney() public payable {
        assert(msg.value == uint64(msg.value));
        balanceReceived[msg.sender] += uint64(msg.value);
        assert(balanceReceived[msg.sender] >= uint64(msg.value));
    }

    function withdrawMoney(address payable _to, uint64 _amount) public {
        require(_amount <= balanceReceived[msg.sender], "Not Enough Funds, aborting");
        assert(balanceReceived[msg.sender] >= balanceReceived[msg.sender] - _amount);
        balanceReceived[msg.sender] -= _amount;
        _to.transfer(_amount);
    }
}
```

Run it again. Try to input 20 Ether. Or also try run two transactions with 10 Ether each, so it doesn't overflow for the transaction itself, but for the second assertion, where it checks if the balance is still valid.

Last update: June 23, 2021

11.6 Understanding Try/Catch

There is a new concept in Solidity since Solidity 0.6, which allows for basic try/catch inside a Smart Contract. Before that you had to use constructs like address.call (which we will do later in the course as well). But here I quickly want to give you a hint of what's possible now with Error handling.

Let's create a Smart Contract which will always fail to execute.

Create a new file in Remix with the following content:

```
// SPDX-License-Identifier: MIT
pragma solidity 0.8.4;

contract WillThrow {
    function aFunction() public {
        require(false, "Error message");
    }
}
```

Now let's add a contract directly underneath that catches the error within a function call and instead emits an event with the error message. I am aware that we haven't covered events quite yet, so, let me quickly explain what happens. It will catch the error, and instead of unsuccessfully showing an error, it will successfully mine the transaction. During the transaction it will emit an event that shows the error message. You can see it later in the transaction logs.

```
// SPDX-License-Identifier: MIT
pragma solidity 0.8.4;

contract WillThrow {
    function aFunction() public {
        require(false, "Error message");
    }
}

contract ErrorHandling {
    event ErrorLogging(string reason);
    function catchError() public {
        WillThrow will = new WillThrow();
        try will.aFunction() {
            //here we could do something if it works
        } catch Error(string memory reason) {
            emit ErrorLogging(reason);
        }
    }
}
```

Head over to the Deploy and Run Transactions Plugin and Deploy the "ErrorHandling" Contract:

The screenshot shows the Remix Ethereum IDE interface. On the left, the 'DEPLOY & RUN TRANSACTIONS' sidebar is visible, showing a transaction record for 'ERRORHANDLING AT 0XDA0...42B53' with a status of 'mined' and a transaction hash. The main area displays the Solidity code for 'trycatch.sol' which includes a 'WillThrow' contract that reverts with an error message, and an 'ErrorHandler' contract that catches this error and logs it. The bottom right pane shows the transaction details, including the event 'ErrorLogging' with the reason 'Error message'.

You can see in the logs on the bottom right side that the transaction is mined successfully. And when you open the transaction details you see an event with the error message:

The screenshot shows the same Remix interface after the transaction has been mined. The transaction details pane now includes a 'logs' section. A red arrow points to this section, which shows the event 'ErrorLogging' with the argument 'Error message'.

I know, this is a lot of new stuff which we haven't covered in depth yet. The point here is that Try/Catch fits into the exception handling and this is the most simplistic example I could come up with. It's something you should've seen before going on with the rest of the course. Now back to the content!

Last update: May 21, 2021

12. Fallback Function / Constructor / View and Pure

12.1 Fallback Function, View/Pure Functions, Constructor

In this Lab you will learn more about the Fallback Functions `receive()` and `fallback()`, then more about reading functions like `view` and `pure` and also about the constructor, to set initial values of your Smart Contract.

12.1.1 What You Know At The End Of The Lab

View and Pure Functions

Receive fallback function

Fallback function

The Constructor

12.1.2 Prerequisites - You need:

1. Chrome or Firefox browser.
2. An Internet connection
3. About 60 Minutes of your precious time

12.1.3 Videos

Full Video Walkthrough: <https://www.udemy.com/course/blockchain-developer/?referralCode=E8611DF99D7E491DFD96>

12.1.4 Get Started

Let's get started!

Using Solidity 0.8

These labs were updated to Solidity 0.8 and can differ from the videos slightly. Please pay attention to the callouts where appropriate.

Last update: May 23, 2021

12.2 Contract Example

Let's start with a simple wallet-like Smart Contract that you probably know already from previous labs:

```
// SPDX-License-Identifier: MIT

pragma solidity 0.8.3;

contract FunctionsExample {

    mapping(address => uint) public balanceReceived;

    function receiveMoney() public payable {
        assert(balanceReceived[msg.sender] + msg.value >= balanceReceived[msg.sender]);
        balanceReceived[msg.sender] += msg.value;
    }

    function withdrawMoney(address payable _to, uint _amount) public {
        require(_amount <= balanceReceived[msg.sender], "not enough funds.");
        assert(balanceReceived[msg.sender] >= balanceReceived[msg.sender] - _amount);
        balanceReceived[msg.sender] -= _amount;
        _to.transfer(_amount);
    }
}
```

12.2.1 Try the Smart Contract

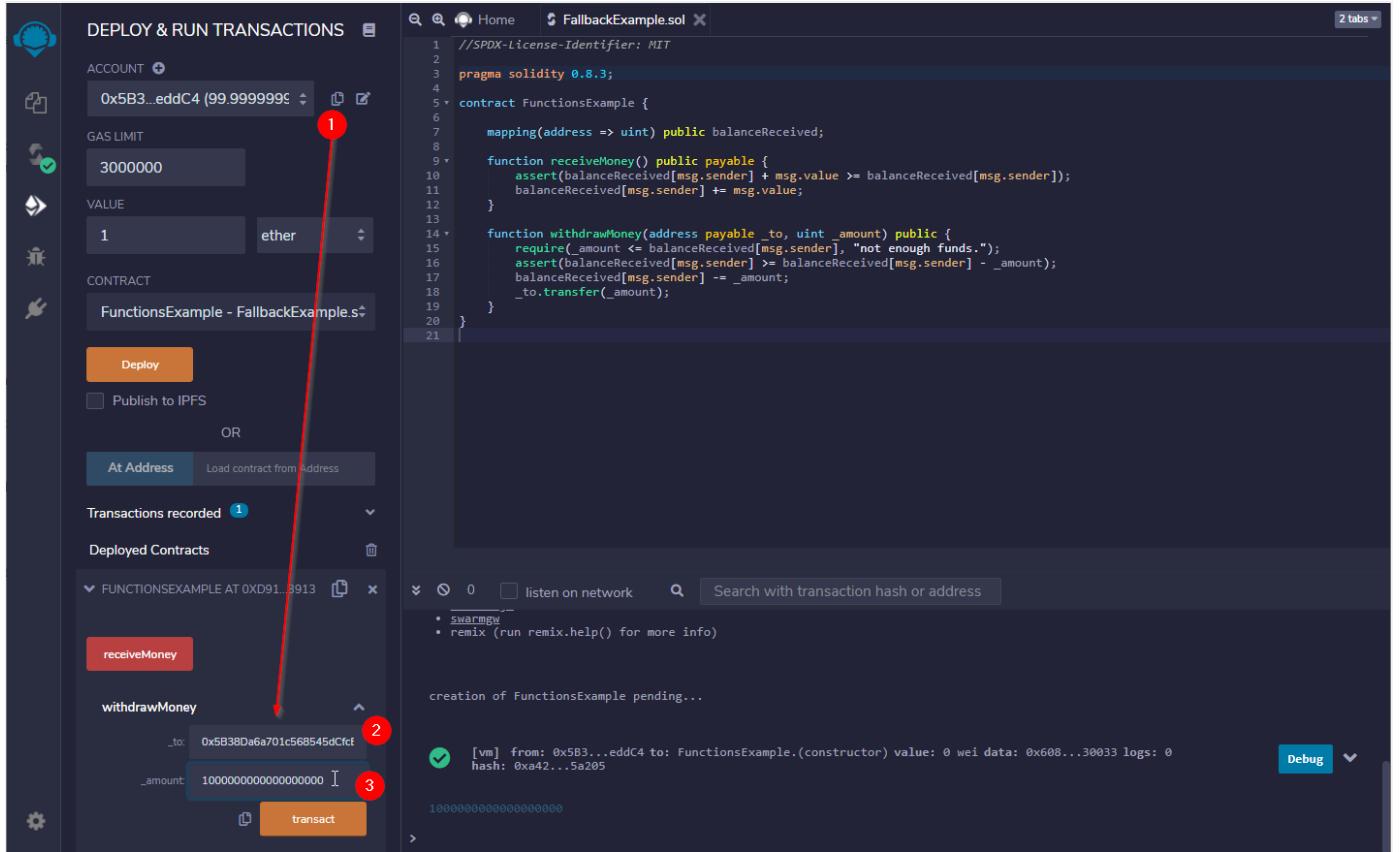
What does the contract do? Let's give it a try! Head over to the Deploy and Run Transactions tab.

1. Deploy the Contract
2. Ether 1 Ether in the input field
3. Send it to the receive Money Function

The screenshot shows the Remix IDE interface. On the left, the 'DEPLOY & RUN TRANSACTIONS' sidebar is open, showing the environment set to 'JavaScript VM', account '0x5B3...eddC4 (99.99999999999999)', gas limit '3000000', and value '1 ether'. The main area displays the Solidity code for the 'FunctionsExample' contract, which includes functions for receiving and withdrawing money. A transaction record for the constructor deployment is visible at the bottom.

Great, you have 1 Ether in your on-chain Wallet. Let's bring it back out!

1. Copy your address
2. Enter it into the withdraw money address field
3. Enter 1 Ether in Wei (10^{18}): 1000000000000000000 into the amount field



Superb, you got your Ether back out.

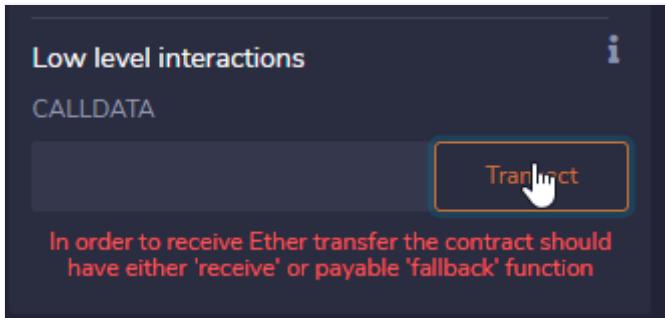
12.2.2 Problem

Right now, if you want to deposit Ether into the Smart Contract, you need to directly interact with the receiveMoney function. There is no way to simply send 1 Ether to the Contract address and let it deal with the rest. It would simply error out! Give it a try:

1. Enter 1 Ether into the input field
2. Hit the "transact" button within the low-level interaction section

The screenshot shows the Truffle UI interface. On the left, there's a sidebar with icons for deploying contracts, publishing to IPFS, and other tools. The main area has tabs for 'Home' and 'FallbackExample.sol'. The code editor shows a Solidity contract named 'FunctionsExample' with two functions: 'receiveMoney' and 'withdrawMoney'. Below the code, under 'Transactions recorded', it shows a deployed contract at address 'FUNCTIONSEXAMPLE AT 0xD91...3913'. It lists two transactions: one for 'receiveMoney' and one for 'withdrawMoney'. Both transactions are shown as pending. A red circle with the number '2' is placed over the 'Transact' button for the withdrawMoney transaction.

You will see it will produce an error that looks like this or similar:



Let's add a low level fallback function so we can simply send Ether to our Wallet...

Last update: May 23, 2021

12.3 The Receive Fallback Function

⚠ Solidity 0.6/0.8 Update

Prior Solidity 0.6 the fallback function was simply an anonymous function that looked like this:

```
function () external {  
}
```

It's now two different functions. `receive()` to receive money and `fallback()` to just interact with the Smart Contract without receiving Ether. This example uses the updated version.

Let's add a receive fallback function to the Smart Contract so we can simply send 1 Ether to the Contract without directly interacting with a concrete function.

```
// SPDX-License-Identifier: MIT  
  
pragma solidity 0.8.3;  
  
contract FunctionsExample {  
  
    mapping(address => uint) public balanceReceived;  
  
    function receiveMoney() public payable {  
        assert(balanceReceived[msg.sender] + msg.value >= balanceReceived[msg.sender]);  
        balanceReceived[msg.sender] += msg.value;  
    }  
  
    function withdrawMoney(address payable _to, uint _amount) public {  
        require(_amount <= balanceReceived[msg.sender], "not enough funds.");  
        assert(balanceReceived[msg.sender] >= balanceReceived[msg.sender] - _amount);  
        balanceReceived[msg.sender] -= _amount;  
        _to.transfer(_amount);  
    }  
  
    receive() external payable {  
        receiveMoney();  
    }  
}
```

Let's try this again:

1. Deploy a new Version
2. Enter 1 Ether in the value field
3. Hit the Transact button
4. Observe the Transaction Log, see that the transaction goes through now.

The screenshot shows the Truffle UI interface. On the left, there's a sidebar with various icons. The main area has tabs for 'Home' and 'FallbackExample.sol'. The code editor shows a Solidity contract named 'FunctionsExample' with several functions: receiveMoney(), withdrawMoney(address payable _to, uint _amount), and balanceReceived(address). Below the code, the 'Transactions recorded' section shows a deployed contract at address 0xD7A...F771 with three functions listed: receiveMoney, withdrawMoney, and balanceReceived. The 'Low level interactions' section contains a 'CALldata' section with a 'Transact' button. A red circle labeled '1' is over the 'Deploy' button. A red circle labeled '2' is over the 'VALUE' input field set to '1 ether'. A red circle labeled '3' is over the 'Transact' button in the 'Low level interactions' section.

```
// SPDX-License-Identifier: MIT
pragma solidity 0.8.3;
contract FunctionsExample {
    mapping(address => uint) public balanceReceived;
    function receiveMoney() public payable {
        assert(balanceReceived[msg.sender] + msg.value >= balanceReceived[msg.sender]);
        balanceReceived[msg.sender] += msg.value;
    }
    function withdrawMoney(address payable _to, uint _amount) public {
        require(_amount <= balanceReceived[msg.sender], "not enough funds.");
        assert(balanceReceived[msg.sender] >= balanceReceived[msg.sender] - _amount);
        balanceReceived[msg.sender] -= _amount;
        _to.transfer(_amount);
    }
    receive() external payable {
        receiveMoney();
    }
}
```

Did you see it? Just works like this. It even says `.(receive)` in the transaction. That's great!

Now onto the constructor!

Last update: May 23, 2021

12.4 The Solidity Constructor

A constructor is a function that is called once during deployment of the Smart Contract. It's also called once only and can't be called again afterwards.

This lets you set specific things in your Smart Contract during deployment. For example, you could specify who deployed the Smart Contract - and then let only that person destroy the Smart Contract. Like an owner. Let's try this!

```
// SPDX-License-Identifier: MIT

pragma solidity 0.8.3;

contract FunctionsExample {

    mapping(address => uint) public balanceReceived;

    address payable public owner;

    constructor() {
        owner = payable(msg.sender);
    }

    function destroySmartContract() public {
        require(msg.sender == owner, "You are not the owner");
        selfdestruct(owner);
    }

    function receiveMoney() public payable {
        assert(balanceReceived[msg.sender] + msg.value >= balanceReceived[msg.sender]);
        balanceReceived[msg.sender] += msg.value;
    }

    function withdrawMoney(address payable _to, uint _amount) public {
        require(_amount <= balanceReceived[msg.sender], "not enough funds.");
        assert(balanceReceived[msg.sender] >= balanceReceived[msg.sender] - _amount);
        balanceReceived[msg.sender] -= _amount;
        _to.transfer(_amount);
    }

    receive() external payable {
        receiveMoney();
    }
}
```

The screenshot shows the Remix IDE interface. On the left, there's a sidebar with various icons for deploying, running, and publishing contracts. The main area has tabs for 'Home' and 'FallbackExample.sol'. The code editor contains the Solidity code provided above. Below the code editor, there are sections for 'ENVIRONMENT' (set to 'JavaScript VM'), 'ACCOUNT' (set to '0x5B3...eddC4 (100 ether)'), 'GAS LIMIT' (set to '3000000'), and 'VALUE' (set to '0 wei'). A 'CONTRACT' section shows 'FunctionsExample - FallbackExample.sol'. At the bottom, there are buttons for 'Deploy' and 'Publish to IPFS', and a terminal window with some instructions and accessible libraries listed.

What does it do?

1. In the constructor it sets the owner address to the address who deployed the Smart Contract
2. Upon destruction, it checks who called the function.
 - a. If the owner called, then the Smart Contract is destroyed
 - b. If it is not the owner, then an error is thrown

12.4.1 Running the Smart Contract

Let's try this!

1. Deploy the Smart Contract
2. Check the owner address: you should see the same account as selected!
3. Destroy the Smart Contract
4. Click on the owner address again: it's zero now, because the Smart Contract is not longer existing.

It should work fine! No error.

Before hitting Destroy:

```
// SPDX-License-Identifier: MIT
pragma solidity 0.8.3;

contract FunctionsExample {
    mapping(address => uint) public balanceReceived;
    address payable public owner;

    constructor() {
        owner = payable(msg.sender);
    }

    function destroySmartContract() public {
        require(msg.sender == owner, "You are not the owner");
        selfdestruct(owner);
    }

    function receiveMoney() public payable {
        assert(balanceReceived[msg.sender] + msg.value >= balanceReceived[msg.sender]);
        balanceReceived[msg.sender] += msg.value;
    }

    function withdrawMoney(address payable _to, uint _amount) public {
        require(_amount <= balanceReceived[msg.sender], "not enough funds.");
        assert(balanceReceived[msg.sender] >= balanceReceived[msg.sender] - _amount);
        balanceReceived[msg.sender] -= _amount;
        _to.transfer(_amount);
    }

    receive() external payable {
        receiveMoney();
    }
}
```

creation of FunctionsExample pending...

[vm] from: 0x5B38Da6a701c568545dCfcB03FcB875f56beddC4 to: FunctionsExample.(constructor) value: 0 wei data: 0x608...30033 logs: 0 hash: 0x314...16fe1

call to FunctionsExample.owner()

call [call] from: 0x5B38Da6a701c568545dCfcB03FcB875f56beddC4 to: FunctionsExample.owner() data: 0x8da...5cb5b

After hitting Destroy:

```

// SPDX-License-Identifier: MIT
pragma solidity 0.8.3;
contract FunctionsExample {
    mapping(address => uint) public balanceReceived;
    address payable public owner;
    constructor() {
        owner = payable(msg.sender);
    }
    function destroySmartContract() public {
        require(msg.sender == owner, "You are not the owner");
        selfdestruct(owner);
    }
    function receiveMoney() public payable {
        assert(balanceReceived[msg.sender] + msg.value >= balanceReceived[msg.sender]);
        balanceReceived[msg.sender] += msg.value;
    }
    function withdrawMoney(address payable _to, uint _amount) public {
        require(_amount <= balanceReceived[msg.sender], "not enough funds.");
        assert(balanceReceived[msg.sender] >= balanceReceived[msg.sender] - _amount);
        balanceReceived[msg.sender] -= _amount;
        _to.transfer(_amount);
    }
    receive() external payable {
        receiveMoney();
    }
}

```

ContractDefinition FunctionsExample 0 reference(s)

Transactions recorded: 8

Deployed Contracts: FUNCTIONS EXAMPLE AT 0xD91...3913

Buttons: destroySmart..., receiveMoney, withdrawMoney, balanceReceived..., owner

Logs:

- [vm] From: 0x5B3...eddC4 to: FunctionsExample.destroySmartContract() 0xd91...39138 value: 0 wei
- [call] from: 0x5B380a6a701c568545dCfcB03Fc8875f56beddC4 to: FunctionsExample.owner() data: 0x8da...5cb5b

Executing the Constructor

The constructor is executed only during deployment. There is no way to execute the constructor code afterwards.

If you look at the interface of your Smart Contract (the buttons on the left side), there is "destroySmartContract", "receiveMoney", "withdrawMoney", "balanceReceived" and "owner", but no way to call the constructor code again. This is intentional and a feature of Solidity.

But what about the require statement?

Let's deploy a new version of the Smart Contract, but this time try to call `destroySmartContract` with a different account:

1. Deploy Smart Contract
2. Select a different account from the Accounts Dropdown
3. Hit the "destroySmartContract" Button

It should give you an error.

```

// SPDX-License-Identifier: MIT
pragma solidity 0.8.3;

contract FunctionsExample {
    mapping(address => uint) public balanceReceived;
    address payable public owner;

    constructor() {
        owner = payable(msg.sender);
    }

    function destroySmartContract() public {
        require(msg.sender == owner, "You are not the owner");
        selfdestruct(owner);
    }

    function receiveMoney() public payable {
        assert(balanceReceived[msg.sender] + msg.value >= balanceReceived[msg.sender]);
        balanceReceived[msg.sender] += msg.value;
    }

    function withdrawMoney(address payable _to, uint _amount) public {
        require(_amount <= balanceReceived[msg.sender], "not enough funds.");
        assert(balanceReceived[msg.sender] >= balanceReceived[msg.sender] - _amount);
        balanceReceived[msg.sender] -= _amount;
        _to.transfer(_amount);
    }

    receive() external payable {
        receiveMoney();
    }
}

```

Do you see the different Account when you hit "owner"?

12.4.2 Summary

Why is that so powerful?

We automatically set a variable depending on who deployed the Smart Contract. You can also have constructor arguments, just like any other function. It will be executed once and once only.

Last update: May 23, 2021

12.5 View and Pure Functions in Solidity

So far, we have mostly interacted and modified state variables from our Smart Contract. For example, when we write the owner, we modify a state variable. When we update the balance, we modify a state variable (`balanceReceived`).

For this, we needed to send a transaction. That works very transparently in Remix and also looks instantaneous and completely free of charge, but in reality it isn't. Modifying the State costs gas, is a concurrent operation that requires mining and doesn't return any values.

Reading values, on the other hand, is virtually free and doesn't require mining.

There are two types of reading functions:

1. view: Accessing state variables
2. pure: Not accessing state variables

12.5.1 View Function

Let's make our owner-variable private and instead add a simple getter function function

```
// SPDX-License-Identifier: MIT
pragma solidity 0.8.3;

contract FunctionsExample {
    mapping(address => uint) public balanceReceived;

    address payable owner;

    constructor() {
        owner = payable(msg.sender);
    }

    function getOwner() public view returns(address) {
        return owner;
    }

    function destroySmartContract() public {
        require(msg.sender == owner, "You are not the owner");
        selfdestruct(owner);
    }

    function receiveMoney() public payable {
        assert(balanceReceived[msg.sender] + msg.value >= balanceReceived[msg.sender]);
        balanceReceived[msg.sender] += msg.value;
    }

    function withdrawMoney(address payable _to, uint _amount) public {
        require(_amount <= balanceReceived[msg.sender], "not enough funds.");
        assert(balanceReceived[msg.sender] >= balanceReceived[msg.sender] - _amount);
        balanceReceived[msg.sender] -= _amount;
        _to.transfer(_amount);
    }

    receive() external payable {
        receiveMoney();
    }
}
```

```
// SPDX-License-Identifier: MIT
pragma solidity 0.8.3;

contract FunctionsExample {
    mapping(address => uint) public balanceReceived;
    address payable owner;

    constructor() {
        owner = payable(msg.sender);
    }

    function getOwner() public view returns(address) {
        return owner;
    }

    function destroySmartContract() public {
        require(msg.sender == owner, "You are not the owner");
        selfdestruct(owner);
    }

    function receiveMoney() public payable {
        assert(balanceReceived[msg.sender] + msg.value >= balanceReceived[msg.sender]);
        balanceReceived[msg.sender] += msg.value;
    }

    function withdrawMoney(address payable _to, uint _amount) public {
        require(_amount <= balanceReceived[msg.sender], "not enough funds.");
        assert(balanceReceived[msg.sender] >= balanceReceived[msg.sender] - _amount);
        balanceReceived[msg.sender] -= _amount;
        _to.transfer(_amount);
    }

    receive() external payable {
        receiveMoney();
    }
}
```

Transactions recorded: 8

Deployed Contracts: FUNCTIONSEXAMPLE AT 0X652...BA59

Low-level interactions:

- destroySmart...
- receiveMoney
- withdrawMoney address _to, uint256 _amount
- balanceReceiv...
- getOwner

creation of FunctionsExample pending...

Let's give this a try: 1. Deploy the Smart Contract 2. click on "getOwner" 3. Observe the Transaction Log

creation of FunctionsExample pending...

1 [vm] from: 0xAb8...35cb2 to: FunctionsExample.(constructor) value: 0 wei data: 0x608...30033 logs: 0 hash: 0xa4e...07cf0

call to FunctionsExample.getOwner

2 [call] from: 0xAb8483F64d9C6d1EcF9b849Ae677dD3315835cb2 to: FunctionsExample.getOwner() data: 0x893...d20e8

You can observe that the deployment is a transaction, marked by the little green checkmark (1), while the reading operation is a call (2). In reality a transaction would need to get signed by a private key and mined by the network, while a reading operation does not need to get signed.

12.5.2 Pure Functions

So, view functions are reading functions - what are pure functions?

Pure functions are functions that are not accessing any state variables. They can call other pure functions, but not view functions.

Let's do a quick example:

```
// SPDX-License-Identifier: MIT

pragma solidity 0.8.3;

contract FunctionsExample {
    mapping(address => uint) public balanceReceived;

    address payable owner;

    constructor() {
        owner = payable(msg.sender);
    }

    function getOwner() public view returns(address) {
        return owner;
    }

    function convertWeiToEth(uint _amount) public pure returns(uint) {
        return _amount / 1 ether;
    }

    function destroySmartContract() public {
        require(msg.sender == owner, "You are not the owner");
        selfdestruct(owner);
    }

    function receiveMoney() public payable {
        assert(balanceReceived[msg.sender] + msg.value >= balanceReceived[msg.sender]);
        balanceReceived[msg.sender] += msg.value;
    }

    function withdrawMoney(address payable _to, uint _amount) public {
        require(_amount <= balanceReceived[msg.sender], "not enough funds.");
        assert(balanceReceived[msg.sender] >= balanceReceived[msg.sender] - _amount);
        balanceReceived[msg.sender] -= _amount;
        _to.transfer(_amount);
    }

    receive() external payable {
        receiveMoney();
    }
}
```

Let's run it:

1. Deploy a new Instance
2. Run "convertWeiToEth" with 100
3. Observe the Transaction log

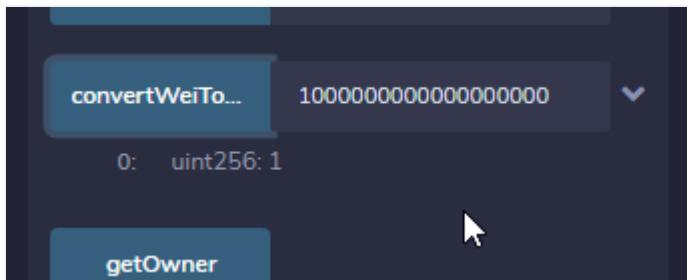
The screenshot shows the Truffle UI interface. On the left, the 'DEPLOY & RUN TRANSACTIONS' tab is active, displaying the 'FUNCTIONSEXAMPLE' contract at address 0x417...2600. It features several buttons: 'destroySmart...', 'receiveMoney', 'withdrawMoney', 'balanceReceiv...', 'convertWeiTo...', 'getOwner', and 'Low level interactions'. A red circle highlights the 'convertWeiTo...' button. On the right, the 'FallbackExample.sol' file is open in the code editor, showing the Solidity code. The code defines a contract with various functions, including pure functions for Wei-to-Ether conversion and balance withdrawal. The 'convertWeiToEth' function is highlighted with a red circle. The UI also shows transaction history and deployed contracts.

Do you know why the returned amount is 0? Think about it for a moment, then look into the solution!

i Why the amount is 0 solution

The amount is zero, because we return an integer. We divide $100 / 1000000000000000000000000000000 = 0.0000000000000001$. Integers in Solidity are cut off (not even rounded, or *always* rounded down).

If you enter 1000000000000000000000000000000 into the amount field, then the returned amount is 1 (1 Ether)



Alright, that's it, there's nothing much more to say about view and pure functions at this moment. On to the next lecture!

Last update: May 23, 2021

13. LAB: Shared Wallet

13.1 Project Shared Wallet

13.1.1 Real-World Use-Case for this Project

Allowance for Children per day/week/month to be able to spend a certain amount of funds.

Employers give employees an allowance for their travel expenses.

Businesses give contractors an allowance to spend a certain budget.

13.1.2 Development Goal

Have an on-chain wallet smart contract.

This wallet contract can store funds and let users withdraw again.

You can also give "allowance" to other, specific user-addresses.

Restrict the functions to specific user-roles (owner, user)

Re-Use existing smart contracts which are already audited to the greatest extent

13.1.3 Videos

Full Video Walkthrough: <https://www.udemy.com/course/blockchain-developer/?referralCode=E8611DF99D7E491DFD96>

13.1.4 Get Started

Let's get started by creating your **Basic Smart Contract**

Last update: May 23, 2021

13.2 We Define the Basic Smart Contract

This is the very basic smart contract. It can receive Ether and it's possible to withdraw Ether, but all in all, not very useful quite yet. Let's see if we can improve this a bit in the next step.

Sharedwallet.sol

```
// SPDX-License-Identifier: MIT

pragma solidity 0.8.1;

contract SharedWallet {

    function withdrawMoney(address payable _to, uint _amount) public {
        _to.transfer(_amount);
    }

    receive() external payable {

    }
}
```

Solidity Updates

Prior Solidity 0.6 the fallback function was simply called "function() external payable" - a Function without a name. Since Solidity 0.6 there are two different functions: one called fallback and the other one called "receive". Only "receive" can receive ether. You can read more about this in [my walkthrough!](#)

Also, the code in this lab has been ported to Solidity 0.8.

The most prominent change is the removal of the SafeMath library, since Solidity 0.8 doesn't do automatic integer rollovers anymore. Read more about this in the topic about [Overflow and Underflow](#). In the lab are notes where Solidity 0.8 changes come in.

Last update: May 23, 2021

13.3 Permissions: Allow only the Owner to Withdraw Ether

In this step we restrict withdrawal to the owner of the wallet. How can we determine the owner? It's the user who deployed the smart contract.

```
// SPDX-License-Identifier: MIT

pragma solidity 0.8.1;

contract SharedWallet {
    address owner;

    constructor() {
        owner = msg.sender;
    }

    modifier onlyOwner() {
        require(msg.sender == owner, "You are not allowed");
        _;
    }

    function withdrawMoney(address payable _to, uint _amount) public onlyOwner {
        _to.transfer(_amount);
    }

    receive() external payable {
    }
}
```

Whatch out that you also add the "onlyOwner" modifier to the withdrawMoney function!

Last update: May 23, 2021

13.4 Use Re-Usable Smart Contracts from OpenZeppelin

Having the owner-logic directly in one smart contract isn't very easy to audit. Let's break it down into smaller parts and re-use existing audited smart contracts from OpenZeppelin for that. The latest OpenZeppelin contract does not have an `isOwner()` function anymore, so we have to create our own. Note that the `owner()` is a function from the `Ownable.sol` contract.

```
// SPDX-License-Identifier: MIT

pragma solidity 0.8.1;

import "https://github.com/OpenZeppelin/openzeppelin-contracts/blob/master/contracts/access/Ownable.sol";

contract SharedWallet is Ownable {

    function isOwner() internal view returns(bool) {
        return owner() == msg.sender;
    }

    function withdrawMoney(address payable _to, uint _amount) public onlyOwner {
        _to.transfer(_amount);
    }

    receive() external payable {
    }
}
```

Last update: May 23, 2021

13.5 Permissions: Add Allowances for External Roles

In this step we are adding a mapping so we can store address => uint amounts. This will be like an array that stores [0x123546...] an address, to a specific number. So, we always know how much someone can withdraw. We also add a new modifier that checks: Is it the owner itself or just someone with allowance?

```
// SPDX-License-Identifier: MIT

pragma solidity 0.8.1;

import "https://github.com/OpenZeppelin/openzeppelin-contracts/blob/master/contracts/access/Ownable.sol";

contract SharedWallet is Ownable {
    function isOwner() internal view returns(bool) {
        return owner() == msg.sender;
    }

    mapping(address => uint) public allowance;

    function addAllowance(address _who, uint _amount) public onlyOwner {
        allowance[_who] = _amount;
    }

    modifier ownerOrAllowed(uint _amount) {
        require(isOwner() || allowance[msg.sender] >= _amount, "You are not allowed!");
        _;
    }

    function withdrawMoney(address payable _to, uint _amount) public ownerOrAllowed(_amount) {
        require(_amount <= address(this).balance, "Contract doesn't own enough money");
        _to.transfer(_amount);
    }

    receive() external payable {
    }
}
```

Did you catch the bug?

Have a look at the withdrawMoney functionality and think it through!

In the next lecture we're going to improve our smart contract a little bit and avoid double spending.

Last update: May 23, 2021

13.6 Improve/Fix Allowance to avoid Double-Spending

Without reducing the allowance on withdrawal, someone can continuously withdraw the same amount over and over again. We have to reduce the allowance for everyone other than the owner.

```
function reduceAllowance(address _who, uint _amount) internal ownerOrAllowed(_amount) {
    allowance[_who] -= _amount;
}

function withdrawMoney(address payable _to, uint _amount) public ownerOrAllowed(_amount) {
    require(_amount <= address(this).balance, "Contract doesn't own enough money");
    if(!isOwner()) {
        reduceAllowance(msg.sender, _amount);
    }
    _to.transfer(_amount);
}
```

Last update: May 23, 2021

13.7 Improve Smart Contract Structure

Now we know our basic functionality, we can structure the smart contract differently. To make it easier to read, we can break the functionality down into two distinct smart contracts.

Note

Note that since Allowance is Ownable, and the SharedWallet is Allowance, therefore by commutative property, SharedWallet is also Ownable.

```
// SPDX-License-Identifier: MIT

pragma solidity 0.8.1;

import "https://github.com/OpenZeppelin/openzeppelin-contracts/blob/master/contracts/access/Ownable.sol";

contract Allowance is Ownable {
    function isOwner() internal view returns(bool) {
        return owner() == msg.sender;
    }

    mapping(address => uint) public allowance;

    function setAllowance(address _who, uint _amount) public onlyOwner {
        allowance[_who] = _amount;
    }

    modifier ownerOrAllowed(uint _amount) {
        require(isOwner() || allowance[msg.sender] >= _amount, "You are not allowed!");
        _;
    }

    function reduceAllowance(address _who, uint _amount) internal ownerOrAllowed(_amount) {
        allowance[_who] -= _amount;
    }
}

contract SharedWallet is Allowance {

    function withdrawMoney(address payable _to, uint _amount) public ownerOrAllowed(_amount) {
        require(_amount <= address(this).balance, "Contract doesn't own enough money");
        if(!isOwner()) {
            reduceAllowance(msg.sender, _amount);
        }
        _to.transfer(_amount);
    }

    receive() external payable {
    }
}
```

Both contracts are still in the same file, so we don't have any imports (yet). That's something for another lecture later on. Right now, the important part to understand is inheritance.

Last update: May 23, 2021

13.8 Add Events in the Allowances Smart Contract

One thing that's missing is events.

```
// SPDX-License-Identifier: MIT
pragma solidity 0.8.1;

import "https://github.com/OpenZeppelin/openzeppelin-contracts/blob/master/contracts/access/Ownable.sol";

contract Allowance is Ownable {

    event AllowanceChanged(address indexed _forWho, address indexed _byWhom, uint _oldAmount, uint _newAmount);
    mapping(address => uint) public allowance;

    function isOwner() internal view returns(bool) {
        return owner() == msg.sender;
    }

    function setAllowance(address _who, uint _amount) public onlyOwner {
        emit AllowanceChanged(_who, msg.sender, allowance[_who], _amount);
        allowance[_who] = _amount;
    }

    modifier ownerOrAllowed(uint _amount) {
        require(isOwner() || allowance[msg.sender] >= _amount, "You are not allowed!");
        _;
    }

    function reduceAllowance(address _who, uint _amount) internal ownerOrAllowed(_amount) {
        emit AllowanceChanged(_who, msg.sender, allowance[_who], allowance[_who] - _amount);
        allowance[_who] -= _amount;
    }
}

contract SharedWallet is Allowance {
    //...
}
```

Last update: May 23, 2021

13.9 Add Events in the SharedWallet Smart Contract

Obviously we also want to have events in our shared wallet, when someone deposits or withdraws funds:

```
contract SharedWallet is Allowance {  
  
    event MoneySent(address indexed _beneficiary, uint _amount);  
    event MoneyReceived(address indexed _from, uint _amount);  
  
    function withdrawMoney(address payable _to, uint _amount) public ownerOrAllowed(_amount) {  
        require(_amount <= address(this).balance, "Contract doesn't own enough money");  
        if(!isOwner()) {  
            reduceAllowance(msg.sender, _amount);  
        }  
        emit MoneySent(_to, _amount);  
        _to.transfer(_amount);  
    }  
  
    receive() external payable {  
        emit MoneyReceived(msg.sender, msg.value);  
    }  
}
```

Last update: May 23, 2021

13.10 Add the SafeMath Library safeguard Mathematical Operations

Directly from the [SafeMath Library source code](#):

Arithmetic operations in Solidity wrap on overflow. This can easily result in bugs, because programmers usually assume that an overflow raises an error, which is the standard behavior in high level programming languages. `SafeMath` restores this intuition by reverting the transaction when an operation overflows.

Solidity changed

In a recent update of Solidity the Integer type variables cannot overflow anymore. Read more about the following [Solidity 0.8 release notes!](#).

Add the following code only if you are using solidity < 0.8!!!

```
pragma solidity ^0.6.1;

import "https://github.com/OpenZeppelin/openzeppelin-contracts/blob/master/contracts/access/Ownable.sol";
import "https://github.com/OpenZeppelin/openzeppelin-contracts/contracts/math/SafeMath.sol";

contract Allowance is Ownable {

    using SafeMath for uint;

    event AllowanceChanged(address indexed _forWho, address indexed _byWhom, uint _oldAmount, uint _newAmount);
    mapping(address => uint) public allowance;

    function isOwner() internal view returns(bool) {
        return owner() == msg.sender;
    }

    function setAllowance(address _who, uint _amount) public onlyOwner {
        ...
    }

    modifier ownerOrAllowed(uint _amount) {
        ...
    }

    function reduceAllowance(address _who, uint _amount) internal ownerOrAllowed(_amount) {
        emit AllowanceChanged(_who, msg.sender, allowance[_who], allowance[_who].sub(_amount));
        allowance[_who] = allowance[_who].sub(_amount);
    }
}

contract SharedWallet is Allowance {
    ...
}
```

Last update: May 23, 2021

13.11 Remove the Renounce Ownership functionality

Now, let's remove the function to remove an owner. We simply stop this with a revert. Add the following function to the SharedWallet:

```
contract SharedWallet is Allowance {  
    ...  
    function renounceOwnership() public override onlyOwner {  
        revert("can't renounceOwnership here"); //not possible with this smart contract  
    }  
    ...  
}
```

Last update: May 23, 2021

13.12 Move the Smart Contracts into separate Files

As a last step, let's move the smart contracts into separate files and use import functionality:

Allowance.sol

```
// SPDX-License-Identifier: MIT

pragma solidity 0.8.1;

import "https://github.com/OpenZeppelin/openzeppelin-contracts/blob/master/contracts/access/Ownable.sol";

contract Allowance is Ownable {

    event AllowanceChanged(address indexed _forWho, address indexed _byWhom, uint _oldAmount, uint _newAmount);
    mapping(address => uint) public allowance;

    function isOwner() internal view returns(bool) {
        return owner() == msg.sender;
    }

    function setAllowance(address _who, uint _amount) public onlyOwner {
        emit AllowanceChanged(_who, msg.sender, allowance[_who], _amount);
        allowance[_who] = _amount;
    }

    modifier ownerOrAllowed(uint _amount) {
        require(isOwner() || allowance[msg.sender] >= _amount, "You are not allowed!");
       _;
    }

    function reduceAllowance(address _who, uint _amount) internal ownerOrAllowed(_amount) {
        emit AllowanceChanged(_who, msg.sender, allowance[_who], allowance[_who] - _amount);
        allowance[_who] -= _amount;
    }
}
```

SharedWallet.sol

```
// SPDX-License-Identifier: MIT

pragma solidity 0.8.1;

import "./Allowance.sol";

contract SharedWallet is Allowance {

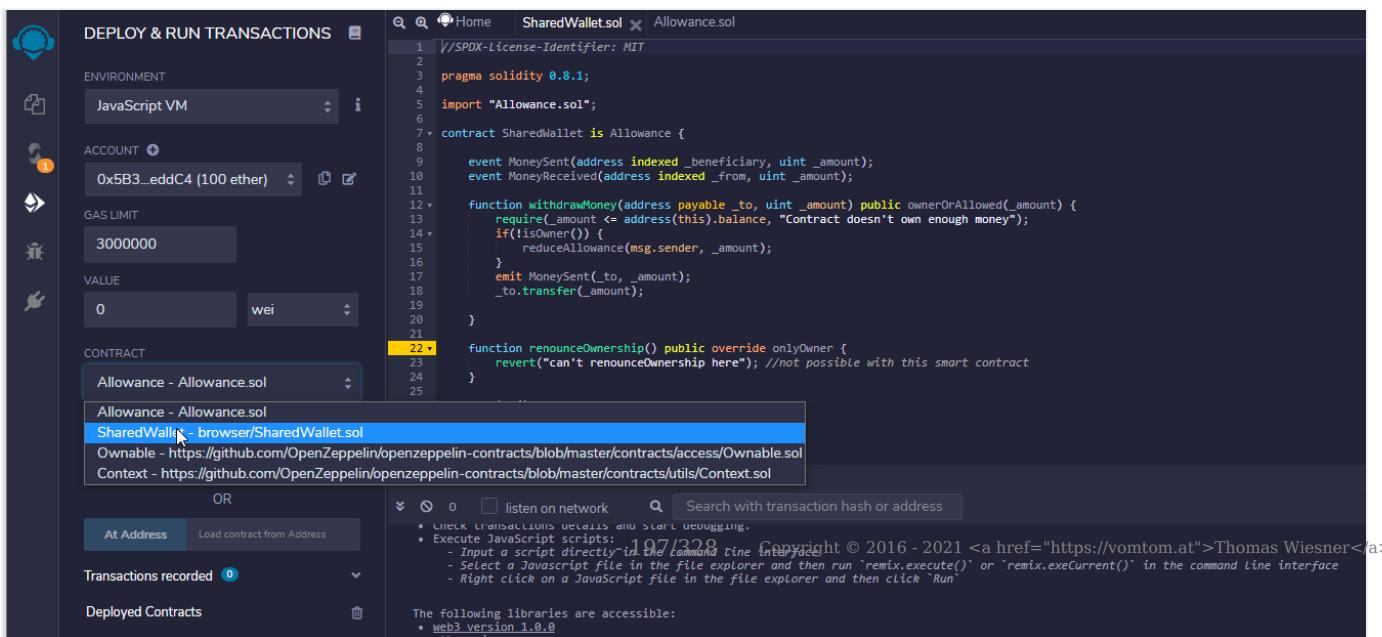
    event MoneySent(address indexed _beneficiary, uint _amount);
    event MoneyReceived(address indexed _from, uint _amount);

    function withdrawMoney(address payable _to, uint _amount) public ownerOrAllowed(_amount) {
        require(_amount <= address(this).balance, "Contract doesn't own enough money");
        if(!isOwner()) {
            reduceAllowance(msg.sender, _amount);
        }
        emit MoneySent(_to, _amount);
        _to.transfer(_amount);
    }

    function renounceOwnership() public override onlyOwner {
        revert("can't renounceOwnership here"); //not possible with this smart contract
    }

    receive() external payable {
        emit MoneyReceived(msg.sender, msg.value);
    }
}
```

If you run it, then don't forget to select the correct Smart Contract from the dropdown:



Last update: May 23, 2021

13.13 Finishing Words

13.13.1 Congratulations, LAB is completed

From the Course "Ethereum Blockchain Developer -- Build Projects in Solidity"

FULL COURSE:

<https://www.udemy.com/course/blockchain-developer/?referralCode=E8611DF99D7E491DFD96>

Last update: May 23, 2021

14. LAB: Supply Chain Project

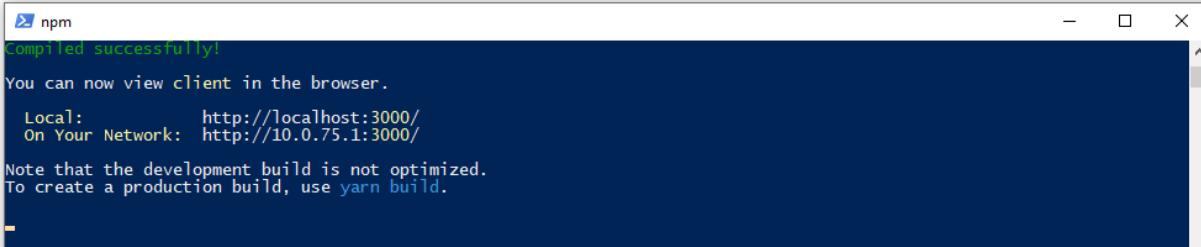
14.1 Project Supply Chain

Simply Payment/Supply Chain Example!

Items

Add Element

Cost: Item Name:



```

npm
Compiled successfully!
You can now view client in the browser.
  Local:          http://localhost:3000/
  On Your Network: http://10.0.75.1:3000/
Note that the development build is not optimized.
To create a production build, use yarn build.
  
```

14.1.1 Real-World Use-Case for this Project

- Can be part of a supply-chain solution
- Automated Dispatch upon payment
- Payment collection without middlemen

14.1.2 Development-Goal

- Showcase Event-Triggers
- Understand the low-level function address.call.value()
- Understand the Workflow with Truffle
- Understand Unit Testing with Truffle
- Understand Events in HTML

14.1.3 Videos

■ Full Video Walkthrough: <https://www.udemy.com/course/blockchain-developer/?referralCode=E8611DF99D7E491DFD96>

14.1.4 Get Started

- Let's get started by creating your [Initial Itemmanager](#)

Last update: April 17, 2021

14.2 The ItemManager Smart Contract

The first thing we need is a "Management" Smart Contract, where we can add items.

```
pragma solidity ^0.6.0;

contract ItemManager{

    enum SupplyChainSteps{Created, Paid, Delivered}

    struct S_Item {
        ItemManager.SupplyChainSteps _step;
        string _identifier;
        uint _priceInWei;
    }
    mapping(uint => S_Item) public items;
    uint index;

    event SupplyChainStep(uint _itemIndex, uint _step);

    function createItem(string memory _identifier, uint _priceInWei) public {

        items[index]._priceInWei = _priceInWei;
        items[index]._step = SupplyChainSteps.Created;
        items[index]._identifier = _identifier;
        emit SupplyChainStep(index, uint(items[index]._step));
        index++;
    }

    function triggerPayment(uint _index) public payable {
        require(items[_index]._priceInWei <= msg.value, "Not fully paid");
        require(items[_index]._step == SupplyChainSteps.Created, "Item is further in the supply chain");
        items[_index]._step = SupplyChainSteps.Paid;
        emit SupplyChainStep(_index, uint(items[_index]._step));
    }

    function triggerDelivery(uint _index) public {
        require(items[_index]._step == SupplyChainSteps.Paid, "Item is further in the supply chain");
        items[_index]._step = SupplyChainSteps.Delivered;
        emit SupplyChainStep(_index, uint(items[_index]._step));
    }
}
```

With this it's possible to add items and pay them, move them forward in the supply chain and trigger a delivery.

But that's something I don't like, because ideally I just want to give the user a simple address to send money to.

Last update: April 17, 2021

14.3 Item Smart Contract

Let's add another smart contract:

```
pragma solidity ^0.6.0;

import "./ItemManager.sol";

contract Item {
    uint public priceInWei;
    uint public paidWei;
    uint public index;

    ItemManager parentContract;

    constructor(ItemManager _parentContract, uint _priceInWei, uint _index) public {
        priceInWei = _priceInWei;
        index = _index;
        parentContract = _parentContract;
    }

    receive() external payable {
        require(msg.value == priceInWei, "We don't support partial payments");
        require(paidWei == 0, "Item is already paid!");
        paidWei += msg.value;
        (bool success,) = address(parentContract).call{value:msg.value}(abi.encodeWithSignature("triggerPayment(uint256)", index));
        require(success, "Delivery did not work");
    }

    fallback () external {

    }
}
```

Solidity Changes

Note that `call.value(msg.value)(abi.encodeWithSignature("triggerPayment(uint256)", index))`, due to changes at Solidity version 6.4 it is recommended it should be changed to `call{value:msg.value}(abi.encodeWithSignature("triggerPayment(uint256)", index))`.

And change the ItemManager Smart Contract to use the Item Smart Contract instead of the Struct only:

```
pragma solidity ^0.6.0;

import "./Item.sol";

contract ItemManager {

    struct S_Item {
        Item _item;
        ItemManager.SupplyChainSteps _step;
        string _identifier;
    }
    mapping(uint => S_Item) public items;
    uint index;

    enum SupplyChainSteps {Created, Paid, Delivered}

    event SupplyChainStep(uint _itemIndex, uint _step, address _address);

    function createItem(string memory _identifier, uint _priceInWei) public {
        Item item = new Item(this, _priceInWei, index);
        items[index]._item = item;
        items[index]._step = SupplyChainSteps.Created;
        items[index]._identifier = _identifier;
        emit SupplyChainStep(index, uint(items[index]._step), address(item));
        index++;
    }

    function triggerPayment(uint _index) public payable {
        Item item = items[_index]._item;
        require(address(item) == msg.sender, "Only items are allowed to update themselves");
        require(item.priceInWei() == msg.value, "Not fully paid yet");
        require(items[_index]._step == SupplyChainSteps.Created, "Item is further in the supply chain");
        items[_index]._step = SupplyChainSteps.Paid;
        emit SupplyChainStep(_index, uint(items[_index]._step), address(item));
    }

    function triggerDelivery(uint _index) public {
```

```
require(items[_index]._step == SupplyChainSteps.Paid, "Item is further in the supply chain");
items[_index]._step = SupplyChainSteps.Delivered;
emit SupplyChainStep(_index, uint(items[_index]._step), address(items[_index]._item));
}
```

Now with this we just have to give a customer the address of the Item Smart Contract created during "createItem" and he will be able to pay directly by sending X Wei to the Smart Contract. But the smart contract isn't very secure yet. We need some sort of owner functionality.

Last update: April 17, 2021

14.4 Ownable Functionality

Normally we would add the OpenZeppelin Smart Contracts with the Ownable Functionality. But at the time of writing this document they are not updated to solidity 0.6 yet. So, instead we will add our own Ownable functionality very much like the one from OpenZeppelin:

Ownable.sol

```
pragma solidity ^0.6.0;

contract Ownable {
    address public _owner;

    constructor () internal {
        _owner = msg.sender;
    }

    /**
     * @dev Throws if called by any account other than the owner.
     */
    modifier onlyOwner() {
        require(isOwner(), "Ownable: caller is not the owner");
        _;
    }

    /**
     * @dev Returns true if the caller is the current owner.
     */
    function isOwner() public view returns (bool) {
        return (msg.sender == _owner);
    }
}
```

Then modify the ItemManager so that all functions, that should be executable by the "owner only" have the correct modifier:

```
pragma solidity ^0.6.0;

import "./Ownable.sol";
import "./Item.sol";

contract ItemManager is Ownable {

    //...

    function createItem(string memory _identifier, uint _priceInWei) public onlyOwner {
    //...
    }

    function triggerPayment(uint _index) public payable {
    //...
    }

    function triggerDelivery(uint _index) public onlyOwner {
    //...
    }
}
```

Last update: April 17, 2021

14.5 Install Truffle

To install truffle open a terminal (Mac/Linux) or a PowerShell (Windows 10)

Type in:

```
npm install -g truffle
```

```
Windows PowerShell
Copyright (C) Microsoft Corporation. All rights reserved.

Try the new cross-platform PowerShell https://aka.ms/pscore6

thoma> npm install -g truffle
C:\Users\thoma\AppData\Roaming\npm\truffle -> C:\Users\thoma\AppData\Roaming\npm\node_modules\truffle\build\cli.bundled.js

> truffle@5.1.8 postinstall C:\Users\thoma\AppData\Roaming\npm\node_modules\truffle
> node ./scripts/postinstall.js

- Fetching solc version list from solc-bin. Attempt #1
+ truffle@5.1.8
updated 1 package in 9.586s
thoma> _
```

Hint: I am working here with version 5.1.8 of Truffle. If you want to follow the exact same version then type in

```
npm install -g truffle@5.1.8
```

Then create an empty folder, in this case I am creating "s06-eventtrigger"

```
mkdir s06-eventtrigger
cd s06-eventtrigger
ls
```

```
ebd> mkdir s06-eventtrigger

Directory: C:\101Tmp\ebd

Mode                LastWriteTime         Length  Name
----                -----          -----  -
d----- 1/11/2020 10:39 AM           0 s06-eventtrigger

ebd> cd .\s06-eventtrigger\
s06-eventtrigger> ls_
s06-eventtrigger>
```

And unbox the react box:

```
truffle unbox react
```

this should download a repository and install all dependencies in the current folder:

```
s06-eventtrigger> truffle unbox react
✓ Preparing to download box
✓ Downloading
✓ cleaning up temporary files
✓ Setting up box
s06-eventtrigger> ls
```

```
Directory: C:\101Tmp\ebd\s06-eventtrigger
```

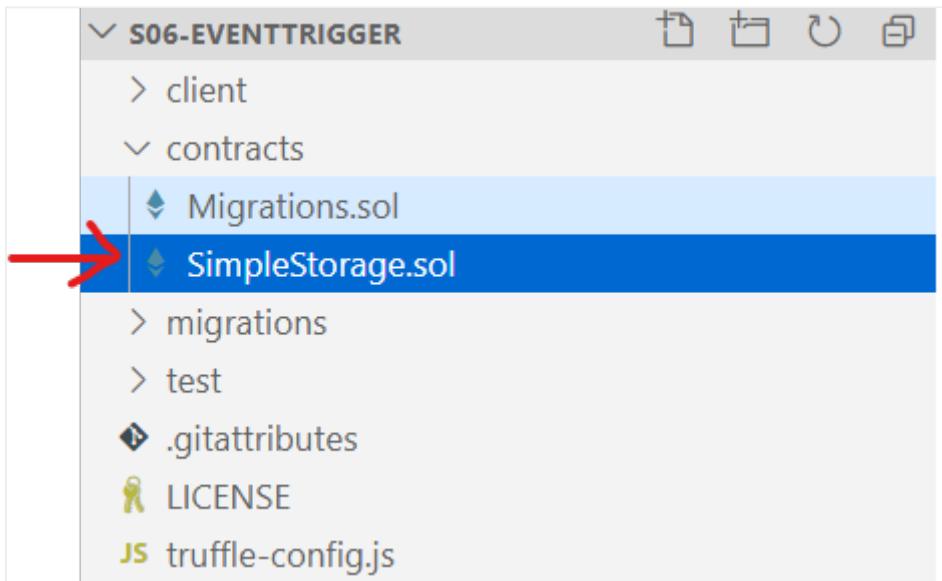
Mode	LastWriteTime	Length	Name
d----	1/11/2020 10:41 AM		client
d----	1/11/2020 10:41 AM		contracts
d----	1/11/2020 10:41 AM		migrations
d----	1/11/2020 10:41 AM		test
-a---	1/11/2020 10:41 AM	33	.gitattributes
-a---	1/11/2020 10:41 AM	1075	LICENSE
-a---	1/11/2020 10:41 AM	297	truffle-config.js

```
s06-eventtrigger> █
```

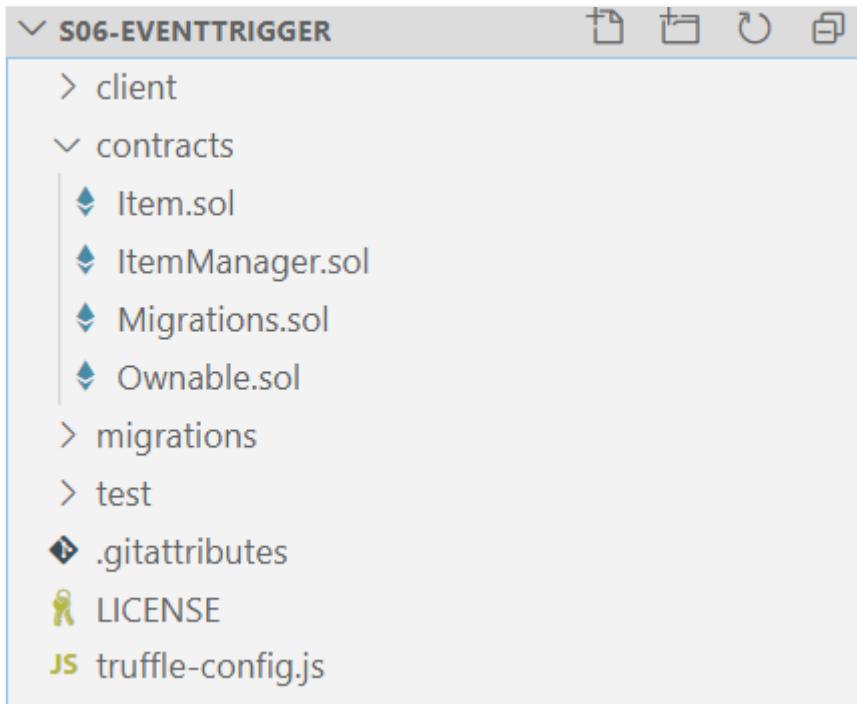
Last update: April 17, 2021

14.6 Add Contracts

Remove the existing SimpleStorage Smart Contract but leave the "Migrations.sol" file:



Add in our Files:



Then modify the "migration" file in the migrations/ folder:

migrations/2_deploy_contracts.js

```

var ItemManager = artifacts.require("./ItemManager.sol");

module.exports = function(deployer) {
  deployer.deploy(ItemManager);
};
  
```

Modify the truffle-config.js file to lock in a specific compiler version:

truffle-config.js

```
const path = require("path");

module.exports = {
  // See <http://truffleframework.com/docs/advanced/configuration>
  // to customize your Truffle configuration!
  contracts_build_directory: path.join(__dirname, "client/src/contracts"),
  networks: {
    develop: {
      port: 8545
    }
  },
  compilers: {
    solc: {
      version: "^0.6.0"
    }
  }
};
```

Compiler Versions

You can choose the version to be an exact version like "0.6.4", or you could add the "^" to specify all versions above greater or equal to 0.6.0, which means, it will download the latest 0.6.x version.

Run the truffle develop console to check if everything is alright and can be migrated. On the terminal/powershell run

```
truffle develop
```

and then simply type in

```
migrate
```

```
truffle(develop)> migrate

Compiling your contracts...
=====
> Compiling ./contracts\Item.sol
> Compiling ./contracts\ItemManager.sol
> Compiling ./contracts\Ownable.sol
> Artifacts written to C:\101Tmp\ebd\s06-eventtrigger\client\src\contracts
> Compiled successfully using:
  - solc: 0.6.1+commit.e6f7d5a4.Emscripten.clang

Starting migrations...
=====
> Network name: 'development'
```

Last update: April 17, 2021

14.7 Modify HTML

Now it's time that we modify our HTML so we can actually interact with the Smart Contract from the Browser.

Open "client/App.js" and modify a few things inside the file:

```
import React, { Component } from "react";
import ItemManager from "./contracts/ItemManager.json";
import Item from "./contracts/Item.json";
import getWeb3 from "./getWeb3";
import "./App.css";

class App extends Component {
  state = {cost: 0, itemName: "exampleItem1", loaded:false};

  componentDidMount = async () => {
    try {
      // Get network provider and web3 instance.
      this.web3 = await getWeb3();

      // Use web3 to get the user's accounts.
      this.accounts = await this.web3.eth.getAccounts();

      // Get the contract instance.
      const networkId = await this.web3.eth.net.getId();

      this.itemManager = new this.web3.eth.Contract(
        ItemManager.abi,
        ItemManager.networks[networkId] && ItemManager.networks[networkId].address,
      );
      this.item = new this.web3.eth.Contract(
        Item.abi,
        Item.networks[networkId] && Item.networks[networkId].address,
      );

      this.setState({loaded:true});
    } catch (error) {
      // Catch any errors for any of the above operations.
      alert(`Failed to load web3, accounts, or contract. Check console for details.`);
      console.error(error);
    }
  };
}

//... more code here ...
```

Then add in a form to the HTML part on the lower end of the App.js file, in the "render" function:

```
render() {
  if (!this.state.loaded) {
    return <div>Loading Web3, accounts, and contract...</div>;
  }
  return (
    <div className="App">
      <h1>Simply Payment/Supply Chain Example!</h1>
      <h2>Items</h2>

      <h2>Add Element</h2>
      Cost: <input type="text" name="cost" value={this.state.cost} onChange={this.handleInputChange} />
      Item Name: <input type="text" name="itemName" value={this.state.itemName} onChange={this.handleInputChange} />
      <button type="button" onClick={this.handleSubmit}>Create new Item</button>
    </div>
  );
}
```

And add two functions, one for handleInputChange, so that all input variables are set correctly. And one for sending the actual transaction off to the network:

```
handleSubmit = async () => {
  const { cost, itemName } = this.state;
  console.log(itemName, cost, this.itemManager);
  let result = await this.itemManager.methods.createItem(itemName, cost).send({ from: this.accounts[0] });
  console.log(result);
  alert(`Send "+cost+" Wei to "+result.events.SupplyChainStep.returnValues._address`);
};

handleInputChange = (event) => {
  const target = event.target;
  const value = target.type === 'checkbox' ? target.checked : target.value;
  const name = target.name;
```

```

    this.setState({
      [name]: value
    });
}

```

Open *another* terminal/powershell (leave the one running that you have already opened with truffle) and go to the client folder and run

```
npm start
```

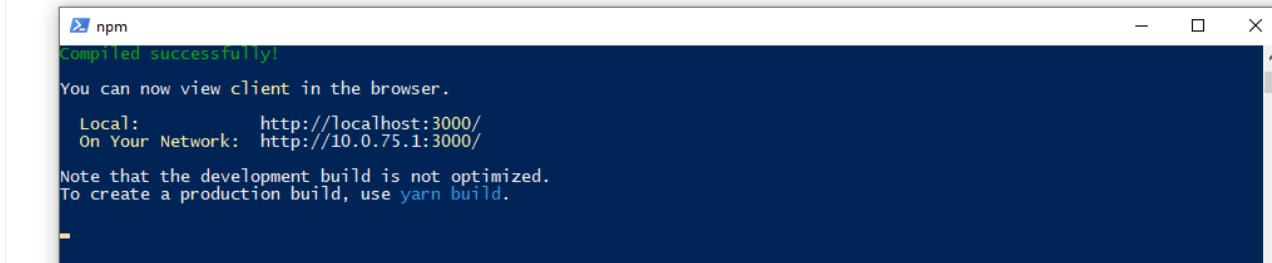
This will start the development server on port 3000 and should open a new tab in your browser:

Simply Payment/Supply Chain Example!

Items

Add Element

Cost: Item Name: Create new Item



⚠ See an Error?

If you see an error message that the network wasn't found or the contract wasn't found under the address provided -- don't worry! Follow along in the next step where you change the network in MetaMask! As long as there is no error in our terminal and it says "Compiled successfully" you're good to go!

Last update: April 17, 2021

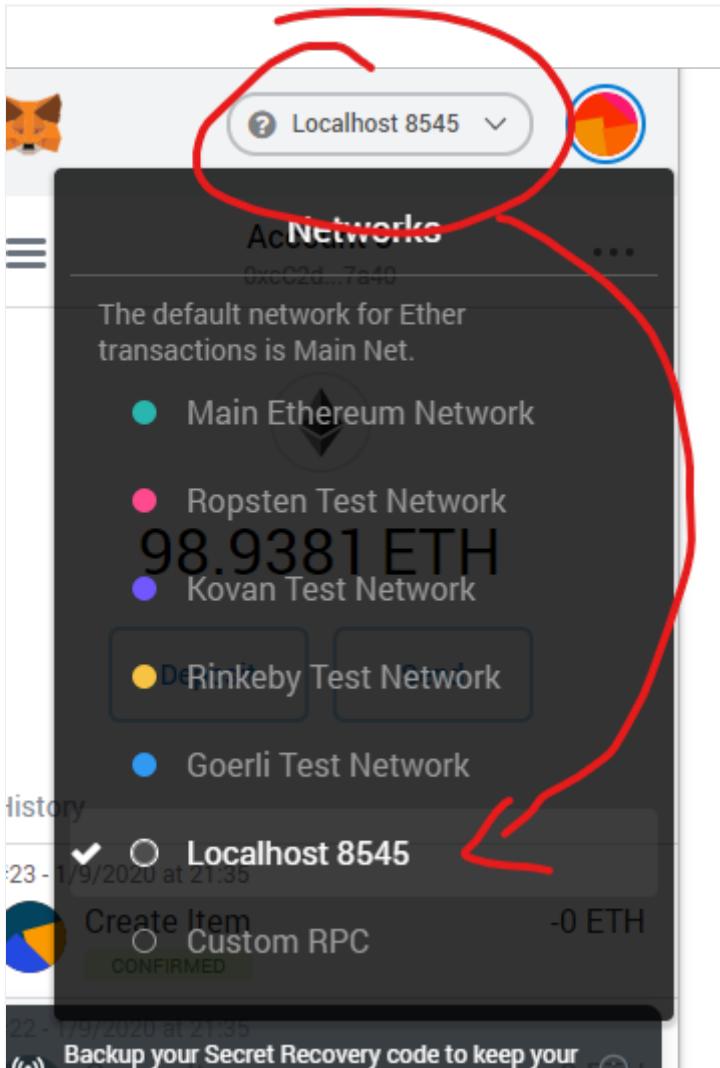
14.8 Connect with MetaMask

14.8.1 What We Do

In this section we want to connect our React App with MetaMask and use MetaMask as a Keystore to sign transactions. It will also be a proxy to the correct blockchain.

14.8.2 Steps to follow

First, connect with MetaMask to the right network:



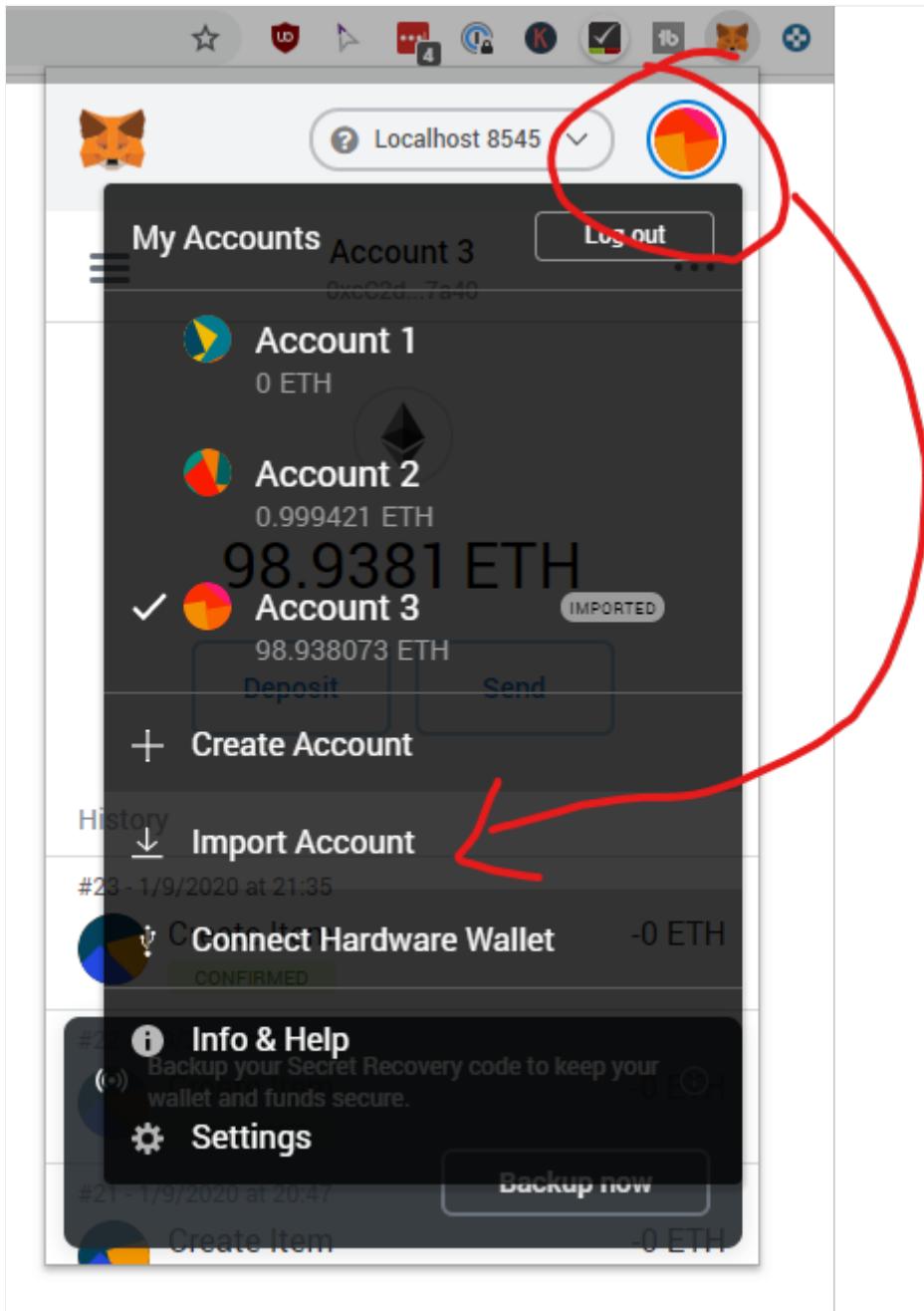
When we migrate the smart contracts with Truffle Developer console, then the first account in the truffle developer console is the "owner". So, either we disable MetaMask in the Browser to interact with the app or we add in the private key from truffle developer console to MetaMask.

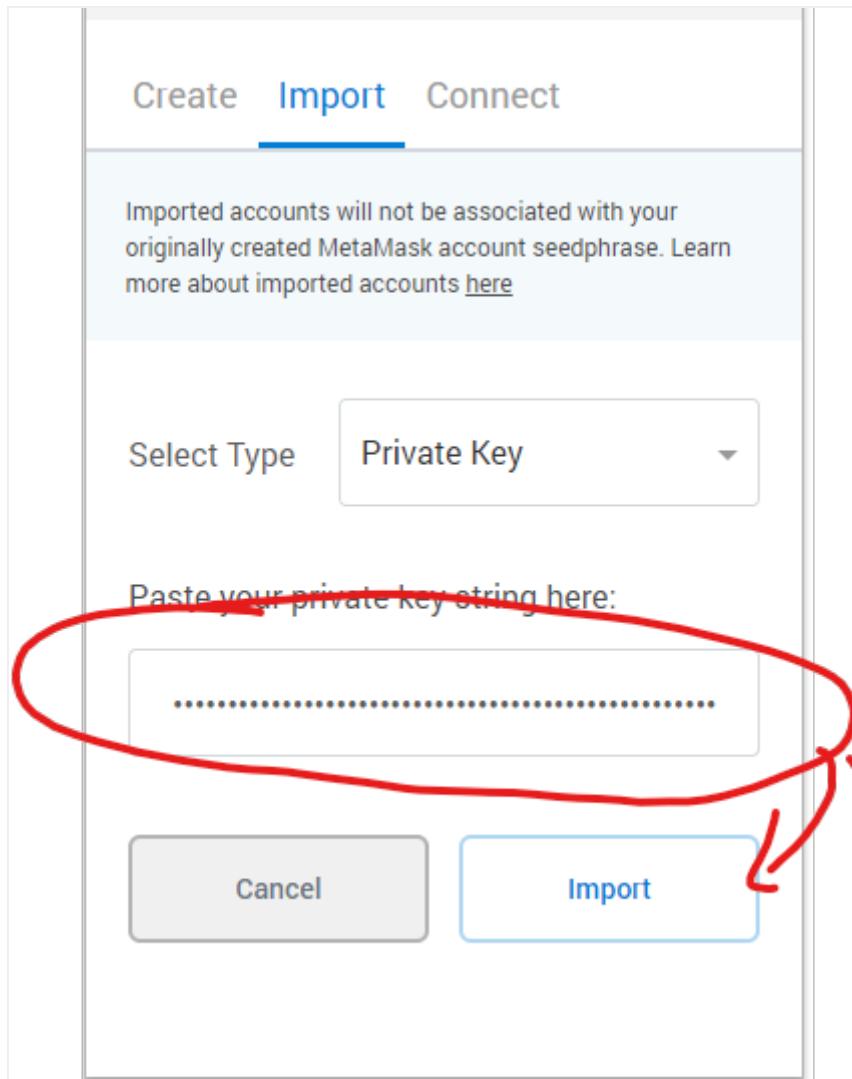
In the Terminal/Powershell where Truffle Developer Console is running scroll to the private keys on top:

Private Keys:

(0) 2a9ed36cdb66f81093a82443c2b9f237f3534ef75f4f044fa6ebd76d5d05f615
(1) f9c941a67e63fe4b84fe63ad652c29b2f225eb57562b246bf44bd3527b94b486

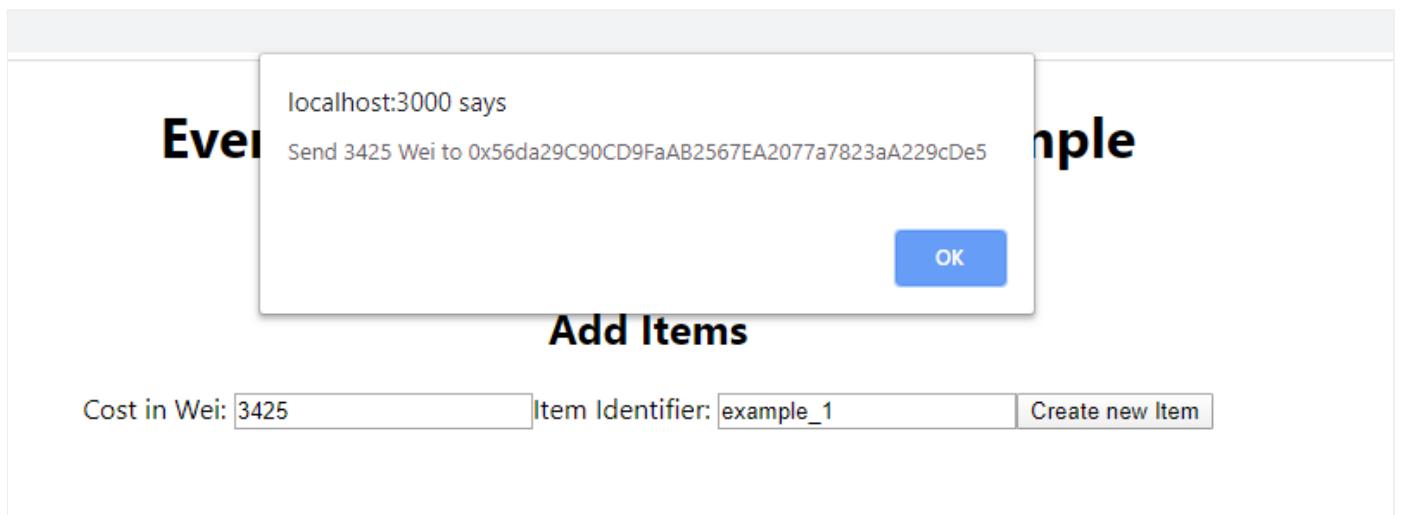
Copy the Private Key and add it into MetaMask:





Then your new Account should appear here with ~100 Ether in it.

Now let's add a new Item to our Smart Contract. You should be presented with the popup to send the message to an end-user.



Last update: April 17, 2021

14.9 Listen to Payments

Now that we know *how much* to pay to *which address* we need some sort of feedback. Obviously we don't want to wait until the customer tells us he paid, we want to know right on the spot if a payment happened.

There are multiple ways to solve *this particular issue*. For example you could poll the Item smart contract. You could watch the address on a low-level for incoming payments. But that's not what we want to do.

What we want is to wait for the event "SupplyChainStep" to trigger with `_step == 1` (Paid).

Let's add another function to the App.js file:

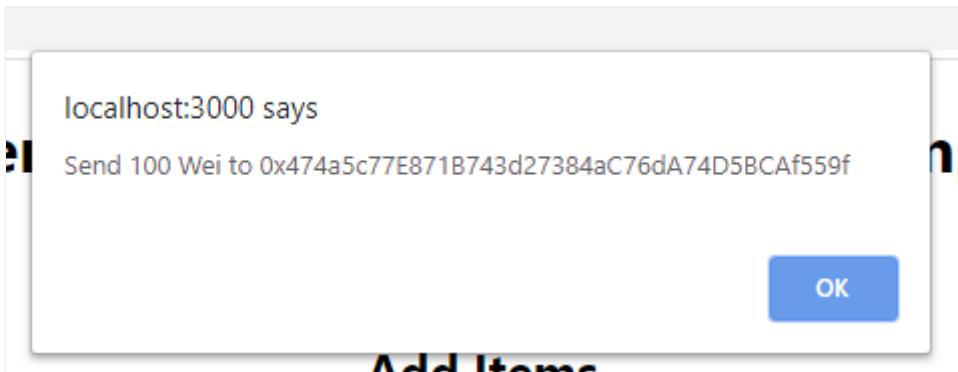
```
listenToPaymentEvent = () => {
  let self = this;
  this.itemManager.events.SupplyChainStep().on("data", async function(evt) {
    if(evt.returnValue._step == 1) {
      let item = await self.itemManager.methods.items(evt.returnValue._itemIndex).call();
      console.log(item);
      alert("Item " + item._identifier + " was paid, deliver it now!");
    };
    console.log(evt);
  });
}
```

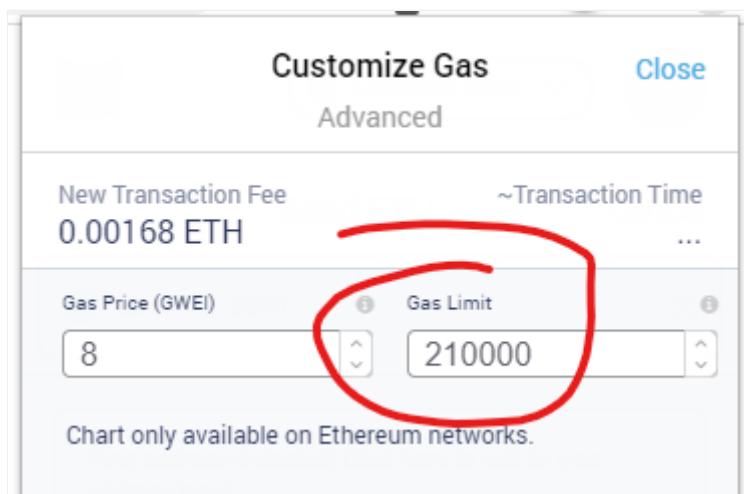
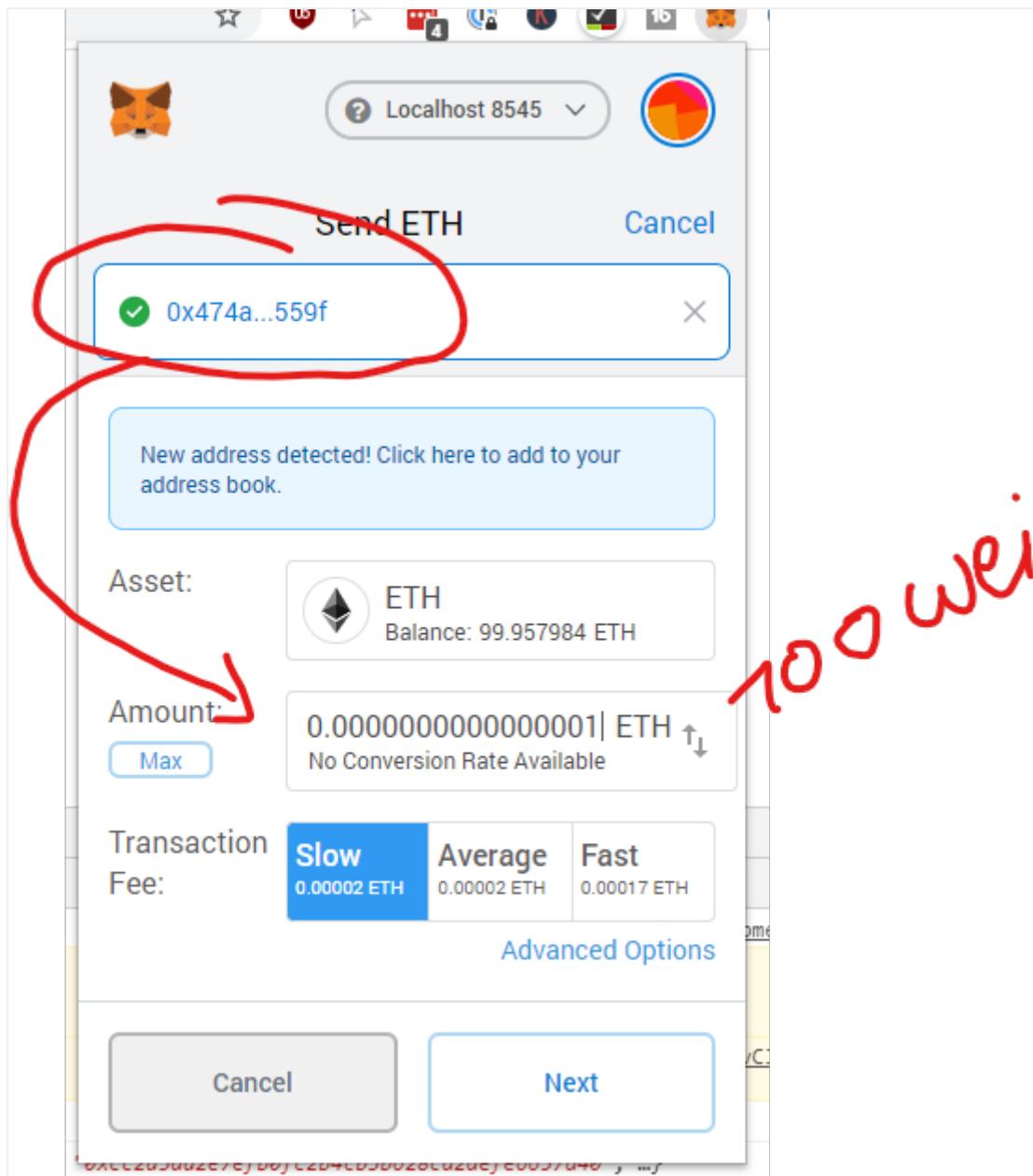
And call this function when we initialize the app in "componentDidMount":

```
//...
this.item = new this.web3.eth.Contract(
  ItemContract.abi,
  ItemContract.networks[this.networkId] && ItemContract.networks[this.networkId].address,
);

// Set web3, accounts, and contract to the state, and then proceed with an
// example of interacting with the contract's methods.
this.listenToPaymentEvent();
this.setState({ loaded:true });
} catch (error) {
  // Catch any errors for any of the above operations.
  alert(
    `Failed to load web3, accounts, or contract. Check console for details.`,
  );
  console.error(error);
}
//...
```

Whenever someone pays the item a new popup will appear telling you to deliver. You could also add this to a separate page, but for simplicity we just add it as an alert popup to showcase the trigger-functionality:

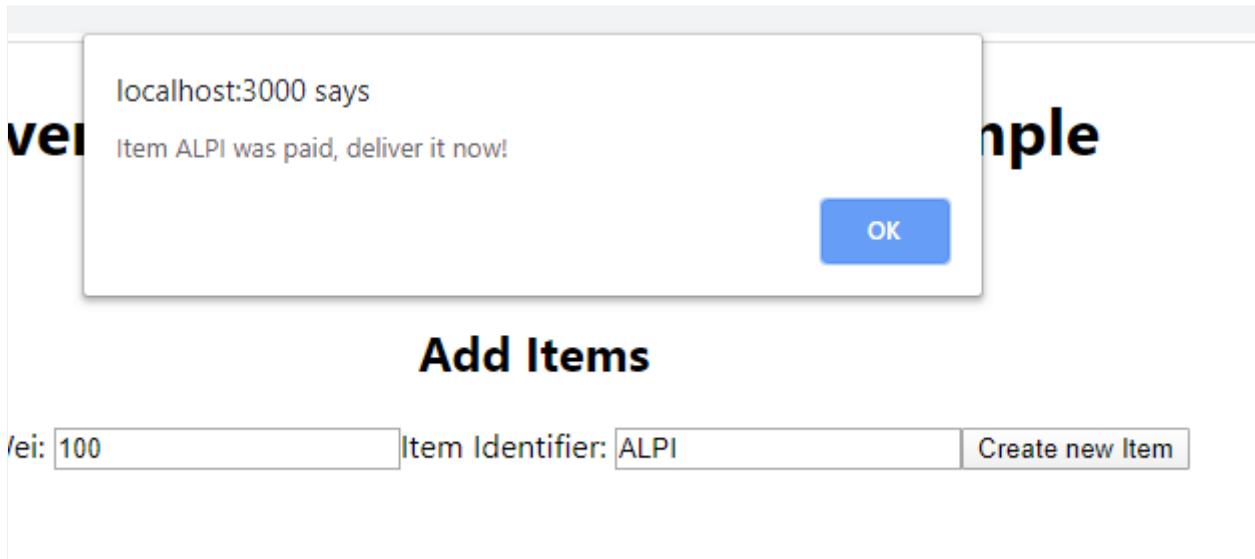




Take the address, give it to someone telling them to send 100 wei (0.0000000000000001 Ether) and a bit more gas to the specified address. You can do this either via MetaMask or via the truffle console:

```
web3.eth.sendTransaction({to: "ITEM_ADDRESS", value: 100, from: accounts[1], gas: 2000000});
```

Then a popup should appear on the website



Last update: April 17, 2021

14.10 Unit Test

Unit testing is important, that's out of the question. But how to write unit tests?

There is something special in Truffle about unit testing. The problem is that in the testing suite you get contract-abstractions using truffle-contract, while in the normal app you worked with web3-contract instances.

Let's implement a super simple unit test and see if we can test that items get created.

First of all, delete the tests in the "/test" folder. They are for the simplestorage smart contract which doesn't exist anymore. Then add new tests:

test/ItemManager.test.js

```
const ItemManager = artifacts.require("./ItemManager.sol");

contract("ItemManager", accounts => {
  it("... should let you create new Items.", async () => {
    const itemManagerInstance = await ItemManager.deployed();
    const itemName = "test1";
    const itemPrice = 500;

    const result = await itemManagerInstance.createItem(itemName, itemPrice, { from: accounts[0] });
    assert.equal(result.logs[0].args._itemIndex, 0, "There should be one item index in there")
    const item = await itemManagerInstance.items(0);
    assert.equal(item._identifier, itemName, "The item has a different identifier");
  });
});
```



Truffle Contract vs Web3js

Mind the difference: In web3js you work with "instance.methods.createItem" while in truffle-contract you work with "instance.createItem". Also, the events are different. In web3js you work with result.events.returnValues and in truffle-contract you work with result.logs.args. The reason is that truffle-contract mostly took the API from web3js 0.20 and they did a major refactor for web3js 1.0.0.

Keep the truffle development console open and type in a new terminal/powershell window:

```
truffle test
```

It should bring up a test like this:

```
Compiling your contracts...
=====
> Compiling .\contracts\Item.sol
> Compiling .\contracts\ItemManager.sol
> Compiling .\contracts\Ownable.sol
```

```
Contract: ItemManager
```

```
✓ ... should let you create new Items. (160ms)
```

```
1 passing (216ms)
```

```
s06-eventtrigger> █
```

This is how you add unit tests to your smart contracts.

Last update: April 17, 2021

14.11 Congratulations

Congratulations, LAB is completed

From the Course "Ethereum Blockchain Developer -- Build Projects in Solidity"

FULL COURSE: <https://www.udemy.com/course/blockchain-developer/?referralCode=E8611DF99D7E491DFD96>

Last update: April 17, 2021

15. LAB: ERC20 Token Sale

15.1 Project Tokenization Overview

Capuccino Token for StarDucks

Enable your account

Address to allow: Add Address to Whitelist

Buy Cappucino-Tokens

Send Ether to this address: 0x18d9d5d60c6063a63Bd424D59dbbcBE0DA233BC6

You have: 0

Buy more tokens

15.1.1 Real-World Use-Case for this Project

 Tokenization of any Assets as fungible Tokens (ERC20)

 Creation of Bonus Programs, Vouchers, etc.

 Creation of a new crypto currency

 Creation of a Payment-layer on top of Ethereum

15.1.2 Development-Goal

 Understand truffle-config json file

 Understand deployment of dApps

 Understand Tokenization using Open-Zeppelin Smart Contracts

Deeper dive into Unit-Testing

15.1.3 Videos

 Full Video Walkthrough: <https://www.udemy.com/course/blockchain-developer/?referralCode=E8611DF99D7E491DFD96>

15.1.4 Get Started

   Let's get started by [installing Truffle](#)

Last update: April 17, 2021

15.2 Truffle Initialization

Let's install Truffle and initialize a new project.

15.2.1 Truffle Installation

Before we get started, let's make sure we have the latest version of truffle installed:

console

```
npm install -g truffle
```

15.2.2 Project Initialization

Then create a new folder, "cd" into it and unbox the react-box from truffle:

console

```
mkdir s06_tokenization
cd s06_tokenization
truffle unbox react
```

Having troubles?

If you are experiencing troubles with truffle and the error has things like "npm ERR! gyp info using node@16.3.0 | darwin | arm64" then have a look at your node version. Truffle has troubles with node version 16 - install node 14 instead.

If truffle installs fine, but you are experiencing troubles running truffle, because something with "remote signed execution policy" comes up in PowerShell then run `Set-ExecutionPolicy -ExecutionPolicy RemoteSigned -Scope CurrentUser` in a PowerShell window.

Another thing that can cause errors is directories with spaces. Make sure you are working from a directory without spaces

For anything else google the error message, it should bring you a solution, and if it doesn't reach out in the course Q&A, we're on standby to help out.

Running in WSL2?: One person solved it by first initializing a new project in the folder with `npm init -y`

Macbook (pro) M1 Users

Some people reported problems with Macbook M1 and Truffle developer console. Quote from one of the Students: "This program works only on node 10, 12 or 14. And in case you are lucky ones and got Macbook pro M1 then you wont be able to run 'Truffle developer or truffle develop' command with node 14. If you downgrade to node 12 and run 'truffle develop' command then you would get " wasm assemble issue ... memory over run error" ... so better you keep node 14.17.0 and run the program on Ganache ... as truffle support on node 14 version does not run the truffle develop command successfully."

And leave only the scaffolding for a blank new project:

1. Remove all contracts in the "/contracts" folder, *except* the Migrations.sol file.
2. Remove all the tests in the "/tests" folder.
3. Remove all migrations *except* the 01_intial_migration.js.

Now, let's get started with the solidity part!

Last update: June 23, 2021

15.3 ERC20 Smart Contract

The first smart contract is the Token. We don't invent it ourselves, we take the ERC20 Smart Contract from OpenZeppelin. In this version open-zeppelin v3, with Solidity 0.6 smart contracts:

15.3.1 Installation

In the console type:

```
npm install --save @openzeppelin/contracts@v3.0.0
```

Update from the Video

Note we will be using the v3.0.0 of openzeppelin contracts, instead of v3.0.0-beta.0

15.3.2 Possible Scenario

Let's think about a possible work-scenario. We will create a Token which let's you redeem a coffee at your favorite Coffee Store: StarDucks Coffee from Duckburg. It will look slightly different from other ERC20 tokens, since a coffee is hardly divisible, but still transferrable. Let's create our Token.

15.3.3 Adding the Token

Add a "MyToken.sol" file to the "/contracts" folder:

/contracts/MyToken.sol

```
pragma solidity >=0.6.0;

import "@openzeppelin/contracts/token/ERC20/ERC20.sol";

contract MyToken is ERC20 {
    constructor(uint256 initialSupply) ERC20("StarDucks Capu-Token", "SCT") public {
        _mint(msg.sender, initialSupply);
        _setupDecimals(0);
    }
}
```

Note

The ERC20Detailed has been deprecated and combined into the ERC20 contract default. The new ERC20 contract has a constructor with arguments for the name and symbol of the token. It has a name "StarDucks Capu-Token", a symbol "SCT". The new ERC20 contract has a default decimal points of 18, we can change it to decimal points of 0 in the constructor by calling the `setupDecimals(uint8 decimals)` function in the ERC20 contract, with 0 as the argument.

Last update: April 17, 2021

15.4 Migration and Compilation

Let's see if we can deploy the smart contract to a developer-only test blockchain.

15.4.1 Configuring Migrations

Add in a migration in "migrations/2_deploy_contracts.js":

migrations/2_deploy_contracts.js

```
var MyToken = artifacts.require("./MyToken.sol");

module.exports = async function(deployer) {
    await deployer.deploy(MyToken, 100000000);
};
```

Also lock in the compiler version in *truffle-config.js*:

truffle-config.js

```
const path = require("path");

module.exports = {
// See <http://truffleframework.com/docs/advanced/configuration>
// to customize your Truffle configuration!
contracts_build_directory: path.join(__dirname, "client/src/contracts"),
networks: {
    develop: {
        port: 8545
    }
},
compilers: {
    solc: {
        version: "^0.6.0"
    }
}
};
```

15.4.2 Running Migrations

Try to run this in the truffle developer console:

```
truffle develop
```

and then simply type in

```
migrate
```

Last update: April 17, 2021

15.5 Unit Test ERC20

To test the token, we want to change our usual setup a bit. Let's use chai's expect to test the transfer of tokens from the owner to another account.

15.5.1 Install Chai

First we need some additional npm packages:

```
npm install --save chai chai-bn chai-as-promised
```

Then create our test in the tests folder. Create a new file called /tests/MyToken.test.js:

```
/tests/MyToken.test.js

const Token = artifacts.require("MyToken");

var chai = require("chai");

const BN = web3.utils.BN;
const chaiBN = require('chai-bn')(BN);
chai.use(chaiBN);

var chaiAsPromised = require("chai-as-promised");
chai.use(chaiAsPromised);

const expect = chai.expect;

contract("Token Test", async accounts => {
  const [ initialHolder, recipient, anotherAccount ] = accounts;

  it("All tokens should be in my account", async () => {
    let instance = await Token.deployed();
    let totalSupply = await instance.totalSupply();
    //old style:
    //let balance = await instance.balanceOf.call(initialHolder);
    //assert.equal(balance.valueOf(), 0, "Account 1 has a balance");
    //condensed, easier readable style:
    await expect(instance.balanceOf(initialHolder)).to.eventually.be.a.bignumber.equal(totalSupply);
  });
});
```

Note

The next step would be testing, but the truffle version I was using has problems with the internal developer network from truffle. See this screenshot:

```
TypeError [ERR_INVALID_REPL_INPUT]: Listeners for `uncaughtException` cannot be used in the REPL
  at process.<anonymous> (repl.js:227:15)
  at process.emit (events.js:215:7)
  at process.emit (C:\Users\thoma\AppData\Roaming\npm\node_modules\truffle\build\webpack:\node_modules\source-map-support\source-map-support.js:485:1)
  at _addListener (events.js:236:14)
  at process.addListener (events.js:284:10)
  at Runner.run (C:\Users\thoma\AppData\Roaming\npm\node_modules\truffle\node_modules\mocha\lib\runner.js:868:11)
  at Mocha.run (C:\Users\thoma\AppData\Roaming\npm\node_modules\truffle\node_modules\mocha\lib\mocha.js:612:17)
  at C:\Users\thoma\AppData\Roaming\npm\node_modules\truffle\build\webpack:\packages\core\lib\test.js:139:1
  at new Promise (<anonymous>)
  at Object.run (C:\Users\thoma\AppData\Roaming\npm\node_modules\truffle\build\webpack:\packages\core\lib\test.js:138:1)
  at noProcessTicksAndRejections (internal/process/task_queues.js:93:5)
```

So, in order to make this work, I had to use Ganache + Truffle.

1. Open Ganache
2. Adjust the truffle-config.js file
3. Run the tests

15.5.2 Open Ganache GUI or Ganache-cli

If you want to strictly stay on the command line, then install ganache-cli (npm install -g ganache-cli) and run it from the command line. Mind the PORT number, which we need in the next step!

```
Gas Price
=====
20000000000

Gas Limit
=====
6721975

Call Gas Limit
=====
9007199254740991

Listening on 127.0.0.1:8545
```

Ganache CLI Output

Otherwise roll with the GUI version of Ganache, which runs on Port 7545 usually (but double-check!)

The screenshot shows the Ganache UI interface. At the top, there are tabs for ACCOUNTS, BLOCKS, TRANSACTIONS, CONTRACTS, EVENTS, and LOGS. Below the tabs, there are several status indicators: CURRENT BLOCK (0), GAS PRICE (20000000000), GAS LIMIT (6721975), HARDFORK (PETERSBURG), NETWORK ID (5777), RPC SERVER (HTTP://127.0.0.1:7545), MINING STATUS (AUTOMINING), and WORKSPACE (QUICKSTART). There are also buttons for SAVE, SWITCH, and a gear icon.

MNEMONIC	ADDRESS	BALANCE	TX COUNT	INDEX	Key
nasty brush upper leisure pioneer social swallow father saddle side mixture method	0xeeEa556133B5C76a2b92e8Df8F0FF90BbbbD8ce6	100.00 ETH	0	0	🔑
	0xEddC05d9B2CB4D3965ee9d01C0c47960FAAbf273	100.00 ETH	0	1	🔑
	0xD152FdAea0F5c39bD38Ce6c29312af14B93F40E3	100.00 ETH	0	2	🔑
	0xf2Af5a487b989EcFd4F6310E2A964c1649C0CD43	100.00 ETH	0	3	🔑
	0x4FFF1eD88e721140729fd3C179c807984bc70dfe	100.00 ETH	0	4	🔑
	0xc0BBBc1Eb8F66b494B08Ec843e12742c351499fDa	100.00 ETH	0	5	🔑
	0x4AC266A48d587e541b6f6520246Ec1Fd94B9F6bd	100.00 ETH	0	6	🔑

Ganache UI Output

15.5.3 Adjust the truffle-config.js file

If you are running Ganache-GUI then adjust the `truffle-config.js` file, so that the default development network is going to use the right host and port.

Also make sure the solc-version is the correct one and lock it in, if you haven't already:

truffle-config.js

```
const path = require("path");

module.exports = {
  // See <http://truffleframework.com/docs/advanced/configuration>
  // to customize your Truffle configuration!
  contracts_build_directory: path.join(__dirname, "client/src/contracts"),
  networks: {
    development: {
      port: 7545,
      network_id: "*",
      host: "127.0.0.1"
    }
  },
  compilers: {
    solc: {
      version: "^0.6.0",
    }
  }
};
```

15.5.4 Test the Smart Contract

By going to your console, to the root folder of the project, and typing in `truffle test`, you will call the Truffle testing suite. If all goes well it will give you this output:

```
PROBLEMS 10 OUTPUT DEBUG CONSOLE TERMINAL

> Compiling .\contracts\KycContract.sol
> Compiling .\contracts\Migrations.sol
> Compiling .\contracts\MyToken.sol
> Compiling .\contracts\MyTokenSale.sol
> Artifacts written to C:\Users\thoma\AppData\Local\Temp\test-2020121-3016-435ywg.1c9vd
> Compiled successfully using:
  - solc: 0.6.1+commit.e6f7d5a4.Emscripten clang

Contract: Token Test
  ✓ All tokens should be in my account

1 passing (116ms)
```

Truffle Test Output

15.5.5 Add more Tests to your Token-Test

Add some more tests to make sure everything works as expected.

```
// add this into the contract token test:

it("I can send tokens from Account 1 to Account 2", async () => {
  const sendTokens = 1;
  let instance = await Token.deployed();
  let totalSupply = await instance.totalSupply();
  await expect(instance.balanceOf(initialHolder)).to.eventually.be.a.bignumber.equal(totalSupply);
```

```

await expect(instance.transfer(recipient, sendTokens)).to.eventually.be.fulfilled;
await expect(instance.balanceOf(initialHolder)).to.eventually.be.a.bignumber.equal(totalSupply.sub(new BN(sendTokens)));
await expect(instance.balanceOf(recipient)).to.eventually.be.a.bignumber.equal(new BN(sendTokens));
});

it("It's not possible to send more tokens than account 1 has", async () => {
let instance = await Token.deployed();
let balanceOfAccount = await instance.balanceOf(initialHolder);
await expect(instance.transfer(recipient, new BN(balanceOfAccount+1))).to.eventually.be.rejected;

//check if the balance is still the same
await expect(instance.balanceOf(initialHolder)).to.eventually.be.a.bignumber.equal(balanceOfAccount);

});
//...

```

And run it again:

```
> Compiled successfully using:
- solc: 0.6.1+commit.e6f7d5a4.Emscripten.clang
```

Contract: Token Test

- ✓ All tokens should be in my account
- ✓ I can send tokens from Account 1 to Account 2 (39ms)
- ✓ It's not possible to send more tokens than account 1 has (157ms)

3 passing (328ms)

Truffle Test Output chai-as-promised

Last update: June 24, 2021

15.6 Add Crowdsale Contracts

Here we do two things:

1. We adapt the old Crowdsale Smart Contract from Open-Zeppelin to be Solidity 0.6 compliant
2. We write our own Crowdsale on Top of it

Note

With OpenZeppelin approaching Solidity 0.6 the Crowdsale contracts were removed. Some people are inclined to add a "mintToken" functionality or something like that to the Token Smart Contract itself, but that would be bad design. We should add a separate Crowdsale Contract that handles token distribution.

Let's modify the Crowdsale Contract from Open-Zeppelin 2.5 to be available for Solidity 0.6:

Copy the contents from this file <https://github.com/OpenZeppelin/openzeppelin-contracts/blob/release-v2.5.0/contracts/crowdsale/Crowdsale.sol> to /contracts/Crowdsale.sol and change a few lines to make it project compliant.

1. The pragma line and the import statements
2. The fallback function
3. The virtual Keyword

15.6.1 The Pragma line and the Import Statements

If we copy the smart contract out of another repository instead of just *using* it, then we have to adjust the import statements. Replace the existing ones with this:

contracts/Crowdsale.sol

```
pragma solidity ^0.6.0;

import "@openzeppelin/contracts/utils/ReentrancyGuard.sol";
import "@openzeppelin/contracts/GSN/Context.sol";
import "@openzeppelin/contracts/token/ERC20/IERC20.sol";
import "@openzeppelin/contracts/math/SafeMath.sol";
import "@openzeppelin/contracts/token/ERC20/SafeERC20.sol";
```

15.6.2 The Fallback Function for Solidity 0.6

The unnamed fallback function is gone. We need to replace the function() with a receive function, since it will be possible to send Ether directly to our smart contract without really interacting with it.

Replace the "fallback ()" function with this one:

```
receive () external payable {
    buyTokens(_msgSender());
}
```

15.6.3 The Virtual Keyword in Solidity 0.6

If you want to override functions in Solidity 0.6 then the base smart-contract must define all functions as *virtual* to be overwritten. In the Crowdsale we must add the *virtual* keyword to functions that are potentially overwritten:

```
function _preValidatePurchase(address beneficiary, uint256 weiAmount) internal view virtual {
    require(beneficiary != address(0), "Crowdsale: beneficiary is the zero address");
    require(weiAmount != 0, "Crowdsale: weiAmount is 0");
    this; // silence state mutability warning without generating bytecode - see https://github.com/ethereum/solidity/issues/2691
}

function _postValidatePurchase(address beneficiary, uint256 weiAmount) internal view virtual {
```

```

    // solhint-disable-previous-line no-empty-blocks
}

function _deliverTokens(address beneficiary, uint256 tokenAmount) internal virtual {
    _token.safeTransfer(beneficiary, tokenAmount);
}

function _processPurchase(address beneficiary, uint256 tokenAmount) internal virtual {
    _deliverTokens(beneficiary, tokenAmount);
}

function _updatePurchasingState(address beneficiary, uint256 weiAmount) internal virtual {
    // solhint-disable-previous-line no-empty-blocks
}

function _getTokenAmount(uint256 weiAmount) internal view virtual returns (uint256) {
    return weiAmount.mul(_rate);
}

```

15.6.4 Create your own Crowdsale Contract

Add in a contracts/MyTokenSale.sol file with the following content:

contracts/MyTokenSale.sol

```

pragma solidity ^0.6.0;

import "./Crowdsale.sol";

contract MyTokenSale is Crowdsale {

    KyContract kyc;
    constructor(
        uint256 rate,    // rate in TKNbits
        address payable wallet,
        IERC20 token
    )
        Crowdsale(rate, wallet, token)
    public
    {
    }
}

```

15.6.5 Adopt the Migration for the Crowdsale Contract

In order for our crowdsale smart contract to work, we must send all the money to the contract. This is done on the migrations stage in our truffle installation:

The problem is now that the Test is failing. Let's change the standard Truffle-Test-Suite to the openzeppelin test suite:

migrations/2_deploy_contracts.js

```

var MyToken = artifacts.require("./MyToken.sol");
var MyTokenSales = artifacts.require("./MyTokenSale.sol");

module.exports = async function(deployer) {
    let addr = await web3.eth.getAccounts();
    await deployer.deploy(MyToken, 1000000000);
    await deployer.deploy(MyTokenSales, 1, addr[0], MyToken.address);
    let tokenInstance = await MyToken.deployed();
    await tokenInstance.transfer(MyTokenSales.address, 1000000000);
};

```

Perfect, now that we have that covered, let's have a look at the unit tests again.

Last update: April 17, 2021

15.7 Change the UnitTests To Support TokenSales

The truffle tests setup is not really suitable if you want to test specific scenarios which are not covered by the migration files. After migrating a smart contract, it usually ends up in a specific state. So testing the Token Smart Contract in this way wouldn't be possible anymore. You would have to test the whole token-sale, but that's something not what we want.

We could also integrate the openzeppelin test environment. It's blazing fast and comes with an internal blockchain for testing. But it has one large drawback: It only lets you use the internal blockchain, it's not configurable so it would use an outside blockchain. That's why I would still opt to use the Truffle Environment.

We just have to make a small change:

Update /tests/MyToken.test.js

```
//... chai token setup

contract("Token Test", function(accounts) {
  const [ initialHolder, recipient, anotherAccount ] = accounts;

  beforeEach(async () => {
    this.myToken = await Token.new(1000);
  });

  it("All tokens should be in my account", async () => {
    //let instance = await Token.deployed();
    let instance = this.myToken;
    let totalSupply = await instance.totalSupply();
    //... more content
  });

  it("I can send tokens from Account 1 to Account 2", async () => {
    const sendTokens = 1;
    let instance = this.myToken;
    let totalSupply = await instance.totalSupply();
    //... more content
  });

  it("It's not possible to send more tokens than account 1 has", async () => {
    let instance = this.myToken;
    //... more content
  });
});
```

Now open your Terminal and test the smart contract:

```
Contract: Token Test
  ✓ All tokens should be in my account
  ✓ I can send tokens from Account 1 to Account 2
  ✓ It's not possible to send more tokens than account 1 has
```

3 passing (688ms)

s06 - tokenization> []

15.7.1 Add in a Central Configuration with DotEnv

One of the larger problems is that we now have a constant for the migrations-file and a constant in our test -- the amount of tokens that are created. It would be better to have this constant through an environment file.

Install Dot-Env:

```
npm install --save dotenv
```

Then create a new file .env in your root directory of the project with the following content:

/.env

```
INITIAL_TOKENS = 10000000
```

Then change the migrations file to:

migrations/2_deploy_contracts.js

```
var MyToken = artifacts.require("./MyToken.sol");
var MyTokenSales = artifacts.require("./MyTokenSale.sol");
require('dotenv').config({path: '../.env'});

module.exports = async function(deployer) {
  let addr = await web3.eth.getAccounts();
  await deployer.deploy(MyToken, process.env.INITIAL_TOKENS);
  await deployer.deploy(MyTokenSales, 1, addr[0], MyToken.address);
  let tokenInstance = await MyToken.deployed();
  await tokenInstance.transfer(MyTokenSales.address, process.env.INITIAL_TOKENS);

};
```

Update also the tests file:

Update /tests/MyToken.test.js

```
const Token = artifacts.require("MyToken");

// Rest of the code ...

require('dotenv').config({path: '../.env'});

contract("Token Test", function(accounts) {
  const [ initialHolder, recipient, anotherAccount ] = accounts;

  beforeEach(async () => {
    this.myToken = await Token.new(process.env.INITIAL_TOKENS);
  });

//Rest of the Code ...
```

Now run the tests again and make sure everything still works as expected! All the tests, as well as the migration itself have one single point of truth. That is the .env file.

Last update: April 17, 2021

15.8 Crowdsale Unit-Test

Now, let's test our Crowdsale Token. Create a new file in /tests/MyTokenSale.test.js:

/tests/MyTokenSale.test.js

```
const Token = artifacts.require("MyToken");
const TokenSale = artifacts.require("MyTokenSale");

var chai = require("chai");
const expect = chai.expect;

const BN = web3.utils.BN;
const chaiBN = require('chai-bn')(BN);
chai.use(chaiBN);

var chaiAsPromised = require("chai-as-promised");
chai.use(chaiAsPromised);

contract("TokenSale", async function(accounts) {
  const [ initialHolder, recipient, anotherAccount ] = accounts;

  it("there shouldnt be any coins in my account", async () => {
    let instance = await Token.deployed();
    expect(instance.balanceOf.call(initialHolder)).to.eventually.be.a.bignumber.equal(new BN(0));
  });
});
```

If you run this, it will give you an error:

```
4) Contract: TokenSale
  there shouldnt be any coins in my account:
  AssertionError: expected { _events: {},
  emit: [Function: emit],
  on: [Function: on],
  once: [Function: once],
  off: [Function: removeListener],
  listeners: [Function: listeners],
  addListener: [Function: on],
  removeListener: [Function: removeListener],
  removeAllListeners: [Function: removeAllListeners] } to be an instance of BN or string
```

Problem is: this won't work out of the box for two reasons.

1. The shared Chai setup and
2. The missing return statements in the previous smart contract.

15.8.1 General Setup for Chai and Chai-as-Promised

i A note on the Videos and truffle-assertions

In the videos I am mentioning that you need to return the `expect()`.... An attentive student asked where to find more about this, as it seems to be undocumented.

This is where I believe it comes from: If you look at [Chai-As-Promised](#) then "should.eventually.be" will return a promise, which means the testing framework needs to be informed about a pending promise. This is the actual example on their website: `return doSomethingAsync().should.eventually.equal("foo");`. Having said that, I am not 100% convinced that it's necessary (anymore) since it also works without the return in most cases.

In the meantime I found another wrapper which I can wholeheartedly recommend: Truffle-Assertions. So, as an alternative (or in addition), check out <https://github.com/rkalis/truffle-assertions>, they are easy to use and cover pretty much anything you will probably come across to test for in Solidity.

Create a new file in tests/chaisetup.js with the following content:

tests/chaisetup.js

```
"use strict";
var chai = require("chai");
const expect = chai.expect;

const BN = web3.utils.BN;
const chaiBN = require('chai-bn')(BN);
chai.use(chaiBN);

var chaiAsPromised = require("chai-as-promised");
chai.use(chaiAsPromised);
module.exports = chai;
```

Then update the tests/Token.test.js file. Mind the "return" keywords:

Update tests/Token.test.js

```
const Token = artifacts.require("MyToken");

const chai = require("./chaisetup.js");
const BN = web3.utils.BN;
const expect = chai.expect;

require('dotenv').config({path: '../.env'});

contract("Token Test", function(accounts) {
// rest of the code...
  it("All tokens should be in my account", async () => {
// rest of the code...
    return expect(instance.balanceOf(initialHolder)).to.eventually.be.a.bignumber.equal(totalSupply);

  });
  it("I can send tokens from Account 1 to Account 2", async () => {
// rest of the code...
    return expect(instance.balanceOf(recipient)).to.eventually.be.a.bignumber.equal(new BN(sendTokens));
  });

  it("It's not possible to send more tokens than account 1 has", async () => {
    return expect(instance.balanceOf(initialHolder)).to.eventually.be.a.bignumber.equal(balanceOfAccount);
  });
});
```

And then fix the TokenSale.test.js:

Update /tests/TokenSale.test.js

```
const Token = artifacts.require("MyToken");
const TokenSale = artifacts.require("MyTokenSale");

const chai = require("./chaisetup.js");
const BN = web3.utils.BN;
const expect = chai.expect;

contract("TokenSale", async function(accounts) {
  const [ initialHolder, recipient, anotherAccount ] = accounts;

  it("there shouldnt be any coins in my account", async () => {
    let instance = await Token.deployed();
    return expect(instance.balanceOf.call(initialHolder)).to.eventually.be.a.bignumber.equal(new BN(0));
  });
});
```

Run the tests:

Contract: Token Test

- ✓ All tokens should be in my account (66ms)
- ✓ I can send tokens from Account 1 to Account 2 (90ms)
- ✓ It's not possible to send more tokens than account 1 has (65ms)

Contract: TokenSale

- ✓ there shouldnt be any coins in my account (69ms)

4 passing (887ms)

15.8.2 Add more Unit-Tests for actually purchasing a Token

In the tests/TokenSale.test.js add the following:

Add in tests/TokenSale.test.js

```
//other code in test

it("all coins should be in the tokensale smart contract", async () => {
  let instance = await Token.deployed();
  let balance = await instance.balanceOf.call(TokenSale.address);
  let totalSupply = await instance.totalSupply.call();
  return expect(balance).to.be.a.bignumber.equal(totalSupply);
});

it("should be possible to buy one token by simply sending ether to the smart contract", async () => {
  let tokenInstance = await Token.deployed();
  let tokenSaleInstance = await TokenSale.deployed();
  let balanceBeforeAccount = await tokenInstance.balanceOf.call(recipient);

  await expect(tokenSaleInstance.sendTransaction({from: recipient, value: web3.utils.toWei("1", "wei")}).to.be.fulfilled);
  return expect(balanceBeforeAccount + 1).to.be.bignumber.equal(await tokenInstance.balanceOf.call(recipient));
});
```

Run the tests and it should work:

Contract: Token Test

- ✓ All tokens should be in my account (39ms)
- ✓ I can send tokens from Account 1 to Account 2 (84ms)
- ✓ It's not possible to send more tokens than account 1 has (69ms)

Contract: TokenSale

- ✓ there shouldnt be any coins in my account (58ms)
- ✓ all coins should be in the tokensale smart contract (43ms)
- ✓ should be possible to buy one token by simply sending ether to the smart contract (351ms)

6 passing (1s)

s06 - tokenization> █

Errors?

If you are running into troubles, unexpected errors, try to restart Ganache!

In the next step we model some sort of Know-Your-Customer Whitelisting Smart Contract. This can be a mockup for a larger KYC solution. But in our case, it will just whitelist addresses by the admin of the system.

Last update: June 24, 2021

15.9 Add in a Kyc Mockup

KYC, or "know your customer", is necessary for many different applications nowadays. In its simplest form, it's just a whitelist, where, based on some criteria, *someone* gets the permission to do *something*.

Let's add a simple whitelist, or KYC functionality.

15.9.1 The KYC Smart Contract

First, we're going to add a KYC Smart Contract which handles the white-listing. In contracts/KycContract.sol add the following content.

contracts/KycContract.sol

```
pragma solidity ^0.6.0;

import "@openzeppelin/contracts/access/Ownable.sol";

contract KycContract is Ownable {
    mapping(address => bool) allowed;

    function setKycCompleted(address _addr) public onlyOwner {
        allowed[_addr] = true;
    }

    function setKycRevoked(address _addr) public onlyOwner {
        allowed[_addr] = false;
    }

    function kycCompleted(address _addr) public view returns(bool) {
        return allowed[_addr];
    }
}
```

And in our TokenSale.sol we have to check -- before the actual sale -- if the user is whitelisted. Change the contracts/MyTokenSale.sol to:

contracts/MyTokenSale.sol

```
pragma solidity ^0.6.0;

import "./Crowdsale.sol";
import "./KycContract.sol";

contract MyTokenSale is Crowdsale {

    KycContract kyc;
    constructor(
        uint256 rate, // rate in TKNbits
        address payable wallet,
        IERC20 token,
        KycContract _kyc
    ) Crowdsale(rate, wallet, token)
        public
    {
        kyc = _kyc;
    }

    function _preValidatePurchase(address beneficiary, uint256 weiAmount) internal view override {
        super._preValidatePurchase(beneficiary, weiAmount);
        require(kyc.kycCompleted(beneficiary), "KYC not completed yet, aborting");
    }
}
```

And now we also have to change the migration obviously, or else it won't work:

migrations/02_deploy_contracts.js

```
var MyToken = artifacts.require("./MyToken.sol");
var MyTokenSales = artifacts.require("./MyTokenSale.sol");
var KycContract = artifacts.require("./KycContract.sol");
require('dotenv').config({path: '../.env'});

module.exports = async function(deployer) {
  let addr = await web3.eth.getAccounts();
  await deployer.deploy(MyToken, process.env.INITIAL_TOKENS);
  await deployer.deploy(KycContract);
  await deployer.deploy(MyTokenSales, 1, addr[0], MyToken.address, KycContract.address);
  let tokenInstance = await MyToken.deployed();
  await tokenInstance.transfer(MyTokenSales.address, process.env.INITIAL_TOKENS);

};
```

Now let's change also the Unit-Tests to reflect this:

tests/MyTokenSale.test.js

```
const Token = artifacts.require("MyToken");
const TokenSale = artifacts.require("MyTokenSale");
const KycContract = artifacts.require("KycContract");

const chai = require("./chaisetup.js");
const BN = web3.utils.BN;
const expect = chai.expect;

contract("TokenSale", async function(accounts) {
  const [ initialHolder, recipient, anotherAccount ] = accounts;

  //the rest of the code here

  it("should be possible to buy one token by simply sending ether to the smart contract", async () => {
    let tokenInstance = await Token.deployed();
    let tokenSaleInstance = await TokenSale.deployed();
    let balanceBeforeAccount = await tokenInstance.balanceOf.call(recipient);
    await expect(tokenSaleInstance.sendTransaction({from: recipient, value: web3.utils.toWei("1", "wei"})).to.be.rejected;
    await expect(balanceBeforeAccount).to.be.bignumber.equal(await tokenInstance.balanceOf.call(recipient));

    let kycInstance = await KycContract.deployed();
    await kycInstance.setKycCompleted(recipient);
    await expect(tokenSaleInstance.sendTransaction({from: recipient, value: web3.utils.toWei("1", "wei"})).to.be.fulfilled;
    return expect(balanceBeforeAccount + 1).to.be.bignumber.equal(await tokenInstance.balanceOf.call(recipient));
  });
});
```

Last update: June 24, 2021

15.10 Frontend: Load Contracts to React

Now it's time to load the contracts into the frontend. We haven't touched it yet, so let's get started by modifying the App.js file.

Let's modify the client/App.js file and add in the right contracts to import:

```
import React, { Component } from "react";
import MyToken from "./contracts/MyToken.json";
import MyTokenSale from "./contracts/MyTokenSale.json";
import KycContract from "./contracts/KycContract.json";
import getWeb3 from "./getWeb3";

import "./App.css";

class App extends Component {
//more code ...
```

⚠ MetaMask / Ganache Problems (or Changes)

Two problems here:

1. There is a problem with `this.web3.eth.net.getId()`; using MetaMask. See [deprecated features from MetaMask](#). Instead we need to use the ChainId. The Code below is already fixed!
2. Ganache has sometimes the wrong ChainId <https://github.com/trufflesuite/ganache-core/issues/575>. This means, at the time of writing this, we need to use ganache-cli with custom network id and chain id. Start ganache cli with `ganache-cli --networkId 1337 --chainId 1337`

Then change the state variable, as well as the componentDidMount function to load all the Smart Contracts using web3.js:

```
state = { loaded: false };

componentDidMount = async () => {
  try {
    // Get network provider and web3 instance.
    this.web3 = await getWeb3();

    // Use web3 to get the user's accounts.
    this.accounts = await this.web3.eth.getAccounts();

    // Get the contract instance.
    //this.networkId = await this.web3.eth.net.getId(); <- this doesn't work with MetaMask anymore
    this.networkId = await this.web3.eth.getChainId();

    this.myToken = new this.web3.eth.Contract(
      MyToken.abi,
      MyToken.networks[this.networkId] && MyToken.networks[this.networkId].address,
    );

    this.myTokenSale = new this.web3.eth.Contract(
      MyTokenSale.abi,
      MyTokenSale.networks[this.networkId] && MyTokenSale.networks[this.networkId].address,
    );
    this.kycContract = new this.web3.eth.Contract(
      KycContract.abi,
      KycContract.networks[this.networkId] && KycContract.networks[this.networkId].address,
    );

    // Set web3, accounts, and contract to the state, and then proceed with an
    // example of interacting with the contract's methods.
    this.setState({ loaded:true });
  } catch (error) {
    // Catch any errors for any of the above operations.
    alert(`Failed to load web3, accounts, or contract. Check console for details.`);
    console.error(error);
  }
};
```

Finally change the bottom part to listen for "loaded" instead of web3:

```
render() {
  if (!this.state.loaded) {
```

```

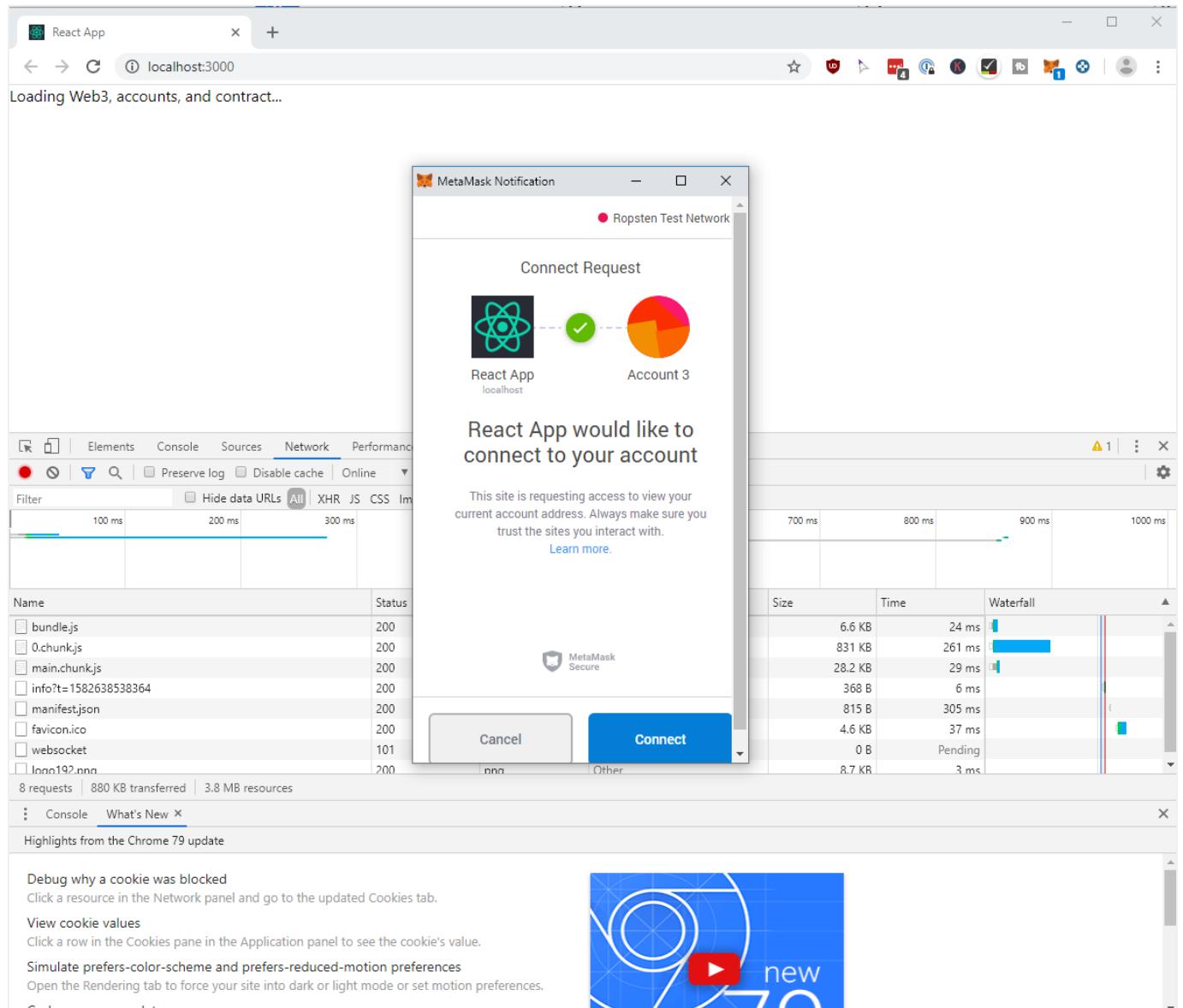
    return <div>Loading Web3, accounts, and contract...</div>;
}
return (
  <div className="App">
    <h1>Good to Go!</h1>
    <p>Your Truffle Box is installed and ready.</p>
    <h2>Smart Contract Example</h2>
    <p>
      If your contracts compiled and migrated successfully, below will show
      a stored value of 5 (by default).
    </p>
    <p>
      Try changing the value stored on <strong>line 40</strong> of App.js.
    </p>
    <div>The stored value is: {this.state.storageValue}</div>
  </div>
);
}

```

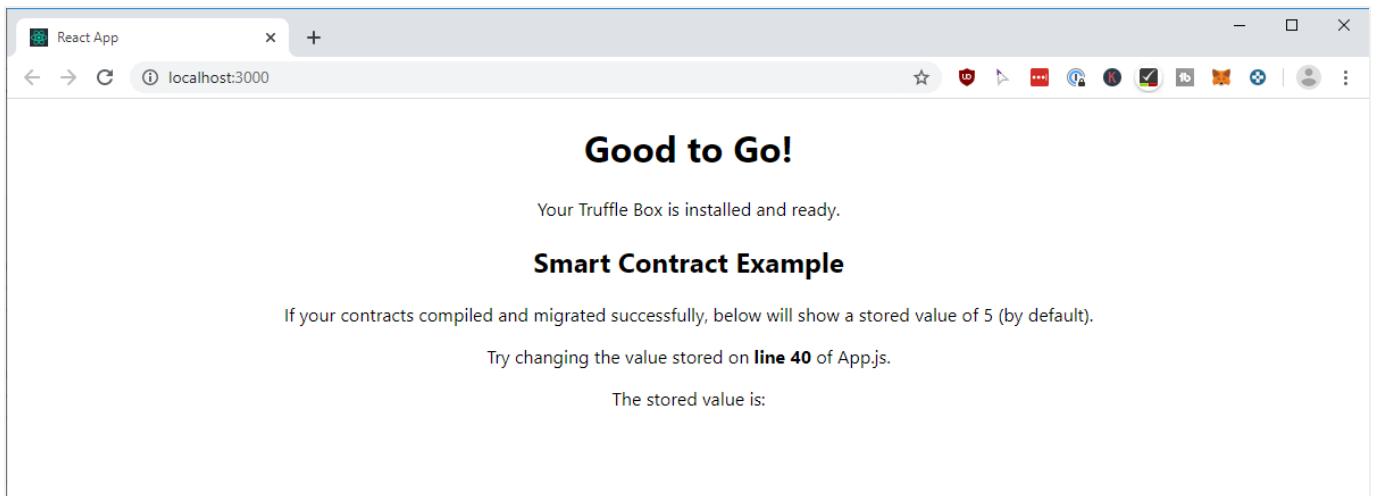
Start the development server and see if there are any obvious errors being thrown:

```
cd client && npm run start
```

First, if installed, MetaMask should ask you if you want to connect:



If you say "Connect" then you should be able to see this page:



Let's start by developing our KYC Rules...

Last update: April 17, 2021

15.11 Update KYC

First, re-model the Frontend part:

```
render() {
  if (!this.state.loaded) {
    return <div>Loading Web3, accounts, and contract...</div>;
  }
  return (
    <div className="App">
      <h1>Capuccino Token for StarDucks</h1>

      <h2>Enable your account</h2>
      Address to allow: <input type="text" name="kycAddress" value={this.state.kycAddress} onChange={this.handleInputChange} />
      <button type="button" onClick={this.handleKycSubmit}>Add Address to Whitelist</button>
    </div>
  );
}
```

Secondly, add the functions "handleInputChange" and "handleKycSubmit":

```
handleInputChange = (event) => {
  const target = event.target;
  const value = target.type === "checkbox" ? target.checked : target.value;
  const name = target.name;
  this.setState({
    [name]: value
  });
}

handleKycSubmit = async () => {
  const {kycAddress} = this.state;
  await this.kycContract.methods.setKycCompleted(kycAddress).send({from: this.accounts[0]});
  alert("Account "+kycAddress+" is now whitelisted");
}
```

Also don't forget to change the state on the top of your App.js to modify the KYC Whitelist:

```
class App extends Component {
  state = { loaded: false, kycAddress: "0x123" };

  componentDidMount = async () => {
```

Finally, it should look like this:

The screenshot shows a web browser window titled "React App" at "localhost:3000". The page content is titled "Capuccino Token for StarDucks" and has a section titled "Enable your account" with a text input field containing "0x123" and a button "Add Address to Whitelist". Below the browser window is the Chrome DevTools Console tab, which displays a warning message from MetaMask about its network change behavior.

```

[1]: Download the React DevTools for a better development experience: https://fb.me/react-devtools
[2]: > MetaMask: MetaMask will soon stop reloading pages on network change.
  If you rely upon this behavior, add a 'networkChanged' event handler to trigger the reload manually: https://metamask.github.io/metamask-docs/API Reference/Ethereum Provider#ethereum.on(eventName%2C callback)
  Set "ethereum.autoRefreshOnNetworkChange" to 'false' to silence this warning: https://metamask.github.io/metamask-docs/API Reference/Ethereum Provider#ethereum.autorefreshonnetworkchange'

```

The problem is now, your accounts to deploy the smart contract is in ganache, the account to interact with the dApp is in MetaMask. These are two different sets of private keys. We have two options:

1. Import the private key from Ganache into MetaMask (we did this before)
2. Use MetaMask Accounts to deploy the smart contract in Ganache (hence making the MetaMask account the "admin" account)
3. But first we need Ether in our MetaMask account. Therefore: First transfer Ether from Ganache-Accounts to MetaMask Accounts

Last update: April 17, 2021

15.12 Deploy Smart Contracts With MetaMask

One of the problems is during deployment of the smart contracts, we use Ganache Accounts

In order to transfer Ether from an Account in Ganache to an account in MetaMask, we have to start a transaction. The easiest way to do this is to use the truffle console to transfer ether from one of the networks defined in the truffle-config.js file to another account. In your project root in a terminal enter:

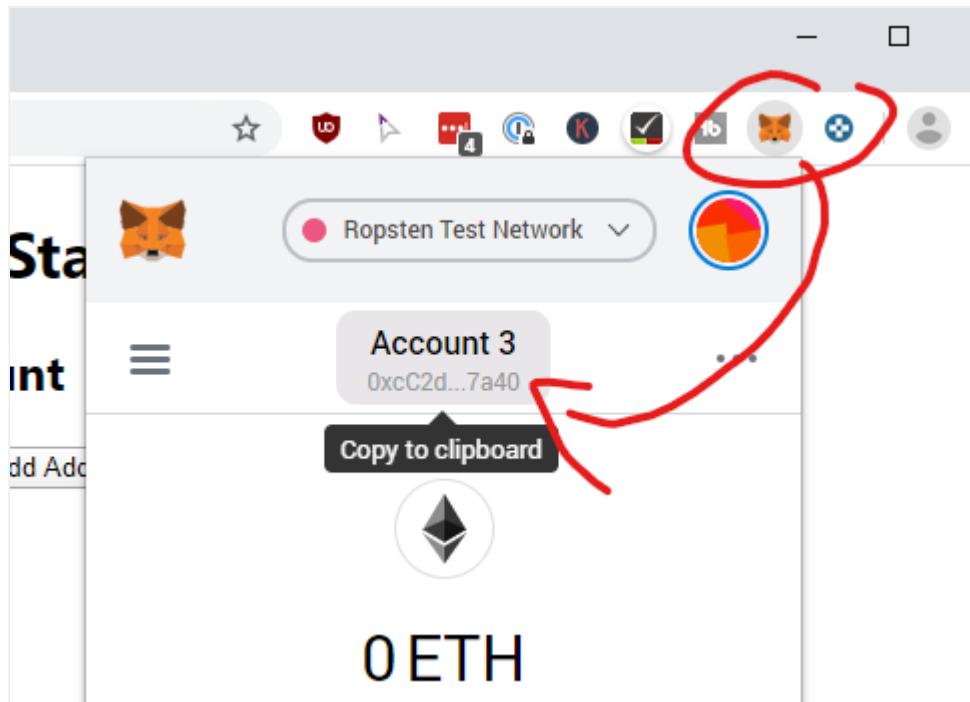
```
truffle console --network development
```

Then a new truffle console should pop up. You should be able to list the accounts by simply typing in "accounts":

```
s06 - tokenization> truffle console --network development
truffle(development)> accounts
[
  '0xeeEa556133B5C76a2b92e8Df8F0Ff90BbbbD8ce6',
  '0xEddC05d9B2CB4D3965ee9d01C0c47960FAAbf273',
  '0xD152FdAea0F5c39bD38Ce6c29312af14B93F40E3',
  '0xf2Af5a487b989EcFd4F6310E2A964c1649C0CD43',
  '0x4FFF1eD88e721140729fd3C179c807984bc70dfe',
  '0xc0BBc1Eb8F66b494B08Ec843e12742c351499fDa',
  '0x4AC266A48d587e541b6f6520246Ec1Fd94B9F6bd',
  '0x0e369aEDD00dC0bcc3fa3fff63A46fA5fDD55A4c',
  '0x34C027923c8c3cE277E2aE8b0eadc4b7f486804c',
  '0xAeC5b09f722d36622F811631493E60f7ce6dB4c4'
]
truffle(development)>
```

These are the same accounts as in Ganache. You are connected to your node via RPC. The node is Ganache. You can send off transactions using the private keys behind these accounts. Ganache will sign them.

We have to send a transaction from these accounts to MetaMask. Copy the account in MetaMask:

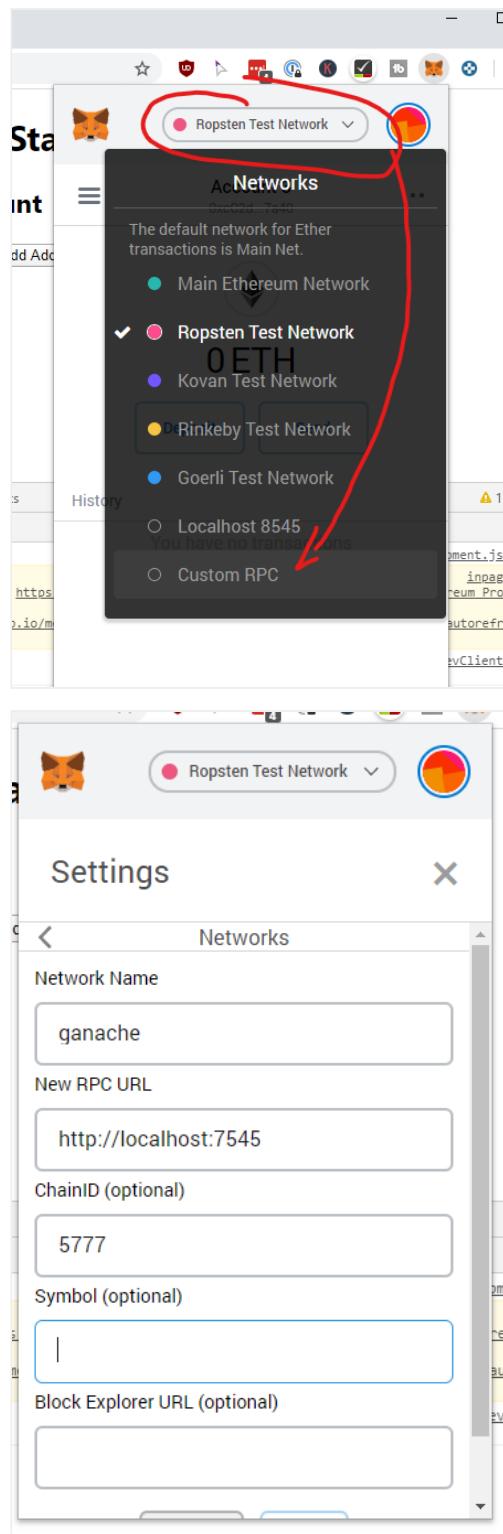


Type in:

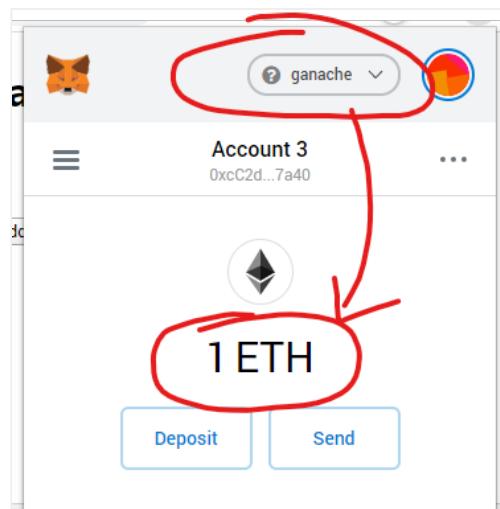
```
web3.eth.sendTransaction({from: accounts[0], to:"PASTE_ACCOUNT_FROM_METAMASK", value: web3.utils.toWei("1","ether"))}
```

don't forget the quotes around the account! It should return a transaction object:

And your account in MetaMask should have now 1 Ether, *if connected to the right network*. Connect MetaMask to Ganache first:



Hit Save.



15.12.1 Add HDWalletProvider and the Mnemonic to Truffle and modify truffle-config.js

The first step is to add the HDWalletProvider to truffle. On the command line type in:

```
npm install --save @truffle/hdwallet-provider
```

The next step is to add the hdwallet provider and the mnemonic from MetaMask to the truffle-config.js in a secure way. The best suited place for the mnemonic would be the .env file, which should never be shared!

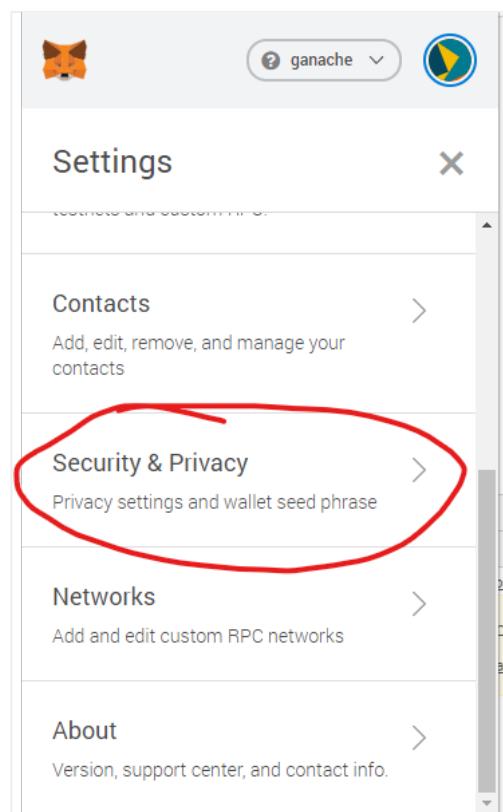
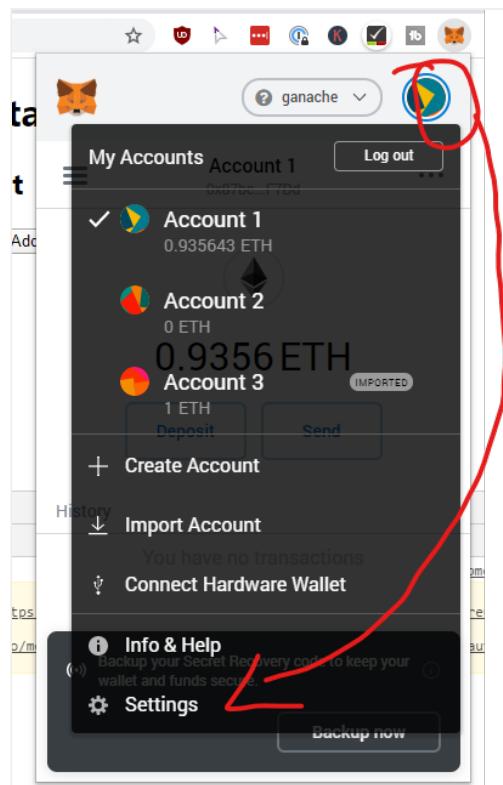
Let's start with the HDWalletProvider. Open the truffle-config.js file and add these parts:

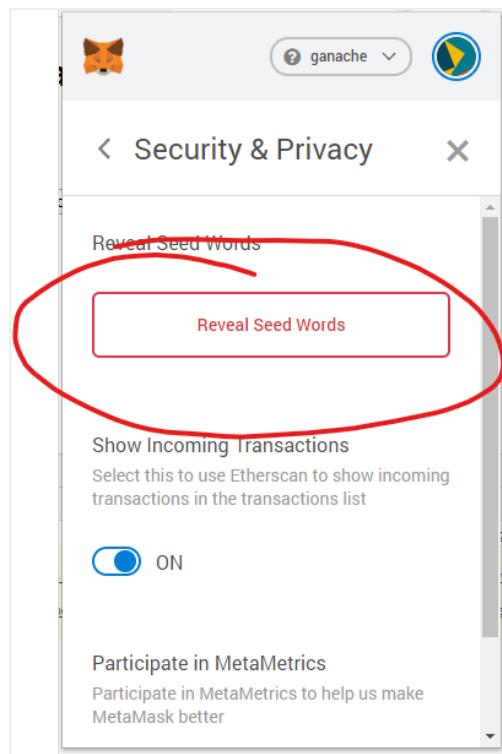
truffle-config.js

```
const path = require("path");
require('dotenv').config({path: './.env'});
const HDWalletProvider = require("@truffle/hdwallet-provider");
const MetaMaskAccountIndex = 0;

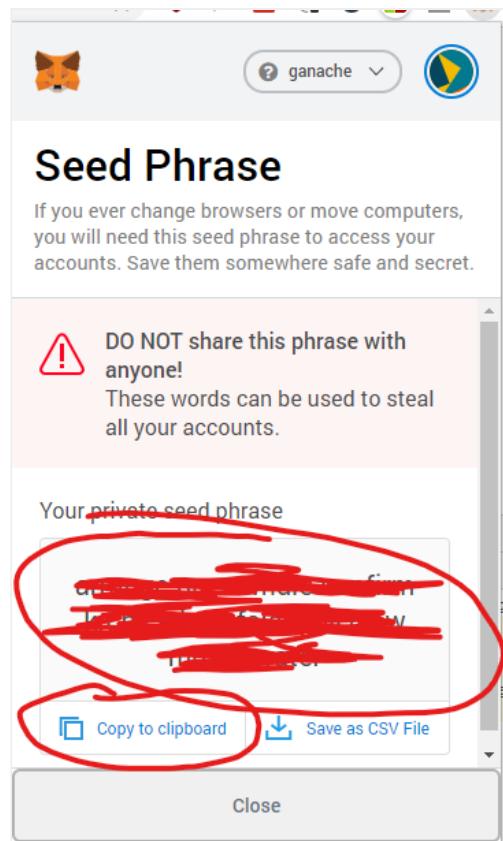
module.exports = {
// See <http://truffleframework.com/docs/advanced/configuration>
// to customize your Truffle configuration!
contracts_build_directory: path.join(__dirname, "client/src/contracts"),
networks: {
  development: {
    port: 7545,
    network_id: "*",
    host: "127.0.0.1"
  },
  ganache_local: {
    provider: function() {
      return new HDWalletProvider(process.env.MNEMONIC, "http://127.0.0.1:7545", MetaMaskAccountIndex )
    },
    network_id: 5777
  }
},
compilers: {
  solc: {
    version: "0.6.1",
  }
}
};
```

And add the Mnemonic from MetaMask to the .env file:





Copy the Mnemonic and add it to the env-file:



```
.env
1 INITIAL_TOKENS=10000000
2 MNEMONIC=
```

A red arrow points from the number '2' in the .env file to the 'MNEMONIC' field, which is also highlighted with a red circle.

Then run the migrations again with the right network and see how your smart contracts are deployed:

```
truffle migrate --network ganache_local
```

It should come up as these migrations:

```
Replacing 'MyTokenSale'
```

```
> transaction hash: 0x0d7ef4cca2edb03b9b574d4f8c66c196de6ca04c3b02641354b7a2122576f079
> Blocks: 0 Seconds: 0
> contract address: 0x89416e57C05DF790F80E46d32cBe719F7DDF8aCd
> block number: 17
> block timestamp: 1582654868
> account: 0x87bc6aE16286b1D848E0ac25E7205554671aF7Dd
> balance: 0.93691332
> gas used: 941369
> gas price: 20 gwei
> value sent: 0 ETH
> total cost: 0.01882738 ETH

> Saving migration to chain.
> Saving artifacts
-----
> Total cost: 0.05847164 ETH
```

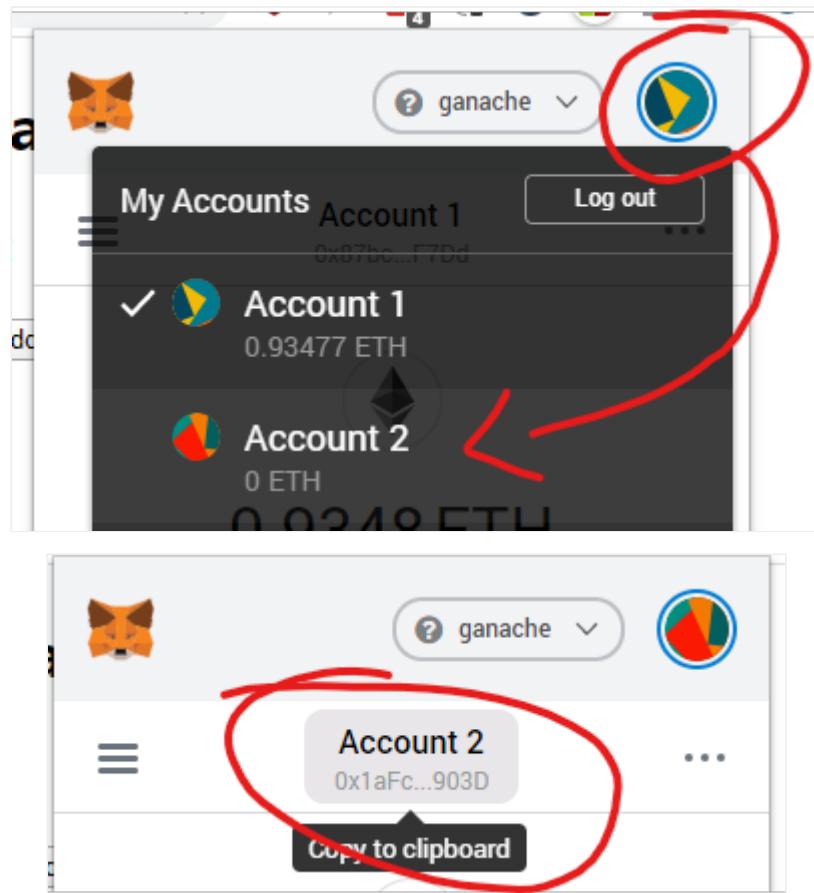
```
Summary
```

```
=====
> Total deployments: 4
> Final cost: 0.06224666 ETH
```

15.12.2 Use the KycContract from your DApp using MetaMask

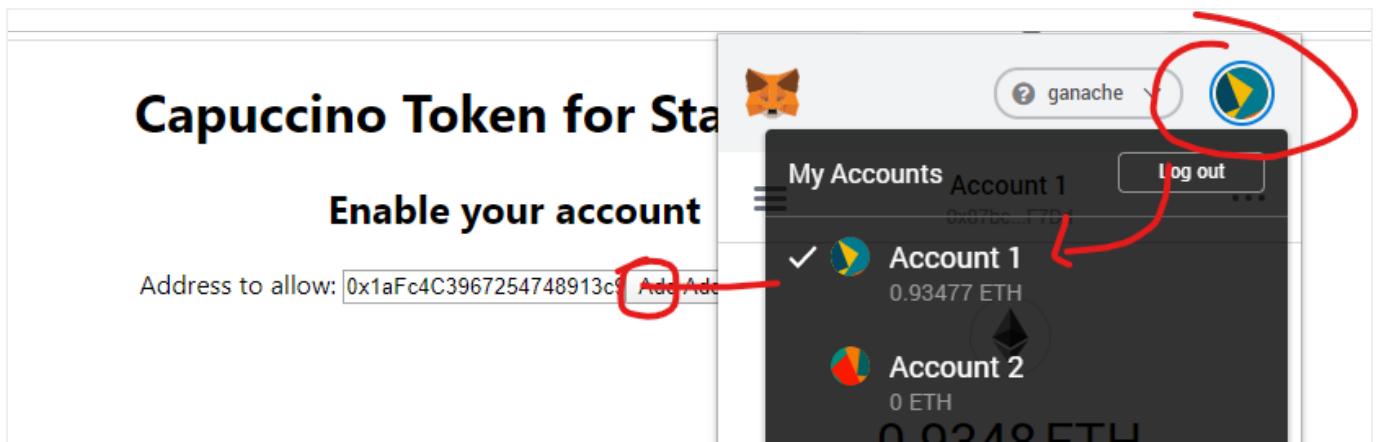
This was the groundwork. Next up is to actually white list an account. We could use another account in MetaMask to whitelist it.

Copy one of your accounts in MetaMask (other than your account#1) to whitelist:

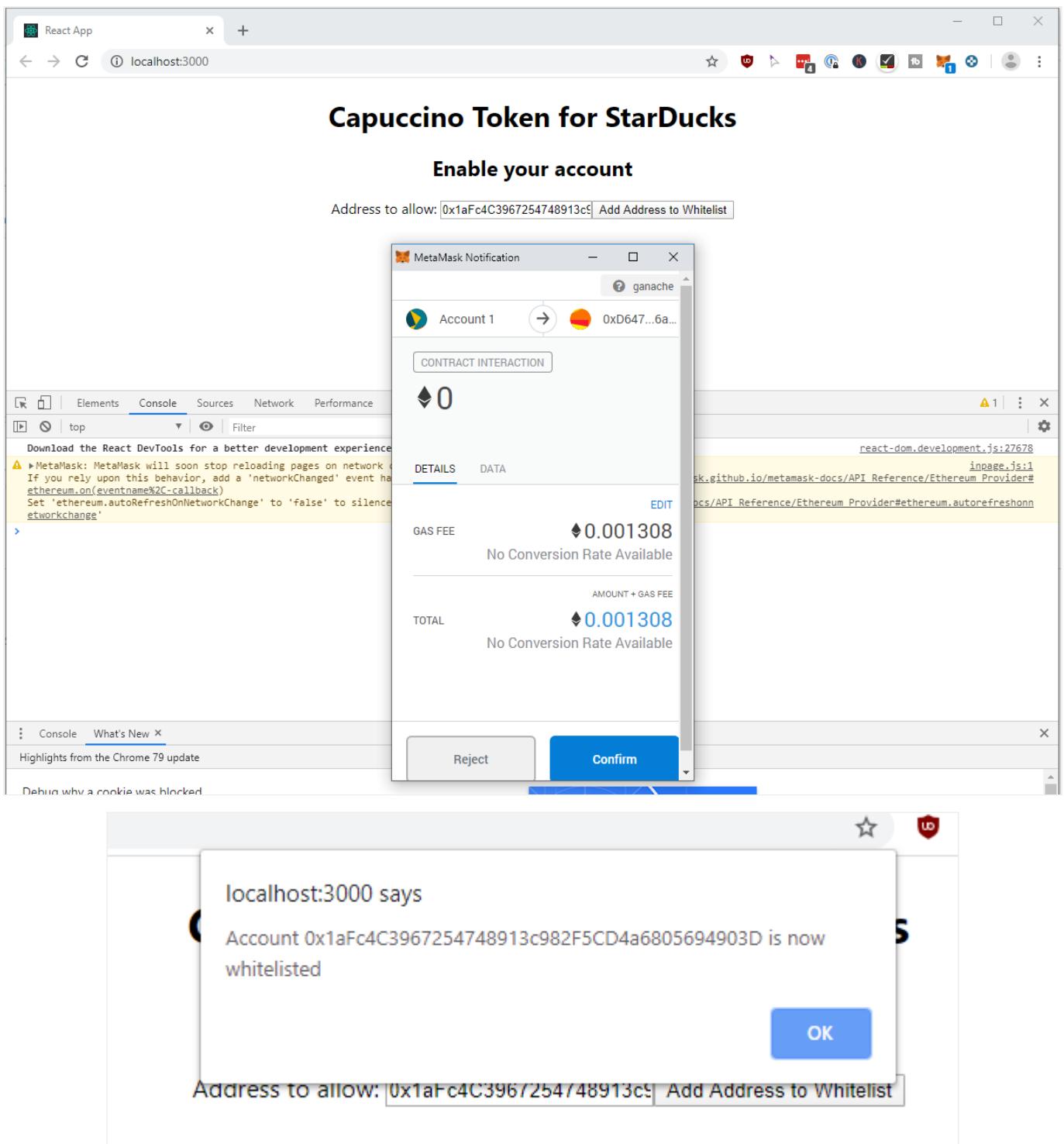


Now, paste this account into the account-field in your new HTML UI:

But before sending off the transaction, make sure you switch back to Account #1 (the account that created the smart contract from truffle migrate):



You should see a popup to confirm the transaction and then an alert box, that tells you that your account is now whitelisted:

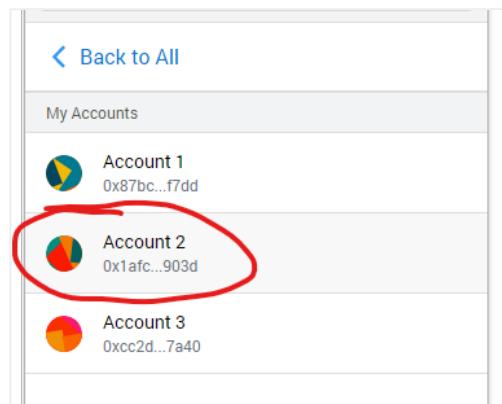
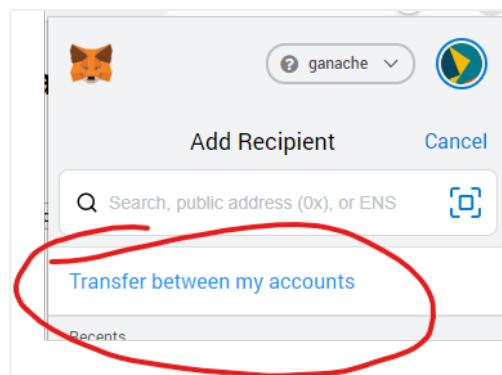
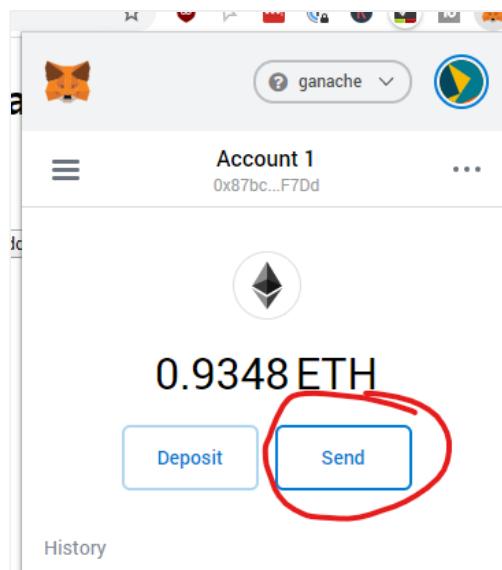


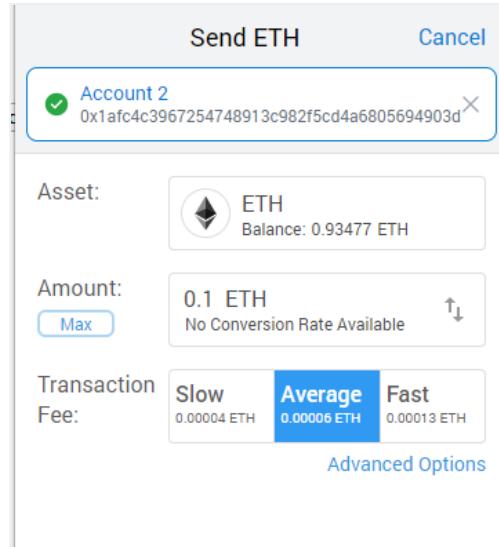
Account #2 is now whitelisted. But how to purchase Tokens?

Last update: April 17, 2021

15.13 Buy Coffee Tokens

To actually purchase any tokens, we must first get some ether into the account. Every token has a price, so, let's first send Ether from Account #1 to Account #2:





Enter 0.1 Ether, Hit confirm and wait for the 0.1 to arrive in Account#2. Using Ganache, it should take no longer than 5 seconds.

Now the interesting part. How to get Tokens?

First, we have to send Wei (or Ether) to the right address. Let's display the address inside the UI.

```
render() {
  if (!this.state.loaded) {
    return <div>Loading Web3, accounts, and contract...</div>;
  }
  return (
    <div className="App">
      <h1>Capuccino Token for StarDucks</h1>

      <h2>Enable your account</h2>
      Address to allow: <input type="text" name="kycAddress" value={this.state.kycAddress} onChange={this.handleInputChange} />
      <button type="button" onClick={this.handleKycSubmit}>Add Address to Whitelist</button>
      <h2>Buy Cappuccino-Tokens</h2>
      <p>Send Ether to this address: {this.state.tokenSaleAddress}</p>
    </div>
  );
}
```

And also add the variable to the state:

```
class App extends Component {
  state = { loaded: false, kycAddress: "0x123", tokenSaleAddress: "" };

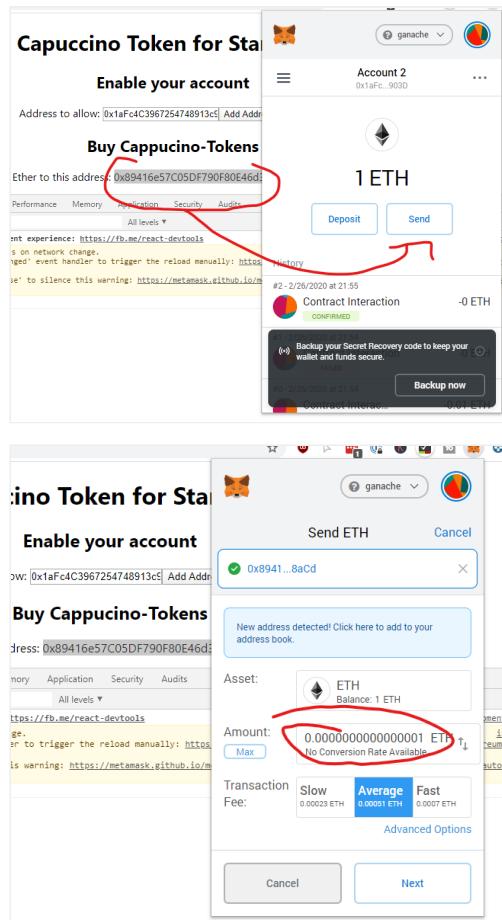
  componentDidMount = async () => {
```

And in componentDidMount write the tokenSaleAddress:

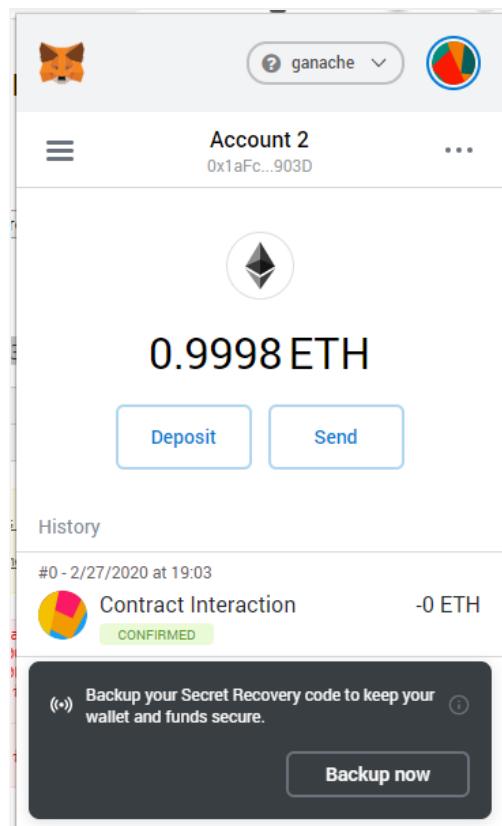
```
this.kycContract = new this.web3.eth.Contract(
  KyccContract.abi,
  KyccContract.networks[this.networkId] && KyccContract.networks[this.networkId].address,
);

// Set web3, accounts, and contract to the state, and then proceed with an
// example of interacting with the contract's methods.
this.setState({ loaded:true, tokenSaleAddress: this.myTokenSale._address });
} catch (error) {
```

Then simply send 1 Wei from your account. Initially, we set 1 Wei equals 1 Token, we might want to change that later on, but for testing it's okay:



1 Ether = 10^{18} Wei, so 1 Wei = 0.0000000000000001 Ether. A tool I use to convert is [Eth Converter](#)



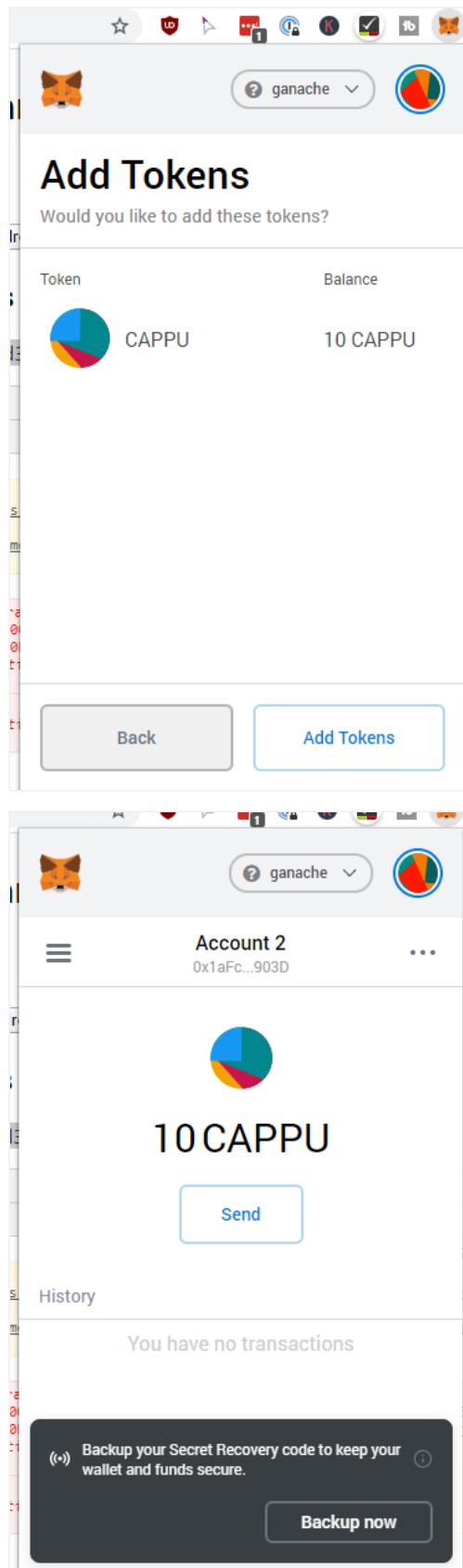
15.13.1 How to Display the Tokens within MetaMask?

We need to open MetaMask and add a custom Token to our UI. Follow the following pictures to add the Token:

The image consists of two screenshots of the MetaMask extension. The top screenshot shows the main dashboard. At the top, there is a network selection dropdown showing 'Rinkeby Test Network'. Below it, the account status is 'Not connected' and the account address is 'Account 1 0x5AD2...053E'. The balance is displayed as '0 ETH' with a small ETH icon. Below the balance are three buttons: 'Buy', 'Send', and 'Swap'. Below these buttons are two tabs: 'Assets' (which is selected) and 'Activity'. Under the 'Assets' tab, there is a list item for '0 ETH' with a red oval highlighting the 'Add Token' button below it. The bottom screenshot shows the 'Add Tokens' dialog. At the top, there is a network selection dropdown showing 'ganache'. Below it, the title is 'Add Tokens'. There are two tabs: 'Search' and 'Custom Token', with 'Custom Token' being the active tab. The dialog has three input fields: 'Token Contract Address' (empty), 'Token Symbol' (empty), and 'Decimals of Precision' (set to 0). At the bottom are two buttons: 'Cancel' and 'Next'.

You need the Token-Address, not the TokenSaleAddress. You can either print the address to the UI or copy it directly from the json file in the client/contracts/MyToken.json file.

Add in the Token-Address from the Token and the Symbol "CAPPU", then click next. You should see your token appear in MetaMask for your account:



You could also send one CAPPU token to your other account, directly through MetaMask!

15.13.2 How to Buy and Display the Tokens Amount on the Website

Let's also add in the Tokens amount on the website, as well as a method to buy directly tokens via the website, without calculating yourself how much you want to buy.

```
render() {
  if (!this.state.loaded) {
    return <div>Loading Web3, accounts, and contract...</div>;
  }
  return (
    <div className="App">
      <h1>Capuccino Token for StarDucks</h1>

      <h2>Enable your account</h2>
      Address to allow: <input type="text" name="kycAddress" value={this.state.kycAddress} onChange={this.handleInputChange} />
      <button type="button" onClick={this.handleKycSubmit}>Add Address to Whitelist</button>
      <h2>Buy Cappuccino-Tokens</h2>
      <p>Send Ether to this address: {this.state.tokenSaleAddress}</p>
      <p>You have: {this.state.userTokens}</p>
      <button type="button" onClick={this.handleBuyToken}>Buy more tokens</button>
    </div>
  );
}
```

Then add in first the function to handleBuyToken:

```
handleBuyToken = async () => {
  await this.myToken.methods.buyTokens(this.accounts[0]).send({from: this.accounts[0], value: 1});
}
```

And also update the userTokens...

Add the state:

```
state = { loaded: false, kycAddress: "0x123", tokenSaleAddress: "", userTokens: 0 };
```

And add both, a function to update the userTokens, as well as an event-listener that updates the variable upon purchase:

```
updateUserTokens = async() => {
  let userTokens = await this.myToken.methods.balanceOf(this.accounts[0]).call();
  this.setState({userTokens: userTokens});
}

listenToTokenTransfer = async() => {
  this.myToken.events.Transfer({to: this.accounts[0]}).on("data", this.updateUserTokens);
}
```

The last step is to call these functions at the appropriate place in the code. Add/Change this in the componentDidMount function:

```
this.kycContract = new this.web3.eth.Contract(
  KycContract.abi,
  KycContract.networks[this.networkId] && KycContract.networks[this.networkId].address,
);

// Set web3, accounts, and contract to the state, and then proceed with an
// example of interacting with the contract's methods.
this.listenToTokenTransfer();
this.setState({ loaded:true, tokenSaleAddress: this.myTokenSale._address }, this.updateUserTokens);

} catch (error) {
  // Catch any errors for any of the above operations.
  alert(
    `Failed to load web3, accounts, or contract. Check console for details.`,
  );
  console.error(error);
}
```

Let's give it a try:

Capuccino Token for StarDucks

Enable your account

Address to allow:

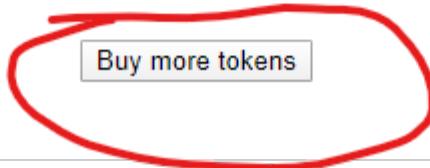
[Add Address to Whitelist](#)

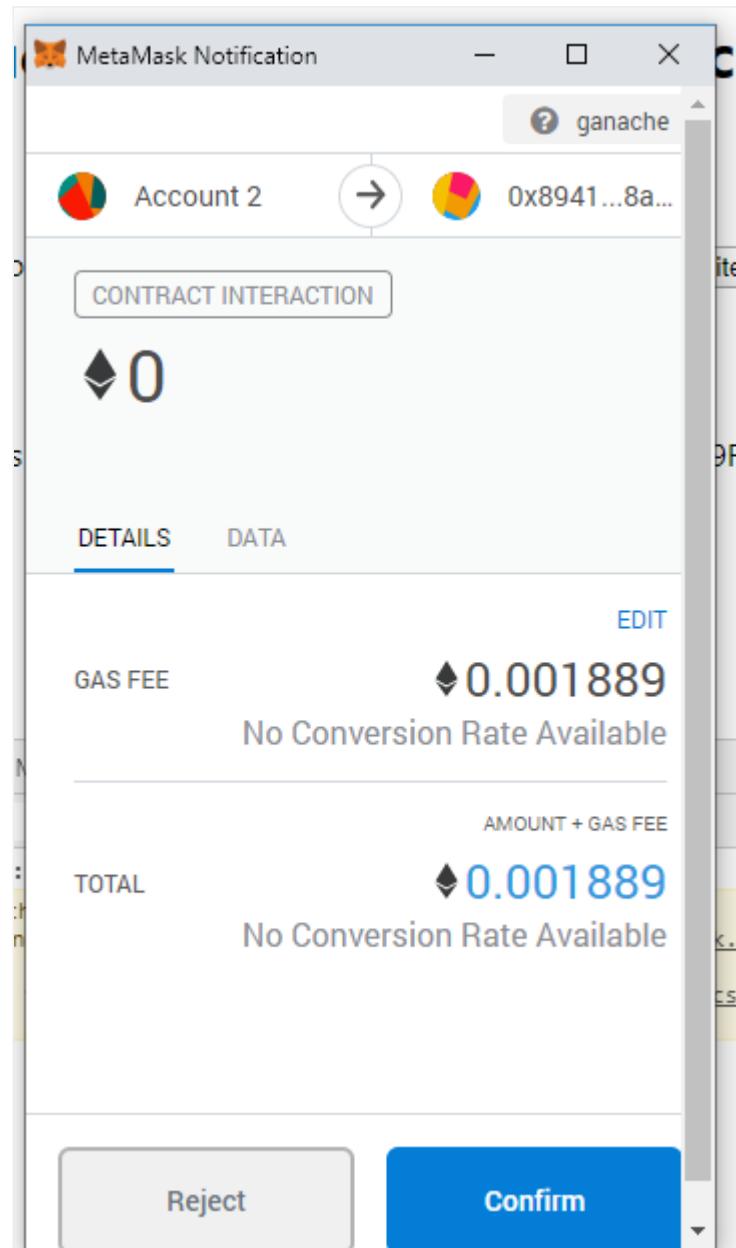
Buy Cappucino-Tokens

Send Ether to this address: 0x89416e57C05DF790F80E46d32cBe719F7DDF8aCd

You have: 10

[Buy more tokens](#)





The screenshot shows a web page with the following content:

- no Token for Site**
- Enable your account**
- A text input field containing `: 0x123` with an **Add** button.
- Buy Cappuccino-Tokens**
- Address: `0x89416e57C05DF790F80E`
- You have: 11** (This text is circled in red.)
- Buy more tokens**

Last update: April 17, 2021

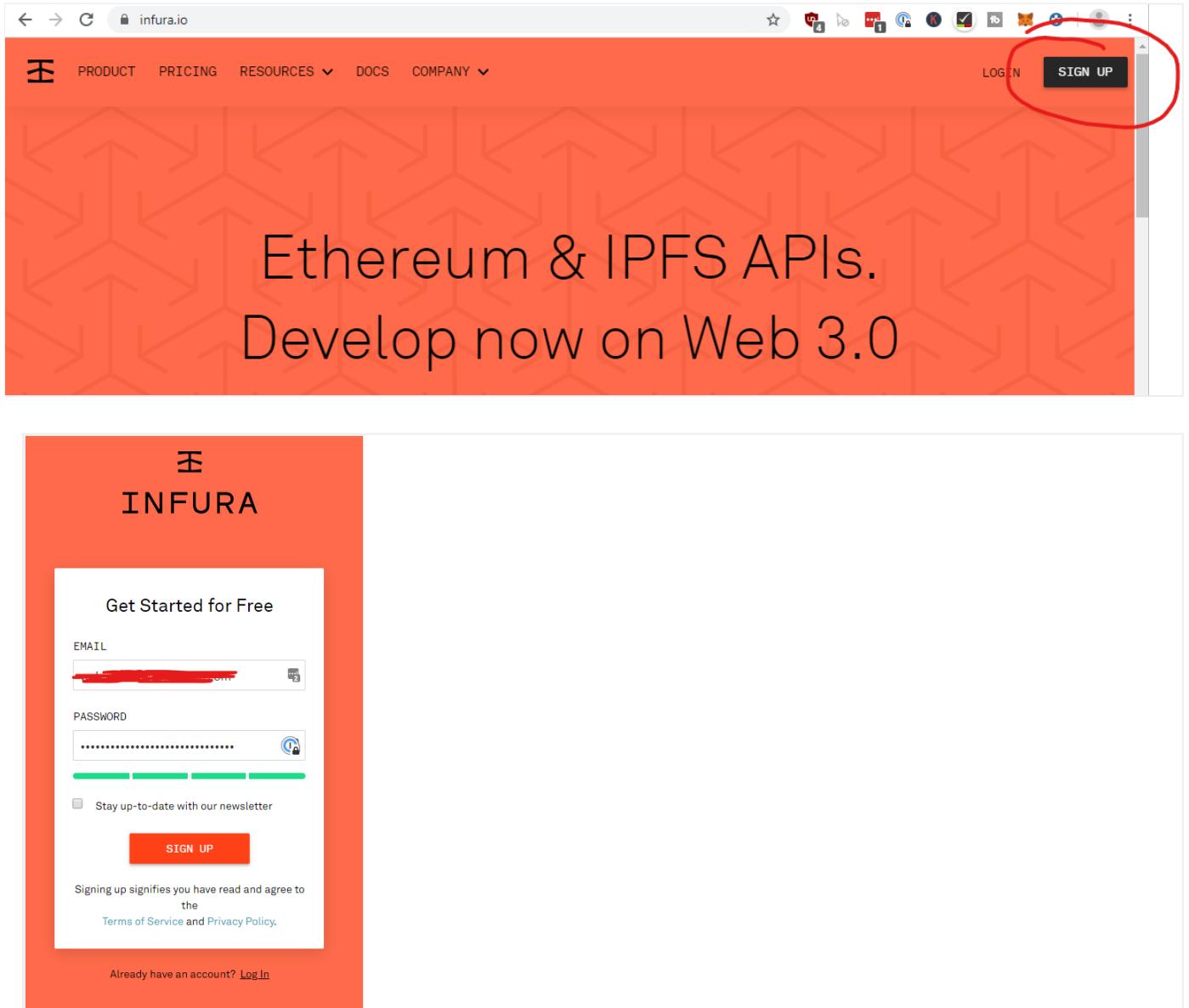
15.14 Deployment with Infura

In this step we are deploying our token into the Test-Network, either Görli or Ropsten. We do this without setting up our own Blockchain Node. We use a hosted node with Infura.

Because our setup is already so well prepared, it's extremely easy to do so.

15.14.1 Signup with Infura

First thing is to signup with Infura. Go to <https://infura.io> and signup with your email address.



Signup with Infura

Confirm the Mail address and enter the dashboard.

15.14.2 Create a new Infura Project

First you need to create a new Infura Project

The screenshot shows the Infura.io dashboard. At the top, there's a banner for 'INFURA+' with the text 'Upgrade to Plus for more services to grow your application.' and two 'UPGRADE' buttons. Below the banner, there's a section titled 'YOUR PROJECTS' with a note '3 remaining'. In the center, a large red oval highlights the 'CREATE NEW PROJECT' button. To the left of the button, there's a small icon of a network or connection. Below the button, there's a call-to-action: 'Get started by creating your first project' followed by 'Setup your project to generate your project ID, secret, and endpoints as well as to whitelist contracts.'

Give it a name:

The screenshot shows a 'CREATE NEW PROJECT' modal window. Inside the window, there's a 'NAME' input field containing the text 'my-great-project'. At the bottom of the modal, there are two buttons: 'CANCEL' on the left and 'CREATE' on the right. The background of the modal is white, while the rest of the Infura dashboard has an orange gradient.

And hit "CREATE".

View the Project:

YOUR PROJECTS 2 remaining

MY-GREAT-PROJECT

Created on Feb 27, 2020

CREATE NEW PROJECT

VIEW PROJECT

VIEW STATS

This is the important ID you will need:

KEYS

PROJECT ID
7f63b0deb8e7425daafbc0fba88ea811

PROJECT SECRET ⓘ
40731f0bb1e446f788f1cf8e92d1f8ee

ENDPOINT MAINNET ▾

mainnet.infura.io/v3/7f63b0deb8e7425daafbc0fba88ea811

15.14.3 Update the truffle-config.json File

Now let's update the truffle-config.json file so we can deploy using the nodes from Infura. Add a new network:

```

networks: {
  development: {
    port: 7545,
    network_id: "*",
    host: "127.0.0.1"
  },
  ganache_local: {
    provider: function() {
      return new HDWalletProvider(process.env.MNEMONIC, "http://127.0.0.1:7545", MetaMaskAccountIndex)
    },
    network_id: 5777
  },
  ropsten_infura: {
    provider: function() {
      return new HDWalletProvider(process.env.MNEMONIC, "https://ropsten.infura.io/v3/YOUR_INFURA_ID", MetaMaskAccountIndex)
    },
    network_id: 3
  },
  goerli_infura: {
    provider: function() {
      return new HDWalletProvider(process.env.MNEMONIC, "https://goerli.infura.io/v3/YOUR_INFURA_ID", MetaMaskAccountIndex)
    },
    network_id: 5
  }
}

```

```
},
compilers: {
  solc: {

```

Where it says "YOUR_INFURA_ID" enter the ID from your own Infura Dashboard please! That's it. Let's run this!

15.14.4 Run the Migrations

The last part is to run the migrations. At the very beginning of the course we got some test-ether in our MetaMask. You should still have them. Just run the Migrations and see if it works:

```
truffle migrate --network ropsten_infura
```

and watch the output -- this might take a while:

```
> transaction hash: 0x501f819d158d06d54476ebfbba7b6afdf6af2f9bc288c0e22c56cc3a0f6e0118
> Blocks: 1 Seconds: 12
> contract address: 0x89416e57C05DF790F80E46d32cBe719F7DDF8aCd
> block number: 7415251
> block timestamp: 1582832729
> account: 0x87bc6aE16286b1D848E0ac25E7205554671aF7Dd
> balance: 0.76279102
> gas used: 521896
> gas price: 20 gwei
> value sent: 0 ETH
> total cost: 0.01043792 ETH

Deploying 'MyTokenSale'
-----
> transaction hash: 0x943d59b01b001836286d55d5d5001f39730d3d875e9dfb673ebc43e5dc0c655
> Blocks: 2 Seconds: 32
> contract address: 0x18d9d5d60c6063a63bd424D59dbbcBE0DA233BC6
> block number: 7415255
> block timestamp: 1582832750
> account: 0x87bc6aE16286b1D848E0ac25E7205554671aF7Dd
> balance: 0.74745244
> gas used: 766929
> gas price: 20 gwei
> value sent: 0 ETH
> total cost: 0.01533858 ETH

.: Saving migration to chain.
```

Migration is Running

```
> Saving migration to chain.
> Saving artifacts
-----
> Total cost: 0.04799292 ETH

Summary
=====
> Total deployments: 4
> Final cost: 0.05128074 ETH
```

Migration is Finished

And then open your Browser Window again and switch MetaMask to the Ropsten (or Görli) network, depending on which one you deployed. You already can see that you have no tokens there, but also the address of the TokenSale contract changed:

Capuccino Token for StarDucks

Enable your account

Address to allow: 0x123

Buy Cappucino-Tokens

Send Ether to this address: 0x18d9d5d60c6063a63bd424D59dbbcBE0DA233BC6

You have: 0

Deployed on Ropsten

Capuccino Token for StarDucks

Enable your account

Address to allow: 0x123

Buy Cappucino-Tokens

Send Ether to this address: 0x89416e57C05DF790F80E46d32cBe719F7DDF8aCd

You have: 11

Deployed on Ganache

You could go ahead and whitelist another account now and get some tokens. You can also implement a spending token facility, for actually burning tokens once the cappuccino is bought. Before we do that, let's change the whole crowdsale!

Last update: April 17, 2021

16. LEARN: Proxies and Upgrades

16.1 Upgrade Smart Contract and Smart Contract Proxies

This is the lab you've been looking for if you want a tutorial style guide for Smart Contract Upgrades and Proxy Patterns. That is the thing where *storage* and/or Smart Contract *addresses* don't change. You only change the logic of the contract itself.

|

16.1.1 Real-World Use-Case for this Project

- ✖ Iteratively Release new Features
- ✖ Understand the possibilities for Bug-Fixing
- ✖ Pick the right Architecture for your Project
- ✖ ⚡ Avoid Scammers
- ✖ Make Auditors life easier

16.1.2 Development-Goal

- ✖ Understand Storage Collisions
- ✖ Deep Dive Into Storage Patterns
- ✖ Understand All Standards for Proxies
- ✖ Understand the CREATE2 Op-Code

16.1.3 What's in it for you?

At the end of this I want you to know *really all* about upgradeable Smart Contracts as of Q1/2021.

First I want to discuss the different standards. Then I want to do a hands-on deep-dive into OpenZeppelin OS with the Proxy pattern. Lastly I want to discuss Metamorphosis Smart Contracts which can be re-deployed to the same address using CREATE2.

Let's do this!

Last update: April 17, 2021

16.2 Introduction

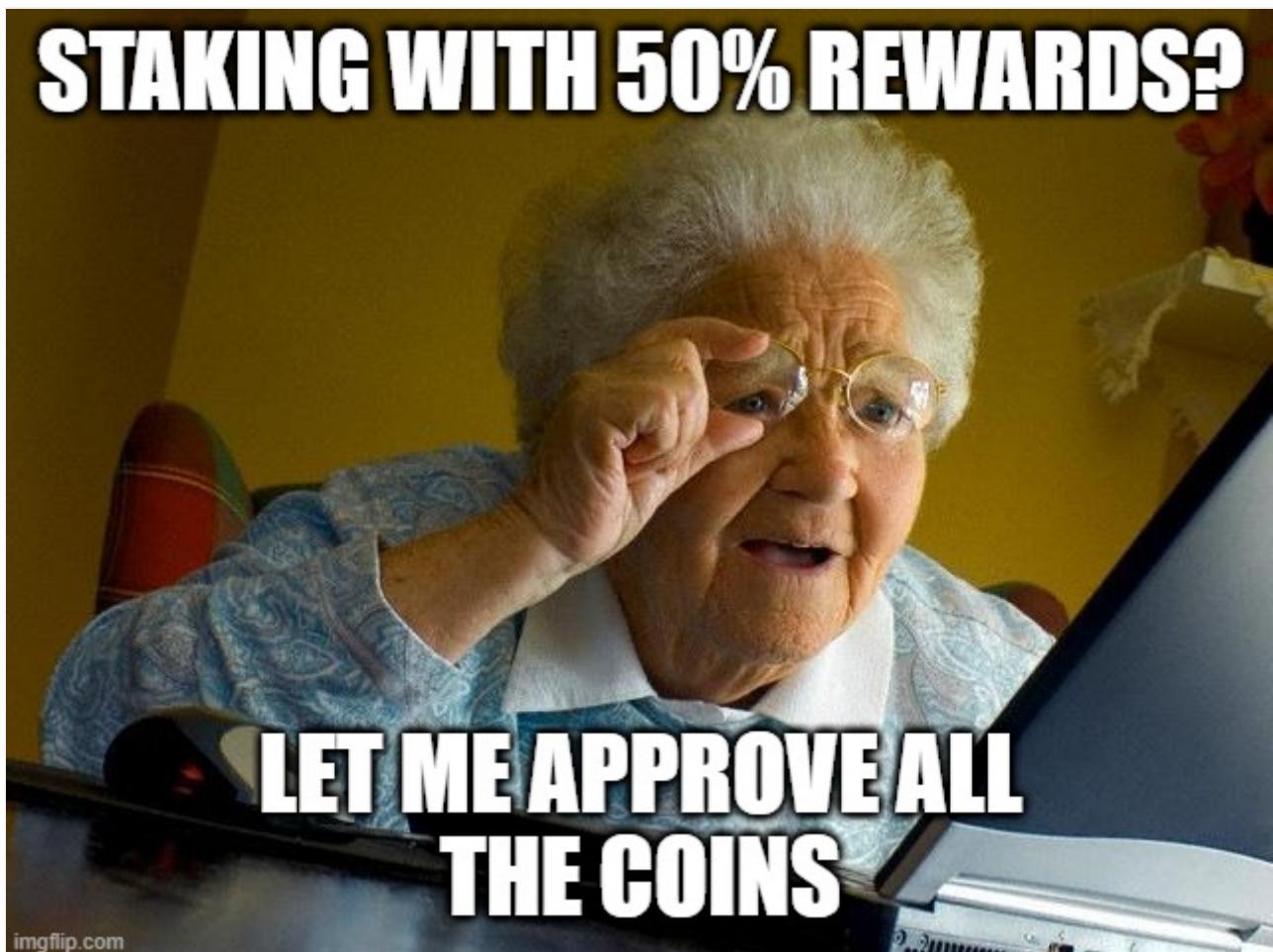
One thing the Blockchain is very often connected to is the immutability of data. For long time it was "*Once it's deployed, it cannot be altered*". That is still true for historical transaction information. But it is not true for Smart Contract storage and addresses.

16.2.1 The Main Reasons For Upgrades

Opinions about this are split in half. A lot of users very much love to have the opportunity of upgradeable Smart Contracts. The others absolutely hate the fact that Smart Contracts are not immutable anymore.

But why would you want to do Smart Contract upgrades in the first place?

The reasons are a diverse mix between Bug-Fixing and Feature-Adding. Sometimes it is updating logic. Sometimes it is combined with a decentralized governance. But hey, sometimes it is also just scamming people into getting their Money.



You will see later how easy it is to fool even seasoned Solidity developers into thinking a Smart Contract is secure.

Enough of the introduction. Let's talk about facts and examples. And how you can detect if you're getting scammed or not.

Last update: April 17, 2021

16.3 The Problematic Smart Contract

One of the main problems with Solidity is that the storage for normal Smart Contracts is bound to the Smart Contract Address. If you deploy a new version you also start with an empty storage.

We can easily try this, and you probably know it already. That's the very basic stuff to get started with, but we need to start *somewhere*, so why not with a simple Smart Contract:

```
// SPDX-License-Identifier: MIT
pragma solidity 0.8.1;

contract LostStorage {
    address public myAddress;

    function setAddress(address _address) public {
        myAddress = _address;
    }
}
```

Deployed in Remix, we can set an address into the variable `myAddress`. Nothing new here.

The screenshot shows the Truffle UI interface. On the left, there's a sidebar with icons for deploying, running, and monitoring transactions. The main area is divided into sections: **ENVIRONMENT** (JavaScript VM), **ACCOUNT** (0x5B3...eddC4 (99.999999)), **GAS LIMIT** (3000000), and **VALUE** (0 wei). The **CONTRACT** section shows the deployed contract **LostStorage - browser/Upgrades/01-lo**. Below it are buttons for **Deploy** and **Publish to IPFS**, and an **OR** button with options **At Address** and **Load contract from Address**.

The **Transactions recorded** section shows two entries:

- setAddress** at address **0x5B38Da6a701c568545dC**
- myAddress** at address **0: address: 0x5B38Da6a701c568545dCfcB 03FcB875f56beddC4**

The right side of the screen displays the Solidity code for **01-lost-storage.sol**:

```

1 // SPDX-License-Identifier: MIT
2 pragma solidity 0.8.1;
3
4 contract LostStorage {
5     address public myAddress;
6
7     function setAddress(address _address) public {
8         myAddress = _address;
9     }
10}

```

Below the code, the transaction history is shown:

- [vm] from: 0x5B3...eddC4 to: LostStorage.(constructor) value: 0 wei
- transact to LostStorage.setAddress pending ...
- [vm] from: 0x5B3...eddC4 to: LostStorage.setAddress(address) 0xd91...

The important part is this: When we re-deploy the Smart Contract, the Smart Contract not only gets a new address, but also the storage is empty again.

The screenshot shows the Truffle UI interface for managing deployed contracts. It displays two separate contracts, each with its own storage value.

Contract 1 (Top):

- Address:** 0x5B38Da6a701c568545dCfcB03FcB875f56beddC4
- Storage:** 0: address: 0x5B38Da6a701c568545dCfcB03FcB875f56beddC4
- Low level interactions:** A "Transact" button is available.

Contract 2 (Bottom):

- Address:** 0x00000000000000000000000000000000
- Storage:** 0: address: 0x00000000000000000000000000000000
- Low level interactions:** A "Transact" button is available.

We end up with two Smart Contracts on - two different addresses - with different storage.

So, we're tackling one problem after the other one.

Last update: April 17, 2021

16.4 Overview of Standards for Smart Contract Upgrades

Here are the different standards that emerged for Smart Contract Upgrades:

1. We're trying the [Eternal Storage Pattern](#)

Actually it was initially proposed by [Elena Dimitrova on this Blog](#)

2. We expand with Proxies where it all started (apparently):

the [upgradeable.sol gist](#) from Nick Johnson, Lead developer of ENS & Ethereum Foundation alum.

3. [EIP-897: ERC DelegateProxy](#)

Created 2018-02-21 by Jorge Izquierdo and Manuel Araoz

4. [EIP-1822: Universal Upgradeable Proxy Standard \(UUPS\)](#)

Created 2019-03-04 by Gabriel Barros and Patrick Gallagher

5. [EIP-1967: Standard Proxy Storage Slots](#)

Created 2019-04-24 by Santiago Palladino That's OpenZeppelin is using.

6. [EIP-1538: Transparent Contract Standard](#) Created 2018-10-31 by Nick Mudge

7. [EIP-2535: Diamond Standard](#) Created 2020-02-22 by Nick Mudge

8. Not really a standard, but I think [Metamorphic Smart Contracts](#) should be covered as well. Those are Smart Contracts that get re-deployed to the same address with different logic using [EIP-1014 CREATE2](#). It's said to be [wild magic](#) in Ethereum.



Simplified Contracts

For me it is important to understand the essence of what's going on under the hood. I will therefore reduce the Smart Contract examples to its absolute necessity for the architectural explanation.

There is no ownership, no control, no governance, just barebones the theory behind the Storage Patterns.

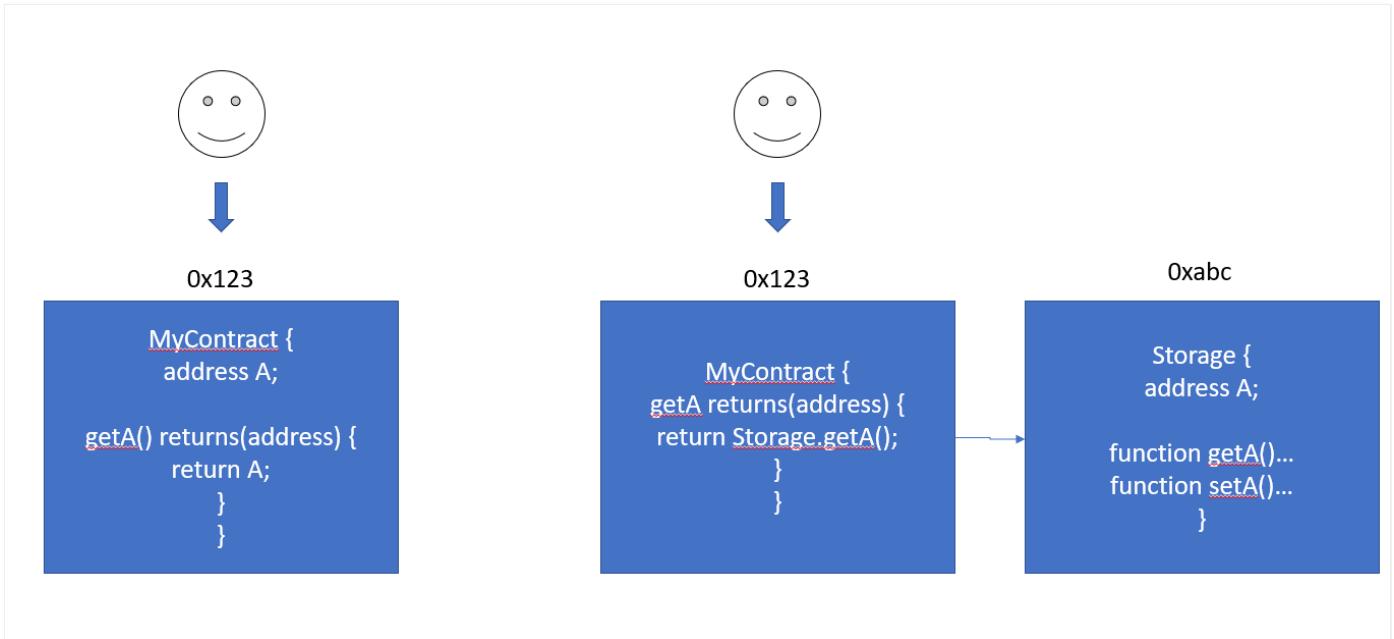
If you need a full blown solution that works out of the box, checkout OpenZeppelin.

Last update: April 17, 2021

16.5 Eternal Storage *without Proxy*

The first thing to tackle is the loss of data during re-deployment. What comes to mind is to separate logic from storage. The question is *how* are we doing that?

We go from the left side of this graphics to the right side.



In the Eternal Storage pattern, we move the storage with setters and getters to a separate Smart Contract and let only read/write the logic Smart Contract from it.

This can be a Smart Contract which deals with *exactly* the variables you need, or you generalize by variable types. Let me show you what I mean by that in the example below.

For sake of simplicity, I will closely take what Elena Dimitrova was using in her [Example](#). But I will greatly simplify this and boil it down to the essence. The Smart Contracts are not therefore remotely *complete*, but show the most important part to understand what's going on under the hood.

I've ported them to Solidity 0.8.1. Just fyi.

It could look like this:

```

// SPDX-License-Identifier: MIT
pragma solidity 0.8.1;

contract EternalStorage{
    mapping(bytes32 => uint) UIntStorage;

    function getUIntValue(bytes32 record) public view returns (uint){
        return UIntStorage[record];
    }

    function setUIntValue(bytes32 record, uint value) public {
        UIntStorage[record] = value;
    }

    mapping(bytes32 => bool) BooleanStorage;

    function getBooleanValue(bytes32 record) public view returns (bool){
        return BooleanStorage[record];
    }
}

```

```

function setBooleanValue(bytes32 record, bool value) public
{
    BooleanStorage[record] = value;
}

library ballotLib {

    function getNumberOfVotes(address _eternalStorage) public view returns (uint256) {
        return EternalStorage(_eternalStorage).getUIntValue(keccak256('votes'));
    }

    function setVoteCount(address _eternalStorage, uint _voteCount) public {
        EternalStorage(_eternalStorage).setUIntValue(keccak256('votes'), _voteCount);
    }
}

contract Ballot {
    using ballotLib for address;
    address eternalStorage;

    constructor(address _eternalStorage) {
        eternalStorage = _eternalStorage;
    }

    function getNumberOfVotes() public view returns(uint) {
        return eternalStorage.getNumberOfVotes();
    }

    function vote() public {
        eternalStorage.setVoteCount(eternalStorage.getNumberOfVotes() + 1);
    }
}

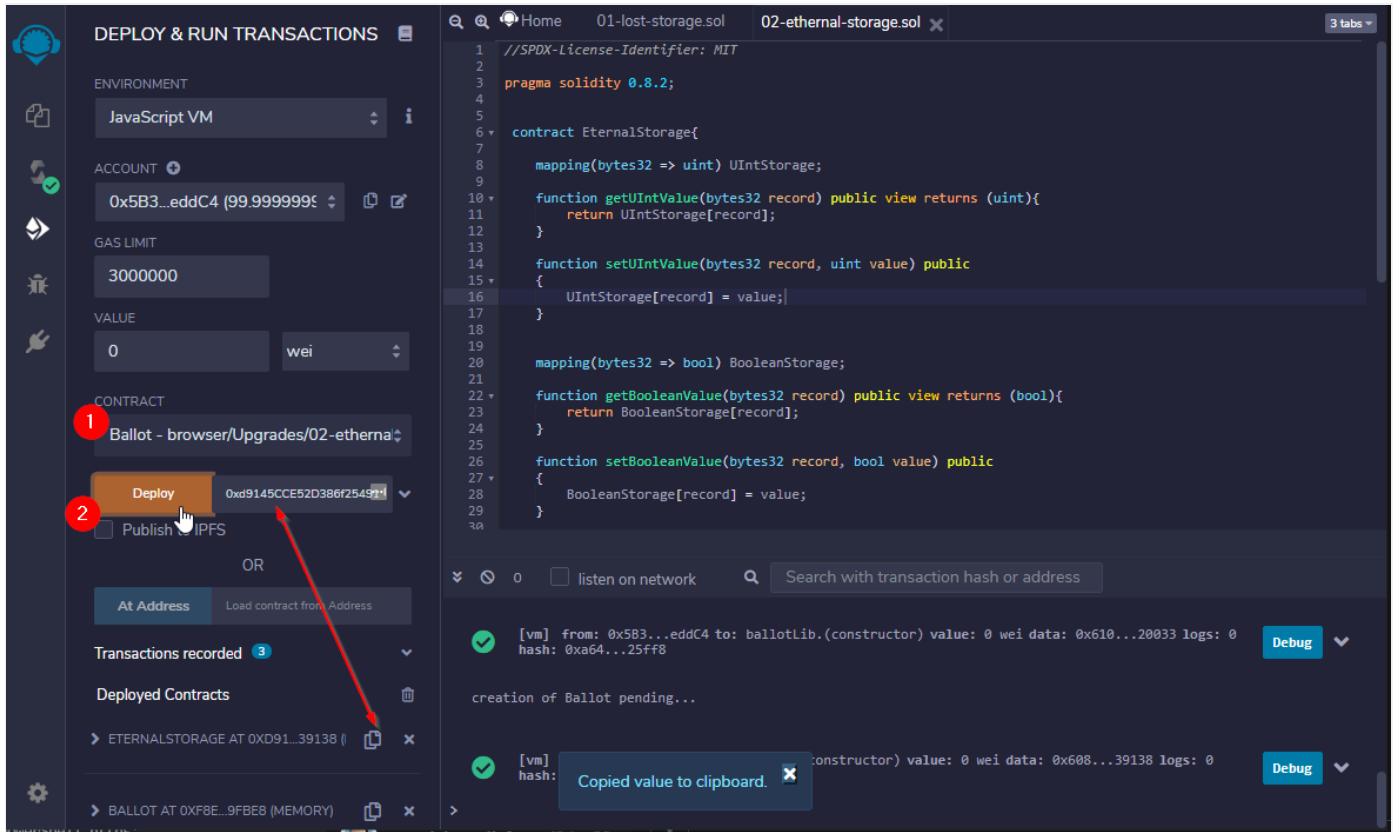
```

This is a simple voting Smart Contract. You call `vote()` and increase a number - pretty basic business logic. Under the hood is the magic.

First we need to deploy the Eternal Storage. This contract remains a constant and isn't changed at all.

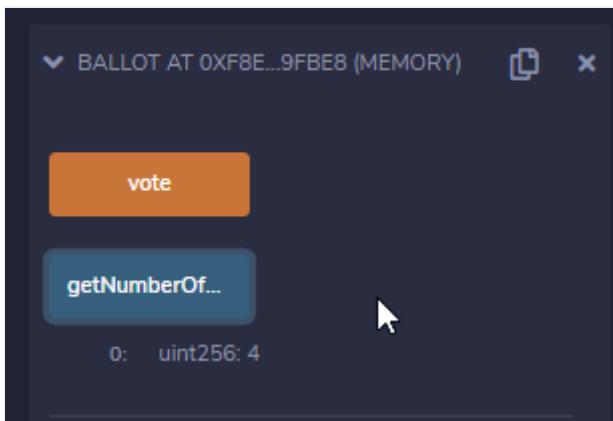
The screenshot shows the Remix IDE interface. On the left, there's a sidebar with various icons for deploying, running, and interacting with contracts. The main area is divided into tabs: Home, 01-lost-storage.sol, and 02-ethernal-storage.sol. The 02-ethernal-storage.sol tab is active, displaying the Solidity code for the EternalStorage contract. The code defines a mapping for UIntStorage and BooleanStorage, and provides functions to get and set values. Below the code editor, there are buttons for 'Deploy' (step 1) and 'Run' (step 2). The status bar at the bottom indicates that no contracts are currently deployed.

Then we deploy the Ballot Smart Contract, which will take the library and the Ballot Contract to do the actual logic.



Under the hood, a library does a `delegatecall`, which executes the libraries code in the context of the Ballot Smart Contract. If you were to use `msg.sender` in the library, then it has the same value as in the Ballot Smart Contract itself.

Let's test this by voting a few times in the new Ballot Instance:



Let's say we found a bug, because everyone can vote as many times as they want. We fix it and re-deploy *only the Ballot* Smart Contract (neglecting that the old version still runs and that there is no way to stop it without extra code).

Replace everything with the following code. Highlighted are the actual changes:

```
// SPDX-License-Identifier: MIT
pragma solidity 0.8.1;

contract EternalStorage{
    mapping(bytes32 => uint) UIntStorage;

    function getUIntValue(bytes32 record) public view returns (uint){
        return UIntStorage[record];
    }
}
```

```

}

function setUIntValue(bytes32 record, uint value) public
{
    UIntStorage[record] = value;
}

mapping(bytes32 => bool) BooleanStorage;

function getBooleanValue(bytes32 record) public view returns (bool){
    return BooleanStorage[record];
}

function setBooleanValue(bytes32 record, bool value) public
{
    BooleanStorage[record] = value;
}

}

library ballotLib {

    function getNumberOfVotes(address _eternalStorage) public view returns (uint256) {
        return EternalStorage(_eternalStorage).getUIntValue(keccak256('votes'));
    }

    function getUserHasVoted(address _eternalStorage) public view returns(bool) {
        return EternalStorage(_eternalStorage).getBooleanValue(keccak256(abi.encodePacked("voted",msg.sender)));
    }

    function setUserHasVoted(address _eternalStorage) public {
        EternalStorage(_eternalStorage).setBooleanValue(keccak256(abi.encodePacked("voted",msg.sender)), true);
    }

    function setVoteCount(address _eternalStorage, uint _voteCount) public {
        EternalStorage(_eternalStorage).setUIntValue(keccak256('votes'), _voteCount);
    }
}

contract Ballot {
    using ballotLib for address;
    address eternalStorage;

    constructor(address _eternalStorage) {
        eternalStorage = _eternalStorage;
    }

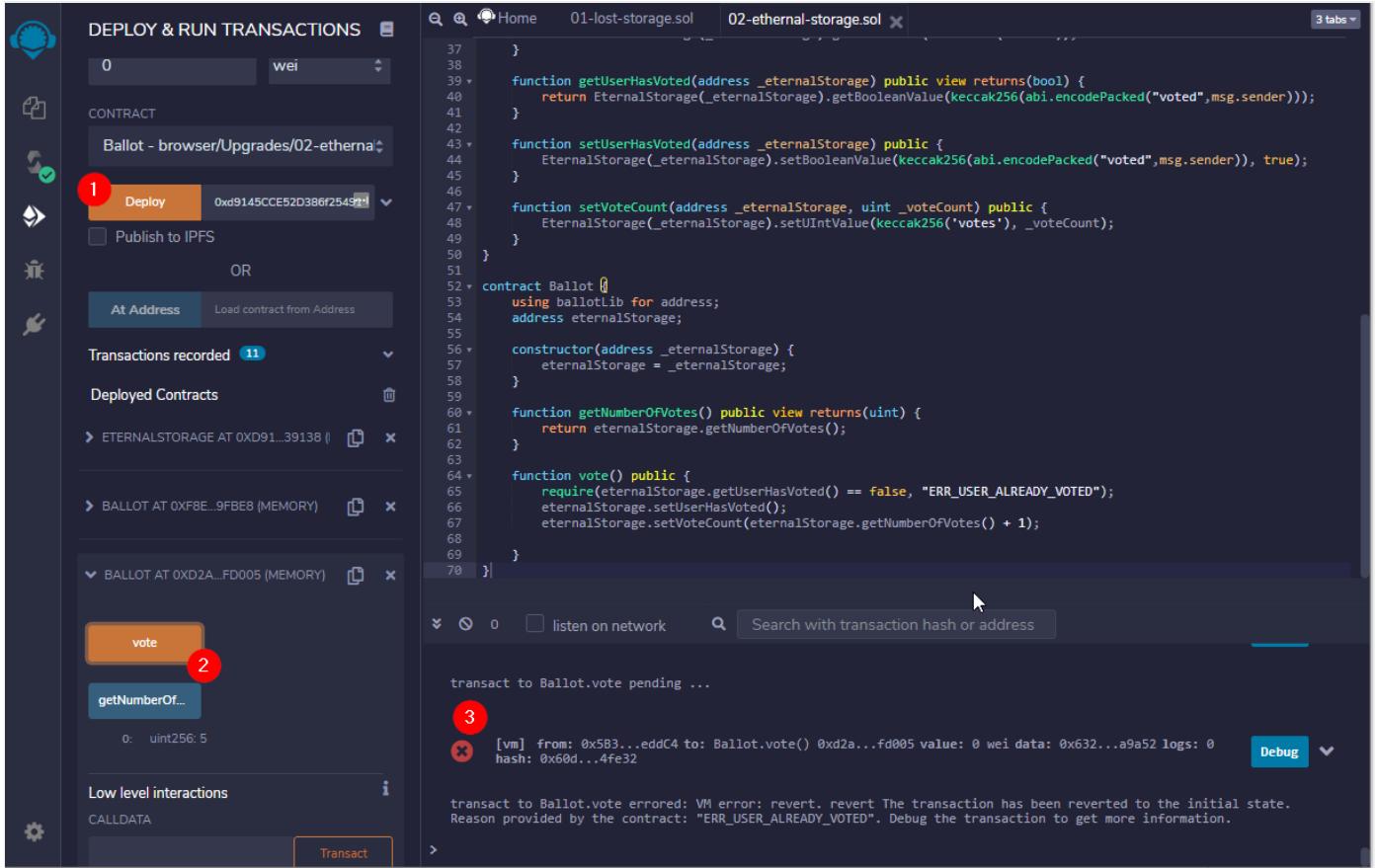
    function getNumberOfVotes() public view returns(uint) {
        return eternalStorage.getNumberOfVotes();
    }

    function vote() public {
        require(eternalStorage.getUserHasVoted() == false, "ERR_USER_ALREADY_VOTED");
        eternalStorage.setUserHasVoted();
        eternalStorage.setVoteCount(eternalStorage.getNumberOfVotes() + 1);
    }
}

```

You see, only the Library changed. The Storage is exactly the same as before. But how to deploy the update?

Re-Deploy the "Ballot" Smart Contract and give it the address of the Storage Contract. That's all.



The Storage Contract hasn't changed at all, we don't even need to redeploy it. Just use the one that already exists! You see then that you can vote one last time - so we flag your account, then you get an error (3) in the screenshot.

The original Storage Smart Contract from Elena has a couple more variable types of course, as uint and boolean would not be enough.

While it sounds good, this has some advantages and some disadvantages.

Relatively easy to understand: It doesn't involve any assembly magic at all. If you come from traditional software development, these patterns should look fairly familiar.

Would also work without Libraries, just a Storage Smart Contract running under its own address.

Eliminates the Storage Migration after Contract Updates.

Address of Contracts change - this can also be good for transparency reasons. E.g. you run an online service and fees change for new signups.

Quite difficult access pattern for variables.

Doesn't work out of the box for existing Smart Contracts like Tokens etc.

It is simple, but a very viable solution - depending on the use case. Sometimes, especially with Smart Contracts, simpler is better. If you want a real-world example of this, checkout the Smart Contracts `MorpherState` and `MorpherToken`. They are linked together simply with getters and setters, but have the same effect. They are easy to audit and it's very easy to grasp what's going on under the hood in terms of data storage and retrieval.

Many other project use a proxy pattern where the address of the upgraded Smart Contract stays constant.

That's what we're talking next!

Last update: April 17, 2021

16.6 The First Proxy Contract

The first proxy that was ever proposed (to my best knowledge), came from Nick Johnson. If you don't know him, he's founder and lead dev at the ENS (Ethereum Name Service). Also, make sure to checkout his twitter, he's quite active. And he's always ahead of time, literally: he's from New Zealand - GMT+13.

The proxy looks like [this](#). I believe it was written for Sol 0.4.0 (or alike), since later Solidity version would require function visibility specifiers and an actual `pragma` line.

So, here is a copy of the same Smart Contract ported to Solidity 0.8.1 and stripped of any comments and the replace-method made `public` so that we can actually replace Smart Contracts. Again, it's a simplified version without any governance or control, simply showing the upgrade architecture:

```
// SPDX-License-Identifier: No-Idea!

pragma solidity 0.8.1;

abstract contract Upgradeable {
    mapping(bytes4 => uint32) _sizes;
    address _dest;

    function initialize() virtual public;

    function replace(address target) public {
        _dest = target;
        target.delegatecall(abi.encodeWithSelector(bytes4(keccak256("initialize()))));
    }
}

contract Dispatcher is Upgradeable {
    constructor(address target) {
        replace(target);
    }

    function initialize() override public{
        // Should only be called by on target contracts, not on the dispatcher
        assert(false);
    }

    fallback() external {
        bytes4 sig;
        assembly { sig := calldataload(0) }
        uint len = _sizes[sig];
        address target = _dest;

        assembly {
            // return _dest.delegatecall(msg.data)
            calldatacopy(0x0, 0x0, calldatasize())
            let result := delegatecall(sub(gas(), 10000), target, 0x0, calldatasize(), 0, len)
            return(0, len) //we throw away any return data
        }
    }
}

contract Example is Upgradeable {
    uint _value;

    function initialize() override public {
        _sizes[bytes4(keccak256("getUint()"))] = 32;
    }

    function getUint() public view returns (uint) {
        return _value;
    }

    function setUint(uint value) public {
        _value = value;
    }
}
```

So, what's going on here? Before we try the contract, let me quickly explain the assembly in the fallback function.

What happens is basically a `delegatecall` to the `Example` Smart Contract. What's a `delegate call` anyways?

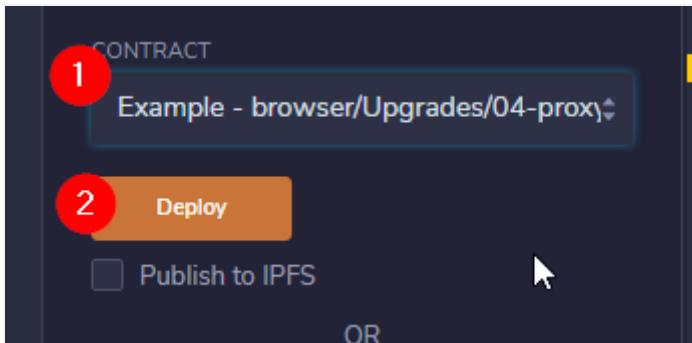
Delegatecall from the Solidity Docs

There exists a special variant of a message call, named `delegatecall` which is identical to a message call apart from the fact that the code at the target address is executed in the context of the calling contract and `msg.sender` and `msg.value` do not change their values.

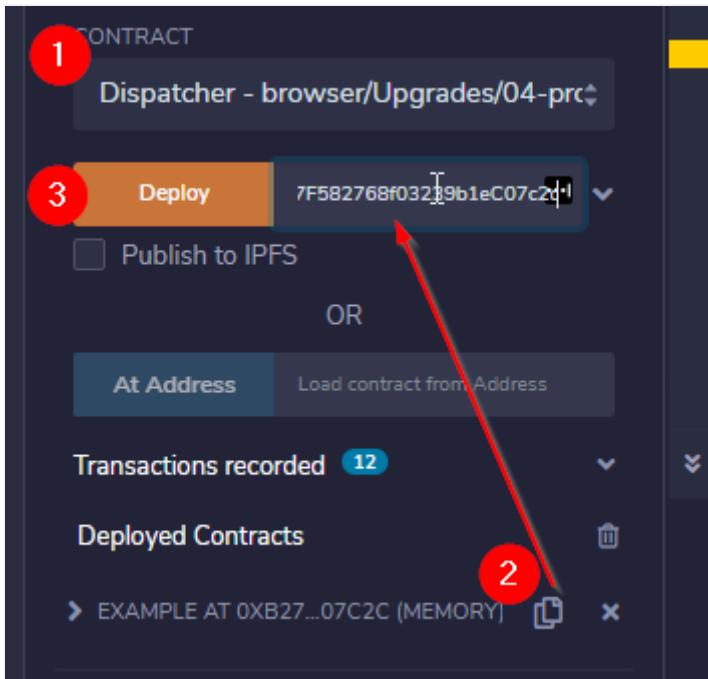
If that doesn't tell you much: Instead of running the code of the target contract on the target contracts address, we're running the code of the target contract on the contract that called the target. WOOH! Complicated sentence.

Let's play around and see where this is going:

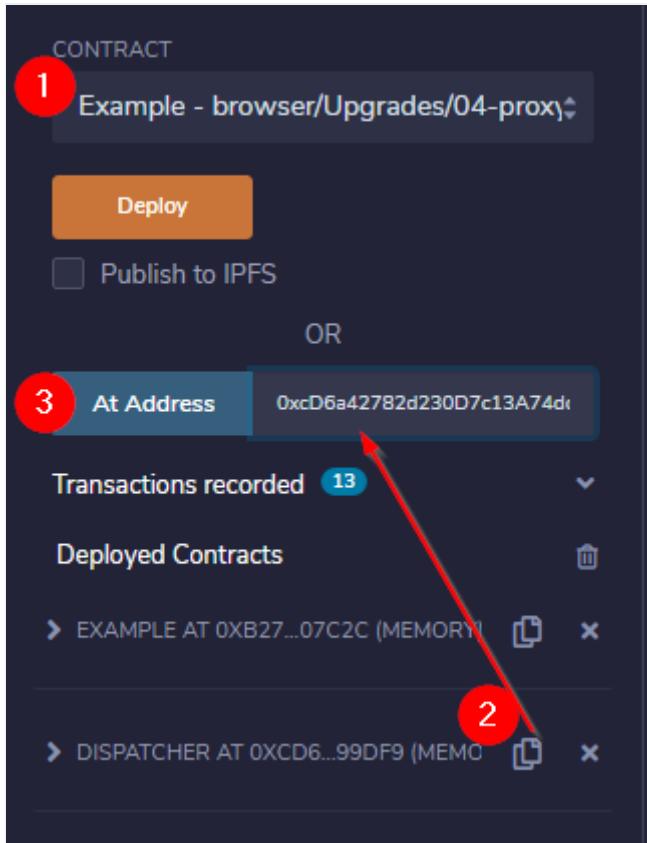
1. Deploy Example
2. Deploy the Dispatcher using the Example address as the Dispatcher's constructor argument.
3. Tell Remix that the Example Contract is now running on the Dispatcher address.



then deploy the dispatcher:



then use the Example on the Dispatcher's address:



⚡ Storage Pointer

Attention: This implementation only works, because the Upgradeable contract has the target address on storage slot 0. If you're interested why the other implementations use `mload(0x40)` and what happens here with the storage pointers, then checkout the following [guide](#) from OpenZeppelin, which explains this quite elegantly.

In the Example-via-Dispatcher Contract, set a uint and get a uint. Voilà, variables are stored correctly, although our Dispatcher doesn't know any `setUint` or `getUint` functions. It also doesn't inherit from Example.

The screenshot shows the Ethernal Storage interface with the following details:

- Deploy & Run Transactions** tab is active.
- Deploy** button is visible.
- Publish to IPFS** checkbox is unchecked.
- OR** section:
 - At Address**: 0xD6a42782d230D7c13A74d
- Transactions recorded**: 14
- Deployed Contracts** list:
 - EXAMPLE AT 0XB27...07C2C (MEMORY)
 - DISPATCHER AT 0XC6D...99DF9 (MEMO)
 - EXAMPLE AT 0CD6...99DF9 (MEMORY)
 - initialize** button
 - replace** button: address target
 - Step 1: **setUInt**: value 555
 - Step 2: **getUInt**: value 555
- Code Editor** (top right):

```
// SPDX-License-Identifier: No-Ideal!
pragma solidity 0.8.1;

abstract contract Upgradeable {
    mapping(bytes4 => uint32) _sizes;
    address _dest;

    function initialize() virtual public;

    function replace(address target) public {
        _dest = target;
        target.delegatecall(abi.encodeWithSelector(bytes4(keccak256("initialize()"))));
    }
}

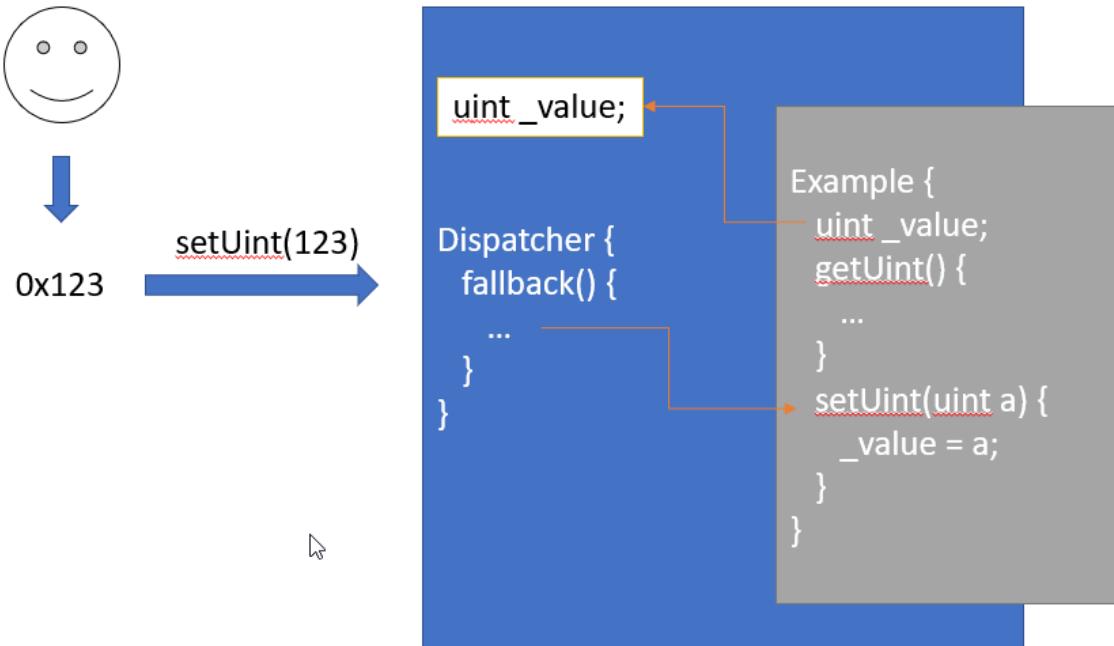
contract Dispatcher is Upgradeable {
    constructor(address target) {
        replace(target);
    }

    function initialize() override public{
        // Should only be called by on target contracts, not on the dispatcher
        assert(false);
    }

    fallback() external {
        bytes4 sig;
        assembly { sig := calldataload(0) }
        uint len = _sizes[sig];
        address target = _dest;
        assembly {
            . .
        }
    }
}
```
- Logs** (bottom right):
 - [vm] from: 0x5B3...eddC4 to: Dispatcher.(fallback) 0xD6...99DF9 value: 0 wei data: 0x4ef...0022b logs: 0 hash: 0x86c...bfdd2
 - call to Example.getUInt
 - [call] from: 0x5B38Da6a701c568545dCfcB03FcB875f56beddC4 to: Dispatcher.(fallback) data: 0x000...267a4
- Debug** buttons (bottom right):

Pretty cool!

This will essentially use the Dispatcher as a storage, but use the logic stored on the Example contract to control what happens. Instead of the Dispatcher "*talking to*" the Example contract, we're now moving the code of the Example contract into the scope of the Dispatcher and executing it there - changing the Dispatchers storage. That is a huge difference to before with the EternalStorage pattern.



The op-code `delegatecall` will "move" the Example contract into the Dispatcher and use the Dispatcher's storage.

It's a great example of a first proxy implementation. Especially, considering it was *early days* for Solidity development, that was quite forward thinking!

Let's say we want to upgrade our Smart Contract returning 2^* the uint value from `getUint()`:

```

//... more code
contract Example is Upgradeable {
    uint _value;

    function initialize() override public {
        _sizes[bytes4(keccak256("getUint()"))] = 32;
    }

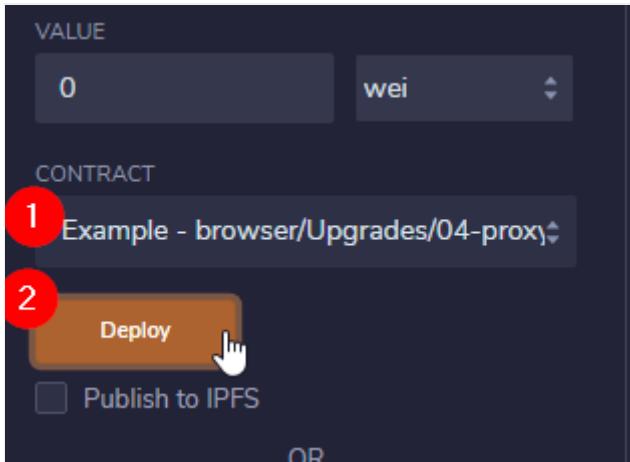
    function getUint() public view returns (uint) {
        return _value*2;
    }

    function setUint(uint value) public {
        _value = value;
    }
}

```

That's how you can upgrade your logic contract using the `replace` method:

1. Update the Example Contract, for example return 2^* the value in `getUint()`
2. Deploy the Example Contract
3. Copy the Example Contract address
4. Call `replace` in the Dispatcher with the new Example Contract address



then call replace:

The screenshot shows the Remix IDE interface. On the left, there's a sidebar with icons for file operations and a 'DEPLOY & RUN TRANSACTIONS' section. In the center, there's a code editor with tabs for '01-lost-storage.sol', '02-ethernal-storage.sol', and '04-proxy.sol'. The '04-proxy.sol' tab is active, showing the proxy contract code. A red circle labeled '1' is over the 'replace' button in the sidebar. Another red circle labeled '2' is over the same 'replace' button, with a mouse cursor pointing at it. A red arrow points from the 'replace' button to the deployed contract address 'D07FB8d73e86ebcA8a5692' in the sidebar. The bottom right shows a transaction history with a successful call to the dispatcher and a message 'Copied value to clipboard.'

You can still use the old instance, it will return now 2* the value.

```

// Should only be called by own target contracts, not on the dispatcher
assert(false);
}

fallback() external {
    bytes4 sig;
    assembly { sig := calldataload(0) }
    uint len = _sizes[bytes4(sig)];
    address target = _dest;

    assembly {
        // return _dest.delegatecall(msg.data)
        calldatadcopy(0x0, 0x0, calldatasize())
        let result := delegatecall(sub(gas(), 10000), target, 0x0, calldatasize(), 0, len)
        return(0, len) // we throw away any return data
    }
}

contract Example is Upgradeable {
    uint _value;

    function initialize() override public {
        _sizes[bytes4(keccak256("getUInt"))] = 32;
    }

    function getUInt() public view returns (uint) {
        return _value*2;
    }

    function setUInt(uint value) public {
        _value = value;
    }
}

```

ContractDefinition Example 0 reference(s)

Call to Example.getUInt

[call] from: 0x58380a6a791c568545dCfc803Fc8875f56beddC4 to: Dispatcher.(fallback)

Obviously there's a lot going on under the hood. And this is not the end of the whole story, but it's the beginning of how Proxies work internally.

It has a great disadvantage though: You need to extend from the Upgradeable Smart Contract in all Contracts that are using the Dispatcher, otherwise you will get Storage collisions.

But what are Storage Collisions anyways?

Last update: April 17, 2021

16.7 Understanding Storage and Storage Collisions

Let's try a set of two Smart Contracts, where one is a proxy pattern. You'll see in a second how the storage clashes in the proxy with the first variable.

Copy and paste this contract to Remix:

```
// SPDX-License-Identifier: MIT
pragma solidity 0.8.1;

contract LostStorage {
    address public myAddress;
    uint public myUint;

    function setAddress(address _address) public {
        myAddress = _address;
    }

    function setMyUint(uint _uint) public {
        myUint = _uint;
    }
}

contract ProxyClash {
    address public otherContractAddress;

    constructor(address _otherContract) {
        otherContractAddress = _otherContract;
    }

    function setOtherAddress(address _otherContract) public {
        otherContractAddress = _otherContract;
    }

    fallback() external {
        address _impl = otherContractAddress;

        assembly {
            let ptr := mload(0x40)
            calldatadcopy(ptr, 0, calldatasize())
            let result := delegatecall(gas(), _impl, ptr, calldatasize(), 0, 0)
            let size := returndatasize()
            returndatadcopy(ptr, 0, size)

            switch result
            case 0 { revert(ptr, size) }
            default { return(ptr, size) }
        }
    }
}
```

This fallback function looks slightly more complicated than the previous one, but it does essentially the same thing. Here it also can return values and throw exceptions if there were any in the target contract. A lot happened since Solidity 0.4 and 0.8...

One **major** difference is that the LostStorage is not inheriting the Proxy. So, internally they have separated storage layout and both start from storage slot 0.

What are we going to do with this?

1. Deploy the LostStorage Contract
2. Deploy the Proxy, setting the LostStorage contract address as the constructor argument
3. Tell Remix that the LostStorage is running on the Proxy address
4. Call `myAddress()`. It surprisingly returns a non-zero address. BAM! Collision.

```

function setMyUint(uint _uint) public {
    myUint = _uint;
}

contract ProxyClash {
    address public otherContractAddress;

    constructor(address _otherContract) {
        otherContractAddress = _otherContract;
    }

    function setOtherAddress(address _otherContract) public {
        otherContractAddress = _otherContract;
    }

    fallback() external {
        address _impl = otherContractAddress;

        assembly {
            let ptr := mload(0x40)
            calldatadcopy(ptr, 0, calldatasize())
            let result := delegatecall(gas(), _impl, ptr, calldatasize(), 0, 0)
            let size := returndatasize()
            returndatadcopy(ptr, 0, size)

            switch result
            case 0 { revert(ptr, size) }
            default { return(ptr, size) }
        }
    }
}

```

Transactions recorded:

- LOSTSTORAGE AT 0xD91...39138 (MEM)
- PROXYCLASH AT 0xDBB...33FAB (MEM)
- LOSTSTORAGE AT 0xD8B...33FAB (MEM)

Deployed Contracts:

- setAddress address _address
- setMyUint uint256 _uint
- myAddress
- myUint

Logs:

- [vm] from: 0x5B3...eddC4 to: ProxyClash.(constructor) value: 0 wei data: 0x608...39138 logs: 0 hash: 0x3cf...31635
- call to LostStorage.myAddress
- call [call] from: 0x5B38Da6a701c568545dCfcB03FcB875f56beddC4 to: ProxyClash.(fallback) data: 0x26b...85ee1

That is exactly why we do inheritance with a Storage Contract, so that the Solidity compiler knows where the Storage slots are used. And we will later see that there's an elegant solution around that.

Let's start with the first EIP for Proxies!

Last update: April 17, 2021

16.8 EIP-897: The first *real* Proxy

In order to avoid having two variables taking the same storage slot, we need all contracts to be aware of the additional storage necessary for the proxy. In other words: If we had a separate Smart Contract that does only the storage for the Proxy, then we can use this as a base contract for our `LostStorage`, which is now not lost anymore.

```
// SPDX-License-Identifier: MIT
pragma solidity 0.8.1;

contract ProxyStorage {
    address public otherContractAddress;

    function setOtherAddressStorage(address _otherContract) internal {
        otherContractAddress = _otherContract;
    }
}

contract NotLostStorage is ProxyStorage {
    address public myAddress;
    uint public myUint;

    function setAddress(address _address) public {
        myAddress = _address;
    }

    function setMyUint(uint _uint) public {
        myUint = _uint;
    }
}

contract ProxyNoMoreClash is ProxyStorage {
    constructor(address _otherContract) {
        setOtherAddress(_otherContract);
    }

    function setOtherAddress(address _otherContract) public {
        super.setOtherAddressStorage(_otherContract);
    }

    /**
     * @dev Fallback function allowing to perform a delegatecall to the given implementation.
     * This function will return whatever the implementation call returns
     */
    fallback() payable external {
        address _impl = otherContractAddress;

        assembly {
            let ptr := mload(0x40)
            calldatadcopy(ptr, 0, calldatasize())
            let result := delegatecall(gas(), _impl, ptr, calldatasize(), 0, 0)
            let size := returndatasize()
            returndatadcopy(ptr, 0, size)

            switch result
            case 0 { revert(ptr, size) }
            default { return(ptr, size) }
        }
    }
}
```

If you have a look at the [EIP-897](#), then you'll see it references an implementation from [aragonOS](#) and [zeppelinOS](#). Under the hood it is *this* sample-implementation here. They just add more *bang* like ownership so that only the admin can do upgrades etc. In its essence: *that's it. Period.*

Let's give it a try?

Same pattern as above:

1. Deploy the `NoLostStorage`
2. Deploy the Proxy with the `NoLostStorage` address as the constructor argument
3. Tell Remix that the `NoLostStorage` contract is running on the Proxy
4. Call `myAddress()` - it's zero now, and you can set it to whatever you want.

```

24 }
25 }
26 }
27 }
28 * contract ProxyNoMoreClash is ProxyStorage {
29     constructor(address _otherContract) {
30         setOtherAddress(_otherContract);
31     }
32 }
33 }
34 * function setOtherAddress(address _otherContract) public {
35     super.setOtherAddressStorage(_otherContract);
36 }
37 }
38 */
39 * @dev Fallback function allowing to perform a delegatecall to the given implementation.
40 * This function will return whatever the implementation call returns
41 */
42 fallback() payable external {
43     address _impl = otherContractAddress;
44 }
45 assembly {
46     let ptr := mload(0x40)
47     calldatadcopy(ptr, 0, calldatasize())
48     let result := delegatecall(gas(), _impl, ptr, calldatasize(), 0, 0)
49     let size := returndatasize()
50     returndatadcopy(ptr, 0, size)
51 }
52 switch result
53 case 0 { revert(ptr, size) }
54 default { return(ptr, size) }
55 }
56 }
57 }
```

ContractDefinition ProxyClash → 0 reference(s) ▾

setAddress address_address

setMyLink uint256_uint

myAddress

0: address: 0x00000000000000000000000000000000

myUint

[vm] from: 0x5B3...eddC4 to: ProxyNoMoreClash.(constructor) value: 0 wei data: 0x608...9fbe8 logs: 0 hash: 0xff2...e52a3

call to NotLostStorage.myAddress

call [call] from: 0x5B38Da6a701c568545dFcB03FcB875f56beddC4 to: ProxyNoMoreClash.(fallback) data: 0x26b...85ee1

As the ProxyStorage contract is inherited by both, the NoLostStorage and the Proxy, the compiler will know that it can't just start again from storage slot 0. You will not overwrite the storage slot anymore.

But there are also some downsides to this.

The Downside: Contract Modifications

While this solution sounds pretty cool at first, there is an obvious downside to this approach! All upgradeable Smart Contracts have to extend ProxyStorage for this to work.

If you develop all your Smart Contracts yourself, then you can probably add in the ProxyStorage Smart Contract to all your Smart Contracts, but as soon as you go *standardized* - maybe with Smart Contract packages from OpenZeppelin .., then it becomes increasingly harder.

So, what if there was another way to avoid those storage collisions?

Last update: April 17, 2021

16.9 EIP-1822: Proxies without Storage Collision without common Storage Contracts

Welcome [EIP-1822: Universal Upgradeable Proxy Standard \(UUPS\)](#). A clever solution without the need for a common Storage Smart Contract to let the compiler know which storage slots to use.

So, instead this methods just simply uses a pseudo-random storage slot to store the address of the logic contract.

Before I show you the example, the two important lines are these ones:

```
sstore(0xc5f16f0fcc639fa48a6947836d9850f504798523bf8c9a3a87d5876cf622bcf7, contractLogic)
```

and

```
let contractLogic := sload(0xc5f16f0fcc639fa48a6947836d9850f504798523bf8c9a3a87d5876cf622bcf7)
```

So, in assembly you can store some variable to a specific storage slot and then load it again from that slot. In this case the EIP-1822 uses the keccak256("PROXIALE") = "0xc5f16f0fcc639fa48a6947836d9850f504798523bf8c9a3a87d5876cf622bcf7" which results in the storage slot. It's not 100% random, but random enough so that there's no collision happening. Under normal circumstances at least. You can deep dive into the [Layout of Storage Variables in Solidity](#) then you'll see that there is little chance to create a collision.

The full example using EIP-1822 could look like this:

```
// SPDX-License-Identifier: MIT

pragma solidity 0.8.1;

contract Proxy {
    // Code position in storage is keccak256("PROXIALE") = "0xc5f16f0fcc639fa48a6947836d9850f504798523bf8c9a3a87d5876cf622bcf7"
    constructor(bytes memory constructData, address contractLogic) {
        // save the code address
        assembly { // solium-disable-line
            sstore(0xc5f16f0fcc639fa48a6947836d9850f504798523bf8c9a3a87d5876cf622bcf7, contractLogic)
        }
        (bool success, bytes memory result) = contractLogic.delegatecall(constructData); // solium-disable-line
        require(success, "Construction failed");
    }

    fallback() external payable {
        assembly { // solium-disable-line
            let contractLogic := sload(0xc5f16f0fcc639fa48a6947836d9850f504798523bf8c9a3a87d5876cf622bcf7)
            calldatadcopy(0x0, 0x0, calldatasize())
            let success := delegatecall(sub(gas(), 10000), contractLogic, 0x0, calldatasize(), 0, 0)
            let retSz := returndatasize()
            returndatacopy(0, 0, retSz)
            switch success
            case 0 {
                revert(0, retSz)
            }
            default {
                return(0, retSz)
            }
        }
    }
}

contract Proxiable {
    // Code position in storage is keccak256("PROXIALE") = "0xc5f16f0fcc639fa48a6947836d9850f504798523bf8c9a3a87d5876cf622bcf7"

    function updateCodeAddress(address newAddress) internal {
        require(
            bytes32(0xc5f16f0fcc639fa48a6947836d9850f504798523bf8c9a3a87d5876cf622bcf7) == Proxiable(newAddress).proxiableUUID(),
            "Not compatible"
        );
        assembly { // solium-disable-line
            sstore(0xc5f16f0fcc639fa48a6947836d9850f504798523bf8c9a3a87d5876cf622bcf7, newAddress)
        }
    }

    function proxiableUUID() public pure returns (bytes32) {
        return 0xc5f16f0fcc639fa48a6947836d9850f504798523bf8c9a3a87d5876cf622bcf7;
    }
}

contract MyContract {

    address public owner;
    uint public myUint;
```

```

function constructor1() public {
    require(owner == address(0), "Already initialized");
    owner = msg.sender;
}

function increment() public {
    //require(msg.sender == owner, "Only the owner can increment"); //someone forgot to uncomment this
    myUint++;
}
}

contract MyFinalContract is MyContract, Proxiable {

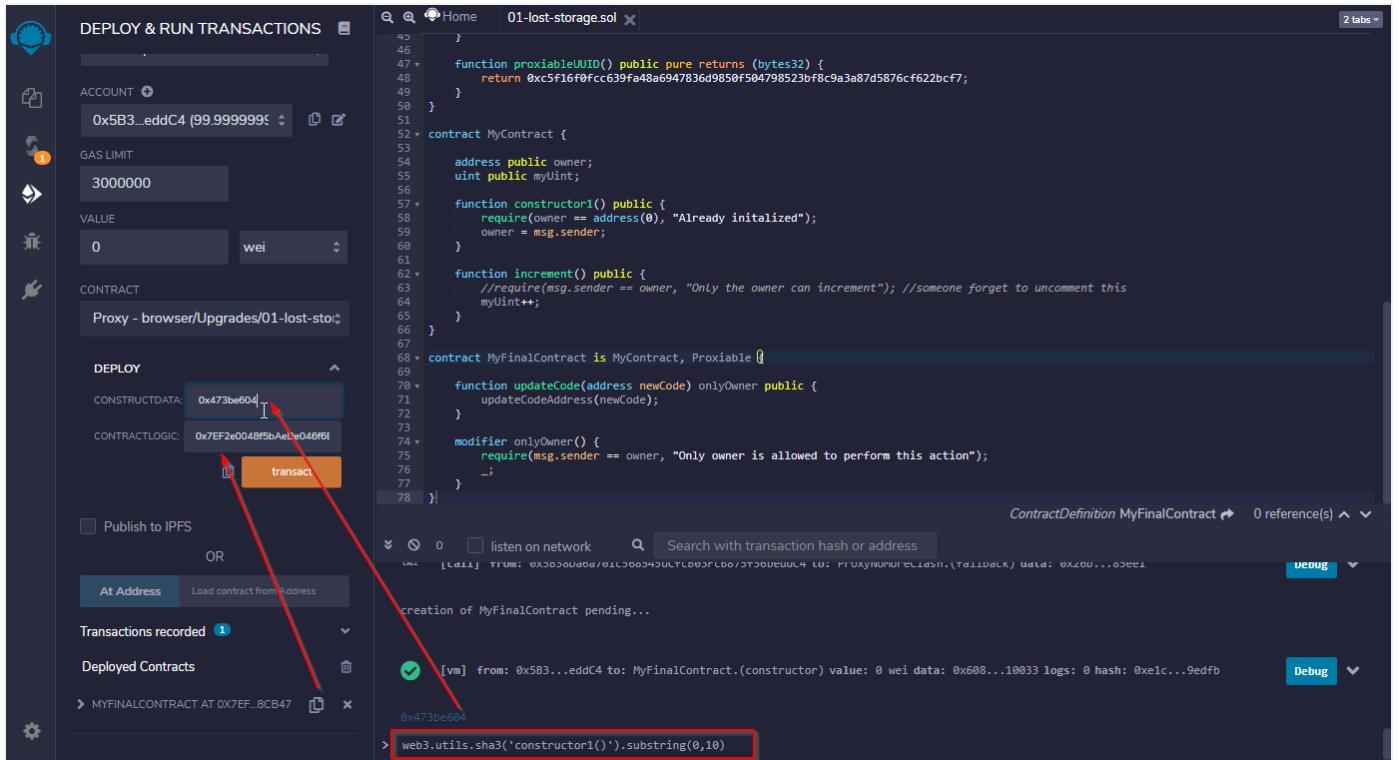
    function updateCode(address newCode) onlyOwner public {
        updateCodeAddress(newCode);
    }

    modifier onlyOwner() {
        require(msg.sender == owner, "Only owner is allowed to perform this action");
        _;
    }
}

```

1. Deploy the MyFinalContract

2. Deploy the Proxy, argument is the `MyFinalContract` Address and as a calldata the `bytes4(keccak256("constructor1"))`. This can be done with `web3.utils.sha3('constructor1()').substring(0,10)` in the Remix Console. See picture below.
3. Then simply tell Remix that `MyFinalContract` is running on the address of the Proxy Contract. As you did before.



As you can see, if you follow the steps, the Contract is now aware of the logic from the `MyFinalContract` - which can inherit any contract, neglecting any Storage inheritance, because it can actually start from storage slot 0.

The screenshot shows the Truffle UI interface. On the left, there's a sidebar with icons for Deploy & Run Transactions, Deployed Contracts, and Low level interactions. The Deployed Contracts section lists three contracts: MYFINALCONTRACT AT 0X7EF...8CB47 (1), PROXY AT 0XDA0...42B53 (MEMORY) (2), and MYFINALCONTRACT AT 0XDA0...42B53 (3). Below these are buttons for constructor1, increment, updateCode, myUint, owner, and proxiableUUID. The updateCode button is highlighted with a red circle containing the number 4. The Low level interactions section has a Transaction button.

The main area shows the Solidity code for 01-lost-storage.sol:

```

45 }
46 
47 + function proxiableUUID() public pure returns (bytes32) {
48     return 0xc5f16f0fcc639fa48a694783d9850f504798523bf8c9a3a87d5876cf622bcf7;
49 }
50 }
51 
52 + contract MyContract {
53     address public owner;
54     uint public myUint;
55 
56     function constructor1() public {
57         require(owner == address(0), "Already initialized");
58         owner = msg.sender;
59     }
60 
61     function increment() public {
62         //require(msg.sender == owner, "Only the owner can increment"); //someone forgot to uncomment this
63         myUint++;
64     }
65 }
66 
67 + contract MyFinalContract is MyContract, Proxiable {
68     function updateCode(address newCode) onlyOwner public {
69         updateCodeAddress(newCode);
70     }
71 
72     modifier onlyOwner() {
73         require(msg.sender == owner, "Only owner is allowed to perform this action");
74         -
75     }
76 }
77 }
78 
```

Below the code, there are two transaction logs:

- CALL [call] from: 0x5B38Da6a701c568545dCfcB03FcB875f56beddC4 to: Proxy.(fallback) data: 0x65...40f7e Debug
- call to MyFinalContract.owner
- CALL [call] from: 0x5B38Da6a701c568545dCfcB03FcB875f56beddC4 to: Proxy.(fallback) data: 0x8da...5cb5b Debug
- > web3.utils.sha3('constructor1()').substring(0,10)

If there's a change: Deploy a new version of the `MyFinalContract` then update the Proxy with the new address.

Removal of Variables is impossible

One very important thing to note is that you can't remove or mix variables that were defined earlier. The problem is that they still reside in a specific storage slot in the Proxy contract (pulled in the scope of the logic contract).

If you remove a variable, then the Solidity compiler will simply assume that the next variable is on the place of the previous one. Your storage will clash again.

It's already a pretty good implementation! The only problem here is that the storage slot isn't really standardized. That means, you can pretty much choose any storage slot you want to store the logic contract address.

For block explorers that makes it very hard to act upon and show information to the user.

Welcome EIP-1967...

Last update: April 17, 2021

16.10 EIP-1967 Standard Proxy Storage Slots

This EIP standardizes how proxies store the logic contract address. Having this makes it easier for outside services, such as block explorers, to show the correct information to the end-user. Etherscan [added support for this](#) end of 2019. The EIP-1967 also adds a few more gimmicks to the overall pattern!

What's the main function? The storage slot, obviously. While in EIP-1822 it was somewhat keccak256("PROXYABLE") - or anything of your choice really - in EIP-1967 it is well defined:

```
Storage slot 0x360894a13ba1a3210667c828492db98dca3e2076cc3735a920a3ca505d382bbc (obtained as
bytes32(uint256(keccak256('eip1967.proxy.implementation')) - 1)) is reserved for the logic contract.
```

But EIP-1967 also adds beacon contracts and storage for the actual admin functionality.

16.10.1 The Beacon Contract

The idea behind the beacon contract is re-usability. If you have several proxies pointing to the same logic contract address then, every time you want to update the logic contract, you'd have to update all proxies. As this can become gas intensive, it would make more sense to have a *beacon* contract that returns the address of the logic contract for *all* proxies.

So, if you use beacons, you are having another layer of Smart Contract in between that returns the address of the actual logic contract.

A really good sample implementation is used by OpenZeppelin [in their Repository](#).

As this is basically the same functionality as EIP-1822, just with a clear defined namespace, I'll refer at this point to the examples we did in the previous explanation.

Instead of repeating the same experiment as before, I want to talk about another pattern: The diamond storage pattern.

Last update: April 17, 2021

16.11 EIP-1538: Transparent Contract Standard

Now it's time to talk about two things: [EIP-1538: Transparent Contract Standard](#) and [EIP-2535: Diamond Standard](#). EIP-2535 replaces EIP-1538 and both were created by Nick Mudge, so we will briefly touch on the idea of EIP-1538 without going into too much detail, just to understand what's going on.

This was the first implementation, which does something very *clever*: Instead of defining a logic contract as a whole, it basically extracts the functions of logic contracts and sets an address for it.

This way you can have as many logic contracts as you want, and update functions incrementally.

A sample implementation can be seen [in the repository](#).

I will explain how it works, but not further dive into EIP-1538, because it was withdrawn and superseded by EIP-2535.

From [the test case](#), you see it all revolves around "MyTransparentContract", which also contains the fallback function that does the delegatecall. It gets the address of ERC1538Delegate, which contains functionality to map function-signatures (bytes4) to addresses.

Later, the fallback function in MyTransparentContract will use lookups to determine which function signature runs on which address and does the `delegatecall` from within the MyTransparentContract.

It needs quite a bit of setup: For example for an ERC20 Token, you would need to give it all function signatures that are running on the ERC20 address and add it to the mappings through MyTransparentContracts `updateContract` which is the logic used from ERC1538Delegate.

It's quite complex to understand and, at least in my opinion, does solve only one thing: You can get around the 24KB maximum contract size limitation.

I might be wrong, but I don't see gas savings by adding functions atomically, because to upgrade a function I would still need to deploy the whole contract first. I do understand that you can [get around](#) this to some extend, by providing virtual functions, but not enough to count as atomic updates for my understanding. So, for example, if you deploy a mintable ERC20 contract and you want to change the mint-function somehow, you would still need to re-deploy the whole ERC20 contract with all the functions the mint function depends on, including the new mint function, to change it.

But it seems Nick Mudge came up with a better solution. So, let's talk about Diamonds here...

Last update: April 17, 2021

16.12 EIP-2535: Diamond Standard

The Diamond Standard is an improvement over EIP-1538. It has the same idea: To map single functions for a delegatecall to addresses, instead of proxying a whole contract through.

The important part of the Diamond Standard is the way storage works. Unlike the unstructured storage pattern that OpenZeppelin uses, the *Diamond Storage* is putting a single `struct` to a specific storage slot.

Function wise it looks like this, given from the EIP Page:

```
// A contract that implements diamond storage.
library LibA {

    // This struct contains state variables we care about.
    struct DiamondStorage {
        address owner;
        bytes32 dataA;
    }

    // Returns the struct from a specified position in contract storage
    // ds is short for DiamondStorage
    function diamondStorage() internal pure returns(DiamondStorage storage ds) {
        // Specifies a random position from a hash of a string
        bytes32 storagePosition = keccak256("diamond.storage.LibA")
        // Set the position of our struct in contract storage
        assembly {ds.slot := storagePosition}
    }
}

// Our facet uses the diamond storage defined above.
contract FacetA {

    function setDataA(bytes32 _dataA) external {
        LibA.DiamondStorage storage ds = LibA.diamondStorage();
        require(ds.owner == msg.sender, "Must be owner.");
        ds.dataA = _dataA
    }

    function getDataA() external view returns (bytes32) {
        return LibDiamond.diamondStorage().dataA
    }
}
```

Having this, you can have as many LibXYZ and FacetXYZ as you want, they are always in a separate storage slot as a whole, because of the whole `struct`. To completely understand it, this is stored in the Proxy contract that does the delegatecall, not in the Faucet itself.

That's why you can share storage across other faucets. Every storage slot is defined manually (`keccak256("diamond.storage.LibXYZ")`).

16.12.1 The Proxy Contract

In the "Diamond Standard" everything revolves around the Diamond terms. The idea is quite visually cutting a Diamond to add functions (or mapping of addresses to functions and vice versa).

The function to add Facets and functions is called "diamondCut".

The functionality to *view* what functions a Facet has is called "Loupe": It returns the function signatures and addresses and everything else you might want to know about a Facet.

There is not *one* way to implement this functionality. Nick went ahead and created three different ways to do a reference implementation, which can be seen on [his repository](#).

First, checkout how the Smart Contracts are deployed in [the migration file](#). This reveals that deploying the `Diamond` contract already gives the addresses and function selectors of the `DiamondCutFacet` and the `DiamondLoupeFacet`. Essentially making them part of the Diamond Proxy.

If you checkout [the test-case](#), then you see exactly that the first test cases are getting back address<->signature mapping and checking that these were really set in the Diamond proxy. Line 121 is where the Test1Facet and then later Test2Facet functions are added.

16.12.2 Giving It A Try

First, we need to clone the repository:

```
git clone https://github.com/mudgen/diamond-1.git
```

then we start ganache-cli (download it with `npm install -g ganache-cli` if you don't have it), in a second terminal window:

```
ganache-cli
```

then we simply run the tests and have a look what happens

```
truffle test
```

```

PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL
> Compiling .\contracts\interfaces\IERC173.sol
> Compiling .\contracts\libraries\libDiamond\ERC173.sol
> Compiling .\contracts\libraries\libDiamond\Proxy.sol
> Compiling .\contracts\interfaces\IDiamondApp.sol
> Compiling .\contracts\interfaces\IERC165.sol
> Compiling .\contracts\interfaces\IERC173.sol
> Compiling .\contracts\libraries\libDiamond.sol
> Artifacts written to: C:\Users\thomas\AppData\Local\Temp\test--28568-TAsM4AcG5KF
> Compiler successfully used:
  solc: 0.7.6+commit.7338295f.Emscripten.clang

Contract: Cache bug test
  ✓ should not exhibit the cache bug (75ms)

Contracts: DiamondTest
  ✓ should have the facets -- call to facetAddresses function (56ms)
  ✓ facets should have the right function selectors -- call to facetFunctionSelectors function (124ms)
  ✓ selectors should be associated to facets correctly -- multiple calls to facetAddress function (100ms)
  ✓ should get all the facets and function selectors of the diamond -- call to facets function (54ms)
  ✓ should add test1 functions (23ms)
  ✓ should add test2 functions (117ms)
  ✓ should replace test1 function (38ms)
  ✓ should add test2 functions (38ms)
  ✓ should remove some test2 functions (219ms)
  ✓ should remove some test1 functions (208ms)
  ✓ remove all functions and facets except diamondCut and facets (775ms)
  ✓ add most functions and facets (730ms)

13 passing (4s)
diamond-1: []

```

What you can observe is that the diamondCut interface is only available through the library and called in the Diamond contract in the constructor. If you were to remove the complete update functionality, you can simply remove the diamondCut function.

Let's add a new file "FacetA.sol" in the contracts/facets folder with a *bugfixed version of the content given above* to write a simple variable and add it to the Diamond in the test case!

contracts/facets/FacetA.sol

```
// SPDX-License-Identifier: MIT
pragma solidity ^0.7.6;

library LibA {

    // This struct contains state variables we care about.
    struct DiamondStorage {
        address owner;
        bytes32 dataA;
    }

    // Returns the struct from a specified position in contract storage
    // ds is short for DiamondStorage
    function diamondStorage() internal pure returns(DiamondStorage storage ds) {
        // Specifies a random position from a hash of a string
        bytes32 storagePosition = keccak256("diamond.storage.LibA");
        // Set the position of our struct in contract storage
        assembly {
            ds.slot := storagePosition
        }
    }
}

// Our facet uses the diamond storage defined above.
contract FacetA {

    function setDataA(bytes32 _dataA) external {
        LibA.DiamondStorage storage ds = LibA.diamondStorage();
        ds.dataA = _dataA;
    }

    function getDataA() external view returns (bytes32) {
        return LibA.diamondStorage().dataA;
    }
}
```

Let's also adapt our migrations file:

/migrations/03_faceta.js

```
const FacetA = artifacts.require('Test2Facet')

module.exports = function (deployer, network, accounts) {
    deployer.deploy(FacetA)
}
```

If you paid attention so far, then you'll see the code, as it is right now, isn't very secure because anyone in any facet can retrieve keccak256("diamond.storage.LibA"); and overwrite the storage slot.

Add the following unit-test:

/test/facetA.test.js

```
/* eslint-disable prefer-const */
/* global contract artifacts web3 before it assert */

const Diamond = artifacts.require('Diamond')
const DiamondCutFacet = artifacts.require('DiamondCutFacet')
const DiamondLoupeFacet = artifacts.require('DiamondLoupeFacet')
const OwnershipFacet = artifacts.require('OwnershipFacet')
const FacetA = artifacts.require('FacetA')
const FacetCutAction = {
  Add: 0,
  Replace: 1,
  Remove: 2
}

const zeroAddress = '0x0000000000000000000000000000000000000000000000000000000000000000';

function getSelectors (contract) {
  const selectors = contract.abi.reduce((acc, val) => {
    if (val.type === 'function') {
      acc.push(val.signature)
    }
    return acc
  }, [])
  return selectors
}

contract('FacetA Test', async (accounts) => {

it('should add FacetA functions', async () => {
  let facetA = await FacetA.deployed();
  let selectors = getSelectors(facetA);
  let addresses = [];
  addresses.push(facetA.address);
  let diamond = await Diamond.deployed();
  let diamondCutFacet = await DiamondCutFacet.at(diamond.address);
  await diamondCutFacet.diamondCut([[facetA.address, FacetCutAction.Add, selectors]], zeroAddress, '0x');

  let diamondLoupeFacet = await DiamondLoupeFacet.at(diamond.address);
  result = await diamondLoupeFacet.facetFunctionSelectors(addresses[0]);
  assert.sameMembers(result, selectors)
})

it('should test function call', async () => {
  let diamond = await Diamond.deployed();
  let facetAViaDiamond = await FacetA.at(diamond.address);
  const dataToStore = '0xabcdef';
  await facetAViaDiamond.setDataA(dataToStore);
  let dataA = await facetAViaDiamond.getDataA();
  assert.equal(dataA, web3.eth.abi.encodeParameter('bytes32', dataToStore));
})
})
})
```

If you run the test with `truffle test test/facetA.test.js` then you'll see that it adds the functions from `FacetA.sol` to the `Diamond`. In the second test case it stores a value and retrieves it again.

```
PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL
Compiling your contracts...
> Compiling .\contracts\Diamond.sol
> Compiling .\contracts\Migrations.sol
> Compiling .\contracts\Facets\DiamondCutFacet.sol
> Compiling .\contracts\Facets\DiamondLoupeFacet.sol
> Compiling .\contracts\Facets\OwnershipFacet.sol
> Compiling .\contracts\Facets\TestFacet.sol
> Compiling .\contracts\Facets\Test2Facet.sol
> Compiling .\contracts\Interfaces\IDiamondCut.sol
> Compiling .\contracts\Interfaces\IDiamond.sol
> Compiling .\contracts\Interfaces\IERC165.sol
> Compiling .\contracts\Interfaces\IERC173.sol
> Compiling .\contracts\Libraries\IDiamond.sol
> Compiling .\contracts\Libraries\IDiamondStorage.sol
> Compiling .\contracts\Interfaces\IERC165.sol
> Compiling .\contracts\Interfaces\IERC173.sol
> Compiling .\contracts\Libraries\IDiamond.sol
> artifactутьи успешно!
> Compiled successfully using:
  - solc: 0.6.6+commit.7338295f.Emscripten clang

Contract: FacetA Test
  ✓ should add FacetA functions (103ms)
  ✓ should test function call (100ms)

2 passing (390ms)
diamond->
```

16.12.3 Pros and Cons

On the plus side, this is an interesting concept for circumventing very large Smart Contracts limits and gradually updating your Contracts. It definitely is in its infancy and should be investigated further.

I was hoping you could get a *framework* that let's you break up your Smart Contracts into smaller parts and deploy and update each one of them separately. It does that, somehow, but it also doesn't, since Facets still need a complete picture of internally used functions and signatures.

All in all, I believe Nick is on a good way to get there. There are, however, a few major drawbacks which need makes it unusable for us:

- The proxy could be a central point of entry to a larger ecosystem of Smart Contracts. Unfortunately, larger systems often make use of inheritance quite heavily and therefore you have to be *extremely* careful with adding functions to the Diamond proxy. Also function signatures could easily collide for two different parts of the system with the same name.
- Every Smart Contract in the System needs adoption for the Diamond Storage, unless you use only one single facet that uses unstructured storage. Simply adding the OpenZeppelin ERC20 or ERC777 tokens wouldn't be advised, as they would start writing to the Diamond Contract storage slot 0.
- Sharing storage between facets is dangerous. It puts a lot of liability on the admin.
- Adding functions to the Diamond via diamondCut is quite cumbersome. I do understand that there are other techniques where the facets bring their own configuration - which is much better, like in [this blog post](#).
- Adding functions to the Diamond via DiamondCut could become quite gas heavy. Adding the two functions for our FacetA Contract costs 109316. That's \$20. Extra.

Alright, now we come to the last part of this article. Wild Magic with CREATE2...

Last update: April 17, 2021

16.13 Metamorphosis Smart Contracts using CREATE2

So far, all of the Smart Contracts are linking a Proxy to another Smart Contract through `delegatecall`. So the proxy address stays constant and all calls are forwarded from (or executed in scope of) the Proxy.

What if there was a way to replace a Smart Contract all-together?

Turns out, there is! It's called "Metamorphosis Smart Contracts" and feels a bit like this:



With this solution you deploy a Smart Contract that deploys a Smart Contract that replaces its own bytecode with another Smart Contract. So, like Jim talks to Scotty to beam stuff around. Let's see how that works.

Very low level

Attention, we're going very low level here now. It's super advanced stuff, it might take some time to fully grasp the full details of what we're doing here. I will try my best to go as detailed as possible on the underlaying architecture.

16.13.1 How CREATE2 works - A Primer

A quick primer on how CREATE2 works. CREATE2 is an assembly op-code for Solidity to create a Smart Contract on a specific address. CREATE2 has a cool advantage: This address is known in advance.

The address of Smart Contracts is *normally* created by taking the `deployersAddress` and the nonce. The nonce is ever increasing, but with CREATE2 there's no nonce, instead a salt. The salt can be defined by the user.

So, you can know the address of a Smart Contract in advance. CREATE2 has the following specification:

```
keccak256(0xff ++ deployersAddr ++ salt ++ keccak256(bytecode))[12:]
```

1. 0xFF, a constant
2. the address of the deployer, so the Smart Contracts address that sends the CREATE2
3. A random salt
4. And the hashed bytecode that will be deployed on that particular address

this will give you the address where the new Smart Contract is deployed.

Let's try this:

First, we need a factory contract that deploys contracts:

```
// SPDX-License-Identifier: MIT
pragma solidity 0.8.1;
```

```

contract Factory {
    event Deployed(address _addr);
    function deploy(uint salt, bytes calldata bytecode) public {
        bytes memory implInitCode = bytecode;
        address addr;
        assembly {
            let encoded_data := add(0x20, implInitCode) // load initialization code.
            let encoded_size := mload(implInitCode) // load init code's length.
            addr := create2(0, encoded_data, encoded_size, salt)
        }
        emit Deployed(addr);
    }
}

```

That's hopefully fairly straight forward: When a new contract is deployed we emit the address as event.

And then we can use this to deploy other smart contracts. The address at which the Smart Contracts get deployed is deterministic. That's what [EIP-1014](#) says.

```
keccak256( 0xff ++ address ++ salt ++ keccak256(init_code))[12:]
```

[Miguel Mota](#) did a great job in writing a single function that computes the address for CREATE2. But we're not using this, we do it step by step!

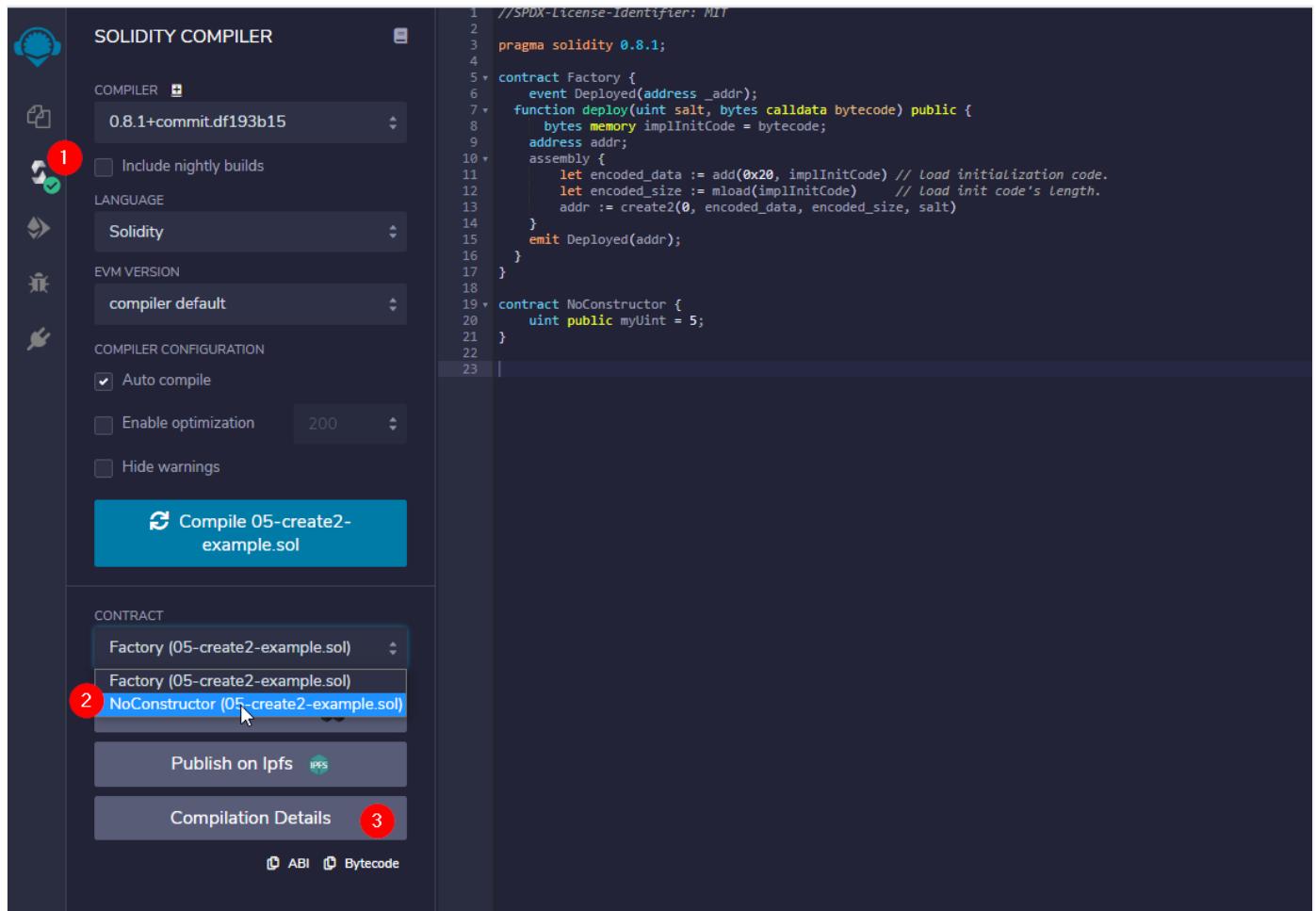
First, let's deploy the following Smart Contract with the Factory. Add it into the existing file.

```

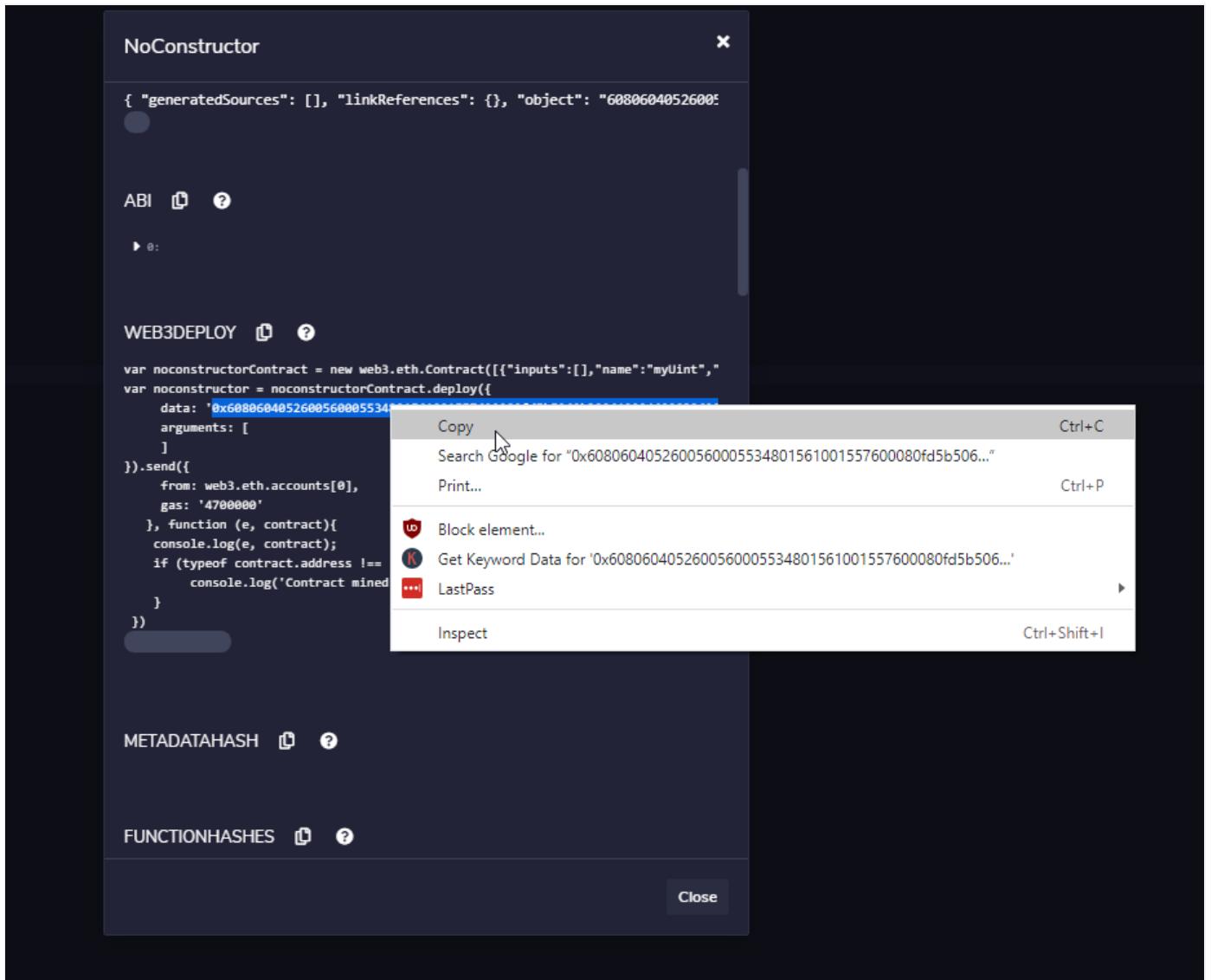
contract NoConstructor {
    uint public myUint = 5;
}

```

Then head over to the Solidity Compiler, copy the Bytecode from the Web3-create. Make sure you selected the correct Contract:



Checkout the popup:



Then head over to the Deploy tab, deploy the Factory first and then use the bytecode to deploy the NoConstructor Contract with Create2.

```

1 // SPDX-License-Identifier: MIT
2
3 pragma solidity 0.8.1;
4
5+ contract Factory {
6     event Deployed(address _addr);
7     function deploy(uint salt, bytes calldata bytecode) public {
8         bytes memory implInitCode = bytecode;
9         address addr;
10        assembly {
11            let encoded_data := add(0x20, implInitCode) // Load initialization code.
12            let encoded_size := mload(implInitCode) // Load init code's length.
13            addr := create2(0, encoded_data, encoded_size, salt)
14        }
15        emit Deployed(addr);
16    }
17 }
18
19+ contract NoConstructor {
20     uint public myUint = 5;
21 }
22
23

```

The salt is currently a number, you can start with any number, I am starting with 1. It's used to determine the final contracts address. The bytecode is simply the bytecode we copied from before. Hit "transact" and open the Transaction details. It should show you the address of your newly deployed NoConstructor contract via the Factory contract:

The screenshot shows the Remix IDE interface. On the left, there's a sidebar with 'DEPLOY & RUN TRANSACTIONS' settings: Environment (JavaScript VM), Account (0x5B3...eddC4), Gas Limit (6000000), Value (0 wei). Below that are sections for CONTRACT (Factory - browser/Upgrades/OS-create) with Deploy and Publish to IPFS buttons, and Transactions recorded and Deployed Contracts. On the right, the Solidity code for Factory and NoConstructor contracts is shown. The logs section displays an emitted event:

```
ContractDefinition WithConstructor 0 reference(s) ▾
22019e87f67a50e9a888075265bb077e909763324a0aae35530f13579e4756a46664736f6c634300000000
033" }

decoded output
logs
[ { "from": "0xDA0bab807633f07f013f94DD0E6A4F96F8742B53", "topic": "0xf40fce21964ffbf566044d083b4073f29f7f7929110ea19e1b03be375d9955e", "event": "Deployed", "args": { "0": "0xE78D6Eda1AaC98753e1Bb0C5e771b55AF1102FD", "_addr": "0xE78D6Eda1AaC98753e1Bb0C5e771b55AF1102FD" } } ]
```

How to calculate this address in advance? Very easy! We can do this directly in the console of Remix:

```
factoryAddress = "ENTER_FACTORY_ADDRESS"

bytecode =
"0x6080604052600560005534801561001557600080fd5b5060b3806100246000396000f3fe6080604052348015600f57600080fd5b506004361060285760003560e01c806306540f7e14602d57

salt = 1;

"0x" + web3.utils.sha3('0xff' + factoryAddress.slice(2) + web3.eth.abi.encodeParameter('uint256',salt).slice(2).toString() +
web3.utils.sha3(bytecode).slice(2).toString().slice(-40);
```

The screenshot shows the Remix IDE interface. On the left, there's a sidebar with a deployed contract (FACTORY AT 0XDA0...42B53 (MEMORY)) and a transact button. The right pane shows the Solidity code for the Factory and NoConstructor contracts, and the logs section showing the emitted Deployed event with the new contract address. In the bottom right corner of the right pane, there's a console window with the following text:

```
Contr
22019e87f67a50e9a888075265bb077e909763324a0aae35530f13579e4756a46664736f6c634300000000
033" }

decoded output
logs
[ { "from": "0xDA0bab807633f07f013f94DD0E6A4F96F8742B53", "topic": "0xf40fce21964ffbf566044d083b4073f29f7f7929110ea19e1b03be375d9955e", "event": "Deployed", "args": { "0": "0xE78D6Eda1AaC98753e1Bb0C5e771b55AF1102FD", "_addr": "0xE78D6Eda1AaC98753e1Bb0C5e771b55AF1102FD" } } ]
```

Below the logs, the console has the following text:

```
value
0 wei
> factoryAddress = "0xDA0bab807633f07f013f94DD0E6A4F96F8742B53"
```

Pretty much copy and paste one line after the other. The result should be the same address as was emitted by the Factory Smart Contract:

The screenshot shows the Truffle UI interface. On the left, there's a sidebar with icons for deploying, publishing to IPFS, and managing contracts. The main area has tabs for "DEPLOY & RUN TRANSACTIONS" and "ContractDefinition WithConstructor".

ContractDefinition WithConstructor:

```

1 // SPDX-License-Identifier: MIT
2
3 pragma solidity 0.8.1;
4
5 contract Factory {
6     event Deployed(address _addr);
7     function deploy(uint salt, bytes calldata bytecode) public {
8         bytes memory implInitCode = bytecode;
9         address addr;
10        assembly {
11            let encoded_data := add(0x20, implInitCode) // Load initialization code.
12            let encoded_size := mload(implInitCode) // Load init code's length.
13            addr := create2(0, encoded_data, encoded_size, salt)
}

```

Logs:

- From: 0x0DA0bab807633f07f013f94D00E6A4F96F8742B53
 Topic: 0x0f40fcec21964ff5b56044d083b4073f20f7f792911ea19e1b3ebe375d89055a
 Event: Deployed
 Args: { "0": "0xe78d6eda1aaC98753e1bb0c5e771b55af1102fd" }] }

Value:

wei

0x0DA0bab807633f07f013f94D00E6A4F96F8742B53

0x60806040805600055348015610015...500080fd5b5060b3806100246000396000f3fe6080604052348015600f57600080fd5b50600436106028576
0003560e01c806306540f7e14602d57...00080fd5b6036047565b604051603e9190605a565b60405180910390f35b60005481565b6054816073565b2
525050565b6000602082019050606...00030184604d565b92915050565b60008190509105056fea264697066735822122019e87f67a50e9a888075265
bb077e909763324a0aae35530f11...9e047b40e06064736f6c63430008010033

Deploy:

salt: 1

bytecode: 0x6080604052600560005534

transact

Low level interactions:

CALLDATA

Transact

16.13.2 CREATE2 with Constructor Argument

How does it work with a Constructor? A little bit different. Essentially the data that the constructor gets as argument needs to be attached to the init-bytecode. Appended. Let's run an example.

Add this to the already existing file:

```

contract WithConstructor {
    address public owner;

    constructor(address _owner) {
        owner = _owner;
    }
}

```

So, if you want to deploy this Smart Contract then you need to add a properly encoded address at the end of it. How to encode the address?

First, copy the address from the address dropdown. Then type in the console `web3.eth.abi.encodeParameter('address', "THE_ADDRESS")`

```
// SPDX-License-Identifier: MIT
pragma solidity 0.8.1;

contract Factory {
    event Deployed(address _addr);
    function deploy(uint salt, bytes calldata bytecode) public {
        bytes memory implInitCode = bytecode;
        address addr;
        assembly {
            let encoded_data := add(0x20, implInitCode) // Load initialization code.
            let encoded_size := mload(implInitCode) // Load init code's Length.
            addr := create2(0, encoded_data, encoded_size, salt)
        }
        emit Deployed(addr);
    }
}

contract NoConstructor {
    uint public myUint = 5;
}

contract WithConstructor {
    address public owner;
    constructor(address _owner) {
        owner = _owner;
    }
}
```

Deploy

OR

At Address

Transactions recorded 0

Deployed Contracts

Currently you have no contract instances to interact with.

Then copy the output, but remove the starting "0x" and append it to the bytecode that you are deploying using the Factory contract.

In my case I am deploying the following bytecode + address:

0x608060405234801561001057600080fd5b506040516102043803806102048339818101604052810190610032919061008d565b806000806101000a81548173ffff

So, now interact with the Smart Contract:

Deploy & RUN TRANSACTIONS

3000000

VALUE 0 wei

CONTRACT WithConstructor - browser/Upgrades/05-create2

Deploy address _owner

OR

At Address 0x62cf9075968FAeBC03E9e41

Transactions recorded 2

Deployed Contracts

FACTORY AT 0xD91_39138 (MEMORY)

WITHCONSTRUCTOR AT 0x62C...21B3

owner

0: address: 0x5B38Da6a701c568545dCfcB03FcB875f56beddC4

Low level interactions

CALLDATA

decoded output

logs

[{ "from": "0xd9145CE12146f254917e481e844e9943F39138", "topic": "0xf48fce21964Fb56604d4d835c4F29f7F7929113e9a19e13ebe375d8095Se", "event": "Deployed", "args": { "0": "0x62cf9075968FAeBC03E9e41d8417781131121837", "_addr": "0x62cf9075968FAeBC03E9e41d8417781131121837" } }]

value 0 wei

It should output the address that was given in the constructor.

Well, great, now you know how to deploy Smart Contracts using a CREATE2 op-code. The problem is, you can't change the bytecode, because the hash of the bytecode is used to create the new contract address, right?

WRONG! (I think you knew that there was a way...)

16.13.3 Overwriting Smart Contracts

SELFDESTRUCT Removal

The overwrite function needs to selfdestruct a Smart Contract to work. This might be removed in upcoming Protocol Upgrades

The idea is to deploy a smart contract that, upon deployment, replaces its own bytecode with a different bytecode. So, the bytecode you run through CREATE2 is always the same, and that calls back to the Factory and replaces itself during deployment.

Clever, right?!

And dangerous!

Let's give it a try. The full example can be found here, <https://github.com/0age/metamorphic>, I am running a minimal example here for you to understand what's going on under the hood!

Create a new file in Remix and add the following Smart Contracts:

```
// SPDX-License-Identifier: MIT

pragma solidity 0.8.1;

contract Factory {
    mapping (address => address) _implementations;

    event Deployed(address _addr);

    function deploy(uint salt, bytes calldata bytecode) public {
        bytes memory implInitCode = bytecode;

        // assign the initialization code for the metamorphic contract.
        bytes memory metamorphicCode = (
            hex"5860208158601c335a63aa10f428752fa158151803b80938091923cf3"
        );

        // determine the address of the metamorphic contract.
        address metamorphicContractAddress = _getMetamorphicContractAddress(salt, metamorphicCode);

        // declare a variable for the address of the implementation contract.
        address implementationContract;

        // load implementation init code and length, then deploy via CREATE.
        /* solhint-disable no-inline-assembly */
        assembly {
            let encoded_data := add(0x20, implInitCode) // load initialization code.
            let encoded_size := mload(implInitCode) // load init code's length.
            implementationContract := create( // call CREATE with 3 arguments.
                0, // do not forward any endowment.
                encoded_data, // pass in initialization code.
                encoded_size // pass in init code's length.
            )
        } /* solhint-enable no-inline-assembly */

        // first we deploy the code we want to deploy on a separate address
        // store the implementation to be retrieved by the metamorphic contract.
        _implementations[metamorphicContractAddress] = implementationContract;
    }

    address addr;
    assembly {
        let encoded_data := add(0x20, metamorphicCode) // load initialization code.
        let encoded_size := mload(metamorphicCode) // load init code's length.
        addr := create2(0, encoded_data, encoded_size, salt)
    }

    require(
        addr == metamorphicContractAddress,
        "Failed to deploy the new metamorphic contract."
    );
}
```

```

        emit Deployed(addr);
    }

    /**
     * @dev Internal view function for calculating a metamorphic contract address
     * given a particular salt.
     */
    function _getMetamorphicContractAddress(
        uint256 salt,
        bytes memory metamorphicCode
    ) internal view returns (address) {

        // determine the address of the metamorphic contract.
        return address(
            uint160(
                uint256(
                    keccak256(
                        abi.encodePacked(
                            hex"ff",
                            address(this),
                            salt,
                            keccak256(
                                abi.encodePacked(
                                    metamorphicCode
                                )
                            )
                        )
                    )
                )
            )
        );
    }

    //those two functions are getting called by the metamorphic Contract
    function getImplementation() external view returns (address implementation) {
        return _implementations[msg.sender];
    }
}

contract Test1 {
    uint public myUint;

    function setUint(uint _myUint) public {
        myUint = _myUint;
    }

    function killme() public {
        selfdestruct(payable(msg.sender));
    }
}

contract Test2 {
    uint public myUint;

    function setUint(uint _myUint) public {
        myUint = 2*_myUint;
    }

    function killme() public {
        selfdestruct(payable(msg.sender));
    }
}

```

What does it do? 1. It deploys a contract that does only two things: 1. Call back the msg.sender and inquire an address. 1. Copy the bytecode running on that address over its own bytecode

That's it. If you look through the code then that's exactly what it does.

How do you use it?

1. Deploy the Factory
2. use Test1 bytecode with salt=1 to deploy the Test1.
3. Tell Remix that Test1 runs on the address of the Metamorphic contract
4. Set the "myUint" to whatever value you want, it works
5. Kill Test1
6. Deploy Test2 bytecode using the same salt=1
7. It will deploy a different bytecode to the same address!!!
8. Get comfortable that setUint now doubles the input amount.
9. Imagine what this does with a Token Contract you thought it safe to use.

Now imagine for a moment that this is a token contract. Or a new shiny DeFi Project. Imagine people start investing, and suddenly the contract logic changes. All the trust you put into Blockchain is lost. How to avoid getting scammed here? Glad you are asking: First look for a selfdestruct functionality. If it has one, then it's necessary to follow the whole chain of deployers and see if one used the create2 opcode. If yes, then further investigate what they deployed. If it's a Metamorphic Smart Contract, then you know that something fishy is going on...

Alright, that's it all together and I am not aware of any other method to upgrade Smart Contracts. Let's do a quick re-cap.

Last update: April 17, 2021

16.14 Conclusion

In this lab you learned to use all available methods to upgrade Smart Contracts. From an audit perspective, it's always better to use a simpler method. I am *personally* a big fan of KISS (keep it simple stupid), although it sometimes means that it doesn't look *elegant*.

I think the Diamond Storage is a very interesting way to "deconstruct" a Smart Contract into smaller parts and plug them back together in a Proxy contract. At this point I would not choose the architecture, because it adds a new layer of complexity to an ecosystem that often manages large amounts of money.

Knowing what's happening under the hood, if I'd start a new larger project from scratch, I'd use [OpenZeppelin Plugins](#) now, if upgradeability is necessary to keep an address constant.

If I don't need a constant address, I'd probably go with either the Eternal Storage pattern or something even simpler. It's easier to audit, easier to grasp, and less error prone.

I hope this lab helped you to choose the right pattern for your project.

Last update: April 17, 2021

17. LEARN: ERC721 Tokens with OpenZeppelin Presets

17.1 ERC721 with Physical Asset Shipping

A Project that explores how to ship real, physical products, which are connected to ERC721 NFTs

17.1.1 Background

Beginning of 2021 we (the Team behind the Ethereum Blockchain Course) had an intriguing idea: What if we can auction tokens like traditional NFTs, but have a physical component to it? [Project Aishtisi](#) was born. This page contains the technical lessons learned and a full rundown of the Smart Contract architecture we're using for the project.

17.1.2 Content

This is the lab you've been looking for if you want a tutorial style guide for ERC721 Smart Contracts which contain a Supply Chain component. All following industry best practices.

17.1.3 Real-World Use-Case for this Project

- ☒ ERC721 Token generation
- ☒ Auction of Real World Items
- ☒ Understand the Supply Chain Component
- ☒ Applicable for Oil, Wine, and all kinds of Commodities

17.1.4 Development-Goal

- ☒ Deep Dive Into ERC721 and MetaData
- ☒ Understand how tokens are auctioned on Opensea or Mintable
- ☒ Understand the OpenZeppelin ERC721 Contracts

Let's get started!

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17.2 The Project Idea

Before directly diving into the Smart Contract, this time I want to briefly talk about the underlying idea. The Smart Contracts will be just *the tool* to make the idea happen. But first we need a strategy how we actually deliver tokens.

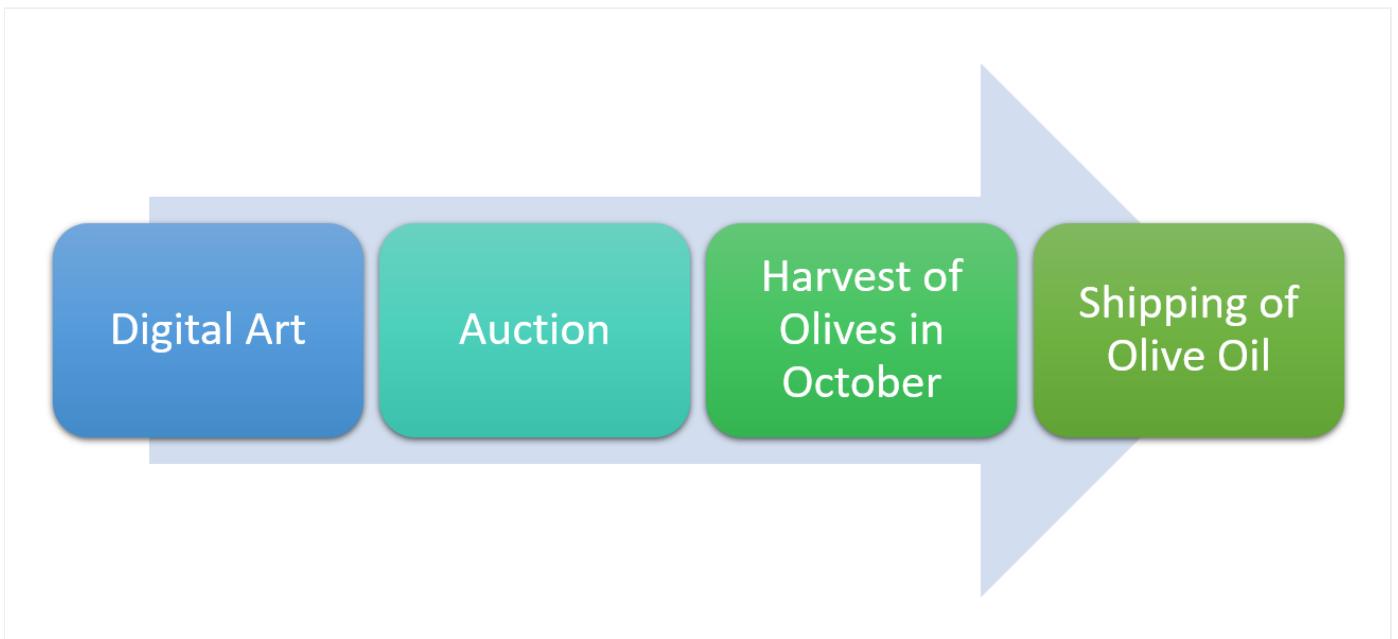
For our project, we are using olive oil as the product that gets shipped. We are experimenting with a small batch where we collaborate with Artists around the world, who create digital art, which then gets printed as labels for the bottles:

We have a few components that play together:

1. A digital Art piece
2. A physical olive oil (that doesn't exist yet!)
3. A physical label
4. A customized video message of the harvest

The Process to get the art + oil to the end-customer is supposedly a simple 4 step process:

1. Some artist creates a digital art piece
2. We mint an ERC721 NFT and auction it
3. We harvest the olives and press the olive oil
4. And then we stick the label on the bottle and ship the olive oil to the NFT holder



What can possibly go wrong? ...

17.2.1 Physical<->Digital Twin Challenges

Each one of these steps have their unique challenges. To give you a brief rundown:

1. Pay to Play - Gas Costs: Creating the initial ERC721 contract requires about 4 million gas, which is \$250 to \$500 in Ether just to deploy the contract the first time at 40 Gwei. Lazy Minting is not an option in this case, more on that later.
2. 10 Artists: That means 10 deliverables that need to be on time, and it also means 10 different opinions on how branding/ packaging/bottles should look like.
3. Authenticity of the Owner: Who to ship to? That needs to be a trustable address.
4. The video isn't known upfront before the auction
5. It is a variable time when the harvest occurs. It's nature after all, we can't predict in May at which day exactly in October the olives will be half-ripe.

Before we write the code, let's dive into the mechanics of Authenticity first. Then write the code and see if we can bring down the gas costs.

17.2.2 Authenticity and Shipping Address

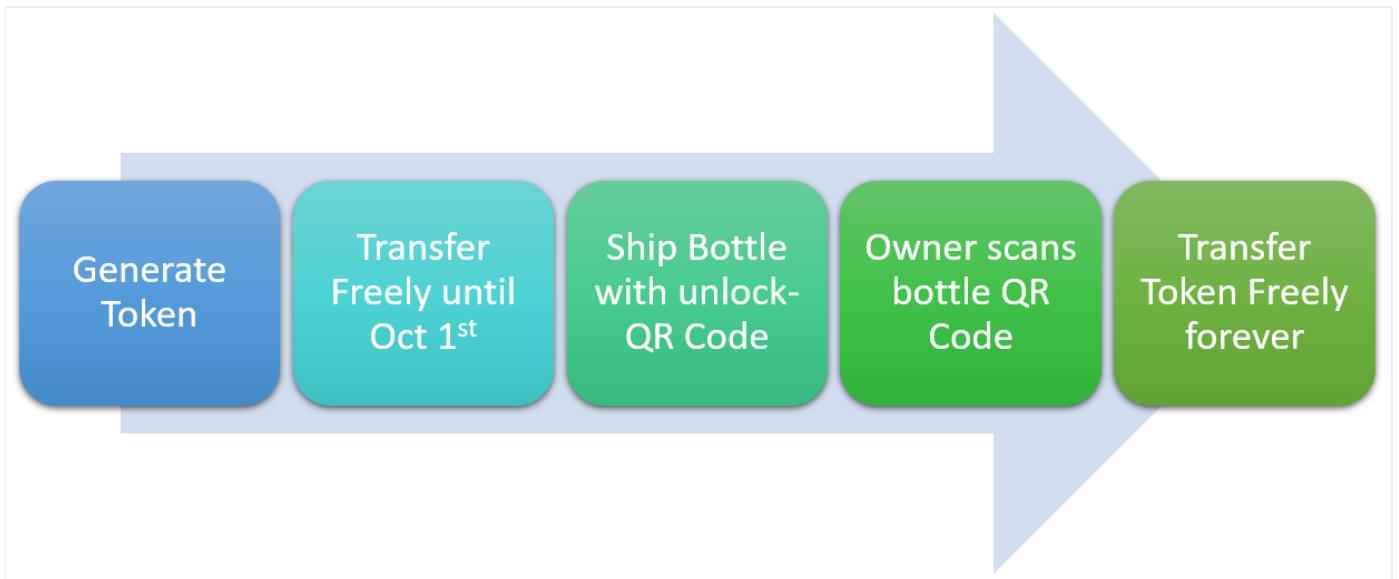
The difference between ERC20 and ERC721 tokens is that every token in the ERC721 contract is unique. It's like deploying many ERC20 contracts, just under one address. ERC20 Tokens can be sent from one address to another. This is a very fundamental property why ERC20 tokens are so popular.

NFTs are usually ERC-721 contracts and should adhere to the ERC-721 interface. This means, they should also contain a function called `function transferFrom(address from, address to, uint256 tokenId) external;`. With this function you can transfer a token from one address to another address, just like with ERC20 tokens. With ERC721 you need to add an additional tokenId, because every token is unique. But the functionality is essentially the same.

That causes a problem when we want to ship the physical product that is represented by a token. There is a very real way to game the system.

How to Game the System

Let's say Mr.X has the token and wants the bottle to ship to New York. We're shipping the bottle to New York. While the bottle is on the way, he sells the token to Mr.Y in Russia. Mr.X gets the bottle, Mr.Y gets no physical product. That can happen intentional, but also unintentional.



This is why we will introduce a novel locking mechanism that requires the physical product to unlock the token transfer again.

Time-Based Locking Mechanism

The token will lock itself automatically on Oct 1st, the month in which the harvest takes place. The token owner can then send us the shipping address in a secure way (more on that later). Then we harvest the olives, produce the oil and ship the bottle. On the bottle there will be a QR code to unlock the token.

This can be done only by the token owner, by nobody else.



The QR code will either be directly in the label or an additional flyer added to the packaging. We will provide a simple website to scan the QR code later and generate a simple transaction to unlock the token, which should work from every wallet - MetaMask, Fortmatic, Portis, etc... without problems.

With this in mind, let's start to create a simple version of our ERC721 Token.

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17.3 Truffle Setup

Let's setup Truffle and import the OpenZeppelin Token Library. We are using Truffle 5.3.7 and OpenZeppelin 4.1.0 for this project.

17.3.1 ERC721 Token Prototype

For our token, we will be using Truffle and the OpenZeppelin Contracts. The first step is therefore to initialize a new Truffle Project and add in the OpenZeppelin contracts.

If you haven't installed truffle globally yet, then install truffle first:

```
npm install -g truffle
```

Then create a new folder, open VSCode (or PowerShell, or a Terminal), init a new Truffle project and install OpenZeppelin Contracts:

```
truffle init
npm install @openzeppelin/contracts
```

```
File Edit Selection View Go Run Terminal Help oiltoken-writeup - Visual Studio Code
EXPLORER
OPEN EDITORS
OILTOKEN-WRITEUP
  contracts
  migrations
  node_modules
  test
  package-lock.json
  truffle-config.js
PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL 1: powershell
- Fetching solc version list from solc-bin. Attempt #1
npm [WARN] optional SKIPPING OPTIONAL DEPENDENCY: fsevents@~2.1.2 (node_modules\truffle\node_modules\cho
kidar\node_modules\fsevents):
npm [WARN] notsup SKIPPING OPTIONAL DEPENDENCY: Unsupported platform for fsevents@2.1.3: wanted {"os": "d
arwin", "arch": "any"} (current: {"os": "win32", "arch": "x64"})
+ truffle@5.3.7
added 1 package from 1 contributor, removed 1 package and updated 71 packages in 60.359s
oiltoken-writeup> truffle init
Starting init...
=====
> Copying project files to C:\101Projects\oiltoken-writeup
Init successful, sweet!
oiltoken-writeup> npm install @openzeppelin/contracts
npm [WARN] saveError ENOENT: no such file or directory, open 'C:\101Projects\oiltoken-writeup\package.js
on'
npm [notice] created a lockfile as package-lock.json. You should commit this file.
npm [WARN] enoent ENOENT: no such file or directory, open 'C:\101Projects\oiltoken-writeup\package.json'
npm [WARN] oiltoken-writeup No description
npm [WARN] oiltoken-writeup No repository field.
npm [WARN] oiltoken-writeup No README data
npm [WARN] oiltoken-writeup No license field.

+ @openzeppelin/contracts@4.1.0
added 1 package from 1 contributor and audited 1 package in 4.38s
found 0 vulnerabilities
oiltoken-writeup
```

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17.4 OpenZeppelin Preset Contracts

Let's add a simple ERC721 Token Preset.

17.4.1 Why use OpenZeppelin Contracts

From the [OpenZeppelin Github Page](#): A library for secure smart contract development. Build on a solid foundation of community-vetted code.

They come with a preset, so we can easily do an ERC721 Contract that is mintable, pausable, burnable and supports all functions we possibly need to be ERC721 compliant.

For this first implementation we will be using <https://github.com/OpenZeppelin/openzeppelin-contracts/blob/master/contracts/token/ERC721/presets/ERC721PresetMinterPauserAutoId.sol>

17.4.2 Creating the ERC721 Token

Create a new file in `/contracts/AisthisiToken.sol` with the following content:

```
// SPDX-License-Identifier: MIT
pragma solidity 0.8.3;

import "@openzeppelin/contracts/token/ERC721/presets/ERC721PresetMinterPauserAutoId.sol";

contract AisthisiToken is ERC721PresetMinterPauserAutoId {

    constructor() ERC721PresetMinterPauserAutoId("AisthisiToken", "AIS", "https://aisthisi.art/metadata/") {}

    function tokenURI(uint256 tokenId) public view virtual override returns (string memory) {
        return string(abi.encodePacked(super.tokenURI(tokenId), ".json"));
    }
}
```

This is a normal ERC721 Contract based on the preset that OpenZeppelin gives us. It might look overwhelming at this point, but there is nothing special to it - let's look what happens under the hood. If we open the [ERC721PresetMinterPauserAutoId](#) Contract then you see that it actually does a few things in the constructor ([here](#) is the documentation of the preset):

1. It sets up a new ERC721 Token Contract with the name and the symbol, in this case "AisthisiToken" and "AIS".
2. It sets the tokenURI base url to "https://aisthisi.art/metadata/"
3. It will grant the deployer pausing rights and minting rights.
4. Additionally, and completely optional, but we decided to add ".json" to the url for the metadata file automatically, hence modified the `tokenURI` function.

```
constructor(string memory name, string memory symbol, string memory baseTokenURI) ERC721(name, symbol) {
    _baseTokenURI = baseTokenURI;
    _setupRole(DEFAULT_ADMIN_ROLE, _msgSender());
    _setupRole(MINTER_ROLE, _msgSender());
    _setupRole(PAUSER_ROLE, _msgSender());
}
```

Let's give this a try in Truffle.

17.4.3 Adding Migrations to Truffle

Create a migrations file to `migrations/2_token_migration.js` with the following content

```
const AisthisiToken = artifacts.require("AisthisiToken");

module.exports = function (deployer) {
    deployer.deploy(AisthisiToken);
};
```

It should look like this now:

```

1 const AisthisIToken = artifacts.require("AisthisIToken");
2
3 module.exports = function (deployer) {
4   deployer.deploy(AisthisIToken);
5 };

```

PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL
1: powershell + -

Windows PowerShell
Copyright (C) Microsoft Corporation. All rights reserved.
Try the new cross-platform PowerShell https://aka.ms/pscore6
Loading personal and system profiles took 1078ms.
oiltoken-writeup>

In the truffle-config.js file, edit the compiler settings to:

```

// Configure your compilers
compilers: {
  solc: {
    version: "0.8.3", // Fetch exact version from solc-bin (default: truffle's version)
    docker: true, // Use "0.5.1" you've installed locally with docker (default: false)
    settings: {} // See the solidity docs for advice about optimization and evmVersion
    optimizer: {
      enabled: true,
      runs: 200
    },
    evmVersion: "byzantium"
  }
},

```

We will later have a look how we can use the optimizer and other techniques to save gas costs.

17.4.4 Deploying the Token to the Truffle Development Network

Then simply run the truffle development console

```
truffle development
```

This should open the Truffle Development console:

```

const AisthisIToken = artifacts.require("AisthisIToken");
module.exports = function (deployer) {
  deployer.deploy(AisthisIToken);
};

Private Keys:
(0) dc6c3c0ddf7a0a89a1f13456ada284686a4fc22bda5c3ca9e433bae85650389d
(1) 1de9798a7515d3db6f55216db73e3d2b28fc6412f0ef475b84d0d09292b2b4c
(2) d262e32d25fc13ff3fa2ed2d5570eed540d8456d094342893e17d5aff586c
(3) f6bfc9e11d48a78b1fc09ffe5d012d979db5044351674ae45bf865491f0f1a3
(4) bc15510d314e1718d7bd4a4dde97949b34838c36d22bd9bf1bb7b78ac05435c
(5) 0c3b65908babb2fb3e9af95fd9391a0fcfc4ca15992fd8084330f11530e8c0ca
(6) 0325d3a5c2eb7664a2d11714a1e4de3430ff9110cff879761e8b0577bcd69c64
(7) a7cbb031658386bd4165f31da9771305d5cdda3e09f564f1475757ba962f9563
(8) e5992f2dc764a470f5d4a38d6b827b204738919cc3e64e4bbddc70d00bbb9b6
(9) 8370aa3ef16fb6d8e7a3ecf805a806a09774682cb5c09164736b82c5cdb98f77

Mnemonic: wheat horse hammer tilt rotate draft fork book donor dad spell gym

⚠️ Important ⚠️ : This mnemonic was created for you by Truffle. It is not secure. Ensure you do not use it on production blockchains, or else you risk losing funds.

truffle(develop)>

```

Now lets just migrate the token and then mint one token:

```
migrate
```

will deploy the tokens to this test-chain.

17.4.5 Testing the Token on the Truffle Development Console

Then you can simply type in

```
let token = await AisthisIToken.deployed();
token.mint(accounts[0]);
```

This will mint one token to your address.

That also means we can freely send it around!

```
token.transferFrom(accounts[0], accounts[1], 0);
```

Will transfer the token from account 0 to account #1.

Let's check the balance:

```
(await token.balanceOf(accounts[1])).toString()
```

Should output 1:

The screenshot shows the Visual Studio Code interface with the following details:

- File Bar:** File, Edit, Selection, View, Go, Run, Terminal, Help.
- Title Bar:** ERC721.sol - oiltoken-writeup - Visual Studio Code.
- Explorer:** Shows the project structure under "OPEN EDITORS" and "OILTOKEN-WRITEUP".
- Code Editor:** Displays Solidity code for the ERC721 contract, specifically the balanceOf function. A tooltip for the "balanceOf" function is visible, stating: "* @dev See {IERC721-balanceOf}.".
- Terminal:** Shows the Truffle development console output. It includes a command to check the balance of account 0, followed by the result '8'.
- Status Bar:** Shows the line number (Ln 58), column number (Col 33), selected text count (7 selected), and file encoding (UTF-8 LF).

That's that. But what about that locking functionality?

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17.5 Token Time Based Locking

The problem with this Smart Contract is that the transfer is always possible. That means, if we ship the actual physical product to someone, he can just send the NFT somewhere else in the meantime. There is no proof that the product ever received correctly. It is possible to send the NFT to someone else, that person now knowing if the product was already shipped - a property we want to have on-chain.

Our Token just doesn't have the Supply Chain component yet built in.

Let's add a locking mechanism to the Smart Contract.

We need several things for this to work:

1. A timestamp for each token from when this token isn't transferrable anymore. This can be potentially be set on minting.
2. Some unlock code, which is hashed twice (e.g. `hash(hash(code))`), so on the blockchain the original passphrase is never revealed, we just send `hash(code)`. More on that later.
3. A variable if the token was unlocked already or not.
4. A hook into the transfer function to only allow token transfer of tokens which are not yet locked or which have been successfully unlocked

Let's have a look at how we can do this in code with the OpenZeppelin Preset.

17.5.1 Modifying the Smart Contract

And here is the final contract for a first try:

```
// SPDX-License-Identifier: MIT
pragma solidity 0.8.3;

import "@openzeppelin/contracts/token/ERC721/presets/ERC721PresetMinterPauserAutoId.sol";
import "@openzeppelin/contracts/utils/Counters.sol";

contract AisthisToken is ERC721PresetMinterPauserAutoId {
    using Counters for Counters.Counter;
    Counters.Counter private _tokenIds;

    mapping (uint => uint) public tokenLockedFromTimestamp;
    mapping (uint => bytes32) public tokenUnlockCodeHashes;
    mapping (uint => bool) public tokenUnlocked;

    event TokenUnlocked(uint tokenId, address unlockerAddress);

    constructor() ERC721PresetMinterPauserAutoId("AisthisToken", "AIS", "https://aisthis.art/metadata/") {}

    function _beforeTokenTransfer(address from, address to, uint256 tokenId) internal override {
        require(tokenLockedFromTimestamp[tokenId] > block.timestamp || tokenUnlocked[tokenId], "AisthisToken: Token locked");
        super._beforeTokenTransfer(from, to, tokenId);
    }

    function unlockToken(bytes32 unlockHash, uint256 tokenId) public {
        require(msg.sender == ownerOf(tokenId), "AisthisToken: Only the Owner can unlock the Token"); //not 100% sure about that one yet
        require(keccak256(abi.encode(unlockHash)) == tokenUnlockCodeHashes[tokenId], "AisthisToken: Unlock Code Incorrect");
        tokenUnlocked[tokenId] = true;
        emit TokenUnlocked(tokenId, msg.sender);
    }

    /**
     * This one is the mint function that sets the unlock code, then calls the parent mint
     */
    function mint(address to, uint lockedFromTimestamp, bytes32 unlockHash) public {
        tokenLockedFromTimestamp[_tokenIds.current()] = lockedFromTimestamp;
        tokenUnlockCodeHashes[_tokenIds.current()] = unlockHash;
        _tokenIds.increment();
        super.mint(to);
    }

    function tokenURI(uint256 tokenId) public view virtual override returns (string memory) {
        return string(abi.encodePacked(super.tokenURI(tokenId), ".json"));
    }
}
```

17.5.2 Testing it in the Truffle Development Console

Let's give it a try again: 1. Open `truffle develop` 2. Deploy the contracts to this test-network with `migrate` 3. Then mint a new token which locks 3 seconds in the future:

```
let token = await AisthisiToken.deployed()
let txMint = await token.mint(accounts[1], Math.round(Date.now()/1000)+3, web3.utils.sha3(web3.utils.sha3('mySecretHash')))

txMint.receipt.status
```

That should return true

The screenshot shows the Visual Studio Code interface with the following details:

- File Explorer:** Shows the project structure under "OPEN EDITORS".
 - AishtisiToken.sol contracts:** Contains `ERC721.sol`, `2_token_migration.js`, and `truffle-config.js`.
 - OLTOKEN-WRITEUP:** Contains `build`, `contracts` (with `AishtisiToken.sol` and `Migrations.sol`), `migrations` (with `1_initial_migration.js` and `2_token_migration.js`), `node_modules\@openzeppelin\contracts`, `test`, `package-lock.json`, and `truffle-config.js`.
- Editor:** The main editor pane displays the `AishtisiToken.sol` file, specifically the `mint` function and its documentation.
- Terminal:** The terminal shows the output of the Truffle migration command, including deployment logs and a summary table.
- Bottom Status Bar:** Shows the current line (Ln 35, Col 77) and mode (Spaces: 4, UTF-8, CRLF, solidity).

Let's wait 3 seconds and then try to send the token from account[1] to account[2]:

```
let txTransfer = await token.transferFrom(accounts[1], accounts[2], 0, {from: accounts[1]});
```

This will output an error:

Error: Returned error: VM Exception while processing transaction: revert AishtisiToken: Token locked -- Reason given: AishtisiToken: Token locked.

```

File Edit Selection View Go Run Terminal Help
EXPLORER OPEN EDITORS ...
AishtisiToken.sol - oiltoken-writeup - Visual Studio Code
contracts > AishtisiToken.sol > AishtisiToken > mint ( complex: 8 state: 0 )
16   ftrace | funcSig
17   constructor() ERC721PresetMinterPauserAutoId("AishtisiToken", "AIS", "https://
18   ftrace | funcSig
19   function _beforeTokenTransfer(address from, address to, uint256 tokenId) {
20     require(tokenLockedFromTimestamp[tokenId] > block.timestamp || tokenUnl
21     super._beforeTokenTransfer(from, to, tokenId);
22   }
23   ftrace | funcSig
24   function unlockToken(bytes32 unlockHash, uint256 tokenId) public {
25     require(msg.sender == ownerOf(tokenId), "AishtisiToken: Only the Owner"
26     require(keccak256(abi.encode(unlockHash)) == tokenUnlockCodeHashes[tokenId]
PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL
1:node + - ^ X
truffle(develop)> let txTransfer = await token.transferFrom(accounts[1], accounts[2], 0, {from: accounts[1]}));
Uncaught:
Error: Returned error: VM Exception while processing transaction: revert AishtisiToken: Token locked -- Reason given: AishtisiToken: Token locked.
    at evalmachine.<anonymous>:1:15
    at evalmachine.<anonymous>:2:49
    at signInHandlersWrap (vm.js:273:12)
    at Script.runInContext (vm.js:140:14)
    at runScript (C:\Users\thoma\AppData\Roaming\npm\node_modules\truffle\build\webpack:\packages\core\lib\console.js:270:1)
    at Console.interpret (C:\Users\thoma\AppData\Roaming\npm\node_modules\truffle\build\webpack:\packages\core\lib\Console.js:285:1)
    at bound (domain.js:413:15)
    at REPServer.runBound [as eval] (domain.js:424:12)
    at REPServer.onLine (repl.js:817:10)
    at REPServer.emit (events.js:315:20)
    at REPServer.EventEmitter.emit (domain.js:467:12)
    at REPServer.Interface._online (readline.js:337:10)
    at REPServer.Interface._line (readline.js:666:8)
    at REPServer.Interface._ttyWrite (readline.js:1010:14)
data: {
  '0x18e47e0ad55482623ce624fbaeca60239749b1d22519aa89f46c52fd9f7c9412': {
Ln 35, Col 77  Spaces: 4  UTF-8  CRLF  solidity  ⌂ [off] R D

```

Let's unlock the token then. We have to do it from the current token holder address, because only the current NFT token holder can unlock the token:

```

let txUnlock = await token.unlockToken(web3.utils.sha3('mySecretHash'), 0, {from: accounts[1]})

txUnlock.receipt.status

```

That should return true:

AishtisiToken.sol - oiltoken-writeup - Visual Studio Code

File Edit Selection View Go Run Terminal Help

EXPLORER OPEN EDITORS contracts > AishtisiToken.sol > AishtisiToken > mint (complex: 8 state: 0)

```

16   ftrace | funcSig
17   constructor() ERC721PresetMinterPauserAutoId("AishtisiToken", "AIS", "https://
18
19   ftrace | funcSig
20   function _beforeTokenTransfer(address from, address to, uint256 tokenId) {
21     require(tokenLockedFromTimestamp[tokenId] > block.timestamp || tokenUnl
22     super._beforeTokenTransfer(from, to, tokenId);
23
24   ftrace | funcSig
25   function unlockToken(bytes32 unlockHash, uint256 tokenId) public {
26     require(msg.sender == ownerOf(tokenId), "AishtisiToken: Only the Owner
      require(keccak256(abi.encode(unlockHash)) == tokenUnlockCodeHashes[toke

```

PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL 1: node

```

es\\truffle\\build\\webpack:\\node_modules\\web3\\node_modules\\web3-providers-http\\lib\\index.js:98:1)\\n
+
  at XMLHttpRequestEventTarget.dispatchEvent (C:\\Users\\thoma\\AppData\\Roaming\\npm\\node_modules\\truffle\\build\\webpack:\\node_modules\\xhr2-cookies\\dist\\xmlhttp-request-event-target.js:34:1)\\n
  at XMLHttpRequest.exports.modules.996763.XMLHttpRequest._setReadyState (C:\\Users\\thoma\\AppData\\Roaming\\npm\\node_modules\\truffle\\build\\webpack:\\node_modules\\xhr2-cookies\\dist\\xmlhttp-request.js:208:1)\\n
  at XMLHttpRequest.exports.modules.996763.XMLHttpRequest._onHttpResponseEnd (C:\\Users\\thoma\\AppData\\Roaming\\npm\\node_modules\\truffle\\build\\webpack:\\node_modules\\xhr2-cookies\\dist\\xmlhttp-request.js:318:1)\\n
  at IncomingMessage.<anonymous> (C:\\Users\\thoma\\AppData\\Roaming\\npm\\node_modules\\truffle\\build\\webpack:\\node_modules\\xhr2-cookies\\dist\\xmlhttp-request.js:289:47)\\n
  at IncomingMessage.emit (events.js:327:22)\\n
  at IncomingMessage.EventEmitter.emit (domain.js:529:15)\\n
  at endReadableNT (internal/streams/readable.js:1327:12)\\n
  at processTicksAndRejections (internal/process/task_queues.js:80:21)
}
truffle(develop)> let txUnlock = await token.unlockToken(web3.utils.sha3('mySecretHash'), 0, {from: accounts[1]})
undefined
truffle(develop)> txUnlock.receipt.status
true
truffle(develop)>
```

Ln 35, Col 77 Spaces: 4 UTF-8 CRLF solidity ⚡ [off] ⌂ ⌂

Now it should be possible to send tokens again:

```
let txTransfer2 = await token.transferFrom(accounts[1], accounts[2], 0, {from: accounts[1]});  
txTransfer2.receipt.status
```

should return true.

```
truffle(develop)> let txTransfer2 = await token.transferFrom(accounts[1], accounts[2], 0, {from: accounts[1]});  
undefined  
truffle(develop)> txTransfer2.receipt.status  
true  
truffle(develop)>
```

The current owner of token #0 is account #2:

```
await token.ownerOf(0)  
accounts[2]
```

Should be equal:

```
truffle(develop)> await token.ownerOf(0);  
'0xc03d9F27B701a1d52ebAEA7386435De2a436ae65'  
truffle(develop)> accounts[2]  
'0xc03d9F27B701a1d52ebAEA7386435De2a436ae65'  
truffle(develop)>
```

Now, let's exit the truffle developer console with `.exit` so you are on a regular terminal inside the project folder.

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17.6 Final Words and Next Part

This time we introduced a novel locking mechanism. Once locked and unlocked, it give proof that a physical item was shipped and received. It needs to be unlocked by the token holder to allow further transfer.

In the next part I want to tackle a few Gas optimizations. So stay tuned.

In the meantime follow us on <https://aisthisi.art>

Last update: June 23, 2021