Solidity Illustrated

Intro & State Variables

A video discussing all of this material is available here: https://youtu.be/4XQsHBJScEk

variables declared outside a function are state variables, they are stored on the blockchain when they are **public**

variables declared inside a function are only available during a call of that function, and such variables are not stored on the blockchain

Smart contracts can be written and deployed to a test environment here: https://remix.ethereum.org The site cookies save your work

STEP 1: Write a smart contract in this file explorer

STEP 2: Compile the smart contract with compiler version compatible with this

STEP 3: Deploy the smart contract here ... to see how it can be accessed on the blockchain with these options here

NOTE: If you hold down both Left-Alt and left-Shift at the same time, you can make the terminal font larger or smaller with the mouse wheel

state variable of type string

Taking the **public** statement out of the state variable will cause you to loose the **text** button on the blockchain

Variables in Solidity are stored in one of these three locations https://docs.soliditylang.org/en/v0.5.3/types.html

- **storage** this is where data can be permanently stored; these are state variables
- **memory** variables in memory are only available when the function is executing
- **calldata** special data location that contains the function arguments, only available for external function call parameters

Types of Functions in Solidity
- ones that create transactions
- ones that do not create transactions

functions that create transactions write data on the blockchain by changing the value of a state variable, which in turn either changes the state of the smart contract, or sends Ether (ETH) to another account, which in turn changes the balance of accounts recorded on the blockchain. Functions that do not create any transaction on the blockchain are free to call (require no gas) and they do not change the state of the blockchain

This function has a single input of type **string**; for certain data types, you have to specifically declare the data location (here it must be **memory** because we (the users) are assigning the **text** value and we are outside the smart contract https://docs.soliditylang.org/en/v0.5.3/types.html#data-location

We need to declare the data location for our string type variable **text**; our **text** variable is stored in a contract storage, but need the actual value stored in the **text** variable, not the reference to the variable, so we will declare it as **memory**

this function will update the state variable

The convention in Solidity is to prefix a function input variable with an underscore "_" so as to avoid using the same names as state variables

We need to tell solidity that this function does not modify any state variables; we do this by using the keyword **view** or **pure**

view

If a function returns a value, it need a **returns** keyword in the function definition

returns

view ensures that your function does not change the state of the blockchain, **pure** declares that your function neither changes the state of the blockchain nor does it read any state variables

pure

Two ways to get state variables
1.) write your own function
2.) let Solidity compiler write it

When you want to return multiple values from a single function call you will use this option

Otherwise use this option

This example shows a state variable (of type **string**) called **text** as well as a get function that returns the value of the same **text** variable; You would actually choose one of these two options but you do not need both!

Use this one or this one in the smart contract, but don't use both of them

Ether and Wei

A video discussing all of this material is available here: https://youtu.be/ybPQsjssyNw

The currency used within Ethereum is Ether; it can be used to:
- pay block reward
- pay transaction fee
- transfer between accounts

1 Ether = 10^18 Wei

The smallest unit of Ether is Wei. 1 Ether is equal to 10^{18} Wei

= x wei

uint is an unsigned integer which means it cannot have a sign in front of it like "-" or "+" ... this means that the integer cannot be negative

units can only be added after literal numbers; for example, **1 ether** is valid whereas **x wei** is not

giga-wei

Gwei stands for Giga-Wei and is equal to one billion wei; the most common situation where you would see the word Gwei is when you submit a transaction to the blockchain because for the transaction, Gwei is used to set the Gas prince

Etherscan

If you head over to etherscan.io and look at any of the Latest Transactions, the Gas Price is listed in Gwei

Gas and Gas Price

A video discussing all of this material is available here: https://youtu.be/oTS9uxU6cAM

Transaction (Tx) fee = gas used * gas price (Gwei)

Each thing you do costs gas; the amount of gas required for each computation depends on what amount miners accept

Transaction (Tx)
Gas limit: 3,000
Gas Price: 2 gwei
Ether: 3,000 gas x 2 (gwei / gas) = 6,000 gwei in weight

In this transaction, we are setting the gas limit to 3,000 and the gas price to 2 gwei, and thus, when this transaction is processed it will cost 6,000 gwei (3,000 x 2)

In abstract terms, let's assume 2 gwei is lower than the current average and we're specifying 2 gwei because we're not in a hurry to have our transaction added to the blockchain

Assuming you had 7,000 gwei in your Ether wallet

Your Account
Previous balance: 7,000 gwei
Transaction 'cost': 6,000 gwei
Current balance: 4,000 gwei

Assuming the transaction computations were such that they cost 1000 gas to to process (per this) - then the cost would be 1000 gas * 2 gwei which would equal 2000 gwei, and that would mean that your account would be refunded 4,000 gwei since you effectively overpaid for the transaction and so the transaction 'cost' isn't the actual amount of gas that this whole thing actually costs you in the end.

happens when you overallocate gas

happens when you underallocate gas

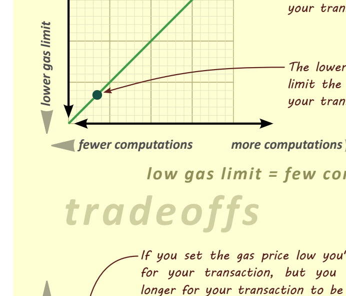
An infinite loop would cost infinity gas to process; let's assume we alocate 6,000 gwei in weight (like we did here) and that each iteration happens to cost 1,800 gwei per supply and demand; here's what would happen:

- after first iteration (- 1,800 gwei, 4,200 gas left)
- after second iteration (- 1,800 gas, 2,400 gas left)
- after third iteration (- 1,800 gas, 600 gas left)
- after forth iteration (- 1,800 gas, 0 gas left)

At every step of function execution gas is deducted until either the function finished execution or all of the gas is used up at which point the execution is avoided

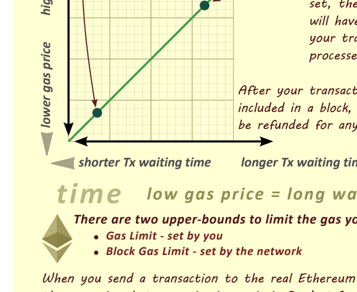
not enough gas

On the fourth iteration it uses up all remaining 600 gas midway through the iteration and then the function is forcefully stopped; **any changes that were made to a state variable will be undone, but you still have to pay for the gas spent!**



tradeoffs

If you set the gas price low you'll have to pay less for your transaction, but you will have to wait longer for your transaction to be included in a block



After your transaction is sent, and included in a block, your account will be refunded for any unspent gas

time — low gas price = long waiting time

There are two upper-bounds to limit the gas you can spend:
- Gas Limit - set by you
- Block Gas Limit - set by the network

When you send a transaction to the real Ethereum network you set the gas price, but gas price in remix is fixed at 1 wei, and we can verify that by checking the output of this function

we can see our balance here

we can click here to check the transaction cost

we can change the gas limit here

Invalid Functions

A video discussing all of this material is available here: https://youtu.be/71cmPaD_AnQ

Invalid Inputs & Outputs for Public Functions
- { } map
- [ ] [ ] multi-dimensional arrays (unfixed size)

In Solidity, there are certain data types that cannot be input variables in public functions (e.g. "{ }") and there are also data types that are not reccomended (e.g. "[ ]") as well. This is also true for function outputs: "{ }" is not allowed and "[ ]" is not reccomended.

inputs

if you get rid of this statement and replace it with this statement, then this function will compile; otherwise it will not compile; the other two functions will compile just fine without using this statement. It is not reccomended that you use any array as an input variable because different array sizes require different amounts of gas to process, and so sometimes the function will process just fine and other times it will run out of gas when using an array as an input variable.

One way to make an array more reliable (as an input variable) and avoid the problem with gas (discussed above) is to put an upper-bound to the array size that will in turn limit the amount of gas consumed

outputs

If we try using maps and/or multi-dimensional arrays of an unfixed size as function outputs, we will also get compile errors

this function will not compile

this function will not compile

Using a one dimensional array with an unfixed size is not reccomended because your contract might get called by a second contract and so your contract's function output is another contract's function input; one way to solve these issues is to write functions that have a bounded consumption of gas

In Solidity, you can return multiple values, and those values can also be named; the options on the left are all valid ones

- multiple un-named values
- multiple named values
- explicitly assigned to return variables and omit the last return statement

function that returns multiple functions

We can call **firstFunc** and then call **secondFunc** seperately, or we can just call **thirdFunc** instead

destructuring assignments

Destructuring assignments can be used to assign variables to the output of a function which returns multiple values

Here we are assigning the outputs of the function **returnMultipleVals()** and the variable types declared here are consistant with the types of values here that are being returned by the function being called

If a function returns three parameters, but you don't care about the second one (in this case, the 5) then you can use destructuring by adding in an empty-space with a comma to let Solidity know to skip that value

Inheritance (Constructor-1)

A video discussing all of this material is available here: https://youtu.be/dcNplOhTNQg

In Solidity, constructors are always executed in a certian order. You cannot override a state variable that is declared in a parent contract by simply redeclaring it in a child contract

this is one way to call the constructors of multiple parent contracts ... this is another way to call the parent constructor inside the constructor of the child contract; here we do not put commas between contracts when listing them

commas needed outside the constructor

no commas needed inside the constructor

this is how you pass variables to parent contracts, the syntax is similiar to this, except here we are passing in a fixed input and here we are passing in variables

here the constructor is accepting two different inputs to be passed to the parent constructors (X & Y) and here it passes the _name variable to contract X and here it passes _text to contract Y

compile and then deploy contract D, and then upon deployment, set the string_name to "foo" and the string_text to "bar"

Calling the state variable **name** returns the string "foo" and calling the state variable **text** returns the string "bar"

View and Pure Functions

A video discussing all of this material is available here: https://youtu.be/xknoxALAL8c

- view functions do not modify the state of the blockchain
- pure functions do not modify the state of the blockchain, nor do they read the state either

According to the Solidity docs here, The following statements are considered modifying the state:

1. Writing to state variables
2. Emitting events - also knows as 'logging'
3. Creating other contracts
4. Using **selfdestruct**
5. Sending Ether via calls
6. Calling any function not marked **view** or **pure**
7. Using low-level calls
8. Using inline assembly that contains certain opcodes.

NOTE: this is a function to call when you want to delete your contract from the blockchain

pure makes a stronger statement than **view**

According to the Solidity docs here, the following are considered reading from the state:

1. Reading from state variables
2. Accessing **address(this).balance** or
3. **<address>.balance**
4. Accessing any of the members of **block**, **tx**, **msg**
5. (with the exception of **msg.sig** and **msg.data**)
   Calling any function not marked **pure**
   Using inline assembly that contains certain opcodes.

this is a valid **view** function, but because it reads from the state, it could not be a **pure** function

A view function cannot call another function that is neither **view** or **pure**

This is an invalid **pure** function because pure functions cannot call a non-pure function, even if that function is a **view** function

will not compile

this is a valid **pure** function since it doesn't read and/or modify any state

Function Modifiers

A video discussing all of this material is available here: https://youtu.be/thADMg9cKPM

Function Modifiers are used for:
- restricting write access
- input validation
- reentrancy guard

Function modifiers are reuseable code that can be attached to a function; this reuseable code can be executed before and or after the function itself is executed

when the contract is deployed, it sets the **owner** to **msg.sender**

the "_" is a special character that you can only use in a function modifier; it tells Solidity to execute the rest of the code inside the parent function

if the message sender is not the current owner, the transaction fails

You attach a modifier to a function by declaring it here in the function signature

reentrancy guard

this modifier prevents recursive calls by first setting the **locked** to **false**; then when decrement is called here it sets the **locked** to **true**, and it starts executing its code here, and next it calls itself again here but since **locked** is set to **true** at this point, the **require** statement fails here and the transaction therefore fails so as to prevent a reentrancy hack

Inheritance (Constructor-2)

A video discussing all of this material is available here. This section starts at time: 3:26 / 8:09

Below we see in what order parent constructors will be called and executed; whereas on the right (Constructor-1) we detail how to pass input variables in a child constructor to a parent constructor

the order in which the parent constructors are called is determined by the inheritance order here and not by the order in which the parent constructors are called on these lines here

NOTE: constructors inherit opposite of functions

compile and then deploy contract E and then do contract F; both produce the same order of firing in the logs here

click here to see this dropdown

Two ways to call parent contracts
- using the keyword **super**
- explicitly

Inheritance (Super)

A video discussing all of this material is available here. This section starts at time: 8:42 / 12:37

This example on the left shows how the parent (more baselike) functions will be called when using the keyword **super**; contracts A, B, & C first emit an event then call the parent contract by using the keyword **super**

super

in this example here the parent contract is called directly whereas here, **super** is used to call all parent contracts in the order of inheritance because the **bar()** function in contract A is being overidden by the **bar()** functions in contracts B and C

emit

here, X, Y, & Z are hypothetical

click here to see this dropdown

Constructor

A video discussing all of this material is available here: https://youtu.be/HpJZZ9tASGs

a constructor is an optional function that is executed only once when the contract is initially deployed to the blockchain; if it accepts input variables, they are entered upon deployment

this will give you the unix timestamp for when the contract was deployed to the blockchain

constructor() has access to special variables like **msg.sender** & **block.timestamp**

Inheritance (Override-1)

A video discussing all of this material is available here: https://youtu.be/GnztHR8-1o8

contract B is inheriting from contract A, and they both have a function with the same name; normally, the function in contract B would overide the one in contract A if they have the same name, but here, contract B's function accepts an input variable whereas contract A's function does not; therefore, contract B will have two functions of the same name available to it when deployed.

When using the Remix IDE, make sure to specify that you are compiling contract B (you can also compile contract A, but it is unnecessary here) within the compiler window; likewise, when you go to the deploy window, make sure to specify that you are deploying contract B

One way to pass variables from a parent constructor to a child constructor is like this ...

...but another way to pass such variables is like this ...the later case is used when you want to set the variable upon the initial deployment of the smart contract such that you would define the variable here upon deployment - this input field will not exist if you compile the version of contract B shown here

Inheritance (Order)

A video discussing all of this material is available here: https://youtu.be/Q5_Gmm_IZSI

The order of inheritance determines which contract is inherited; according to the docs, parent contracts must be ordered from most baselike, to most derived (the reverse in Python)

most baselike (doesn't inherit)

most derived (inherits the most)

meaning that baselike = less inheritance while derived = more inheritance; this gives you this and vice-versa

In the example above, contract A and contract B are both equally baselike, so contract C inherits whichever one is listed last in the order; if this order has contracts listed out of order (from most base-like to most derived) then the Solidity compiler might throw an error, otherwise the order of inheritance will go from right to left for functions, but left to right (the opposite) for constructors which inherit from left to right

depth first

Solidity will perform a depth-first search when inheriting, such that in the example on the left, if you call **foo()** on **contract D** it will return A because it will first look in itself (1) then search from right to left (2 3 4) until it finds the function that it is looking for (5)

Inheritance (Events)

A video discussing all of this material is available here. This section starts at time: 6:56 / 12:37

Solidity uses events to log things on the blockchain, and applications can be notified when events have been emitted so that those same applications don't have to constantly monitor the contract (on the blockchain) to see if such changes have occured

emit

Events are declared with the **event** keyword and are capitalized by convention; you can pass parameters that you want the event to log in the most baselike contract where the event is found and those parameters will get passed to the more derived contracts downstream

Unlike **return** statements to a function call, emitted events with the same name will get called twice, and not be overidden

click here to see this dropdown

Inheritance (Override-2)

A video discussing all of this material is available here. This section starts at time: 5:05 / 8:09

Here is an example of how not to override a variable in a parent contract

If we deploy contract B and then call **myAddress** here, we get the address that is redefined here in contract B, and not the original definition found here in contract A - this is what we want to get, but if we were to then call **getAddress()** from contract B here, we would get original definition for address found in contract A, instead of the redefined address in contract B this is because you cannot override a state variable that is declared in a parent contract by redeclaring it inside of a child contract

The correct way to override state variables (that are defined in a parent contract) is to redefine such variables inside a child contract's **constructor()** like this so when you deploy such a contract, the redefinition will hold whether or not it is called in a parent contract's function like this or in the child contract like this; in both cases the

Visibility

A video discussing all of this material is available here: https://youtu.be/NBzQVJ6OrrQ

These are the 4 key words that determine the visibility of state variables and functions:

- **private** - visible inside the contract
- **internal** - visible inside the contract and child contract(s)
- **public** - visible to everyone
- **external** - visible to other contracts and accounts

A state variable or function declared **private** is only accessable to the **contract** that defines it

A state variable or function declared **internal** is only accessable to the **contract** that defines it as well as any child contracts it has

A state variable or function declared **public** is accessable by any **contract** and any **account**

A function declared **external** can only be called by other contracts and accounts, not the contract it is defined in; a state variable like this cannot be declared **external** since it doesn't make sense to have a state variable that stores data that is only accessable to other contracts and accounts

external

public

If you deploy this contract, you can not call this **private** function here from outside the contract; but if you deploy the same contract with a **private** function nested inside another **public** function like this; then that **private** function will be accessable here from outside the contract.

private

Although **private state variables** are only accessable inside the contract, you should not store sensitive information inside them because everything on the blockchain is visible to everyone; the same could be said for **internal** state variables.

internal

A child function can not inherit a private function from a parent **contract** because a **private** function is only visible in the **contract** it is defined in; an **internal** function can be inherited by the child contracts of the contract in which the function was defined

Events

A video discussing all of this material is available here: https://youtu.be/BduMOagAuKs

Smart contracts can log that something has happened on the blockchain by firing events; applications can be automatically notified when events happen so they do not have to monitor a contract on a blockchain to see what state changes have occured

Anyone on the blockchain can query a smart contract's logs with input variable(s) if such variables are declared **indexed** - this keyword allows anyone to query a log for specific event(s) that match such criteria

this query would return these

indexed

It is possible to create an event where no parameter is passed

To see the events that were fired via the **emit** keyword, execute the **fireEvents()** function and then open the transaction log and scroll down to the keyword log where you will find the events that were fired

These logs will be stored on the blockchain but smart contracts will not be able to access information on these logs; the purpose of emitting events is to store information on the blockchain that smart contracts do not need access to, because storing such information on logs is cheaper than storing it on smart contracts

Error

A video discussing all of this material is available here: https://youtu.be/k4mdv97up5M

Sometimes you want your function to fail if something is not right

In Solidity, there are 3 ways to throw an error which would stop the further execution of the function being called:

- **assert** - used to check for conditions that should never be possible; should always evaluate to true
  - uses up all the gas
- **require** - used to validate inputs, state conditions before execution, and to check outputs of other functions
  - does not use up all the gas
- **revert** - will only accept one argument (the error message to be thrown) whereas **require** will accept two;
  - does not use up all the gas

When a function throws an error, it will undo all of the changes that were made during the current call; Solidity errors **'bubble-up'** (like in Python or JavaScript) meaning that if function x calls another function y, and y throws an error, then x will also fail and all of the changes that were made during the call of x and y will be undone.

overflow

This is the largest number possible for the data type **uint** in Solidity; when you exceed it, the number 'overflows' back to 0 like on a clock. Likewise, a number 'underflows' when it reaches the lowest possible number for datatype **uint**, which is 0

underflow

x+y = x+y

y+(2**256-1) = y

If a number is deposited here and then the max number is added to it, than this error message will be generated; if the amount of money withdrawn here is greater than the balance here, then this error message will be generated

NOTE: newer versions of Solidity will have different error messages as they auto-detect discrepancies in Ether sent from an account vs. Ether remaining in that same account

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YouTube Tutorial References:

Learn Solidity (0.5) by Examples
Smart Contract Programmer

github.com/Richard-Burd/solidity-sandbox
last updated @ 12:59pm on 26/July/2021 by Richard Burd rick.a.burd@gmail.com

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