CS251
Programming in Solidity
Agenda

- Solidity basics
- Interacting with smart contracts
- Understanding gas costs
- Security considerations
- Common patterns
Useful links

- http://bit.do/cs251solidity
- https://gist.github.com/abandeali1/74d8b73f457add6b1bf7255a90b0adf5
- https://remix.ethereum.org/
Value types

- `uint256`
- `address (bytes20)`
  - `balance`, `transfer`,
  - `call`: send Tx to another contract
  - `delegatecall`: load code from another contract into current context
- `bytes32`
- `bool`
Reference types

- structs
- arrays
- bytes
- strings
- mappings:
  - Declaration: mapping (address => unit256) balances;
  - Assignment: balances[addr] = value;
Globally available variables

- block
  - blockhash, coinbase, difficulty, gaslimit, number, timestamp
- gasLeft()
- msg
  - data, sender, sig, value
- tx
  - gasprice, origin
- abi
  - encode, encodePacked, encodeWithSelector, encodeWithSignature
- Keccak256, sha256, sha3
- require, assert
Function visibilities

- **external**: function can only be called from outside contract.
  Arguments read from calldata
- **public**: function can be called externally and internally.
  Arguments copied from calldata to memory
- **internal**
- **private**
- **view**: only read storage
- **pure**: does not touch storage
Using imports

- Inheritance
  - contract A is SafeMath {}
  - uint256 a = safeAdd(b, c);

- Libraries
  - using SafeMath for uint256;
  - uint256 a = b.safeAdd(c);
ERC20 tokens

- A standard API for fungible tokens that provides basic functionality to transfer tokens or allow the tokens to be spent by a third party.
- An ERC20 token is itself a smart contract that contains its own ledger of balances.
- A standard interface allows other smart contracts to interact with all ERC20 tokens, rather than using special logic for each different token.
ERC20 token interface

- function transfer(address _to, uint256 _value) external returns (bool);
- function transferFrom(address _from, address _to, uint256 _value) external returns (bool);
- function approve(address _spender, uint256 _value) external returns (bool);
- function totalSupply() external view returns (uint256);
- function balanceOf(address _owner) external view returns (uint256);
- function allowance(address _owner, address _spender) external view returns (uint256);
How are ERC20 tokens transferred?

- The `transfer` function checks a few conditions, updates balances of the sender and receiver, and logs an event.
- Alice wants to transfer 100 StanfordCoin to Bob. She calls StanfordCoin.transfer(Bob.address, 100). What is happening under the hood?
**ABI encoding and decoding**

- Every function has a 4 byte selector that is calculated as the first 4 bytes of the hash of the function signature.
  - In the case of `transfer`, this looks like `bytes4(keccak256("transfer(address,uint256)"))`;
- The function arguments are then ABI encoded into a single byte array and concatenated with the function selector. ABI encoding simple types means left padding each argument to 32 bytes.
- This data is then sent to the address of the contract, which is able to decode the arguments and execute the code.
- Functions can also be implemented within the fallback function.
  - [https://github.com/0xProject/0x-monorepo/blob/development/packages/contracts/contracts/protocol/Asset](https://github.com/0xProject/0x-monorepo/blob/development/packages/contracts/contracts/protocol/Asset)
Calling other contracts

- Addresses can be cast to contract types.
  - IERC20Token tokenContract = IERC20Token(_token);
  - ERC20Token tokenContract = ERC20Token(_token);
- When calling a function on an external contract, Solidity will automatically handle ABI encoding, copying to memory, and copying return values.
  - tokenContract.transfer(_to, _value);
Gas cost considerations

- Everything costs gas, including processes that are happening under the hood (ABI decoding, copying variables to memory, etc).
- How often do we expect a certain function to be called? Is the bottleneck the cost of deploying the contract or the cost of each individual function call?
- Are the variables being used in calldata, the stack, memory, or storage?
Stack variables

- Stack variables are generally the cheapest to use and can be used for any simple types (anything that is <= 32 bytes).
  - `uint256 a = 123;`
- All simple types are represented as `bytes32` at the EVM level.
- Only 16 stack variables can exist within a single scope.
Calldata

- Calldata is a read-only byte array.
- Every byte of a transaction’s calldata costs gas (68 gas per non-zero byte, 4 gas per zero byte).
  - All else equal, a function with more arguments (and larger calldata) will always cost more gas.
- It is cheaper to load variables directly from calldata, rather than copying them to memory.
  - For the most part, this can be accomplished by marking a function as `external`. 
Memory

- Memory is a byte array.
- Complex types (anything > 32 bytes such as structs, arrays, and strings) must be stored in memory or in storage.
  - string memory name = “Alice”;
- Arguments must be copied to memory before calling an `internal` function or when a contract makes an external call (AKA calling a function on another contract).
- Memory is cheap, but the cost of memory grows quadratically.
Storage

- Using storage is very expensive and should be used sparingly.
- Writing to storage is most expensive.
- Reading from storage is cheaper, but still relatively expensive.
- Mappings and state variables are always in storage.
- Some gas is refunded when storage is deleted or set to 0 (checkout https://gastoken.io/ for an interesting use of this).
- Variables < 32 bytes can be packed into 32 byte slots.
Event logs

- Event logs are a cheap way of storing data that does not need to be accessed by any contracts.
- Events are stored in transaction receipts, rather than in storage.
- Log arguments can be indexed for quick filtering using a block’s bloom filter.
Security considerations

- Are we checking math calculations for overflows and underflows?
- What assertions should be made about function inputs, return values, and contract state?
- Who is allowed to call each function?
- Are we making any assumptions about the functionality of external contracts that are being called?
Common patterns

- Approve and call
- Off-chain signed messages with on-chain verification
- Compressing data using 32 byte hash
- Low level calls
Questions?

- https://0xproject.com/
- https://github.com/0xProject/0x-monorepo/tree/development/packages/contracts