Banks vs Blockchains

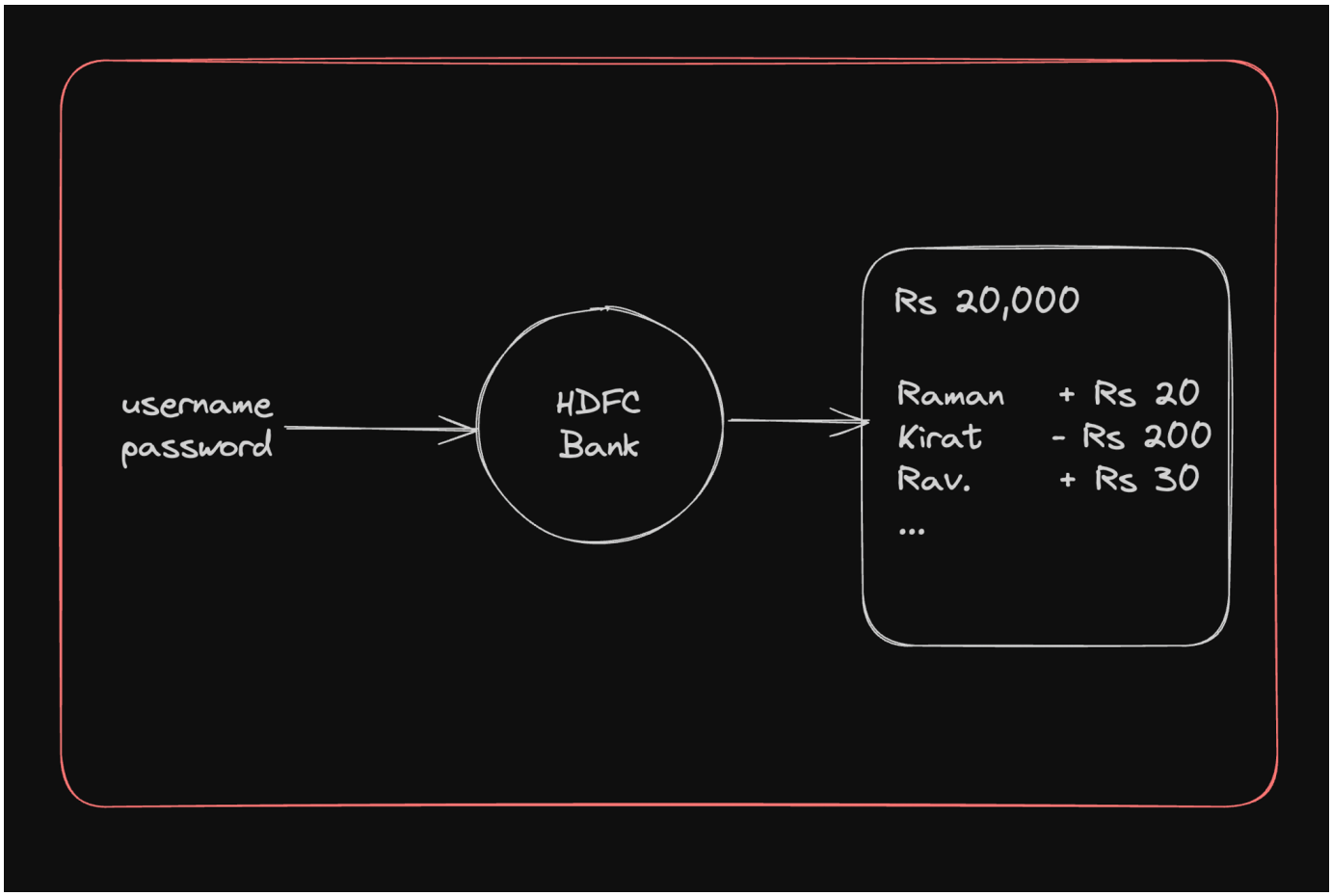
Goal of today's class -

1. Create a simple web based wallet.
2. Look at the codebase of some wallets to see how they generate private keys

How banks do Auth

In traditional banks, you have a `username` and `password` that are enough for you to

1. Look at your funds
2. Transfer funds
3. Look at your existing transactions



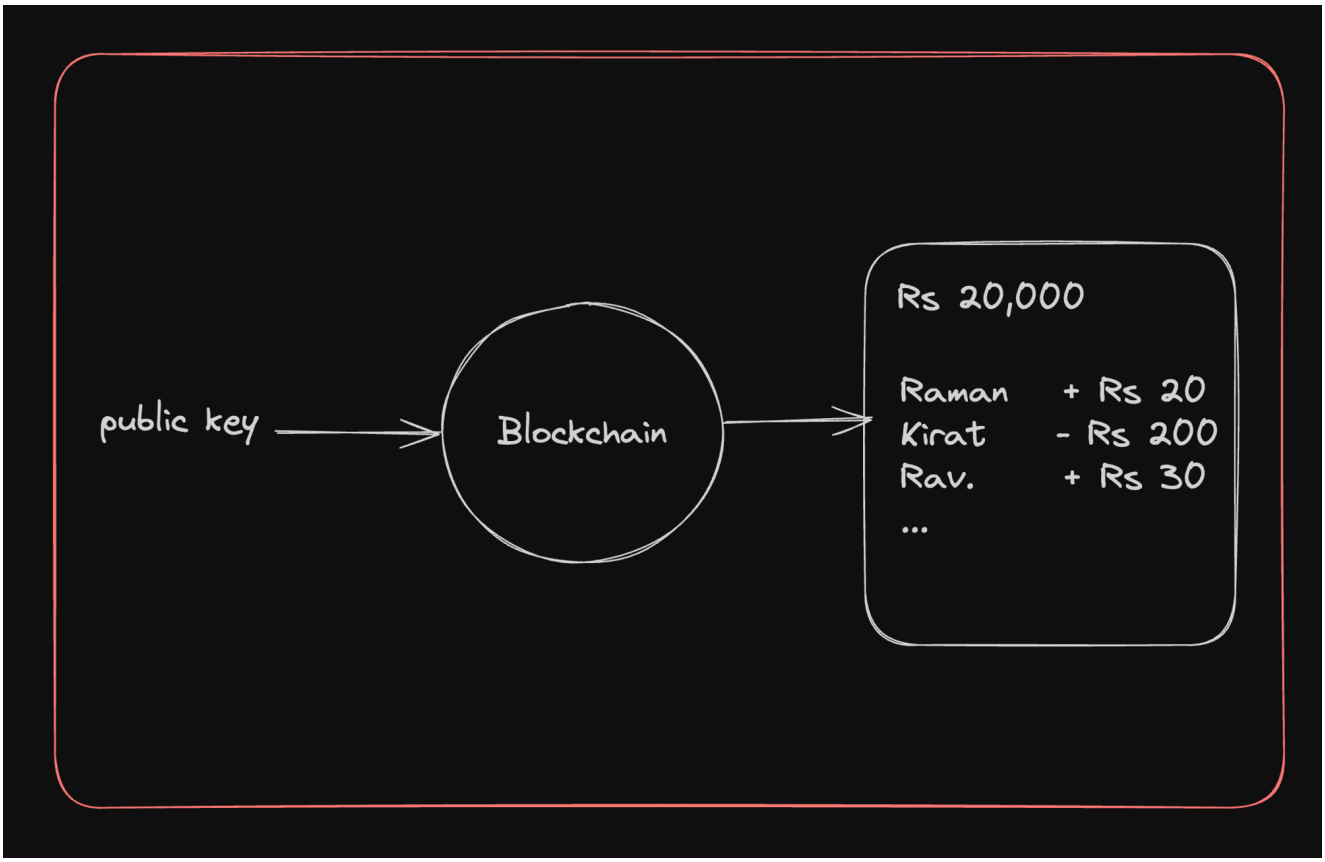
How Blockchains do auth

If you ever want to create an `account` on a blockchain, you need to generate a `public-private` keypair.

Public private Keypair

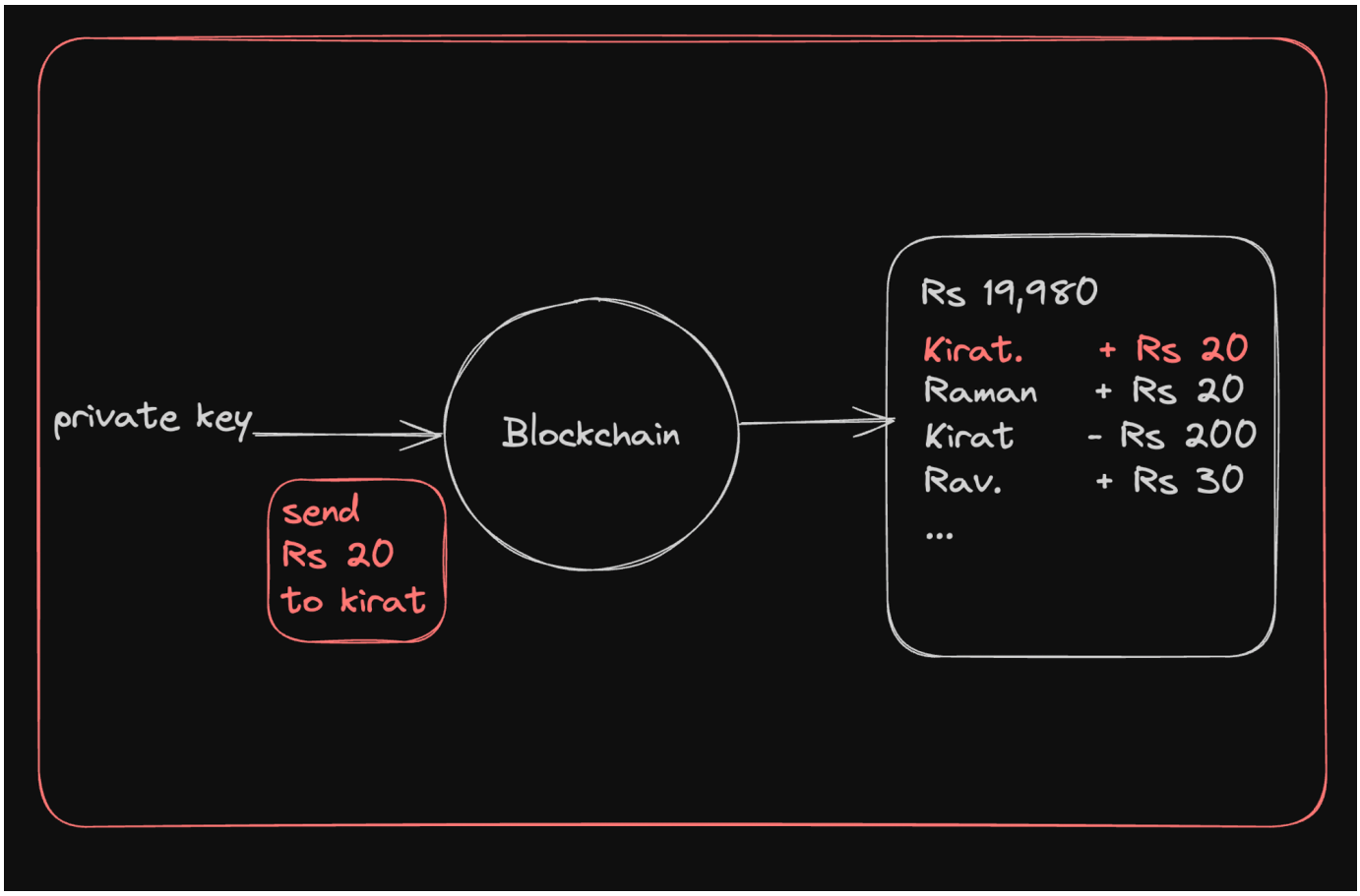
A public-private key pair is a set of two keys used in `asymmetric cryptography` . These two keys have the following characteristics:

Public Key: The public key is a string that can be shared openly.



For example - https://etherscan.io/address/0xD9a657ACB3960DB92AaaA32942019bD3c473FCCB

Private key: The private key is a secret string that must be kept confidential.


private key
send
Rs 20
to kirat
Blockchain
Rs 19,980
Kirat. + Rs 20
Raman + Rs 20
Kirat - Rs 200
Rav. + Rs 30
...

Assignments

Adding support for ETH

Given we just derived a few public keys in SOL, can you try doing the same for ETH?

Again for reference, this is how backpack does it - https://github.com/coral-xyz/backpack/blob/master/packages/secure-background/src/services/evm/util.ts#L3

Creating a web based wallet

Create a simple web based wallet where someone can come and create a pneumonic, add multiple wallets and see the public key associated with each wallet

Bits and bytes

What is a Bit?

A bit is the smallest unit of data in a computer and can have one of two values: 0 or 1.

Think of a bit like a light switch that can be either off (0) or on (1).

What is a byte?

A byte is a group of `8` bits. It's the standard unit of data used to represent a single character in memory. Since each bit can be either 0 or 1, a byte can have 2^8 (256) possible values, ranging from 0 to 255

Assignment

What is the `11001010` converted to a `decimals` ?

▼ Answer

- **2^7:** 1×27=1×128=128
- **2^6:** 1×26=1×64=64
- **2^5:** 0×25=0×32=0
- **2^4:** 0×24=0×16=0
- **2^3:** 1×23=1×8=8
- **2^2:** 0×22=0×4=0
- **2^1:** 1×21=1×2=2

- **2^0:** 0×20=0×1=0
  = 202

Representing bits and bytes in JS

- Bit

```
const x = 0;
console.log(x);
```

- Byte

```
const x = 202
console.log(x);
```

- Array of bytes

```
const bytes = [202, 244, 1, 23]
console.log(bytes);
```

UInt8Array

A better way to represent an array of bytes is to use a `UInt8Array` in JS

```
let bytes = new Uint8Array([0, 255, 127, 128]);
console.log(bytes)
```

Why use `UInt8Array` over `native arrays` ?

- They use less space. Every number takes 64 bits (8 bytes). But every value in a `UInt8Array` takes 1 byte.
- UInt8Array Enforces constraints - It makes sure every element doesn't exceed 255.

Assignment -

What do you think happens to the first element here? Does it throw an error?

```
let uint8Arr = new Uint8Array([0, 255, 127, 128]);
uint8Arr[1] = 300;
```

Encodings

Bytes are cool but highly unreadable. Imagine telling someone

```
Hey, my name is 00101011101010101020
```

It's easier to `encode` data so it is more `human readable` . Some common encodings include -

1. Ascii
2. Hex
3. Base64
4. Base58

Ascii

`1 character = 7 bits`

Every byte corresponds to a `text` on the `computer` .
Here is a complete list - https://www.w3schools.com/charsets/ref_html_ascii.asp#:~:text=The ASCII Character Set&text=ASCII is a 7-bit,are all based on ASCII.

▼ Bytes to Ascii

```
function bytesToAscii(byteArray) {
  return byteArray.map(byte => String.fromCharCode(byte)).join('');
}

// Example usage:
const bytes = [72, 101, 108, 108, 111]; // Corresponds to "Hello"
const asciiString = bytesToAscii(bytes);
console.log(asciiString); // Output: "Hello"
```

▼ Ascii to bytes

```
function asciiToBytes(asciiString) {
  const byteArray = [];
  for (let i = 0; i < asciiString.length; i++) {
    byteArray.push(asciiString.charCodeAt(i));
  }
  return byteArray;
```

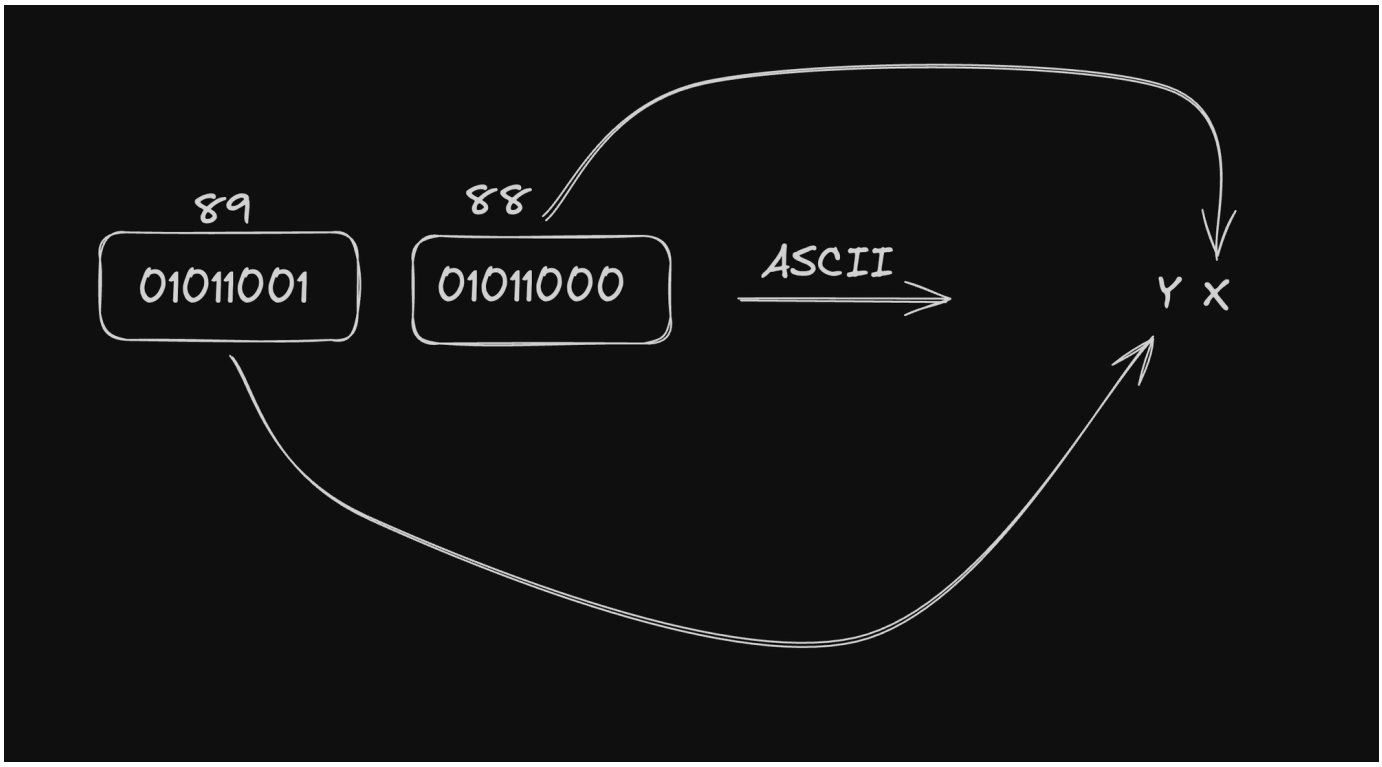
```
}

// Example usage:
const ascii = "Hello";
const byteArray = asciiToBytes(ascii);
console.log(byteArray); // Output: [72, 101, 108, 108, 111]
```

▼ UInt8Array to ascii

```
function bytesToAscii(byteArray) {
  return new TextDecoder().decode(byteArray);
}

// Example usage:
const bytes = new Uint8Array([72, 101, 108, 108, 111]); // Corresponds to "He
const asciiString = bytesToAscii(bytes);
console.log(asciiString); // Output: "Hello"
```

▼ Ascii to UInt8Array

```
function asciiToBytes(asciiString) {
  return new Uint8Array([...asciiString].map(char => char.charCodeAt(0)));
}

// Example usage:
const ascii = "Hello";
const byteArray = asciiToBytes(ascii);
console.log(byteArray); // Output: Uint8Array(5) [72, 101, 108, 108, 111]
```



Hex

`1 character = 4 bits`

A single hex character can be any of the 16 possible values: `0-9` and `A-F`.

▼ Array to hex

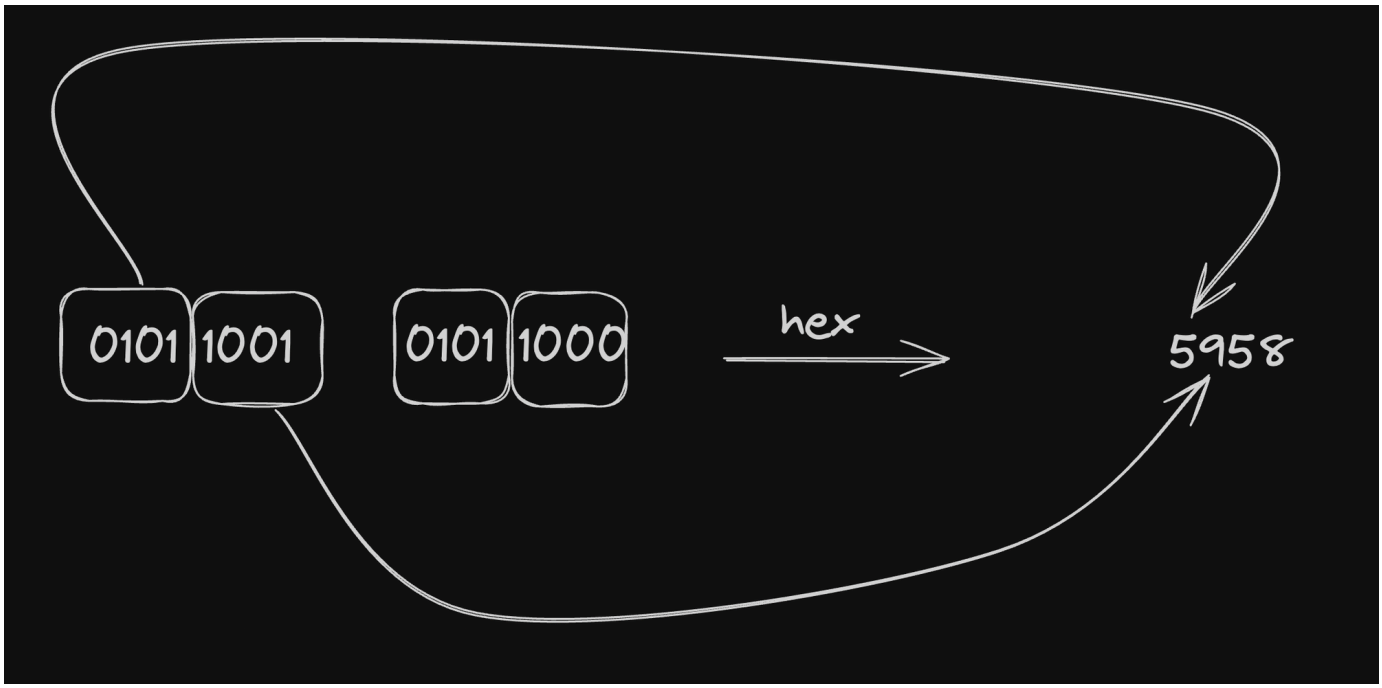
```
function arrayToHex(byteArray) {
  let hexString = '';
  for (let i = 0; i < byteArray.length; i++) {
    hexString += byteArray[i].toString(16).padStart(2, '0');
  }
  return hexString;
}

// Example usage:
const byteArray = new Uint8Array([72, 101, 108, 108, 111]); // Corresponds to
const hexString = arrayToHex(byteArray);
console.log(hexString); // Output: "48656c6c6f"
```

▼ Hex to array

```
function hexToArray(hexString) {
  const byteArray = new Uint8Array(hexString.length / 2);
  for (let i = 0; i < byteArray.length; i++) {
    byteArray[i] = parseInt(hexString.substr(i * 2, 2), 16);
  }
```

```
  return byteArray;
}

// Example usage:
const hex = "48656c6c6f";
const byteArrayFromHex = hexToArray(hex);
console.log(byteArrayFromHex); // Output: Uint8Array(5) [72, 101, 108, 108, 1
```

Ref - https://developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/parseInt



Base64

`1 character = 6 bits`

Base64 encoding uses 64 different characters (`A-Z` , `a-z` , `0-9` , `+` , `/`), which means each character can represent one of 64 possible values.

https://www.base64encode.org/

https://www.base64decode.org/

▼ Encode

```
const uint8Array = new Uint8Array([72, 101, 108, 108, 111]);
const base64Encoded = Buffer.from(uint8Array).toString("base64");
console.log(base64Encoded);
```

Base58

It is similar to Base64 but uses a different set of characters to avoid visually similar characters and to make the encoded output more user-friendly

Base58 uses 58 different characters:

- Uppercase letters: `A-Z` (excluding `I` and `O`)
- Lowercase letters: `a-z` (excluding `l`)
- Numbers: `1-9` (excluding `0`)
- `+`, `/`

▼ Encode

```
const bs58 = require('bs58');

function uint8ArrayToBase58(uint8Array) {
  return bs58.encode(uint8Array);
}

// Example usage:
const byteArray = new Uint8Array([72, 101, 108, 108, 111]); // Corresponds to
const base58String = uint8ArrayToBase58(byteArray);
console.log(base58String); // Output: Base58 encoded string
```

▼ Decode

```
const bs58 = require('bs58');

function base58ToUint8Array(base58String) {
  return bs58.decode(base58String);
}

// Example usage:
const base58 = base58String; // Use the previously encoded Base58 string
const byteArrayFromBase58 = base58ToUint8Array(base58);
console.log(byteArrayFromBase58); // Output: Uint8Array(5) [72, 101, 108, 108,
```

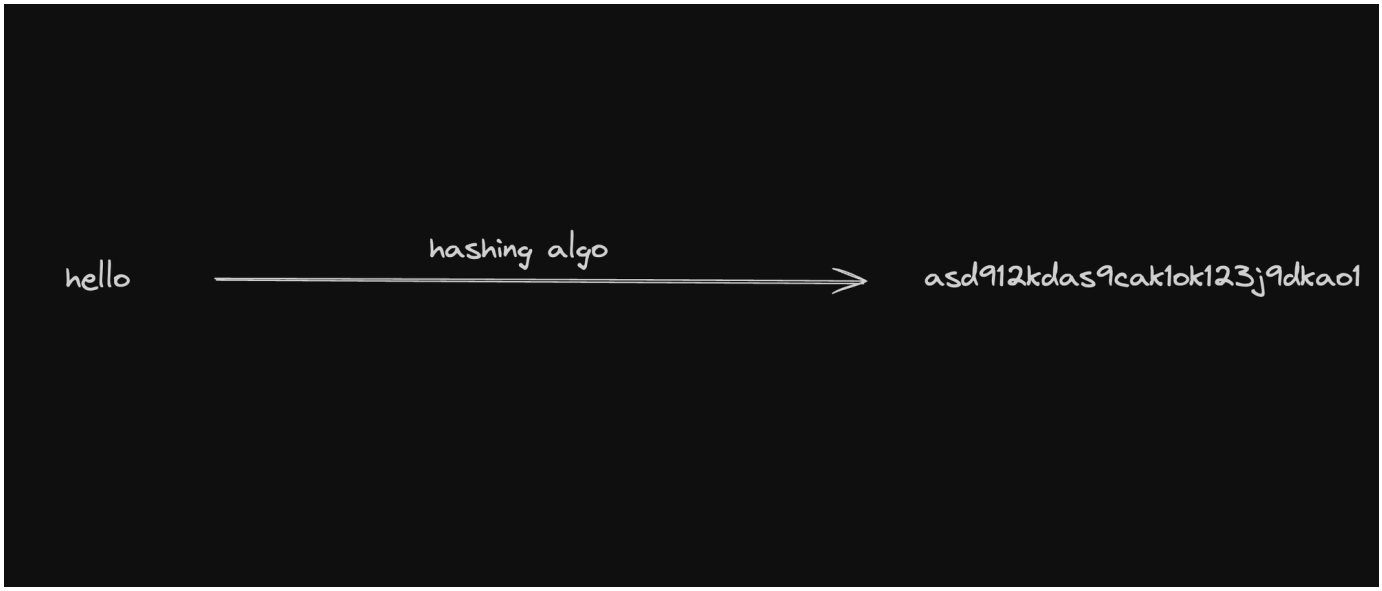
Ascii vs UTF-8

- ASCII uses a 7-bit encoding scheme.

Hashing vs encryption

Hashing

Hashing is a process of converting data (like a file or a message) into a fixed-size string of characters, which typically appears random.



Common hashing algorithms - SHA-256, MD5

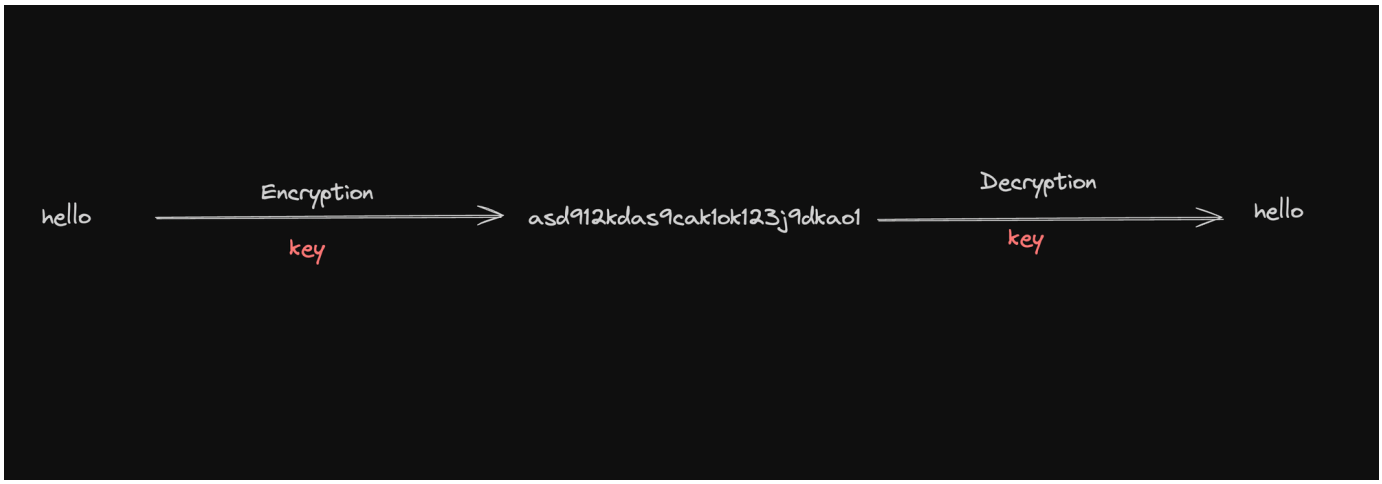
Encryption

Encryption is the process of converting plaintext data into an unreadable format, called ciphertext, using a specific algorithm and a key. The data can be decrypted back to its original form only with the appropriate key.

Key Characteristics:

- **Reversible**: With the correct key, the ciphertext can be decrypted back to plaintext.
- **Key-dependent**: The security of encryption relies on the secrecy of the key.
- **Two main types**:
  - **Symmetric encryption**: The same key is used for both encryption and decryption.
  - **Asymmetric encryption**: Different keys are used for encryption (public key) and decryption (private key).

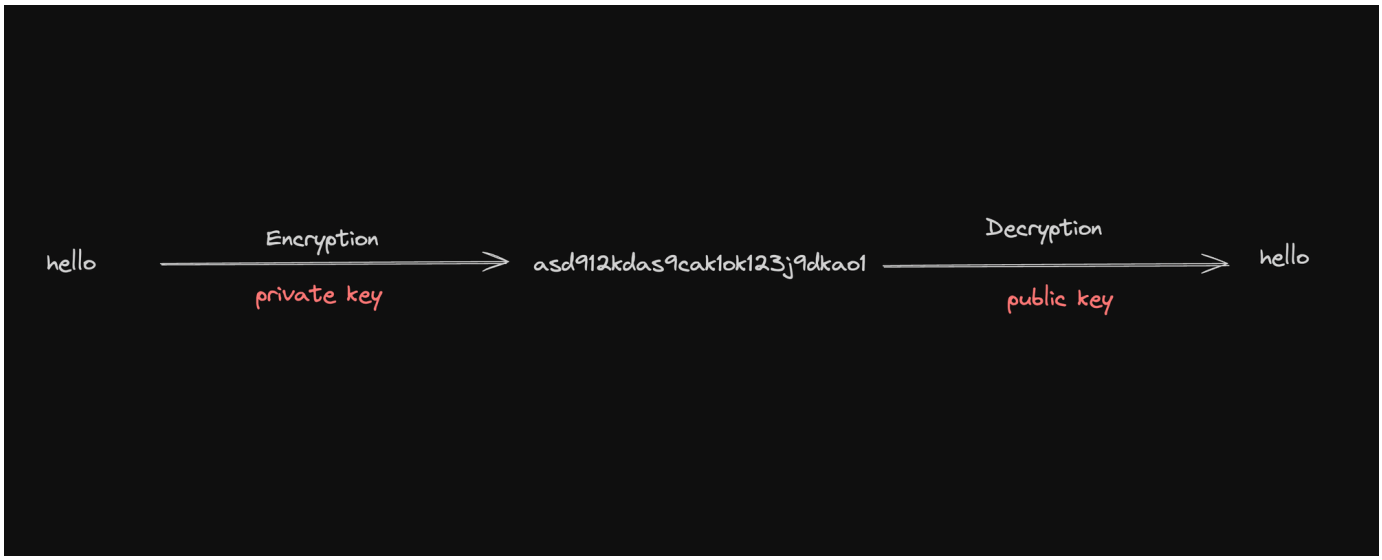
Symetric encryption



▼ Code

```
const crypto = require('crypto');

// Generate a random encryption key
const key = crypto.randomBytes(32); // 32 bytes = 256 bits
const iv = crypto.randomBytes(16); // Initialization vector (IV)

// Function to encrypt text
function encrypt(text) {
    const cipher = crypto.createCipheriv('aes-256-cbc', key, iv);
    let encrypted = cipher.update(text, 'utf8', 'hex');
    encrypted += cipher.final('hex');
    return encrypted;
}

// Function to decrypt text
function decrypt(encryptedText) {
    const decipher = crypto.createDecipheriv('aes-256-cbc', key, iv);
    let decrypted = decipher.update(encryptedText, 'hex', 'utf8');
    decrypted += decipher.final('utf8');
    return decrypted;
}

// Example usage
const textToEncrypt = 'Hello, World!';
const encryptedText = encrypt(textToEncrypt);
const decryptedText = decrypt(encryptedText);

console.log('Original Text:', textToEncrypt);
console.log('Encrypted Text:', encryptedText);
console.log('Decrypted Text:', decryptedText);
```

Asymetric encryption

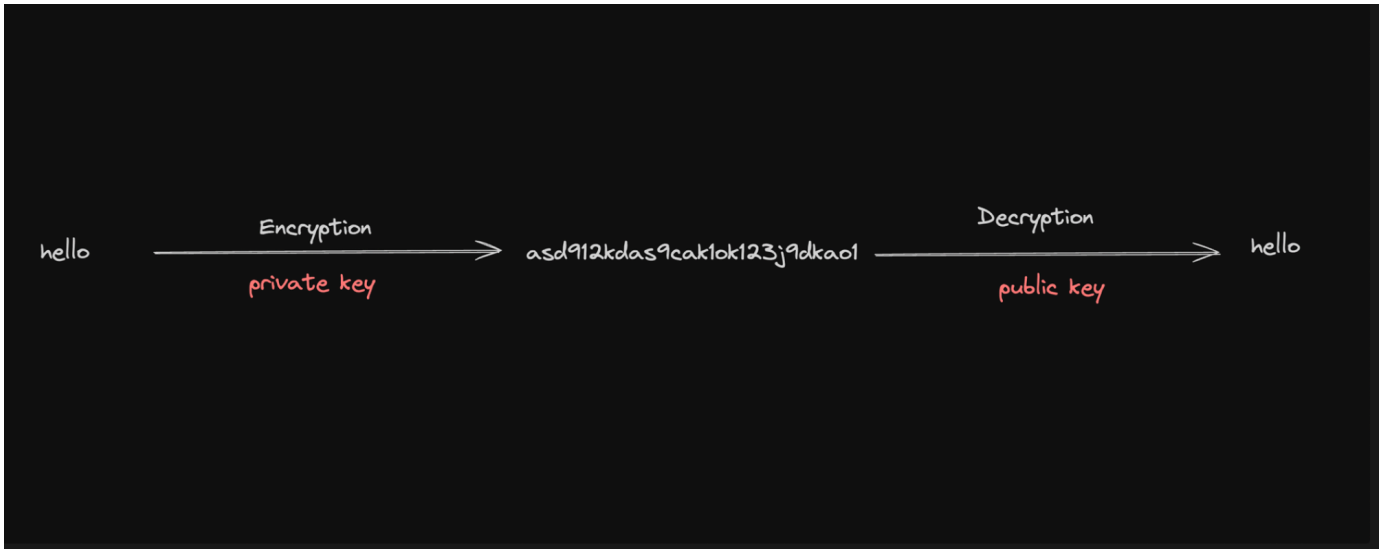


Asymetric Encryption

Asymmetric encryption, also known as public-key cryptography, is a type of encryption that uses a pair of keys: a public key and a private key. The keys are mathematically related, but it is computationally infeasible to derive the `private key` from the `public key` .

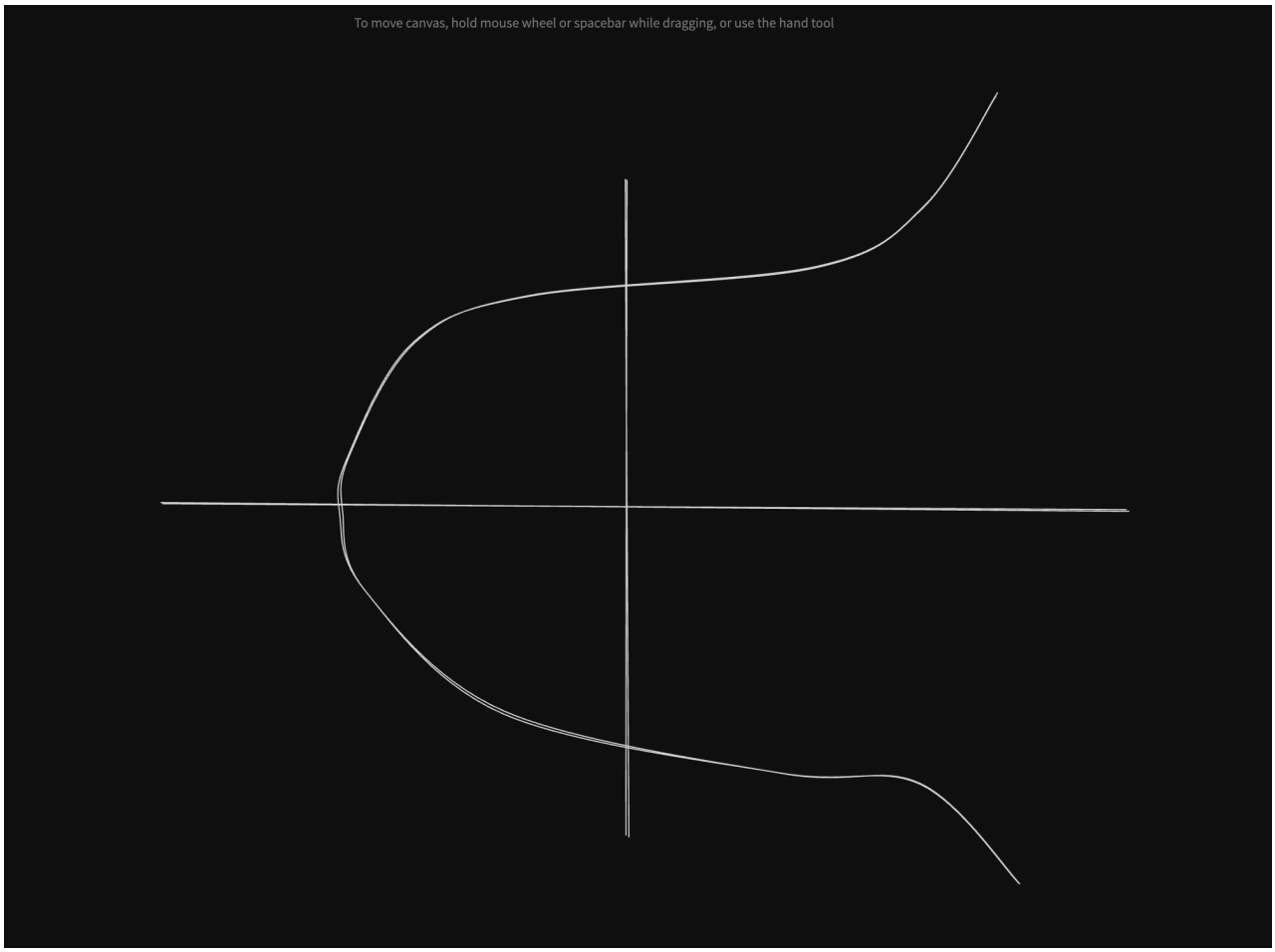
Public Key: The public key is a string that can be shared openly

Private Key: The private key is a secret cryptographic code that must be kept confidential. It is used to decrypt data encrypted with the corresponding public key or to create digital signatures.



Common Asymmetric Encryption Algorithms:

1. RSA - Rivest–Shamir–Adleman
2. **ECC** - Elliptic Curve Cryptography (ECDSA) - ETH and BTC
3. **EdDSA -** Edwards-curve Digital Signature Algorithm - SOL



How eliptic curves work - https://www.youtube.com/watch?v=NF1pwjL9-DE&

Common eleptic curves

1. secp256k1 - BTC and ETH
2. ed25519 - SOL

Few usecases of public key cryptography -

1. SSL/TLS certificates
2. SSH keys to connect to servers/push to github
3. Blockchains and cryptocurrencies

Creating a public/private keypair

Let's look at various ways of creating public/private keypairs, signing messages and verifying them

EdDSA - Edwards-curve Digital Signature Algorithm - ED25519

▼ Using `@noble/ed25519`

```
import * as ed from "@noble/ed25519";

async function main() {
  // Generate a secure random private key
  const privKey = ed.utils.randomPrivateKey();

  // Convert the message "hello world" to a Uint8Array
  const message = new TextEncoder().encode("hello world");

  // Generate the public key from the private key
  const pubKey = await ed.getPublicKeyAsync(privKey);
```

```
  // Sign the message
  const signature = await ed.signAsync(message, privKey);

  // Verify the signature
  const isValid = await ed.verifyAsync(signature, message, pubKey);

  // Output the result
  console.log(isValid); // Should print `true` if the signature is valid
}

main();
```

▼ Using `@solana/web3.js`

```
import { Keypair } from "@solana/web3.js";
import nacl from "tweetnacl";

// Generate a new keypair
const keypair = Keypair.generate();

// Extract the public and private keys
const publicKey = keypair.publicKey.toString();
const secretKey = keypair.secretKey;

// Display the keys
console.log("Public Key:", publicKey);
console.log("Private Key (Secret Key):", secretKey);

// Convert the message "hello world" to a Uint8Array
const message = new TextEncoder().encode("hello world");

const signature = nacl.sign.detached(message, secretKey);
const result = nacl.sign.detached.verify(
  message,
  signature,
  keypair.publicKey.toBytes(),
);

console.log(result);
```

ECDSA (Elliptic Curve Digital Signature Algorithm) - secp256k1

▼ Using `@noble/secp256k1`

```
import * as secp from "@noble/secp256k1";

async function main() {
  const privKey = secp.utils.randomPrivateKey(); // Secure random private key
  // sha256 of 'hello world'
  const msgHash =
    "b94d27b9934d3e08a52e52d7da7dabfac484efe37a5380ee9088f7ace2efcde9";
  const pubKey = secp.getPublicKey(privKey);
  const signature = await secp.signAsync(msgHash, privKey); // Sync methods be
  const isValid = secp.verify(signature, msgHash, pubKey);
  console.log(isValid);
}

main();
```

▼ Using `ethers`

```
import { ethers } from "ethers";

// Generate a random wallet
const wallet = ethers.Wallet.createRandom();

// Extract the public and private keys
const publicKey = wallet.address;
const privateKey = wallet.privateKey;

console.log("Public Key (Address):", publicKey);
console.log("Private Key:", privateKey);

// Message to sign
const message = "hello world";

// Sign the message using the wallet's private key
const signature = await wallet.signMessage(message);
console.log("Signature:", signature);

// Verify the signature
const recoveredAddress = ethers.verifyMessage(message, signature);

console.log("Recovered Address:", recoveredAddress);
console.log("Signature is valid:", recoveredAddress === publicKey);
```

How to transactions work on the blockchain?

Ref - https://andersbrownworth.com/blockchain/

User side

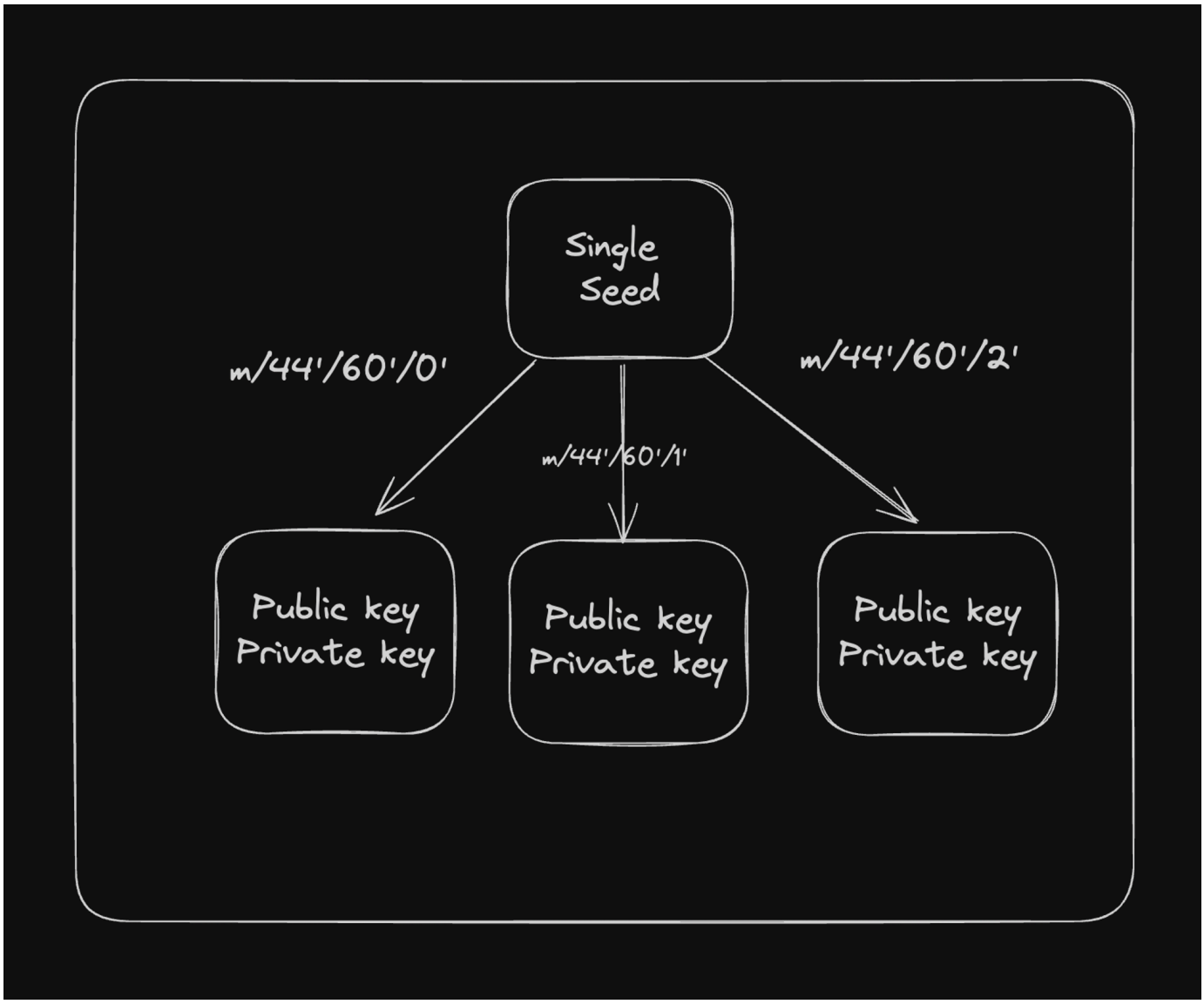
1. User first creates a `public/private` keypair
2. They create a `transaction` that they want to do (send Rs 50 to Alice). The transaction includes all necessary details like the recipient's address, the amount and some blockchain specific parameters (for eg - latestBlockHash in case of solana)
3. They hash the `transaction`
4. They `sign` the transaction using their private key
5. They send the `raw transaction` , `signature` and their `public key` to a node on the blockchain.

Miner

1. Hashes the original message to generate a `hash`
2. Verifies the `signature` using the users `public key` and the `hash` generated in step 1
3. Transaction validation - The miner/validator checks additional aspects of the transaction, such as ensuring the user has sufficient funds
4. If everything checks out, adds the transaction to the block

Hierarchical Deterministic (HD) Wallet

Hierarchical Deterministic (HD) wallets are a type of wallet that can generate a tree of key pairs from a single seed. This allows for the generation of multiple addresses from a single root seed, providing both security and convenience.



Problem

You have to maintain/store multiple `public private` keys if you want to have multiple wallets.

Solution - BIP-32

Bitcoin Improvement Proposal 32 (BIP-32) provided the solution to this problem in 2012. It was proposed by Pieter Wuilla, a Bitcoin Core developer, to simplify the recovery process of crypto wallets. BIP-32 introduced a hierarchical tree-like structure for wallets that allowed you to

manage multiple accounts much more easily than was previously possible. It's essentially a standardized way to derive private and public keys from a master seed.

How to create a wallet

Mnemonics

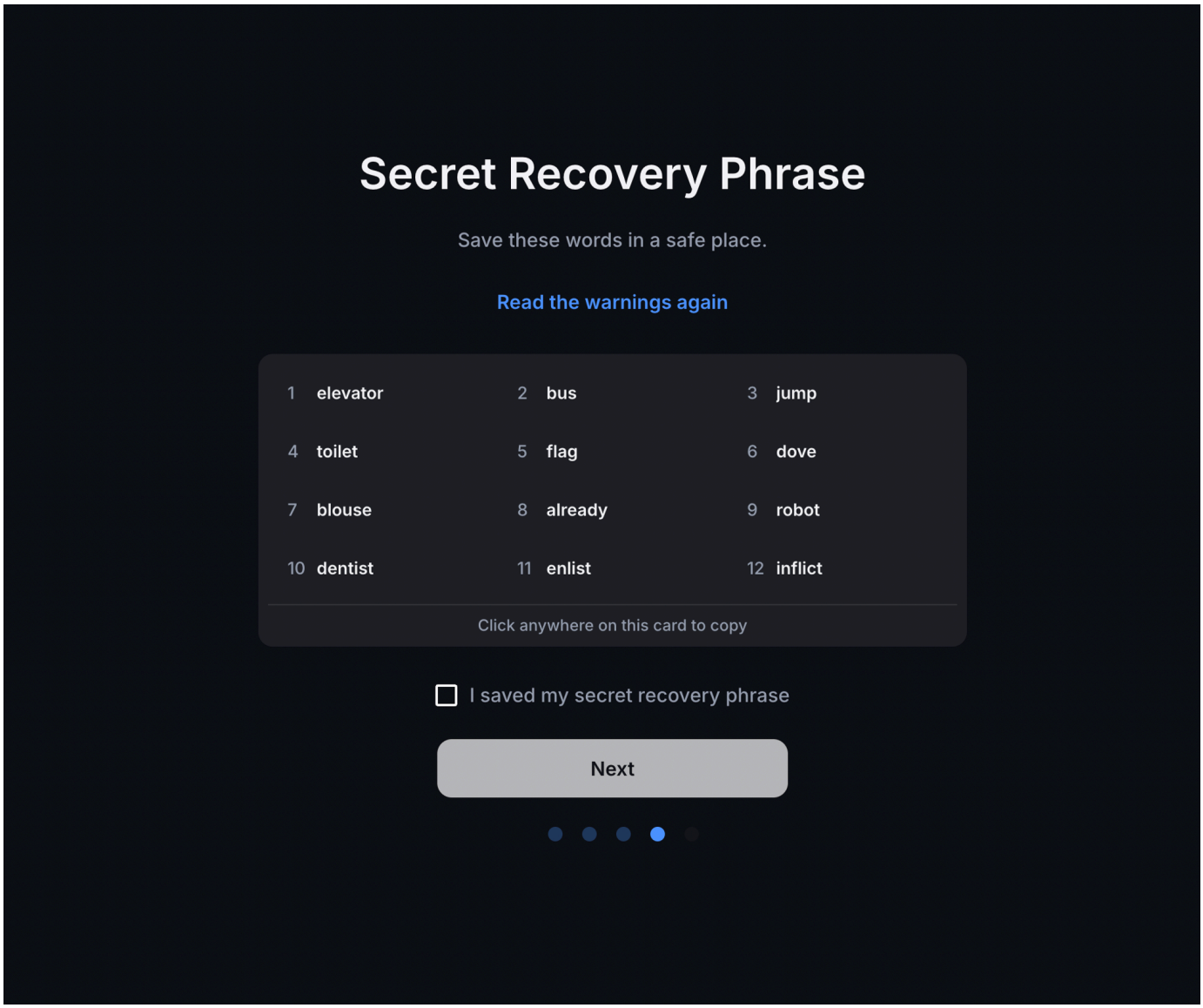
A mnemonic phrase (or seed phrase) is a human-readable string of words used to generate a cryptographic seed. BIP-39 (Bitcoin Improvement Proposal 39) defines how mnemonic phrases are generated and converted into a seed.

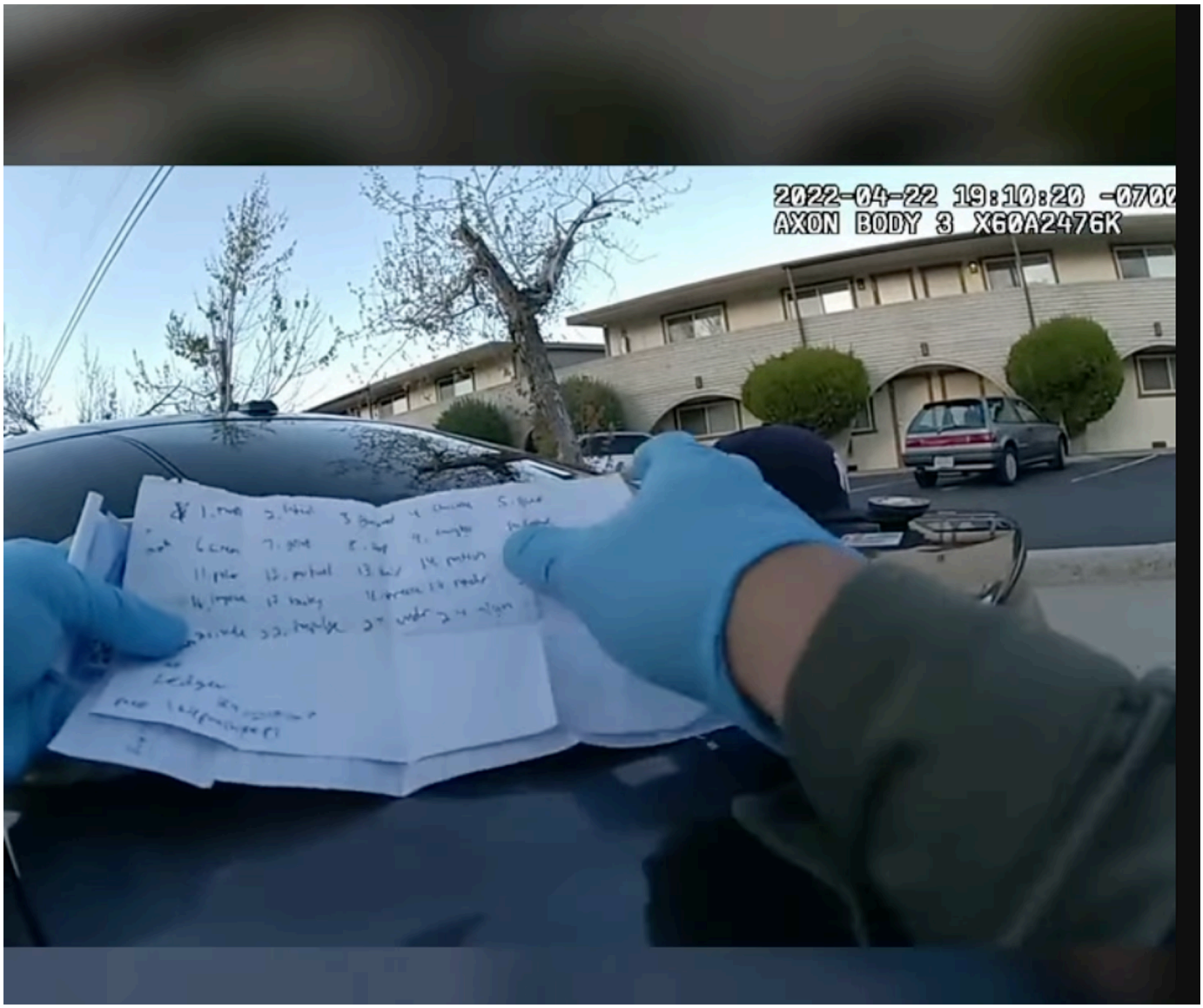
Ref - https://github.com/bitcoin/bips/blob/master/bip-0039/english.txt

Where this is done in Backpack - https://github.com/coral-xyz/backpack/blob/master/packages/app-extension/src/components/common/Account/MnemonicInput.tsx#L143

▼ Code

```
import { generateMnemonic } from 'bip39';

// Generate a 12-word mnemonic
const mnemonic = generateMnemonic();
console.log('Generated Mnemonic:', mnemonic);
```


Secret Recovery Phrase
Save these words in a safe place.
Read the warnings again
1 elevator
2 bus
3 jump
4 toilet
5 flag
6 dove
7 blouse
8 already
9 robot
10 dentist
11 enlist
12 inflict
Click anywhere on this card to copy
I saved my secret recovery phrase
Next



Ref - https://www.youtube.com/shorts/ojBIcnPOk6k

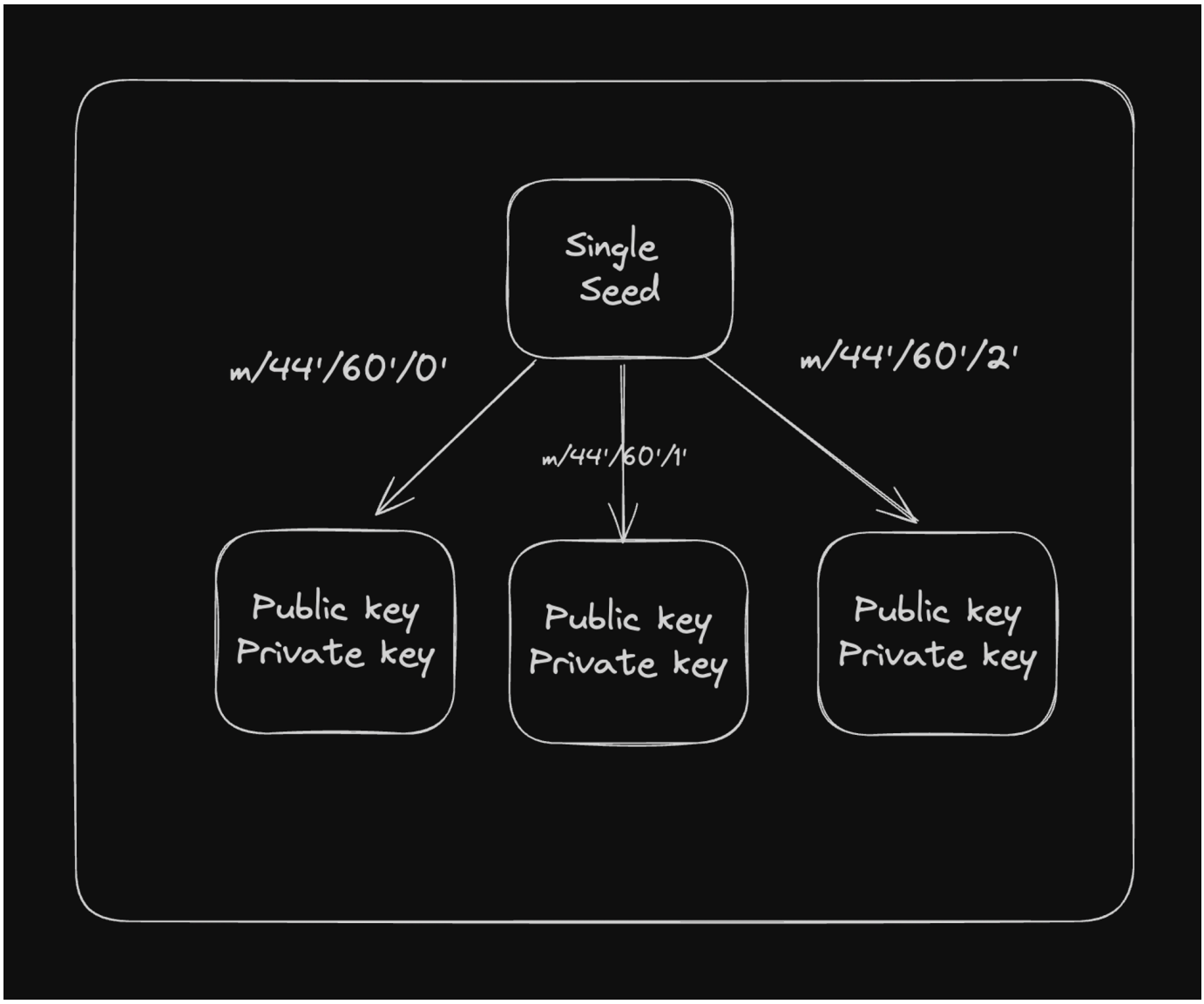
Seed phrase

The seed is a binary number derived from the mnemonic phrase.

```
import { generateMnemonic, mnemonicToSeedSync } from "bip39";

const mnemonic = generateMnemonic();
console.log("Generated Mnemonic:", mnemonic);
const seed = mnemonicToSeedSync(mnemonic);
```

Ref - https://github.com/coral-xyz/backpack/blob/master/packages/secure-background/src/services/svm/keyring.ts#L131

Derivation paths



- Derivation paths specify a systematic way to derive various keys from the master seed.
- They allow users to recreate the same set of addresses and private keys from the seed across different wallets, ensuring interoperability and consistency. (for example if you ever want to port from Phantom to Backpack)
- A derivation path is typically expressed in a format like `m / purpose' / coin_type' / account' / change / address_index`.
  - `m` : Refers to the master node, or the root of the HD wallet.
  - `purpose` : A constant that defines the purpose of the wallet (e.g., `44'` for BIP44, which is a standard for HD wallets).
  - `coin_type` : Indicates the type of cryptocurrency (e.g., `0'` for Bitcoin, `60'` for Ethereum, `501'` for solana).
  - `account` : Specifies the account number (e.g., `0'` for the first account).
  - `change` : This is either `0` or `1`, where `0` typically represents external addresses (receiving addresses), and `1` represents internal addresses (change addresses).

- `address_index` : A sequential index to generate multiple addresses under the same account and change path.

```
import nacl from "tweetnacl";
import { generateMnemonic, mnemonicToSeedSync } from "bip39";
import { derivePath } from "ed25519-hd-key";
import { Keypair } from "@solana/web3.js";

const mnemonic = generateMnemonic();
const seed = mnemonicToSeedSync(mnemonic);
for (let i = 0; i < 4; i++) {
  const path = `m/44'/501'/${i}'/0'`; // This is the derivation path
  const derivedSeed = derivePath(path, seed.toString("hex")).key;
  const secret = nacl.sign.keyPair.fromSeed(derivedSeed).secretKey;
  console.log(Keypair.fromSecretKey(secret).publicKey.toBase58());
}
```

Ref SOL - https://github.com/coral-xyz/backpack/blob/master/packages/secure-background/src/blockchain-configs/solana/config.ts#L38

https://github.com/coral-xyz/backpack/blob/master/packages/secure-background/src/services/svm/util.ts#L22