Blockchain Technology and Data Economics

Practise 5 – Building One Blockchain

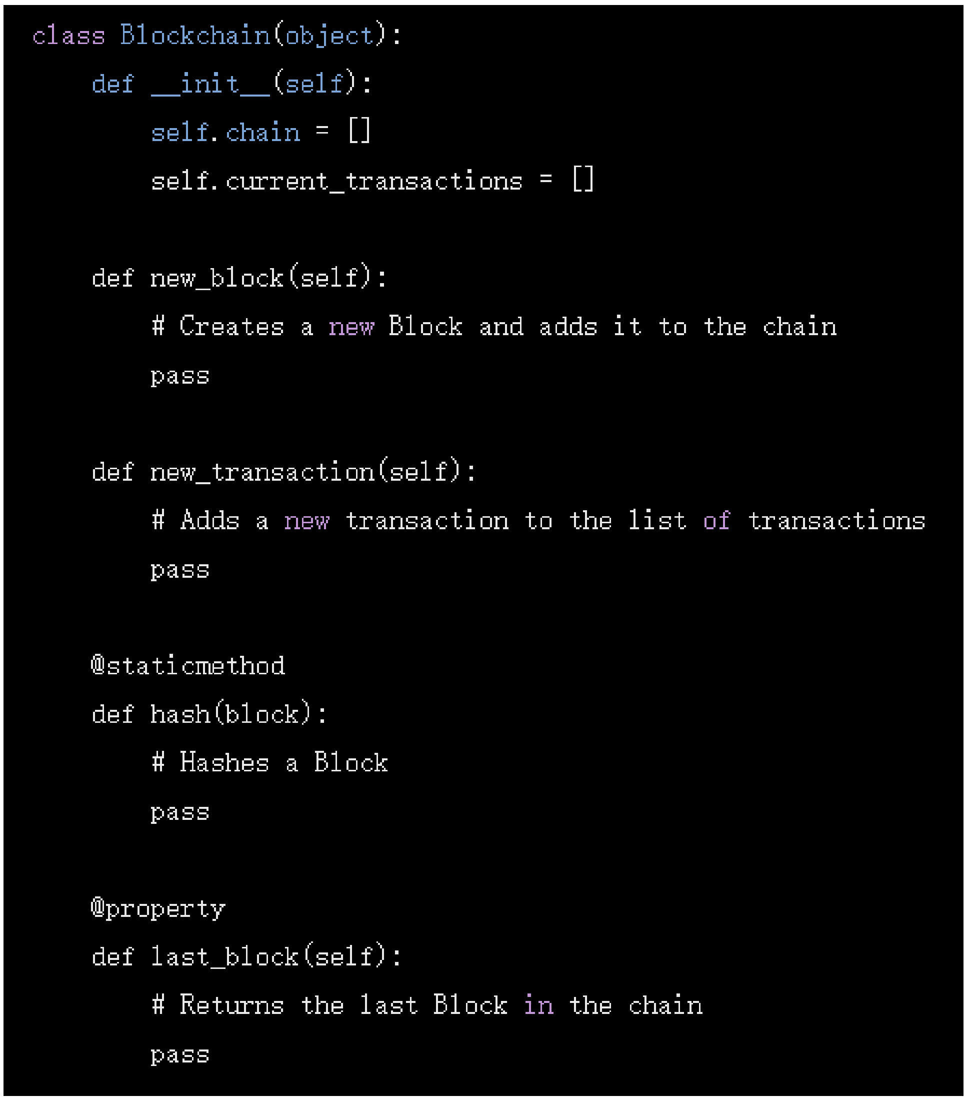
Version: 2020 Spring

Introduction

Recall a blockchain is an *immutable*, *sequential* chain of records called Blocks. They can contain transactions, files or any data you like, really. But the important thing is that they're *chained* together using *hashes*.

I. Building a Blockchain

Open up your text editor or IDE, e.g. PyCharm. Create a new file, called blockchain.py
We'll create a Blockchain class whose constructor creates an initial empty list (to store our blockchain), and another to store transactions. Here's the blueprint for our class:



```
class Blockchain(object):
    def __init__(self):
        self.chain = []
        self.current_transactions = []

    def new_block(self):
        # Creates a new Block and adds it to the chain
        pass

    def new_transaction(self):
        # Adds a new transaction to the list of transactions
        pass

    @staticmethod
    def hash(block):
        # Hashes a Block
        pass

    @property
    def last_block(self):
        # Returns the last Block in the chain
        pass
```

Our Blockchain class is responsible for managing the chain. It will store transactions and have some helper methods for adding new blocks to the chain. Let's start fleshing out some methods.

1. What does a Block look like?

Each Block has an index, a timestamp (in Unix time), a list of transactions, a proof (more on that later), and the hash of the previous Block.
Here’s an example of what a single Block looks like:

```
block = {
    'index': 1,
    'timestamp': 1506057125.900785,
    'transactions': [
        {
            'sender': "8527147fe1f5426f9dd545de4b27ee00",
            'recipient': "a77f5cdfa2934df3954a5c7c7da5df1f",
            'amount': 5,
        }
    ],
    'proof': 324984774000,
    'previous_hash': "2cf24dba5fb0a30e26e83b2ac5b9e29e1b161e5c1fa7425e73043362938b9824"
}
```

At this point, the idea of a *chain* should be apparent—each new block contains within itself, the hash of the previous Block. **This is crucial because it’s what gives blockchains immutability:** If an attacker corrupted an earlier Block in the chain then *all* subsequent blocks will contain incorrect hashes.

2. Adding Transactions to a Block

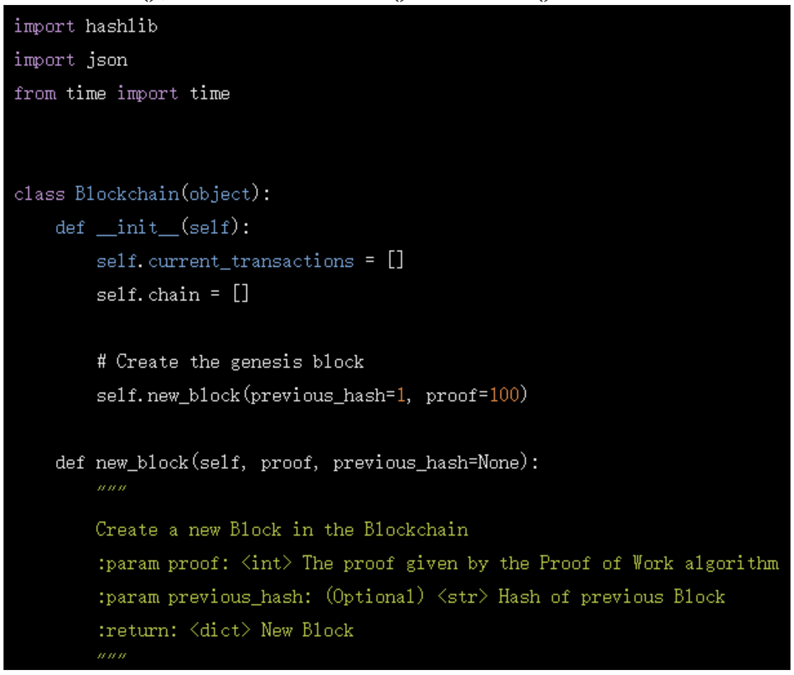
We’ll need a way of adding transactions to a Block. Our *new_transaction()* method is responsible for this, and it’s pretty straight-forward:

```
class Blockchain(object):
    ...

    def new_transaction(self, sender, recipient, amount):
        """
        Creates a new transaction to go into the next mined Block
        :param sender: <str> Address of the Sender
        :param recipient: <str> Address of the Recipient
        :param amount: <int> Amount
        :return: <int> The index of the Block that will hold this transaction
        """

        self.current_transactions.append({
            'sender': sender,
            'recipient': recipient,
            'amount': amount,
        })

        return self.last_block['index'] + 1
```

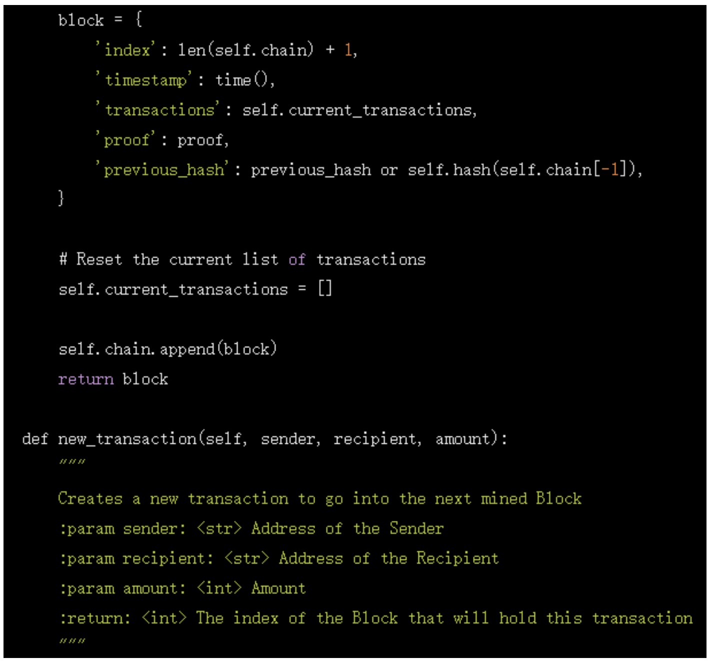
After *new_transaction()* adds a transaction to the list, it returns the index of the block which the transaction will be added to—the next one to be mined. This will be useful later on, to the user submitting the transaction.

3. Creating new Blocks

When our Blockchain is instantiated we'll need to seed it with a genesis block—a block with no predecessors. We'll also need to add a "proof" to our genesis block which is the result of mining (or proof of work). We'll talk more about mining later.
In addition to creating the genesis block in our constructor, we'll also flesh out the methods for *new_block()*, *new_transaction()* and *hash()*:



```
import hashlib
import json
from time import time


class Blockchain(object):
    def __init__(self):
        self.current_transactions = []
        self.chain = []

        # Create the genesis block
        self.new_block(previous_hash=1, proof=100)

    def new_block(self, proof, previous_hash=None):
        """
        Create a new Block in the Blockchain
        :param proof: <int> The proof given by the Proof of Work algorithm
        :param previous_hash: (Optional) <str> Hash of previous Block
        :return: <dict> New Block
        """
```



```
        block = {
            'index': len(self.chain) + 1,
            'timestamp': time(),
            'transactions': self.current_transactions,
            'proof': proof,
            'previous_hash': previous_hash or self.hash(self.chain[-1]),
        }

        # Reset the current list of transactions
        self.current_transactions = []

        self.chain.append(block)
        return block

    def new_transaction(self, sender, recipient, amount):
        """
        Creates a new transaction to go into the next mined Block
        :param sender: <str> Address of the Sender
        :param recipient: <str> Address of the Recipient
        :param amount: <int> Amount
        :return: <int> The index of the Block that will hold this transaction
        """
        self.current_transactions.append({
            'sender': sender,
            'recipient': recipient,
            'amount': amount,
        })

        return self.last_block['index'] + 1

    @property
    def last_block(self):
        return self.chain[-1]

    @staticmethod
    def hash(block):
        """
        Creates a SHA-256 hash of a Block
        :param block: <dict> Block
        :return: <str>
        """
```

```
# We must make sure that the Dictionary is Ordered, or we'll have inconsistent hashes
block_string = json.dumps(block, sort_keys=True).encode()
return hashlib.sha256(block_string).hexdigest()
```

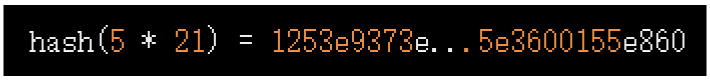
The above should be straight-forward—I've added some comments and *docstrings* to help keep it clear. We're almost done with representing our blockchain. But at this point, you must be wondering how new blocks are created, forged or mined.

4. Understanding Proof of Work

A Proof of Work algorithm (PoW) is how new Blocks are created or *mined* on the blockchain. The goal of PoW is to discover a number which solves a problem. The number must be **difficult to find but easy to verify**—computationally speaking—by anyone on the network. This is the core idea behind Proof of Work.
We'll look at a very simple example to help this sink in.
Let's decide that the hash of some integer x multiplied by another y must end in 0. So, hash(x * y) = ac23dc...0. And for this simplified example, let's fix x = 5. Implementing this in Python:

```
from hashlib import sha256
x = 5
y = 0  # We don't know what y should be yet...
while sha256(f'{x*y}'.encode()).hexdigest()[-1] != "0":
    y += 1
print(f'The solution is y = {y}')
```

The solution here is y = 21. Since, the produced hash ends in 0:

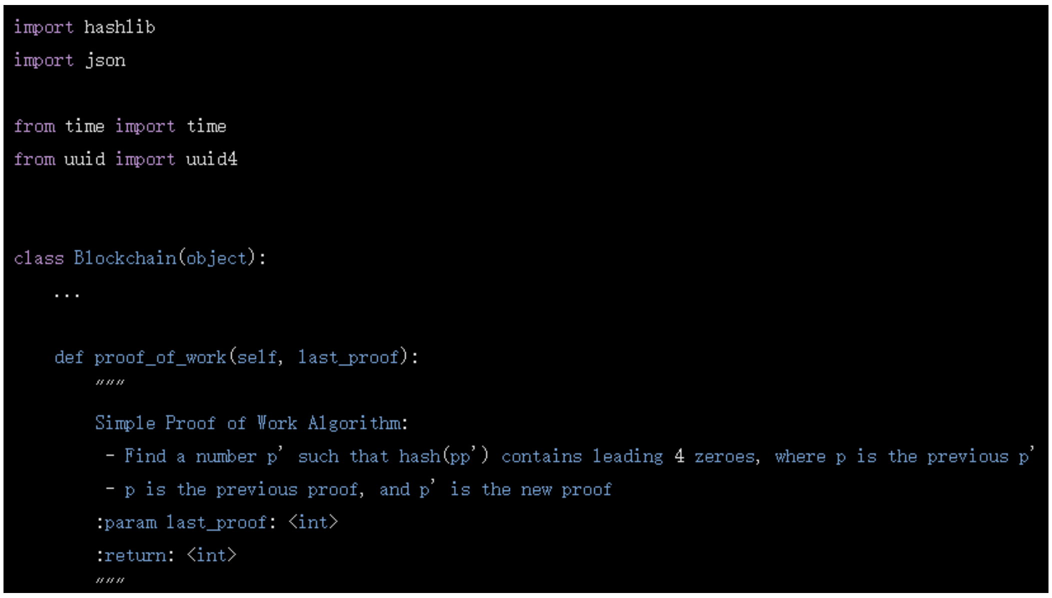


```
hash(5 * 21) = 1253e9373e...5e3600155e860
```

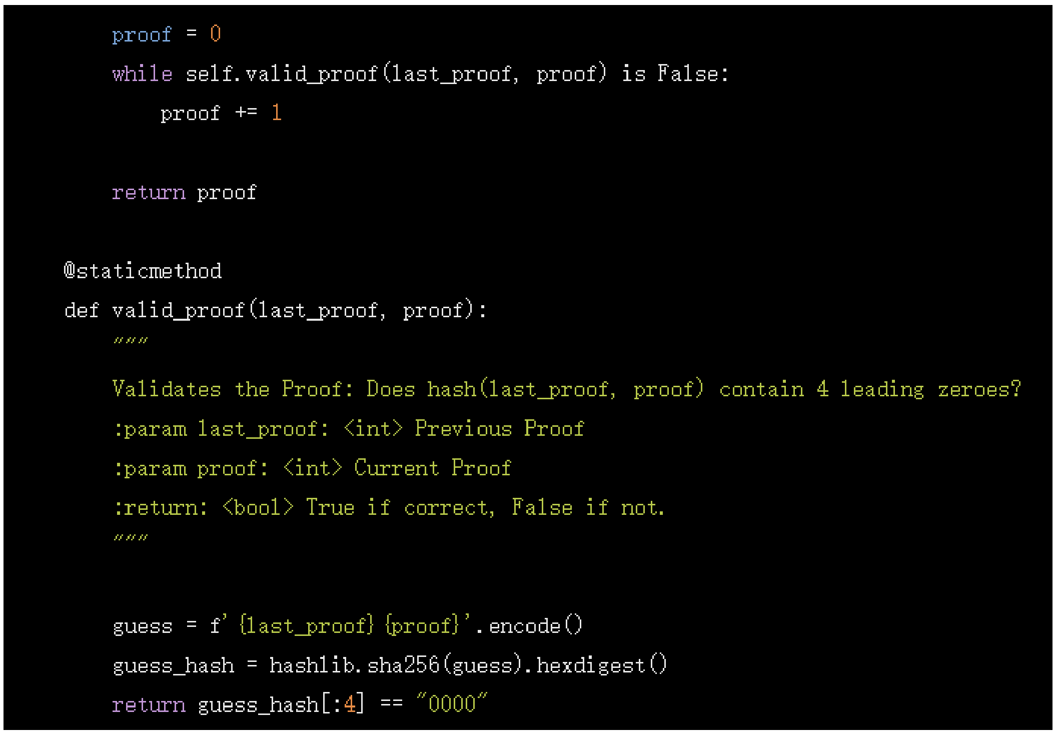
In Bitcoin, the Proof of Work algorithm is called Hashcash. And it’s not too different from our basic example above. It’s the algorithm that miners race to solve in order to create a new block. In general, the difficulty is determined by the number of characters searched for in a string. The miners are then rewarded for their solution by receiving a coin—in a transaction.

5. Implementing basic Proof of Work

Let’s implement a similar algorithm for our blockchain. Our rule will be similar to the example above: *Find a number p that when hashed with the previous block’s solution a hash with 4 leading 0s is produced.*



```
import hashlib
import json

from time import time
from uuid import uuid4


class Blockchain(object):
    ...

    def proof_of_work(self, last_proof):
        """
        Simple Proof of Work Algorithm:
         - Find a number p' such that hash(pp') contains leading 4 zeroes, where p is the previous p'
         - p is the previous proof, and p' is the new proof
        :param last_proof: <int>
        :return: <int>
        """
```



```
        proof = 0
        while self.valid_proof(last_proof, proof) is False:
            proof += 1

        return proof

    @staticmethod
    def valid_proof(last_proof, proof):
        """
        Validates the Proof: Does hash(last_proof, proof) contain 4 leading zeroes?
        :param last_proof: <int> Previous Proof
        :param proof: <int> Current Proof
        :return: <bool> True if correct, False if not.
        """

        guess = f'{last_proof}{proof}'.encode()
        guess_hash = hashlib.sha256(guess).hexdigest()
        return guess_hash[:4] == "0000"
```

To adjust the difficulty of the algorithm, we could modify the number of leading zeroes. But 4 is sufficient. You'll find out that the addition of a single leading zero makes a mammoth difference to the time required to find a solution.
Here the practise is almost complete and we're ready to begin interacting with it using HTTP requests.

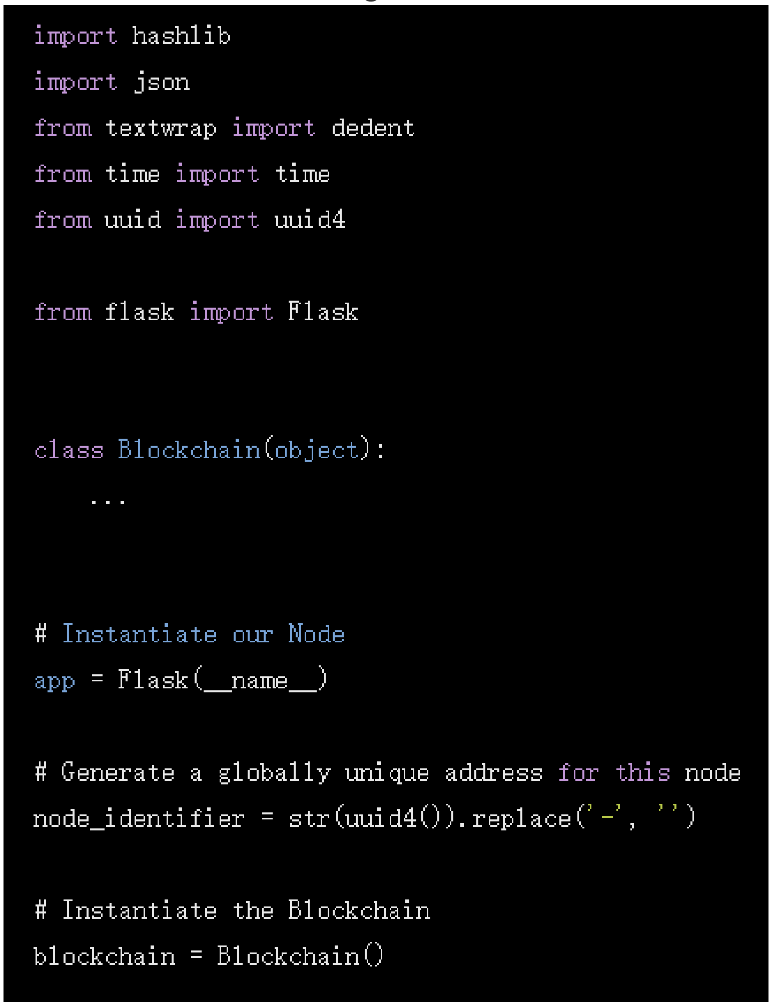
II. Our Blockchain as an API

We're going to use the Python Flask Framework. It's a micro-framework and it makes it easy to map endpoints to Python functions. This allows us talk to our blockchain over the web using HTTP requests. We'll create three methods:

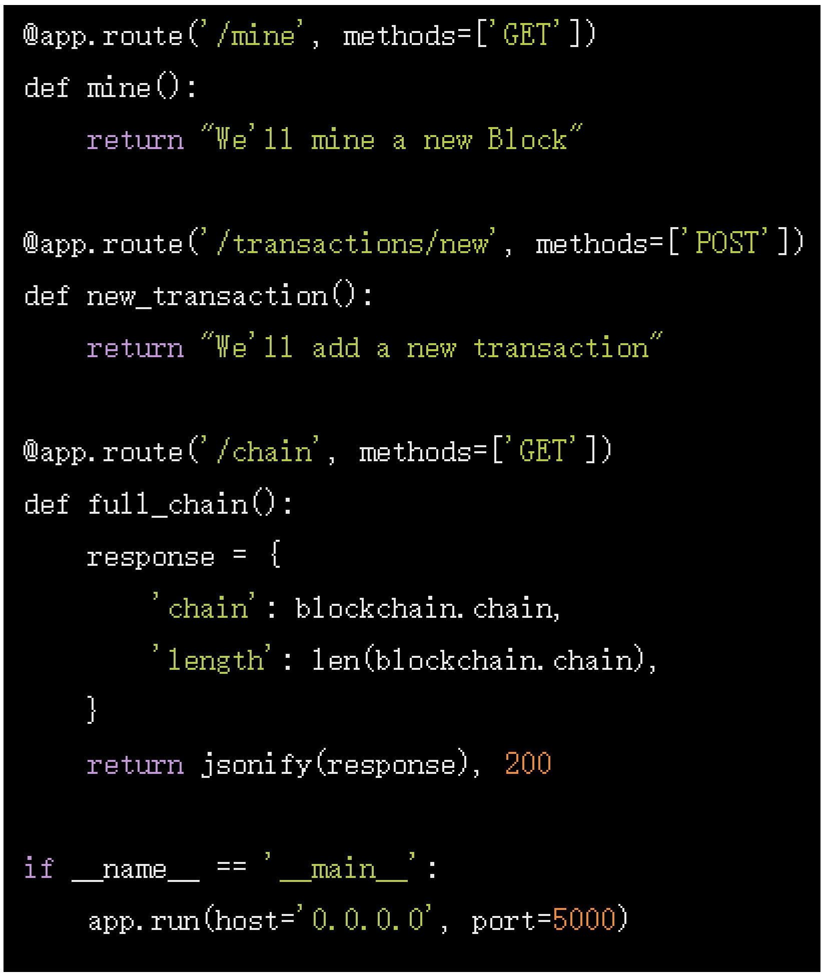
- `/transactions/new`
  to create a new transaction to a block
- `/mine`
  to tell our server to mine a new block.
- `/chain`
  to return the full Blockchain

1. Setting up Flask

Our "server" will form a single node in our blockchain network. Let's create some boilerplate code:



```
import hashlib
import json
from textwrap import dedent
from time import time
from uuid import uuid4

from flask import Flask


class Blockchain(object):
    ...


# Instantiate our Node
app = Flask(__name__)

# Generate a globally unique address for this node
node_identifier = str(uuid4()).replace('-', '')

# Instantiate the Blockchain
blockchain = Blockchain()
```



```
@app.route('/mine', methods=['GET'])
def mine():
    return "We'll mine a new Block"

@app.route('/transactions/new', methods=['POST'])
def new_transaction():
    return "We'll add a new transaction"

@app.route('/chain', methods=['GET'])
def full_chain():
    response = {
        'chain': blockchain.chain,
        'length': len(blockchain.chain),
    }
    return jsonify(response), 200

if __name__ == '__main__':
    app.run(host='0.0.0.0', port=5000)
```

A brief explanation of what we've added above:
Line 15: Instantiates our Node. Read more about Flask here.
Line 18: Create a random name for our node.
Line 21: Instantiate our
`Blockchain`
class.
Line 24–26: Create the
`/mine`
endpoint, which is a
`GET`
request.
Line 28–30: Create the
`/transactions/new`
endpoint, which is a
`POST`
request, since we'll be sending data to it.
Line 32–38: Create the
`/chain`
endpoint, which returns the full Blockchain.
Line 40–41: Runs the server on port 5000.

2. The Transactions Endpoint

This is what the request for a transaction will look like. It’s what the user sends to the server:

```
{
 "sender": "my address",
 "recipient": "someone else's address",
 "amount": 5
}
```

Since we already have our class method for adding transactions to a block, the rest is easy. Let’s write the function for adding transactions:

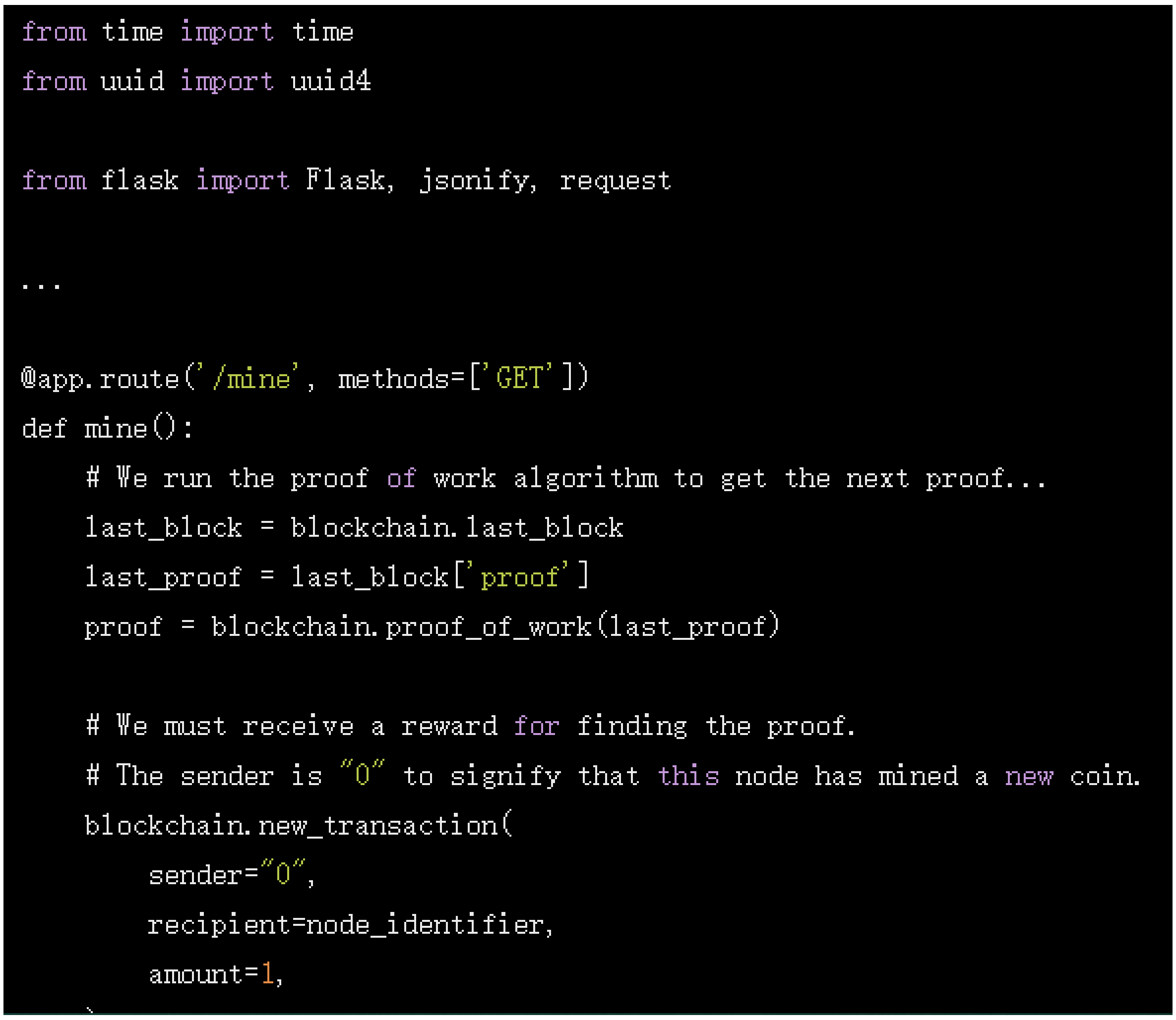
```
import hashlib
import json
from textwrap import dedent
from time import time
from uuid import uuid4

from flask import Flask, jsonify, request


...


@app.route('/transactions/new', methods=['POST'])
def new_transaction():
    values = request.get_json()

    # Check that the required fields are in the POST'ed data
    required = ['sender', 'recipient', 'amount']
    if not all(k in values for k in required):
        return 'Missing values', 400
```

```
# Create a new Transaction
index = blockchain.new_transaction(values['sender'], values['recipient'], values['amount'])

response = {'message': f'Transaction will be added to Block {index}'}
return jsonify(response), 201
```

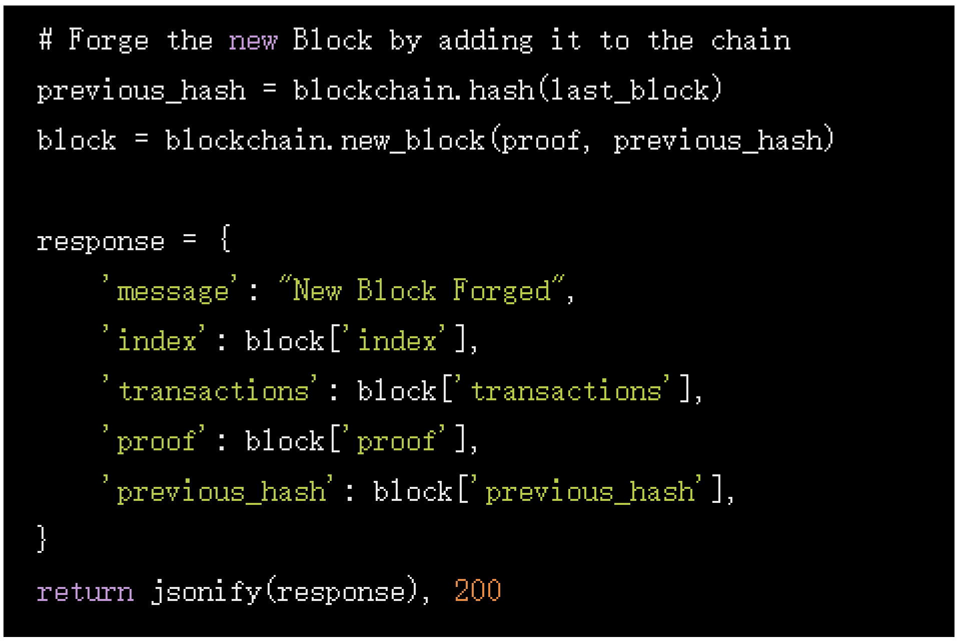
3. The Mining Endpoint

Our mining endpoint is where the magic happens, and it’s easy. It has to do three things:

- Calculate the Proof of Work
- Reward the miner (us) by adding a transaction granting us 1 coin
- Forge the new Block by adding it to the chain



```
from time import time
from uuid import uuid4

from flask import Flask, jsonify, request


...

@app.route(’/mine’, methods=[’GET’])
def mine():
    # We run the proof of work algorithm to get the next proof...
    last_block = blockchain.last_block
    last_proof = last_block[’proof’]
    proof = blockchain.proof_of_work(last_proof)

    # We must receive a reward for finding the proof.
    # The sender is “0” to signify that this node has mined a new coin.
    blockchain.new_transaction(
        sender=“0”,
        recipient=node_identifier,
        amount=1,
    )
```



```
 # Forge the new Block by adding it to the chain
 previous_hash = blockchain.hash(last_block)
 block = blockchain.new_block(proof, previous_hash)

 response = {
     ’message’: “New Block Forged”,
     ’index’: block[’index’],
     ’transactions’: block[’transactions’],
     ’proof’: block[’proof’],
     ’previous_hash’: block[’previous_hash’],
 }
 return jsonify(response), 200
```

Note that the recipient of the mined block is the address of our node. And most of what we've done here is just interact with the methods on our Blockchain class. At this point, we're done, and can start interacting with our blockchain.

III. Interacting with our Blockchain

You can use plain old cURL or Postman to interact with our API over a network.
Fire up the server:

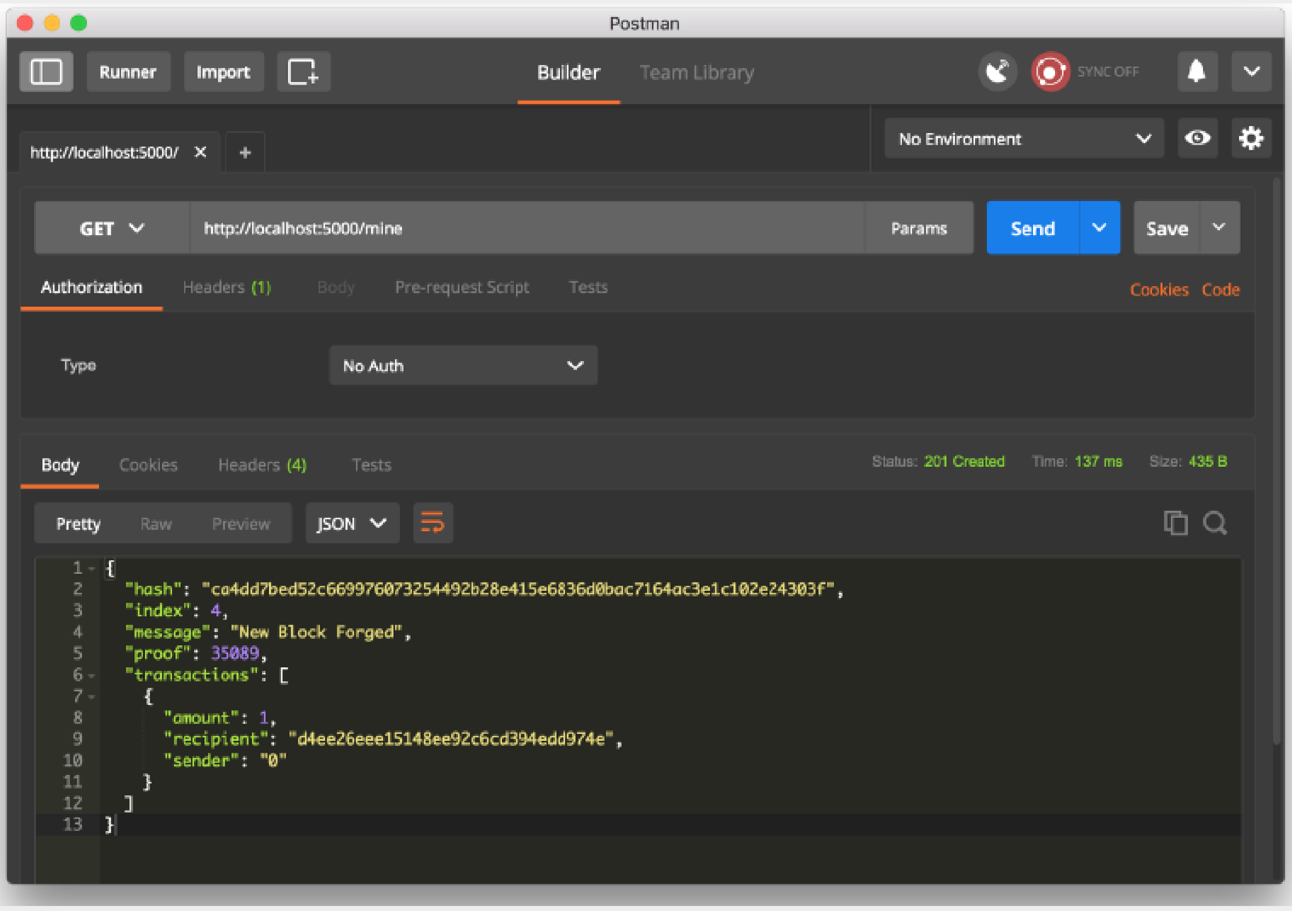
```
$ python blockchain.py
* Running on http://127.0.0.1:5000/ (Press CTRL+C to quit)
```

Let's try mining a block by making a

`GET`

request to

`http://localhost:5000/mine`:



GET http://localhost:5000/mine

Type: No Auth

Status: 201 Created Time: 137 ms Size: 435 B

```
{
  "hash": "ca4dd7bed52c669976073254492b28e415e6836d0bac7164ac3e1c102e24303f",
  "index": 4,
  "message": "New Block Forged",
  "proof": 35089,
  "transactions": [
    {
      "amount": 1,
      "recipient": "d4ee26eee15148ee92c6cd394edd974e",
      "sender": "0"
    }
  ]
}
```

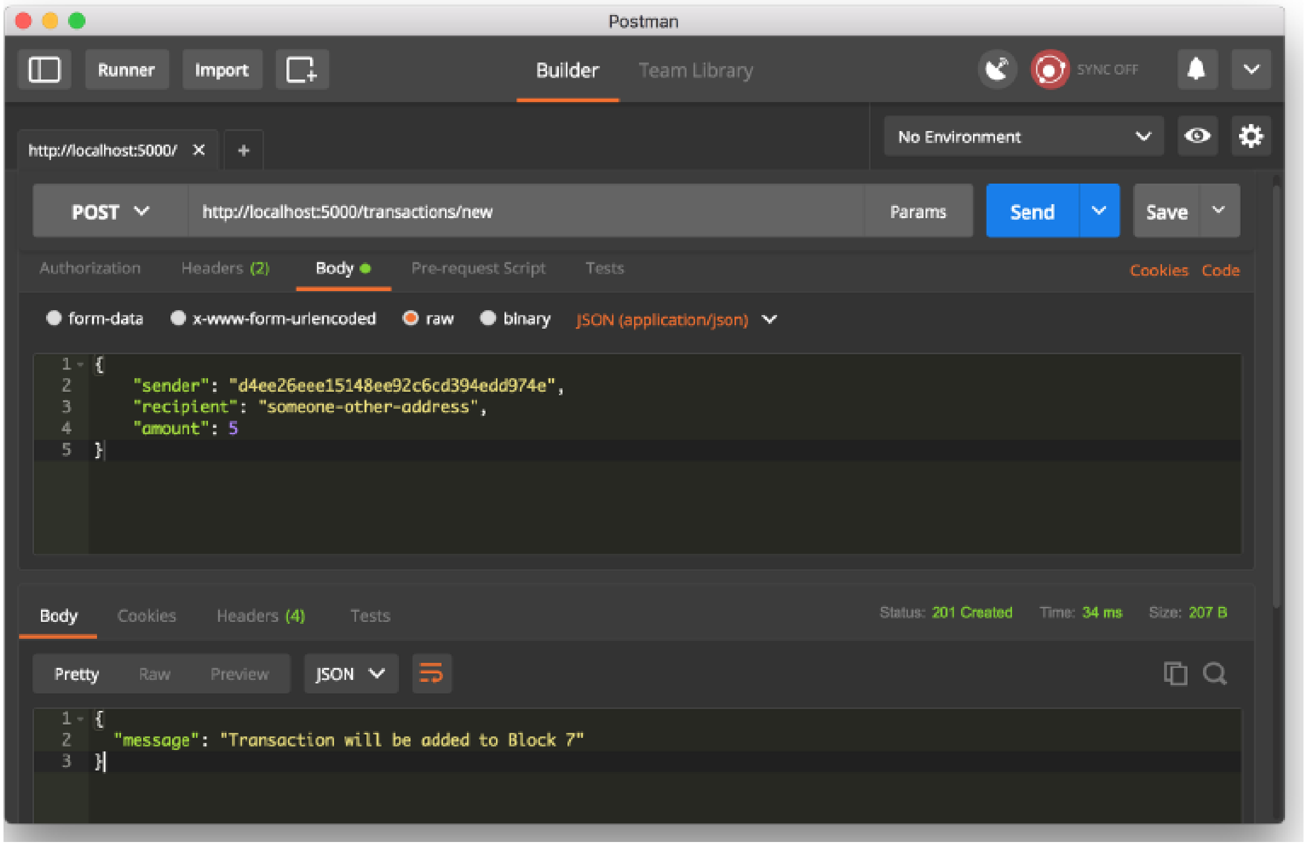
(Using Postman to make a GET request)

Let's create a new transaction by making a

`POST`

request to

`http://localhost:5000/transactions/new` with a body containing our transaction structure:



```
{
    "sender": "d4ee26eee15148ee92c6cd394edd974e",
    "recipient": "someone-other-address",
    "amount": 5
}
```

```
{
  "message": "Transaction will be added to Block 7"
}
```

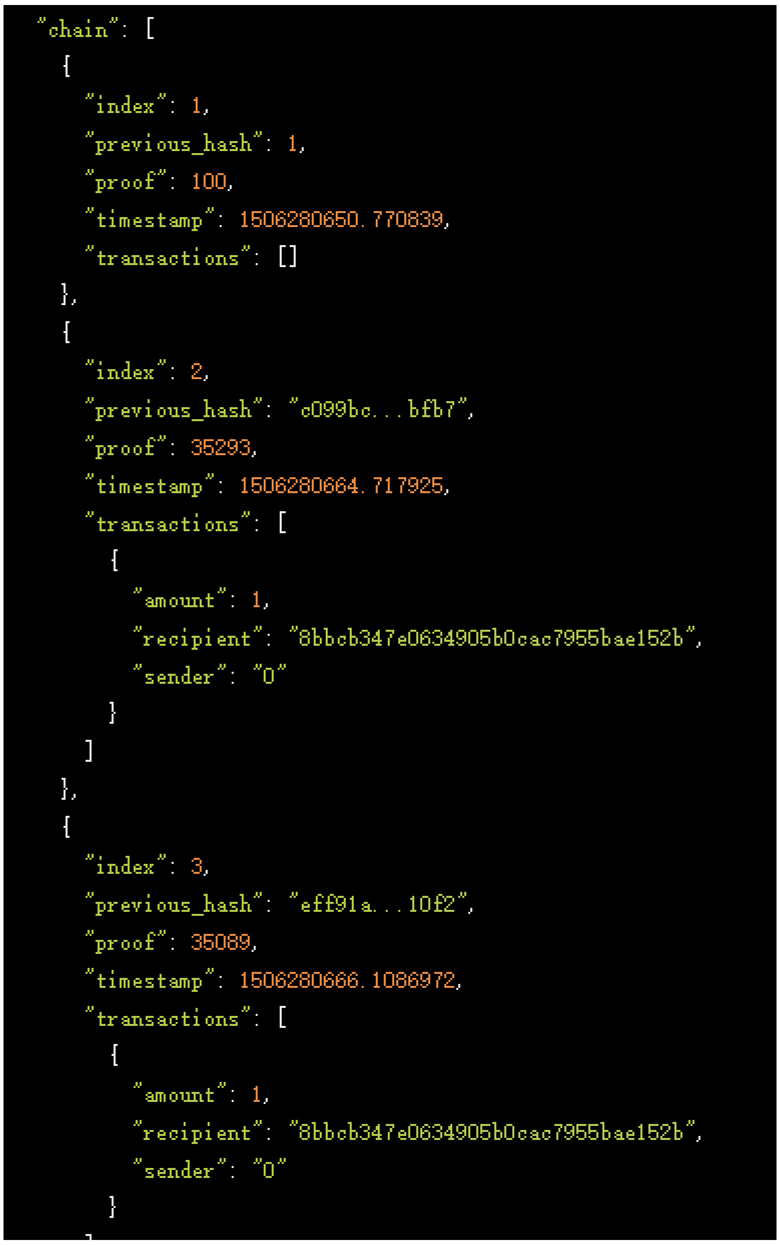
(Using Postman to make a POST request)

If you aren't using Postman, then you can make the equivalent request using cURL:

```
$ curl -X POST -H "Content-Type: application/json" -d '{
 "sender": "d4ee26eee15148ee92c6cd394edd974e",
 "recipient": "someone-other-address",
 "amount": 5
}' "http://localhost:5000/transactions/new"
```

I restarted my server, and mined two blocks, to give 3 in total. Let's inspect the full chain by requesting

```
http://localhost:5000/chain
```



```
"chain": [
  {
    "index": 1,
    "previous_hash": 1,
    "proof": 100,
    "timestamp": 1506280650.770839,
    "transactions": []
  },
  {
    "index": 2,
    "previous_hash": "c099bc...bfb7",
    "proof": 35293,
    "timestamp": 1506280664.717925,
    "transactions": [
      {
        "amount": 1,
        "recipient": "8bbcb347e0634905b0cac7955bae152b",
        "sender": "0"
      }
    ]
  },
  {
    "index": 3,
    "previous_hash": "eff91a...10f2",
    "proof": 35089,
    "timestamp": 1506280666.1086972,
    "transactions": [
      {
        "amount": 1,
        "recipient": "8bbcb347e0634905b0cac7955bae152b",
        "sender": "0"
      }
```

IV. Consensus

This is very cool. We've got a basic Blockchain that accepts transactions and allows us to mine new Blocks. But the whole point of Blockchains is that they should be *decentralized*. And if they're decentralized, how on earth do we ensure that they all reflect the same chain? This is called the problem of *Consensus*, and we'll have to implement a Consensus Algorithm if we want more than one node in our network.

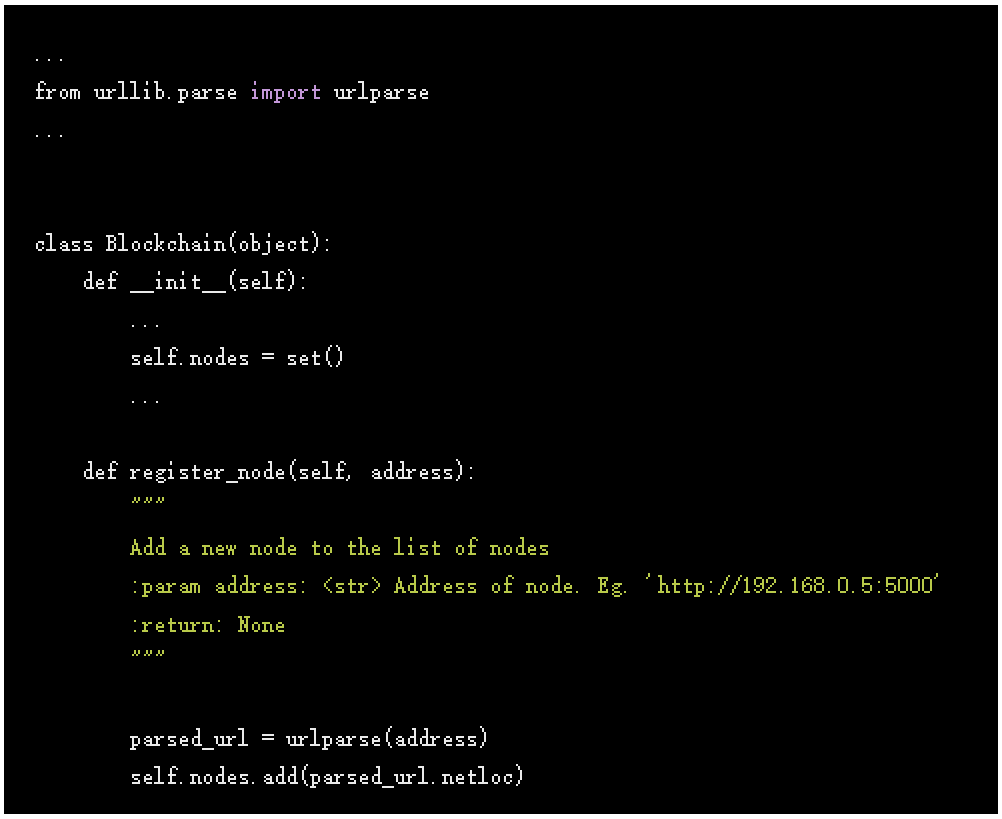
1. Registering new Nodes

Before we can implement a Consensus Algorithm, we need a way to let a node know about neighbouring nodes on the network. Each node on our network should keep a registry of other nodes on the network. Thus, we'll need some more endpoints:

- `/nodes/register` to accept a list of new nodes in the form of URLs.

- `/nodes/resolve` to implement our Consensus Algorithm, which resolves any conflicts—to ensure a node has the correct chain.

We'll need to modify our Blockchain's constructor and provide a method for registering nodes:

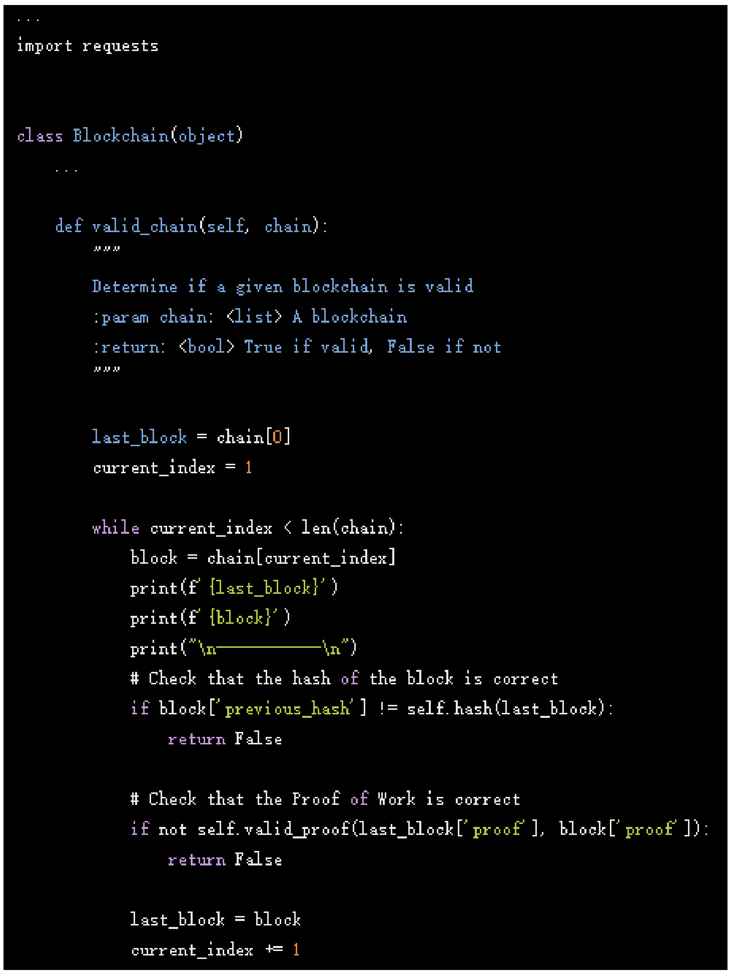


```
...
from urllib.parse import urlparse
...


class Blockchain(object):
    def __init__(self):
        ...
        self.nodes = set()
        ...

    def register_node(self, address):
        """
        Add a new node to the list of nodes
        :param address: <str> Address of node. Eg. 'http://192.168.0.5:5000'
        :return: None
        """

        parsed_url = urlparse(address)
        self.nodes.add(parsed_url.netloc)
```

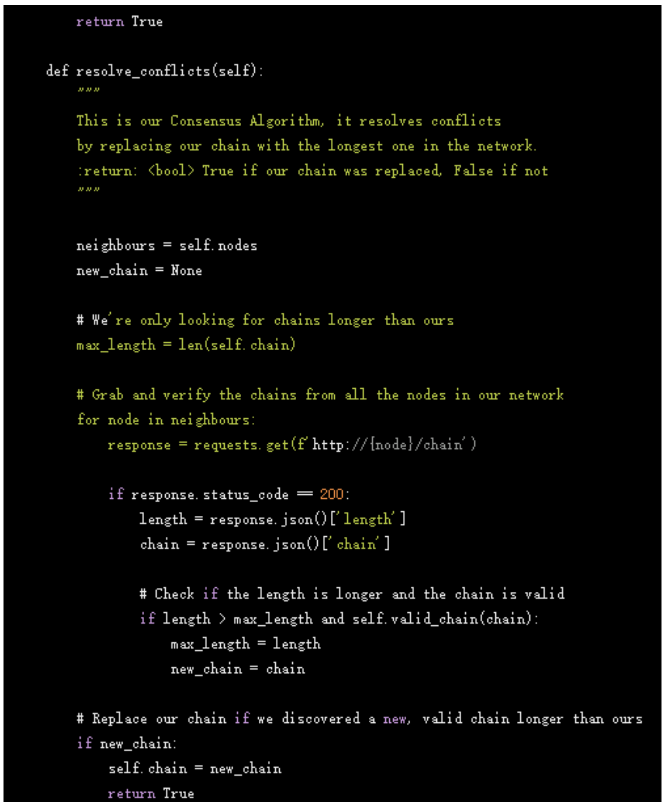
Note that we've used a *set()* to hold the list of nodes. This is a cheap way of ensuring that the addition of new nodes is idempotent—meaning that no matter how many times we add a specific node, it appears exactly once.

2. Implementing the Consensus Algorithm

As mentioned, a conflict is when one node has a different chain to another node. To resolve this, we'll make the rule that *the longest valid chain is authoritative*. In other words, the longest chain on the network is the *de-facto* one. Using this algorithm, we reach *Consensus* amongst the nodes in our network.

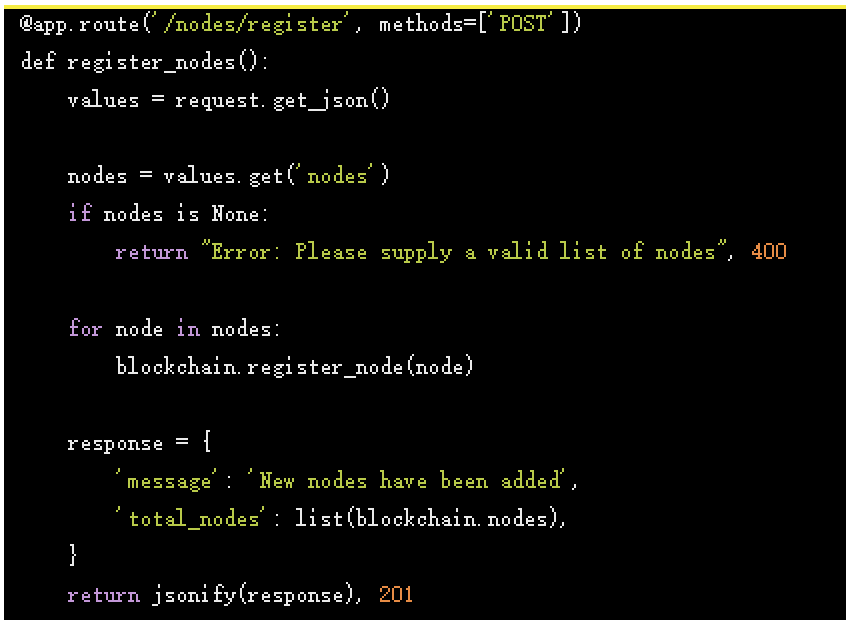


```python
...
import requests


class Blockchain(object)
    ...

    def valid_chain(self, chain):
        """

        Determine if a given blockchain is valid
        :param chain: <list> A blockchain
        :return: <bool> True if valid, False if not
        """

        last_block = chain[0]
        current_index = 1

        while current_index < len(chain):
            block = chain[current_index]
            print(f'{last_block}')
            print(f'{block}')
            print("\n-----------\n")
            # Check that the hash of the block is correct
            if block['previous_hash'] != self.hash(last_block):
                return False

            # Check that the Proof of Work is correct
            if not self.valid_proof(last_block['proof'], block['proof']):
                return False

            last_block = block
            current_index += 1
```

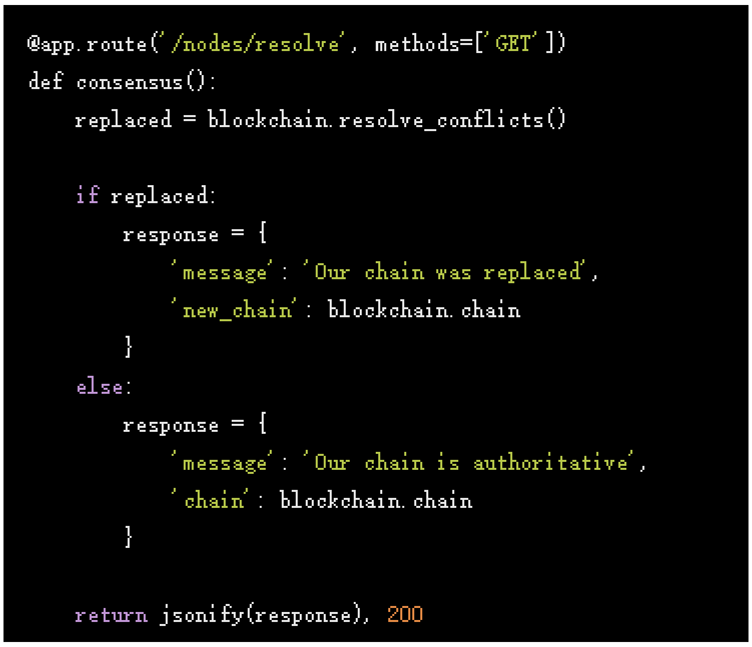


```python
        return True

    def resolve_conflicts(self):
        """
        This is our Consensus Algorithm, it resolves conflicts
        by replacing our chain with the longest one in the network.
        :return: <bool> True if our chain was replaced, False if not
        """

        neighbours = self.nodes
        new_chain = None

        # We're only looking for chains longer than ours
        max_length = len(self.chain)

        # Grab and verify the chains from all the nodes in our network
        for node in neighbours:
            response = requests.get(f'http://{node}/chain')

            if response.status_code == 200:
                length = response.json()['length']
                chain = response.json()['chain']

                # Check if the length is longer and the chain is valid
                if length > max_length and self.valid_chain(chain):
                    max_length = length
                    new_chain = chain

        # Replace our chain if we discovered a new, valid chain longer than ours
        if new_chain:
            self.chain = new_chain
            return True
```

The first method *valid_chain()* is responsible for checking if a chain is valid by looping through each block and verifying both the hash and the proof.
resolve_conflicts() is a method which loops through all our neighbouring nodes, downloads their chains and verifies them using the above method. If a valid chain is found, whose length is greater than ours, we replace ours.
Let’s register the two endpoints to our API, one for adding neighbouring nodes and the another for resolving conflicts:

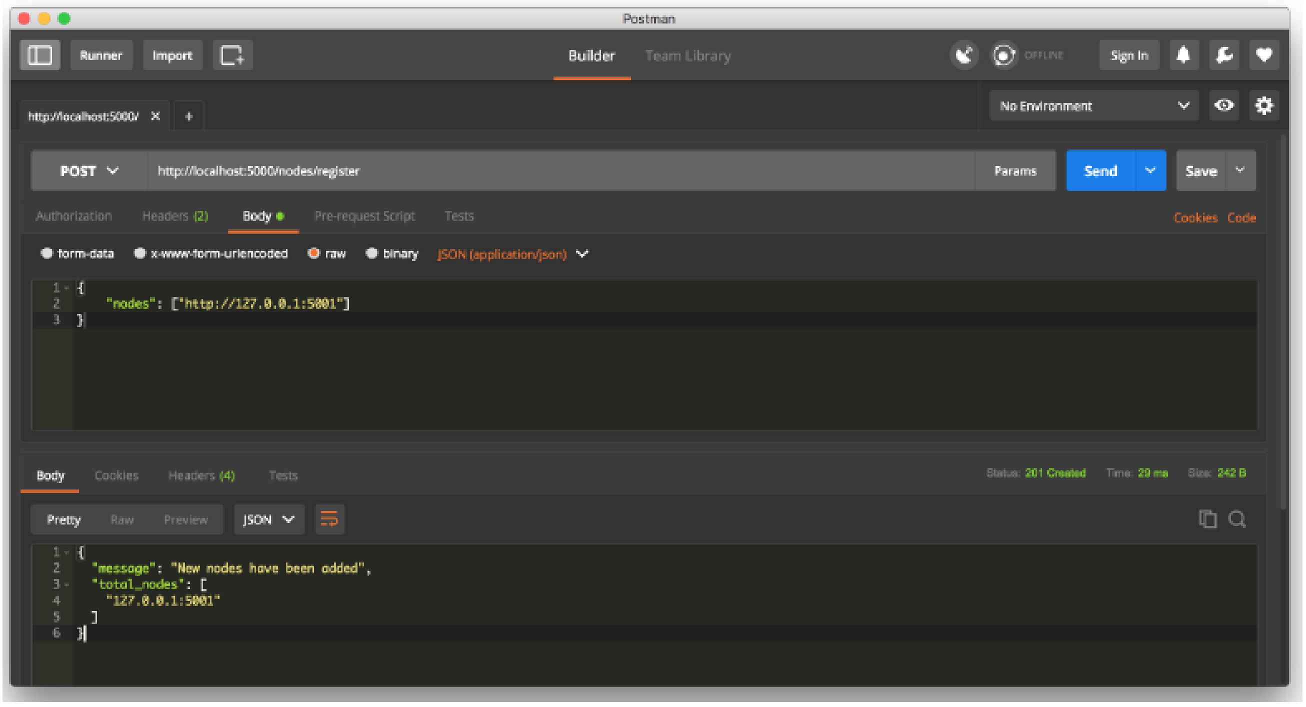


```
@app.route('/nodes/register', methods=['POST'])
def register_nodes():
    values = request.get_json()

    nodes = values.get('nodes')
    if nodes is None:
        return "Error: Please supply a valid list of nodes", 400

    for node in nodes:
        blockchain.register_node(node)

    response = {
        'message': 'New nodes have been added',
        'total_nodes': list(blockchain.nodes),
    }
    return jsonify(response), 201
```



```
@app.route('/nodes/resolve', methods=['GET'])
def consensus():
    replaced = blockchain.resolve_conflicts()

    if replaced:
        response = {
            'message': 'Our chain was replaced',
            'new_chain': blockchain.chain
        }
    else:
        response = {
            'message': 'Our chain is authoritative',
            'chain': blockchain.chain
        }

    return jsonify(response), 200
```

At this point you can grab a different machine if you like, and spin up different nodes on your network. Or spin up processes using different ports on the same machine. I spun up another node on my machine, on a different port, and registered it with my current node. Thus, I have two nodes:
http://localhost:5000
 and
http://localhost:5001

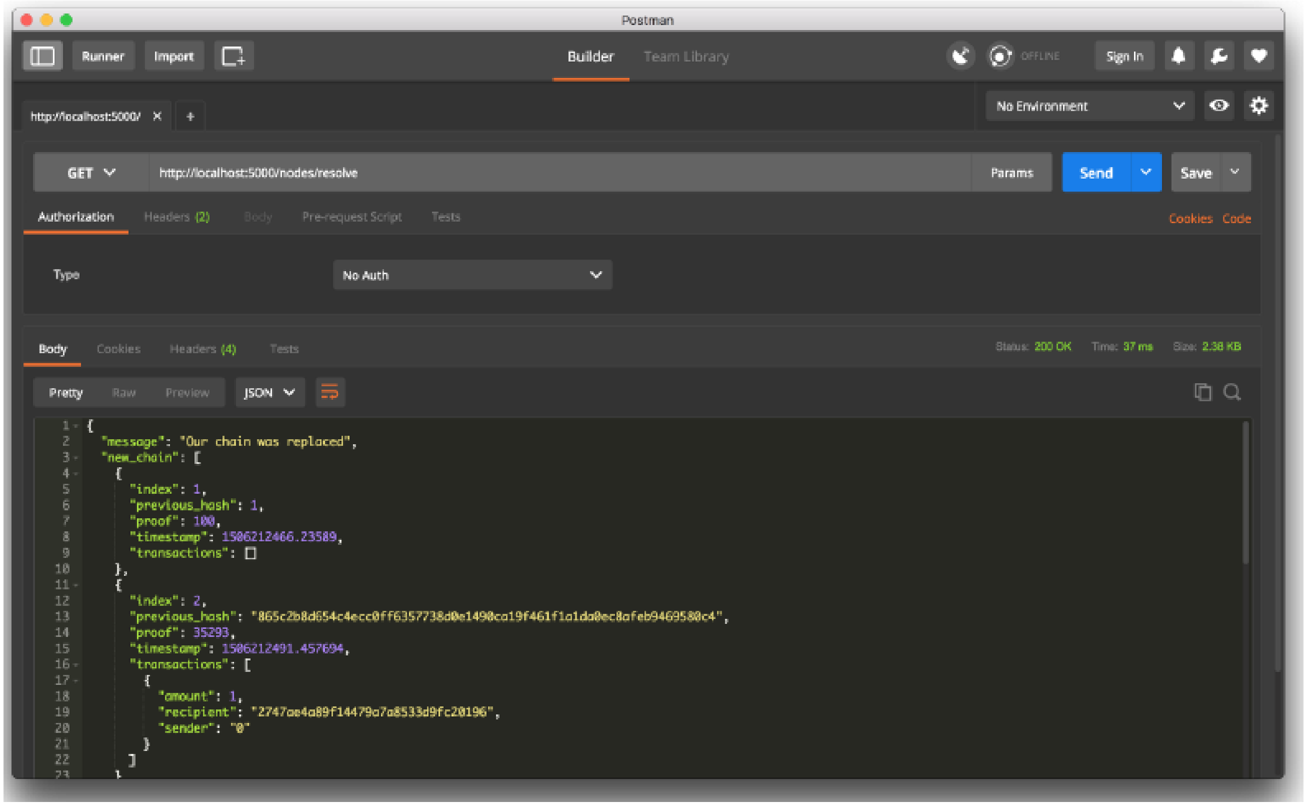

POST http://localhost:5000/nodes/register

```
{
    "nodes": ["http://127.0.0.1:5001"]
}
```

Status: 201 Created   Time: 29 ms   Size: 242 B

```
{
  "message": "New nodes have been added",
  "total_nodes": [
    "127.0.0.1:5001"
  ]
}
```

(Registering a new Node)
I then mined some new Blocks on node 2, to ensure the chain was longer. Afterward, I called GET /nodes/resolve on node 1, where the chain was replaced by the Consensus Algorithm:


GET http://localhost:5000/nodes/resolve

Type: No Auth

Status: 200 OK   Time: 37 ms   Size: 2.38 KB

```
{
  "message": "Our chain was replaced",
  "new_chain": [
    {
      "index": 1,
      "previous_hash": 1,
      "proof": 100,
      "timestamp": 1506212466.23589,
      "transactions": []
    },
    {
      "index": 2,
      "previous_hash": "865c2b8d654c4ecc0ff6357738d0e1490ca19f461f1a1da0ec8afeb9469580c4",
      "proof": 35293,
      "timestamp": 1506212491.457694,
      "transactions": [
        {
          "amount": 1,
          "recipient": "2747ae4a89f14479a7a8533d9fc20196",
          "sender": "0"
        }
      ]
    }
```

(Consensus Algorithm at Work)
And that's a wrap... Go get some friends together to help test out your Blockchain.
I hope that this has inspired you to create something new. I'm ecstatic about Cryptocurrencies because

I believe that Blockchains will rapidly change the way we think about economies, governments and record-keeping.

Tutorial from: https://hackernoon.com/learn-blockchains-by-building-one-117428612f46

The End of Practice