F20CN – Computer Network Security: Coursework 2

Group Number: 2

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Task 1: Alternative Method of Public-Key Encryption

Description:

This program took the approach of delegating key tasks to functions such as the generation of each part of the private key, the public key, encryption, decryption and non-functional tasks such as converting between binary and string or read/writing to a file.

The input is read in by a path presented by the user, the program then generates random keys, then encrypts the input with the easy key to produce a cipertext which is then decrypted to present the plaintext. Each key attribute, ciphertext & plaintext is saved.

Pseudocode:

```
def convertToBinary(m):
        for i in m: binary.append(bin(i))
return binary
def convertToString(b)
        for i in b: string = string + char(i)
        return string
def getW(q):
do: w=randomInt while: gcd(w, q) != 1
return w
def generateEasyKey(m):
        for x in m: E.append(sum(e) + randomInt(>=1))
        return e
def generateHardKey(e, q, w)
return w.e(i) mod q of every i in e
def encrypt(m, h)
return sum(h(i)m(i) of every i in h
def decrypt(c, e, q, w):
cPrime = cw^-1 mod q
From e(n) to e(1) there is i:
if cPrime >= i: m(i) = 1 and cPrime = cPrime-1
Else: m(i) = 0
Return m
message = input("Enter file path")
m = convertToBinary(readFile(message)),
e = generateEasyKey(m.size()),
q = nextPrime(2en), w = getW(q),
h = generateHardKey(e, q, w)
```

```
ciphertext = encrypt(m, h),
recoveredtext = decrypt(ciphertext, e, q ,w)
writeFile(e, q, w, h, ciphertext, recoveredtext)
```

Task 1: Testing

To test whether the encryption and decryption algorithms function as intended, the original plaintext and the decrypted ciphertext can be compared. If the original plaintext and the decrypted ciphertext are a match, this means the encryption and decryption implementations are successful:

Input plaintext:

To Timothy Hayes:
A wonderful serenity has taken possession of my entire soul, like these sweet mornings of spring which I enjoy with my whole heart. I am alone, and feel the charm of existence in this spot, which was created for the bliss of souls like mine. I am so happy, my dear friend, so absorbed in the exquisite sense of mere tranquil existence, that I neglect my talents. I should be incapable of drawing a single stroke at the present moment; and yet I feel that I never was a greater artist than now.

Output deciphered ciphertext:

To Timothy Hayes:
A wonderful serenity has taken possession of my entire soul, like these sweet mornings of spring which I enjoy with my whole heart. I am alone, and feel the charm of existence in this spot, which was created for the bliss of souls like mine. I am so happy, my dear friend, so absorbed in the exquisite sense of mere tranquil existence, that I neglect my talents. I should be incapable of drawing a single stroke at the present moment; and yet I feel that I never was a greater artist than now.

These two strings are identical, and so both the encryption and decryption algorthims work as intended.

Additionally, the first four elements of the easy key e have been generated as follows: [1508, 3379, 6323, 11984…].

To test if this satisfies $e_i > \sum_{j=1}^{i-1} e_j$ for $1 \leq i \leq n$., we check e(4) > Σ(e(1) + e(2) + e(3)). So, we compute: (1508 + 3379 + 6323) = 11,210. As e(4) (11,984) is greater than 11,210 this proves the generation of e satisfies this condition.

The value for q generated by the test is a valid prime number as can be found in the appendix. And when performing gcd(w, q), we find that this results in 1, satisfying this condition specified in the specification.

As for h, this has been stored as a type "mpz" as per the import of gmpy2 found in the appendix. As a result, any of these values are too large to be presented here, but it may be worth noting that len(e) = len(h).

Gmpy2's next_prime method was used to significantly improve performance for finding q. This is due to the previous methodology's computationally expensiveness due to needing to check every number's primality following 2e(n) until a prime was found.

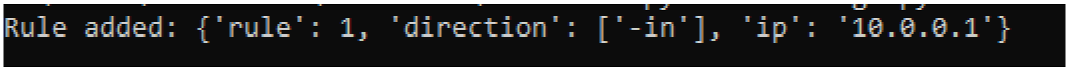
Task 2: Firewall Rules Application

Description & Pseudocode:

```
Function parse_arguments(command):
If no command or unrecognized command: Raise "Invalid Command"
For each expected argument in the command syntax:
if argument exists in the input:
Validate argument based on type:
if Valid, add to parameters
if Invalid, raise specific error
        Else if argument is mandatory: Raise "Missing Required Argument"
    If unused arguments remain: Raise "Unexpected argument"
    Assign default values for optional arguments
    Return parsed_parameters
    Function add_rule(new_rule):
    Format new_rule to ensure direction  always a list and to maintain structure
    Load rules
    If a rule with same IP exists:
    merge directions
    sort directions for consistent order
    Else:
    add new rule
    adjust priorities of existing rules
    sort ruleset by priority
    Save ruleset
    Function remove_rule(params):
    Load rules
    Find rule with specified priority
    If no matching rule found: print "no rule found"
            Return
        If a direction is provided:
            Remove the direction
            If no direction remain, remove the whole rule
        Else:
        Remove the whole rule
        Save the ruleset
    Function list_rules(params)
    Load rules
        For each rule in rules:
        If rule matches all specified parameters:
        add to filtered list
        Print filtered rules
        If no matches, print "No matching rules found"
```

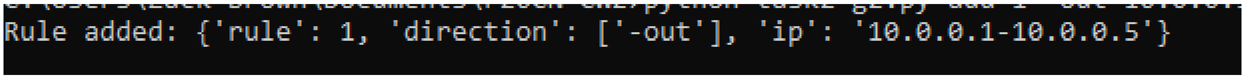
Task 2: Testing

add 1 -in 10.0.0.1



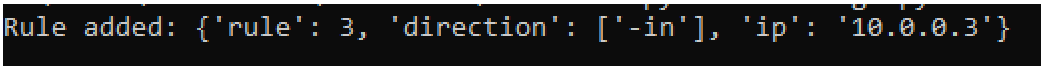
```
Rule added: {'rule': 1, 'direction': ['-in'], 'ip': '10.0.0.1'}
```

add 2 –out 10.0.0.1-10.0.0.5



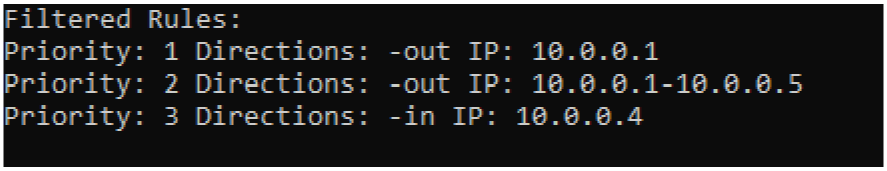
```
Rule added: {'rule': 1, 'direction': ['-out'], 'ip': '10.0.0.1-10.0.0.5'}
```

add 3 –in 10.0.0.4



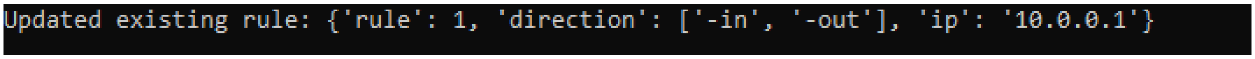
```
Rule added: {'rule': 3, 'direction': ['-in'], 'ip': '10.0.0.3'}
```

list



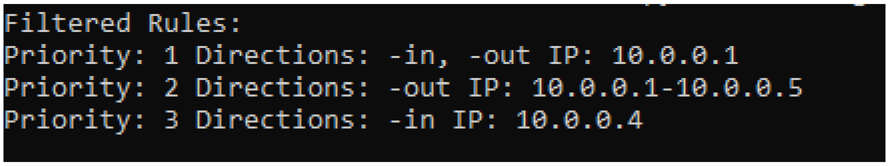
```
Filtered Rules:
Priority: 1 Directions: -out IP: 10.0.0.1
Priority: 2 Directions: -out IP: 10.0.0.1-10.0.0.5
Priority: 3 Directions: -in IP: 10.0.0.4
```

add 1 –out 10.0.0.1



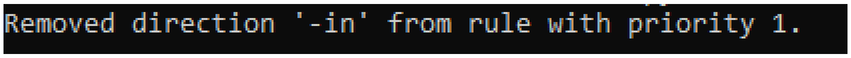
```
Updated existing rule: {'rule': 1, 'direction': ['-in', '-out'], 'ip': '10.0.0.1'}
```

list



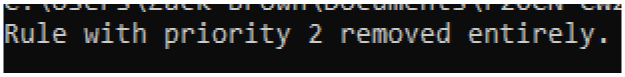
```
Filtered Rules:
Priority: 1 Directions: -in, -out IP: 10.0.0.1
Priority: 2 Directions: -out IP: 10.0.0.1-10.0.0.5
Priority: 3 Directions: -in IP: 10.0.0.4
```

remove 1 –in



```
Removed direction '-in' from rule with priority 1.
```

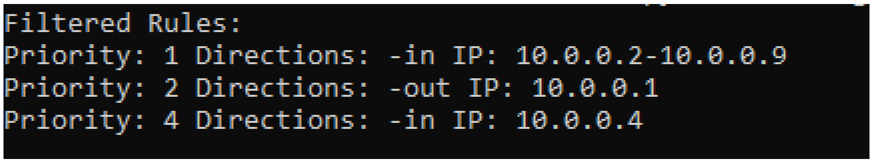
remove 2



```
Rule with priority 2 removed entirely.
```

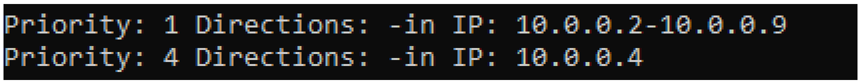
add –in 10.0.0.2-10.0.0.8

list



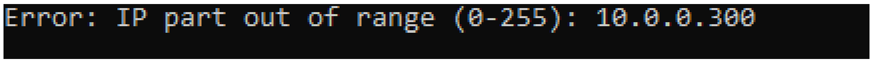
```
Filtered Rules:
Priority: 1 Directions: -in IP: 10.0.0.2-10.0.0.9
Priority: 2 Directions: -out IP: 10.0.0.1
Priority: 4 Directions: -in IP: 10.0.0.4
```

list –in



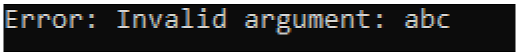
```
Priority: 1 Directions: -in IP: 10.0.0.2-10.0.0.9
Priority: 4 Directions: -in IP: 10.0.0.4
```

add 10.0.0.300



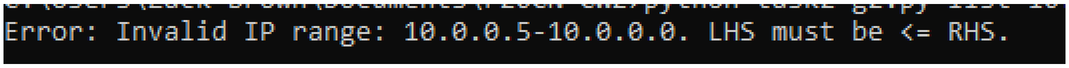
```
Error: IP part out of range (0-255): 10.0.0.300
```

add abc –in 10.0.0.1



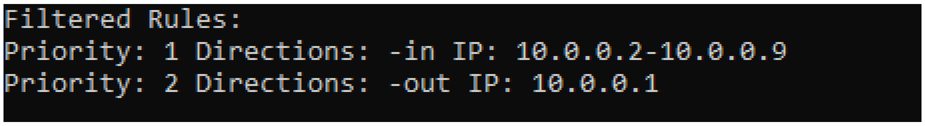
```
Error: Invalid argument: abc
```

list 10.0.0.5-10.0.0.0



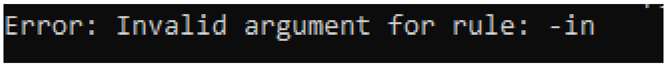
```
Error: Invalid IP range: 10.0.0.5-10.0.0.0. LHS must be <= RHS.
```

list 10.0.0.1-10.0.0.2



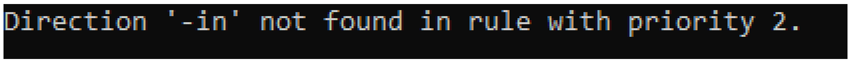
```
Filtered Rules:
Priority: 1 Directions: -in IP: 10.0.0.2-10.0.0.9
Priority: 2 Directions: -out IP: 10.0.0.1
```

remove –in



```
Error: Invalid argument for rule: -in
```

remove –in 2



```
Direction '-in' not found in rule with priority 2.
```

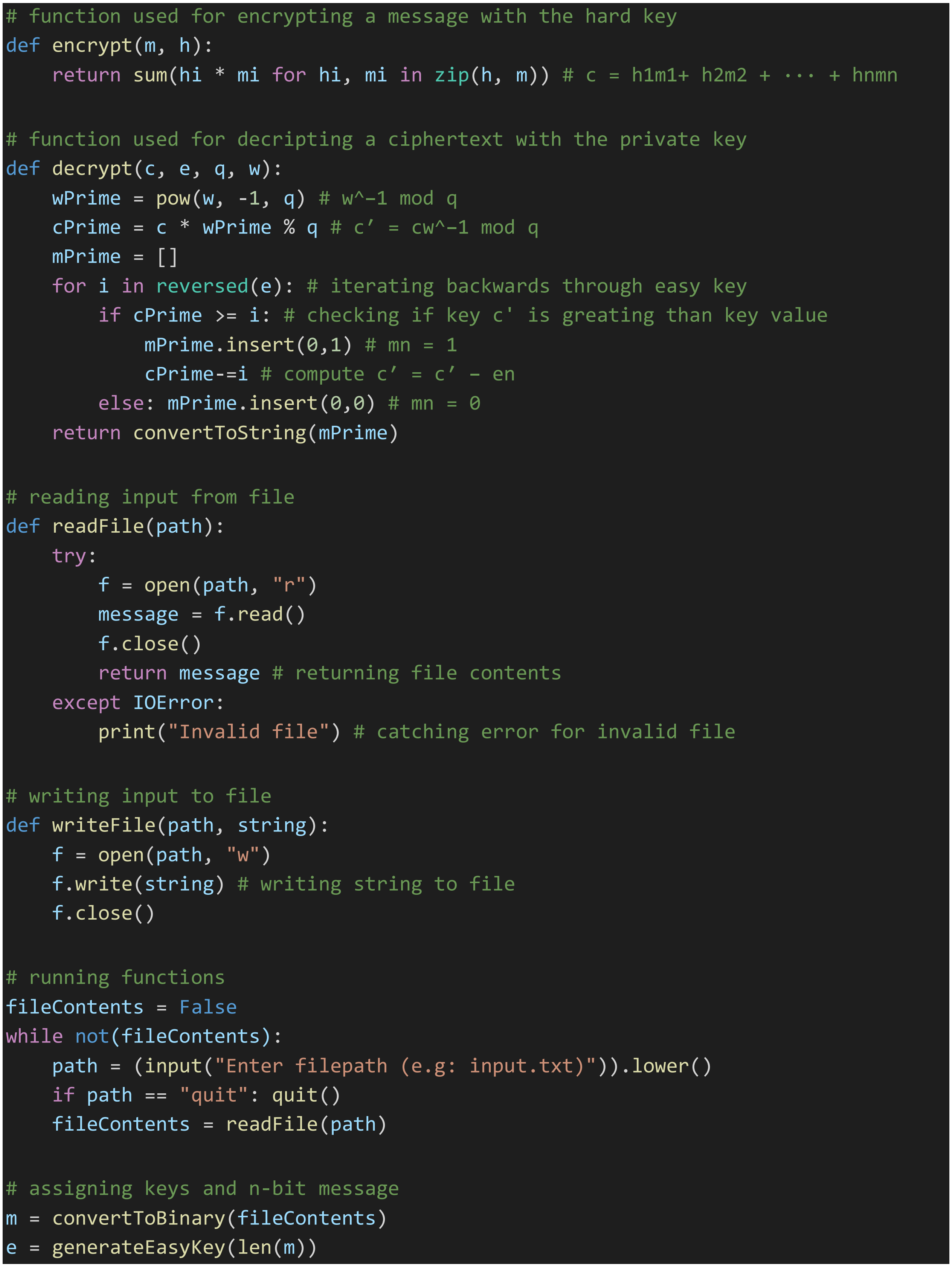
Summary

1. add:
    a. Successfully added rules with valid parameters
    b. Adjusts rule priorities as expected when a rule is added with the same priority as an existing rule
    c. Validates input and raises correct errors when an argument is not valid (ip and rule in the tests)
2. list:
    a. Displays all rules when no parameters are given
    b. Filters rules to display only rules with inputted parameters when any are given
    c. When an ip-range is given, lists rules that fall into or overlap with that range
    d. Validates input and raises correct errors when an argument is invalid (malformed ip range in the tests)
3. remove:
    a. Removes full rule when just rule is provided
    b. Successfully removes just direction from a rule when it is provided.
    c. When a direction is given and is the only direction for the rule, removes whole rule
    d. When a direction is given that is not in the rule, throws an error
    e. Validates input and raises correct errors (malformed rule parameter in the tests)

Appendix:

Task 1: Python Code

```
import math
import random
import gmpy2
# Case Van Horsen (2024). Welcome to gmpy2’s documentation! — gmpy2 2.2.1
documentation. [online] Available at: https://gmpy2.readthedocs.io/en/latest/.

# function for converting plaintext to n-bit message
def convertToBinary(m):
    binary = []  # Initialize list to hold all binary digits
    for char in m: binary.extend(int(digit) for digit in
bin(ord(char))[2:].zfill(8))
    return binary

# function for converting listing consisting of binary values into plaintext
def convertToString(b):
    return''.join(chr(int(("".join(str(x) for x in b))[i*8:i*8+8],2)) for i in
range(len(b)//8)) # every 8 binary values are converted into its string
counterpart to form the message

# function used for getting w in gcd(w, q) = 1
def getW(q):
    w = random.randint(0, 2*q) # generates random int between 0 & 2q
    if (math.gcd(w, q)) == 1: return w # base case: returns w checks if the gcd
is 1
    else: return getW(q) # recursive case: if gcd is not 1 then try a new w

# function for generating easy key (e)
def generateEasyKey(m):
    e = [] # initialising e as empty list
    for i in range(m): e.append(sum(e) + random.randint(1, int(m/2))) # creating
a key with same length as n-bit message and adding numbers which satisfy the
conditio
    return e

# function for generating hard key
def generateHardKey(e, q, w):
    return [(w * i) % q for i in e] # creating a key with same length as easy
key, following hi = w.ei mod q
```



```python
# function used for encrypting a message with the hard key
def encrypt(m, h):
    return sum(hi * mi for hi, mi in zip(h, m)) # c = h1m1+ h2m2 + ··· + hnmn

# function used for decripting a ciphertext with the private key
def decrypt(c, e, q, w):
    wPrime = pow(w, -1, q) # w^−1 mod q
    cPrime = c * wPrime % q # c’ = cw^−1 mod q
    mPrime = []
    for i in reversed(e): # iterating backwards through easy key
        if cPrime >= i: # checking if key c' is greating than key value
            mPrime.insert(0,1) # mn = 1
            cPrime-=i # compute c’ = c’ − en
        else: mPrime.insert(0,0) # mn = 0
    return convertToString(mPrime)

# reading input from file
def readFile(path):
    try:
        f = open(path, "r")
        message = f.read()
        f.close()
        return message # returning file contents
    except IOError:
        print("Invalid file") # catching error for invalid file

# writing input to file
def writeFile(path, string):
    f = open(path, "w")
    f.write(string) # writing string to file
    f.close()

# running functions
fileContents = False
while not(fileContents):
    path = (input("Enter filepath (e.g: input.txt)")).lower()
    if path == "quit": quit()
    fileContents = readFile(path)

# assigning keys and n-bit message
m = convertToBinary(fileContents)
e = generateEasyKey(len(m))
```

```
q = gmpy2.next_prime((2 * e[-1])+1) # used import for getting next prime: https://gmpy2.readthedocs.io/en/latest/ - Case Van Horsen (2024)
w = getW(q)
h = generateHardKey(e,q,w)
# encrypting and decrypting text
ciphertext = encrypt(m, h)
deciphertext = decrypt(ciphertext, e, q, w)

# writing keys, ciphertext, and decrypted text to file
writeFile("e.txt", str(e))
writeFile("q.txt", str(q))
writeFile("w.txt", str(w))
writeFile("h.txt", str(h))
writeFile("ciphertext.txt", str(ciphertext))
writeFile("deciphertext.txt", str(deciphertext))
```

Task 1: Screenshots

Plaintext:

To Timothy Hayes:

A wonderful serenity has taken possession of my entire soul, like these sweet mornings of spring which I enjoy with my whole heart. I am alone, and feel the charm of existence in this spot, which was created for the bliss of souls like mine. I am so happy, my dear friend, so absorbed in the exquisite sense of mere tranquil existence, that I neglect my talents. I should be incapable of drawing a single stroke at the present moment; and yet I feel that I never was a greater artist than now.

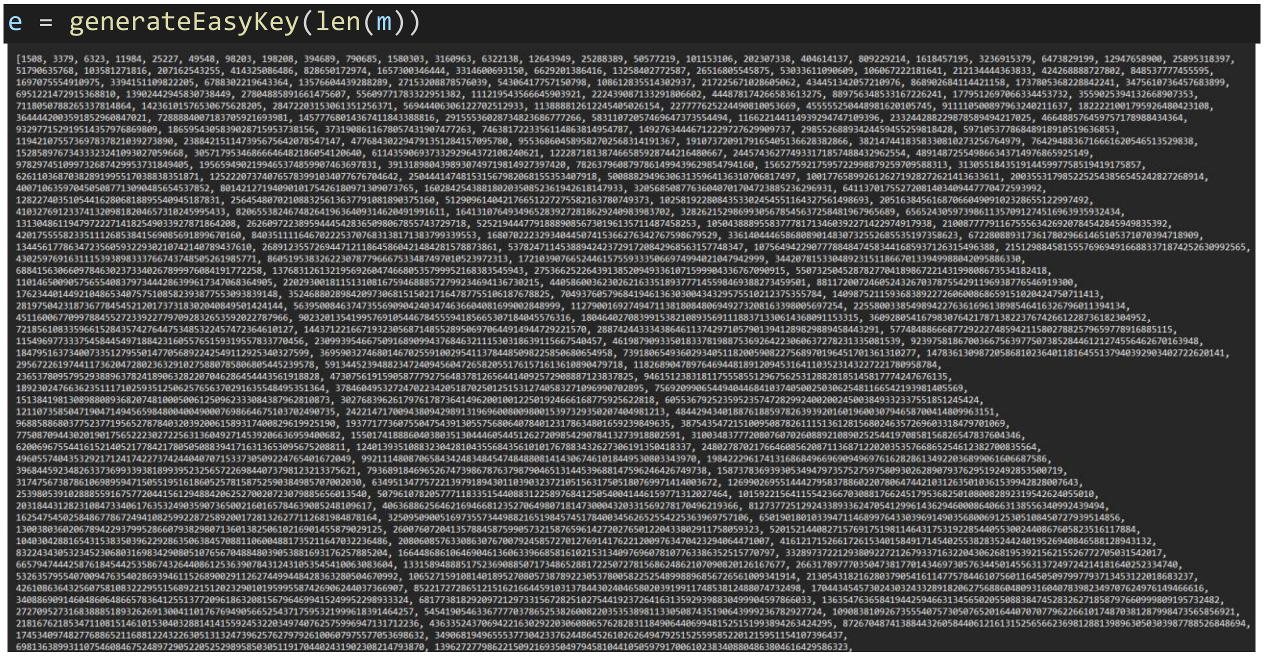
Ciphertext:

```
5748518501048419392338339510103850997038143166481505337197902774173527732
3300868826362168264169297180496736047460572816123077635235138270294573560
1192084601190160941691867357594197337413526511898671178305208152049629922
6066083728937205427174029935777969430532106353867688589045078479786377382
7965287340776473601256253976911152586609707197360114947442704864999975845
3107279707320067854197105504706875987778738377694658108752020133632066299
1057857619629512194190015270397596739477466548520594988779917494776958405
6007654219115222126038538323607097828131974769065239571023337548229510908
6143373442188793708592868118453687716582605719310770153320403004989181360
4109126678657086546163534564557782516492118028425254975448286382030950022
```

1160688595620139162480179649545048610320603544717998802960405924135225294
0038180575129833366234646116971170992409896590104043434723086167059731179
6574560626922391142684547601938587866712554739082091842530540971228207453
9940068334447946793324491457405200029608702311419091958357404749371475296
0237670917607007596087580237371544130513464577424763945531325070410219633
8806003934020222054111959229135213606922503985155455331770406036029201410
0642221992950825989435752370595976917905524207974354191168456091058O9

Key generation:

Private Key (e):



```
e = generateEasyKey(len(m))
```

```
[1508, 3379, 6323, 11984, 25227, 49548, 98203, 198208, 394689, 790685, 1580303, 3160963, 6322138, 12643949, 25288389, 50577219, 101153106, 202307338, 404614137, 809229214, 1618457195, 3236915379, 6473829199, 12947658900, 25895318397,
51790635768, 103581271816, 207162543255, 414325086486, 828650172974, 1657300346444, 3314600693150, 6629201386416, 13258402772587, 26516805545875, 53033611090609, 106067222181641, 212134444363833, 424268888727802, 848537777455595,
1697075554910975, 3394151109822205, 6788302219643364, 13576604439288289, 27153208878576039, 54306417757150798, 108612835514302937, 217225671028605062, 434451342057210976, 868902684114421158, 1737805368228842241, 3475610736457683899,
6951221472915368810, 13902442945830738449, 27804885891661475607, 55609771783322951382, 111219543566645903921, 222439087133291806602, 444878174266583613275, 889756348533167226241, 1779512697066334453732, 3559025394132668907353,
7118050788265337814864, 14236101576530675628205, 28472203153061351256371, 56944406306122702512933, 113888812612245405026154, 227777625224490810053669, 455555250448981620105745, 911110500897963240211637, 1822221001795926480423108,
3644442003591852960847021, 7288884007183705921693981, 14577768014367411843388816, 29155536028734823686777266, 58311072057469647373554494, 116622144114939294747109396, 233244288229878589494217025, 466488576459757178988434364,
932977152919514357976869809, 1865954305839028715953738156, 3731908611678057431907477263, 7463817223356114863814954787, 14927634446712229727629909737, 29855268893424459455259818428, 59710537786848918910519636853,
119421075573697837821039273890, 238842151147395675642078547147, 477684302294791351284157095780, 955368604589582702568314191367, 1910737209179165405136628382866, 3821474418358330810273256764979, 7642948836716661620546513529838,
15285897673433323241093027059668, 30571795346866646482186054120640, 61143590693733292964372108240621, 122287181387466585928744216480667, 244574362774933171857488432962554, 489148725549866343714976865925149,
978297451099732687429953731849405, 1956594902199465374859907463697831, 3913189804398930749719814927397420, 7826379608797861499439629854794160, 15652759217595722998879259709588313, 31305518435191445997758519419175857,
62611036870382891995517038838351871, 125222073740765783991034077676704642, 250444147481531567982068155353407918, 500888294963063135964136310706817497, 1001776589926126271928272621413633611, 2003553179852252543856545242827268914,
4007106359704505087713090485654537852, 8014212719409010175426180971309073765, 16028425438818020350852361942618147933, 32056850877636040701704723885236296931, 64113701755272081403409447770472593992,
128227403510544162806818895540945187831, 256454807021088325613637791081890375160, 512909614042176651227275582163780749373, 1025819228084353302454551164327561498693, 2051638456168706604909102328655122997492,
4103276912337413209818204657310245995433, 8206553824674826419636409314620491991611, 16413107649349652839272818629240983983702, 32826215298699305678545637258481967965689, 65652430597398611357091274516963935932434,
131304861194797222714182549033927871864208, 262609722389594445428365098067855743729718, 525219444779188890856730196135711487458253, 1050438889558377781713460392271422974917938, 2100877779116755563426920784542845949835392,
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```

Private Key (q):

```
q = gmpy2.next_prime((2 * e[-1])+1) # used import for getting next prime: https://gmpy2.readthedocs.io/en/latest/ - Case Van Horsen (2024)
```

```
62968540265269800594565771216486184729621067957182104247654059122026867 29
```

```
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```

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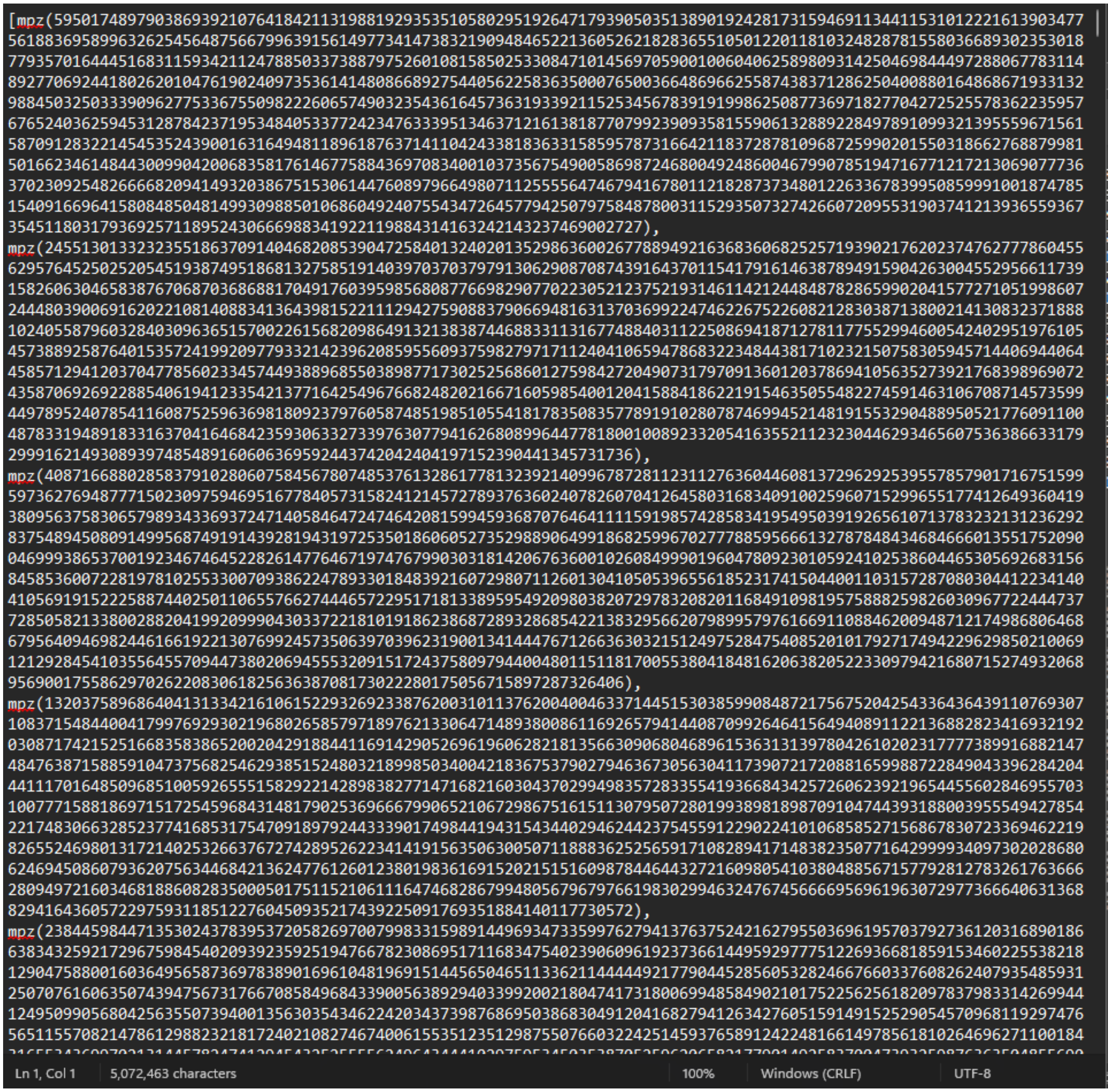
Public Key (h):

```
h = generateHardKey(e,q,w)
```



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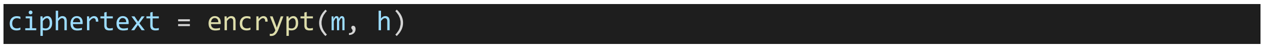
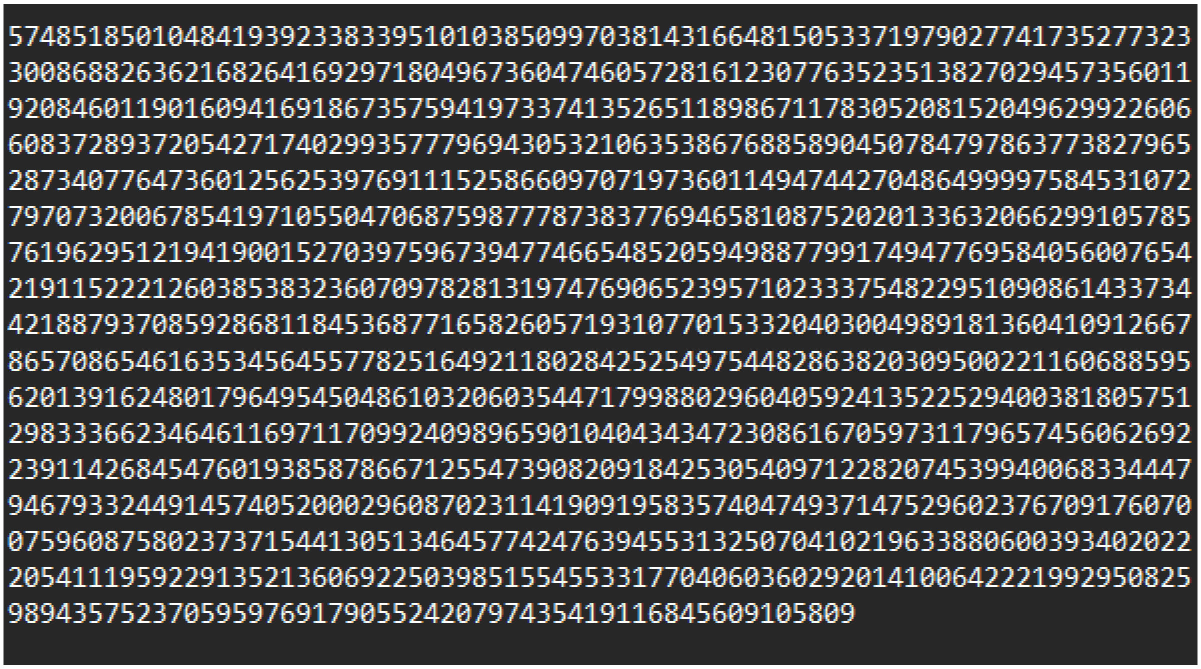
Encryption of Plaintext:



```
ciphertext = encrypt(m, h)
```



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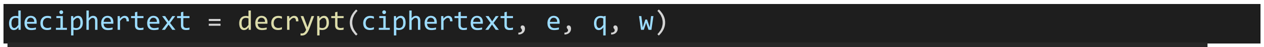
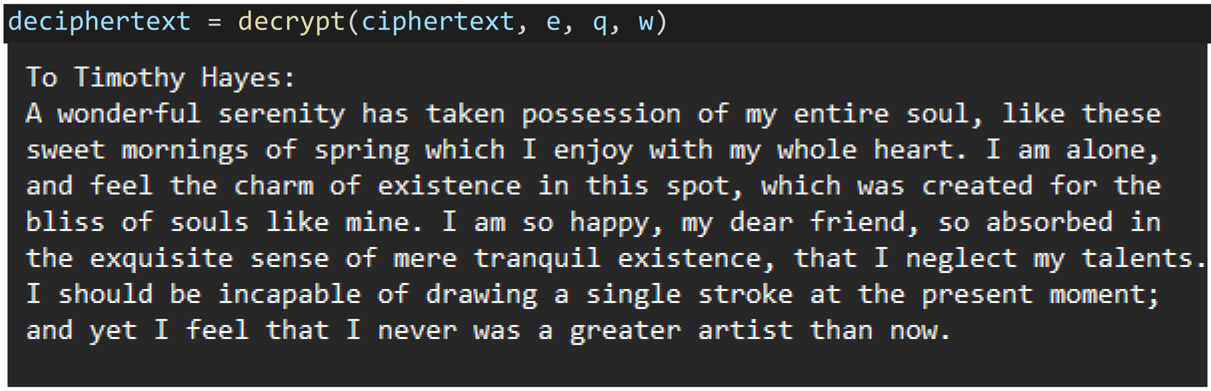
```

Decryption of Ciphertext:



```
deciphertext = decrypt(ciphertext, e, q, w)
```

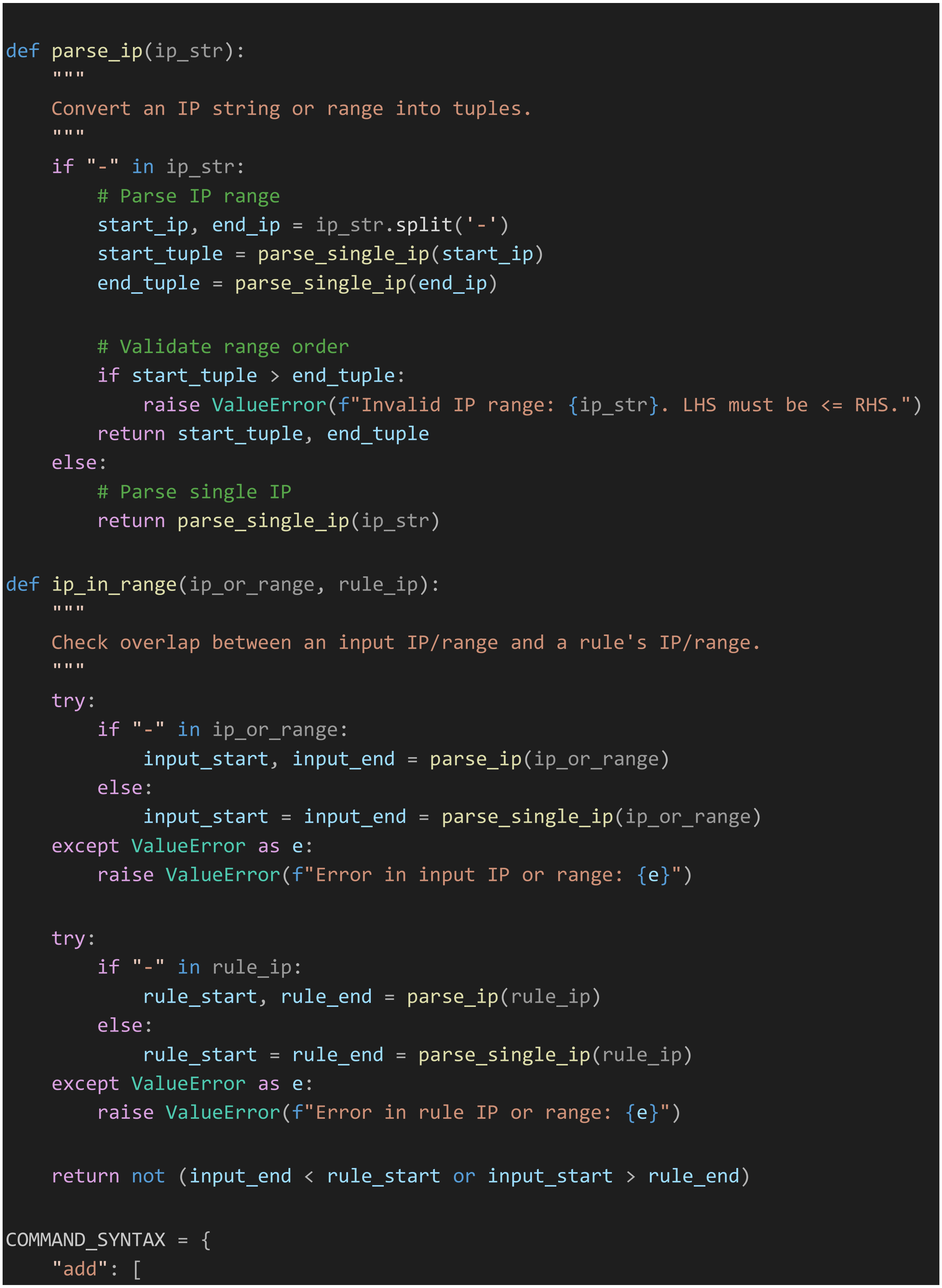


```
To Timothy Hayes:
A wonderful serenity has taken possession of my entire soul, like these
sweet mornings of spring which I enjoy with my whole heart. I am alone,
and feel the charm of existence in this spot, which was created for the
bliss of souls like mine. I am so happy, my dear friend, so absorbed in
the exquisite sense of mere tranquil existence, that I neglect my talents.
I should be incapable of drawing a single stroke at the present moment;
and yet I feel that I never was a greater artist than now.
```

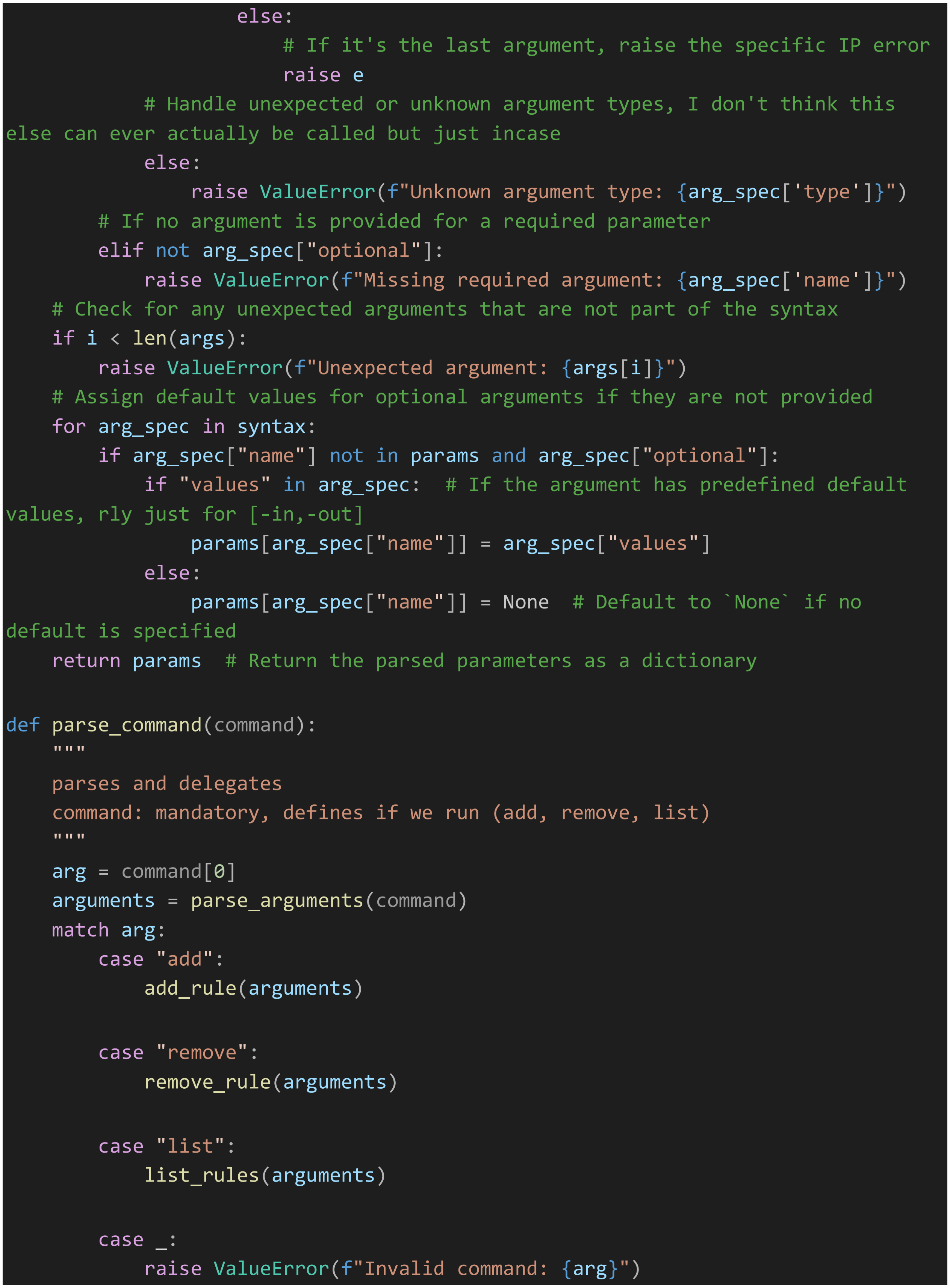
TASK 2 PYTHON CODE ON THE FOLLOWING PAGE!!!

Task 2: Python Code:

```python
import json # need some method to store rules between runs of the program, using a json file for this
import os # just for file operations
import sys # for command line input

RULESET_FILE = "ruleset.json"

def load_ruleset():
    """Load the ruleset from the file. Create an empty file if it doesn't exist."""
    if not os.path.exists(RULESET_FILE):
        # file not here, create it
        save_ruleset([])  # Save an empty list if file does not exist
    with open(RULESET_FILE, "r") as f:
        return json.load(f)

def save_ruleset(ruleset):
    """Save the ruleset to the file."""
    with open(RULESET_FILE, "w") as f:
        json.dump(ruleset, f, indent=4)

def validate_ip_part(part, ip_str):
    """Validate a single part of an IP address."""
    if not part.isdigit():
        raise ValueError(f"Invalid numeric part in IP address: {ip_str}")

    num = int(part)
    if num < 0 or num > 255:
        raise ValueError(f"IP part out of range (0-255): {ip_str}")

    return num

def parse_single_ip(ip_str):
    """Parse and validate a single IP address into a tuple."""
    parts = ip_str.split('.')
    if len(parts) != 4:
        raise ValueError(f"Invalid IP address format: {ip_str}")
    return tuple(validate_ip_part(part, ip_str) for part in parts)
```

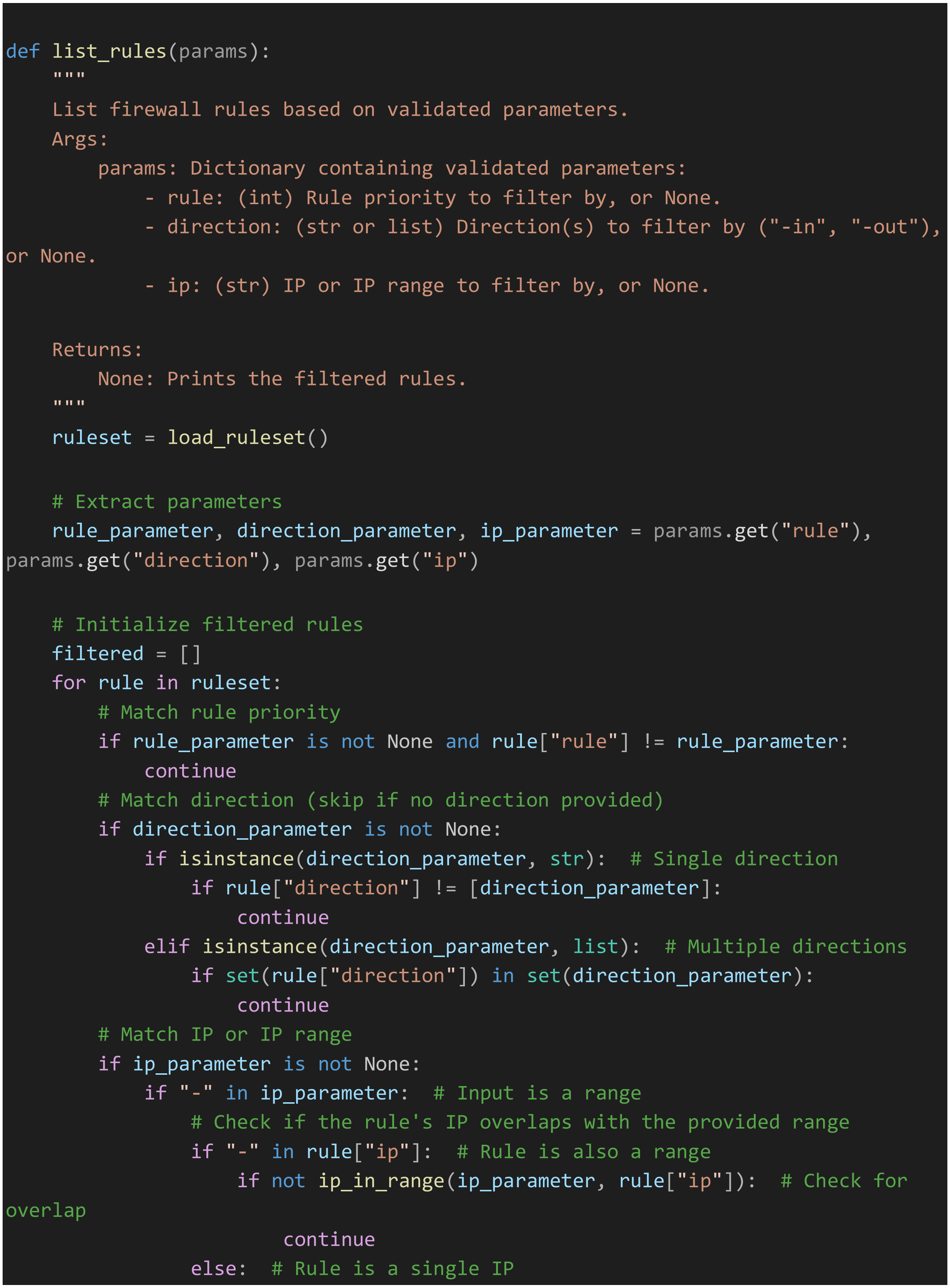


```
def parse_ip(ip_str):
    """
    Convert an IP string or range into tuples.
    """
    if "-" in ip_str:
        # Parse IP range
        start_ip, end_ip = ip_str.split('-')
        start_tuple = parse_single_ip(start_ip)
        end_tuple = parse_single_ip(end_ip)

        # Validate range order
        if start_tuple > end_tuple:
            raise ValueError(f"Invalid IP range: {ip_str}. LHS must be <= RHS.")
        return start_tuple, end_tuple
    else:
        # Parse single IP
        return parse_single_ip(ip_str)

def ip_in_range(ip_or_range, rule_ip):
    """
    Check overlap between an input IP/range and a rule's IP/range.
    """
    try:
        if "-" in ip_or_range:
            input_start, input_end = parse_ip(ip_or_range)
        else:
            input_start = input_end = parse_single_ip(ip_or_range)
    except ValueError as e:
        raise ValueError(f"Error in input IP or range: {e}")

    try:
        if "-" in rule_ip:
            rule_start, rule_end = parse_ip(rule_ip)
        else:
            rule_start = rule_end = parse_single_ip(rule_ip)
    except ValueError as e:
        raise ValueError(f"Error in rule IP or range: {e}")

    return not (input_end < rule_start or input_start > rule_end)

COMMAND_SYNTAX = {
    "add": [
        {"name": "rule", "type": "int", "values": 1,"optional": True},
        {"name": "direction", "type": "choice", "values": ["-in", "-out"], "optional": True},
        {"name": "ip", "type": "ip", "optional": False},
    ],
    "remove": [
        {"name": "rule", "type": "int", "optional": False},
        {"name": "direction", "type": "choice", "values": ["-in", "-out"], "optional": True},
    ],
    "list": [
        {"name": "rule", "type": "int", "optional": True},
        {"name": "direction", "type": "choice", "values": ["-in", "-out"], "optional": True},
        {"name": "ip", "type": "ip", "optional": True},
    ],
}

def parse_arguments(command):
    """
    General command parser based on defined syntax.
    Parses CLI arguments into a dictionary of parameters.

    Args:
        command: List of command-line arguments (e.g., ["add", "3", "-in", "10.0.0.1"]).

    Returns:
        dict: Parsed parameters.

    Raises:
        ValueError: If arguments do not match the expected syntax or are missing required arguments.
    """
    if not command:
        # Raise an error if no command is provided
        raise ValueError("No command provided.")

    cmd = command[0]  # Extract the command (e.g., "add", "remove", "list")
    args = command[1:]  # Extract the arguments following the command

    if cmd not in COMMAND_SYNTAX:
        # Raise an error if the command is not recognized
        raise ValueError(f"Invalid command: {cmd}")

    syntax = COMMAND_SYNTAX[cmd]  # Get the expected syntax for the command
    params = {}  # Dictionary to store parsed parameters
    i = 0  # Current argument index in the `args` list
    for arg_spec in syntax:
        # Iterate over the expected arguments as defined in the syntax
        if i < len(args):  # If there are remaining arguments to parse
            arg = args[i]  # Get the current argument
            # Handle `int` type arguments, for rule
            if arg_spec["type"] == "int":
                if arg.isdigit():  # Check if the argument is a valid integer
                    if int(arg) > 0: # rules cannot be less than 1
                        params[arg_spec["name"]] = int(arg)  # Add to the parsed parameters
                        i += 1  # Move to the next argument
                elif not arg_spec["optional"]:  # If the argument is required and invalid
                    raise ValueError(f"Invalid argument for {arg_spec['name']}: {arg}")
            # Handle `choice` type arguments e.g. direction parameter
            elif arg_spec["type"] == "choice":
                if arg in arg_spec["values"]:  # Check if the argument matches a valid choice
                    params[arg_spec["name"]] = arg  # Add to the parsed parameters
                    i += 1  # Move to the next argument
                elif not arg_spec["optional"]:  # If the argument is required and invalid, this never triggers for this arg type - purely here for good practice as it may be made required for another command
                    raise ValueError(f"Invalid {arg_spec['name']}: {arg}")
            # Handle `ip` type arguments (e.g., "10.0.0.1" or "10.0.0.1-10.0.0.5")
            elif arg_spec["type"] == "ip":
                try:
                    parse_ip(arg)  # Validate the IP address or range
                    params[arg_spec["name"]] = arg  # Add to the parsed parameters
                    i += 1  # Move to the next argument
                except ValueError as e:
                    # If there are more arguments, treat this as an invalid argument
                    if i + 1 < len(args):
                        raise ValueError(f"Invalid argument: {arg}")
```



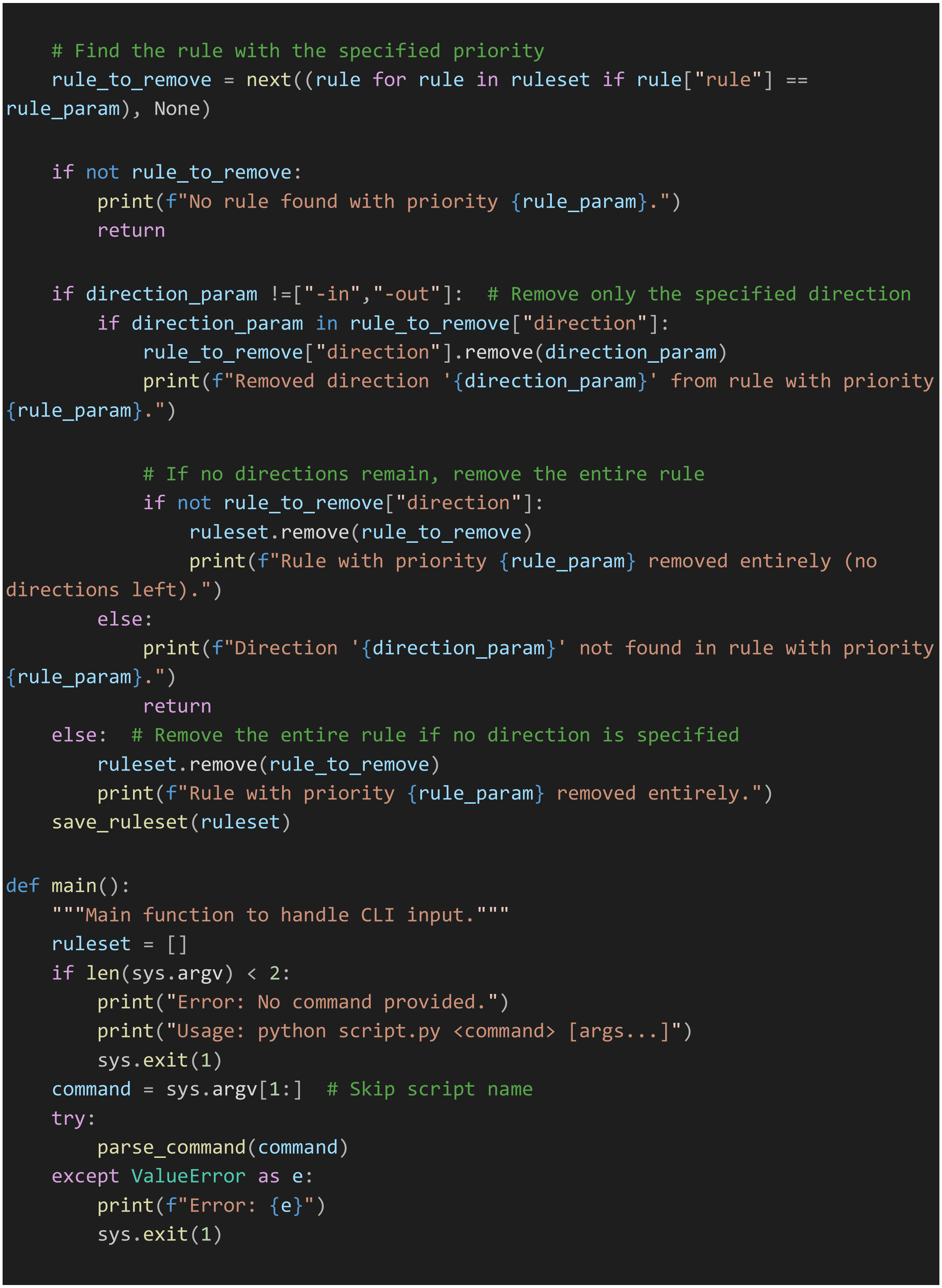
```
                    else:
                        # If it's the last argument, raise the specific IP error
                        raise e
            # Handle unexpected or unknown argument types, I don't think this
else can ever actually be called but just incase
            else:
                raise ValueError(f"Unknown argument type: {arg_spec['type']}")
        # If no argument is provided for a required parameter
        elif not arg_spec["optional"]:
            raise ValueError(f"Missing required argument: {arg_spec['name']}")
    # Check for any unexpected arguments that are not part of the syntax
    if i < len(args):
        raise ValueError(f"Unexpected argument: {args[i]}")
    # Assign default values for optional arguments if they are not provided
    for arg_spec in syntax:
        if arg_spec["name"] not in params and arg_spec["optional"]:
            if "values" in arg_spec:  # If the argument has predefined default
values, rly just for [-in,-out]
                params[arg_spec["name"]] = arg_spec["values"]
            else:
                params[arg_spec["name"]] = None  # Default to `None` if no
default is specified
    return params  # Return the parsed parameters as a dictionary

def parse_command(command):
    """
    parses and delegates
    command: mandatory, defines if we run (add, remove, list)
    """
    arg = command[0]
    arguments = parse_arguments(command)
    match arg:
        case "add":
            add_rule(arguments)

        case "remove":
            remove_rule(arguments)

        case "list":
            list_rules(arguments)

        case _:
            raise ValueError(f"Invalid command: {arg}")
```

```python
def add_rule(new_rule):
    """
    rule(priority): int, if none - rule = 1 by default,
    [-in|-out]: optional, defaults to -in and -out,
    addr: mandatory, raise ValueError if not supplied or incorrect.

    """
    new_rule = { # maintains the order of rules (without this when rule defaults to 1 it gets put at the back of the rule)
        'rule': new_rule['rule'],
        'direction': [new_rule['direction']] if isinstance(new_rule['direction'], str) else new_rule['direction'],
        'ip': new_rule['ip']
    }

    print(new_rule['rule'])
    ruleset = load_ruleset()

    # Check if a rule with the same IP already exists
    existing_rule = next((rule for rule in ruleset if rule["ip"] == new_rule["ip"]), None)

    if existing_rule:
        # Merge directions if IP exists
        for dir_ in new_rule["direction"]:
            if dir_ not in existing_rule["direction"]:
                existing_rule["direction"].append(dir_)
                existing_rule["direction"].sort(key=lambda x: ["-in", "-out"].index(x)) # sorts so in appears first (could hardcode to become -in -out if we update rule, but bad practice)
                print(f"Updated existing rule: {existing_rule}")
                save_ruleset(ruleset)
            return
    ruleset.append(new_rule)
    # Adjust priorities to fit the new rule
    for rule in ruleset:
        if rule["rule"] >= new_rule["rule"] and rule != new_rule:
            rule["rule"] += 1

    ruleset.sort(key=lambda rule: rule["rule"])  # Sort ruleset by priority
    save_ruleset(ruleset)
    print(f"Rule added: {new_rule}")
```



```python
def list_rules(params):
    """
    List firewall rules based on validated parameters.
    Args:
        params: Dictionary containing validated parameters:
            - rule: (int) Rule priority to filter by, or None.
            - direction: (str or list) Direction(s) to filter by ("-in", "-out"), or None.
            - ip: (str) IP or IP range to filter by, or None.

    Returns:
        None: Prints the filtered rules.
    """
    ruleset = load_ruleset()

    # Extract parameters
    rule_parameter, direction_parameter, ip_parameter = params.get("rule"), params.get("direction"), params.get("ip")

    # Initialize filtered rules
    filtered = []
    for rule in ruleset:
        # Match rule priority
        if rule_parameter is not None and rule["rule"] != rule_parameter:
            continue
        # Match direction (skip if no direction provided)
        if direction_parameter is not None:
            if isinstance(direction_parameter, str):  # Single direction
                if rule["direction"] != [direction_parameter]:
                    continue
            elif isinstance(direction_parameter, list):  # Multiple directions
                if set(rule["direction"]) in set(direction_parameter):
                    continue
        # Match IP or IP range
        if ip_parameter is not None:
            if "-" in ip_parameter:  # Input is a range
                # Check if the rule's IP overlaps with the provided range
                if "-" in rule["ip"]:  # Rule is also a range
                    if not ip_in_range(ip_parameter, rule["ip"]):  # Check for overlap
                        continue
                else:  # Rule is a single IP
```

```
                    rule_ip_tuple = parse_ip(rule["ip"])
                    input_start, input_end = parse_ip(ip_parameter)
                    if not (input_start <= rule_ip_tuple <= input_end):  # Single
IP must fall in range
                        continue
            else:  # Input is a single IP
                # Check if the single IP matches the rule
                if "-" in rule["ip"]:  # Rule is a range
                    if not ip_in_range(rule["ip"], ip_parameter):  # Check if
single IP falls in range
                        continue
                else:  # Rule is also a single IP
                    if rule["ip"] != ip_parameter:  # Direct match required
                        continue
        # If rule matches all conditions, add it to filtered list
        filtered.append(rule)

    # Print filtered results
    print("Filtered Rules:")
    if filtered:
        for rule in filtered:
            directions = ", ".join(rule["direction"])
            print(f"Priority: {rule['rule']} Directions: {directions} IP:
{rule['ip']}")
    else:
        print("No matching rules found.")

def remove_rule(params):
    """
    Remove a firewall rule based on validated parameters.

    Args:
        params: Dictionary containing validated parameters:
            - rule: (int) Priority of the rule to remove. Mandatory.
            - direction: (str) Direction to remove ("-in" or "-out"), or None.

    Returns:
        None: Modifies the ruleset in place.
    """
    ruleset = load_ruleset()

    rule_param = params.get("rule")
    direction_param = params.get("direction")
```



```
    # Find the rule with the specified priority
    rule_to_remove = next((rule for rule in ruleset if rule["rule"] ==
rule_param), None)

    if not rule_to_remove:
        print(f"No rule found with priority {rule_param}.")
        return

    if direction_param !=["-in","-out"]:  # Remove only the specified direction
        if direction_param in rule_to_remove["direction"]:
            rule_to_remove["direction"].remove(direction_param)
            print(f"Removed direction '{direction_param}' from rule with priority
{rule_param}.")

            # If no directions remain, remove the entire rule
            if not rule_to_remove["direction"]:
                ruleset.remove(rule_to_remove)
                print(f"Rule with priority {rule_param} removed entirely (no
directions left).")
        else:
            print(f"Direction '{direction_param}' not found in rule with priority
{rule_param}.")
            return
    else:  # Remove the entire rule if no direction is specified
        ruleset.remove(rule_to_remove)
        print(f"Rule with priority {rule_param} removed entirely.")
    save_ruleset(ruleset)

def main():
    """Main function to handle CLI input."""
    ruleset = []
    if len(sys.argv) < 2:
        print("Error: No command provided.")
        print("Usage: python script.py <command> [args...]")
        sys.exit(1)
    command = sys.argv[1:]  # Skip script name
    try:
        parse_command(command)
    except ValueError as e:
        print(f"Error: {e}")
        sys.exit(1)
```

```
if __name__ == "__main__":
    main()
```