山东大学网络空间安全学院

网络空间安全创新创业实践

Project 3 Merkle Tree实现

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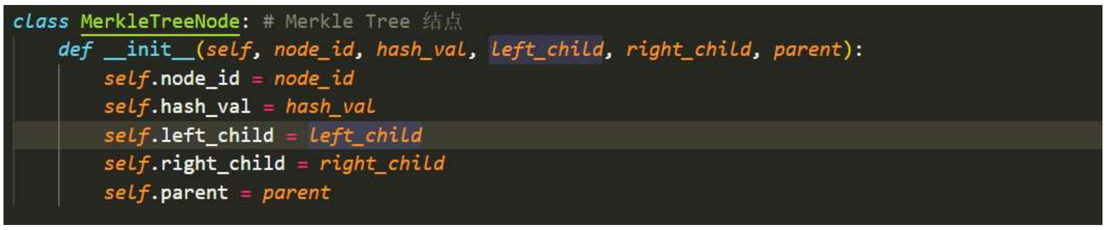
1　原理及其具体实现

1.1　Merkle Tree具体实现

对于Merkle Tree，在本项目中采用Python中的列表数据结构来进行存储。

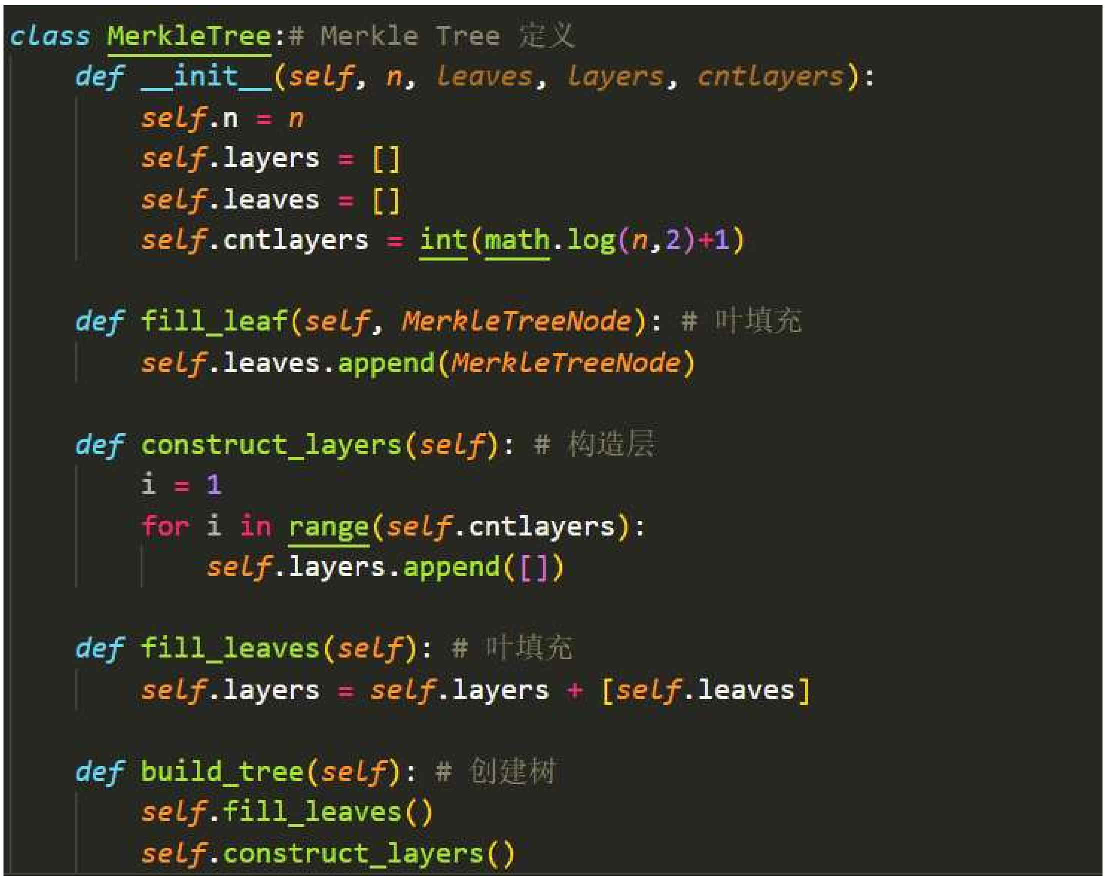
在Merkle Tree的生成过程中，若该层结点个数为偶数，那么两两配对加上前缀（若为叶结点则前缀为0x00、若为非叶结点则前缀为0x01）生成其父结点的杂凑值；如果该层结点个数为奇数，那么令最后一个结点为一个父结点，剩下的结点两两配对加前缀生成父结点的杂凑值。

首先定义Merkle Tree结点类，如下图所示。



```
class MerkleTreeNode: # Merkle Tree 结点
    def __init__(self, node_id, hash_val, left_child, right_child, parent):
        self.node_id = node_id
        self.hash_val = hash_val
        self.left_child = left_child
        self.right_child = right_child
        self.parent = parent
```

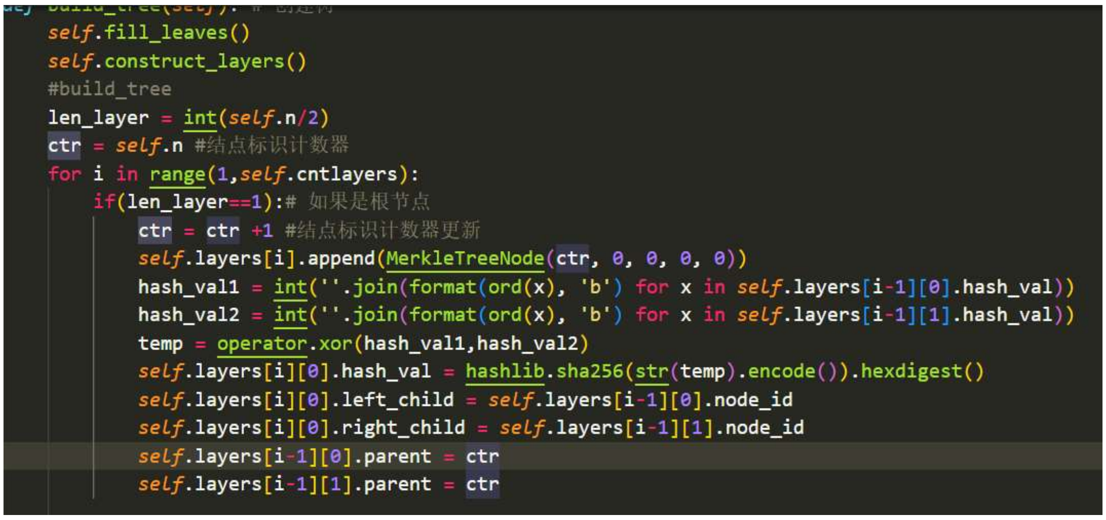
随后定义Merkle Tree类，如下图所示。



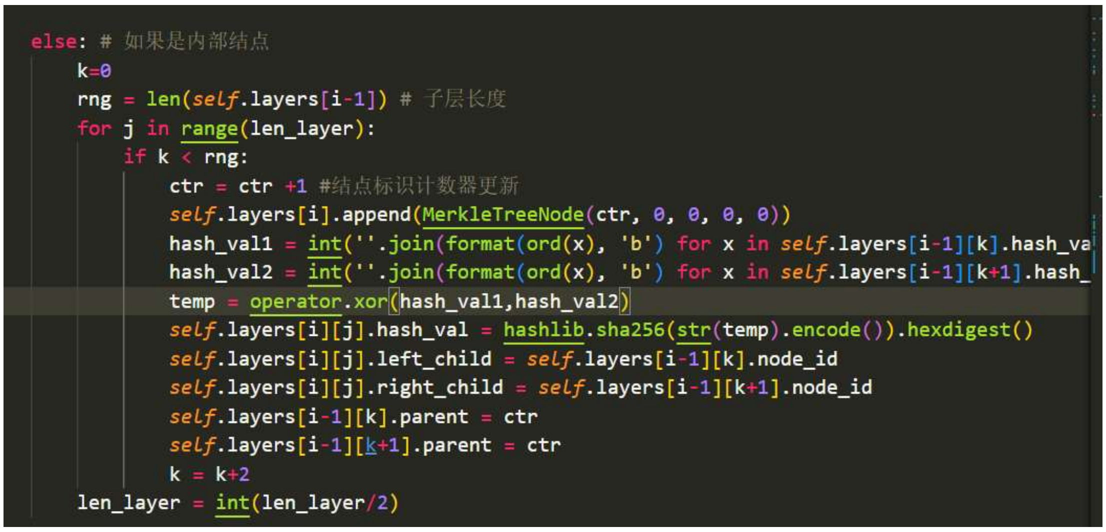
```python
class MerkleTree:# Merkle Tree 定义
    def __init__(self, n, leaves, layers, cntlayers):
        self.n = n
        self.layers = []
        self.leaves = []
        self.cntlayers = int(math.log(n,2)+1)

    def fill_leaf(self, MerkleTreeNode): # 叶填充
        self.leaves.append(MerkleTreeNode)

    def construct_layers(self): # 构造层
        i = 1
        for i in range(self.cntlayers):
            self.layers.append([])

    def fill_leaves(self): # 叶填充
        self.layers = self.layers + [self.leaves]

    def build_tree(self): # 创建树
        self.fill_leaves()
        self.construct_layers()
```

其中方法fill_leaf()用于填充叶结点、construct_layers()用于构造层、fill_leaves()用于填充每一层的所有叶结点。

构建Merkle Tree的过程如下，首先填充叶结点并构造层，计算层数并初始化结点标识计数器，对于各个层进行如下操作：

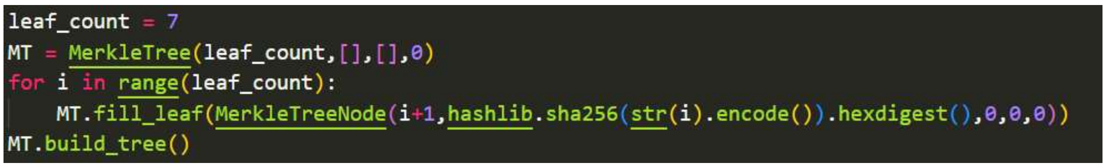


```python
    self.fill_leaves()
    self.construct_layers()
    #build_tree
    len_layer = int(self.n/2)
    ctr = self.n #结点标识计数器
    for i in range(1,self.cntlayers):
        if(len_layer==1):# 如果是根节点
            ctr = ctr +1 #结点标识计数器更新
            self.layers[i].append(MerkleTreeNode(ctr, 0, 0, 0, 0))
            hash_val1 = int(''.join(format(ord(x), 'b') for x in self.layers[i-1][0].hash_val))
            hash_val2 = int(''.join(format(ord(x), 'b') for x in self.layers[i-1][1].hash_val))
            temp = operator.xor(hash_val1,hash_val2)
            self.layers[i][0].hash_val = hashlib.sha256(str(temp).encode()).hexdigest()
            self.layers[i][0].left_child = self.layers[i-1][0].node_id
            self.layers[i][0].right_child = self.layers[i-1][1].node_id
            self.layers[i-1][0].parent = ctr
            self.layers[i-1][1].parent = ctr
```



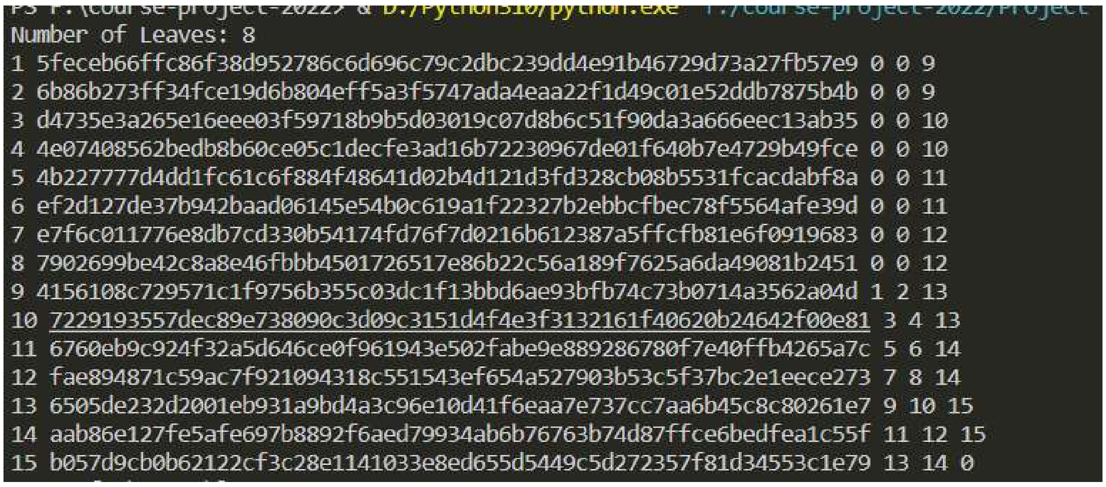
```
else: # 如果是内部结点
    k=0
    rng = len(self.layers[i-1]) # 子层长度
    for j in range(len_layer):
        if k < rng:
            ctr = ctr +1 #结点标识计数器更新
            self.layers[i].append(MerkleTreeNode(ctr, 0, 0, 0, 0))
            hash_val1 = int(''.join(format(ord(x), 'b') for x in self.layers[i-1][k].hash_va
            hash_val2 = int(''.join(format(ord(x), 'b') for x in self.layers[i-1][k+1].hash_
            temp = operator.xor(hash_val1,hash_val2)
            self.layers[i][j].hash_val = hashlib.sha256(str(temp).encode()).hexdigest()
            self.layers[i][j].left_child = self.layers[i-1][k].node_id
            self.layers[i][j].right_child = self.layers[i-1][k+1].node_id
            self.layers[i-1][k].parent = ctr
            self.layers[i-1][k+1].parent = ctr
            k = k+2
    len_layer = int(len_layer/2)
```

定义边长leaf_count标识叶结点个数，随后初始化一个结点个数为leaf_count的Merkle Tree，利用循环依次填充其叶结点为不同的整数值，随后调用build_tree()方法构建Merkle Tree。



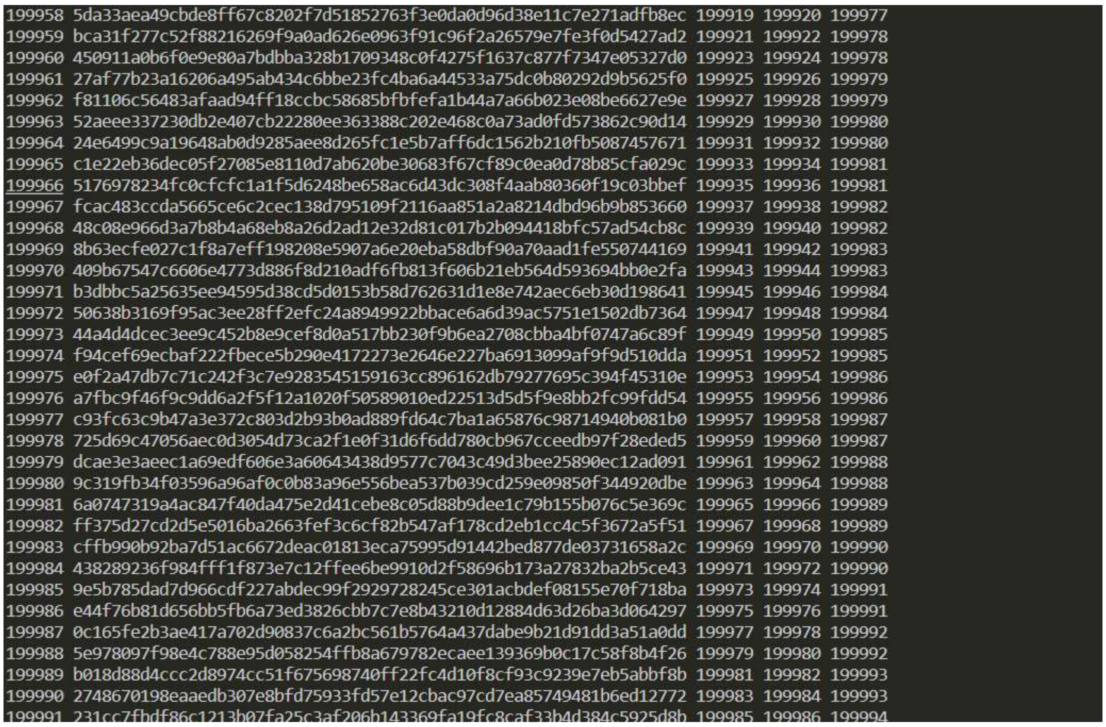
```
leaf_count = 7
MT = MerkleTree(leaf_count,[],[],0)
for i in range(leaf_count):
    MT.fill_leaf(MerkleTreeNode(i+1,hashlib.sha256(str(i).encode()).hexdigest(),0,0,0))
MT.build_tree()
```

以8个结点为例，建立Merkle Tree如下图所示。



```
PS F:\course-project-2022> & D:/Python310/python.exe f:/course-project-2022/Project
Number of Leaves: 8
1 5feceb66ffc86f38d952786c6d696c79c2dbc239dd4e91b46729d73a27fb57e9 0 0 9
2 6b86b273ff34fce19d6b804eff5a3f5747ada4eaa22f1d49c01e52ddb7875b4b 0 0 9
3 d4735e3a265e16eee03f59718b9b5d03019c07d8b6c51f90da3a666eec13ab35 0 0 10
4 4e07408562bedb8b60ce05c1decfe3ad16b72230967de01f640b7e4729b49fce 0 0 10
5 4b227777d4dd1fc61c6f884f48641d02b4d121d3fd328cb08b5531fcacdabf8a 0 0 11
6 ef2d127de37b942baad06145e54b0c619a1f22327b2ebbcfbec78f5564afe39d 0 0 11
7 e7f6c011776e8db7cd330b54174fd76f7d0216b612387a5ffcfb81e6f0919683 0 0 12
8 7902699be42c8a8e46fbbb4501726517e86b22c56a189f7625a6da49081b2451 0 0 12
9 4156108c729571c1f9756b355c03dc1f13bbd6ae93bfb74c73b0714a3562a04d 1 2 13
10 7229193557dec89e738090c3d09c3151d4f4e3f3132161f40620b24642f00e81 3 4 13
11 6760eb9c924f32a5d646ce0f961943e502fabe9e889286780f7e40ffb4265a7c 5 6 14
12 fae894871c59ac7f921094318c551543ef654a527903b53c5f37bc2e1eece273 7 8 14
13 6505de232d2001eb931a9bd4a3c96e10d41f6eaa7e737cc7aa6b45c8c80261e7 9 10 15
14 aab86e127fe5afe697b8892f6aed79934ab6b76763b74d87ffce6bedfea1c55f 11 12 15
15 b057d9cb0b62122cf3c28e1141033e8ed655d5449c5d272357f81d34553c1e79 13 14 0
```

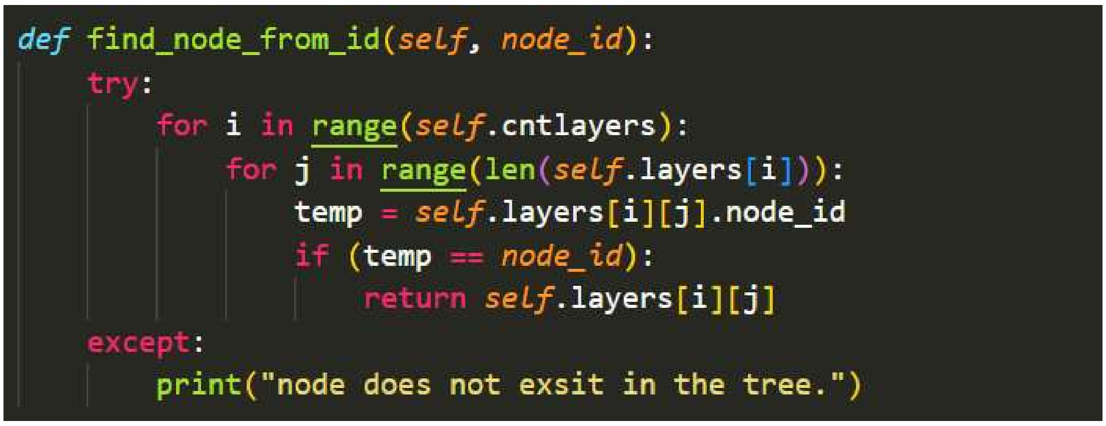
最终构造叶结点数为10w的Merkle Tree，如下图所示。



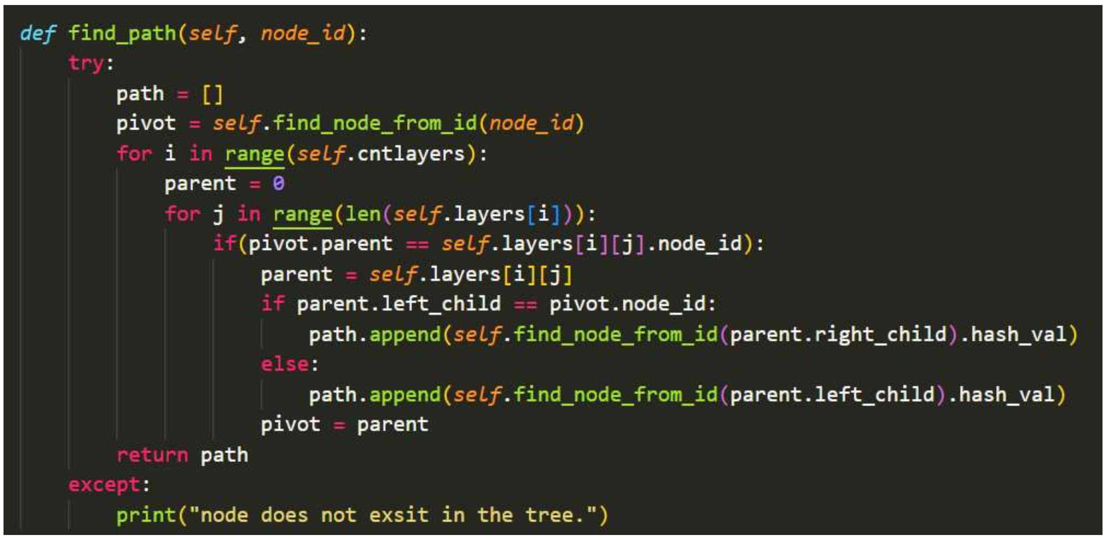
```
199958 5da33aea49cbde8ff67c8202f7d51852763f3e0da0d96d38e11c7e271adfb8ec 199919 199920 199977
199959 bca31f277c52f88216269f9a0ad626e0963f91c96f2a26579e7fe3f0d5427ad2 199921 199922 199978
199960 450911a0b6f0e9e80a7bdbba328b1709348c0f4275f1637c877f7347e05327d0 199923 199924 199978
199961 27af77b23a16206a495ab434c6bbe23fc4ba6a44533a75dc0b80292d9b5625f0 199925 199926 199979
199962 f81106c56483afaad94ff18ccbc58685bfbfefa1b44a7a66b023e08be6627e9e 199927 199928 199979
199963 52aeee337230db2e407cb22280ee363388c202e468c0a73ad0fd573862c90d14 199929 199930 199980
199964 24e6499c9a19648ab0d9285aee8d265fc1e5b7aff6dc1562b210fb5087457671 199931 199932 199980
199965 c1e22eb36dec05f27085e8110d7ab620be30683f67cf89c0ea0d78b85cfa029c 199933 199934 199981
199966 5176978234fc0cfcfc1a1f5d6248be658ac6d43dc308f4aab80360f19c03bbef 199935 199936 199981
199967 fcac483ccda5665ce6c2cec138d795109f2116aa851a2a8214dbd96b9b853660 199937 199938 199982
199968 48c08e966d3a7b8b4a68eb8a26d2ad12e32d81c017b2b094418bfc57ad54cb8c 199939 199940 199982
199969 8b63ecfe027c1f8a7eff198208e5907a6e20eba58dbf90a70aad1fe550744169 199941 199942 199983
199970 409b67547c6606e4773d886f8d210adf6fb813f606b21eb564d593694bb0e2fa 199943 199944 199983
199971 b3dbbc5a25635ee94595d38cd5d0153b58d762631d1e8e742aec6eb30d198641 199945 199946 199984
199972 50638b3169f95ac3ee28ff2efc24a8949922bbace6a6d39ac5751e1502db7364 199947 199948 199984
199973 44a4d4dcec3ee9c452b8e9cef8d0a517bb230f9b6ea2708cbba4bf0747a6c89f 199949 199950 199985
199974 f94cef69ecbaf222fbece5b290e4172273e2646e227ba6913099af9f9d510dda 199951 199952 199985
199975 e0f2a47db7c71c242f3c7e9283545159163cc896162db79277695c394f45310e 199953 199954 199986
199976 a7fbc9f46f9c9dd6a2f5f12a1020f50589010ed22513d5d5f9e8bb2fc99fdd54 199955 199956 199986
199977 c93fc63c9b47a3e372c803d2b93b0ad889fd64c7ba1a65876c98714940b081b0 199957 199958 199987
199978 725d69c47056aec0d3054d73ca2f1e0f31d6f6dd780cb967cceedb97f28eded5 199959 199960 199987
199979 dcae3e3aeec1a69edf606e3a60643438d9577c7043c49d3bee25890ec12ad091 199961 199962 199988
199980 9c319fb34f03596a96af0c0b83a96e556bea537b039cd259e09850f344920dbe 199963 199964 199988
199981 6a0747319a4ac847f40da475e2d41cebe8c05d88b9dee1c79b155b076c5e369c 199965 199966 199989
199982 ff375d27cd2d5e5016ba2663fef3c6cf82b547af178cd2eb1cc4c5f3672a5f51 199967 199968 199989
199983 cffb990b92ba7d51ac6672deac01813eca75995d91442bed877de03731658a2c 199969 199970 199990
199984 438289236f984fff1f873e7c12ffee6be9910d2f58696b173a27832ba2b5ce43 199971 199972 199990
199985 9e5b785dad7d966cdf227abdec99f2929728245ce301acbdef08155e70f718ba 199973 199974 199991
199986 e44f76b81d656bb5fb6a73ed3826cbb7c7e8b43210d12884d63d26ba3d064297 199975 199976 199991
199987 0c165fe2b3ae417a702d90837c6a2bc561b5764a437dabe9b21d91dd3a51a0dd 199977 199978 199992
199988 5e978097f98e4c788e95d058254ffb8a679782ecaee139369b0c17c58f8b4f26 199979 199980 199992
199989 b018d88d4ccc2d8974cc51f675698740ff22fc4d10f8cf93c9239e7eb5abbf8b 199981 199982 199993
199990 2748670198eaaedb307e8bfd75933fd57e12cbac97cd7ea85749481b6ed12772 199983 199984 199993
199991 231cc7fbdf86c1213b07fa25c3af206b143369fa19fc8caf33b4d384c5925d8b 199985 199986 199994
```

1.2　对特定元素的存在性证明

对于特定编号的元素，要判断该元素是否在Merkle Tree的结点中，只需要根据此元素对应的结点计算杂凑值与相邻元素合并依次向上查找。

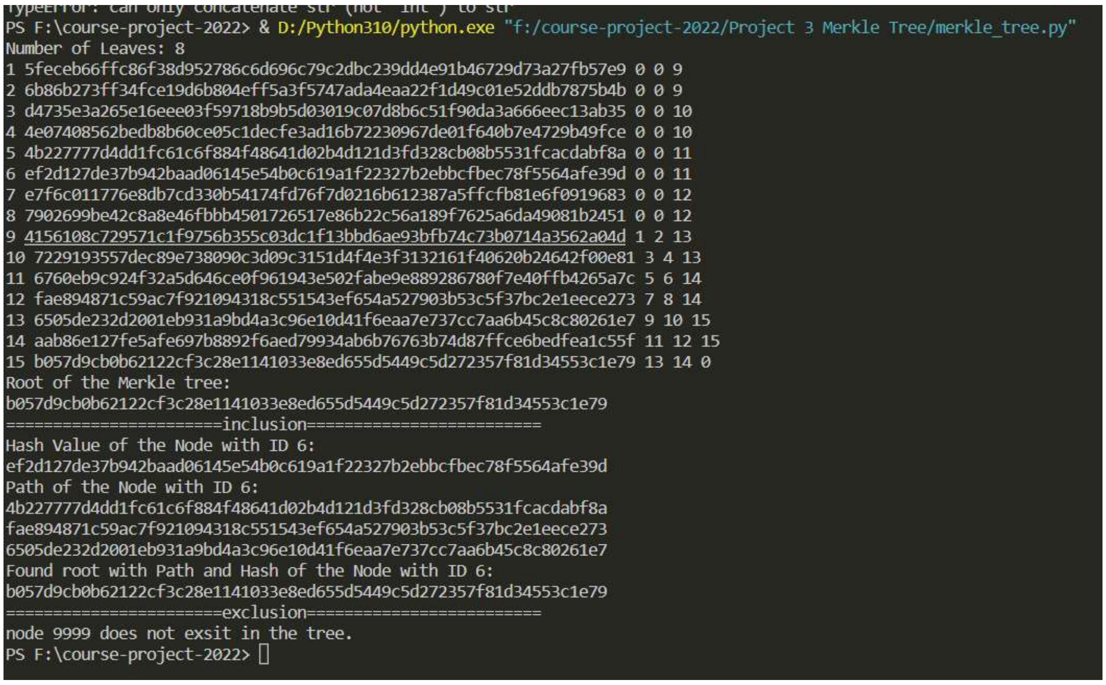


```python
def find_node_from_id(self, node_id):
    try:
        for i in range(self.cntlayers):
            for j in range(len(self.layers[i])):
                temp = self.layers[i][j].node_id
                if (temp == node_id):
                    return self.layers[i][j]
    except:
        print("node does not exsit in the tree.")
```



```python
def find_path(self, node_id):
    try:
        path = []
        pivot = self.find_node_from_id(node_id)
        for i in range(self.cntlayers):
            parent = 0
            for j in range(len(self.layers[i])):
                if(pivot.parent == self.layers[i][j].node_id):
                    parent = self.layers[i][j]
                    if parent.left_child == pivot.node_id:
                        path.append(self.find_node_from_id(parent.right_child).hash_val)
                    else:
                        path.append(self.find_node_from_id(parent.left_child).hash_val)
                    pivot = parent
        return path
    except:
        print("node does not exsit in the tree.")
```

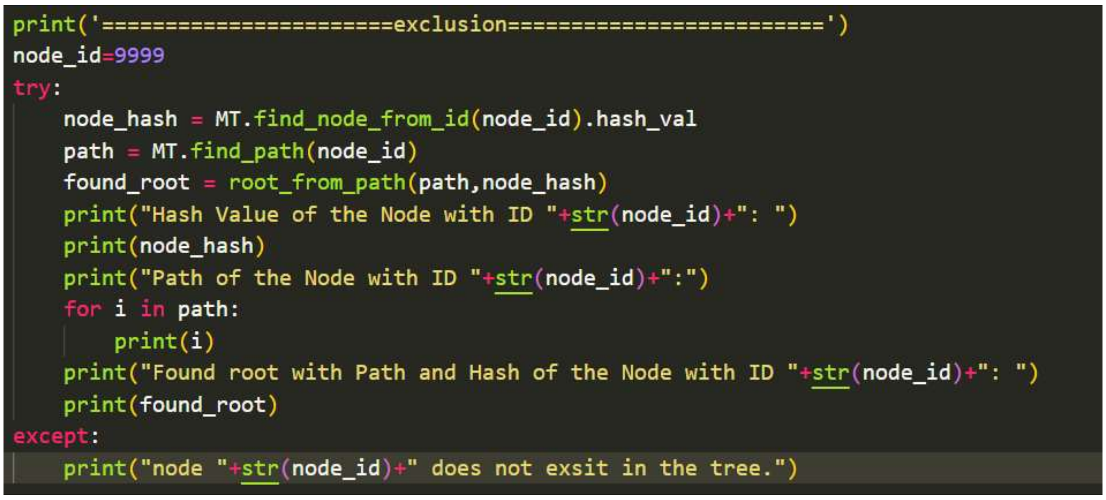
如果能找到根结点哈希值与真实的根结点哈希值相同也即找到了一条路径那么说明此元素在Merkle树中，如果不能则说明不在Merkle Tree中，以8个结点的Merkle Tree为例，存在性证明和不存在证明如下图所示。



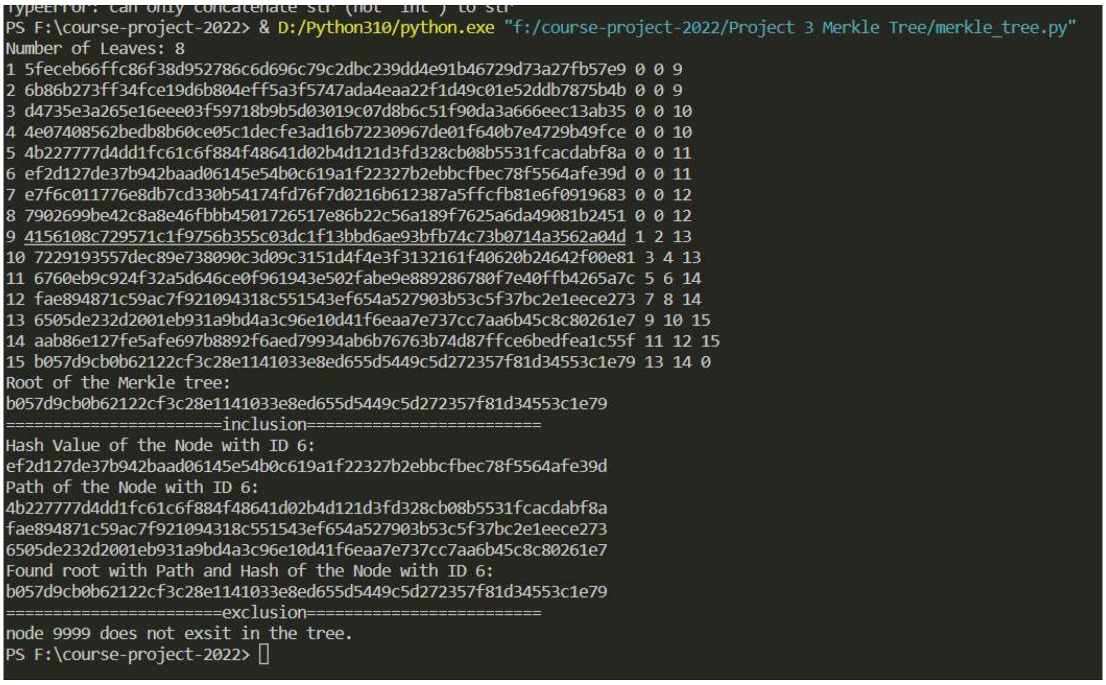
```
TypeError: can only concatenate str (not "int") to str
PS F:\course-project-2022> & D:/Python310/python.exe "f:/course-project-2022/Project 3 Merkle Tree/merkle_tree.py"
Number of Leaves: 8
1 5feceb66ffc86f38d952786c6d696c79c2dbc239dd4e91b46729d73a27fb57e9 0 0 9
2 6b86b273ff34fce19d6b804eff5a3f5747ada4eaa22f1d49c01e52ddb7875b4b 0 0 9
3 d4735e3a265e16eee03f59718b9b5d03019c07d8b6c51f90da3a666eec13ab35 0 0 10
4 4e07408562bedb8b60ce05c1decfe3ad16b72230967de01f640b7e4729b49fce 0 0 10
5 4b227777d4dd1fc61c6f884f48641d02b4d121d3fd328cb08b5531fcacdabf8a 0 0 11
6 ef2d127de37b942baad06145e54b0c619a1f22327b2ebbcfbec78f5564afe39d 0 0 11
7 e7f6c011776e8db7cd330b54174fd76f7d0216b612387a5ffcfb81e6f0919683 0 0 12
8 7902699be42c8a8e46fbbb4501726517e86b22c56a189f7625a6da49081b2451 0 0 12
9 4156108c729571c1f9756b355c03dc1f13bbd6ae93bfb74c73b0714a3562a04d 1 2 13
10 7229193557dec89e738090c3d09c3151d4f4e3f3132161f40620b24642f00e81 3 4 13
11 6760eb9c924f32a5d646ce0f961943e502fabe9e889286780f7e40ffb4265a7c 5 6 14
12 fae894871c59ac7f921094318c551543ef654a527903b53c5f37bc2e1eece273 7 8 14
13 6505de232d2001eb931a9bd4a3c96e10d41f6eaa7e737cc7aa6b45c8c80261e7 9 10 15
14 aab86e127fe5afe697b8892f6aed79934ab6b76763b74d87ffce6bedfea1c55f 11 12 15
15 b057d9cb0b62122cf3c28e1141033e8ed655d5449c5d272357f81d34553c1e79 13 14 0
Root of the Merkle tree:
b057d9cb0b62122cf3c28e1141033e8ed655d5449c5d272357f81d34553c1e79
=======================inclusion=========================
Hash Value of the Node with ID 6:
ef2d127de37b942baad06145e54b0c619a1f22327b2ebbcfbec78f5564afe39d
Path of the Node with ID 6:
4b227777d4dd1fc61c6f884f48641d02b4d121d3fd328cb08b5531fcacdabf8a
fae894871c59ac7f921094318c551543ef654a527903b53c5f37bc2e1eece273
6505de232d2001eb931a9bd4a3c96e10d41f6eaa7e737cc7aa6b45c8c80261e7
Found root with Path and Hash of the Node with ID 6:
b057d9cb0b62122cf3c28e1141033e8ed655d5449c5d272357f81d34553c1e79
=======================exclusion=========================
node 9999 does not exsit in the tree.
PS F:\course-project-2022> 
```

1.3　对特定元素的不存在证明

如果未能找到这某元素对应的路径则输出此结点不存在提示。



```python
print('=======================exclusion========================')
node_id=9999
try:
    node_hash = MT.find_node_from_id(node_id).hash_val
    path = MT.find_path(node_id)
    found_root = root_from_path(path,node_hash)
    print("Hash Value of the Node with ID "+str(node_id)+": ")
    print(node_hash)
    print("Path of the Node with ID "+str(node_id)+":")
    for i in path:
        print(i)
    print("Found root with Path and Hash of the Node with ID "+str(node_id)+": ")
    print(found_root)
except:
    print("node "+str(node_id)+" does not exsit in the tree.")
```



```
TypeError: can only concatenate str (not "int") to str
PS F:\course-project-2022> & D:/Python310/python.exe "f:/course-project-2022/Project 3 Merkle Tree/merkle_tree.py"
Number of Leaves: 8
1 5feceb66ffc86f38d952786c6d696c79c2dbc239dd4e91b46729d73a27fb57e9 0 0 9
2 6b86b273ff34fce19d6b804eff5a3f5747ada4eaa22f1d49c01e52ddb7875b4b 0 0 9
3 d4735e3a265e16eee03f59718b9b5d03019c07d8b6c51f90da3a666eec13ab35 0 0 10
4 4e07408562bedb8b60ce05c1decfe3ad16b72230967de01f640b7e4729b49fce 0 0 10
5 4b227777d4dd1fc61c6f884f48641d02b4d121d3fd328cb08b5531fcacdabf8a 0 0 11
6 ef2d127de37b942baad06145e54b0c619a1f22327b2ebbcfbec78f5564afe39d 0 0 11
7 e7f6c011776e8db7cd330b54174fd76f7d0216b612387a5ffcfb81e6f0919683 0 0 12
8 7902699be42c8a8e46fbbb4501726517e86b22c56a189f7625a6da49081b2451 0 0 12
9 4156108c729571c1f9756b355c03dc1f13bbd6ae93bfb74c73b0714a3562a04d 1 2 13
10 7229193557dec89e738090c3d09c3151d4f4e3f3132161f40620b24642f00e81 3 4 13
11 6760eb9c924f32a5d646ce0f961943e502fabe9e889286780f7e40ffb4265a7c 5 6 14
12 fae894871c59ac7f921094318c551543ef654a527903b53c5f37bc2e1eece273 7 8 14
13 6505de232d2001eb931a9bd4a3c96e10d41f6eaa7e737cc7aa6b45c8c80261e7 9 10 15
14 aab86e127fe5afe697b8892f6aed79934ab6b76763b74d87ffce6bedfea1c55f 11 12 15
15 b057d9cb0b62122cf3c28e1141033e8ed655d5449c5d272357f81d34553c1e79 13 14 0
Root of the Merkle tree:
b057d9cb0b62122cf3c28e1141033e8ed655d5449c5d272357f81d34553c1e79
=======================inclusion========================
Hash Value of the Node with ID 6:
ef2d127de37b942baad06145e54b0c619a1f22327b2ebbcfbec78f5564afe39d
Path of the Node with ID 6:
4b227777d4dd1fc61c6f884f48641d02b4d121d3fd328cb08b5531fcacdabf8a
fae894871c59ac7f921094318c551543ef654a527903b53c5f37bc2e1eece273
6505de232d2001eb931a9bd4a3c96e10d41f6eaa7e737cc7aa6b45c8c80261e7
Found root with Path and Hash of the Node with ID 6:
b057d9cb0b62122cf3c28e1141033e8ed655d5449c5d272357f81d34553c1e79
=======================exclusion========================
node 9999 does not exsit in the tree.
PS F:\course-project-2022> 
```