AES – Mix columns
Cryptography – Lab 3

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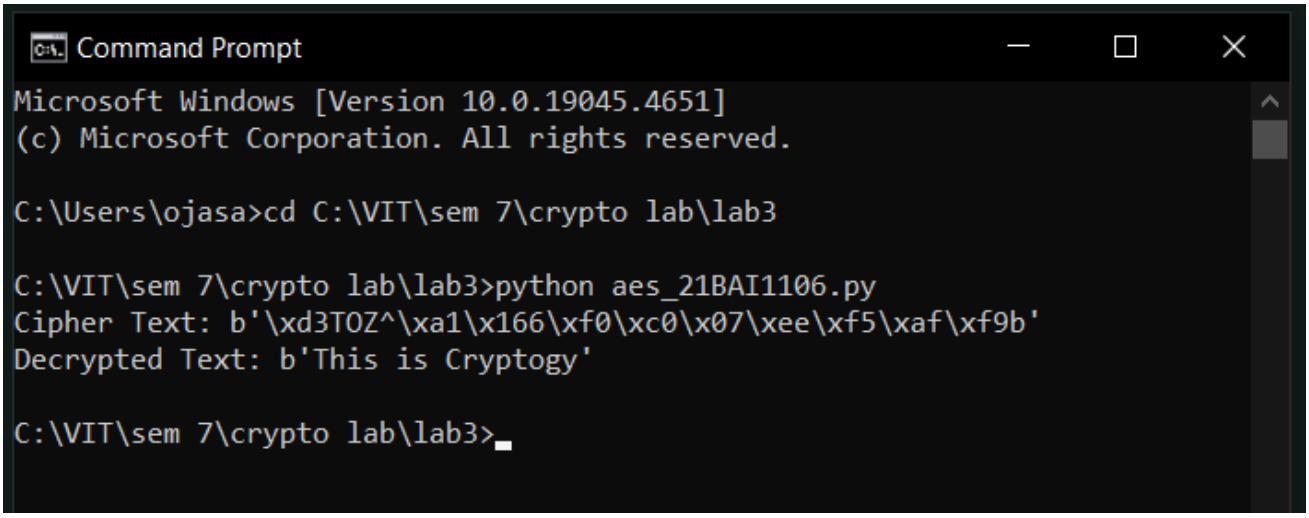
Task

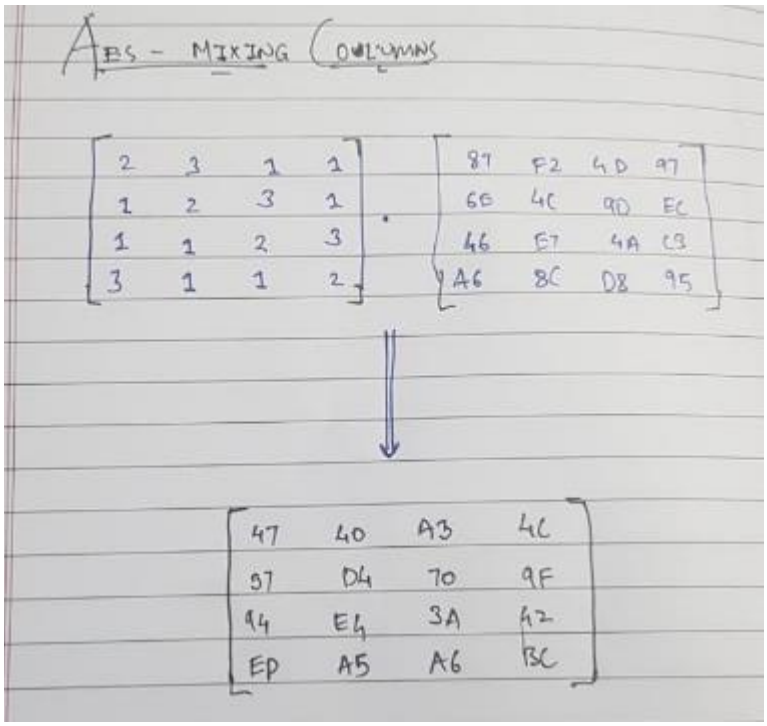
Develop a Python-based AES encryption implementation, including key expansion, S-box transformations, and MixColumns operations.

AES

Output Snapshot



Handwritten sum



Source Code

```
# AES
def break_in_grids_of_16(s):
    all = []
    for i in range(len(s)//16):
        b = s[i*16: i*16 + 16]
        grid = [[], [], [], []]
        for i in range(4):
            for j in range(4):
                grid[i].append(b[i + j*4])
        all.append(grid)
    return all




aes_sbox = [
    [int('63', 16), int('7c', 16), int('77', 16), int('7b', 16), int('f2', 16),
int('6b', 16), int('6f', 16), int('c5', 16), int(
        '30', 16), int('01', 16), int('67', 16), int('2b', 16), int('fe', 16),
int('d7', 16), int('ab', 16), int('76', 16)],
```

```
    [int('ca', 16), int('82', 16), int('c9', 16), int('7d', 16), int('fa', 16),
int('59', 16), int('47', 16), int('f0', 16), int(
        'ad', 16), int('d4', 16), int('a2', 16), int('af', 16), int('9c', 16),
int('a4', 16), int('72', 16), int('c0', 16)],
    [int('b7', 16), int('fd', 16), int('93', 16), int('26', 16), int('36', 16),
int('3f', 16), int('f7', 16), int('cc', 16), int(
        '34', 16), int('a5', 16), int('e5', 16), int('f1', 16), int('71', 16),
int('d8', 16), int('31', 16), int('15', 16)],
    [int('04', 16), int('c7', 16), int('23', 16), int('c3', 16), int('18', 16),
int('96', 16), int('05', 16), int('9a', 16), int(
        '07', 16), int('12', 16), int('80', 16), int('e2', 16), int('eb', 16),
int('27', 16), int('b2', 16), int('75', 16)],
    [int('09', 16), int('83', 16), int('2c', 16), int('1a', 16), int('1b', 16),
int('6e', 16), int('5a', 16), int('a0', 16), int(
        '52', 16), int('3b', 16), int('d6', 16), int('b3', 16), int('29', 16),
int('e3', 16), int('2f', 16), int('84', 16)],
    [int('53', 16), int('d1', 16), int('00', 16), int('ed', 16), int('20', 16),
int('fc', 16), int('b1', 16), int('5b', 16), int(
        '6a', 16), int('cb', 16), int('be', 16), int('39', 16), int('4a', 16),
int('4c', 16), int('58', 16), int('cf', 16)],
    [int('d0', 16), int('ef', 16), int('aa', 16), int('fb', 16), int('43', 16),
int('4d', 16), int('33', 16), int('85', 16), int(
        '45', 16), int('f9', 16), int('02', 16), int('7f', 16), int('50', 16),
int('3c', 16), int('9f', 16), int('a8', 16)],
    [int('51', 16), int('a3', 16), int('40', 16), int('8f', 16), int('92', 16),
int('9d', 16), int('38', 16), int('f5', 16), int(
        'bc', 16), int('b6', 16), int('da', 16), int('21', 16), int('10', 16),
int('ff', 16), int('f3', 16), int('d2', 16)],
    [int('cd', 16), int('0c', 16), int('13', 16), int('ec', 16), int('5f', 16),
int('97', 16), int('44', 16), int('17', 16), int(
        'c4', 16), int('a7', 16), int('7e', 16), int('3d', 16), int('64', 16),
int('5d', 16), int('19', 16), int('73', 16)],
    [int('60', 16), int('81', 16), int('4f', 16), int('dc', 16), int('22', 16),
int('2a', 16), int('90', 16), int('88', 16), int(
        '46', 16), int('ee', 16), int('b8', 16), int('14', 16), int('de', 16),
int('5e', 16), int('0b', 16), int('db', 16)],
    [int('e0', 16), int('32', 16), int('3a', 16), int('0a', 16), int('49', 16),
int('06', 16), int('24', 16), int('5c', 16), int(
        'c2', 16), int('d3', 16), int('ac', 16), int('62', 16), int('91', 16),
int('95', 16), int('e4', 16), int('79', 16)],
    [int('e7', 16), int('c8', 16), int('37', 16), int('6d', 16), int('8d', 16),
int('d5', 16), int('4e', 16), int('a9', 16), int(
        '6c', 16), int('56', 16), int('f4', 16), int('ea', 16), int('65', 16),
int('7a', 16), int('ae', 16), int('08', 16)],
```

```
    [int('ba', 16), int('78', 16), int('25', 16), int('2e', 16), int('1c', 16),
int('a6', 16), int('b4', 16), int('c6', 16), int(
        'e8', 16), int('dd', 16), int('74', 16), int('1f', 16), int('4b', 16),
int('bd', 16), int('8b', 16), int('8a', 16)],
    [int('70', 16), int('3e', 16), int('b5', 16), int('66', 16), int('48', 16),
int('03', 16), int('f6', 16), int('0e', 16), int(
        '61', 16), int('35', 16), int('57', 16), int('b9', 16), int('86', 16),
int('c1', 16), int('1d', 16), int('9e', 16)],
    [int('e1', 16), int('f8', 16), int('98', 16), int('11', 16), int('69', 16),
int('d9', 16), int('8e', 16), int('94', 16), int(
        '9b', 16), int('1e', 16), int('87', 16), int('e9', 16), int('ce', 16),
int('55', 16), int('28', 16), int('df', 16)],
    [int('8c', 16), int('a1', 16), int('89', 16), int('0d', 16), int('bf', 16),
int('e6', 16), int('42', 16), int('68', 16), int(
        '41', 16), int('99', 16), int('2d', 16), int('0f', 16), int('b0', 16),
int('54', 16), int('bb', 16), int('16', 16)]
]


reverse_aes_sbox = [
    [int('52', 16), int('09', 16), int('6a', 16), int('d5', 16), int('30', 16),
int('36', 16), int('a5', 16), int('38', 16), int(
        'bf', 16), int('40', 16), int('a3', 16), int('9e', 16), int('81', 16),
int('f3', 16), int('d7', 16), int('fb', 16)],
    [int('7c', 16), int('e3', 16), int('39', 16), int('82', 16), int('9b', 16),
int('2f', 16), int('ff', 16), int('87', 16), int(
        '34', 16), int('8e', 16), int('43', 16), int('44', 16), int('c4', 16),
int('de', 16), int('e9', 16), int('cb', 16)],
    [int('54', 16), int('7b', 16), int('94', 16), int('32', 16), int('a6', 16),
int('c2', 16), int('23', 16), int('3d', 16), int(
        'ee', 16), int('4c', 16), int('95', 16), int('0b', 16), int('42', 16),
int('fa', 16), int('c3', 16), int('4e', 16)],
    [int('08', 16), int('2e', 16), int('a1', 16), int('66', 16), int('28', 16),
int('d9', 16), int('24', 16), int('b2', 16), int(
        '76', 16), int('5b', 16), int('a2', 16), int('49', 16), int('6d', 16),
int('8b', 16), int('d1', 16), int('25', 16)],
    [int('72', 16), int('f8', 16), int('f6', 16), int('64', 16), int('86', 16),
int('68', 16), int('98', 16), int('16', 16), int(
        'd4', 16), int('a4', 16), int('5c', 16), int('cc', 16), int('5d', 16),
int('65', 16), int('b6', 16), int('92', 16)],
    [int('6c', 16), int('70', 16), int('48', 16), int('50', 16), int('fd', 16),
int('ed', 16), int('b9', 16), int('da', 16), int(
        '5e', 16), int('15', 16), int('46', 16), int('57', 16), int('a7', 16),
int('8d', 16), int('9d', 16), int('84', 16)],
```

```
    [int('90', 16), int('d8', 16), int('ab', 16), int('00', 16), int('8c', 16),
int('bc', 16), int('d3', 16), int('0a', 16), int(
        'f7', 16), int('e4', 16), int('58', 16), int('05', 16), int('b8', 16),
int('b3', 16), int('45', 16), int('06', 16)],
    [int('d0', 16), int('2c', 16), int('1e', 16), int('8f', 16), int('ca', 16),
int('3f', 16), int('0f', 16), int('02', 16), int(
        'c1', 16), int('af', 16), int('bd', 16), int('03', 16), int('01', 16),
int('13', 16), int('8a', 16), int('6b', 16)],
    [int('3a', 16), int('91', 16), int('11', 16), int('41', 16), int('4f', 16),
int('67', 16), int('dc', 16), int('ea', 16), int(
        '97', 16), int('f2', 16), int('cf', 16), int('ce', 16), int('f0', 16),
int('b4', 16), int('e6', 16), int('73', 16)],
    [int('96', 16), int('ac', 16), int('74', 16), int('22', 16), int('e7', 16),
int('ad', 16), int('35', 16), int('85', 16), int(
        'e2', 16), int('f9', 16), int('37', 16), int('e8', 16), int('1c', 16),
int('75', 16), int('df', 16), int('6e', 16)],
    [int('47', 16), int('f1', 16), int('1a', 16), int('71', 16), int('1d', 16),
int('29', 16), int('c5', 16), int('89', 16), int(
        '6f', 16), int('b7', 16), int('62', 16), int('0e', 16), int('aa', 16),
int('18', 16), int('be', 16), int('1b', 16)],
    [int('fc', 16), int('56', 16), int('3e', 16), int('4b', 16), int('c6', 16),
int('d2', 16), int('79', 16), int('20', 16), int(
        '9a', 16), int('db', 16), int('c0', 16), int('fe', 16), int('78', 16),
int('cd', 16), int('5a', 16), int('f4', 16)],
    [int('1f', 16), int('dd', 16), int('a8', 16), int('33', 16), int('88', 16),
int('07', 16), int('c7', 16), int('31', 16), int(
        'b1', 16), int('12', 16), int('10', 16), int('59', 16), int('27', 16),
int('80', 16), int('ec', 16), int('5f', 16)],
    [int('60', 16), int('51', 16), int('7f', 16), int('a9', 16), int('19', 16),
int('b5', 16), int('4a', 16), int('0d', 16), int(
        '2d', 16), int('e5', 16), int('7a', 16), int('9f', 16), int('93', 16),
int('c9', 16), int('9c', 16), int('ef', 16)],
    [int('a0', 16), int('e0', 16), int('3b', 16), int('4d', 16), int('ae', 16),
int('2a', 16), int('f5', 16), int('b0', 16), int(
        'c8', 16), int('eb', 16), int('bb', 16), int('3c', 16), int('83', 16),
int('53', 16), int('99', 16), int('61', 16)],
    [int('17', 16), int('2b', 16), int('04', 16), int('7e', 16), int('ba', 16),
int('77', 16), int('d6', 16), int('26', 16), int(
        'e1', 16), int('69', 16), int('14', 16), int('63', 16), int('55', 16),
int('21', 16), int('0c', 16), int('7d', 16)]
]
```

```
def lookup(byte):
    x = byte >> 4
    y = byte & 15
    return aes_sbox[x][y]




def reverse_lookup(byte):
    x = byte >> 4
    y = byte & 15
    return reverse_aes_sbox[x][y]







def expand_key(key, rounds):


    rcon = [[1, 0, 0, 0]]


    for _ in range(1, rounds):
        rcon.append([rcon[-1][0]*2, 0, 0, 0])
        if rcon[-1][0] > 0x80:
            rcon[-1][0] ^= 0x11b


    key_grid = break_in_grids_of_16(key)[0]


    for round in range(rounds):
        last_column = [row[-1] for row in key_grid]
        last_column_rotate_step = rotate_row_left(last_column)
        last_column_sbox_step = [lookup(b) for b in last_column_rotate_step]
        last_column_rcon_step = [last_column_sbox_step[i]
                                 ^ rcon[round][i] for i in
range(len(last_column_rotate_step))]


        for r in range(4):
            key_grid[r] += bytes([last_column_rcon_step[r]
                                  ^ key_grid[r][round*4]])
```

```
        # Three more columns to go
        for i in range(len(key_grid)):
            for j in range(1, 4):
                key_grid[i] += bytes([key_grid[i][round*4+j]
                                      ^ key_grid[i][round*4+j+3]])


    return key_grid


def extract_key_for_round(expanded_key, round):
  return [row[round*4: round*4 + 4] for row in expanded_key]


def rotate_row_left(row, n=1):
    return row[n:] + row[:n]




def multiply_by_2(v):
    s = v << 1
    s &= 0xff
    if (v & 128) != 0:
        s = s ^ 0x1b
    return s




def multiply_by_3(v):
    return multiply_by_2(v) ^ v




def mix_columns(grid):
    new_grid = [[], [], [], []]
    for i in range(4):
        col = [grid[j][i] for j in range(4)]
        col = mix_column(col)
        for i in range(4):
            new_grid[i].append(col[i])
    return new_grid
```

```
def mix_column(column):
    r = [
        multiply_by_2(column[0]) ^ multiply_by_3(
            column[1]) ^ column[2] ^ column[3],
        multiply_by_2(column[1]) ^ multiply_by_3(
            column[2]) ^ column[3] ^ column[0],
        multiply_by_2(column[2]) ^ multiply_by_3(
            column[3]) ^ column[0] ^ column[1],
        multiply_by_2(column[3]) ^ multiply_by_3(
            column[0]) ^ column[1] ^ column[2],
    ]
    return r


def add_sub_key(block_grid, key_grid):
    r = []


    # 4 rows in the grid
    for i in range(4):
        r.append([])
        # 4 values on each row
        for j in range(4):
            r[-1].append(block_grid[i][j] ^ key_grid[i][j])
    return r




def enc(key, data):


    # First we need to padd the data with \x00 and break it into blocks of 16
    pad = bytes(16 - len(data) % 16)

    if len(pad) != 16:
        data += pad
    grids = break_in_grids_of_16(data)


    # Now we need to expand the key for the multiple rounds
    expanded_key = expand_key(key, 11)
```

```
# And apply the original key to the blocks before start the rounds
# For now on we will work with integers
temp_grids = []
round_key = extract_key_for_round(expanded_key, 0)


for grid in grids:
    temp_grids.append(add_sub_key(grid, round_key))


grids = temp_grids


# Now we can move to the main part of the algorithm
for round in range(1, 10):
    temp_grids = []

    for grid in grids:
        sub_bytes_step = [[lookup(val) for val in row] for row in grid]
        shift_rows_step = [rotate_row_left(
            sub_bytes_step[i], i) for i in range(4)]
        mix_column_step = mix_columns(shift_rows_step)
        round_key = extract_key_for_round(expanded_key, round)
        add_sub_key_step = add_sub_key(mix_column_step, round_key)
        temp_grids.append(add_sub_key_step)


    grids = temp_grids


# A final round without the mix columns
temp_grids = []
round_key = extract_key_for_round(expanded_key, 10)


for grid in grids:
    sub_bytes_step = [[lookup(val) for val in row] for row in grid]
    shift_rows_step = [rotate_row_left(
        sub_bytes_step[i], i) for i in range(4)]
    add_sub_key_step = add_sub_key(shift_rows_step, round_key)
    temp_grids.append(add_sub_key_step)


grids = temp_grids
```

```
    # Just need to recriate the data into a single stream before returning
    int_stream = []

    for grid in grids:
        for column in range(4):
            for row in range(4):
                int_stream.append(grid[row][column])


    return bytes(int_stream)




def dec(key, data):


    grids = break_in_grids_of_16(data)
    expanded_key = expand_key(key, 11)
    temp_grids = []
    round_key = extract_key_for_round(expanded_key, 10)


    # First we undo the final round
    temp_grids = []


    for grid in grids:


        add_sub_key_step = add_sub_key(grid, round_key)
        shift_rows_step = [rotate_row_left(
            add_sub_key_step[i], -1 * i) for i in range(4)]
        sub_bytes_step = [[reverse_lookup(val) for val in row]
                          for row in shift_rows_step]
        temp_grids.append(sub_bytes_step)


    grids = temp_grids


    for round in range(9, 0, -1):
        temp_grids = []
```

```
        for grid in grids:
            round_key = extract_key_for_round(expanded_key, round)
            add_sub_key_step = add_sub_key(grid, round_key)


            # Doing the mix columns three times is equal to using the reverse
matrix
            mix_column_step = mix_columns(add_sub_key_step)
            mix_column_step = mix_columns(mix_column_step)
            mix_column_step = mix_columns(mix_column_step)
            shift_rows_step = [rotate_row_left(
                mix_column_step[i], -1 * i) for i in range(4)]
            sub_bytes_step = [
                [reverse_lookup(val) for val in row] for row in shift_rows_step]
            temp_grids.append(sub_bytes_step)


        grids = temp_grids
        temp_grids = []


    # Reversing the first add sub key
    round_key = extract_key_for_round(expanded_key, 0)


    for grid in grids:
        temp_grids.append(add_sub_key(grid, round_key))


    grids = temp_grids
    # Just transform the grids back to bytes
    int_stream = []
    for grid in grids:
        for column in range(4):
            for row in range(4):
                int_stream.append(grid[row][column])


    return bytes(int_stream)


cipher_text = enc(b"Thats my Fu Kung", b"This is Cryptogy")
print("Cipher Text:",cipher_text)
decrypted_text = dec(b"Thats my Fu Kung", cipher_text)
print("Decrypted Text:",decrypted_text)
```

Conclusion

The implementation of AES encryption in Python successfully demonstrates the core components of the algorithm, including key expansion, S-box transformations, and MixColumns operations. This experiment provides a foundational understanding of AES and its practical application in securing data.