LAPORAN TUGAS KECIL

Penyelesaian Persoalan 15-Puzzle dengan Algoritma *Branch and Bound*

Ditujukan untuk memenuhi salah satu tugas kecil mata kuliah IF2211 Strategi Algoritma pada Semester II Tahun Akademik 2021/2022

Disusun oleh:

Rania Dwi Fadhilah (K1) **13520142**

PROGRAM STUDI TEKNIK INFORMATIKA

SEKOLAH TEKNIK ELEKTRO DAN INFORMATIKA

INSTITUT TEKNOLOGI BANDUNG

BANDUNG

2022

DAFTAR ISI

I. ALGORITMA PROGRAM

1.1 PENJELASAN ALGORITMA

Algoritma *Branch and Bound* merupakan algoritma yang kerap digunakan untuk menyelesaikan persoalan optimasi, dimana program harus meminimalkan atau memaksimalkan suatu fungsi objektif tertentu tanpa melanggar batasan persoalan. Pada dasarnya, algoritma ini merupakan gabungan dari algoritma BFS (*Breadth First Search)* dengan *least cost search*. Oleh karena itu, cara kerja algoritma ini adalah memberikan nilai *cost* pada setiap simpulnya, kemudian mengekspansi simpul berdasarkan urutan nilai *cost* yang paling kecil (apabila ingin meminimalkan) ataupun yang paling besar (apabila ingin memaksimalkan), bukan berdasarkan urutan pembangkitannya. Salah satu contoh aplikasi dari algoritma ini adalah pada permainan 15-puzzle. Pada persoalan 15-puzzle ini, program *Branch and Bound* bekerja dengan cara :

1. Membaca *puzzle* menjadi *array* 4 x 4 dalam bentuk kelas Puzzle yang juga menyimpan nilai :
   cost (harga jalur),
   path (urutan jalur → c/: [[UP], [LEFT]]),
   letak basis,
   bentuk atas, bawah, kanan, dan kirinya.
2. Menghitung nilai kurang(i) dari puzzle dengan cara menghitung jumlah elemen setelah posisi(i) yang memiliki nilai lebih dari elemen pada posisi(i).
3. Menghitung nilai X, apabila nilai baris basis + kolom basis adalah ganjil, maka nilai X adalah 1. Selain itu, nilai X adalah 0.
4. Apabila nilai kurang(i) + X = ganjil, maka *puzzle* tidak dapat diselesaikan
5. Apabila nilai kurang(i) + X = genap, maka pencarian dimulai dengan menginisialisasi *heapqueue*, memasukkan puzzle acuan pertama ke *dictionary* checked puzzle.
6. Apabila puzzle sudah dalam keadaan selesai, maka pencarian dihentikan dan lanjut ke tahap 9
7. Apabila puzzle belum dalam keadaan selesai, maka akan dilakukan :
   a) Inisialisasi *path* dengan path terakhir yang dilalui oleh puzzle untuk menghindari perpindahan balik, seperti sebelumnya UP kemudian DOWN dan sebelumnya LEFT kemudian RIGHT yang akan mengembalikan puzzle ke posisi semula
   b) Apabila posisi baris basis tidak = 0 dan path terakhirnya bukan “DOWN”, dilakukan pencarian ke atas dengan cara menginisialisasi *puzzle* baru dan menduplikasi matriks *puzzle* yang sedang dicari dan menukar posisi basisnya dengan matriks di atasnya.
   c) Matriks diubah ke dalam bentuk list sementara untuk dicek apakah matriks tersebut sudah pernah diselidiki atau belum pada *dictionary* checked puzzle.
   d) Apabila matriks puzzle belum pernah diselidiki, maka *path*-nya ditambahkan, basisnya diinisialisasi, dan *cost*-nya dihitung dengan rumus berikut :

$$c(P) = f(p) + g(p)$$

$$f(p) = panjang\ list\ (path) = panjang\ lintasan\ dari\ simpul\ akar\ ke\ p$$

$$g(p) = jumlah\ elemen\ yang\ tidak\ berada\ pada\ posisinya\ (mengacu\ pada\ goal\ state)$$

   e) Puzzle dimasukkan pada *heapqueue* dengan *tuple value* berupa <*cost* Puzzle, Puzzle>.
   f) Apabila *puzzle* sudah selesai, maka pencarian dihentikan
   g) Apabila posisi baris basis tidak = 3 dan path terakhirnya bukan “UP”, dilakukan pencarian ke bawah dengan cara menginisialisasi *puzzle* baru dan menduplikasi matriks *puzzle* yang sedang dicari dan menukar posisi basisnya dengan matriks di bawahnya. Kemudian, melakukan tahap c,d,e,f.

h) Apabila posisi kolom basis tidak = 0 dan path terakhirnya bukan “RIGHT”, dilakukan pencarian ke kiri dengan cara menginisialisasi *puzzle* baru dan menduplikasi matriks *puzzle* yang sedang dicari dan menukar posisi basisnya dengan matriks di kirinya. Kemudian, melakukan tahap c,d,e,f.
i) Apabila posisi kolom basis tidak = 3 dan path terakhirnya bukan “LEFT”, dilakukan pencarian ke kanan dengan cara menginisialisasi *puzzle* baru dan menduplikasi matriks *puzzle* yang sedang dicari dan menukar posisi basisnya dengan matriks di kanannya. Kemudian, melakukan tahap c,d,e,f.
j) Puzzle yang berada di *heapqueue* dibangkitkan menjadi *puzzle* acuan. Puzzle yang dibangkitkan merupakan *puzzle* dengan nilai *cost* terkecil yang ada pada *heapqueue*.
k) Puzzle acuan dijadikan list dan dimasukan ke *dictionary* checked puzzle.

8. Kembali ke langkah 6
9. Menuliskan solusi pada layar dengan cara mengiterasi *path* dari *puzzle* tersebut

2.1 IMPLEMENTASI

a. puzzle.py

```
import heapq
import numpy as np
import time

# PUZZLE CLASS
class Puzzle :
    goalstate = [[1,2,3,4], [5,6,7,8], [9,10,11,12], [13,14,15,16]]

    # 1. Puzzle Initialization
    def __init__(self):
        self.mtx = np.empty((4,4), int) # Create Empty Matrix
        self.cost = 0 # Cost of the puzzle
        self.zero = (0,0) # Position of the basis
        self.path = [] # Path of the puzzle
        self.up, self.down, self.left, self.right = None, None, None, None # Up, Down,
Left, Right

    # 2. Cost Counter
    def countCost(self):
        count = 0
        for i in range (4) :
            for j in range (4) :
                # Count number of matrix that is not in position
                if (self.mtx[i][j] != Puzzle.goalstate[i][j]) :
                    count += 1

        return count

    # 3. Handle <
    def __lt__ (self,other) :
        return True

# IS FINISH BOOLEAN
def isFinish(puzzle):
    if (puzzle.countCost() == 0) :
```

```
        return True
    else :
        return False

# CHECK PUZZLE VALIDITY
def puzzleValid(puzzle) :
    # 1. Change 2d array -> list
    puzz = (np.reshape(puzzle.mtx, 16)).tolist()
    # 2. Check if 1-16 is in order
    for i in range (1,17) :
        if (SearchI(puzz, i) == -1) :
            return False

    return True

# READ PUZZLE FROM FILE
def readPuzzleFromFile(filename):
    # 1. Initialize Puzzle
    Puz15 = Puzzle()
    # 2. Open Puzzle File
    try :
        f = open(filename, "r")
        # 3. Read Puzzle
        try :
            for i in range(4):
                temp = f.readline()
                Puz15.mtx[i] = temp.split()
                for j in range(4):
                    Puz15.mtx[i][j] = int(Puz15.mtx[i][j])
                    if (Puz15.mtx[i][j] == 0 or Puz15.mtx[i][j] == 16) :
                        Puz15.mtx[i][j] = 16
                        Puz15.zero = (i,j)
            f.close()
            Puz15.cost = Puz15.countCost()

            # 4. Return Puzzle If Puzzle is Valid
            if (puzzleValid(Puz15)) :
                return Puz15
            else :
                print("  ‖         Invalid
input                                                    ‖")
                return None
        except :
            print("  ‖         Invalid
input                                                    ‖")
            return None
    except :
        print("  ‖         File not
found                                                   ‖")
        return None

# READ PUZZLE FROM CONSOLE
def readPuzzleFromConsole():
    try :
        # 1. Initialize Puzzle
```

```
        Puz15 = Puzzle()
        # 2. Read Puzzle
        print("  ‖         Input Puzzle (4x4), consists of
:                                ‖")
        print("  ‖         a. Number 1 -
15                                                ‖")
        print("  ‖         b. 0 or 16 as
basis                                             ‖")
        for i in range(4):
            print("                                     >> ", end="")
            temp = str(input())
            Puz15.mtx[i] = temp.split()
            for j in range(4):
                Puz15.mtx[i][j] = int(Puz15.mtx[i][j])
                if (Puz15.mtx[i][j] == 0 or Puz15.mtx[i][j] == 16) :
                    Puz15.mtx[i][j] = 16
                    Puz15.zero = (i,j)

        Puz15.cost = Puz15.countCost()

        # 3. Return Puzzle If Puzzle is Valid
        if (puzzleValid(Puz15)) :
                return Puz15
        else :
            print("  ‖         Invalid
input                                                 ‖")
            return None
    except :
        print("  ‖         Invalid
input                                                 ‖")
        return None

# SEARCH INDEX OF NUM
def SearchI(puzz, num) :
    for i in range(len(puzz)) :
        if (puzz[i] == num) :
            return i

    return -1

# PRINT PUZZLE
def printPuzzle(puzz):
    print("                                ╔════╦════╦════╦════╗")
    for i in range(4):
        print("                                ", end = "")
        for j in range(4):
            print("‖ ",end="")
            if (puzz[i][j] == 16) :
                print("   ", end = "")
                continue
            print("%02d " % puzz[i][j], end = "")
        print("‖")
        if(i != 3):
            print("                                ╠════╬════╬════╬════╣")
    print("                                ╚════╩════╩════╩════╝")
```

```
# CONVERT PUZZLE TO LIST
def puzzleToList(Puzzle) :
    puzz = ""
    temp = (np.reshape(Puzzle, 16)).tolist()
    for i in range(16) :
        puzz += str(temp[i])

    return puzz

# FIND KURANG(I) + X (BASIS POSITION)
# TO CHECK IF PUZZLE IS REACHABLE
def Reachable(Puzzle) :
    # 1. Convert Puzzle to List
    puzz = (np.reshape(Puzzle.mtx, 16)).tolist()

    # 2. Find Kurang(i)
    count = 0
    print("                                    ╔═══╦═══════════╗      ")
    print("                                    ║  i ║ kurang(i) ║      ")
    print("                                    ╠═══╬═══════════╣      ")
    for i in range (1,17) :
        temp = 0
        index = SearchI(puzz, i)
        for j in range (index, 16) :
            if (i > puzz[j]) :
                temp += 1
        count += temp
        print("                                    ", end = "")
        if (i < 10) :
            print(" %d" % i, end = "")
        else :
            print("%d" % i, end = "")
        print("  ", end="")
        if (temp < 10) :
            print(" %d" % temp, end = "")
        else :
            print("%d" % temp, end = "")
        print("     ")
    print("                                    ╚═══╩═══════════╝")

    # 3. Find basis position
    if ((Puzzle.zero[0] + Puzzle.zero[1]) % 2 != 0) :
        count += 1

    return count

# SOLVE PUZZLE
def solvePuzzle(PuzzPar) :
    # 1. Initialize Time
    now = time.time()
    # 2. Initialize Puzzle
    currPuzz = PuzzPar
    # 3. Initialize Checked Dictionary
    checked = {}
```

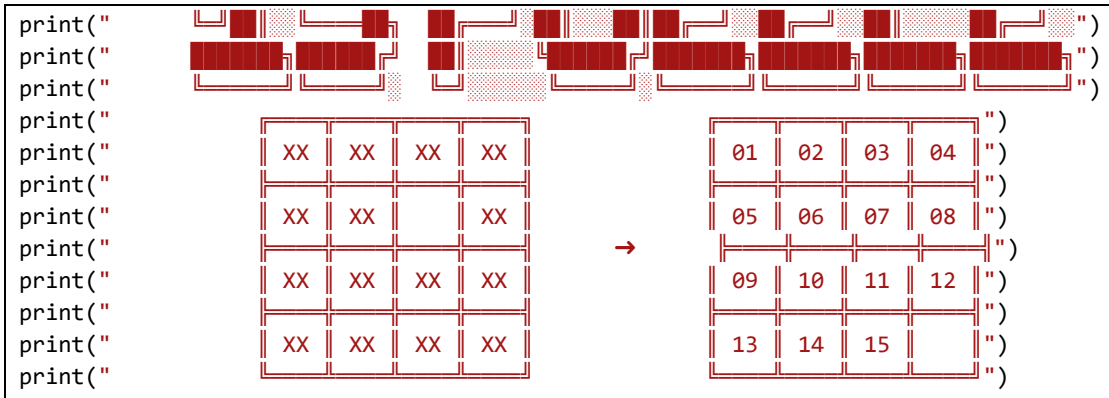
```
    puzz = puzzleToList(currPuzz.mtx)
    checked[puzz] = True
    # 4. Initialize HeapQueue
    pq = []
    # 5. Initialize node
    simpul = 0
    # 6. Loop until Puzzle = Goal State
    while (not (isFinish(currPuzz))) :
        # Check last path
        if (len(currPuzz.path) != 0) :
            path = currPuzz.path[len(currPuzz.path)-1]
        else :
            path = None

        # Check Up
        if (currPuzz.zero[0] != 0 and path != "DOWN") :
            currPuzz.up = Puzzle()
            currPuzz.up.mtx = np.copy(currPuzz.mtx)
            currPuzz.up.mtx[currPuzz.zero[0]][currPuzz.zero[1]] =
currPuzz.up.mtx[currPuzz.zero[0]-1][currPuzz.zero[1]]
            currPuzz.up.mtx[currPuzz.zero[0]-1][currPuzz.zero[1]] = 16
            temp = puzzleToList(currPuzz.up.mtx)
            if (temp not in checked) :
                currPuzz.up.path = currPuzz.path + ["UP"]
                currPuzz.up.zero = [currPuzz.zero[0]-1, currPuzz.zero[1]]
                currPuzz.up.cost = currPuzz.up.countCost() + len(currPuzz.up.path)
                heapq.heappush(pq, (currPuzz.up.cost, currPuzz.up))
                simpul += 1
                if (isFinish(currPuzz.up)) :
                    currPuzz = currPuzz.up
                    break

        # Check Down
        if (currPuzz.zero[0] != 3 and path != "UP") :
            currPuzz.down = Puzzle()
            currPuzz.down.mtx = np.copy(currPuzz.mtx)
            currPuzz.down.mtx[currPuzz.zero[0]][currPuzz.zero[1]] =
currPuzz.down.mtx[currPuzz.zero[0]+1][currPuzz.zero[1]]
            currPuzz.down.mtx[currPuzz.zero[0]+1][currPuzz.zero[1]] = 16
            temp = puzzleToList(currPuzz.down.mtx)
            if (temp not in checked) :
                currPuzz.down.path = currPuzz.path + ["DOWN"]
                currPuzz.down.zero = [currPuzz.zero[0]+1, currPuzz.zero[1]]
                currPuzz.down.cost = currPuzz.down.countCost() + len(currPuzz.down.path)
                heapq.heappush(pq, (currPuzz.down.cost, currPuzz.down))
                simpul += 1
                if (isFinish(currPuzz.down)) :
                    currPuzz = currPuzz.down
                    break

        # Check Left
        if (currPuzz.zero[1] != 0 and path != "RIGHT") :
            currPuzz.left = Puzzle()
            currPuzz.left.mtx = np.copy(currPuzz.mtx)
```

```
            currPuzz.left.mtx[currPuzz.zero[0]][currPuzz.zero[1]] =
currPuzz.left.mtx[currPuzz.zero[0]][currPuzz.zero[1]-1]
            currPuzz.left.mtx[currPuzz.zero[0]][currPuzz.zero[1]-1] = 16
            temp = puzzleToList(currPuzz.left.mtx)
            if (temp not in checked) :
                currPuzz.left.path = currPuzz.path + ["LEFT"]
                currPuzz.left.zero = [currPuzz.zero[0], currPuzz.zero[1]-1]
                currPuzz.left.cost = currPuzz.left.countCost() + len(currPuzz.left.path)
                heapq.heappush(pq, (currPuzz.left.cost, currPuzz.left))
                simpul += 1
                if (isFinish(currPuzz.left)) :
                    currPuzz = currPuzz.left
                    break

        # Check Right
        if (currPuzz.zero[1] != 3 and path != "LEFT") :
            currPuzz.right = Puzzle()
            currPuzz.right.mtx = np.copy(currPuzz.mtx)
            currPuzz.right.mtx[currPuzz.zero[0]][currPuzz.zero[1]] =
currPuzz.right.mtx[currPuzz.zero[0]][currPuzz.zero[1]+1]
            currPuzz.right.mtx[currPuzz.zero[0]][currPuzz.zero[1]+1] = 16
            temp = puzzleToList(currPuzz.right.mtx)
            if (temp not in checked) :
                currPuzz.right.path = currPuzz.path + ["RIGHT"]
                currPuzz.right.zero = [currPuzz.zero[0], currPuzz.zero[1]+1]
                currPuzz.right.cost = currPuzz.right.countCost() +
len(currPuzz.right.path)
                heapq.heappush(pq, (currPuzz.right.cost, currPuzz.right))
                simpul += 1
                if (isFinish(currPuzz.right)) :
                    currPuzz = currPuzz.right
                    break

        currPuzz = heapq.heappop(pq)[1]
        puzz = puzzleToList(currPuzz.mtx)
        checked[puzz] = True

    t = time.time() - now
    # 7. Print Solution Puzzle
    start = PuzzPar.mtx
    zero = PuzzPar.zero
    for i in range (len(currPuzz.path)) :
        # Change Position
        if (currPuzz.path[i] == "UP") :
            start[zero[0]][zero[1]] = start[zero[0]-1][zero[1]]
            start[zero[0]-1][zero[1]] = 16
            zero = (zero[0]-1, zero[1])
        elif (currPuzz.path[i] == "DOWN") :
            start[zero[0]][zero[1]] = start[zero[0]+1][zero[1]]
            start[zero[0]+1][zero[1]] = 16
            zero = (zero[0]+1, zero[1])
        elif (currPuzz.path[i] == "LEFT") :
            start[zero[0]][zero[1]] = start[zero[0]][zero[1]-1]
            start[zero[0]][zero[1]-1] = 16
            zero = (zero[0], zero[1]-1)
```

```python
        elif (currPuzz.path[i] == "RIGHT") :
            start[zero[0]][zero[1]] = start[zero[0]][zero[1]+1]
            start[zero[0]][zero[1]+1] = 16
            zero = (zero[0], zero[1]+1)

        # Print Puzzle
        print("                                  STEP %d = %s" % (i+1, currPuzz.path[i]))
        printPuzzle(start)

    return currPuzz, t, simpul
```

b. main.py

```python
import puzzle

def Mainmenu(first) :
    if first == True :
        print("  ╔═══════════════════════════════════════════════════════════════════════╗")
    print("  ║         1. Input From EXTERNAL FILE (inside the test dir)                ║")
    print("  ║         2. Input From CONSOLE                                            ║")
    print("  ║         3. EXIT                                                          ║")
    print("  ║        =========================================================        ║")
    try :
        op = int(input("            Choose Menu : "))
        if (op == 1) :
            filename = input("            File Path : ")
            Puz15 = puzzle.readPuzzleFromFile(".\\test\\" + filename)
        elif (op == 2) :
            Puz15 = puzzle.readPuzzleFromConsole()
        elif (op == 3) :
            Puz15 = None
        print("  ╚═══════════════════════════════════════════════════════════════════════╝")
        return op, Puz15
    except :
        print("  ║                   T R Y   A G A I N ! (invalid input)                 ║")
        print("  ║        =========================================================        ║")
        return Mainmenu(False)

print("                             W E L C O M E   T O                  ")

print("      ░░███╗░░███████╗  ██████╗░██╗░░░██╗███████╗███████╗██╗░░░░░███████╗")
print("      ░████║░░██╔════╝  ██╔══██╗██║░░░██║╚════██║╚════██║██║░░░░░██╔════╝")
print("      ██╔██║░░██████╗░  ██████╔╝██║░░░██║░░███╔═╝░░███╔═╝██║░░░░░█████╗░░")
```

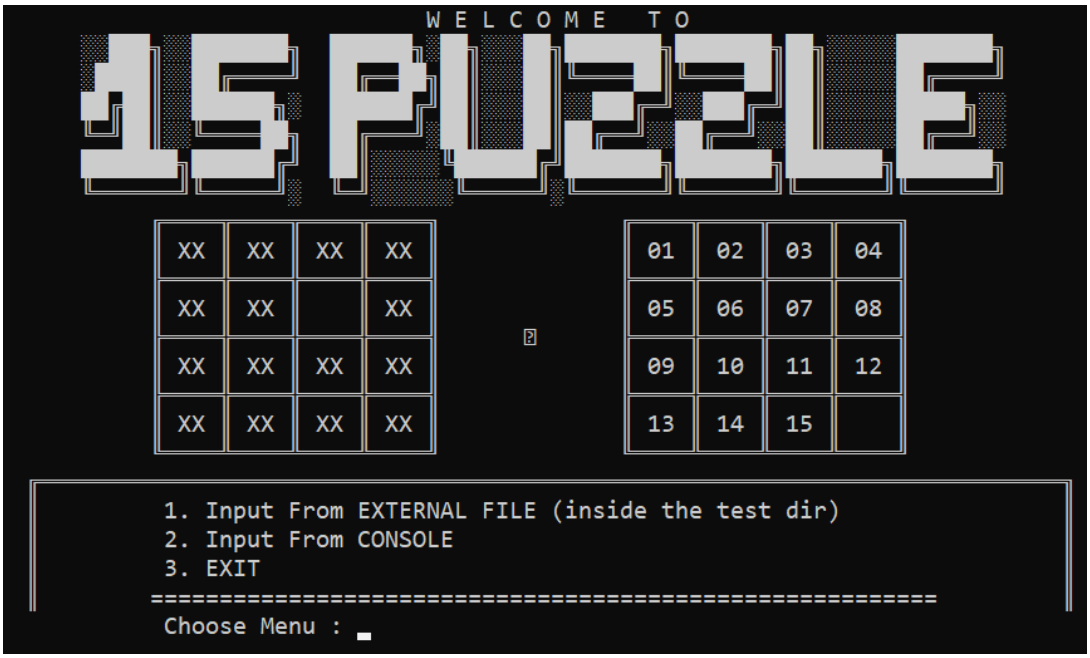



```
op, Puz15 = Mainmenu(True)

while (op!= 3) :
    if (Puz15 != None) :
        print()
        print("                                    P U Z Z L E")
        puzzle.printPuzzle(Puz15.mtx)
        count= puzzle.Reachable(Puz15)
        print("                                  Kurang(i) = %d" % count)
        if (count % 2 == 0) :
            print("\n                      ===========   S O L U T I O N  ===========")
            Result, time, simpul = puzzle.solvePuzzle(Puz15)
            print("                                    Node Count = %d" % simpul)
            print("                                    Time = %f s" % (time))
        else :
            print("                               Puzzle can not be solved !!")


    op, Puz15 = Mainmenu(True)
```

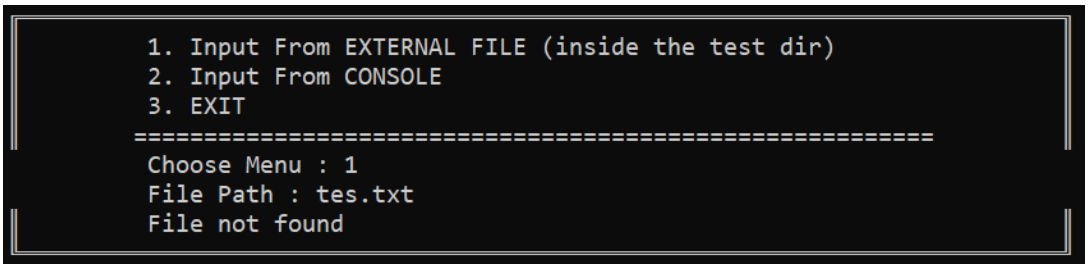
II. HASIL PERCOBAAN

2.1 INTERAKSI I/O

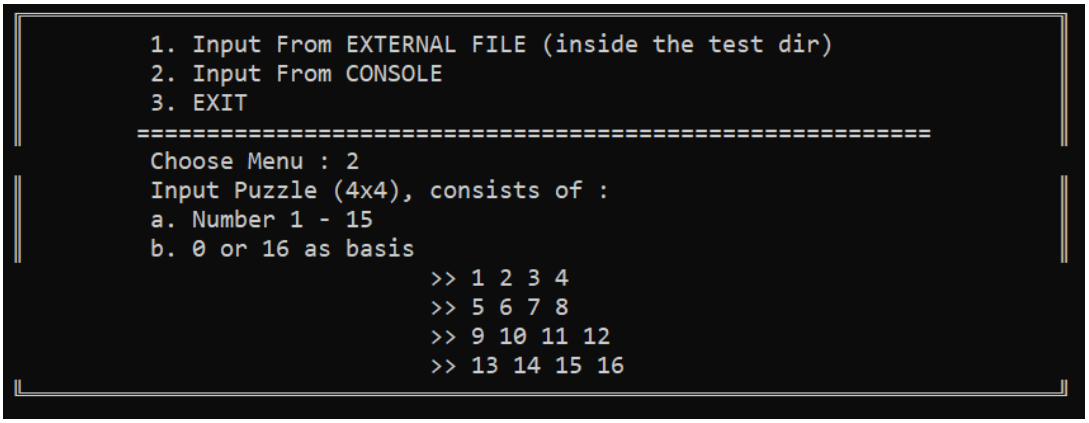
a. Interaksi *Input* Menu Awal



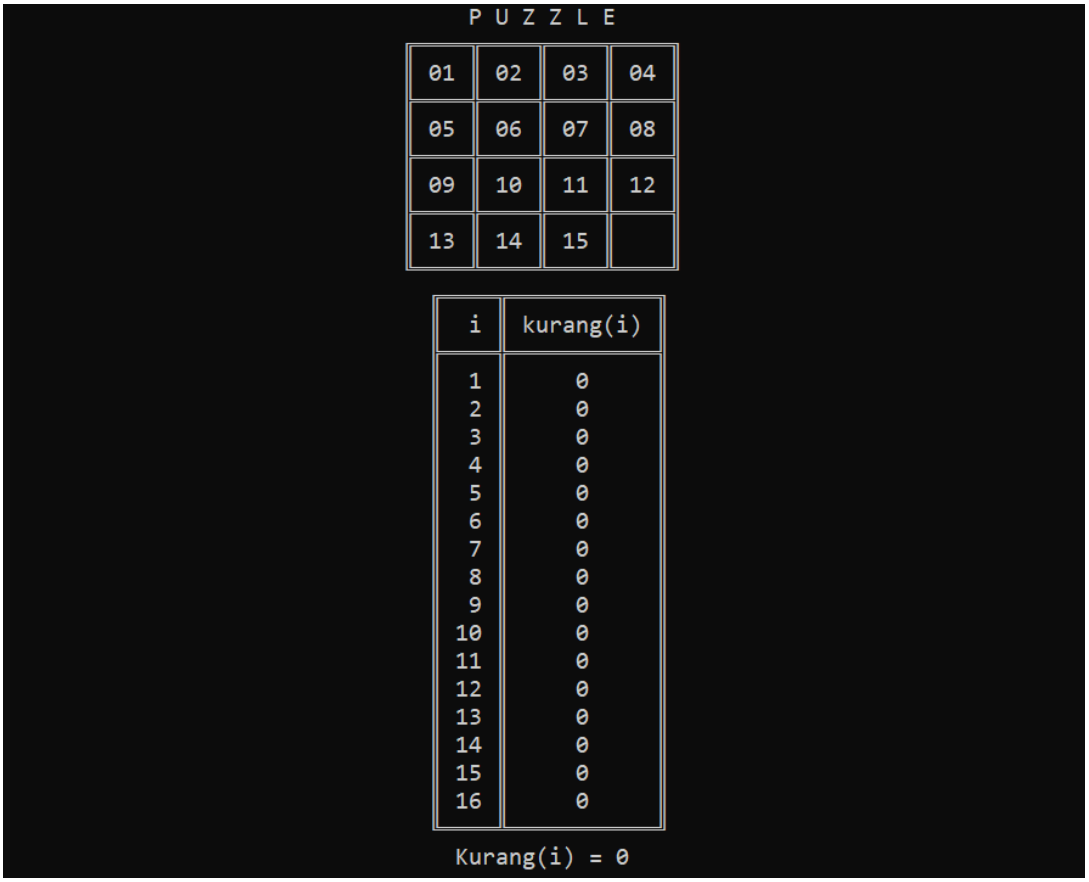
b. Interaksi *Input* Menu 1 *(External File)*



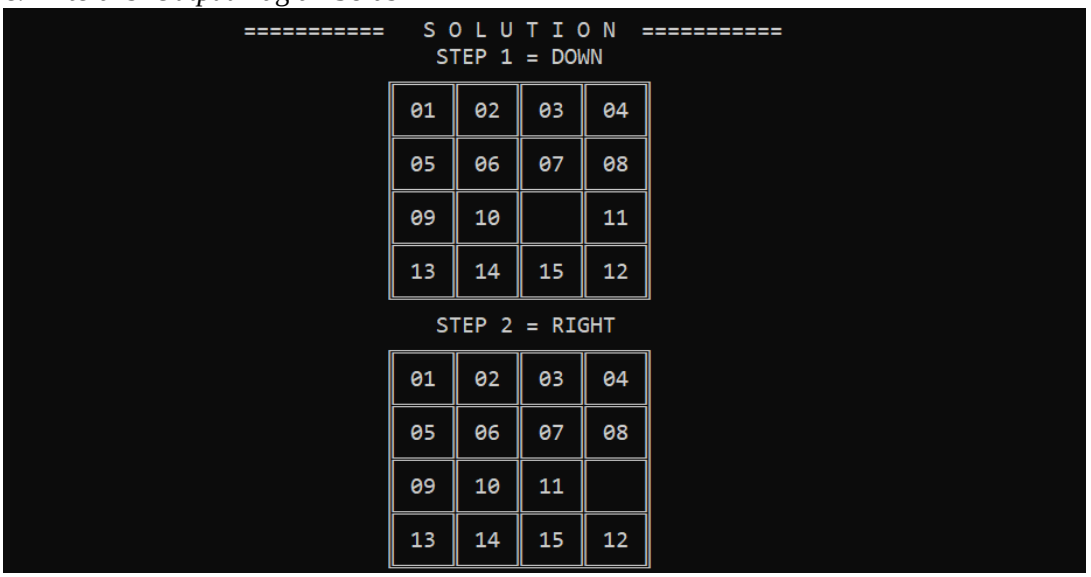
c. Interaksi *Input* Menu 2 (*Console)*



d. Interaksi *Output* Bagian Kurang(i)



e. Interaksi *Output* Bagian Solusi



STEP 3 = DOWN

01	02	03	04
05	06	07	08
09	10	11	12
13	14	15	

Node Count = 9
Time = 0.000000 s

2.2 UJI COBA TXT

Percobaan 1

Nama File	tc1easy.txt
Bentuk Awal	1 2 3 4 5 6 16 8 9 10 7 11 13 14 15 12

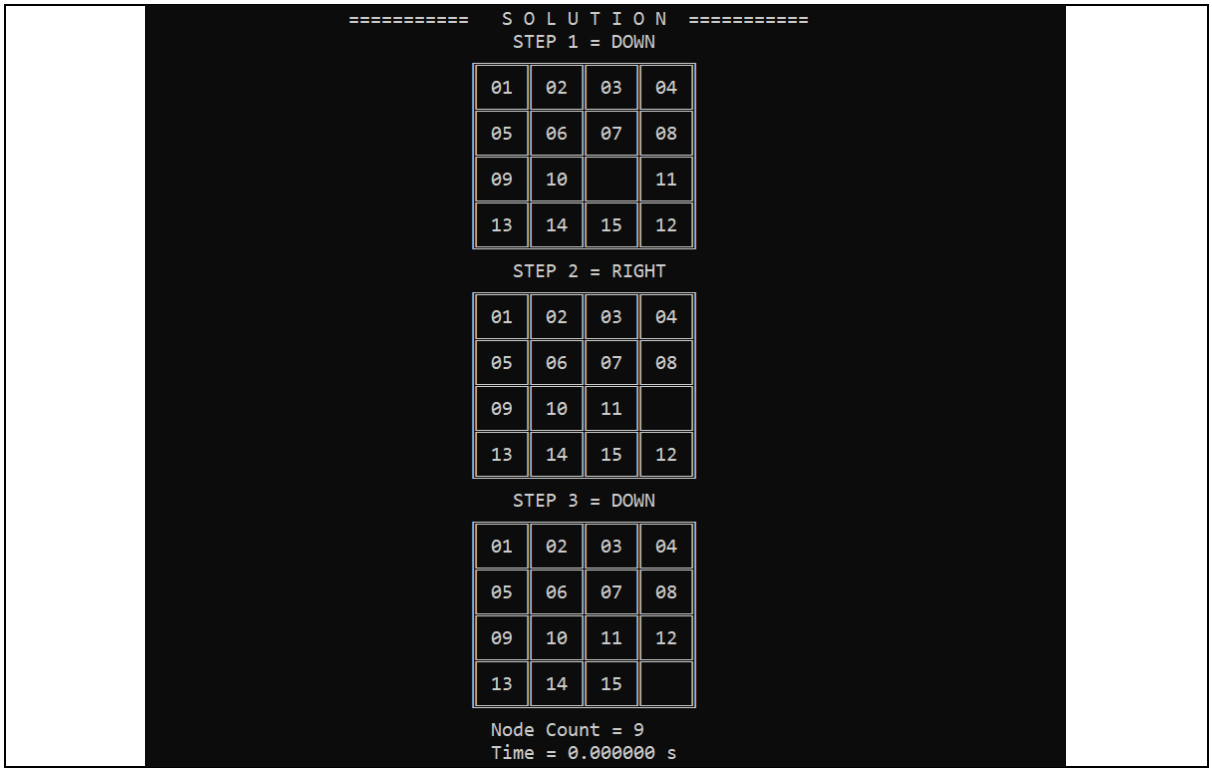
Hasil

P U Z Z L E

01	02	03	04
05	06		08
09	10	07	11
13	14	15	12

i	kurang(i)
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	1
9	1
10	1
11	0
12	0
13	1
14	1
15	1
16	9

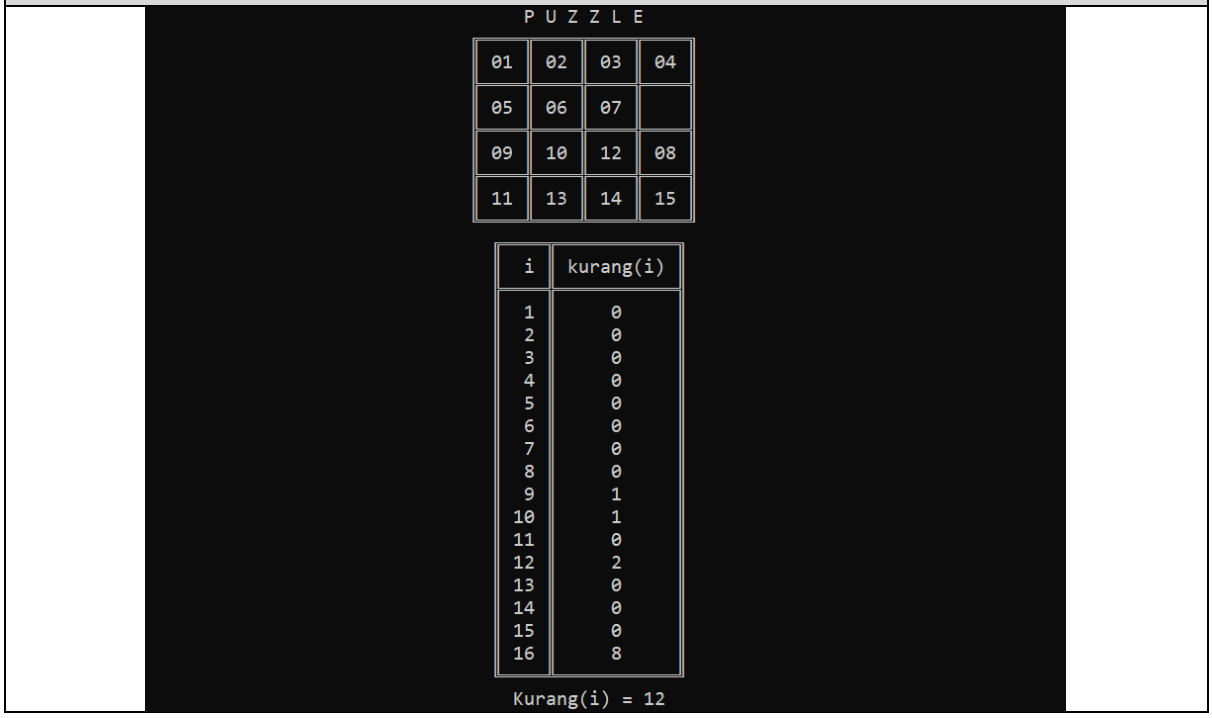
Kurang(i) = 16

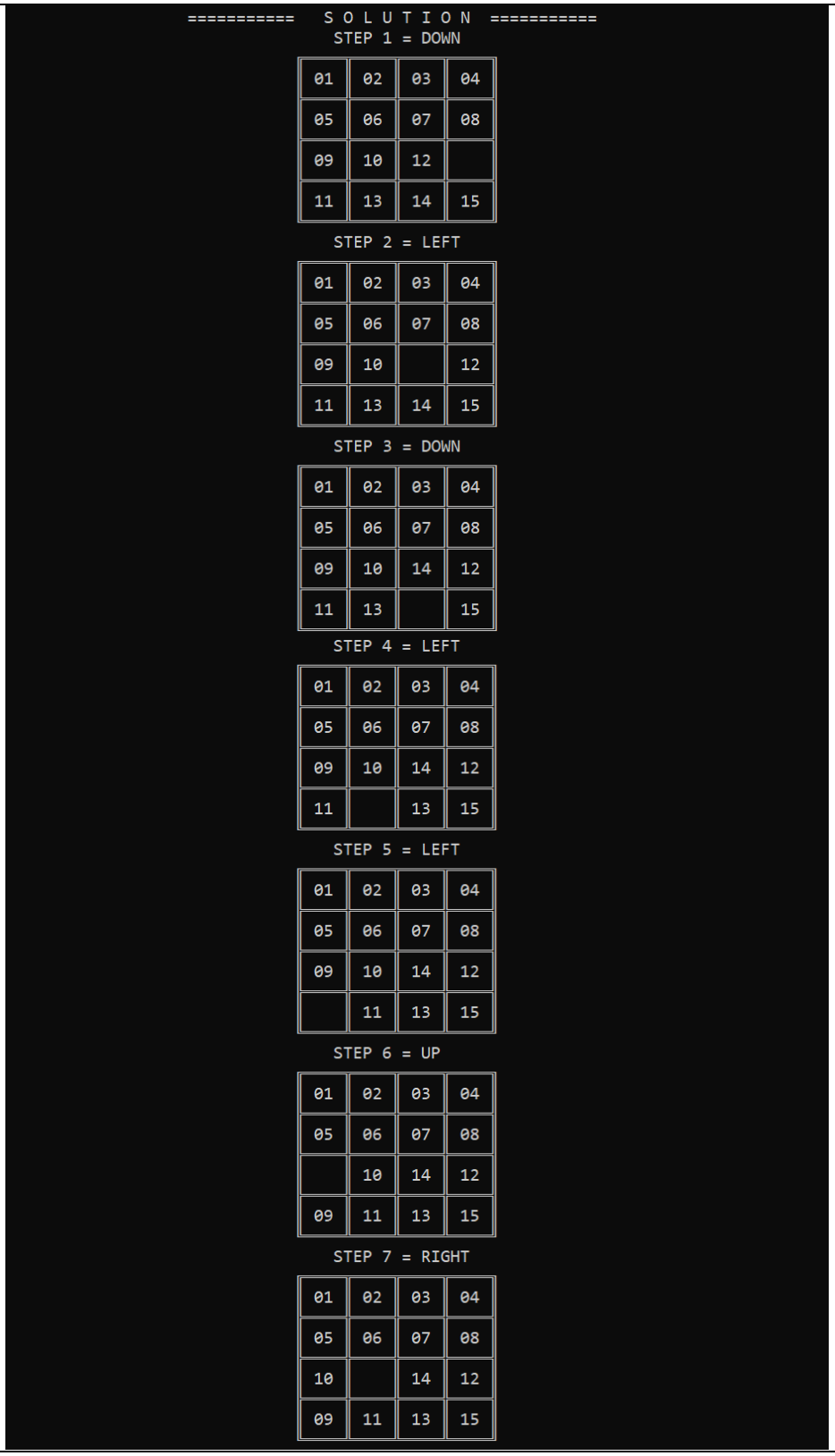


Percobaan 2

Nama File	tc2medium.txt
Bentuk Awal	1 2 3 4 5 6 7 16 9 10 12 8 11 13 14 15

Hasil




========== S O L U T I O N ==========
STEP 1 = DOWN
01 02 03 04
05 06 07 08
09 10 12
11 13 14 15
STEP 2 = LEFT
01 02 03 04
05 06 07 08
09 10 12
11 13 14 15
STEP 3 = DOWN
01 02 03 04
05 06 07 08
09 10 14 12
11 13 15
STEP 4 = LEFT
01 02 03 04
05 06 07 08
09 10 14 12
11 13 15
STEP 5 = LEFT
01 02 03 04
05 06 07 08
09 10 14 12
11 13 15
STEP 6 = UP
01 02 03 04
05 06 07 08
10 14 12
09 11 13 15
STEP 7 = RIGHT
01 02 03 04
05 06 07 08
10 14 12
09 11 13 15

STEP 8 = DOWN

01	02	03	04
05	06	07	08
10	11	14	12
09		13	15

STEP 9 = RIGHT

01	02	03	04
05	06	07	08
10	11	14	12
09	13		15

STEP 10 = UP

01	02	03	04
05	06	07	08
10	11		12
09	13	14	15

STEP 11 = LEFT

01	02	03	04
05	06	07	08
10		11	12
09	13	14	15

STEP 12 = LEFT

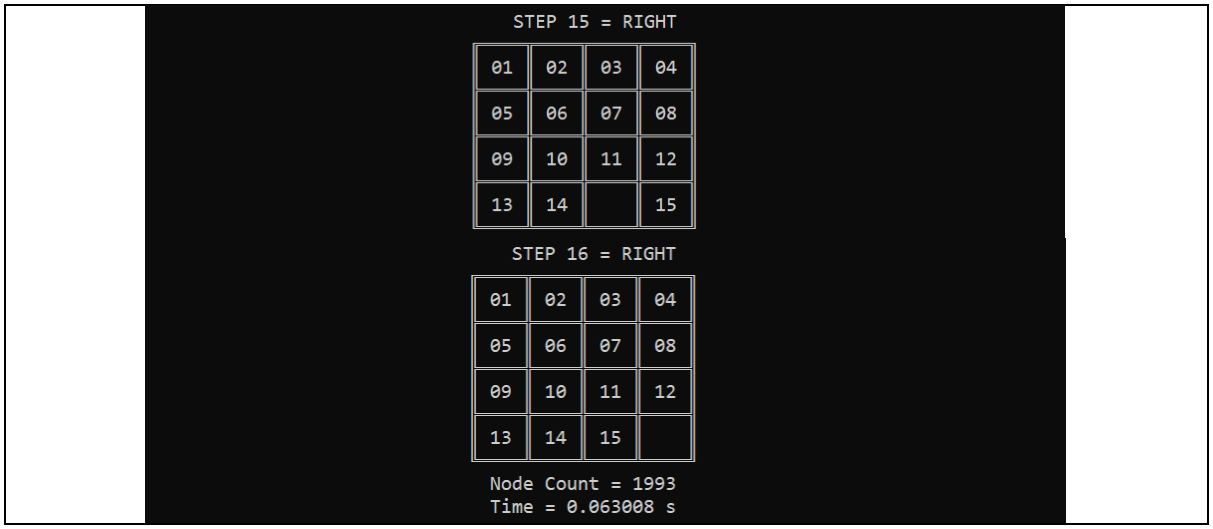
01	02	03	04
05	06	07	08
	10	11	12
09	13	14	15

STEP 13 = DOWN

01	02	03	04
05	06	07	08
09	10	11	12
	13	14	15

STEP 14 = RIGHT

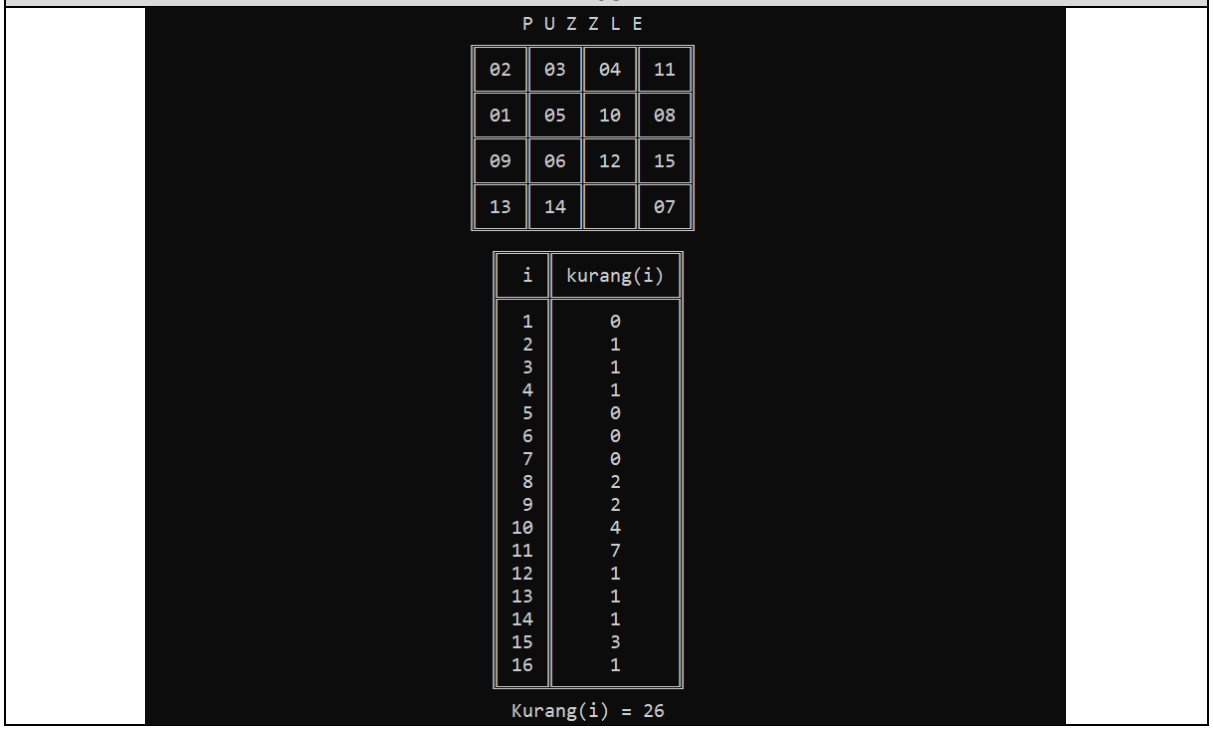
01	02	03	04
05	06	07	08
09	10	11	12
13		14	15

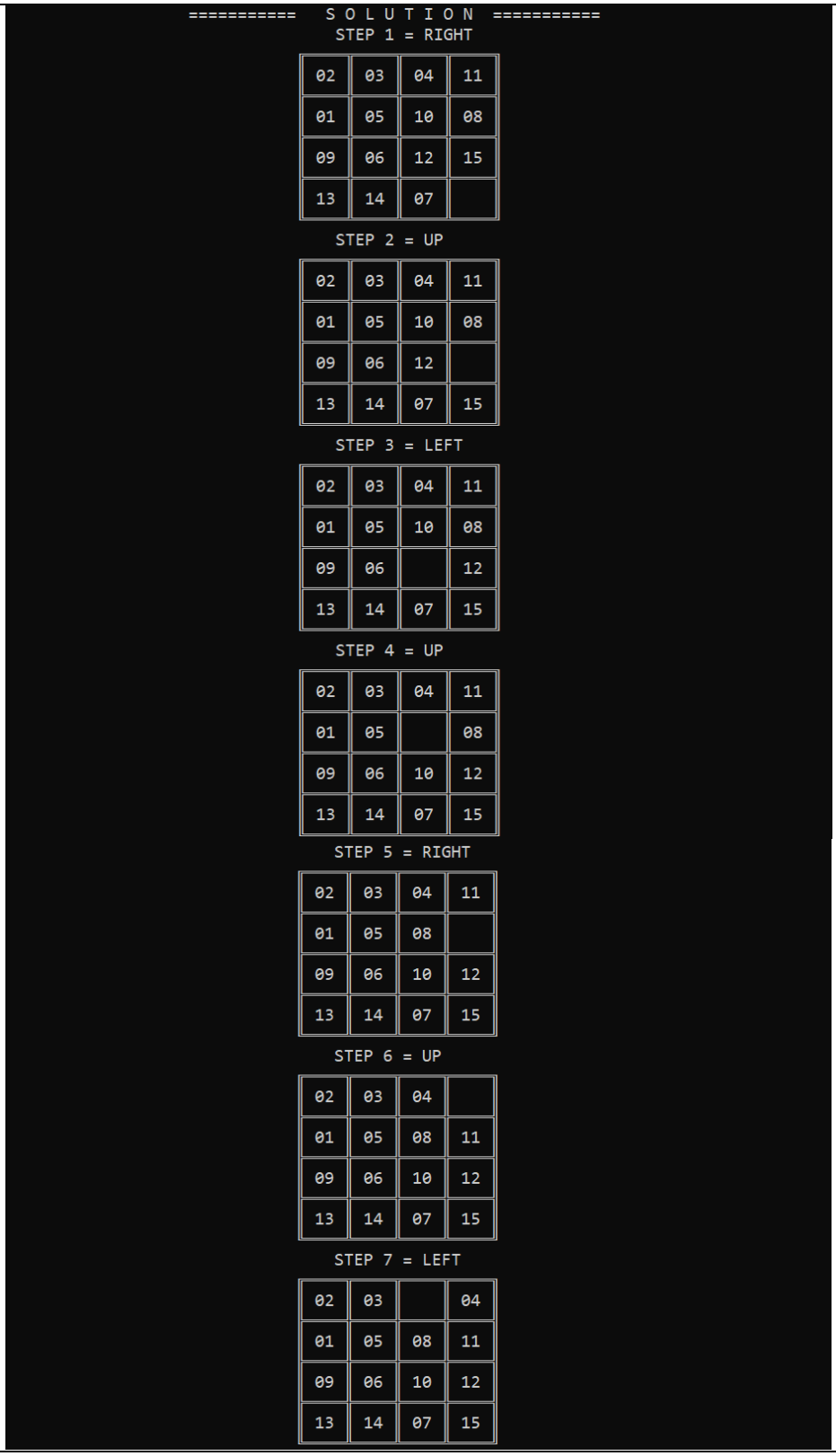


Percobaan 3

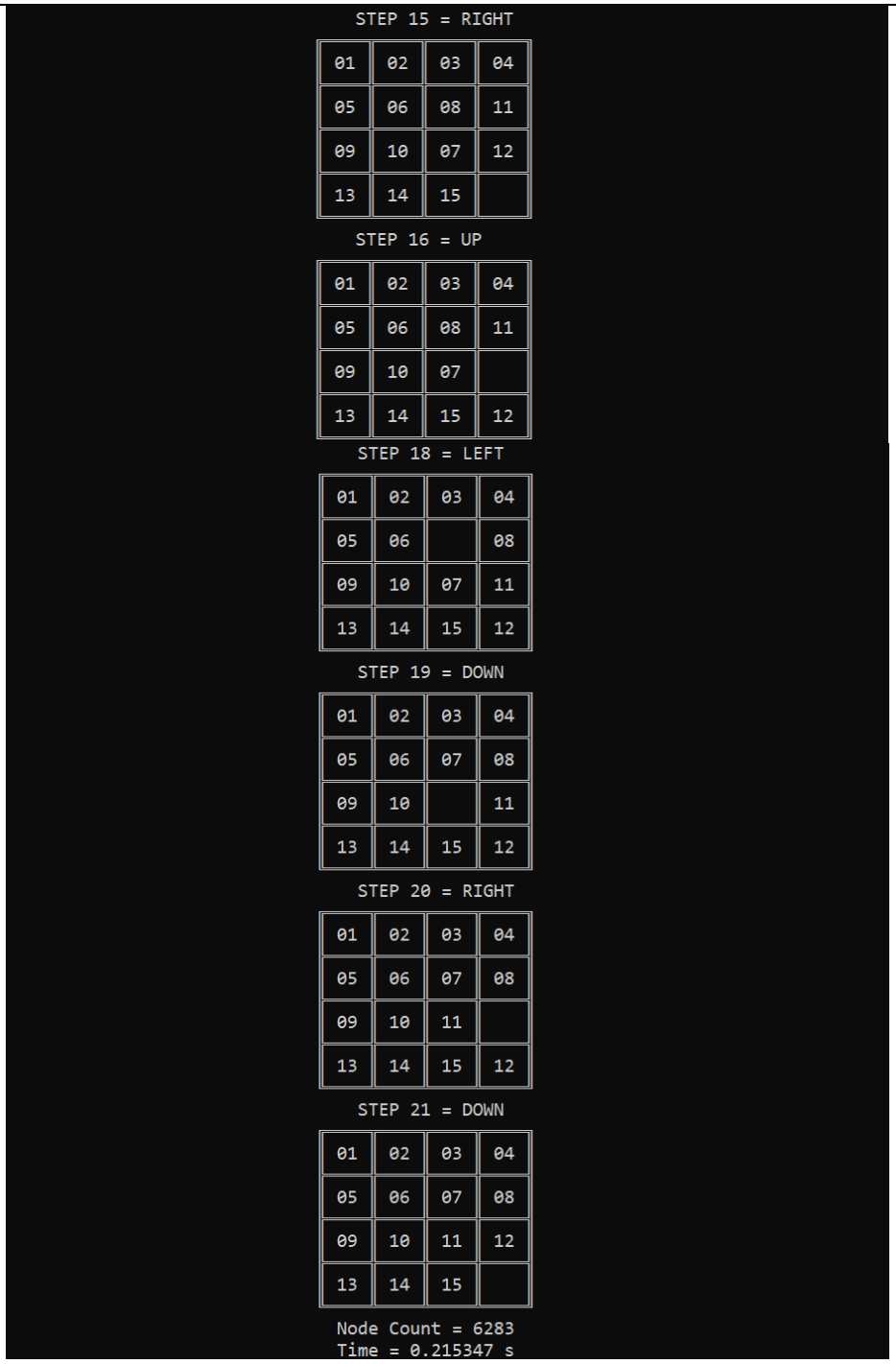
Nama File	tc3intermediate.txt
Bentuk Awal	2 3 4 11 1 5 10 8 9 6 12 15 13 14 16 7

Hasil




========== S O L U T I O N ==========
STEP 1 = RIGHT
02 03 04 11
01 05 10 08
09 06 12 15
13 14 07
STEP 2 = UP
02 03 04 11
01 05 10 08
09 06 12
13 14 07 15
STEP 3 = LEFT
02 03 04 11
01 05 10 08
09 06 12
13 14 07 15
STEP 4 = UP
02 03 04 11
01 05 08
09 06 10 12
13 14 07 15
STEP 5 = RIGHT
02 03 04 11
01 05 08
09 06 10 12
13 14 07 15
STEP 6 = UP
02 03 04
01 05 08 11
09 06 10 12
13 14 07 15
STEP 7 = LEFT
02 03 04
01 05 08 11
09 06 10 12
13 14 07 15


STEP 8 = LEFT
02 03 04
01 05 08 11
09 06 10 12
13 14 07 15
STEP 9 = LEFT
02 03 04
01 05 08 11
09 06 10 12
13 14 07 15
STEP 10 = DOWN
01 02 03 04
05 08 11
09 06 10 12
13 14 07 15
STEP 11 = RIGHT
01 02 03 04
05 08 11
09 06 10 12
13 14 07 15
STEP 12 = DOWN
01 02 03 04
05 06 08 11
09 10 12
13 14 07 15
STEP 13 = RIGHT
01 02 03 04
05 06 08 11
09 10 12
13 14 07 15
STEP 14 = DOWN
01 02 03 04
05 06 08 11
09 10 07 12
13 14 15


STEP 15 = RIGHT
01 02 03 04
05 06 08 11
09 10 07 12
13 14 15
STEP 16 = UP
01 02 03 04
05 06 08 11
09 10 07
13 14 15 12
STEP 18 = LEFT
01 02 03 04
05 06 08
09 10 07 11
13 14 15 12
STEP 19 = DOWN
01 02 03 04
05 06 07 08
09 10 11
13 14 15 12
STEP 20 = RIGHT
01 02 03 04
05 06 07 08
09 10 11
13 14 15 12
STEP 21 = DOWN
01 02 03 04
05 06 07 08
09 10 11 12
13 14 15
Node Count = 6283
Time = 0.215347 s

Percobaan 4

Nama File	tc4expert.txt
Bentuk Awal	1 2 3 4 5 6 11 15 9 14 13 10 16 7 8 12

Hasil

P U Z Z L E

01	02	03	04
05	06	11	15
09	14	13	10
	07	08	12

i	kurang(i)
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	2
10	2
11	4
12	0
13	4
14	5
15	7
16	3

Kurang(i) = 28

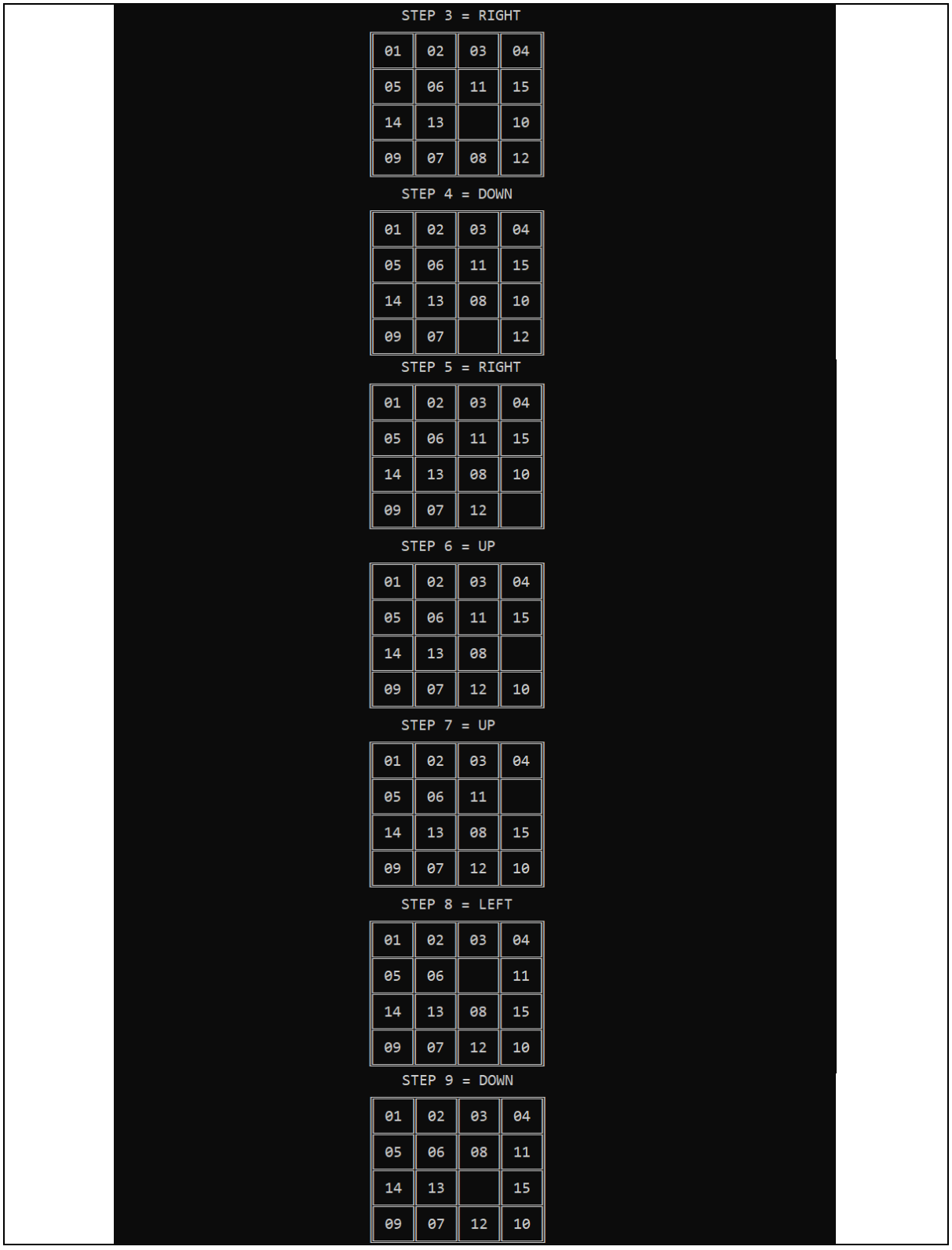
========== S O L U T I O N ==========

STEP 1 = UP

01	02	03	04
05	06	11	15
	14	13	10
09	07	08	12

STEP 2 = RIGHT

01	02	03	04
05	06	11	15
14		13	10
09	07	08	12


STEP 3 = RIGHT
01 02 03 04
05 06 11 15
14 13 10
09 07 08 12
STEP 4 = DOWN
01 02 03 04
05 06 11 15
14 13 08 10
09 07 12
STEP 5 = RIGHT
01 02 03 04
05 06 11 15
14 13 08 10
09 07 12
STEP 6 = UP
01 02 03 04
05 06 11 15
14 13 08
09 07 12 10
STEP 7 = UP
01 02 03 04
05 06 11
14 13 08 15
09 07 12 10
STEP 8 = LEFT
01 02 03 04
05 06 11
14 13 08 15
09 07 12 10
STEP 9 = DOWN
01 02 03 04
05 06 08 11
14 13 15
09 07 12 10

STEP 10 = DOWN

01	02	03	04
05	06	08	11
14	13	12	15
09	07		10

STEP 11 = RIGHT

01	02	03	04
05	06	08	11
14	13	12	15
09	07	10	

STEP 12 = UP

01	02	03	04
05	06	08	11
14	13	12	
09	07	10	15

STEP 13 = LEFT

01	02	03	04
05	06	08	11
14	13		12
09	07	10	15

STEP 14 = DOWN

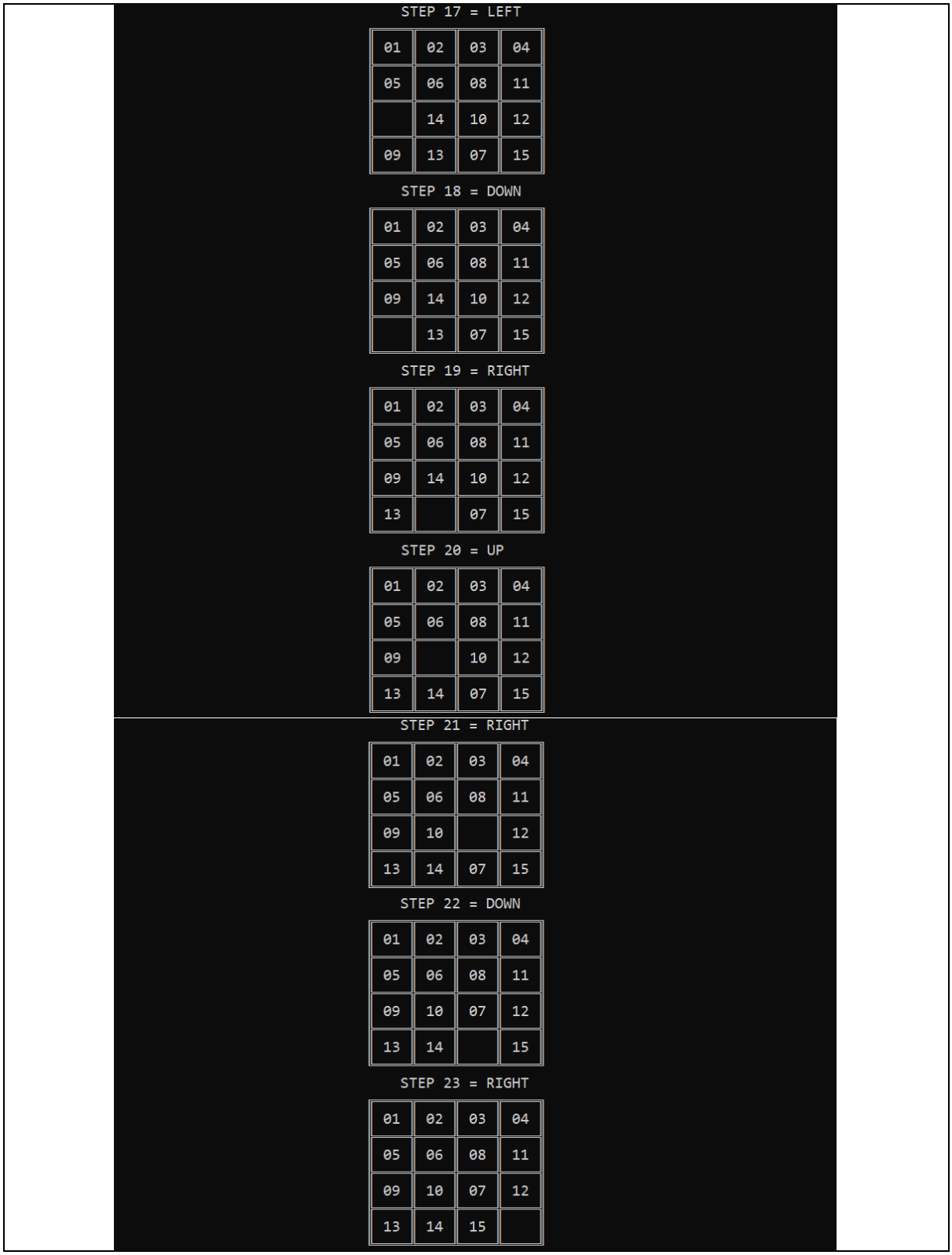
01	02	03	04
05	06	08	11
14	13	10	12
09	07		15

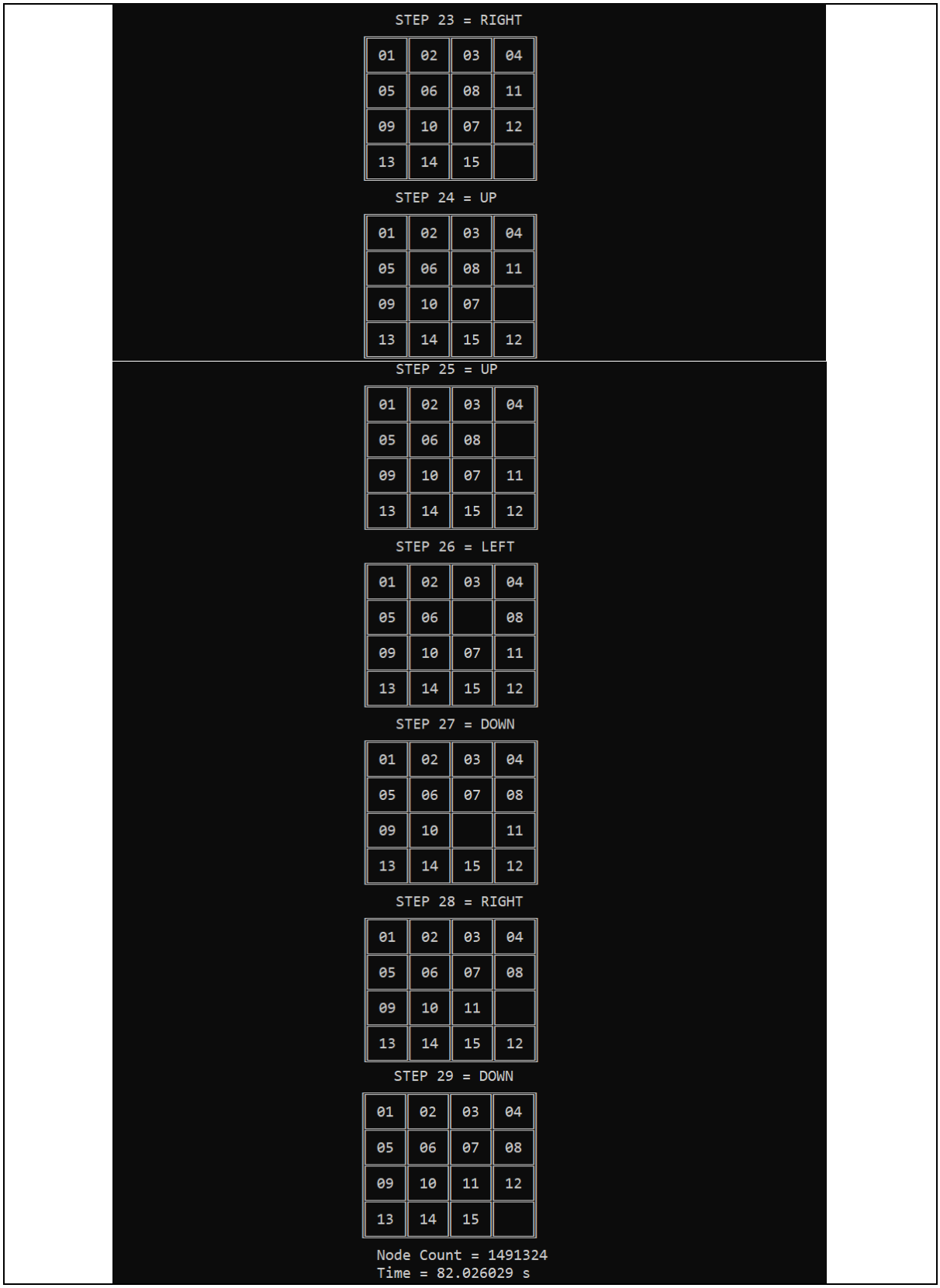
STEP 15 = LEFT

01	02	03	04
05	06	08	11
14	13	10	12
09		07	15

STEP 16 = UP

01	02	03	04
05	06	08	11
14		10	12
09	13	07	15

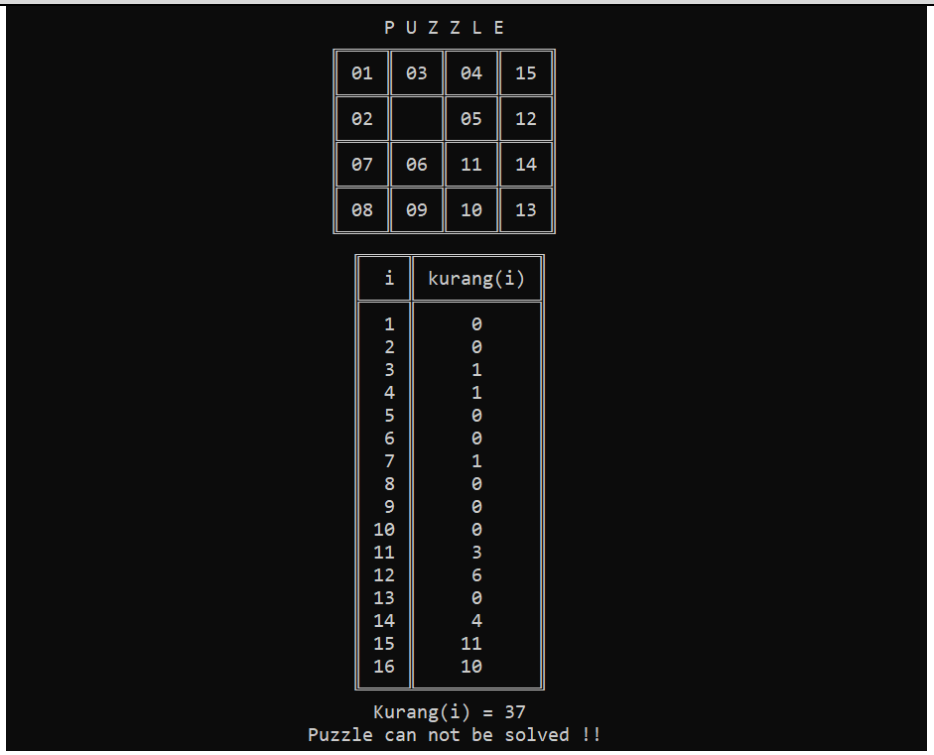

STEP 17 = LEFT
01 02 03 04
05 06 08 11
14 10 12
09 13 07 15
STEP 18 = DOWN
01 02 03 04
05 06 08 11
09 14 10 12
13 07 15
STEP 19 = RIGHT
01 02 03 04
05 06 08 11
09 14 10 12
13 07 15
STEP 20 = UP
01 02 03 04
05 06 08 11
09 10 12
13 14 07 15
STEP 21 = RIGHT
01 02 03 04
05 06 08 11
09 10 12
13 14 07 15
STEP 22 = DOWN
01 02 03 04
05 06 08 11
09 10 07 12
13 14 15
STEP 23 = RIGHT
01 02 03 04
05 06 08 11
09 10 07 12
13 14 15


STEP 23 = RIGHT
01 02 03 04
05 06 08 11
09 10 07 12
13 14 15
STEP 24 = UP
01 02 03 04
05 06 08 11
09 10 07
13 14 15 12
STEP 25 = UP
01 02 03 04
05 06 08
09 10 07 11
13 14 15 12
STEP 26 = LEFT
01 02 03 04
05 06 08
09 10 07 11
13 14 15 12
STEP 27 = DOWN
01 02 03 04
05 06 07 08
09 10 11
13 14 15 12
STEP 28 = RIGHT
01 02 03 04
05 06 07 08
09 10 11
13 14 15 12
STEP 29 = DOWN
01 02 03 04
05 06 07 08
09 10 11 12
13 14 15
Node Count = 1491324
Time = 82.026029 s

Percobaan 5

Nama File	tc5unsolved.txt
Bentuk Awal	1 3 4 15 2 0 5 12 7 6 11 14 8 9 10 13

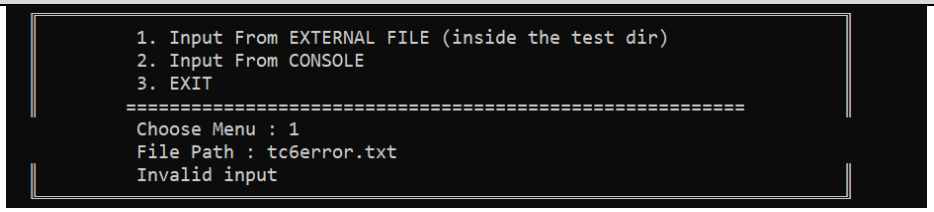
Hasil



Percobaan 6

Nama File	tc6error.txt
Bentuk Awal	1 2 3 4 5 6 16 8 9 10 7 11 13 14 15 11

Hasil



2.3 UJI COBA MANUAL

Percobaan 7

Bentuk Awal

```
>> 1 2 3 16
>> 5 6 7 4
>> 9 10 12 8
>> 13 14 11 15
```

Hasil

```
P U Z Z L E

| 01 | 02 | 03 |    |
| 05 | 06 | 07 | 04 |
| 09 | 10 | 12 | 08 |
| 13 | 14 | 11 | 15 |

| i  | kurang(i) |
| 1  |  0 |
| 2  |  0 |
| 3  |  0 |
| 4  |  0 |
| 5  |  1 |
| 6  |  1 |
| 7  |  1 |
| 8  |  0 |
| 9  |  1 |
| 10 |  1 |
| 11 |  0 |
| 12 |  2 |
| 13 |  1 |
| 14 |  1 |
| 15 |  0 |
| 16 | 12 |

Kurang(i) = 22

========== S O L U T I O N ==========

STEP 1 = DOWN

| 01 | 02 | 03 | 04 |
| 05 | 06 | 07 |    |
| 09 | 10 | 12 | 08 |
| 13 | 14 | 11 | 15 |

STEP 2 = DOWN

| 01 | 02 | 03 | 04 |
| 05 | 06 | 07 | 08 |
| 09 | 10 | 12 |    |
| 13 | 14 | 11 | 15 |

STEP 3 = LEFT

| 01 | 02 | 03 | 04 |
| 05 | 06 | 07 | 08 |
| 09 | 10 |    | 12 |
| 13 | 14 | 11 | 15 |
```

```
STEP 4 = DOWN
```

01	02	03	04
05	06	07	08
09	10	11	12
13	14		15

```
STEP 5 = RIGHT
```

01	02	03	04
05	06	07	08
09	10	11	12
13	14	15	

```
Node Count = 11
Time = 0.000968 s
```

Percobaan 8

Bentuk Awal		>> 1 2 4 3 >> 7 8 0 5 >> 6 9 10 11 >> 12 13 14 15	

Hasil

```
P U Z Z L E
```

01	02	04	03
07	08		05
06	09	10	11
12	13	14	15

i	kurang(i)
1	0
2	0
3	0
4	1
5	0
6	0
7	2
8	2
9	0
10	0
11	0
12	0
13	0
14	0
15	0
16	9

```
Kurang(i) = 15
Puzzle can not be solved !!
```

LAMPIRAN

1. Repository Github :

https://github.com/raniadf/15puzzle

2. Berkas Teks :

tc1easy	1 2 3 4 5 6 16 8 9 10 7 11 13 14 15 12
tc2medium	1 2 3 4 5 6 7 16 9 10 12 8 11 13 14 15
tc3intermediate	2 3 4 11 1 5 10 8 9 6 12 15 13 14 16 7
tc4expert	1 2 3 4 5 6 11 15 9 14 13 10 16 7 8 12
tc5unsolved	1 3 4 15 2 0 5 12 7 6 11 14 8 9 10 13

3. Checklist :

Poin	**Ya**	**Tidak**
1. Program berhasil dikompilasi	✓	
2. Program berhasil *running*	✓	
3. Program dapat menerima input dan menuliskan output	✓	
4. Luaran sudah benar untuk semua data uji	✓	
5. Bonus dibuat		✓