Laporan Tugas Kecil 3

IF2211 Strategi Algoritma

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

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Daftar Isi

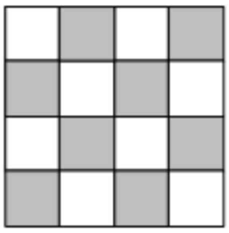
A. Algoritma Branch and Bound

Algoritma Branch and Bound dalam Penyelesaian Persoalan 15-Puzzle

1. Periksa apakah masukkan 15-puzzle dapat mencapai *goal state* (susunan akhir 15-puzzle) dengan menggunakan $\Sigma_{i=1}^{16} \mathrm{KURANG}(i) + X$.

   KURANG(i) adalah banyaknya ubin bernomor j sedemikian sehingga j < i dan POSISI(j) > POSISI(i). POSISI(i) adalah posisi ubin bernomor i pada susunan yang diperiksa.

   X bernilai 1 jika berada pada sel yang diarsir.

   Goal state hanya dapat dicapai dari status awal jika hasil dari $\Sigma_{i=1}^{16} \mathrm{KURANG}(i) + X$ bernilai genap.

   - Jika *goal state* tidak dapat dicapai, maka berhenti dan keluarkan pesan bahwa susunan akhir puzzle tidak dapat dicapai.
   - Jika *goal state* dapat dicapai, lanjut ke langkah kedua.
2. Masukkan puzzle sekarang ke dalam himpunan simpul mati dan periksa apakah puzzle sama dengan *goal state*.
   - Jika sama, berhenti dan tampilkan proses puzzle dari simpul awal sampai *goal state*.
   - Jika tidak sama, lanjut ke langkah ketiga.
3. Bangkitkan simpul anak yang mungkin dari matriks 15-puzzle sekarang.
4. Hitung cost (biaya) tiap simpul anak yang dibangkitkan dengan formula berikut.

   $\hat{c}(i) = \hat{f}(i) + \hat{g}(i)$.

   $\hat{f}(P)$: panjang lintasan dari simpul akar ke P.
   $\hat{g}(P)$: jumlah ubin tidak kosong yang tidak terdapat pada susunan akhir.

5. Masukkan simpul anak ke dalam antrian simpul hidup berdasarkan urutan cost dari terkecil sampai terbesar.
6. Ambil simpul dengan cost terkecil dari antrian simpul hidup dan periksa apakah simpul tersebut ada di himpunan simpul mati.
   - Jika simpul tersebut ada di himpunan simpul mati (berarti sudah pernah diperiksa sebelumnya), perika simpul dengan cost terkecil selanjutnya dari antrian simpul hidup.
   - Jika simpul tersebut belum ada di himpunan simpul mati, ulangi langkah kedua sampai mencapai *goal state* atau antrian simpul hidupnya kosong.

B. Kode Program

a. Modul Graph.py

Modul ini berisi kelas Node dan LiveNodeArray. Kelas Node berfungsi sebagai *blueprint* dari objek node, sedangkan kelas LiveNodeArray berfungsi sebagai *blueprint* dari objek antrian simpul hidup.

```python
class Node:
    def __init__(self, parent, puzzle, child, level, cost, blank, previous_step):
        self.parent = parent
        self.puzzle = puzzle
        self.child = child
        self.level = level
        self.cost = cost
        self.blank = blank # (x, y) blank puzzle
        self.previous_step = previous_step

    def show(self):
    # Menampilkan puzzle
        for row in self.puzzle:
            for col in row:
                if (col != 16):
                    if (col < 10):
                        print(col,end='   ')
                    else:
                        print(col, end='  ')
                else:
                    print('  ', end='  ')
            print()

    def isGoal(self):
    # Memeriksa apakah node merupakan goal state
        goal = True
        i = 0
        while (i < 4 and goal):
            j = 0
            while (j < 4 and goal):
                if (self.puzzle[i,j] != i*4 + j + 1):
                    goal = False
                j += 1
            i += 1
        return goal

class LiveNodeArray:
    def __init__(self, array, length):
        self.array = array
        self.length = length
    def append(self, s):
    # Menambahkan simpul s ke dalam array berdasarkan prioritasnya (cost)
        found = False
        i = 0
        while (not found and i < self.length):
            if (self.array[i].cost >= s.cost):
                found = True
            else:
                i += 1
        self.array.insert(i, s)
        self.length += 1

    def pop(self):
    # Menghapus dan mengembalikan elemen pertama array
        first = self.array[0]
        self.array = self.array[1:]
        self.length -= 1
        return first

    def display(self):
    # Menampilkan seluruh isi array
        for i in range(self.length):
            self.array[i].show()
            print(self.array[i].cost)
            print()
```

b. Modul main.py

Modul ini berisi prosedur-prosedur dan fungsi-fungsi untuk menjalankan program utama.

```
from copy import deepcopy
import random
import numpy as np
from Graph import *
from time import time
import tkinter

def randomPuzzle():
# Membuat random puzzle
    array = [i for i in range(1,17)]
    random.shuffle(array)
    puzzle = np.array(array, dtype='int8').reshape(4,4)
    return puzzle

def readFile(filename):
# Membaca input file
    array = []
```

```python
    f = open(filename,'r')
    lines = f.readlines()

    for line in lines:
        array.append(line.replace('\n','').replace(' ','').split(','))
    f.close()

    for i in range(4):
        for j in range(4):
            if (array[i][j] != ''):
                array[i][j] = int(array[i][j])
            else:
                array[i][j] = 16

    return np.array(array, dtype='int8')

def kurang(m, row, col):
# Realisasi Fungsi KURANG(i)
    count = 0
    e = m[row, col]
    while (row < 4):
        while (col < 4):
            if (e > m[row, col]):
                count += 1
            col += 1
        row += 1
        col = 0
    return count

def achievable(m):
# Memeriksa apakah goal state dapat dicapai dan mengembalikan nilai dari fungsi
Kurang(i) untuk setiap ubin
    sum = 0
    array = np.zeros(16, dtype='int8')
    for row in range(4):
        for col in range(4):
            array[m[row, col] - 1] = kurang(m, row, col)
            sum += array[m[row,col]-1]
            if (m[row, col] == 16 and (row+col) % 2 == 1):
                sum += 1
    return (sum % 2 == 0), sum, array

def searchBlank(m):
# Mencari blok yang kosong pada puzzle
    for i in range(4):
        for j in range(4):
            if (m[i,j] == 16):
                return i,j

def g(m):
# Menghitung jumlah ubin tak kosong yang tidak terdapat pada susunan akhir
    count = 0
    for i in range(4):
        for j in range(4):
            if (m[i,j] != 16 and m[i,j] != i*4+j+1):
                count += 1
    return count

def swap(m, row1, col1, row2, col2):
# Menukar posisi elemen matriks
    mcopy = deepcopy(m)
    mcopy[row1, col1] = m[row2, col2]
    mcopy[row2, col2] = m[row1,col1]
    return mcopy

def checkNode(matrix, array):
# Memeriksa apakah matrix sudah ada di array
    for puzzle in array:
        if ((matrix==puzzle).all()):
            return True
    return False

def Play():
# prosedur untuk gui
    global pace
    if (pace != 0):
        pace = 0
    Play1()

def Play1():
# prosedur untuk gui
    global pace
    play['state'] = 'disabled'
    next['state'] = 'disabled'
    prev['state'] = 'disabled'
    if (pace < len(steps) - 1):
        Next()
        main_windows.after(1000,Play1)
    else:
        play['state'] = 'normal'
        next['state'] = 'normal'
        prev['state'] = 'normal'
```

```python
def Next():
# prosedur untuk gui
    global pace
    if (pace < len(steps) - 1):
        pace  += 1
        puzzle = steps[pace].puzzle
        label1.config(text=puzzle[0][0], background='#7ea098')
        label2.config(text=puzzle[0][1], background='#7ea098')
        label3.config(text=puzzle[0][2], background='#7ea098')
        label4.config(text=puzzle[0][3], background='#7ea098')
        label5.config(text=puzzle[1][0], background='#7ea098')
        label6.config(text=puzzle[1][1], background='#7ea098')
        label7.config(text=puzzle[1][2], background='#7ea098')
        label8.config(text=puzzle[1][3], background='#7ea098')
        label9.config(text=puzzle[2][0], background='#7ea098')
        label10.config(text=puzzle[2][1], background='#7ea098')
        label11.config(text=puzzle[2][2], background='#7ea098')
        label12.config(text=puzzle[2][3], background='#7ea098')
        label13.config(text=puzzle[3][0], background='#7ea098')
        label14.config(text=puzzle[3][1], background='#7ea098')
        label15.config(text=puzzle[3][2], background='#7ea098')
        label16.config(text=puzzle[3][3], background='#7ea098')

        i, j = steps[pace].blank
        if (i == 0 and j == 0):
            label1.config(text='', background="white")
        elif (i == 0 and j == 1):
            label2.config(text='', background="white")
        elif (i == 0 and j == 2):
            label3.config(text='', background="white")
        elif (i == 0 and j == 3):
            label4.config(text='', background="white")
        elif (i == 1 and j == 0):
            label5.config(text='', background="white")
        elif (i == 1 and j == 1):
            label6.config(text='', background="white")
        elif (i == 1 and j == 2):
            label7.config(text='', background="white")
        elif (i == 1 and j == 3):
            label8.config(text='', background="white")
        elif (i == 2 and j == 0):
            label9.config(text='', background="white")
        elif (i == 2 and j == 1):
            label10.config(text='', background="white")
        elif (i == 2 and j == 2):
            label11.config(text='', background="white")
        elif (i == 2 and j == 3):
            label12.config(text='', background="white")
        elif (i == 3 and j == 0):
            label13.config(text='', background="white")
        elif (i == 3 and j == 1):
            label14.config(text='', background="white")
        elif (i == 3 and j == 2):
            label15.config(text='', background="white")
        elif (i == 3 and j == 3):
            label16.config(text='', background="white")

def Prev():
# prosedur untuk gui
    global pace
    if (pace > 0):
        pace -= 1
        puzzle = steps[pace].puzzle
        label1.config(text=puzzle[0][0], background='#7ea098')
        label2.config(text=puzzle[0][1], background='#7ea098')
        label3.config(text=puzzle[0][2], background='#7ea098')
        label4.config(text=puzzle[0][3], background='#7ea098')
        label5.config(text=puzzle[1][0], background='#7ea098')
        label6.config(text=puzzle[1][1], background='#7ea098')
        label7.config(text=puzzle[1][2], background='#7ea098')
        label8.config(text=puzzle[1][3], background='#7ea098')
        label9.config(text=puzzle[2][0], background='#7ea098')
        label10.config(text=puzzle[2][1], background='#7ea098')
        label11.config(text=puzzle[2][2], background='#7ea098')
        label12.config(text=puzzle[2][3], background='#7ea098')
        label13.config(text=puzzle[3][0], background='#7ea098')
        label14.config(text=puzzle[3][1], background='#7ea098')
        label15.config(text=puzzle[3][2], background='#7ea098')
        label16.config(text=puzzle[3][3], background='#7ea098')

        i, j = steps[pace].blank
        if (i == 0 and j == 0):
            label1.config(text='', background="white")
        elif (i == 0 and j == 1):
            label2.config(text='', background="white")
        elif (i == 0 and j == 2):
            label3.config(text='', background="white")
        elif (i == 0 and j == 3):
            label4.config(text='', background="white")
        elif (i == 1 and j == 0):
            label5.config(text='', background="white")
        elif (i == 1 and j == 1):
            label6.config(text='', background="white")
        elif (i == 1 and j == 2):
            label7.config(text='', background="white")
        elif (i == 1 and j == 3):
            label8.config(text='', background="white")
        elif (i == 2 and j == 0):
            label9.config(text='', background="white")
        elif (i == 2 and j == 1):
            label10.config(text='', background="white")
        elif (i == 2 and j == 2):
            label11.config(text='', background="white")
        elif (i == 2 and j == 3):
            label12.config(text='', background="white")
        elif (i == 3 and j == 0):
            label13.config(text='', background="white")
        elif (i == 3 and j == 1):
            label14.config(text='', background="white")
        elif (i == 3 and j == 2):
            label15.config(text='', background="white")
        elif (i == 3 and j == 3):
            label16.config(text='', background="white")

def main():
# program utama
    print("1. Input File")
    print("2. Random")
    while (True):
        try:
            select = int(input("Masukkan angka pilihan: "))
        except Exception:
            print("Masukkan salah")
        else:
            break

    if (select == 1):
        while (True):
            try:
                filename = input("Masukkan nama file: ")
                puzzle = readFile(filename)
            except Exception:
                print("File tidak ditemukan")
            else:
                break
    else:
        puzzle = randomPuzzle()

    print("\nMatriks posisi awal 15-puzzle")
    blank = searchBlank(puzzle)
    root = Node(None, puzzle, None, 0, 0, blank, None)
    root.show()
    print()
    start_time = time()

    solvable, sum, array = achievable(puzzle)

    print("Nilai dari fungsi Kurang (i)")
    for i in range(16):
        print("Kurang({}) = {}".format(i+1, array[i]))

    print()

    print("Nilai KURANG (i) + X =", sum)
    print()

    if (not solvable):
        print("Status tujuan tidak dapat dicapai")
    else:
        global main_windows, play, prev, next, label1, label2, label3, label4,
label5, label6, label7, label8, label9, label10, label11, label12, label13,
label14, label15, label16, steps, pace

        n = 0 # Jumlah simpul yang dibangkitkan
        dNode = []
        lNode = LiveNodeArray([root], 1)
        while (lNode.length != 0):
            solution = lNode.pop()
            if (not checkNode(solution.puzzle, dNode)):
                dNode.append(solution.puzzle)
            else:
                continue

            if (solution.isGoal()):
                break

            row, col = solution.blank

            # geser blok kosong ke atas
            if (row != 0 and solution.previous_step != 'down'):
                m1 = swap(solution.puzzle, row - 1, col, row, col)
                cost = (solution.level + 1) + g(m1)
                s1 =  Node(solution, m1, None, solution.level + 1, cost, (row-1,
col), 'up')
                lNode.append(s1)
                n += 1

            # geser blok kosong ke kanan
            if (col != 3 and solution.previous_step != 'left'):
                m2 = swap(solution.puzzle, row, col + 1, row, col)
                cost = (solution.level + 1) + g(m2)
                s2 =  Node(solution, m2, None, solution.level + 1, cost, (row, 
col+1), 'right')
                lNode.append(s2)
                n += 1

            # geser blok kosong ke bawah
            if (row != 3 and solution.previous_step != 'up'):
                m3 = swap(solution.puzzle, row + 1, col, row, col)
                cost = (solution.level + 1) + g(m3)
                s3 =  Node(solution, m3, None, solution.level + 1, cost, (row+1, 
col), 'down')
                lNode.append(s3)
                n += 1

            # geser blok kosong ke kiri
            if (col != 0 and solution.previous_step != 'right'):
                m4 = swap(solution.puzzle, row, col-1, row, col)
                cost = (solution.level + 1) + g(m4)
                s4 =  Node(solution, m4, None, solution.level + 1, cost, (row, 
col-1), 'left')
                lNode.append(s4)
                n += 1

        steps = []
        p = solution
        while (p is not None):
            steps.insert(0, p)
            p = p.parent

        print("Langkah-langkah\n")
        for step in steps:
            step.show()
            print()

        execution_time = time() - start_time
        print("Waktu eksekusi : ", execution_time)
        print("Jumlah Langkah menuju goal state :", solution.level)
        print("Jumlah simpul yang dibangkitkan :",n)

        main_windows = tkinter.Tk()
        main_windows.title("PUZZLE PROCESS")

        pace = 0

        label1 = tkinter.Label(main_windows, text=puzzle[0,0], 
background='#7ea098', foreground="white", width=3, height=1, font=("Arial", 25))
        label2 = tkinter.Label(main_windows, text=puzzle[0,1], 
background='#7ea098', foreground="white", width=3, height=1, font=("Arial", 25))
```

```
        label3 = tkinter.Label(main_windows, text=puzzle[0,2],
background='#7ea098', foreground="white", width=3, height=1, font=("Arial", 25))
        label4 = tkinter.Label(main_windows, text=puzzle[0,3],
background='#7ea098', foreground="white", width=3, height=1, font=("Arial", 25))
        label5 = tkinter.Label(main_windows, text=puzzle[1,0],
background='#7ea098', foreground="white", width=3, height=1, font=("Arial", 25))
        label6 = tkinter.Label(main_windows, text=puzzle[1,1],
background='#7ea098', foreground="white", width=3, height=1, font=("Arial", 25))
        label7 = tkinter.Label(main_windows, text=puzzle[1,2],
background='#7ea098', foreground="white", width=3, height=1, font=("Arial", 25))
        label8 = tkinter.Label(main_windows, text=puzzle[1,3],
background='#7ea098', foreground="white", width=3, height=1, font=("Arial", 25))
        label9 = tkinter.Label(main_windows, text=puzzle[2,0],
background='#7ea098', foreground="white", width=3, height=1, font=("Arial", 25))
        label10 = tkinter.Label(main_windows, text=puzzle[2,1],
background='#7ea098', foreground="white", width=3, height=1, font=("Arial", 25))
        label11 = tkinter.Label(main_windows, text=puzzle[2,2],
background='#7ea098', foreground="white", width=3, height=1, font=("Arial", 25))
        label12 = tkinter.Label(main_windows, text=puzzle[2,3],
background='#7ea098', foreground="white", width=3, height=1, font=("Arial", 25))
        label13 = tkinter.Label(main_windows, text=puzzle[3,0],
background='#7ea098', foreground="white", width=3, height=1, font=("Arial", 25))
        label14 = tkinter.Label(main_windows, text=puzzle[3,1],
background='#7ea098', foreground="white", width=3, height=1, font=("Arial", 25))
        label15 = tkinter.Label(main_windows, text=puzzle[3,2],
background='#7ea098', foreground="white", width=3, height=1, font=("Arial", 25))
        label16 = tkinter.Label(main_windows, text=puzzle[3,3],
background='#7ea098', foreground="white", width=3, height=1, font=("Arial", 25))

        i, j = steps[pace].blank
        if (i == 0 and j == 0):
            label1.config(text='', background="white")
        elif (i == 0 and j == 1):
            label2.config(text='', background="white")
        elif (i == 0 and j == 2):
            label3.config(text='', background="white")
        elif (i == 0 and j == 3):
            label4.config(text='', background="white")
        elif (i == 1 and j == 0):
            label5.config(text='', background="white")
        elif (i == 1 and j == 1):
            label6.config(text='', background="white")
        elif (i == 1 and j == 2):
            label7.config(text='', background="white")
        elif (i == 1 and j == 3):
            label8.config(text='', background="white")
        elif (i == 2 and j == 0):
            label9.config(text='', background="white")
        elif (i == 2 and j == 1):
            label10.config(text='', background="white")
        elif (i == 2 and j == 2):
            label11.config(text='', background="white")
        elif (i == 2 and j == 3):
            label12.config(text='', background="white")
        elif (i == 3 and j == 0):
            label13.config(text='', background="white")
        elif (i == 3 and j == 1):
            label14.config(text='', background="white")
        elif (i == 3 and j == 2):
            label15.config(text='', background="white")
        elif (i == 3 and j == 3):
            label16.config(text='', background="white")

        next = tkinter.Button(main_windows, text ="NEXT STEP", command = Next)
        prev = tkinter.Button(main_windows, text="PREV STEP", command = Prev)
        play = tkinter.Button(main_windows, text="PLAY", command = Play)

        label1.grid(row=0,column=0,padx=1,pady=1)
        label2.grid(row=0,column=1,padx=1,pady=1)
        label3.grid(row=0,column=2,padx=1,pady=1)
        label4.grid(row=0,column=3,padx=1,pady=1)
        label5.grid(row=1,column=0,padx=1,pady=1)
        label6.grid(row=1,column=1,padx=1,pady=1)
        label7.grid(row=1,column=2,padx=1,pady=1)
        label8.grid(row=1,column=3,padx=1,pady=1)
        label9.grid(row=2,column=0,padx=1,pady=1)
        label10.grid(row=2,column=1,padx=1,pady=1)
        label11.grid(row=2,column=2,padx=1,pady=1)
        label12.grid(row=2,column=3,padx=1,pady=1)
        label13.grid(row=3,column=0,padx=1,pady=1)
        label14.grid(row=3,column=1,padx=1,pady=1)
        label15.grid(row=3,column=2,padx=1,pady=1)
        label16.grid(row=3,column=3,padx=1,pady=1)
        next.grid(row=4, column=3,padx=1,pady=1)
        prev.grid(row=4, column=0,padx=1,pady=1)
        prev.grid(row=4, column=0,padx=1,pady=1)
        play.grid(row=4, column=1, columnspan=2 ,padx=1,pady=1)

        main_windows.mainloop()

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

C. Data Uji

Data uji adalah berupa matriks puzzle yang merepresentasikan keadaan awal puzzle. Setiap elemen matriks dipisahkan dengan koma dan sel kosong puzzle direpresentasikan sebagai elemen kosong pada matriks.

a. Data Uji 1

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

b. Data Uji 2

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

c. Data Uji 3

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

d. Data Uji 4

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

e. Data Uji 5

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

D. Screenshot Input dan Output Program

Data uji berupa teks berada pada folder test, sedangkan program utama ada di file main.py pada folder src. Test case 1 sampai 5 berupa data uji teks, sedangkan test case 6 dan 7 berupa random matriks yang dibangkitkan oleh program.

a. Test Case 1

```
1. Input File
2. Random
Masukkan angka pilihan: 1
Masukkan nama file: test/case1.txt

Matriks posisi awal 15-puzzle
14  11  4   12
5   3   7   1
15  9   8   13
2       6   10

Nilai dari fungsi Kurang (i)
Kurang(1) = 0
Kurang(2) = 0
Kurang(3) = 2
Kurang(4) = 3
Kurang(5) = 3
Kurang(6) = 0
Kurang(7) = 3
Kurang(8) = 2
Kurang(9) = 3
Kurang(10) = 0
Kurang(11) = 10
Kurang(12) = 9
Kurang(13) = 3
Kurang(14) = 13
Kurang(15) = 6
Kurang(16) = 2

Nilai KURANG (i) + X = 59

Status tujuan tidak dapat dicapai
```

b. Test Case 2

```
1. Input File
2. Random
Masukkan angka pilihan: 1
Masukkan nama file: test/case2.txt

Matriks posisi awal 15-puzzle
14  5   7   11
12  6   4   2
3   10  1
8   9   13  15

Nilai dari fungsi Kurang (i)
```

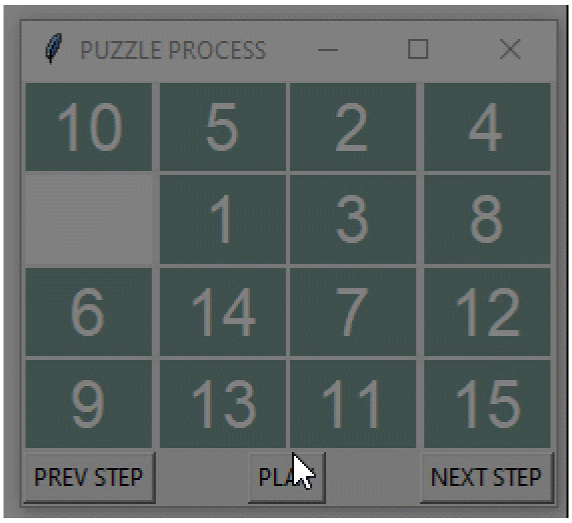
```
Kurang(1) = 0
Kurang(2) = 1
Kurang(3) = 1
Kurang(4) = 3
Kurang(5) = 4
Kurang(6) = 4
Kurang(7) = 5
Kurang(8) = 0
Kurang(9) = 0
Kurang(10) = 3
Kurang(11) = 8
Kurang(12) = 8
Kurang(13) = 0
Kurang(14) = 13
Kurang(15) = 0
Kurang(16) = 4

Nilai KURANG (i) + X = 55

Status tujuan tidak dapat dicapai
```

c. Test Case 3

```
1. Input File
2. Random
Masukkan angka pilihan: 1
Masukkan nama file: test/case3.txt

Matriks posisi awal 15-puzzle
10  5   2   4
    1   3   8
6   14  7   12
9   13  11  15

Nilai dari fungsi Kurang (i)
Kurang(1) = 0
Kurang(2) = 1
Kurang(3) = 0
Kurang(4) = 2
Kurang(5) = 4
Kurang(6) = 0
Kurang(7) = 0
Kurang(8) = 2
Kurang(9) = 0
Kurang(10) = 9
Kurang(11) = 0
Kurang(12) = 2
Kurang(13) = 1
Kurang(14) = 5
Kurang(15) = 0
Kurang(16) = 11

Nilai KURANG (i) + X = 38

Langkah-langkah

10  5   2   4
    1   3   8
```

```
6   14  7   12
9   13  11  15

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

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

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

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

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

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

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

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

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

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

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

1       2   4
```

```
5   6   3   8
9   10  7   12
13  14  11  15

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

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

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

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

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

Waktu eksekusi :  0.391275405883789O6
Jumlah Langkah menuju goal state : 17
Jumlah simpul yang dibangkitkan : 795
```



1.1.mp4

7. Alamat Drive Kode Program

IF2211-Strategi-Algoritma/Tucil1 at main · ikmalalfaozi/IF2211-Strategi-Algoritma (github.com)