

LAPORAN TUGAS KECIL 3

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

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

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**PROGRAM STUDI TEKNIK INFORMATIKA
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2021**

A. Algoritma *Branch and Bound*

Algoritma *Branch and Bound* merupakan algoritma yang digunakan untuk memecahkan persoalan optimasi dengan cara melakukan percabangan (branching) dari node awal menjadi node - node anak dan melakukan pembatasan (bounding) dari node - node tersebut untuk mengarah ke solusi. Proses branching dan bounding tersebut dilakukan berulang kali hingga ditemukan solusi yang optimal. Proses pencarian dengan algoritma ini menggunakan pembentukan pohon ruang status dinamis dengan permasalahan awal menjadi node akar dan bercabang menjadi node - node anak lainnya hingga node solusi. Berbeda dengan Algoritma BFS ataupun DFS, urutan pemeriksaan node dalam algoritma Branch and Bound dipilih berdasarkan node yang memiliki cost terkecil (*Least Cost Search*). Cost tersebut memiliki makna estimasi ongkos termurah lintasan sebuah node yang dihitung secara herustik. Secara umum, berikut adalah persamaan untuk menentukan cost dari sebuah node dalam algoritma *Branch and Bound* :

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

Dimana :

$c(P)$ = estimasi ongkos sebuah node

$f(p)$ = ongkos mencapai node dari akar

$g(p)$ = ongkos mencapai node tujuan dari node tersebut

Dalam Tugas Kecil ini, diimplementasikan algoritma *Branch and Bound* untuk menyelesaikan persoalan 15-Puzzle. Sebelum menerapkan algoritma *Branch and Bound*, program akan menerima sebuah puzzle terlebih dahulu baik melalui file eksternal ataupun mengenerate sendiri secara random. Apabila melalui file eksternal, ubin blank diwakili dengan angka 0 ataupun 16. Dalam program ini, state matriks akan disimpan dalam sebuah node yang direpresentasikan oleh sebuah class yang menyimpan atribut cost, matriks (numpy), serta array yang berisi pergerakan untuk menuju node tersebut. Kemudian, program akan menentukan terlebih dahulu apakah puzzle / matriks yang didapatkan solvable atau tidak. Proses penentuan solvablenya dilakukan dengan metode berikut :

$$status = \sum_{i=1}^{16} kurang(i) + X$$

Dimana :

$kurang(i)$ = Banyaknya ubin di depan posisi(i) yang bernilai lebih kecil

$X = 0$ atau 1 bergantung lokasi awal blank

Program akan mencetak matriks awal dari puzzle serta memberikan luaran tiap nilai dari $kurang(i)$, X , dan status. Apabila nilai status dari puzzle awal adalah ganjil, maka puzzle tersebut merupakan unsolvable dan program akan langsung mencetak pesan unsolvable. Apabila statusnya genap, maka program akan langsung menerapkan algoritma *Branch and Bound* untuk membangkitkan simpul anak dan menghitung costnya hingga ditemukan simpul solusi. Dalam kasus 15-Puzzle Solver, perhitungan cost dilakukan dengan nilai $f(p)$ dan $g(p)$ sebagai berikut:

$f(p)$ = Panjang lintasan dari awal menuju node P (Kedalaman)
 $g(p)$ = Banyaknya ubin tidak kosong yang tidak pada tempatnya

Langkah kerja implementasi algoritma *Branch and Bound* dalam program 15-Puzzle Solver ini adalah sebagai berikut :

1. Memasukkan node puzzle awal dan costnya ke dalam sebuah PriorityQueue. Jika puzzle matriks dari awal sudah solved, maka pencarian berhenti karena sudah merupakan solusi. Apabila belum solved, lanjut ke langkah 2.
2. Pilih sebuah node dalam PriorityQueue yang memiliki nilai cost terkecil. Jika terdapat beberapa node dengan nilai cost yang memenuhi, maka ambil salah satu yang memiliki kedalaman terpendek.
3. Jika node yang dipilih merupakan node solusi, maka solusi sudah ditemukan dan pencarian berhenti.
4. Jika node yang dipilih bukan node solusi, maka bangkitkan semua child nodes dari node tersebut. Kemudian, hitung cost untuk tiap child node tersebut dan masukkan ke dalam PriorityQueue.
5. Ulangi dari langkah 2.

Dengan catatan : Karena sudah diperiksa dari awal apakah puzzle solvable atau tidak, maka diasumsikan bahwa node solusi sudah pasti akan ditemukan dalam proses branching sehingga tidak perlu mengatasi sampai PriorityQueue kosong. Kemudian, setelah program menemukan solusi node dari puzzle tersebut, program akan menampilkan luaran berupa banyaknya simpul yang dibangkitkan, banyaknya step yang dibutuhkan untuk mencapai solusi, progress perubahan state matriks dari awal hingga mencapai solusi per langkahnya, serta waktu eksekusi program.

B. Source Program

Source code program ditulis dalam bahasa pemrograman Python dengan menggunakan library numpy dan pyfiglet. Source code program terbungkus menjadi 2 file utama, yakni solver.py dan main.py

1. **solver.py** : Merupakan file library untuk algoritma *Branch and Bound* dalam implementasi 15-Puzzle Solver yang telah saya buat. Note bahwa penjelasan tiap fungsi sudah disertakan pada source code dalam bentuk komentar

```
# NAMA : SAUL SAYERS
# NIM : 13520094
# KELAS : K-01 STRATEGI ALGORITMA

# MERUPAKAN FILE ALGORITMA PUZZLESOLVER UNTUK TUCIL 3 STRATEGI ALGORITMA

import numpy as np
import os.path
from queue import PriorityQueue
```

```

import random

class Node:
    """ This class is what we use to represent the
        nodes in this program.

        Attributes:
            - prev (array of string) : list of the
              moves to reach this node.
            - matrix (numpy 2d-array) : the matrix
              of integers where we store the puzzle.
            - cost (int) : the cost of the node.
    """

    def __init__(self, prev, cost):
        """ Constructor of the Node Class

        Args:
            - prev (array of string) : list of the
              moves to reach this node.
            - cost (int) : the cost of the node.
        """

        self.prev = prev
        self.matrix = np.arange(16).reshape((4,4))
        self.cost = cost

    def generateMatrix(self) :
        """ this method is used to randomly
            generate the matrix of the node.
        """

        numList = [i for i in range (16)]
        random.shuffle(numList)
        self.matrix = np.array(numList).reshape((4,4))

    def readFile(self):
        """ This method is used to fill the matrix
            from an external txt file.
        """

        numList = []
        while True: # Looping until filename exists
            filename = input("Input filename here (dengan .txt): ")

```

```

        path = "test/" + filename
        if (os.path.isfile(path)):
            break
        else :
            print("Filename doesnt exist! Please re-input filename.")
    file = open(path)
    for i in range(4) :
        numList.extend([int(number) for number in file.readline().split()])
    for i in range(len(numList)):
        if numList[i] == 16: # Handle if blank as 16 then change to 0
            numList[i] = 0
    self.matrix = np.array(numList).reshape((4,4))

def printMatrix(self):
    """ This method is used to print
        the matrix of the node.
    """

    print("-----")
    for arr in self.matrix :
        for angka in arr :
            print("|",end="")
            if angka == 0 :
                print(" ",end=" ")
            elif angka < 10 :
                print(" ",angka,end=" ")
            else :
                print("",angka,end=" ")
        print("|")
    print("-----")

def locateBlank(self):
    """ This method is used to get
        the X of the matrix.

    Returns:
        int : the X of the matrix
    """

    result = np.where(self.matrix == 0)
    return (result[0][0] + result[1][0])%2

def kurang_i(self):
    """ This method is used to get
        the kurang(i) of the matrix

```

```

Returns:
    array of integers : each index i of the
    array refers to the value of kurang(i).
"""

temp = self.matrix
temp = temp.flatten()
arr = [0 for i in range (16)]
for i in range(len(temp)-1):
    count = 0 # Count untuk mendapatkan kurang_i untuk tiap i
    for j in range (i+1, len(temp)):
        if (temp[j] < temp[i] and temp[j] != 0) or (temp[i] == 0):
            count += 1
    arr[temp[i]] = count
return arr

def isSolved(self):
    """ This method is used to check whether
    the matrix is in final state or not.

    Returns:
        boolean : True if matrix is solved,
        False if otherwise.
    """

    list = [i for i in range (1,16)]
    list.append(0)
    list = np.array(list).reshape((4,4))
    return (self.matrix==list).all()

def countSyarat(self):
    """ This method is used to count the condition
    which is the sum of kurang(i) plus X.

    Returns:
        integer : the sum of kurang(i) + X
    """
    return sum(self.kurang_i()) + self.locateBlank()

def countCost(self):
    """ This method is used to count
    the cost of the matrix.

    Returns:

```

```

        int : the cost of the matrix
    """

    temp = self.matrix.flatten()
    count = 0
    for i in range(16) :
        if (temp[i] != (i+1) and temp[i] != 0):
            count += 1
    return count

def isSolvable(self) :
    """ This method is used to check whether
        the puzzle is solveable or not.

    Returns:
        Boolean : If the condition is even then
        solvable so return True, False if otherwise
    """

    if (self.countSyarat())%2 == 0:
        return True
    else:
        return False

def moveBlankLeft(self) :
    """ This method is used to return a
        matrix where the blank is moved left

    Returns:
        numpy 2d-array : the matrix
        of integers where we store the puzzle.
    """

    result = np.where(self.matrix == 0)
    x = result[0][0]
    y = result[1][0]
    hasil = self.matrix.copy()
    hasil[x,y-1] = self.matrix[x,y]
    hasil[x,y] = self.matrix[x,y-1]

    return hasil

def moveBlankRight(self) :
    """ This method is used to return a
        matrix where the blank is moved right

```

```

Returns:
    numpy 2d-array : the matrix
    of integers where we store the puzzle.
"""

result = np.where(self.matrix == 0)
x = result[0][0]
y = result[1][0]
hasil = self.matrix.copy()
hasil[x,y+1] = self.matrix[x,y]
hasil[x,y] = self.matrix[x,y+1]
return hasil

def moveBlankUp(self) :
    """ This method is used to return a
        matrix where the blank is moved up

Returns:
    numpy 2d-array : the matrix
    of integers where we store the puzzle.
"""

result = np.where(self.matrix == 0)
x = result[0][0]
y = result[1][0]
hasil = self.matrix.copy()
hasil[x-1,y] = self.matrix[x,y]
hasil[x,y] = self.matrix[x-1,y]
return hasil

def moveBlankDown(self) :
    """ This method is used to return a
        matrix where the blank is moved down

Returns:
    numpy 2d-array : the matrix
    of integers where we store the puzzle.
"""

result = np.where(self.matrix == 0)
x = result[0][0]
y = result[1][0]
hasil = self.matrix.copy()
hasil[x+1,y] = self.matrix[x,y]

```



```

        hasil[x,y] = self.matrix[x+1,y]
        return hasil

def __lt__(self, other):
    """ Function overloading of the node
        for the lower than operator. Set to
        True so the newest node will be checked last.

    Args:
        other (_type_): _description_

    Returns:
        _type_: _description_
    """
    return False

class Solver:
    """ This class is what we use to contain
        the nodes and solve the puzzle

    Attributes:
        - checked (array): an array of nodes
        where the nodes have been checked before
        - queue (prioqueue) : a prioqueue of nodes that
        haven't been checked and use the cost as the priority
        - mapMatrix (dictionary) : a hashmap to check whether
        the node has already been added or not
        - startMatrix (node) : the start of the puzzle or
        the root of the nodes.
        - solusi (node) : the node that is the solution
        to the puzzle.
    """

    def __init__(self):
        """ The constructor for the Solver.
        """

        self.checked = []
        self.queue = PriorityQueue()
        self.mapMatrix = {}
        self.startMatrix = Node(["-"],0)
        self.solusi = Node(["-"],0)

    def bangkitkanSimpul(self):
        """ The looping part of the solver.

```

Here, we continue to get the child nodes of the node most prioritized in the priority queue.

For each child node we raise, we put them into the priorityqueue with it's cost as the priority.

"""

```
while True:
    # Checking the current node.
    node = self.queue.get()[1]
    self.checked.append(node)
    result = np.where(node.matrix == 0)
    x = result[0][0]
    y = result[1][0]
    currMove = node.prev
    if node.isSolved(): # If current node is solution, stop.
        self.solusi = node
        break

    # If blank is not at the top, then get the child
    # node where the blank moves up.
    if (x != 0 and node.prev[len(node.prev)-1] != "DOWN"):
        newNode = Node(currMove + ["UP"], len(node.prev))
        newNode.matrix = node.moveBlankUp()
        newNode.cost += newNode.countCost()
        if newNode.matrix.tobytes() not in self.mapMatrix.keys() :
            self.mapMatrix[newNode.matrix.tobytes()] = True
            self.queue.put((newNode.cost, newNode))
            if newNode.isSolved():
                self.solusi = newNode # If child node is solution, stop.
                break

    # If blank is not at the buttom, then get the child
    # node where the blank moves down.
    if (x != 3 and node.prev[len(node.prev)-1] != "UP"):
        newNode = Node(currMove + ["DOWN"], len(node.prev))
        newNode.matrix = node.moveBlankDown()
        newNode.cost += newNode.countCost()
        if newNode.matrix.tobytes() not in self.mapMatrix.keys() :
            self.mapMatrix[newNode.matrix.tobytes()] = True
            self.queue.put((newNode.cost, newNode))
            if newNode.isSolved():
                self.solusi = newNode # If child node is solution, stop.
```

```

        break

    # If blank is not at the most left, then get the child
    # node where the blank moves left
    if (y != 0 and node.prev[len(node.prev)-1] != "RIGHT"):
        newNode = Node(currMove + ["LEFT"], len(node.prev))
        newNode.matrix = node.moveBlankLeft()
        newNode.cost += newNode.countCost()
        if newNode.matrix.tobytes() not in self.mapMatrix.keys() :
            self.mapMatrix[newNode.matrix.tobytes()] = True
            self.queue.put((newNode.cost, newNode))
            if newNode.isSolved():
                self.solusi = newNode # If child node is solution, stop.
                break

    # If blank is not at the most right, then get the child
    # node where the blank moves right
    if (y != 3 and node.prev[len(node.prev)-1] != "LEFT"):
        newNode = Node(currMove + ["RIGHT"], len(node.prev))
        newNode.matrix = node.moveBlankRight()
        newNode.cost += newNode.countCost()
        if newNode.matrix.tobytes() not in self.mapMatrix.keys() :
            self.mapMatrix[newNode.matrix.tobytes()] = True
            self.queue.put((newNode.cost, newNode))
            if newNode.isSolved():
                self.solusi = newNode # If child node is solution, stop.
                break

def cetakSolusi(self):
    """ This method is used to print the amount of nodes raised,
        the amount of steps needed to get the solution,
        and print a matrix for each of the step.
    """

    print("Solusi sudah ditemukan!\n")
    print("Banyaknya simpul yang dibangkitkan:", self.queue.qsize() + len(self.checked))
    print("Banyak steps:", len(self.solusi.prev) - 1 ) # the amount of steps
    temp = self.startMatrix
    for i in range(1, len(self.solusi.prev)):
        print("Step ke-" + str(i) + ": ")
        if (self.solusi.prev[i] == "RIGHT") :
            print("Command : Move blank right")
            temp.matrix = temp.moveBlankRight()
        if (self.solusi.prev[i] == "UP") :
            print("Command : Move blank up")

```

```

        temp.matrix = temp.moveBlankUp()
    if (self.solusi.prev[i] == "LEFT") :
        print("Command : Move blank left")
        temp.matrix = temp.moveBlankLeft()
    if (self.solusi.prev[i] == "DOWN") :
        print("Command : Move blank down")
        temp.matrix = temp.moveBlankDown()
    temp.printMatrix()
    print()
print("Banyaknya simpul yang dibangkitkan:", self.queue.qsize() + len(self.checked))

def solve(self):
    """ This method is used to initiate the solving process
        of the puzzle. This method will print the startmatrix,
        the kurang(i), and the X of the startMatrix,
        then determine whether the puzzle is solvable or not.

        If the startMatrix is unsolvable, then the method prints so.
        otherwise, the method will continue to the bangkitkanSimpul method.
    """

    print("\nMatriks awalnya: ")
    self.startMatrix.printMatrix()
    print()
    print("Mencari tiap kurang(i): ")
    arr = self.startMatrix.kurang_i()
    for i in range(1,16):
        if i < 10 :
            print("Kurang("+str(i) +") =", arr[i])
        else :
            print("Kurang("+str(i) +") =", arr[i])
    print("Kurang(16) =",arr[0])
    print("Total sigma(i) =", sum(arr))
    print("X =", self.startMatrix.locateBlank())
    print("\nHasil Sigma kurang(i) + X:", self.startMatrix.countSyarat())

    if (not self.startMatrix.isSolvable()):
        print("Syarat bernilai ganjil, maka puzzle unsolvable.")
    else:
        print("Syarat bernilai genap, maka puzzle solvable.\n")
        print("Sedang proses pencarian solusi... ")
        self.startMatrix.cost = self.startMatrix.countCost()
        self.queue.put((self.startMatrix.cost, self.startMatrix))
        self.mapMatrix[self.startMatrix.matrix.tobytes()] = True
        self.bangkitkanSimpul()

```

2. **main.py** : Merupakan file yang dijalankan untuk mendapatkan solusi dari 15-Puzzle yang tersedia.

```
# NAMA : SAUL SAYERS
# NIM : 13520094
# KELAS : K-01 STRATEGI ALGORITMA

# MERUPAKAN FILE MAIN PUZZLESOLVER UNTUK TUCIL 3 STRATEGI ALGORITMA

import pyfiglet
import solver as s
import time

print("-----")
print(pyfiglet.figlet_format("15-Puzzle"))
print("Welcome to Saul's 15-Puzzle Solver Program")
print("-----")

while (True) :
    puzzlesolver = s.Solver()
    print("Cara generate puzzle:")
    print("1. Dari txt file")
    print("2. Random puzzle generator")

    choice = 0
    while (choice != 1 and choice != 2):
        try:
            choice = int(input("Enter command here (Masukkan angka 1 atau 2) : "))
        except :
            print("Input salah, silahkan coba lagi!")

    if choice == 1 :
        puzzlesolver.startMatrix.readFile()
    else :
        puzzlesolver.startMatrix.generateMatrix()

    waktuawal = time.time()
    puzzlesolver.solve()
    if puzzlesolver.startMatrix.isSolvable():
        puzzlesolver.cetakSolusi()
    waktuakhir = time.time()
    print("Waktu eksekusi:", waktuakhir-waktuawal, "sekon")
```

```

print("Apakah anda ingin solve puzzle lain? (ketik y/n)")
lanjut = input("Enter choice here [defaultnya y] : ")
if lanjut == "n":
    break
print()

print("Terimakasih telah menggunakan program saya :D")

```

C. Screenshots *input* dan *output*

Terdapat 8 testcase yang diujikan menggunakan program ini :

1. pptkuliah.txt

Testcase ini merupakan testcase puzzle yang didapatkan dari slide materi perkuliahan.

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

Sigma kurang(i) + X : 37
 Status : unsolvable
 Waktu eksekusi : 0,02 sekon
 Banyak simpul dibangkitkan : 0
 Banyaknya steps : 0

Berikut adalah screenshots hasil eksekusinya :

```

Cara generate puzzle:
1. Dari txt file
2. Random puzzle generator
Enter command here (Masukkan angka 1 atau 2) : 1
Input filename here (dengan .txt): pptkuliah.txt

Matriks awalnya:
-----
| 1 | 3 | 4 | 15 |
-----
| 2 |   | 5 | 12 |
-----
| 7 | 6 | 11 | 14 |
-----
| 8 | 9 | 10 | 13 |
-----

Hasil Sigma kurang(i) + X: 37
Syarat bernilai ganjil, maka puzzle unsolvable.
Waktu eksekusi: 0.019946575164794922 sekon

Mencari tiap kurang(i):
Kurang(1) = 0
Kurang(2) = 0
Kurang(3) = 1
Kurang(4) = 1
Kurang(5) = 0
Kurang(6) = 0
Kurang(7) = 1
Kurang(8) = 0
Kurang(9) = 0
Kurang(10) = 0
Kurang(11) = 3
Kurang(12) = 6
Kurang(13) = 0
Kurang(14) = 4
Kurang(15) = 11
Kurang(16) = 10
Total sigma(i) = 37
X = 0

```

Membandingkan dengan yang ada pada slide perkuliahan :

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

- $KURANG(i)$ = banyaknya ubin bernomor j sedemikian sehingga $j < i$ dan $POSISI(j) > POSISI(i)$.
 $POSISI(i)$ = posisi ubin bernomor i pada susunan yang diperiksa.
- $KURANG(4) = 1$: terdapat 1 ubin (2)
- Kesimpulan: status tujuan tidak dapat dicapai.

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

$$\sum_{i=1}^{16} Kurang(i) + X = 37 + 0 = 37$$

Tabel kurang(i) dan hasil statusnya terlihat sama, maka luaran output program terbukti benar untuk kasus ini.

2. unsolvable.txt

Testcase ini digunakan untuk mencoba puzzle matrix yang tidak bisa disolve

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

Sigma kurang(i) + X : 47
 Status : unsolvable
 Waktu eksekusi : 0.017 sekon
 Banyak simpul dibangkitkan : 0
 Banyaknya steps : 0

Berikut adalah screenshots hasil eksekusinya :

```

Cara generate puzzle:
1. Dari txt file
2. Random puzzle generator
Enter command here (Masukkan angka 1 atau 2) : 2

Matriks awalnya:
-----
| 9 | 4 | 6 | 3 |
-----
| 1 | 10 | 12 | 11 |
-----
|   | 15 | 2 | 13 |
-----
| 5 | 8 | 7 | 14 |
-----

Hasil Sigma kurang(i) + X: 47
Syarat bernilai ganjil, maka puzzle unsolvable.

Syarat bernilai ganjil, maka puzzle unsolvable.
Waktu eksekusi: 0.016953229904174805 sekon

Mencari tiap kurang(i):
Kurang(1) = 0
Kurang(2) = 0
Kurang(3) = 2
Kurang(4) = 3
Kurang(5) = 0
Kurang(6) = 4
Kurang(7) = 0
Kurang(8) = 1
Kurang(9) = 8
Kurang(10) = 4
Kurang(11) = 4
Kurang(12) = 5
Kurang(13) = 3
Kurang(14) = 0
Kurang(15) = 6
Kurang(16) = 7
Total sigma(i) = 47
X = 0
  
```

3. easy1.txt

Testcase ini digunakan untuk mencoba puzzle yang sangat mudah diselesaikan

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

Sigma kurang(i) + X : 10
Status : solvable
Waktu eksekusi : 0.03 sekon
Banyak simpul dibangkitkan : 10
Banyaknya steps : 3

Berikut adalah screenshots hasil eksekusinya :

```
Cara generate puzzle:
1. Dari txt file
2. Random puzzle generator
Enter command here (Masukkan angka 1 atau 2) : 1
Input filename here (dengan .txt): easy1.txt

Matriks awalnya:
-----
| 1 | 2 | 3 | 4 |
-----
| 5 | 6 | 7 | 8 |
-----
| 9 |   | 10 | 12 |
-----
| 13 | 14 | 11 | 15 |
-----

Mencari tiap kurang(i):
Kurang(1) = 0
Kurang(2) = 0
Kurang(3) = 0
Kurang(4) = 0
Kurang(5) = 0
Kurang(6) = 0
Kurang(7) = 0
Kurang(8) = 0
Kurang(9) = 0
Kurang(10) = 0
Kurang(11) = 0
Kurang(12) = 1
Kurang(13) = 1
Kurang(14) = 1
Kurang(15) = 0
Kurang(16) = 6
Total sigma(i) = 9
X = 1
Banyaknya simpul yang dibangkitkan: 10
Waktu eksekusi: 0.03590059280395508 sekon
Apakah anda ingin solve puzzle lain? (ketik y/n)
Enter choice here [defaultnya y] : █

Hasil Sigma kurang(i) + X: 10
Syarat bernilai genap, maka puzzle solvable.

Sedang proses pencarian solusi...
Solusi sudah ditemukan!

Banyaknya simpul yang dibangkitkan: 10
Banyak steps: 3
Step ke-1:
Command : Move blank right
-----
| 1 | 2 | 3 | 4 |
-----
| 5 | 6 | 7 | 8 |
-----
| 9 | 10 |   | 12 |
-----
| 13 | 14 | 11 | 15 |
-----

Step ke-2:
Command : Move blank down
-----
| 1 | 2 | 3 | 4 |
-----
| 5 | 6 | 7 | 8 |
-----
| 9 | 10 | 11 | 12 |
-----
| 13 | 14 |   | 15 |
-----

Step ke-3:
Command : Move blank right
-----
| 1 | 2 | 3 | 4 |
-----
| 5 | 6 | 7 | 8 |
-----
| 9 | 10 | 11 | 12 |
-----
| 13 | 14 | 15 |   |
-----
```


4. easy2.txt

Testcase ini digunakan untuk mencoba puzzle yang cukup mudah diselesaikan

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

Sigma kurang(i) + X : 20
Status : solvable
Waktu eksekusi : 0.077 sekon
Banyak simpul dibangkitkan : 24
Banyaknya steps : 10

Berikut adalah screenshots hasil eksekusinya :

```
Cara generate puzzle:
1. Dari txt file
2. Random puzzle generator
Enter command here (Masukkan angka 1 atau 2) : 1
Input filename here (dengan .txt): easy2.txt

Matriks awalnya:
-----
| 1 | 6 | 2 | 3 |
-----
| 5 | 10 | 7 | 4 |
-----
| 9 | 14 | 12 | 8 |
-----
| 13 |   | 11 | 15 |
-----

Mencari tiap kurang(i):
Kurang(1) = 0
Kurang(2) = 0
Kurang(3) = 0
Kurang(4) = 0
Kurang(5) = 1
Kurang(6) = 4
Kurang(7) = 1
Kurang(8) = 0
Kurang(9) = 1
Kurang(10) = 4
Kurang(11) = 0
Kurang(12) = 2
Kurang(13) = 1
Kurang(14) = 4
Kurang(15) = 0
Kurang(16) = 2
Total sigma(i) = 20
X = 0

Hasil Sigma kurang(i) + X: 20
Syarat bernilai genap, maka puzzle solvable.

Sedang proses pencarian solusi...
Solusi sudah ditemukan!

Banyaknya simpul yang dibangkitkan: 24
Banyak steps: 10
Step ke-1:
Command : Move blank up
-----
| 1 | 6 | 2 | 3 |
-----
| 5 | 10 | 7 | 4 |
-----
| 9 |   | 12 | 8 |
-----
| 13 | 14 | 11 | 15 |
-----

Step ke-2:
Command : Move blank up
-----
| 1 | 6 | 2 | 3 |
-----
| 5 |   | 7 | 4 |
-----
| 9 | 10 | 12 | 8 |
-----
| 13 | 14 | 11 | 15 |
-----

Step ke-3:
Command : Move blank up
-----
| 1 |   | 2 | 3 |
-----
| 5 | 6 | 7 | 4 |
-----
| 9 | 10 | 12 | 8 |
-----
```

```

Step ke-4:
Command : Move blank right
-----
| 1 | 2 |   | 3 |
-----
| 5 | 6 | 7 | 4 |
-----
| 9 | 10 | 12 | 8 |
-----
| 13 | 14 | 11 | 15 |
-----

Step ke-5:
Command : Move blank right
-----
| 1 | 2 | 3 |   |
-----
| 5 | 6 | 7 | 4 |
-----
| 9 | 10 | 12 | 8 |
-----
| 13 | 14 | 11 | 15 |
-----

Step ke-6:
Command : Move blank down
-----
| 1 | 2 | 3 | 4 |
-----
| 5 | 6 | 7 |   |
-----
| 9 | 10 | 12 | 8 |
-----
| 13 | 14 | 11 | 15 |
-----

Step ke-7:
Command : Move blank down
-----
| 1 | 2 | 3 | 4 |
-----
| 5 | 6 | 7 | 8 |
-----
| 9 | 10 | 12 |   |
-----
| 13 | 14 | 11 | 15 |
-----

Step ke-8:
Command : Move blank left
-----
| 1 | 2 | 3 | 4 |
-----
| 5 | 6 | 7 | 8 |
-----
| 9 | 10 |   | 12 |
-----
| 13 | 14 | 11 | 15 |
-----

Step ke-9:
Command : Move blank down
-----
| 1 | 2 | 3 | 4 |
-----
| 5 | 6 | 7 | 8 |
-----
| 9 | 10 | 11 | 12 |
-----
| 13 | 14 |   | 15 |
-----

Step ke-10:
Command : Move blank right
-----
| 1 | 2 | 3 | 4 |
-----
| 5 | 6 | 7 | 8 |
-----
| 9 | 10 | 11 | 12 |
-----
| 13 | 14 | 15 |   |
-----

Banyaknya simpul yang dibangkitkan: 24
Waktu eksekusi: 0.07779169082641602 sekon
Apakah anda ingin solve puzzle lain? (ketik y/n)
Enter choice here [defaultnva vl : █

```

5. medium1.txt

Testcase ini digunakan untuk mencoba puzzle dengan difficulty sedang

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

Sigma kurang(i) + X : 26
 Status : solvable
 Waktu eksekusi : 0.117 sekon
 Banyak simpul dibangkitkan : 359
 Banyaknya steps : 15

Berikut adalah screenshots hasil eksekusinya :

```

Cara generate puzzle:
1. Dari txt file
2. Random puzzle generator
Enter command here (Masukkan angka 1 atau 2) : 1
Input filename here (dengan .txt): medium1.txt

Matriks awalnya:
-----
| 2 | 7 | 6 | 4 |
| 1 | 3 | 11 | 8 |
| 5 |   | 9 | 12 |
| 13 | 10 | 14 | 15 |
-----

Mencari tiap kurang(i):
Kurang(1) = 0
Kurang(2) = 1
Kurang(3) = 0
Kurang(4) = 2
Kurang(5) = 0
Kurang(6) = 4
Kurang(7) = 5
Kurang(8) = 1
Kurang(9) = 0
Kurang(10) = 0
Kurang(11) = 4
Kurang(12) = 1
Kurang(13) = 1
Kurang(14) = 0
Kurang(15) = 0
Kurang(16) = 6
Total sigma(i) = 25
X = 1

Hasil Sigma kurang(i) + X: 26
Syarat bernilai genap, maka puzzle solvable.

Sedang proses pencarian solusi...
Solusi sudah ditemukan!

Banyaknya simpul yang dibangkitkan: 359
Banyak steps: 15

Step ke-1:
Command : Move blank right
-----
| 2 | 7 | 6 | 4 |
| 1 | 3 | 11 | 8 |
| 5 | 9 |   | 12 |
| 13 | 10 | 14 | 15 |
-----

Step ke-2:
Command : Move blank up
-----
| 2 | 7 | 6 | 4 |
| 1 | 3 |   | 8 |
| 5 | 9 | 11 | 12 |
| 13 | 10 | 14 | 15 |
-----

Step ke-3:
Command : Move blank up
-----
| 2 | 7 |   | 4 |
| 1 | 3 | 6 | 8 |
| 5 | 9 | 11 | 12 |
| 13 | 10 | 14 | 15 |
-----

Step ke-4:
Command : Move blank left
-----
| 2 |   | 7 | 4 |
| 1 | 3 | 6 | 8 |
| 5 | 9 | 11 | 12 |
| 13 | 10 | 14 | 15 |
-----

Step ke-5:
Command : Move blank down
-----
| 2 | 3 | 7 | 4 |
| 1 |   | 6 | 8 |
| 5 | 9 | 11 | 12 |
| 13 | 10 | 14 | 15 |
-----

Step ke-6:
Command : Move blank right
-----
| 2 | 3 | 7 | 4 |
| 1 | 6 |   | 8 |
| 5 | 9 | 11 | 12 |
| 13 | 10 | 14 | 15 |
-----

Step ke-7:
Command : Move blank up
-----
| 2 | 3 |   | 4 |
| 1 | 6 | 7 | 8 |
| 5 | 9 | 11 | 12 |
| 13 | 10 | 14 | 15 |
-----

Step ke-8:
Command : Move blank left
-----
| 2 |   | 3 | 4 |
| 1 | 6 | 7 | 8 |
| 5 | 9 | 11 | 12 |
| 13 | 10 | 14 | 15 |
-----
  
```

```

Step ke-9:
Command : Move blank left
-----
|  | 2 | 3 | 4 |
-----
| 1 | 6 | 7 | 8 |
-----
| 5 | 9 | 11 | 12 |
-----
| 13 | 10 | 14 | 15 |
-----

Step ke-10:
Command : Move blank down
-----
| 1 | 2 | 3 | 4 |
-----
|  | 6 | 7 | 8 |
-----
| 5 | 9 | 11 | 12 |
-----
| 13 | 10 | 14 | 15 |
-----

Step ke-11:
Command : Move blank down
-----
| 1 | 2 | 3 | 4 |
-----
| 5 | 6 | 7 | 8 |
-----
|  | 9 | 11 | 12 |
-----
| 13 | 10 | 14 | 15 |
-----

Step ke-12:
Command : Move blank right
-----
| 1 | 2 | 3 | 4 |
-----
| 5 | 6 | 7 | 8 |
-----
| 9 |  | 11 | 12 |
-----
| 13 | 10 | 14 | 15 |
-----

Step ke-13:
Command : Move blank down
-----
| 1 | 2 | 3 | 4 |
-----
| 5 | 6 | 7 | 8 |
-----
| 9 | 10 | 11 | 12 |
-----
| 13 |  | 14 | 15 |
-----

Step ke-14:
Command : Move blank right
-----
| 1 | 2 | 3 | 4 |
-----
| 5 | 6 | 7 | 8 |
-----
| 9 | 10 | 11 | 12 |
-----
| 13 | 14 |  | 15 |
-----

Step ke-15:
Command : Move blank right
-----
| 1 | 2 | 3 | 4 |
-----
| 5 | 6 | 7 | 8 |
-----
| 9 | 10 | 11 | 12 |
-----
| 13 | 14 | 15 |  |
-----

Banyaknya simpul yang dibangkitkan: 359
Waktu eksekusi: 0.11768436431884766 sekon
Apakah anda ingin solve puzzle lain? (ketik y/n)
Enter choice here [defaultnya y] : 

```

6. medium2.txt

Testcase ini digunakan untuk mencoba puzzle dengan difficulty sedang

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

Sigma kurang(i) + X : 34
 Status : solvable
 Waktu eksekusi : 0.26 sekon
 Banyak simpul dibangkitkan : 2579
 Banyaknya steps : 20

Berikut adalah screenshots hasil eksekusinya :

Cara generate puzzle:
 1. Dari txt file
 2. Random puzzle generator
 Enter command here (Masukkan angka 1 atau 2) : 1
 Input filename here (dengan .txt): medium2.txt

Matriks awalnya:

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

Mencari tiap kurang(i):

```
Kurang(1) = 0
Kurang(2) = 1
Kurang(3) = 1
Kurang(4) = 0
Kurang(5) = 3
Kurang(6) = 0
Kurang(7) = 4
Kurang(8) = 0
Kurang(9) = 4
Kurang(10) = 2
Kurang(11) = 2
Kurang(12) = 1
Kurang(13) = 2
Kurang(14) = 2
Kurang(15) = 4
Kurang(16) = 8
Total sigma(i) = 34
X = 0
```

Hasil Sigma kurang(i) + X: 34
 Syarat bernilai genap, maka puzzle solvable.

Sedang proses pencarian solusi...
 Solusi sudah ditemukan!

Banyaknya simpul yang dibangkitkan: 2579
 Banyak steps: 20

Step ke-1:
 Command : Move blank left

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

Step ke-2:
 Command : Move blank down

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

Step ke-3:
 Command : Move blank right

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

Step ke-4:
 Command : Move blank down

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

Step ke-5:
 Command : Move blank left

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

Step ke-6:
 Command : Move blank up

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

Step ke-7:
 Command : Move blank left

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

Step ke-8:
 Command : Move blank left

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

<p>Step ke-9: Command : Move blank up</p> <pre> ----- 2 5 7 3 ----- 1 6 4 ----- 9 10 11 8 ----- 13 14 15 12 ----- </pre>	<p>Step ke-12: Command : Move blank left</p> <pre> ----- 2 7 3 ----- 1 5 6 4 ----- 9 10 11 8 ----- 13 14 15 12 ----- </pre>	<p>Step ke-16: Command : Move blank up</p> <pre> ----- 1 2 3 ----- 5 6 7 4 ----- 9 10 11 8 ----- 13 14 15 12 ----- </pre>
<p>Step ke-10: Command : Move blank right</p> <pre> ----- 2 5 7 3 ----- 1 6 4 ----- 9 10 11 8 ----- 13 14 15 12 ----- </pre>	<p>Step ke-13: Command : Move blank down</p> <pre> ----- 1 2 7 3 ----- 5 6 4 ----- 9 10 11 8 ----- 13 14 15 12 ----- </pre>	<p>Step ke-17: Command : Move blank right</p> <pre> ----- 1 2 3 ----- 5 6 7 4 ----- 9 10 11 8 ----- 13 14 15 12 ----- </pre>
<p>Step ke-11: Command : Move blank up</p> <pre> ----- 2 7 3 ----- 1 5 6 4 ----- 9 10 11 8 ----- 13 14 15 12 ----- </pre>	<p>Step ke-14: Command : Move blank right</p> <pre> ----- 1 2 7 3 ----- 5 6 4 ----- 9 10 11 8 ----- 13 14 15 12 ----- </pre>	<p>Step ke-18: Command : Move blank down</p> <pre> ----- 1 2 3 4 ----- 5 6 7 ----- 9 10 11 8 ----- 13 14 15 12 ----- </pre>
<p>Step ke-12: Command : Move blank left</p> <pre> ----- 2 7 3 ----- 1 5 6 4 ----- 9 10 11 8 ----- 13 14 15 12 ----- </pre>	<p>Step ke-15: Command : Move blank right</p> <pre> ----- 1 2 7 3 ----- 5 6 4 ----- 9 10 11 8 ----- 13 14 15 12 ----- </pre>	<p>Step ke-19: Command : Move blank down</p> <pre> ----- 1 2 3 4 ----- 5 6 7 8 ----- 9 10 11 ----- 13 14 15 12 ----- </pre>

```

Step ke-20:
Command : Move blank down
-----
| 1 | 2 | 3 | 4 |
-----
| 5 | 6 | 7 | 8 |
-----
| 9 | 10 | 11 | 12 |
-----
| 13 | 14 | 15 |  |
-----

Banyaknya simpul yang dibangkitkan: 2579
Waktu eksekusi: 0.26023387908935547 sekon
Apakah anda ingin solve puzzle lain? (ketik y/n)
Enter choice here [defaultnya y] : 

```

7. hard1.txt

Testcase ini digunakan untuk mencoba puzzle dengan difficulty sulit

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

Sigma kurang(i) + X : 34
 Status : solvable
 Waktu eksekusi : 0.6 sekon
 Banyak simpul dibangkitkan : 10091
 Banyaknya steps : 21

Berikut adalah screenshots hasil eksekusinya :

```

Cara generate puzzle:
1. Dari txt file
2. Random puzzle generator
Enter command here (Masukkan angka 1 atau 2) : 1
Input filename here (dengan .txt): hard1.txt

Matriks awalnya:
-----
| 5 | 11 | 2 | 4 |
-----
| 9 | 1 | 3 | 7 |
-----
| 13 | 10 | 6 | 8 |
-----
|  | 14 | 15 | 12 |
-----

Mencari tiap kurang(i):
Kurang(1) = 0
Kurang(2) = 1
Kurang(3) = 0
Kurang(4) = 2
Kurang(5) = 4
Kurang(6) = 0
Kurang(7) = 1
Kurang(8) = 0
Kurang(9) = 5
Kurang(10) = 2
Kurang(11) = 9
Kurang(12) = 0
Kurang(13) = 4
Kurang(14) = 1
Kurang(15) = 1
Kurang(16) = 3
Total sigma(i) = 33
X = 1

Hasil Sigma kurang(i) + X: 34
Syarat bernilai genap, maka puzzle solvable.

Sedang proses pencarian solusi...
Solusi sudah ditemukan!

Banyaknya simpul yang dibangkitkan: 10091
Banyak steps: 21
Step ke-1:
Command : Move blank up
-----
| 5 | 11 | 2 | 4 |
-----
| 9 | 1 | 3 | 7 |
-----
|  | 10 | 6 | 8 |
-----
| 13 | 14 | 15 | 12 |
-----

Step ke-2:
Command : Move blank up
-----
| 5 | 11 | 2 | 4 |
-----
|  | 1 | 3 | 7 |
-----
| 9 | 10 | 6 | 8 |
-----
| 13 | 14 | 15 | 12 |
-----

```

<p>Step ke-3: Command : Move blank right</p> <table><tr><td> </td><td>5</td><td> </td><td>11</td><td> </td><td>2</td><td> </td><td>4</td><td> </td></tr><tr><td> </td><td>1</td><td> </td><td></td><td> </td><td>3</td><td> </td><td>7</td><td> </td></tr><tr><td> </td><td>9</td><td> </td><td>10</td><td> </td><td>6</td><td> </td><td>8</td><td> </td></tr><tr><td> </td><td>13</td><td> </td><td>14</td><td> </td><td>15</td><td> </td><td>12</td><td> </td></tr></table>		5		11		2		4			1				3		7			9		10		6		8			13		14		15		12		<p>Step ke-7: Command : Move blank down</p> <table><tr><td> </td><td>1</td><td> </td><td>5</td><td> </td><td>2</td><td> </td><td>4</td><td> </td></tr><tr><td> </td><td>9</td><td> </td><td>11</td><td> </td><td>3</td><td> </td><td>7</td><td> </td></tr><tr><td> </td><td></td><td> </td><td>10</td><td> </td><td>6</td><td> </td><td>8</td><td> </td></tr><tr><td> </td><td>13</td><td> </td><td>14</td><td> </td><td>15</td><td> </td><td>12</td><td> </td></tr></table>		1		5		2		4			9		11		3		7					10		6		8			13		14		15		12		<p>Step ke-11: Command : Move blank right</p> <table><tr><td> </td><td>1</td><td> </td><td>2</td><td> </td><td></td><td> </td><td>4</td><td> </td></tr><tr><td> </td><td>9</td><td> </td><td>5</td><td> </td><td>3</td><td> </td><td>7</td><td> </td></tr><tr><td> </td><td>10</td><td> </td><td>11</td><td> </td><td>6</td><td> </td><td>8</td><td> </td></tr><tr><td> </td><td>13</td><td> </td><td>14</td><td> </td><td>15</td><td> </td><td>12</td><td> </td></tr></table>		1		2				4			9		5		3		7			10		11		6		8			13		14		15		12		<p>Step ke-15: Command : Move blank left</p> <table><tr><td> </td><td>1</td><td> </td><td>2</td><td> </td><td>3</td><td> </td><td>4</td><td> </td></tr><tr><td> </td><td>9</td><td> </td><td>5</td><td> </td><td>6</td><td> </td><td>7</td><td> </td></tr><tr><td> </td><td></td><td> </td><td>10</td><td> </td><td>11</td><td> </td><td>8</td><td> </td></tr><tr><td> </td><td>13</td><td> </td><td>14</td><td> </td><td>15</td><td> </td><td>12</td><td> </td></tr></table>		1		2		3		4			9		5		6		7					10		11		8			13		14		15		12	
	5		11		2		4																																																																																																																																												
	1				3		7																																																																																																																																												
	9		10		6		8																																																																																																																																												
	13		14		15		12																																																																																																																																												
	1		5		2		4																																																																																																																																												
	9		11		3		7																																																																																																																																												
			10		6		8																																																																																																																																												
	13		14		15		12																																																																																																																																												
	1		2				4																																																																																																																																												
	9		5		3		7																																																																																																																																												
	10		11		6		8																																																																																																																																												
	13		14		15		12																																																																																																																																												
	1		2		3		4																																																																																																																																												
	9		5		6		7																																																																																																																																												
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<p>Banyaknya simpul yang dibangkitkan: 10091 Waktu eksekusi: 0.5949807167053223 sekon Apakah anda ingin solve puzzle lain? (ketik y/n) Enter choice here [defaultnya y] : █</p>																																																																																																																																																			

8. hard2.txt

Testcase ini digunakan untuk mencoba puzzle dengan difficulty sulit

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

Sigma kurang(i) + X : 28
Status : solvable
Waktu eksekusi : 19,6 sekon
Banyak simpul dibangkitkan : 410029
Banyaknya steps : 28

Berikut adalah screenshots hasil eksekusinya :

```
Cara generate puzzle:
1. Dari txt file
2. Random puzzle generator
Enter command here (Masukkan angka 1 atau 2) : 1
Input filename here (dengan .txt): hard2.txt

Matriks awalnya:
-----
| 6 | 5 | 2 | 3 |
| 1 | 8 | 4 | 12 |
| 14 | 10 | 9 | 7 |
| 13 |   | 11 | 15 |
-----

Mencari tiap kurang(i):
Kurang(1) = 0
Kurang(2) = 1
Kurang(3) = 1
Kurang(4) = 0
Kurang(5) = 4
Kurang(6) = 5
Kurang(7) = 0
Kurang(8) = 2
Kurang(9) = 1
Kurang(10) = 2
Kurang(11) = 0
Kurang(12) = 4
Kurang(13) = 1
Kurang(14) = 5
Kurang(15) = 0
Kurang(16) = 2
Total sigma(i) = 28
X = 0

Hasil Sigma kurang(i) + X: 28
Syarat bernilai genap, maka puzzle solvable.

Sedang proses pencarian solusi...
Solusi sudah ditemukan!

Banyaknya simpul yang dibangkitkan: 410029
Banyak steps: 28

Step ke-1:
Command : Move blank up
-----
| 6 | 5 | 2 | 3 |
| 1 | 8 | 4 | 12 |
| 14 |   | 9 | 7 |
| 13 | 10 | 11 | 15 |
-----

Step ke-2:
Command : Move blank left
-----
| 6 | 5 | 2 | 3 |
| 1 | 8 | 4 | 12 |
|   | 14 | 9 | 7 |
| 13 | 10 | 11 | 15 |
-----

Step ke-3:
Command : Move blank down
-----
| 6 | 5 | 2 | 3 |
| 1 | 8 | 4 | 12 |
| 13 | 14 | 9 | 7 |
|   | 10 | 11 | 15 |
-----

Step ke-4:
Command : Move blank right
-----
| 6 | 5 | 2 | 3 |
| 1 | 8 | 4 | 12 |
| 13 | 14 | 9 | 7 |
| 10 |   | 11 | 15 |
-----

Step ke-5:
Command : Move blank up
-----
| 6 | 5 | 2 | 3 |
| 1 | 8 | 4 | 12 |
| 13 |   | 9 | 7 |
| 10 | 14 | 11 | 15 |
-----

Step ke-6:
Command : Move blank right
-----
| 6 | 5 | 2 | 3 |
| 1 | 8 | 4 | 12 |
| 13 | 9 |   | 7 |
| 10 | 14 | 11 | 15 |
-----

Step ke-7:
Command : Move blank right
-----
| 6 | 5 | 2 | 3 |
| 1 | 8 | 4 | 12 |
| 13 | 9 | 7 |   |
| 10 | 14 | 11 | 15 |
-----

Step ke-8:
Command : Move blank up
-----
| 6 | 5 | 2 | 3 |
| 1 | 8 | 4 |   |
| 13 | 9 | 7 | 12 |
| 10 | 14 | 11 | 15 |
-----
```

```

Step ke-9:
Command : Move blank left
| 6 | 5 | 2 | 3 |
| 1 | 8 |   | 4 |
| 13 | 9 | 7 | 12 |
| 10 | 14 | 11 | 15 |
-----

Step ke-13:
Command : Move blank down
| 1 | 6 | 2 | 3 |
|   | 5 | 8 | 4 |
| 13 | 9 | 7 | 12 |
| 10 | 14 | 11 | 15 |
-----

Step ke-17:
Command : Move blank right
| 1 | 2 | 3 |   |
| 5 | 6 | 8 | 4 |
| 13 | 9 | 7 | 12 |
| 10 | 14 | 11 | 15 |
-----

Step ke-21:
Command : Move blank down
| 1 | 2 | 3 | 4 |
| 5 | 6 | 7 | 8 |
| 13 | 9 | 11 | 12 |
| 10 | 14 |   | 15 |
-----

Step ke-10:
Command : Move blank left
| 6 | 5 | 2 | 3 |
| 1 |   | 8 | 4 |
| 13 | 9 | 7 | 12 |
| 10 | 14 | 11 | 15 |
-----

Step ke-14:
Command : Move blank right
| 1 | 6 | 2 | 3 |
| 5 |   | 8 | 4 |
| 13 | 9 | 7 | 12 |
| 10 | 14 | 11 | 15 |
-----

Step ke-18:
Command : Move blank down
| 1 | 2 | 3 | 4 |
| 5 | 6 | 8 |   |
| 13 | 9 | 7 | 12 |
| 10 | 14 | 11 | 15 |
-----

Step ke-22:
Command : Move blank left
| 1 | 2 | 3 | 4 |
| 5 | 6 | 7 | 8 |
| 13 | 9 | 11 | 12 |
| 10 |   | 14 | 15 |
-----

Step ke-11:
Command : Move blank up
| 6 |   | 2 | 3 |
| 1 | 5 | 8 | 4 |
| 13 | 9 | 7 | 12 |
| 10 | 14 | 11 | 15 |
-----

Step ke-15:
Command : Move blank up
| 1 |   | 2 | 3 |
| 5 | 6 | 8 | 4 |
| 13 | 9 | 7 | 12 |
| 10 | 14 | 11 | 15 |
-----

Step ke-19:
Command : Move blank left
| 1 | 2 | 3 | 4 |
| 5 | 6 |   | 8 |
| 13 | 9 | 7 | 12 |
| 10 | 14 | 11 | 15 |
-----

Step ke-23:
Command : Move blank left
| 1 | 2 | 3 | 4 |
| 5 | 6 | 7 | 8 |
| 13 | 9 | 11 | 12 |
|   | 10 | 14 | 15 |
-----

Step ke-12:
Command : Move blank left
|   | 6 | 2 | 3 |
| 1 | 5 | 8 | 4 |
| 13 | 9 | 7 | 12 |
| 10 | 14 | 11 | 15 |
-----

Step ke-16:
Command : Move blank right
| 1 | 2 |   | 3 |
| 5 | 6 | 8 | 4 |
| 13 | 9 | 7 | 12 |
| 10 | 14 | 11 | 15 |
-----

Step ke-20:
Command : Move blank down
| 1 | 2 | 3 | 4 |
| 5 | 6 | 7 | 8 |
| 13 | 9 |   | 12 |
| 10 | 14 | 11 | 15 |
-----

Step ke-24:
Command : Move blank up
| 1 | 2 | 3 | 4 |
| 5 | 6 | 7 | 8 |
|   | 9 | 11 | 12 |
| 13 | 10 | 14 | 15 |
-----

Step ke-25:
Command : Move blank right
| 1 | 2 | 3 | 4 |
| 5 | 6 | 7 | 8 |
| 9 |   | 11 | 12 |
| 13 | 10 | 14 | 15 |
-----

Step ke-27:
Command : Move blank right
| 1 | 2 | 3 | 4 |
| 5 | 6 | 7 | 8 |
| 9 | 10 | 11 | 12 |
| 13 | 14 |   | 15 |
-----

Step ke-26:
Command : Move blank down
| 1 | 2 | 3 | 4 |
| 5 | 6 | 7 | 8 |
| 9 | 10 | 11 | 12 |
| 13 |   | 14 | 15 |
-----

Step ke-28:
Command : Move blank right
| 1 | 2 | 3 | 4 |
| 5 | 6 | 7 | 8 |
| 9 | 10 | 11 | 12 |
| 13 | 14 | 15 |   |
-----

Step ke-27:
Command : Move blank right
| 1 | 2 | 3 | 4 |
| 5 | 6 | 7 | 8 |
| 9 | 10 | 11 | 12 |
| 13 | 14 |   | 15 |
-----

Banyaknya simpul yang dibangkitkan: 410029
Waktu eksekusi: 19.605494260787964 sekon
Apakah anda ingin solve puzzle lain? (ketik y/n)
Enter choice here [defaultnya y] :

```

9. hard3.txt

Testcase ini digunakan untuk mencoba puzzle dengan difficulty sulit

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

Sigma kurang(i) + X : 34
 Status : solvable
 Waktu eksekusi : 87,8 detik
 Banyak simpul dibangkitkan : 1907331
 Banyaknya steps : 30

Berikut adalah screenshots hasil eksekusinya :

```

Cara generate puzzle:
1. dari txt file
2. Random puzzle generator
Enter command here (Masukkan angka 1 atau 2) :
Input salah, silahkan coba lagi!
Enter command here (Masukkan angka 1 atau 2) :
Input filename here (dengan .txt): hard3.txt

Matriks awalnya:
| 5 | 2 | 8 | 10 |
| 1 | 11 | 6 | 4 |
| 7 | 9 |  | 3 |
| 13 | 14 | 15 | 12 |

Mencari tiap kurang(i):
kurang(1) = 0
kurang(2) = 1
kurang(3) = 0
kurang(4) = 1
kurang(5) = 4
kurang(6) = 2
kurang(7) = 1
kurang(8) = 5
kurang(9) = 1
kurang(10) = 6
kurang(11) = 5
kurang(12) = 0
kurang(13) = 1
kurang(14) = 1
kurang(15) = 1
kurang(16) = 5
total sigma(i) = 34
X = 0

Hasil Sigma kurang(i) + X: 34
Syarat bernilai genap, maka puzzle solvable.
sedang proses pencarian solusi...
Solusi sudah ditemukan!
Banyaknya simpul yang dibangkitkan: 1907331
Banyak steps: 30

Step ke-1:
Command : Move blank up
| 5 | 2 | 8 | 10 |
| 1 | 11 | 6 | 4 |
| 7 | 9 | 6 | 3 |
| 13 | 14 | 15 | 12 |

Step ke-2:
Command : Move blank left
| 5 | 2 | 8 | 10 |
| 1 |  | 11 | 4 |
| 7 | 9 | 6 | 3 |
| 13 | 14 | 15 | 12 |

Step ke-3:
Command : Move blank left
| 5 | 2 | 8 | 10 |
|  | 1 | 11 | 4 |
| 7 | 9 | 6 | 3 |
| 13 | 14 | 15 | 12 |

Step ke-4:
Command : Move blank down
| 5 | 2 | 8 | 10 |
| 7 | 1 | 11 | 4 |
| 9 | 6 | 3 |  |
| 13 | 14 | 15 | 12 |

Step ke-5:
Command : Move blank right
| 5 | 2 | 8 | 10 |
| 7 | 1 | 11 | 4 |
| 9 |  | 6 | 3 |
| 13 | 14 | 15 | 12 |

Step ke-6:
Command : Move blank right
| 5 | 2 | 8 | 10 |
| 7 | 1 | 11 | 4 |
| 9 | 6 |  | 3 |
| 13 | 14 | 15 | 12 |

Step ke-7:
Command : Move blank up
| 5 | 2 | 8 | 10 |
| 7 | 1 |  | 4 |
| 9 | 6 | 11 | 3 |
| 13 | 14 | 15 | 12 |

Step ke-8:
Command : Move blank right
| 5 | 2 | 8 | 10 |
| 7 | 1 |  | 4 |
| 9 | 6 | 11 | 3 |
| 13 | 14 | 15 | 12 |

Step ke-9:
Command : Move blank up
| 5 | 2 | 8 |  |
| 7 | 1 | 4 | 10 |
| 9 | 6 | 11 | 3 |
| 13 | 14 | 15 | 12 |

Step ke-10:
Command : Move blank left
| 5 | 2 |  | 8 |
| 7 | 1 | 4 | 10 |
| 9 | 6 | 11 | 3 |
| 13 | 14 | 15 | 12 |

Step ke-11:
Command : Move blank down
| 5 | 2 | 4 | 8 |
| 7 | 1 |  | 10 |
| 9 | 6 | 11 | 3 |
| 13 | 14 | 15 | 12 |

Step ke-12:
Command : Move blank right
| 5 | 2 | 4 | 8 |
| 7 | 1 | 10 |  |
| 9 | 6 | 11 | 3 |
| 13 | 14 | 15 | 12 |

Step ke-13:
Command : Move blank down
| 5 | 2 | 4 | 8 |
| 7 | 1 | 10 | 3 |
| 9 | 6 | 11 |  |
| 13 | 14 | 15 | 12 |

Step ke-14:
Command : Move blank left
| 5 | 2 | 4 | 8 |
| 7 | 1 | 10 | 3 |
| 9 | 6 | 11 |  |
| 13 | 14 | 15 | 12 |

Step ke-15:
Command : Move blank up
| 5 | 2 | 4 | 8 |
| 7 | 1 |  | 10 |
| 9 | 6 | 11 | 3 |
| 13 | 14 | 15 | 12 |

Step ke-16:
Command : Move blank right
| 5 | 2 | 4 | 8 |
| 7 | 1 |  | 10 |
| 9 | 6 | 11 | 3 |
| 13 | 14 | 15 | 12 |

Step ke-17:
Command : Move blank up
| 5 | 2 | 4 |  |
| 7 | 1 | 3 | 8 |
| 9 | 6 | 10 | 11 |
| 13 | 14 | 15 | 12 |

Step ke-18:
Command : Move blank left
| 5 | 2 |  | 4 |
| 7 | 1 | 3 | 8 |
| 9 | 6 | 10 | 11 |
| 13 | 14 | 15 | 12 |

Step ke-19:
Command : Move blank left
| 5 |  | 2 | 4 |
| 7 | 1 | 3 | 8 |
| 9 | 6 | 10 | 11 |
| 13 | 14 | 15 | 12 |

Step ke-20:
Command : Move blank down
| 5 | 1 | 2 | 4 |
| 7 |  | 3 | 8 |
| 9 | 6 | 10 | 11 |
| 13 | 14 | 15 | 12 |

Step ke-21:
Command : Move blank left
| 5 | 1 | 2 | 4 |
|  | 7 | 3 | 8 |
| 9 | 6 | 10 | 11 |
| 13 | 14 | 15 | 12 |

Step ke-22:
Command : Move blank up
|  | 1 | 2 | 4 |
| 5 | 7 | 3 | 8 |
| 9 | 6 | 10 | 11 |
| 13 | 14 | 15 | 12 |

Step ke-23:
Command : Move blank right
|  | 1 | 2 | 4 |
| 5 | 7 | 3 | 8 |
| 9 | 6 | 10 | 11 |
| 13 | 14 | 15 | 12 |

Step ke-24:
Command : Move blank right
|  | 1 | 2 |  | 4 |
| 5 | 7 | 3 | 8 |
| 9 | 6 | 10 | 11 |
| 13 | 14 | 15 | 12 |

Step ke-25:
Command : Move blank down
| 1 | 2 | 3 | 4 |
| 5 | 7 |  | 8 |
| 9 | 6 | 10 | 11 |
| 13 | 14 | 15 | 12 |

Step ke-26:
Command : Move blank left
| 1 | 2 | 3 | 4 |
| 5 |  | 7 | 8 |
| 9 | 6 | 10 | 11 |
| 13 | 14 | 15 | 12 |

Step ke-27:
Command : Move blank down
| 1 | 2 | 3 | 4 |
| 5 | 6 | 7 | 8 |
| 9 |  | 10 | 11 |
| 13 | 14 | 15 | 12 |

Step ke-28:
Command : Move blank right
| 1 | 2 | 3 | 4 |
| 5 | 6 | 7 | 8 |
| 9 | 10 |  | 11 |
| 13 | 14 | 15 | 12 |

Step ke-29:
Command : Move blank right
| 1 | 2 | 3 | 4 |
| 5 | 6 | 7 | 8 |
| 9 | 10 | 11 |  |
| 13 | 14 | 15 | 12 |

Step ke-30:
Command : Move blank down
| 1 | 2 | 3 | 4 |
| 5 | 6 | 7 | 8 |
| 9 | 10 | 11 | 12 |
| 13 | 14 | 15 |  |

Banyaknya simpul yang dibangkitkan: 1907331
Waktu eksekusi: 87.7984416484328 detik
Apakah anda ingin solve puzzle lain? (ketik y/n)
Enter choice here [defaultnya y] :
  
```

D. Link to Repository (Drive Source Code)

https://github.com/saulsayerz/Tucil3_13520094

E. Tabel Checklist

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