Laporan Tugas Kecil 3
IF2211 Strategi Algoritma
Penyelesaian Persoalan 15-Puzzle dengan Algoritma Branch and Bound

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Daftar Isi

1 Algoritma Branch and Bound Program dalam Menyelesaikan Persoalan

Algoritma branch and bound yang digunakan program untuk menyelesaikan persoalan 15-puzzle diawali dengan pengecekkan nilai dari:

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

dan fungsi KURANG(i) mengembalikan jumlah tile di depan yang lebih kecil dari i, serta X merupakan nilai 0 atau 1 tergantung posisi nilai kosong. X didapatkan dengan penambahan posisi baris dengan kolom, dan dilakukan modulus dengan nilai 2. Jika nilai total tersebut genap, maka puzzle tersebut dapat diselesaikan dan program akan dilanjutkan.

Jika puzzle solvable, algoritma branch and bound akan dilakukan untuk pencarian simpul solusi dari simpul awal. Taksiran cost untuk simpul hidup merupakan jumlah step yang dibutuhkan dari simpul awal hingga suatu simpul tersebut, ditambah dengan jumlah ubin tidak kosong yang tidak berada pada tempat sesuai susunan akhir.

Langkah program dalam penyelesaian 15-puzzle menggunakan branch and bound diawali dengan membangkitkan simpul-simpul yang mungkin dibentuk dengan pertukaran tile kosong ke arah atas, kanan, bawah, dan kiri. Pertukaran dilakukan dengan constraint pertukaran tersebut dapat dilakukan (tidak out of bound) dan tidak kembali ke simpul sebelumnya (misal, tidak ekspansi ke arah kanan jika step simpul saat ini dibuat dari expansi ke arah kiri). Setelah itu, menghitung taksiran cost untuk masing-masing simpul yang telah dibangkitkan. Pembangkitan simpul selanjutnya dilakukan pada simpul dengan cost terkecil dan belum dibangkitkan. Program melakukan looping pencarian hingga ditemukan simpul yang sama dengan goal state.

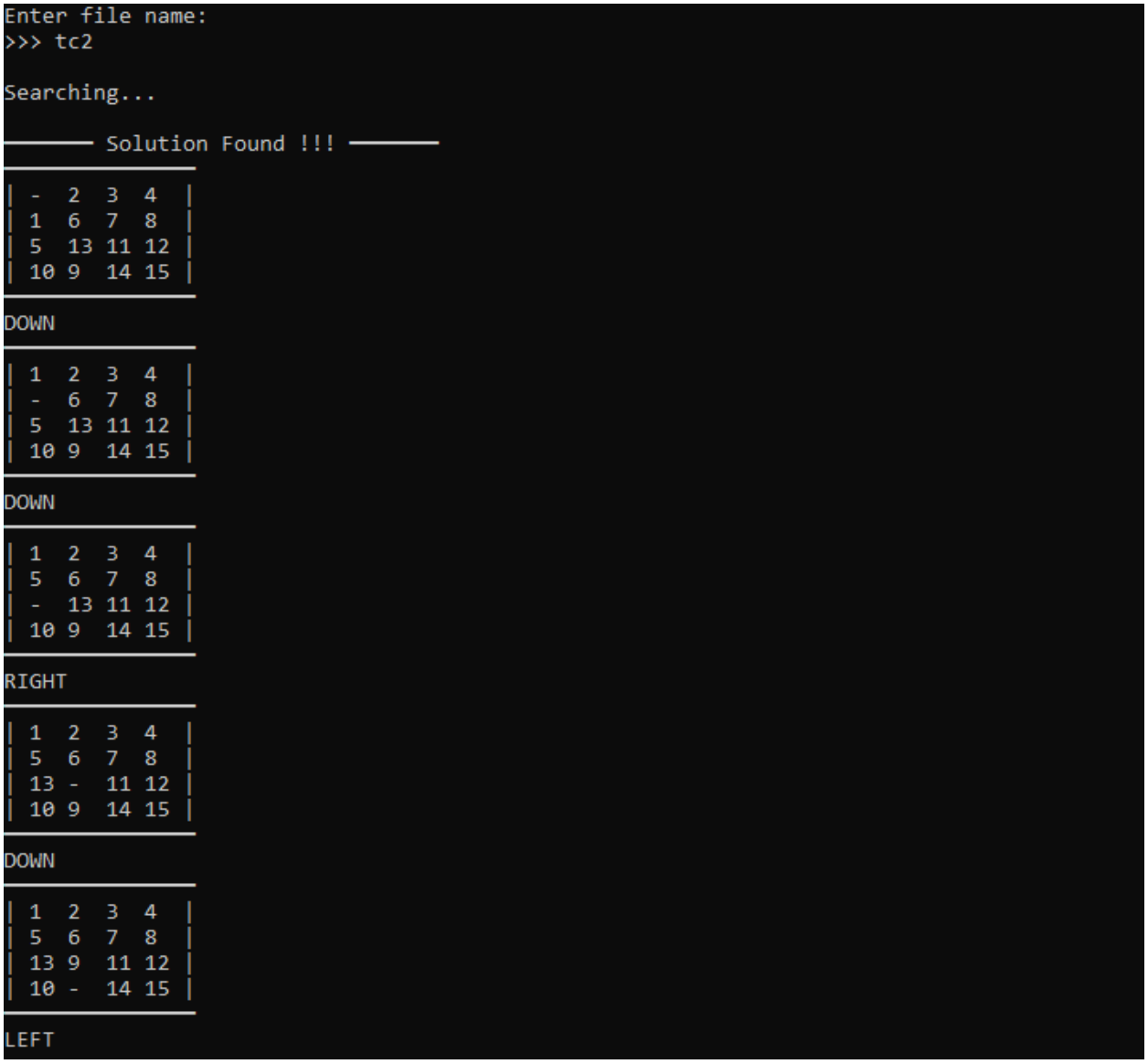
2 *Screenshot Input-Output* Program

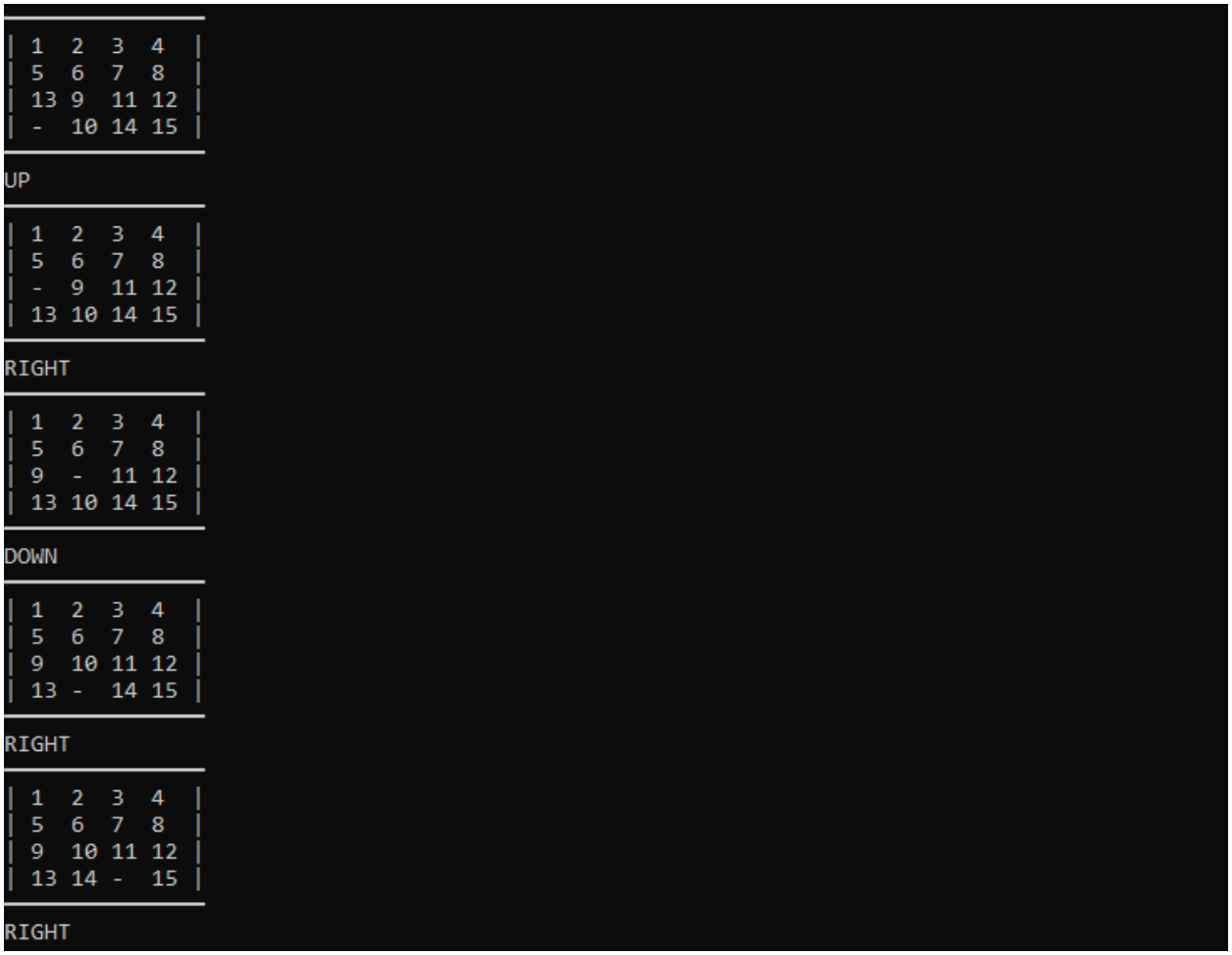
2.1 *Start of Program*

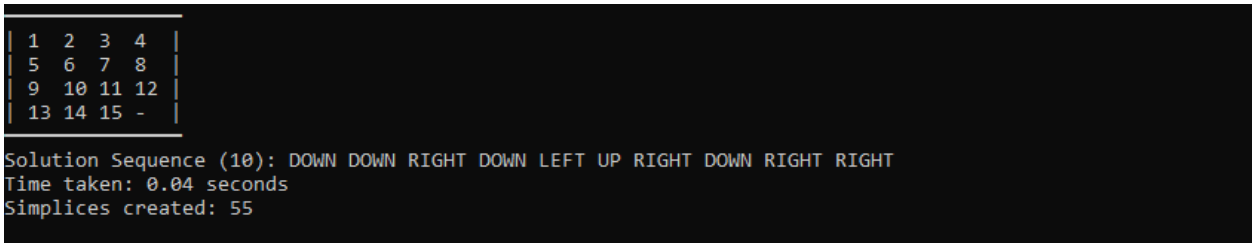
2.2 *Test Case* tc1.txt *Input-Output*

```
Enter file name:
>>> tc1

Searching...

──────── Solution Found !!! ────────
┌──────────────┐
| 1  -  2  3   |
| 5  6  7  4   |
| 9  10 11 8   |
| 13 14 15 12  |
└──────────────┘
RIGHT
┌──────────────┐
| 1  2  -  3   |
| 5  6  7  4   |
| 9  10 11 8   |
| 13 14 15 12  |
└──────────────┘
RIGHT
┌──────────────┐
| 1  2  3  -   |
| 5  6  7  4   |
| 9  10 11 8   |
| 13 14 15 12  |
└──────────────┘
DOWN
┌──────────────┐
| 1  2  3  4   |
| 5  6  7  -   |
| 9  10 11 8   |
| 13 14 15 12  |
└──────────────┘
DOWN
┌──────────────┐
| 1  2  3  4   |
| 5  6  7  8   |
| 9  10 11 -   |
| 13 14 15 12  |
└──────────────┘
DOWN
┌──────────────┐
| 1  2  3  4   |
| 5  6  7  8   |
| 9  10 11 12  |
| 13 14 15 -   |
└──────────────┘
Solution Sequence (5): RIGHT RIGHT DOWN DOWN DOWN
Time taken: 0.003 seconds
Simplices created: 11
```

2.3 *Test Case* tc2.txt *Input-Output*

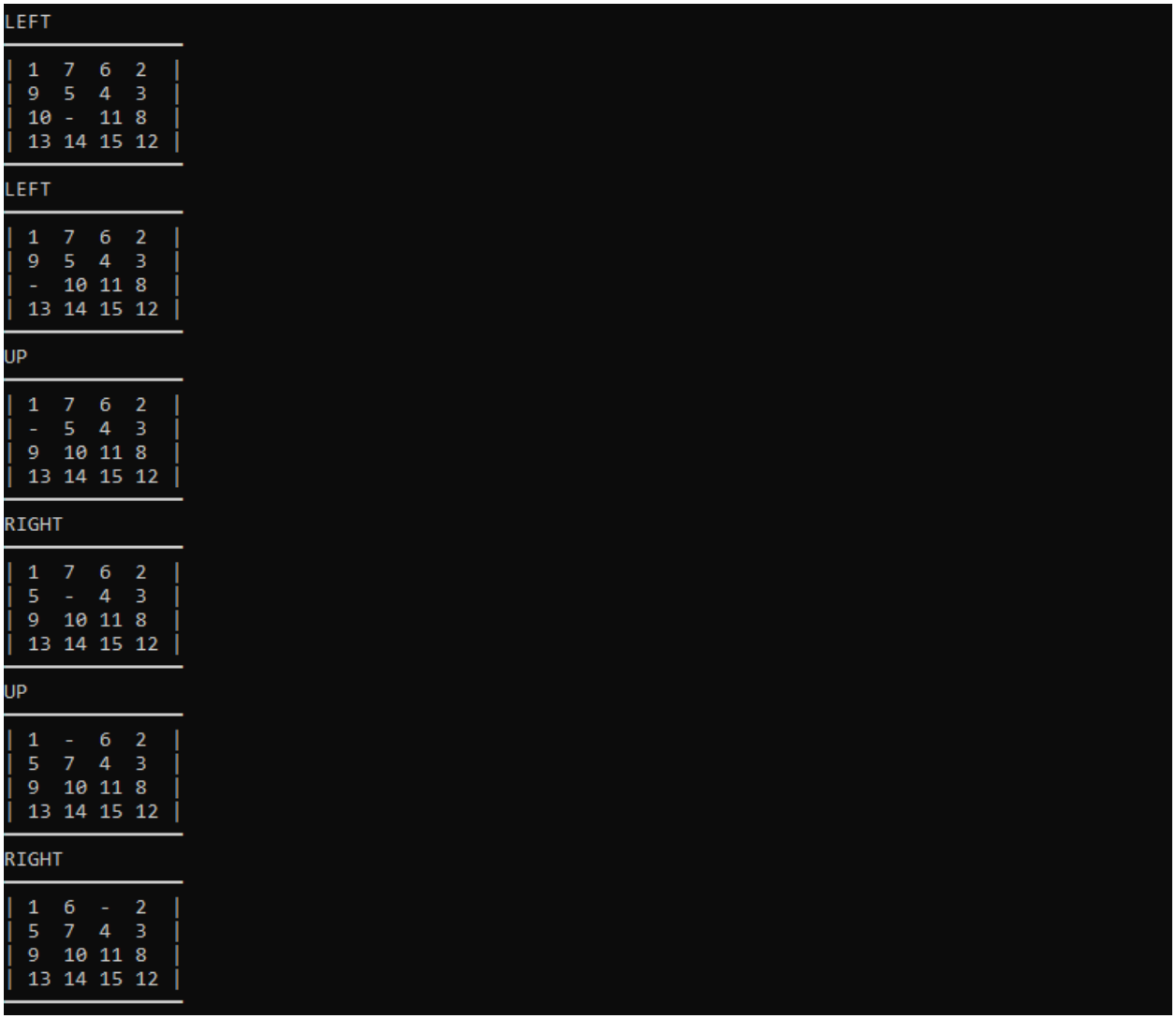


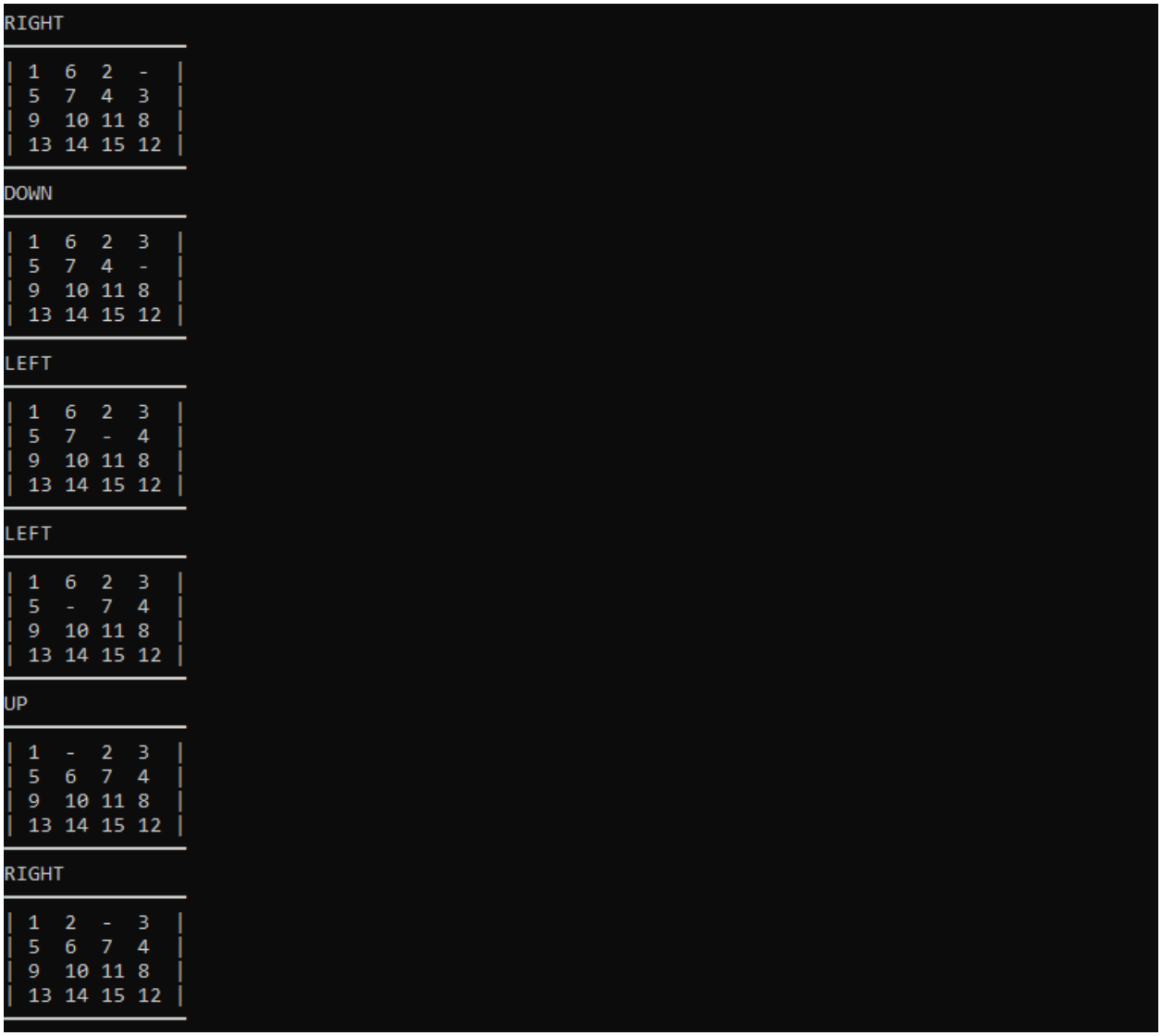

| 1 2 3 4 |
| 5 6 7 8 |
| 13 9 11 12 |
| - 10 14 15 |
UP
| 1 2 3 4 |
| 5 6 7 8 |
| - 9 11 12 |
| 13 10 14 15 |
RIGHT
| 1 2 3 4 |
| 5 6 7 8 |
| 9 - 11 12 |
| 13 10 14 15 |
DOWN
| 1 2 3 4 |
| 5 6 7 8 |
| 9 10 11 12 |
| 13 - 14 15 |
RIGHT
| 1 2 3 4 |
| 5 6 7 8 |
| 9 10 11 12 |
| 13 14 - 15 |
RIGHT


| 1 2 3 4 |
| 5 6 7 8 |
| 9 10 11 12 |
| 13 14 15 - |
Solution Sequence (10): DOWN DOWN RIGHT DOWN LEFT UP RIGHT DOWN RIGHT RIGHT
Time taken: 0.04 seconds
Simplices created: 55

2.4 *Test Case* tc3.txt *Input-Output*

```
Enter file name:
>>> tc3

Searching...

──────── Solution Found !!! ────────
┌──────────────┐
| 1  7  6  2   |
| 9  5  4  3   |
| 10 11 8  12  |
| 13 -  14 15  |
└──────────────┘
RIGHT
┌──────────────┐
| 1  7  6  2   |
| 9  5  4  3   |
| 10 11 8  12  |
| 13 14 -  15  |
└──────────────┘
RIGHT
┌──────────────┐
| 1  7  6  2   |
| 9  5  4  3   |
| 10 11 8  12  |
| 13 14 15 -   |
└──────────────┘
UP
┌──────────────┐
| 1  7  6  2   |
| 9  5  4  3   |
| 10 11 8  -   |
| 13 14 15 12  |
└──────────────┘
LEFT
┌──────────────┐
| 1  7  6  2   |
| 9  5  4  3   |
| 10 11 -  8   |
| 13 14 15 12  |
└──────────────┘
```


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


RIGHT
| 1 6 2 - |
| 5 7 4 3 |
| 9 10 11 8 |
| 13 14 15 12 |
DOWN
| 1 6 2 3 |
| 5 7 4 - |
| 9 10 11 8 |
| 13 14 15 12 |
LEFT
| 1 6 2 3 |
| 5 7 - 4 |
| 9 10 11 8 |
| 13 14 15 12 |
LEFT
| 1 6 2 3 |
| 5 - 7 4 |
| 9 10 11 8 |
| 13 14 15 12 |
UP
| 1 - 2 3 |
| 5 6 7 4 |
| 9 10 11 8 |
| 13 14 15 12 |
RIGHT
| 1 2 - 3 |
| 5 6 7 4 |
| 9 10 11 8 |
| 13 14 15 12 |

```
RIGHT
 ____________
| 1  2  3  -  |
| 5  6  7  4  |
| 9  10 11 8  |
| 13 14 15 12 |
 ____________
DOWN
 ____________
| 1  2  3  4  |
| 5  6  7  -  |
| 9  10 11 8  |
| 13 14 15 12 |
 ____________
DOWN
 ____________
| 1  2  3  4  |
| 5  6  7  8  |
| 9  10 11 -  |
| 13 14 15 12 |
 ____________
DOWN
 ____________
| 1  2  3  4  |
| 5  6  7  8  |
| 9  10 11 12 |
| 13 14 15 -  |
 ____________
Solution Sequence (20): RIGHT RIGHT UP LEFT LEFT LEFT UP RIGHT UP RIGHT RIGHT DOWN LEFT LEFT UP RIGHT RIGHT DOWN DOWN DOWN
Time taken: 5.662 seconds
Simplices created: 5355
```

2.5 *Test Case* tc4.txt *Input-Output*

```
Enter file name:
>>> tc4

 ________________
| 1  2  3  4  |
| 5  6  -  8  |
| 9  7  10 11 |
| 13 14 15 12 |
 ________________
Puzzle is unsolvable.
SigmaKurang(i) + X = 107
```

2.6 *Test Case* tc5.txt *Input-Output*

```
Enter file name:
>>> tc5

 ________________
| 1  2  4  8  |
| 5  -  10 3  |
| 9  6  7  11 |
| 13 14 15 12 |
 ________________
Puzzle is unsolvable.
SigmaKurang(i) + X = 95
```

3 *Checklist* Program

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		√

4 Kode Program

4.1 File main.py

```
# 13520127 Adzka Ahmadetya Zaidan
import numpy as np
import branchandbound as f
import time as t
import os

cwd = os.path.dirname(os.getcwd())
os.chdir(cwd+'\\test')

print('O━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━O'
)
print('|         15-Puzzle Solver         |')
print('| Using Branch and Bound Algorithm |')
print('O━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━O\
n')

while True:
  filename = str(input('Enter file name:\n>>> '))
  if (len(filename) < 4):
    filename += '.txt'
  elif (filename[len(filename)-1] != 't' or filename[len(filename)-2] != 'x' or
filename[len(filename)-3] != 't' or filename[len(filename)-4] != '.'):
    filename += '.txt'
  simplice = np.loadtxt(filename, dtype='str', delimiter=' ')

  # Inisialisasi
  startS = simplice
  path = [[]]
  costs = [f.EstimationG(startS)+len(path[0])]
  directions = ['UP', 'RIGHT', 'DOWN', 'LEFT']

  print()
  # BRANCH AND BOUND
  if not f.Reachable(startS): # Jika puzzle unsolvable
    f.DisplaySimplices(startS, path[0])
    print('Puzzle is unsolvable.')
    print('SigmaKurang(i) + X = '+str(f.SigmaKurang(startS) + f.X(startS))+'\n')
  else: # Jika simpul awal memiliki suatu solusi
    print('Searching...')
    start = t.time()
    idx = 0
    # Melakukan loop jika belum ditemukan solusi
```

```
    # Jika jumlah simpul yang dibangkitkan sudah terlalu banyak, pencarian berhenti
    while not f.IsGoalState(f.SimpliceFromPath(startS, path[idx])):
      currS = f.SimpliceFromPath(startS, path[idx])
      if len(path[idx]) != 0:
        prevMove = path[idx][len(path[idx])-1]
      else:
        prevMove = ''
      # Melakukan branching dari suatu simpul hidup
      for dir in directions:
        if f.ValidMove(currS, dir, prevMove):
          path.append([])
          for i in range(len(path[idx])):
            path[len(path)-1].append(path[idx][i])
          path[len(path)-1].append(dir)
          costs.append(f.Cost(f.Move(currS, dir), len(path[idx])+1))
      costs[idx] = 999 # Berikan nilai cost yang sangat tinggi agar tidak lagi di-expand
      idx = costs.index(min(costs)) # Memilih cost terrendah untuk di-expand

    # Jika ditemukan suatu solusi
    if f.IsGoalState(f.SimpliceFromPath(startS, path[idx])):
      end = t.time()
      timeTaken = round((end-start), 4)
      print('\n━━━━━━━━━━━━ Solution Found !!! ━━━━━━━━━━━━')
      f.DisplaySimplices(startS, path[idx])
      print('Solution Sequence'+' ('+str(len(path[idx]))+'): ', end='')
      for i in range(len(path[idx])):
        print(path[idx][i], end=' ')
      print('\nTime taken:', str(timeTaken), 'seconds')
      print('Simplices created:', len(path), '\n')

  flag = True
  while flag:
    exit = str(input('Continue program? (Y/N)\n>>> '))
    if (exit == 'Y' or exit == 'y'):
      flag = False
    elif (exit == 'N' or exit == 'n'):
      break
    else:
      print('Invalid input.\n')
  if (exit == 'N' or exit == 'n'):
    break
print('\nProgram successfully closed.\n')
```

4.2 File branchandbound.py

```
# 13520127 Adzka Ahmadetya Zaidan
import numpy as np

# Mengembalikan nilai dari Kurang(i)
def Kurang(flatM, i):
  idx = np.where(flatM == i)[0][0]
  count = 0
  for j in range(idx+1, 16):
    if (int(flatM[j]) > int(flatM[idx])):
      count += 1
  return count

# Mengembalikan nilai SigmaKurangi dari M
def SigmaKurang(M):
  flatM = M.flatten()
  emptyIdx = np.where(flatM == '-')
  flatM[emptyIdx] = '16'
  arrOfKurangi = [Kurang(flatM, i) for i in flatM]
  return sum(arrOfKurangi)

# Mengembalikan array of row, col dari nilai '-' simpul M
def IdxofEmpty(M):
  emptyIndexes = np.where(M == '-')
  return [emptyIndexes[0][0], emptyIndexes[1][0]]

# Mengembalikan X
def X(M):
  X = sum(IdxofEmpty(M)) % 2
  return X

# Mengembalikan boolean apakah simpul M reachable atau tidak
def Reachable(M):
  return (SigmaKurang(M) + X(M)) % 2 == 0

# Mengembalikan suatu simpul hasil dari simpul sebelumnya yang sudah digerakkan
def Move(M, direction):
  coords = IdxofEmpty(M)
  tempM = []
  for i in range(len(M)):
    cols = []
    for j in range(len(M[0])):
      cols.append(M[i][j])
    tempM.append(cols)
  if direction == 'UP':
```

```
    tempM[coords[0]][coords[1]] = tempM[coords[0]-1][coords[1]]
    tempM[coords[0]-1][coords[1]] = '-'
  elif direction == 'RIGHT':
    tempM[coords[0]][coords[1]] = tempM[coords[0]][coords[1]+1]
    tempM[coords[0]][coords[1]+1] = '-'
  elif direction == 'DOWN':
    tempM[coords[0]][coords[1]] = tempM[coords[0]+1][coords[1]]
    tempM[coords[0]+1][coords[1]] = '-'
  elif direction == 'LEFT':
    tempM[coords[0]][coords[1]] = tempM[coords[0]][coords[1]-1]
    tempM[coords[0]][coords[1]-1] = '-'
  return np.array([tempM[0], tempM[1], tempM[2], tempM[3]])

# Mengembalikan estimasi g dari simpul M
def EstimationG(M):
  count = 0
  flatM = M.flatten()
  idx = IdxofEmpty(M)[0]*4 + IdxofEmpty(M)[1]
  flatM[idx] = '16'
  for i in range(16):
    if int(flatM[i]) != i+1:
      if i != idx:
        count += 1
  return count

# Mengembalikan estimasi cost dari simpul M
def Cost(M, steps):
  return steps + EstimationG(M)

# Mengembalikan boolean apakah suatu direction adalah valid untuk simpul M atau tidak
def ValidMove(M, direction, prevMove):
  coords = IdxofEmpty(M)
  if (direction == 'UP'):
    return prevMove != 'DOWN' and coords[0] != 0
  elif (direction == 'RIGHT'):
    return prevMove != 'LEFT' and coords[1] != 3
  elif (direction == 'DOWN'):
    return prevMove != 'UP' and coords[0] != 3
  elif (direction == 'LEFT'):
    return prevMove != 'RIGHT' and coords[1] != 0

# Melakukan checking apakah M merupakan goalstate atau bukan
def IsGoalState(M):
  tempM = M.flatten()
  for i in range(15):
    if tempM[i] == '-':
```

```
      return False
    if int(tempM[i]) != i+1:
      return False
  return True

# Mengembalikan Simplice yang terbentuk dengan sequence of directions dari startS
def SimpliceFromPath(startS, path):
  # path = array of direction
  tempM = []
  for i in range(len(startS)):
    cols = []
    for j in range(len(startS[0])):
      cols.append(startS[i][j])
    tempM.append(cols)
  tempM = np.array([tempM[0], tempM[1], tempM[2], tempM[3]])
  for i in range(len(path)):
    tempM = Move(tempM, path[i])
  return np.array([tempM[0], tempM[1], tempM[2], tempM[3]])

# Display sequence simpul hingga menuju simpul startS
def DisplaySimplices(startS, path):
  tempM = []
  for i in range(len(startS)):
    cols = []
    for j in range(len(startS[0])):
      cols.append(startS[i][j])
    tempM.append(cols)
  tempM = np.array([tempM[0], tempM[1], tempM[2], tempM[3]])
  PrintSimplice(tempM) # PRINTING MATRIX
  for i in range(len(path)):
    tempM = Move(tempM, path[i])
    print(path[i])
    PrintSimplice(np.array([tempM[0], tempM[1], tempM[2], tempM[3]]))

# Print suatu simpul M
def PrintSimplice(M):
  print('━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━')
  for i in range(4):
    for j in range(4):
      if j == 0:
        print('| ', end='')
      if (len(M[i][j]) == 2):
        print(M[i][j]+' ',end='')
      else:
        print(M[i][j]+'  ',end='')
      if j == 3:
```

```
    print('|')
print('━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━')
```

5 Berkas Teks Contoh Instansiasi Persoalan 15-puzzle

5.1 tc1.txt (Solvable)

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

5.2 tc2.txt (Solvable)

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

5.3 tc3.txt (Solvable)

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

5.4 tc4.txt (Unsolvable)

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

5.5 tc5.txt (Unsolvable)

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

6 Alamat Github yang Berisi Kode Program

https://github.com/Voguelish/branch-and-bound-tucil-3-stima

Daftar Pustaka

1) “Algoritma Branch & Bound Bagian 1”. informatika.stei.itb.ac.id. 2022. Diakses pada tanggal 1 April 2022. https://informatika.stei.itb.ac.id/~rinaldi.munir/Stmik/2020-2021/Algoritma-Branch-and-Bound-2021-Bagian1.pdf
2) “Penyelesaian Persoalan 15-Puzzle dengan Algoritma Branch and Bound”. informatika.stei.itb.ac.id. 2022. Diakses pada tanggal 2 April 2022. https://informatika.stei.itb.ac.id/~rinaldi.munir/Stmik/2021-2022/Tugas-Kecil-2-(2022).pdf