Laporan Tugas Kecil 3
IF2211 Strategi Algoritma
Penyelesaian Puzzle Rush Hour Menggunakan Algoritma Pathfinding
Semester II Tahun 2024/2025

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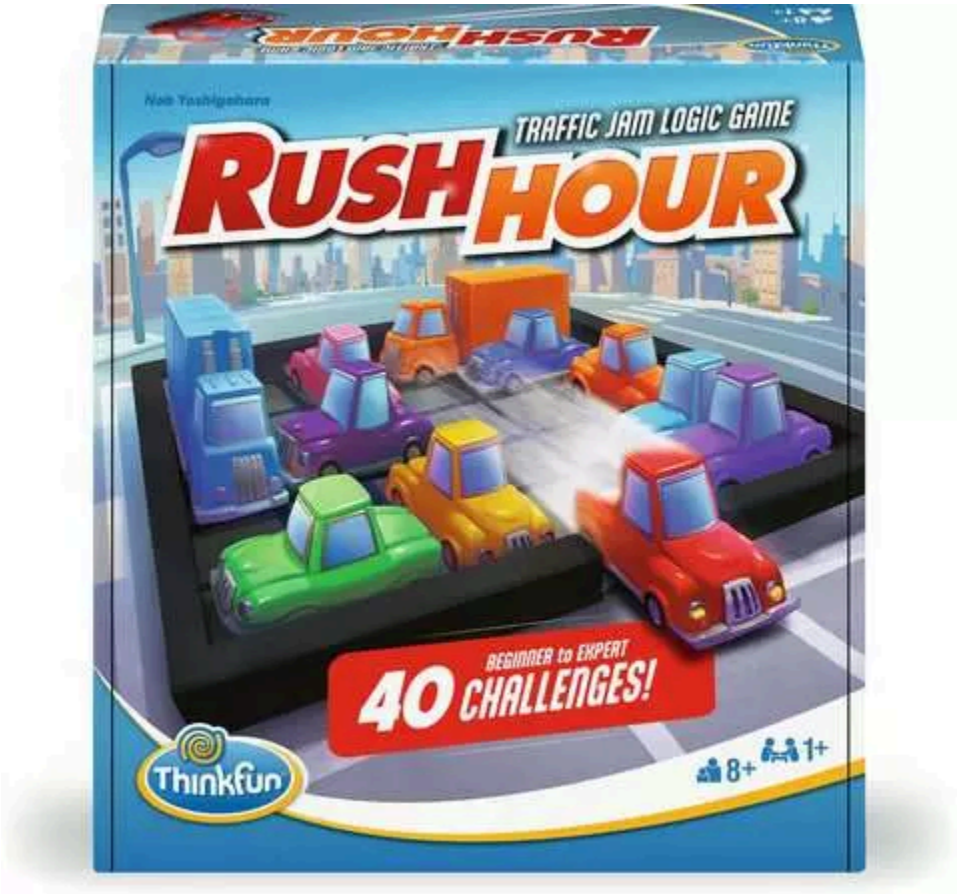
2025

DAFTAR ISI

BAB I
DESKRIPSI TUGAS



(Sumber: https://www.thinkfun.com/en-US/products/educational-games/rush-hour-76582)

Rush Hour adalah sebuah permainan puzzle logika berbasis grid yang menantang pemain untuk menggeser kendaraan di dalam sebuah kotak (biasanya berukuran 6x6) agar mobil utama (biasanya berwarna merah) dapat keluar dari kemacetan melalui pintu keluar di sisi papan. Setiap kendaraan hanya bisa bergerak lurus ke depan atau ke belakang sesuai dengan orientasinya (horizontal atau vertikal), dan tidak dapat berputar. Tujuan utama dari permainan ini adalah memindahkan mobil merah ke pintu keluar dengan jumlah langkah seminimal mungkin.

Komponen penting dari permainan Rush Hour terdiri dari:

1. **Papan** – *Papan* merupakan tempat permainan dimainkan.
   Papan terdiri atas *cell*, yaitu sebuah *singular point* dari papan. Sebuah *piece* akan menempati *cell-cell* pada papan. Ketika permainan dimulai, semua *piece* telah diletakkan di dalam papan dengan konfigurasi tertentu berupa lokasi piece dan *orientasi*, antara *horizontal* atau *vertikal*.
   Hanya *primary piece* yang dapat digerakkan **keluar papan melewati *pintu keluar***. *Piece* yang bukan *primary piece* tidak dapat digerakkan keluar papan. Papan memiliki satu *pintu keluar* yang pasti berada di *dinding papan* dan sejajar dengan orientasi *primary piece*.

2. **Piece –** *Piece* adalah sebuah kendaraan di dalam papan. Setiap *piece* memiliki *posisi*, *ukuran*, dan *orientasi*. *Orientasi* sebuah *piece* hanya dapat berupa horizontal atau vertikal–tidak mungkin diagonal. *Piece* dapat memiliki beragam *ukuran*, yaitu jumlah *cell* yang ditempati oleh *piece*. Secara standar, variasi *ukuran* sebuah *piece* adalah *2-piece* (menempati 2 *cell*) atau *3-piece* (menempati 3 *cell*). Suatu *piece* tidak dapat digerakkan melewati/menembus *piece* yang lain.

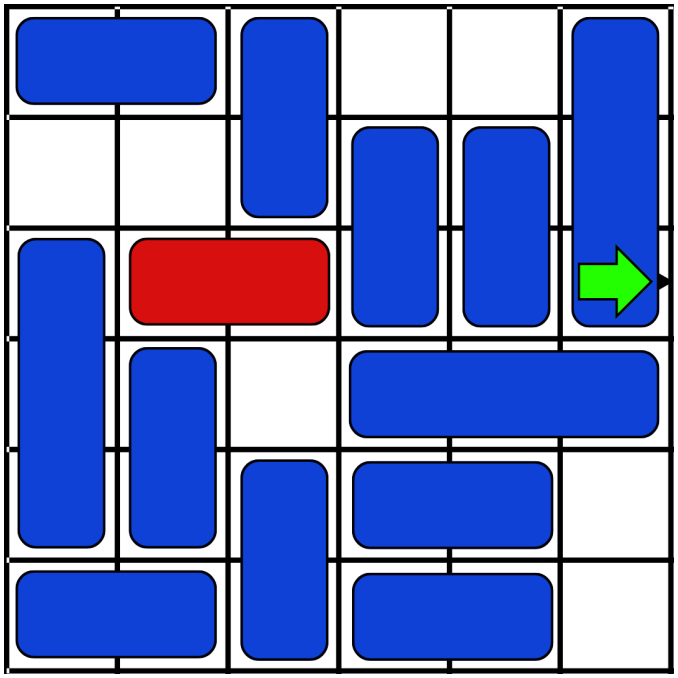
3. **Primary Piece –** *Primary piece* adalah kendaraan utama yang harus dikeluarkan dari *papan* (biasanya berwarna merah). Hanya boleh terdapat satu primary piece.

4. **Pintu Keluar –** *Pintu keluar* adalah tempat *primary piece* dapat digerakkan keluar untuk menyelesaikan permainan

5. **Gerakan** — *Gerakan* yang dimaksudkan adalah pergeseran *piece* di dalam permainan. *Piece* hanya dapat bergerak/bergeser lurus sesuai orientasinya (atas-bawah jika vertikal dan kiri-kanan jika horizontal). Suatu *piece* tidak dapat digerakkan melewati/menembus *piece* yang lain.

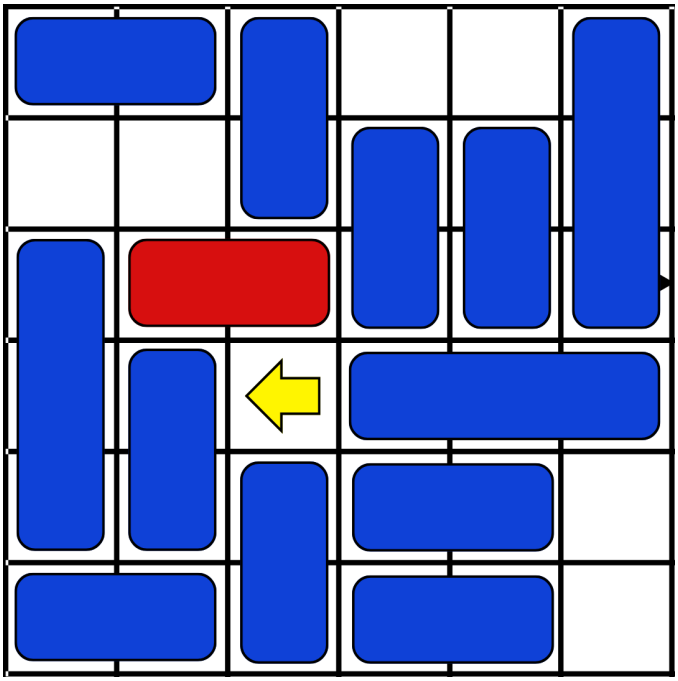
Ilustrasi kasus :

Diberikan sebuah *papan* berukuran 6 x 6 dengan 12 *piece* kendaraan dengan 1 *piece* merupakan *primary piece*. *Piece* ditempatkan pada *papan* dengan posisi dan orientasi sebagai berikut.



Gambar 2. Awal Permainan Game Rush Hour

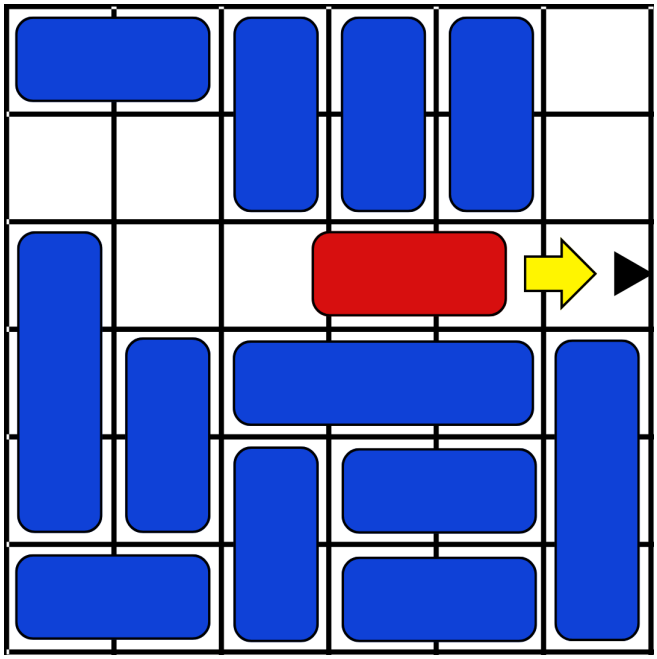
Pemain dapat menggeser-geser *piece* (termasuk *primary piece*) untuk membentuk jalan lurus antara *primary piece* dan *pintu keluar*.



Gambar 3. Gerakan Pertama Game Rush Hour

Gambar 4. Gerakan Kedua Game Rush Hour

Puzzle berikut dinyatakan telah selesai apabila *primary piece* dapat digeser keluar papan melalui *pintu keluar*.



Agar lebih jelas, silahkan amati video cara bermain berikut: The New Rush Hour by ThinkFun!

Anda juga dapat melihat gif berikut untuk melihat contoh permainan Rush Hour Solution.

BAB II
LANDASAN TEORI

2.1. Algoritma UCS, Greedy Best First Search, dan A*

Uniform Cost Search (UCS) adalah algoritma pencarian yang berfokus menemukan jalur dengan total biaya paling rendah dari titik awal sampai tujuan. UCS menggunakan struktur data antrian prioritas yang selalu memilih simpul dengan biaya terkecil yang sudah tercapai untuk diperluas lebih dulu. Algoritma ini dijamin menemukan jalur optimal dan akan selesai jika biaya setiap langkah selalu positif.

Greedy Best First Search adalah algoritma yang memilih simpul berikutnya berdasarkan perkiraan jarak terpendek ke tujuan (heuristik), tanpa memperhatikan biaya perjalanan sejauh ini. Pendekatan ini membuatnya cepat dalam mencari solusi, tetapi tidak selalu menghasilkan jalur terbaik karena hanya mengutamakan pilihan yang terlihat paling menjanjikan saat itu saja.

A* adalah algoritma pencarian yang mengombinasikan pendekatan UCS dan Greedy Best First Search dengan menggunakan fungsi nilai f(n) yang merupakan jumlah dari biaya perjalanan sejauh ini (g(n)) dan perkiraan biaya ke tujuan (h(n)). Dengan cara ini, A* mampu menemukan jalur terpendek secara efisien dan optimal, asalkan perkiraan heuristik yang digunakan tidak melebih-lebihkan biaya sebenarnya.

2.2. Alur Kerja Program

1. **[INPUT] konfigurasi permainan/test case** dalam format ekstensi **.txt**. File *test case* tersebut berisi:
   a. **Dimensi Papan** terdiri atas dua buah variabel **A** dan **B** yang membentuk papan berdimensi AxB
   b. **Banyak *piece* BUKAN** *primary piece* direpresentasikan oleh variabel integer **N**.
   c. **Konfigurasi papan** yang mencakup penempatan *piece* dan *primary piece*, serta lokasi *pintu keluar*. *Primary Piece* dilambangkan dengan huruf **P** dan pintu keluar dilambangkan dengan huruf **K**. *Piece* dilambangkan dengan huruf dan karakter selain *P* dan *K*, dan huruf/karakter berbeda melambangkan *piece* yang berbeda. *Cell* kosong dilambangkan dengan karakter '**.**' (titik). (**Catatan:** ingat bahwa *pintu keluar* pasti berada di *dinding* papan dan sejajar dengan orientasi *primary piece*)

   File .txt yang akan dibaca memiliki format sebagai berikut:

```
A B
N
konfigurasi_papan
```

   Contoh Input

```
6 6
11
AAB..F
..BCDF
GPPCDFK
GH.III
GHJ...
LLJMM.
```

keterangan: “K” adalah pintu keluar, “P” adalah primary piece, Titik (“.”) adalah cell kosong.

Contoh konfigurasi papan lain yang mungkin berdasarkan letak *pintu keluar* (X adalah *piece/cell random*)

K XXX XXX XXX	XXX KXXX XXX	XXX XXX XXX K

2. **[INPUT] algoritma *pathfinding*** yang digunakan
3. **[INPUT] *heuristic*** yang digunakan (**bonus**)
4. **[OUTPUT]** Banyaknya **gerakan** yang diperiksa (alias banyak ‘node’ yang dikunjungi)
5. **[OUTPUT]** Waktu eksekusi program
6. **[OUTPUT] konfigurasi *papan*** pada setiap tahap pergerakan/pergeseran. Output ini tidak harus diimplementasi apabila mengerjakan *bonus output GUI*. **Gunakan print berwarna** untuk menunjukkan pergerakan *piece* dengan jelas. Cukup mewarnakan ***primary piece***, ***pintu keluar***, dan ***piece* yang digerakkan** saja (boleh dengan *highlight* atau *text color*). Pastikan ketiga komponen tersebut memiliki warna berbeda.

Format sekuens adalah sebagai berikut:

```
Papan Awal
[konfigurasi_papan_awal]

Gerakan 1: [piece]-[arah gerak]
[konfigurasi_papan_gerakan_1]

Gerakan 2: [piece]-[arah gerak]
[konfigurasi_papan_gerakan_2]

Gerakan [N]: [piece]-[arah gerak]
```

```
[konfigurasi_papan_gerakan_N]
  dst
```

Contoh Output

```
  Papan Awal
  AAB..F
  ..BCDF
  GPPCDFK
  GH.III
  GHJ...
  LLJMM.

  Gerakan 1: I-kiri
AAB..F
  ..BCDF
  GPPCDFK
  GHIII.
  GHJ...
  LLJMM.

  Gerakan 2: F-bawah
AAB..
  ..BCDF
  GPPCDFK
  GHIIIF
  GHJ...
  LLJMM.

dst
```

Keterangan: **hanya sebagai contoh**. Pastikan output jelas dan mudah dimengerti. Warna dan highlight hanya untuk menunjukan perubahan.

7. **[OUTPUT] animasi** gerakan-gerakan untuk mencapai solusi (**bonus GUI**).

BAB III
ANALISIS ALGORITMA DAN IMPLEMENTASI

3.1. Algoritma Rush Hour Puzzle Solver

Berikut struktur dari source code proyek ini.

```
src/
├── algorithm/
│   ├── AStar.java
│   ├── GreedyBestFirst.java
│   ├── Heuristic.java
│   ├── HeuristicFactory.java
│   ├── Pathfinder.java
│   └── UCS.java
├── gui/
│   ├── BoardPanel.java
│   ├── ControlPanel.java
│   ├── MainFrame.java
│   └── StatusPanel.java
├── model/
│   ├── Board.java
│   ├── Move.java
│   ├── Piece.java
│   └── State.java
├── utility/
│   └── FileHandler.java
└── Main.java
```

3.1.1. Algoritma Uniform Cost Search (UCS)

Algoritma Uniform Cost Search (UCS) yang diimplementasikan dalam file UCS.java bertujuan menemukan jalur solusi dengan biaya langkah terendah secara optimal. Proses diawali dengan inisialisasi state awal papan permainan dan pembuatan priority queue (frontier) yang diurutkan berdasarkan biaya langkah. State awal dimasukkan ke dalam frontier, dan sebuah set explored dibuat untuk melacak state yang sudah dijelajahi. Dalam loop pencarian, algoritma mengambil state dengan biaya terendah dan memeriksa apakah mobil utama (P) dapat mencapai pintu keluar. Jika ya, algoritma merekonstruksi jalur solusi menggunakan parent pointers. Jika belum, state tersebut dimasukkan ke explored, lalu dilakukan ekspansi dengan menghasilkan semua pergerakan legal dari setiap kendaraan, baik secara horizontal maupun vertikal. Untuk setiap gerakan, dibuat state baru yang akan diperiksa apakah sudah dijelajahi atau belum. Jika belum, dan biaya ke state tersebut lebih rendah dari state serupa di frontier, maka state baru itu ditambahkan ke frontier. Ketika state tujuan tercapai, jalur solusi direkonstruksi dan dikembalikan dalam bentuk daftar langkah.

3.1.2. Algoritma Greedy Best First Search

Algoritma Greedy Best First Search (GBFS) dalam file GreedyBestFirst.java melakukan pencarian berdasarkan estimasi heuristik ke tujuan tanpa mempertimbangkan biaya aktual langkah. Inisialisasi dimulai dengan membuat state awal dan priority queue yang diurutkan hanya berdasarkan nilai heuristik. State awal dimasukkan ke frontier, dan dibuat set explored. Dalam loop pencarian, state dengan nilai heuristik terendah diambil, dan dicek

apakah mobil utama sudah mencapai pintu keluar. Jika ya, jalur solusi dikembalikan melalui rekonstruksi dari parent pointers. Jika belum, state tersebut ditambahkan ke explored dan dilakukan ekspansi untuk menghasilkan semua pergerakan legal. Setiap pergerakan menghasilkan state baru yang kemudian diperiksa apakah sudah pernah dijelajahi. Jika belum, state tersebut langsung dimasukkan ke frontier berdasarkan nilai heuristiknya. Berbeda dengan UCS, GBFS hanya mengandalkan nilai heuristik tanpa mempertimbangkan biaya perjalanan aktual, sehingga solusi yang dihasilkan tidak dijamin optimal.

3.1.3. Algoritma A*

Algoritma A* pada file AStar.java menggabungkan pendekatan UCS dan GBFS dengan mempertimbangkan kombinasi biaya aktual (g) dan estimasi heuristik (h). Proses inisialisasi meliputi pembuatan state awal, priority queue berdasarkan penjumlahan g(n) dan h(n), serta map costSoFar untuk menyimpan biaya terbaik menuju setiap state. Set explored juga dibuat untuk mencatat state yang telah dikunjungi. Dalam loop pencarian, state dengan nilai f(n) terendah diambil dari frontier dan diperiksa apakah mobil utama telah mencapai tujuan. Jika sudah, jalur solusi dikembalikan. Jika belum, state ditambahkan ke explored dan diperluas dengan menghasilkan seluruh pergerakan legal kendaraan. Untuk setiap state baru, dilakukan pengecekan apakah sudah pernah dijelajahi atau apakah biaya barunya lebih rendah dari sebelumnya. Jika ya, maka state baru dimasukkan ke frontier dan costSoFar diperbarui. Proses rekonstruksi jalur mirip seperti UCS dan GBFS. A* menjamin solusi optimal selama heuristik yang digunakan bersifat admissible, yaitu tidak melebih-lebihkan estimasi biaya.

3.2. Notasi Pseudocode

3.2.1. AStar.java

```
Class AStar implements Pathfinder:
    private nodesVisited : integer
    private solutionStates : List<State>
    private heuristic : Heuristic

    Constructor AStar(heuristic: Heuristic):
        nodesVisited <- 0
        solutionStates <- new ArrayList<>()
        this.heuristic <- heuristic

    Function findPath(initialBoard: Board):
        nodesVisited <- 0
        solutionStates.clear()
        initialState <- new State(initialBoard, null, null, 0)

              frontier <- new PriorityQueue ordered by (state.getCost() +
heuristic.calculate(state))
        frontier.add(initialState)

        costSoFar <- new Map<String, Integer>()
```

```
            costSoFar.put(initialState.getBoard().toString(), 0)

            explored <- new Set<String>()

            while frontier is not empty:
                currentState <- frontier.poll()
                nodesVisited <- nodesVisited + 1
                boardRep <- currentState.getBoard().toString()

                if currentState.getBoard().canPrimaryPieceExit() then
                    -> reconstructPath(currentState)

                explored.add(boardRep)

                possibleMoves <- generatePossibleMoves(currentState.getBoard())

                for each move in possibleMoves:
                    newBoard <- applyMove(currentState.getBoard(), move)
                    newBoardRep <- newBoard.toString()

                    if newBoardRep not in explored then
                        newCost <- currentState.getCost() + move.getSteps()

                                    if newBoardRep not in costSoFar or newCost <
costSoFar.get(newBoardRep) then
                            costSoFar.put(newBoardRep, newCost)
                               newState <- new State(newBoard, currentState, move,
currentState.getCost() + move.getSteps())
                            frontier.add(newState)

            -> new empty list

        Function generatePossibleMoves(board: Board):
            possibleMoves <- new ArrayList<>()
            pieces <- board.getPieces()

            for each piece in pieces.values():
                id <- piece.getId()

                if piece.isHorizontal() then
                    maxRightSteps <- getMaxStepsInDirection(board, piece, "right")
                    for steps from 1 to maxRightSteps:
                        possibleMoves.add(new Move(id, "right", steps))

                    maxLeftSteps <- getMaxStepsInDirection(board, piece, "left")
                    for steps from 1 to maxLeftSteps:
                        possibleMoves.add(new Move(id, "left", steps))
                else
                    maxDownSteps <- getMaxStepsInDirection(board, piece, "down")
                    for steps from 1 to maxDownSteps:
                        possibleMoves.add(new Move(id, "down", steps))

                    maxUpSteps <- getMaxStepsInDirection(board, piece, "up")
                    for steps from 1 to maxUpSteps:
                        possibleMoves.add(new Move(id, "up", steps))

            -> possibleMoves

          Function getMaxStepsInDirection(board: Board, piece: Piece, direction:
string):
            steps <- 0
            tempBoard <- board.copy()
```

```
            canMove <- true

            while canMove do
                canMove <- tempBoard.movePiece(piece.getId(), direction, 1)
                if canMove then
                    steps <- steps + 1

            -> steps

        Function applyMove(board: Board, move: Move):
            newBoard <- board.copy()
                        newBoard.movePiece(move.getPieceId(),  move.getDirection(),
move.getSteps())
            -> newBoard

        Function reconstructPath(goalState: State):
            path <- new ArrayList<>()
            statePath <- new ArrayList<>()
            current <- goalState

            while current.getParent() != null:
                path.insertAtFront(current.getMoveMade())
                statePath.insertAtFront(current)
                current <- current.getParent()

            statePath.insertAtFront(current)
            solutionStates <- statePath

            -> path

        Function getNodesVisited():
            -> nodesVisited

        Function getSolutionStates():
            -> solutionStates
```

3.2.2. GreedyBestFirst.java

```
    Class GreedyBestFirst implements Pathfinder:
        private nodesVisited : integer
        private solutionStates : List<State>
        private heuristic : Heuristic

        Constructor GreedyBestFirst(heuristic: Heuristic):
            nodesVisited <- 0
            solutionStates <- new ArrayList<>()
            this.heuristic <- heuristic

        Function findPath(initialBoard: Board):
            nodesVisited <- 0
            solutionStates.clear()
            initialState <- new State(initialBoard, null, null, 0)
            frontier <- new PriorityQueue ordered by heuristic.calculate(state)
            frontier.add(initialState)
            explored <- new HashSet<String>()

            while frontier is not empty do
                currentState <- frontier.poll()
                nodesVisited <- nodesVisited + 1
                boardRep <- currentState.getBoard().toString()
                explored.add(boardRep)
```

```
            if currentState.getBoard().canPrimaryPieceExit() then
                -> reconstructPath(currentState)

            possibleMoves <- generatePossibleMoves(currentState.getBoard())

            for each move in possibleMoves:
                newBoard <- applyMove(currentState.getBoard(), move)
                newBoardRep <- newBoard.toString()

                if newBoardRep not in explored then
                            newState <- new State(newBoard, currentState, move,
currentState.getCost() + move.getSteps())
                    frontier.add(newState)

        -> new empty list

    Function generatePossibleMoves(board: Board):
        possibleMoves <- new ArrayList<>()
        pieces <- board.getPieces()

        for each piece in pieces.values():
            id <- piece.getId()
            if piece.isHorizontal() then
                maxRightSteps <- getMaxStepsInDirection(board, piece, "right")
                for steps from 1 to maxRightSteps:
                    possibleMoves.add(new Move(id, "right", steps))
                maxLeftSteps <- getMaxStepsInDirection(board, piece, "left")
                for steps from 1 to maxLeftSteps:
                    possibleMoves.add(new Move(id, "left", steps))
            else
                maxDownSteps <- getMaxStepsInDirection(board, piece, "down")
                for steps from 1 to maxDownSteps:
                    possibleMoves.add(new Move(id, "down", steps))
                maxUpSteps <- getMaxStepsInDirection(board, piece, "up")
                for steps from 1 to maxUpSteps:
                    possibleMoves.add(new Move(id, "up", steps))

        -> possibleMoves

      Function getMaxStepsInDirection(board: Board, piece: Piece, direction:
string):
        steps <- 0
        tempBoard <- board.copy()
        canMove <- true
        while canMove:
            canMove <- tempBoard.movePiece(piece.getId(), direction, 1)
            if canMove then
                steps <- steps + 1
        -> steps

    Function applyMove(board: Board, move: Move):
        newBoard <- board.copy()
                  newBoard.movePiece(move.getPieceId(),  move.getDirection(),
move.getSteps())
        -> newBoard

    Function reconstructPath(goalState: State):
        path <- new ArrayList<>()
        statePath <- new ArrayList<>()
        current <- goalState
```

```
            while current.getParent() != null do
                path.insertAtFront(current.getMoveMade())
                statePath.insertAtFront(current)
                current <- current.getParent()

            statePath.insertAtFront(current)
            solutionStates <- statePath

            -> path

        Function getNodesVisited():
            -> nodesVisited

        Function getSolutionStates():
            -> solutionStates
```

3.2.3. Heuristic.java

```
    Interface Heuristic:
        Function calculate(state: State) -> integer

    Class DistanceHeuristic implements Heuristic:
        Function calculate(state: State):
            board <- state.getBoard()
            primaryPiece <- board.getPrimaryPiece()

            if primaryPiece.isHorizontal() then
                row <- primaryPiece.getRow()
                exitRow <- board.getExitRow()
                exitCol <- board.getExitCol()

                if exitRow == row then
                                        primaryRight  <-  primaryPiece.getCol()  +
primaryPiece.getLength() - 1

                    if exitCol > primaryRight then
                        -> exitCol - primaryRight
                    else if exitCol < primaryPiece.getCol() then
                        -> primaryPiece.getCol() - exitCol

            -> board.getWidth() + board.getHeight()

    Class BlockingVehiclesHeuristic implements Heuristic:
        Function calculate(state: State):
            board <- state.getBoard()
            primaryPiece <- board.getPrimaryPiece()
            blockingCount <- 0

            exitRow <- board.getExitRow()
            exitCol <- board.getExitCol()

            if primaryPiece.isHorizontal() then
                row <- primaryPiece.getRow()
                if exitRow == row then
                    if exitCol > primaryPiece.getCol() then
                                            startCol  <-  primaryPiece.getCol()  +
primaryPiece.getLength()
                        endCol <- exitCol
                    else
                        startCol <- exitCol + 1
                        endCol <- primaryPiece.getCol()
```

```
                for col from startCol to endCol - 1:
                    if board.getCell(row, col) != '.' then
                        blockingCount <- blockingCount + 1
            else
                -> Integer.MAX_VALUE / 2
        else
            col <- primaryPiece.getCol()
            if exitCol == col then
                if exitRow > primaryPiece.getRow() then
                                        startRow  <-  primaryPiece.getRow()  +
primaryPiece.getLength()
                    endRow <- exitRow
                else
                    startRow <- exitRow + 1
                    endRow <- primaryPiece.getRow()

                for row from startRow to endRow - 1:
                    if board.getCell(row, col) != '.' then
                        blockingCount <- blockingCount + 1
            else
                -> Integer.MAX_VALUE / 2

        -> blockingCount

Class CombinedHeuristic implements Heuristic:
    distanceHeuristic <- new DistanceHeuristic()
    blockingHeuristic <- new BlockingVehiclesHeuristic()

    Function calculate(state: State) -> integer:
        distance <- distanceHeuristic.calculate(state)
        blocking <- blockingHeuristic.calculate(state)

        -> distance + (2 * blocking)
```

3.2.4. HeuristicFactory.java

```
Class HeuristicFactory:
    Constant DISTANCE_HEURISTIC = 1
    Constant BLOCKING_VEHICLES_HEURISTIC = 2
    Constant COMBINED_HEURISTIC = 3

    Static Function createHeuristic(type: integer) -> Heuristic:
        switch (type):
            case DISTANCE_HEURISTIC:
                -> new DistanceHeuristic()
            case BLOCKING_VEHICLES_HEURISTIC:
                -> new BlockingVehiclesHeuristic()
            case COMBINED_HEURISTIC:
                -> new CombinedHeuristic()
            default:
                -> new CombinedHeuristic()
```

3.2.5. PathFinder.java

```
Interface Pathfinder:
    Function findPath(initialBoard: Board) -> List<Move>

    Function getNodesVisited() -> integer
```

```
    Function getSolutionStates() -> List<State>
```

3.2.6. UCS.java

```
 Class UCS implements Pathfinder:
    private nodesVisited : integer
    private solutionStates : List<State>

    Constructor UCS():
        nodesVisited <- 0
        solutionStates <- new ArrayList<>()

    Function findPath(initialBoard: Board):
        nodesVisited <- 0
        solutionStates.clear()
        initialState <- new State(initialBoard, null, null, 0)
        frontier <- new PriorityQueue sorted by State.getCost()
        frontier.add(initialState)
        explored <- new HashSet<String>()

        while frontier is not empty do
            currentState <- frontier.poll()
            nodesVisited <- nodesVisited + 1
            boardRep <- currentState.getBoard().toString()
            explored.add(boardRep)

            if currentState.getBoard().canPrimaryPieceExit() then
                -> reconstructPath(currentState)

            possibleMoves <- generatePossibleMoves(currentState.getBoard())

            for each move in possibleMoves:
                newBoard <- applyMove(currentState.getBoard(), move)
                newBoardRep <- newBoard.toString()

                if newBoardRep not in explored then
                        newState <- new State(newBoard, currentState, move,
currentState.getCost() + move.getSteps())
                    shouldAdd <- true

                    for each frontierState in frontier:
                         if frontierState.getBoard().toString() == newBoardRep
and frontierState.getCost() <= newState.getCost() then
                            shouldAdd <- false
                            break

                    if shouldAdd then
                                    remove from frontier any state s where
s.getBoard().toString() == newBoardRep and s.getCost() > newState.getCost()
                        frontier.add(newState)

        -> new empty list

    Function generatePossibleMoves(board: Board):
        possibleMoves <- new ArrayList<>()
        pieces <- board.getPieces()

        for each piece in pieces.values():
            id <- piece.getId()
            if piece.isHorizontal() then
```

```
                    maxRightSteps <- getMaxStepsInDirection(board, piece, "right")
                    for steps from 1 to maxRightSteps:
                        possibleMoves.add(new Move(id, "right", steps))
                    maxLeftSteps <- getMaxStepsInDirection(board, piece, "left")
                    for steps from 1 to maxLeftSteps:
                        possibleMoves.add(new Move(id, "left", steps))
                else:
                    maxDownSteps <- getMaxStepsInDirection(board, piece, "down")
                    for steps from 1 to maxDownSteps:
                        possibleMoves.add(new Move(id, "down", steps))
                    maxUpSteps <- getMaxStepsInDirection(board, piece, "up")
                    for steps from 1 to maxUpSteps:
                        possibleMoves.add(new Move(id, "up", steps))

            -> possibleMoves

        Function getMaxStepsInDirection(board: Board, piece: Piece, direction:
string):
            steps <- 0
            tempBoard <- board.copy()
            canMove <- true
            while canMove:
                canMove <- tempBoard.movePiece(piece.getId(), direction, 1)
                if canMove then
                    steps <- steps + 1
            -> steps

        Function applyMove(board: Board, move: Move):
            newBoard <- board.copy()
                        newBoard.movePiece(move.getPieceId(),  move.getDirection(),
move.getSteps())
            -> newBoard

        Function reconstructPath(goalState: State):
            path <- new ArrayList<>()
            statePath <- new ArrayList<>()
            current <- goalState

            while current.getParent() != null do
                path.insertAtFront(current.getMoveMade())
                statePath.insertAtFront(current)
                current <- current.getParent()

            statePath.insertAtFront(current)
            solutionStates <- statePath

            -> path

        Function getNodesVisited():
            -> nodesVisited

        Function getSolutionStates():
            -> solutionStates
```

3.2.7. File Board.java

```
 Class Board:
     private width : integer
     private height : integer
     private pieces : Map<Character, Piece>
     private exitRow : integer
```

```
private exitCol : integer
private exitOnRight : boolean
private exitOnBottom : boolean
private primaryPieceId : char

Constructor Board(width: integer, height: integer):
    width <- width
    height <- height
    pieces <- new HashMap<>()

Function copy():
    newBoard <- new Board(width, height)
    newBoard.exitRow <- exitRow
    newBoard.exitCol <- exitCol
    newBoard.exitOnRight <- exitOnRight
    newBoard.exitOnBottom <- exitOnBottom
    newBoard.primaryPieceId <- primaryPieceId

    for each piece in pieces.values():
        newPiece <- piece.copy()
        newBoard.pieces.put(newPiece.getId(), newPiece)

    -> newBoard

Procedure addPiece(piece: Piece):
    pieces.put(piece.getId(), piece)
    if piece.isPrimary() then
        primaryPieceId <- piece.getId()

Procedure setExit(row: integer, col: integer):
    exitRow <- row
    exitCol <- col
    exitOnRight <- (col == width - 1)
    exitOnBottom <- (row == height - 1)

Function movePiece(pieceId: char, direction: string, steps: integer):
    piece <- pieces.get(pieceId)
    if piece is null then
        -> false

    newRow <- piece.getRow()
    newCol <- piece.getCol()

    switch direction:
        case "up":
            if piece.isHorizontal() then
                -> false
            newRow <- newRow - steps
            break
        case "down":
            if piece.isHorizontal() then
                -> false
            newRow <- newRow + steps
            break
        case "left":
            if not piece.isHorizontal() then
                -> false
            newCol <- newCol - steps
            break
        case "right":
            if not piece.isHorizontal() then
                -> false
```

```
                    newCol <- newCol + steps
                    break
                default:
                    -> false

            if not isValidMove(piece, newRow, newCol) then
                -> false

               if piece.isPrimary() and piece.isHorizontal() and exitOnRight and
newCol + piece.getLength() > width then
                if exitRow == piece.getRow() then
                    piece.setCol(newCol)
                    -> true
                -> false
                   else if piece.isPrimary() and not piece.isHorizontal() and
exitOnBottom and newRow + piece.getLength() > height then
                if exitCol == piece.getCol() then
                    piece.setRow(newRow)
                    -> true
                -> false

            piece.setRow(newRow)
            piece.setCol(newCol)
            -> true

        Function isValidMove(piece: Piece, newRow: integer, newCol: integer):
            if newRow < 0 or newCol < 0 then
                -> false

            if piece.isHorizontal():
                  if newCol + piece.getLength() > width and not (piece.isPrimary()
and exitOnRight and piece.getRow() == exitRow) then
                    -> false
            else:
                 if newRow + piece.getLength() > height and not (piece.isPrimary()
and exitOnBottom and piece.getCol() == exitCol) then
                    -> false

            r traversal [0..height - 1]:
                c traversal [0..width - 1]:
                    wouldOccupy <- false
                    if piece.isHorizontal():
                         wouldOccupy <- r == newRow and c >= newCol and c < newCol
+ piece.getLength()
                    else:
                         wouldOccupy <- c == newCol and r >= newRow and r < newRow
+ piece.getLength()

                    if wouldOccupy then
                        for each otherPiece in pieces.values():
                                    if otherPiece.getId() != piece.getId() and
otherPiece.occupies(r, c) then
                                -> false

            -> true

        Function canPrimaryPieceExit():
            primaryPiece <- pieces.get(primaryPieceId)

        if primaryPiece.isHorizontal():
            if primaryPiece.getRow() != exitRow then
                -> false
```

```
          exitDirection <- 1 if exitOnRight else -1
                  startCol  <-  primaryPiece.getCol()  +  (exitDirection  >  0  ?
primaryPiece.getLength() : -1)
          endCol <- exitDirection > 0 ? width : -1

          for c from startCol to endCol with step exitDirection:
              for each piece in pieces.values():
                  if piece.getId() != primaryPieceId and piece.occupies(exitRow,
c) then
                      -> false

          -> true

      else:
          if primaryPiece.getCol() != exitCol then
              -> false

          exitDirection <- 1 if exitOnBottom else -1
                  startRow  <-  primaryPiece.getRow()  +  (exitDirection  >  0  ?
primaryPiece.getLength() : -1)
          endRow <- exitDirection > 0 ? height : -1

          for r from startRow to endRow with step exitDirection:
              for each piece in pieces.values():
                   if piece.getId() != primaryPieceId and piece.occupies(r,
exitCol) then
                      -> false

          -> true

      Function getCell(row: integer, col: integer) -> char:
          for each piece in pieces.values():
              if piece.occupies(row, col) then
                  -> piece.getId()
          -> '.'

      Function toString() -> String:
          sb <- new StringBuilder()
          r traversal [0..height - 1]:
              c traversal [0..width - 1]:
                  sb.append(getCell(r, c))
              if r < height - 1 then
                  sb.append('\n')
          -> sb.toString()

      Function getWidth():
          -> width

      Function getHeight():
          -> height

      Function getPieces():
          -> pieces

      Function getExitRow():
          -> exitRow

      Function getExitCol():
          -> exitCol

      Function getPrimaryPiece():
```

```
            -> pieces.get(primaryPieceId)

        Function getPrimaryPieceId():
            -> primaryPieceId
```

3.2.8. File Move.java

```
    Class Move:
        private pieceId : char
        private direction : string
        private steps : integer

        Constructor Move(pieceId: char, direction: string, steps: integer):
            pieceId <- pieceId
            direction <- direction
            steps <- steps

        Function getPieceId():
            -> pieceId

        Function getDirection():
            -> direction

        Function getSteps():
            -> steps

        Function toString():
            if steps > 1 then
                -> pieceId + "-" + direction + " " + steps
            else
                -> pieceId + "-" + direction
```

3.2.9. File Piece.java

```
    Class Piece:
        private id : char
        private row : integer
        private col : integer
        private length : integer
        private isHorizontal : boolean
        private isPrimary : boolean

         Constructor Piece(id: char, row: integer, col: integer, length: integer,
isHorizontal: boolean, isPrimary: boolean):
            id <- id
            row <- row
            col <- col
            length <- length
            isHorizontal <- isHorizontal
            isPrimary <- isPrimary

        Function copy():
            -> new Piece(id, row, col, length, isHorizontal, isPrimary)

        Function getId():
            -> id

        Function getRow():
            -> row
```

```
    Function getCol():
        -> col

    Procedure setRow(row: integer):
        this.row <- row

    Procedure setCol(col: integer):
        this.col <- col

    Function getLength():
        -> length

    Function isHorizontal():
        -> isHorizontal

    Function isPrimary():
        -> isPrimary

    Function occupies(r: integer, c: integer):
        if isHorizontal then
            -> (r == row) and (c >= col) and (c < col + length)
        else
            -> (c == col) and (r >= row) and (r < row + length)

    Function toString():
        str <- id
        if isPrimary then
            str <- str + "(P)"
        str <- str + "[" + row + "," + col + "]"
        -> str
```

3.2.10. File State.java

```
  Class State:
      private board : Board
      private parent : State
      private moveMade : Move
      private cost : integer
      private heuristicValue : integer

        Constructor State(board: Board, parent: State, moveMade: Move, cost:
integer):
          board <- board
          parent <- parent
          moveMade <- moveMade
          cost <- cost
          heuristicValue <- 0

      Function getBoard():
          -> board

      Function getParent():
          -> parent

      Function getMoveMade():
          -> moveMade

      Function getCost():
          -> cost
```

```
        Function getHeuristicValue():
            -> heuristicValue

        Procedure setHeuristicValue(value: integer):
            heuristicValue <- value

        Function getF():
            -> cost + heuristicValue

        Function generateNextStates():
            nextStates <- new List<State>()

            for each piece in board.getPieces().values():
                if piece.isHorizontal() then
                    {move left}
                    for steps from 1 to board.getWidth():
                        newBoard <- board.copy()
                        if newBoard.movePiece(piece.getId(), "left", steps) then
                            move <- new Move(piece.getId(), "left", steps)
                             nextStates.add(new State(newBoard, this, move, cost +
1))
                        else
                            break

                    {move right}
                    for steps from 1 to board.getWidth():
                        newBoard <- board.copy()
                        if newBoard.movePiece(piece.getId(), "right", steps) then
                            move <- new Move(piece.getId(), "right", steps)
                             nextStates.add(new State(newBoard, this, move, cost +
1))
                        else
                            break
                else
                    {move up}
                    for steps from 1 to board.getHeight():
                        newBoard <- board.copy()
                        if newBoard.movePiece(piece.getId(), "up", steps) then
                            move <- new Move(piece.getId(), "up", steps)
                             nextStates.add(new State(newBoard, this, move, cost +
1))
                        else
                            break

                    {move down}
                    for steps from 1 to board.getHeight():
                        newBoard <- board.copy()
                        if newBoard.movePiece(piece.getId(), "down", steps) then
                            move <- new Move(piece.getId(), "down", steps)
                             nextStates.add(new State(newBoard, this, move, cost +
1))
                        else
                            break

            -> nextStates

        Function isSolution():
            -> board.canPrimaryPieceExit()

        Function getStateKey():
            -> board.toString()
```

```
    Function equals(obj: Object):
        if this == obj then
            -> true
        if obj == null or getClass() != obj.getClass() then
            -> false
        other <- (State) obj
        -> getStateKey() == other.getStateKey()

    Function hashCode():
        -> getStateKey().hashCode()
```

3.2.11. File FileHandler.java

```
 Class FileHandler:
    Function loadBoardFromFile(filePath: string) throws IOException:
        reader <- new BufferedReader(new FileReader(filePath))

        try:
            line <- reader.readLine()
            if line == null then
                throw IOException("File is empty or incomplete")

            dimensions <- line.split(" ")
            if length(dimensions) < 2 then
                  throw IOException("Invalid board dimensions format. Expected
'width height'")

            width <- Integer.parseInt(dimensions[0])
            height <- Integer.parseInt(dimensions[1])

            line <- reader.readLine() {skip number of pieces line}

            board <- new Board(width, height)

            grid <- new char[height][width]
            r traversal [0..height - 1]:
                line <- reader.readLine()
                if line == null or length(line) < width then
                          throw IOException("Invalid grid row " + (r + 1) + ":
insufficient length")
                c traversal [0..width - 1]:
                    grid[r][c] <- line.charAt(c)

            exitRow <- -1
            exitCol <- -1
            primaryRow <- -1

            {Find primary piece 'P' row
            r traversal [0..height - 1]:
                c traversal [0..width - 1]:
                    if grid[r][c] == 'P' then
                        primaryRow <- r
                        break
                if primaryRow >= 0 then break

            {Find exit 'K' in same row as 'P'}
            if primaryRow >= 0 then
                for c from 0 to width - 1:
                    if grid[primaryRow][c] == 'K' then
                        exitRow <- primaryRow
                        exitCol <- c
```

```
                            grid[exitRow][exitCol] <- '.'
                            break

                {If 'K' not found, find 'K' anywhere}
                if exitRow < 0 then
                    r traversal [0..height - 1]:
                        c traversal [0..width - 1]:
                            if grid[r][c] == 'K' then
                                exitRow <- r
                                exitCol <- c
                                grid[r][c] <- '.'
                                break
                        if exitRow >= 0 then break

                {Default exit if still not found}
                if exitRow < 0 then
                    exitRow <- if primaryRow >= 0 then primaryRow else height / 2
                    exitCol <- width - 1

                board.setExit(exitRow, exitCol)

                pieceBounds <- new Map<Character, int[]>()

                {Find pieces and their boundaries}
                r traversal [0..height - 1]:
                    c traversal [0..width - 1]:
                        id <- grid[r][c]
                        if id != '.' then
                            if not pieceBounds.containsKey(id) then
                                pieceBounds.put(id, [r, c, r, c])
                            else
                                bounds <- pieceBounds.get(id)
                                bounds[2] <- max(bounds[2], r)
                                bounds[3] <- max(bounds[3], c)

                {Create pieces and add to board}
                for each entry in pieceBounds:
                    id <- entry.key
                    bounds <- entry.value
                    startRow <- bounds[0]
                    startCol <- bounds[1]
                    endRow <- bounds[2]
                    endCol <- bounds[3]

                    isHorizontal <- (startRow == endRow)
                      length <- if isHorizontal then (endCol - startCol + 1) else
(endRow - startRow + 1)
                    isPrimary <- (id == 'P')

                             piece <- new Piece(id, startRow, startCol, length,
isHorizontal, isPrimary)
                    board.addPiece(piece)

                -> board

            finally:
                reader.close()

        Procedure printBoard(board: Board, movingPieceId: char):
            height <- board.getHeight()
            width <- board.getWidth()
            exitRow <- board.getExitRow()
```

```
            exitCol <- board.getExitCol()

            RESET <- "\u001B[0m"
            RED <- "\u001B[91m"
            GREEN <- "\u001B[92m"

            {Print top border}
            print "+"
            c traversal [0..width - 1]:
                print "---+"
            println()

            r traversal [0..height - 1]:
                print "|"
                c traversal [0..width - 1]:
                    cell <- board.getCell(r, c)
                    color <- ""
                    if cell == movingPieceId then
                        color <- GREEN
                    else if cell == 'P' then
                        color <- RED

                    print " " + color + cell + RESET + " "

                    if c == width - 1 and r == exitRow then
                        print " "
                    else
                        print "|"
                println()

                {Print row separator}
                print "+"
                c traversal [0..width - 1]:
                    print "---+"
                println()

              Procedure  saveSolutionToFile(solution:  List<Move>,  boardStates:
List<Board>, filePath: string, timeTaken: long, nodesVisited: integer) throws
IOException:
            if not filePath.endsWith(".txt") then
                  throw IOException("Invalid file format. The file must be a .txt
file.")

            writer <- new BufferedWriter(new FileWriter(filePath))
            try:
                writer.write("============================================")
                writer.write("\n              SOLUTION FOUND")
                writer.write("\n============================================")

                if solution.isEmpty() then
                    writer.write("\nNo solution found.")
                    return
                else
                    writer.write("\nSolution path contains " + solution.size() + "
moves.\n")

                writer.write("Step by step solution:\n")
                i traversal [0..solution.size() - 1]:
                    move <- solution.get(i)
                    writer.write("\nStep " + (i + 1) + ": " + move + "\n")
                    currentBoard <- boardStates.get(i)
                    height <- currentBoard.getHeight()
```

```
                width <- currentBoard.getWidth()
                exitRow <- currentBoard.getExitRow()
                exitCol <- currentBoard.getExitCol()

                {Print top border}
                writer.write("+")
                c traversal [0 to width - 1]:
                    writer.write("---+")
                writer.write("\n")

                r traversal [0..height - 1]:
                    writer.write("|")
                    c traversal [0..width - 1]:
                        cell <- currentBoard.getCell(r, c)
                        writer.write(" " + cell + " ")
                        if c == width - 1 and r == exitRow then
                            writer.write(" ")
                        else
                            writer.write("|")
                    writer.write("\n")

                {Print row separator}
                writer.write("+")
                c traversal [0..width - 1]:
                    writer.write("---+")
                writer.write("\n")

            writer.write("\n==========================================\n")
            writer.write("              STATISTICS\n")
            writer.write("==========================================\n")
            writer.write("Path length: " + solution.size() + " moves\n")
            writer.write("Nodes visited: " + nodesVisited + "\n")
            writer.write("Execution time: " + timeTaken + " ms\n")
            writer.write("==========================================\n")

        finally:
            writer.close()
```

3.2.12. File BoardPanel.java (GUI)

```
Class BoardPanel extends JPanel:
    private board : Board
    private pieceColors : Map<Character, Color>
    private static CELL_SIZE : integer = 50

    Constructor BoardPanel():
        setPreferredSize(new Dimension(600, 600))

    Function setBoard(board: Board):
        this.board <- board
        assignColors()
        width <- board.getWidth()
        height <- board.getHeight()
        setPreferredSize(new Dimension(width * CELL_SIZE, height * CELL_SIZE))
        revalidate()
        repaint()

    Function assignColors():
        pieceColors.clear()
        if board is null then
            return
```

```
            colors <- [Color.RED, Color.BLUE, Color.GREEN.darker(), Color.ORANGE,
    Color.MAGENTA, Color.CYAN.darker(), Color.PINK, Color.YELLOW.darker()]
            idx <- 0
            for each id in board.getPieces().keySet():
                pieceColors.put(id, colors[idx % colors.length])
                idx <- idx + 1

        Override Function paintComponent(g: Graphics):
            super.paintComponent(g)
            if board is null then
                return

            width <- board.getWidth()
            height <- board.getHeight()
            g2 <- (Graphics2D) g
            oldStroke <- g2.getStroke()

            r traversal [0..height - 1]:
                c traversal [0..width - 1]:
                    cellChar <- board.getCell(r, c)
                    bgColor <- Color.LIGHT_GRAY
                    if cellChar == '.' then
                        bgColor <- Color.WHITE
                    else if cellChar == 'P' then
                        bgColor <- Color.RED
                    else if pieceColors contains key cellChar then
                        bgColor <- pieceColors.get(cellChar)

                    g.setColor(bgColor)
                    g.fillRect(c * CELL_SIZE, r * CELL_SIZE, CELL_SIZE, CELL_SIZE)
                    g.setColor(Color.BLACK)
                    g.drawRect(c * CELL_SIZE, r * CELL_SIZE, CELL_SIZE, CELL_SIZE)

                    if cellChar != '.':
                        g.setColor(Color.BLACK)
                        g.setFont(g.getFont().deriveFont(Font.BOLD, 20f))
                        fm <- g.getFontMetrics()
                        text <- String.valueOf(cellChar)
                        textWidth <- fm.stringWidth(text)
                        textHeight <- fm.getAscent()
                        x <- c * CELL_SIZE + (CELL_SIZE - textWidth) / 2
                        y <- r * CELL_SIZE + (CELL_SIZE + textHeight) / 2 - 4
                        g.drawString(text, x, y)

            exitRow <- board.getExitRow()
            exitCol <- board.getExitCol()
            g2.setStroke(new BasicStroke(5))
            g2.setColor(Color.GREEN.darker())

            if exitRow >= 0 and exitRow < height and exitCol == -1 then
                x <- 0
                y <- exitRow * CELL_SIZE
                g2.drawLine(x, y, x, y + CELL_SIZE)
            else if exitRow >= 0 and exitRow < height and exitCol == width then
                x <- width * CELL_SIZE - 1
                y <- exitRow * CELL_SIZE
                g2.drawLine(x, y, x, y + CELL_SIZE)
            else if exitCol >= 0 and exitCol < width and exitRow == -1 then
                x <- exitCol * CELL_SIZE
                y <- 0
                g2.drawLine(x, y, x + CELL_SIZE, y)
            else if exitCol >= 0 and exitCol < width and exitRow == height then
```

```
                x <- exitCol * CELL_SIZE
                y <- height * CELL_SIZE - 1
                g2.drawLine(x, y, x + CELL_SIZE, y)

            g2.setStroke(oldStroke)
```

3.2.13. File ControlPanel.java (GUI)

```
 Class ControlPanel extends JPanel:
     private filePathField : JTextField
     private browseButton : JButton
     private algorithmComboBox : JComboBox<String>
     private heuristicComboBox : JComboBox<String>
     private solveButton : JButton
     private playButton : JButton
     private pauseButton : JButton
     private prevButton : JButton
     private nextButton : JButton
     private saveButton : JButton  // tambahan tombol Save opsional

     private browseAction : Consumer<Void>
     private solveAction : Consumer<Void>
     private playAction : Consumer<Void>
     private pauseAction : Consumer<Void>
     private prevAction : Consumer<Void>
     private nextAction : Consumer<Void>

          Constructor  ControlPanel(browseCallback:  Runnable,  solveCallback:
Runnable,
                            playCallback: Runnable, pauseCallback: Runnable,
                            prevCallback: Runnable, nextCallback: Runnable,
                            saveButton: JButton):
         this.saveButton <- saveButton
         this.browseAction <- lambda v: browseCallback.run()
         this.solveAction <- lambda v: solveCallback.run()
         this.playAction <- lambda v: playCallback.run()
         this.pauseAction <- lambda v: pauseCallback.run()
         this.prevAction <- lambda v: prevCallback.run()
         this.nextAction <- lambda v: nextCallback.run()
         initComponents()
         layoutComponents()

     Procedure initComponents():
         filePathField <- new JTextField(30)
         filePathField.setEditable(false)

         browseButton <- new JButton("Browse")
         browseButton.addActionListener(e -> browseAction.accept(null))

            algorithmComboBox <- new JComboBox(["Uniform Cost Search (UCS)",
"Greedy Best First Search (GBFS)", "A* Search"])
         algorithmComboBox.addActionListener(e -> {
             idx <- algorithmComboBox.getSelectedIndex()
             heuristicComboBox.setEnabled(idx == 1 or idx == 2)
         })

            heuristicComboBox <- new JComboBox(["Distance to Exit", "Blocking
Vehicles", "Combined (Distance + Blocking Vehicles)"])
         heuristicComboBox.setEnabled(false)

         solveButton <- new JButton("Solve")
```

```
        solveButton.addActionListener(e -> solveAction.accept(null))

        playButton <- new JButton("Play")
        playButton.setEnabled(false)
        playButton.addActionListener(e -> playAction.accept(null))

        pauseButton <- new JButton("Pause")
        pauseButton.setEnabled(false)
        pauseButton.addActionListener(e -> pauseAction.accept(null))

        prevButton <- new JButton("Prev")
        prevButton.setEnabled(false)
        prevButton.addActionListener(e -> prevAction.accept(null))

        nextButton <- new JButton("Next")
        nextButton.setEnabled(false)
        nextButton.addActionListener(e -> nextAction.accept(null))

    Procedure layoutComponents():
        setLayout(FlowLayout(LEFT))
        add(new JLabel("Puzzle file:"))
        add(filePathField)
        add(browseButton)
        add(new JLabel("Algorithm:"))
        add(algorithmComboBox)
        add(new JLabel("Heuristic:"))
        add(heuristicComboBox)
        add(solveButton)
        add(playButton)
        add(pauseButton)
        add(prevButton)
        add(nextButton)
        if saveButton != null then
            add(saveButton)

    Procedure addSaveButton(button: JButton):
        saveButton <- button
        add(saveButton)
        revalidate()
        repaint()

    Procedure setFilePath(path: string):
        filePathField.setText(path)

    Function getSelectedAlgorithmIndex():
        -> algorithmComboBox.getSelectedIndex()

    Function getSelectedHeuristicIndex():
        -> heuristicComboBox.getSelectedIndex()

    Procedure setControlsEnabled(enabled: boolean):
        solveButton.setEnabled(enabled)
        playButton.setEnabled(enabled)
        pauseButton.setEnabled(false)
        prevButton.setEnabled(enabled)
        nextButton.setEnabled(enabled)
        if saveButton != null then
            saveButton.setEnabled(enabled)

    Procedure setPlaying(isPlaying: boolean):
        playButton.setEnabled(not isPlaying)
        pauseButton.setEnabled(isPlaying)
```

```
            solveButton.setEnabled(not isPlaying)
            browseButton.setEnabled(not isPlaying)
            prevButton.setEnabled(not isPlaying)
            nextButton.setEnabled(not isPlaying)
            if saveButton != null then
                saveButton.setEnabled(not isPlaying)
```

3.2.14. File StatusPanel.java (GUI)

```
  Class StatusPanel extends JPanel:
      private statusLabel : JLabel
      private prevButton : JButton
      private nextButton : JButton
      private saveButton : JButton

        Constructor StatusPanel(prevCallback: Runnable, nextCallback: Runnable,
saveCallback: Runnable):
          setLayout(BorderLayout(horizontalGap=10, verticalGap=0))
          setBorder(emptyBorder(top=5, left=10, bottom=5, right=10))

          statusLabel <- new JLabel("Load a puzzle to start.")
          statusLabel.setFont("SansSerif", PLAIN, 16)
          statusLabel.setHorizontalAlignment(LEFT)
          statusLabel.setPreferredSize(width=500, height=25)

          buttonPanel <- new JPanel(new FlowLayout(RIGHT, hgap=10, vgap=0))

          prevButton <- new JButton("Prev")
          prevButton.setEnabled(false)
          prevButton.addActionListener(e -> prevCallback.run())

          nextButton <- new JButton("Next")
          nextButton.setEnabled(false)
          nextButton.addActionListener(e -> nextCallback.run())

          saveButton <- new JButton("Save")
          saveButton.setEnabled(false)
          saveButton.addActionListener(e -> saveCallback.run())

          buttonPanel.add(prevButton)
          buttonPanel.add(nextButton)
          buttonPanel.add(saveButton)

          add(statusLabel, BorderLayout.CENTER)
          add(buttonPanel, BorderLayout.EAST)

      Procedure setStatus(status: string):
          statusLabel.setText(status)

      Procedure setPrevEnabled(enabled: boolean):
          prevButton.setEnabled(enabled)

      Procedure setNextEnabled(enabled: boolean):
          nextButton.setEnabled(enabled)

      Procedure setSaveEnabled(enabled: boolean):
          saveButton.setEnabled(enabled)

      Function getPreferredSize():
          baseSize <- super.getPreferredSize()
          -> new Dimension(baseSize.width, 40)
```

3.2.15. File MainFrame.java (GUI)

```
Class MainFrame extends JFrame:
    private controlPanel : ControlPanel
    private boardPanel : BoardPanel
    private statusPanel : StatusPanel

    private currentBoard : Board
    private solutionMoves : List<Move>
    private boardStates : List<Board>
    private pathfinder : Pathfinder

    private animationTimer : Timer
    private animationStep : integer = 0

    private saveButton : JButton

    private startTime : long
    private endTime : long

    Constructor MainFrame():
        setTitle("Rush Hour Puzzle Solver")
        setDefaultCloseOperation(EXIT_ON_CLOSE)
        setLayout(BorderLayout)
        setSize(900, 700)
        setLocationRelativeTo(null)

        saveButton <- new JButton("Save Solution")
        saveButton.setEnabled(false)
        saveButton.addActionListener(e -> onSaveClicked())

           controlPanel <- new ControlPanel(onBrowseClicked, onSolveClicked,
onPlayClicked, onPauseClicked, onPrevClicked, onNextClicked, saveButton)
        boardPanel <- new BoardPanel()
              statusPanel <- new StatusPanel(onPrevClicked, onNextClicked,
onSaveClicked)

        add(controlPanel, BorderLayout.NORTH)
        add(new JScrollPane(boardPanel), BorderLayout.CENTER)
        add(statusPanel, BorderLayout.SOUTH)

        animationTimer <- new Timer(800, e -> {
             if boardStates != null and animationStep < size(boardStates) - 1
then
                animationStep <- animationStep + 1
                updateBoardState(animationStep)
            else
                animationTimer.stop()
                controlPanel.setPlaying(false)
        })

    Procedure onSaveClicked():
        if solutionMoves == null or solutionMoves is empty then
            showMessage("No solution to save!", "Warning")
            return

        chooser <- new JFileChooser()
        chooser.setFileFilter("Text Files", "txt")
        chooser.setDialogTitle("Save Solution")
```

```
            result <- chooser.showSaveDialog(this)

            if result == APPROVE_OPTION then
                filePath <- chooser.getSelectedFile().getAbsolutePath()
                if not filePath.endsWith(".txt") then
                    filePath <- filePath + ".txt"

                try
                    timeTaken <- endTime - startTime
                        FileHandler.saveSolutionToFile(solutionMoves, boardStates,
filePath, timeTaken, pathfinder.getNodesVisited())
                        showMessage("Solution saved successfully to " + filePath,
"Success")
                catch IOException as ex
                       showMessage("Failed to save solution: " + ex.getMessage(),
"Error")

        Procedure onBrowseClicked():
            chooser <- new JFileChooser()
            chooser.setFileFilter("Text Files", "txt")
            result <- chooser.showOpenDialog(this)

            if result == APPROVE_OPTION then
                file <- chooser.getSelectedFile()
                controlPanel.setFilePath(file.getAbsolutePath())
                try
                                                                currentBoard    <-
FileHandler.loadBoardFromFile(file.getAbsolutePath())
                    boardPanel.setBoard(currentBoard)
                    statusPanel.setStatus("Puzzle loaded. Ready to solve.")
                    resetAnimation()
                catch Exception as ex
                        showMessage("Failed to load puzzle:\n" + ex.getMessage(),
"Error")

        Procedure onSolveClicked():
            if currentBoard == null then
                showMessage("Please load a puzzle file first.", "Warning")
                return

            algoIndex <- controlPanel.getSelectedAlgorithmIndex()
            heuristicIndex <- controlPanel.getSelectedHeuristicIndex() + 1

            switch algoIndex:
                case 0:
                    pathfinder <- new UCS()
                case 1:
                                                            pathfinder    <-    new
GreedyBestFirst(HeuristicFactory.createHeuristic(heuristicIndex))
                case 2:
                                                            pathfinder    <-    new
AStar(HeuristicFactory.createHeuristic(heuristicIndex))
                default:
                    showMessage("Invalid algorithm selection.", "Error")
                    return

            statusPanel.setStatus("Solving...")
            controlPanel.setControlsEnabled(false)
            saveButton.setEnabled(false)
            statusPanel.setPrevEnabled(false)
            statusPanel.setNextEnabled(false)
            statusPanel.setSaveEnabled(false)
```

```
            worker <- new SwingWorker<Void, Void>():
                solution : List<Move>
                states : List<State>

                override doInBackground():
                    startTime <- currentTimeMillis()
                    solution <- pathfinder.findPath(currentBoard)
                    endTime <- currentTimeMillis()
                    states <- pathfinder.getSolutionStates()
                    return null

                override done():
                    try
                        get() // check exceptions
                        solutionMoves <- solution
                        boardStates <- map(states, state -> state.getBoard())

                        if solutionMoves is empty then
                            statusPanel.setStatus("No solution found.")
                            showMessage("No solution found!", "Info")
                            resetAnimation()
                        else
                                    statusPanel.setStatus("Solution found with " +
size(solutionMoves) + " moves, nodes visited: " +
                                                          pathfinder.getNodesVisited() + ",
execution time: " + (endTime - startTime) + " ms")
                            animationStep <- 0
                            boardPanel.setBoard(boardStates[0])
                            controlPanel.setControlsEnabled(true)
                            controlPanel.setPlaying(false)
                            saveButton.setEnabled(true)
                            statusPanel.setPrevEnabled(false)
                            statusPanel.setNextEnabled(size(boardStates) > 1)
                            statusPanel.setSaveEnabled(true)
                    catch Exception as e
                           showMessage("Error during solving:\n" + e.getMessage(),
"Error")
                        resetAnimation()

            worker.execute()

        Procedure onPlayClicked():
            animationTimer.start()
            controlPanel.setPlaying(true)
            statusPanel.setPrevEnabled(false)
            statusPanel.setNextEnabled(false)

        Procedure onPauseClicked():
            animationTimer.stop()
            controlPanel.setPlaying(false)
            statusPanel.setPrevEnabled(animationStep > 0)
              statusPanel.setNextEnabled(boardStates != null and animationStep <
size(boardStates) - 1)

        Procedure onNextClicked():
             if boardStates == null or animationStep >= size(boardStates) - 1 then
return
            animationStep <- animationStep + 1
            updateBoardState(animationStep)

        Procedure onPrevClicked():
```

```
            if boardStates == null or animationStep <= 0 then return
            animationStep <- animationStep - 1
            updateBoardState(animationStep)

        Procedure updateBoardState(step: integer):
            boardPanel.setBoard(boardStates[step])
              statusPanel.setStatus("Step " + step + " / " + (size(boardStates) -
 1))
            statusPanel.setPrevEnabled(step > 0)
            statusPanel.setNextEnabled(step < size(boardStates) - 1)

        Procedure resetAnimation():
            animationTimer.stop()
            animationStep <- 0
            solutionMoves <- null
            boardStates <- null
            controlPanel.setControlsEnabled(true)
            controlPanel.setPlaying(false)
            saveButton.setEnabled(false)
            statusPanel.setPrevEnabled(false)
            statusPanel.setNextEnabled(false)
            statusPanel.setSaveEnabled(false)

            if currentBoard != null then
                boardPanel.setBoard(currentBoard)
            else
                boardPanel.setBoard(null)

            statusPanel.setStatus("Load a puzzle to start.")

        Procedure main(args):
            SwingUtilities.invokeLater(() -> new MainFrame().setVisible(true))
```

3.3. Analisis Algoritma UCS, Greedy Best First Search, dan A*

Dalam algoritma pencarian seperti UCS, Greedy Best First Search, dan A*, fungsi evaluasi f(n) sangat penting untuk menentukan urutan perluasan simpul. Fungsi ini biasanya didefinisikan sebagai f(n) = g(n) + h(n), di mana g(n) adalah biaya yang sudah dikeluarkan untuk mencapai simpul n, dan h(n) adalah estimasi biaya dari nnn menuju tujuan. Dengan definisi ini, masing-masing algoritma memiliki cara berbeda dalam menghitung f(n): jika f(n) = g(n), maka algoritmanya adalah Uniform Cost Search (UCS) yang hanya memperhitungkan biaya jalur sejauh ini; jika f(n) = h(n), maka algoritmanya Greedy Best First Search yang hanya mengandalkan estimasi heuristik tanpa mempedulikan biaya yang sudah ditempuh; dan jika f(n) = g(n) + h(n), maka algoritmanya adalah A* yang menggabungkan keduanya.

Heuristik yang digunakan dalam A* disebut *admissible* jika tidak pernah melebih-lebihkan biaya sebenarnya dari simpul nnn ke tujuan, artinya nilai h(n)h(n)h(n) selalu lebih kecil atau sama dengan biaya sesungguhnya untuk mencapai tujuan dari n. Heuristik admissible ini penting agar A* dapat menjamin menemukan solusi optimal, karena algoritma tidak akan melewatkan solusi terbaik akibat perkiraan biaya yang terlalu optimis. Dengan kata lain, heuristik admissible memberikan batas bawah realistis yang menjaga keakuratan pencarian.

Dalam konteks permainan Rush Hour, jika semua langkah memiliki biaya yang sama, UCS akan berperilaku sama dengan Breadth-First Search (BFS) karena keduanya memperluas simpul berdasarkan jarak langkah yang sudah ditempuh tanpa membedakan biaya per langkah. Namun, jika biaya langkah berbeda, UCS dapat menghasilkan urutan simpul yang diperluas dan jalur yang berbeda dari BFS, karena UCS selalu memilih jalur dengan biaya terendah sejauh ini.

Secara teoritis, A* lebih efisien daripada UCS dalam menyelesaikan Rush Hour, karena A* memanfaatkan heuristik untuk mengarahkan pencarian ke tujuan sehingga mengurangi jumlah simpul yang harus diperiksa. UCS hanya mempertimbangkan biaya kumulatif tanpa petunjuk menuju tujuan, sehingga berpotensi menjelajah banyak simpul yang tidak relevan. Dengan heuristik yang baik dan *admissible*, A* dapat memangkas ruang pencarian secara signifikan, mempercepat proses pencarian solusi.

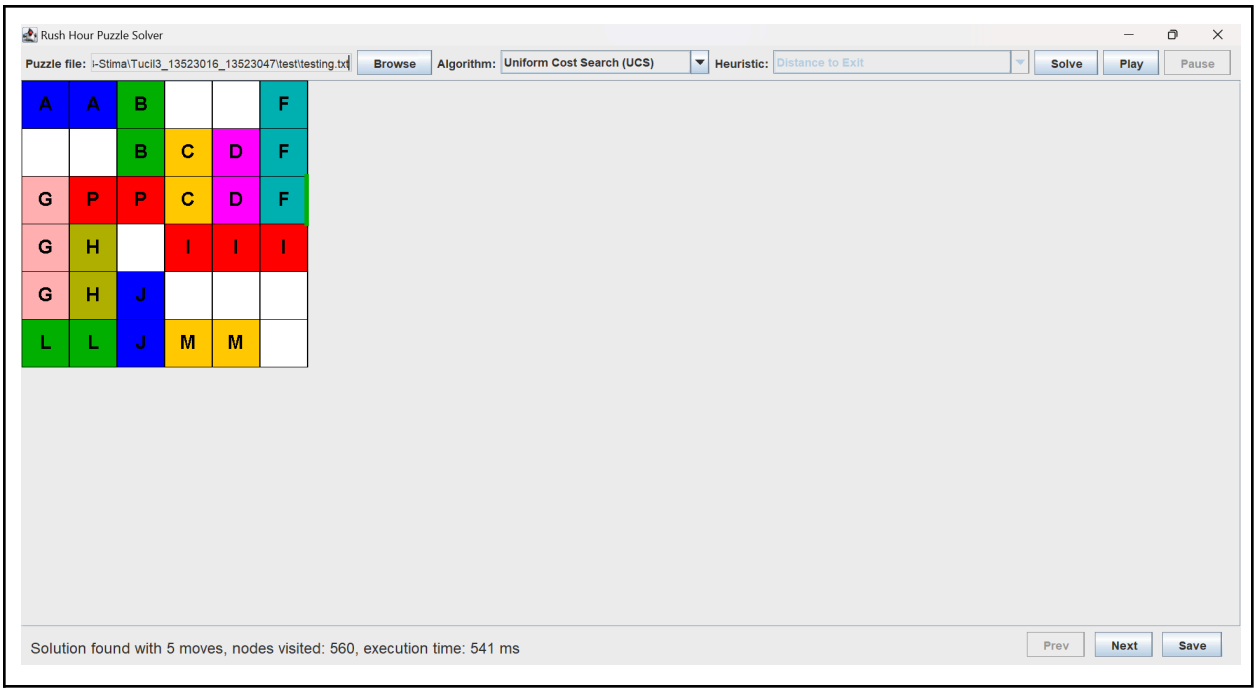
Di sisi lain, Greedy Best First Search mengandalkan heuristik saja tanpa mempertimbangkan biaya jalur yang sudah ditempuh, sehingga meskipun sering lebih cepat dalam menemukan solusi, algoritma ini tidak menjamin solusi yang optimal. Dalam Rush Hour, hal ini berarti Greedy bisa menemukan jalan keluar dengan cepat, tetapi jalur yang ditemukan mungkin tidak paling efisien atau paling sedikit langkahnya. Oleh karena itu, Greedy Best First Search lebih cocok untuk situasi di mana kecepatan pencarian lebih diutamakan daripada optimalitas hasil.

BAB IV
PENGUJIAN

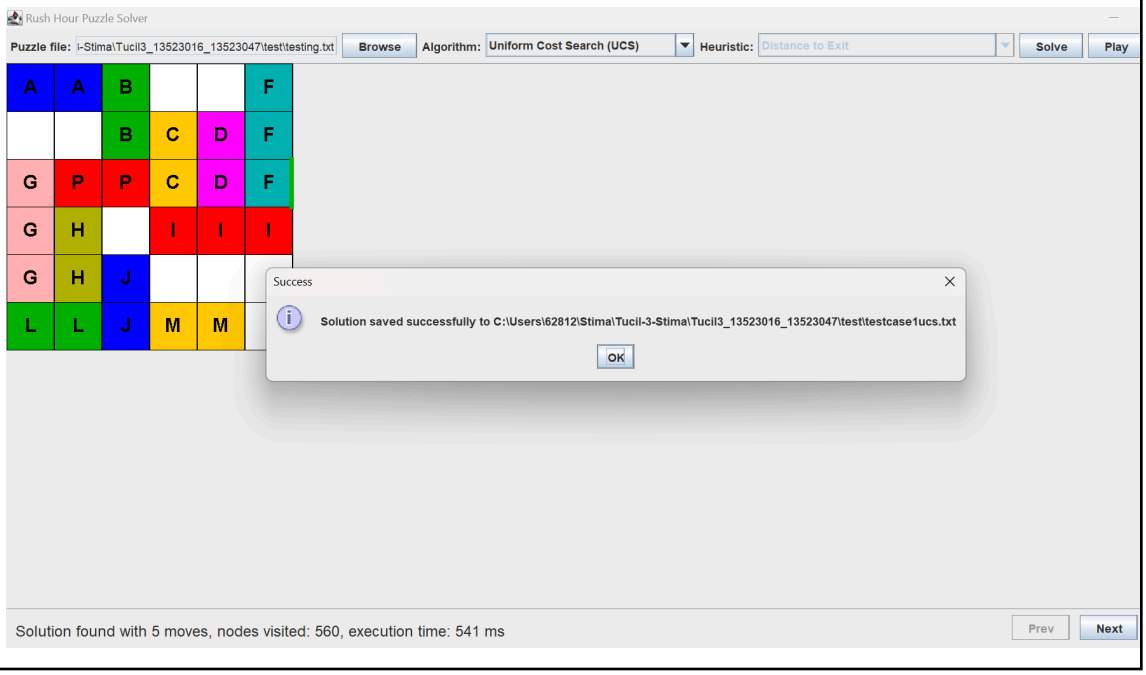
4.1. Test Case 1 - UCS

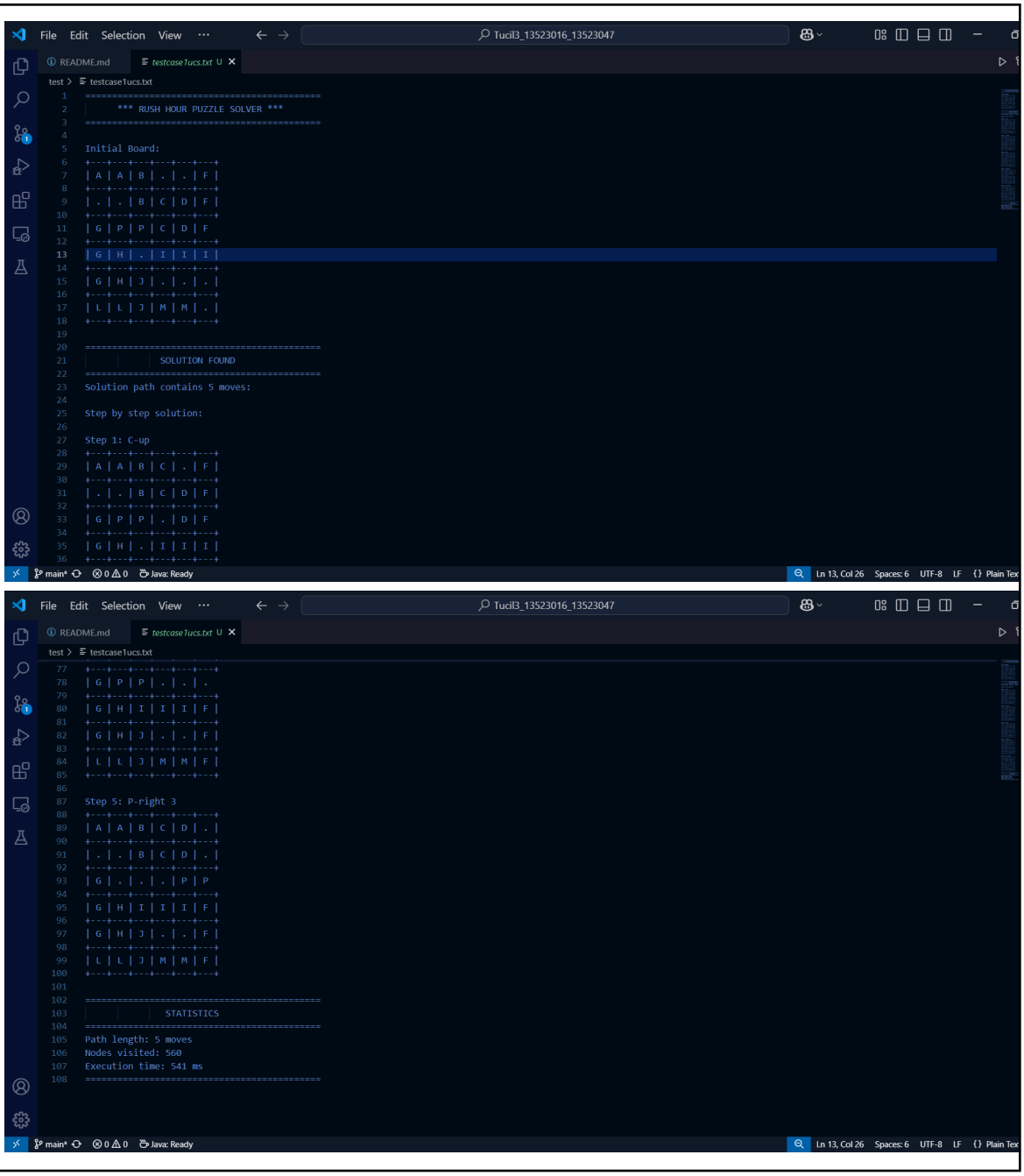
Input : test/testing.txt
6 6 11 AAB..F ..BCDF GPPCDFK GH.III GHJ... LLJMM.

Output GUI



Output Simpan di File



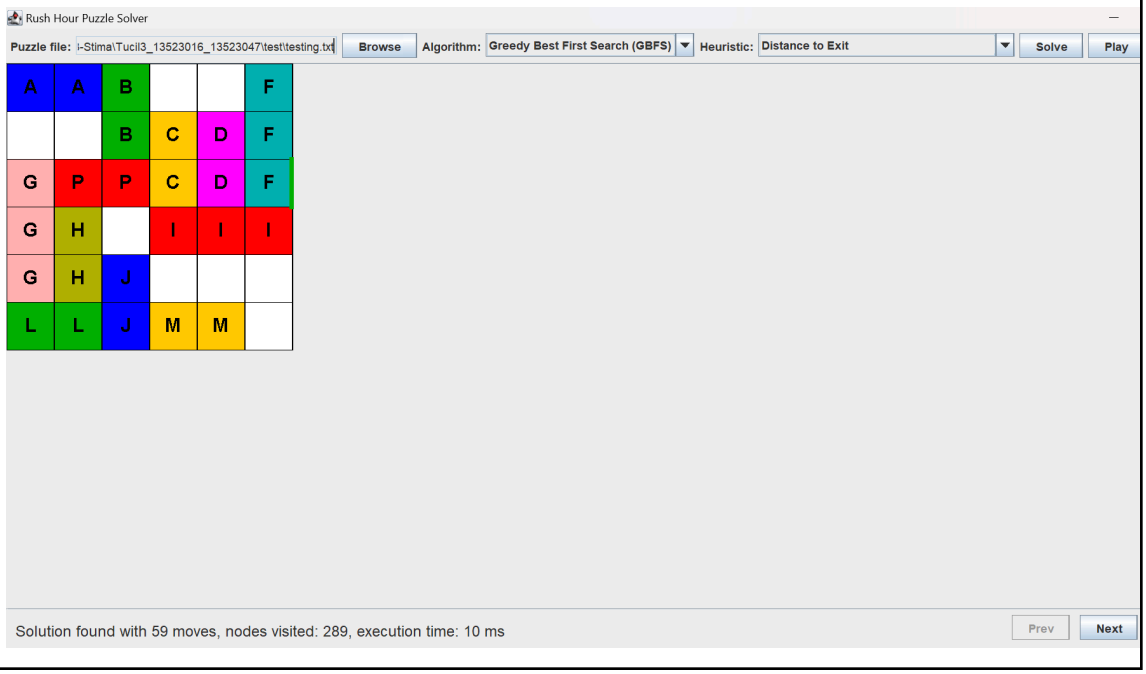


4.2. Test Case 1 - GBFS Heuristik Distance to Exit

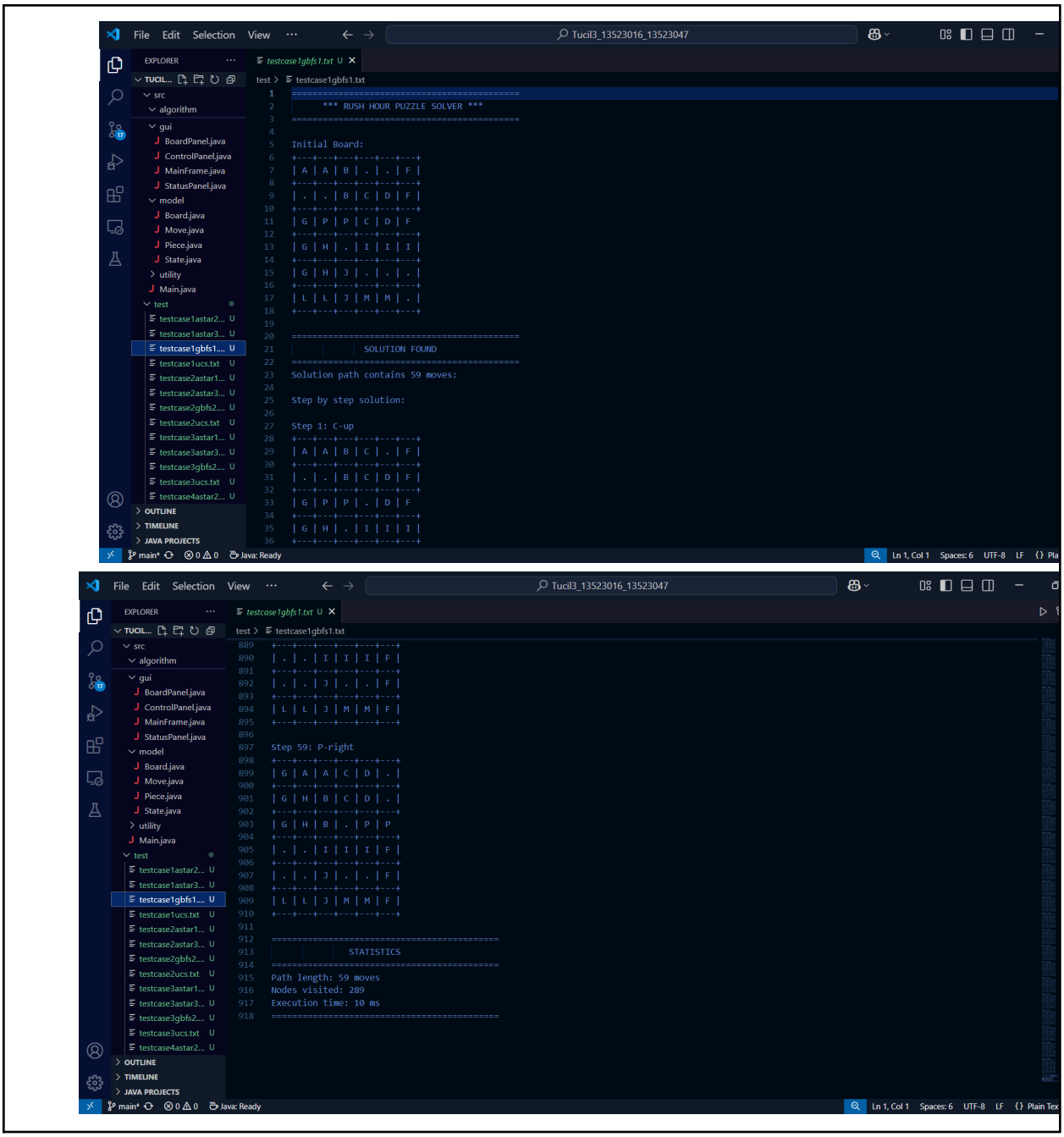
Input : test/testing.txt
6 6 11 AAB..F ..BCDF GPPCDFK

GH.III
GHJ...
LLJMM.

Output GUI



Output Simpan di File

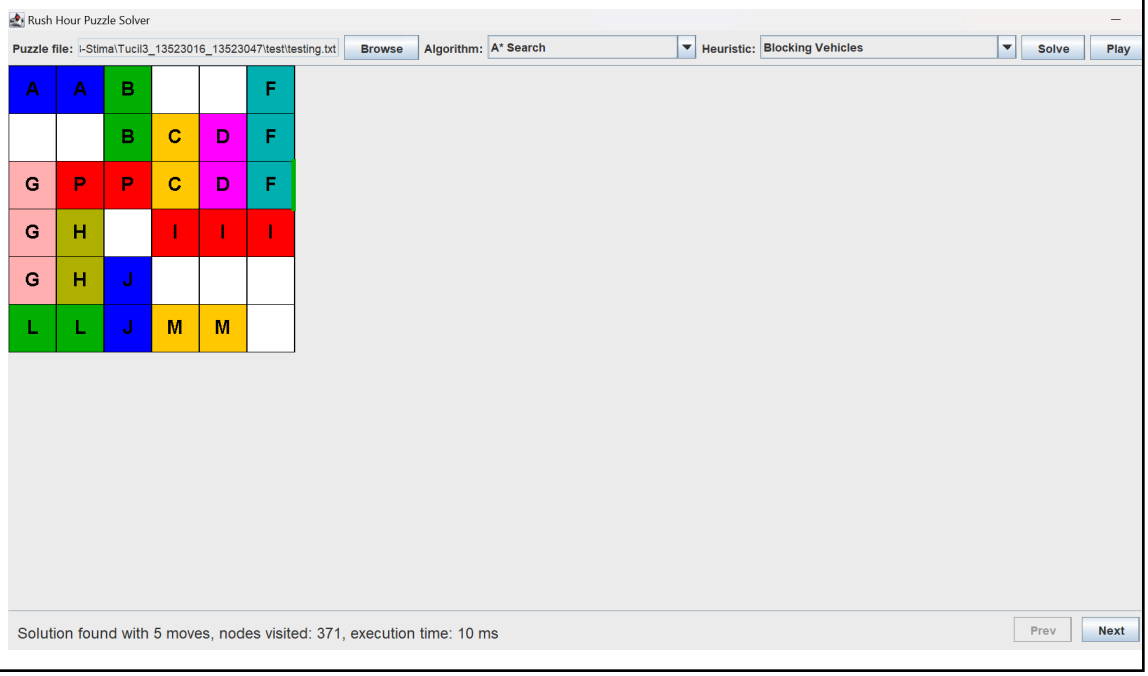


4.3. Test Case 1 - A* Heuristik Blocked Vehicles

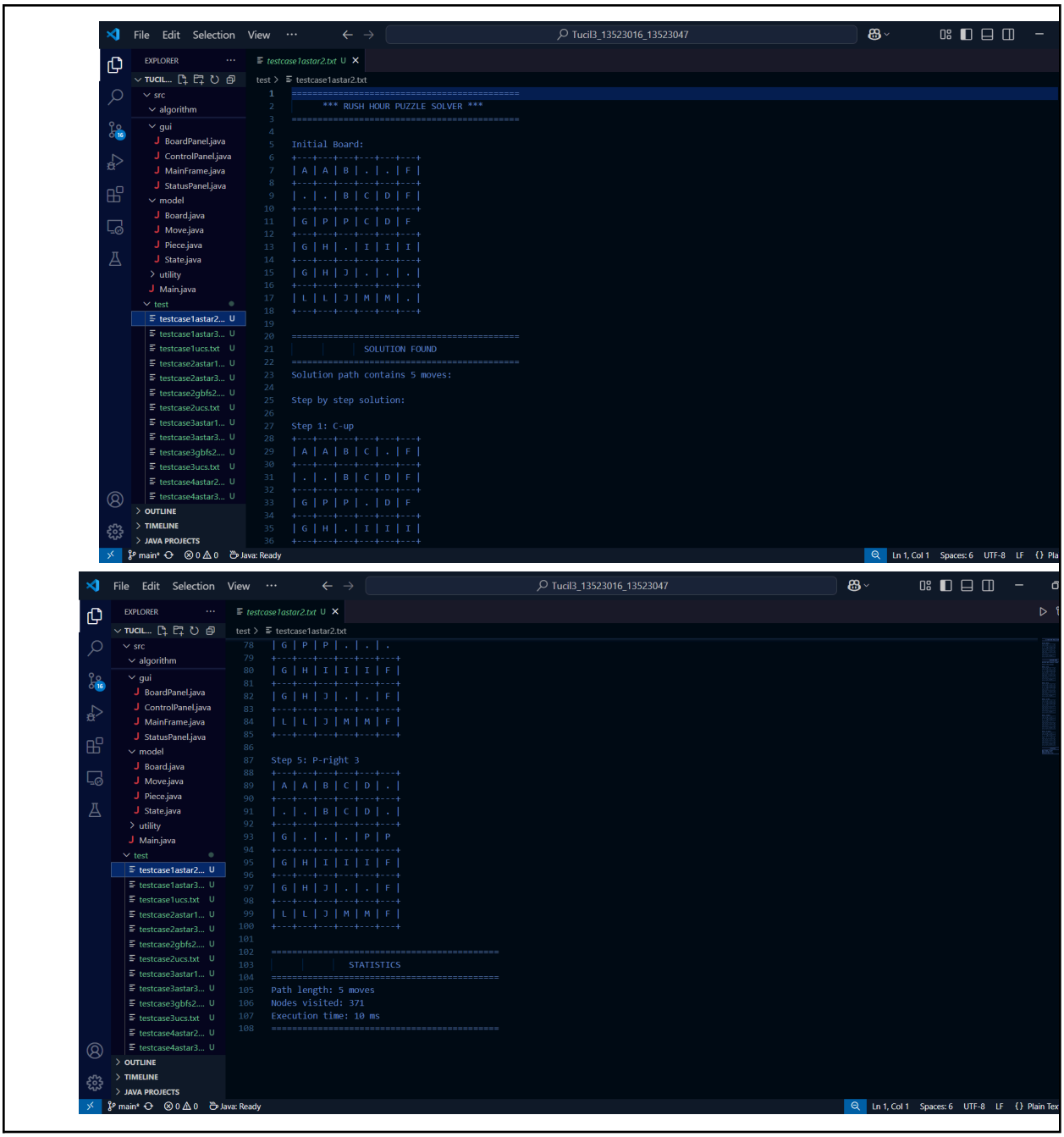
Input : test/testing.txt
6 6 11 AAB..F ..BCDF GPPCDFK

GH.III
GHJ...
LLJMM.

Output GUI



Output Simpan di File

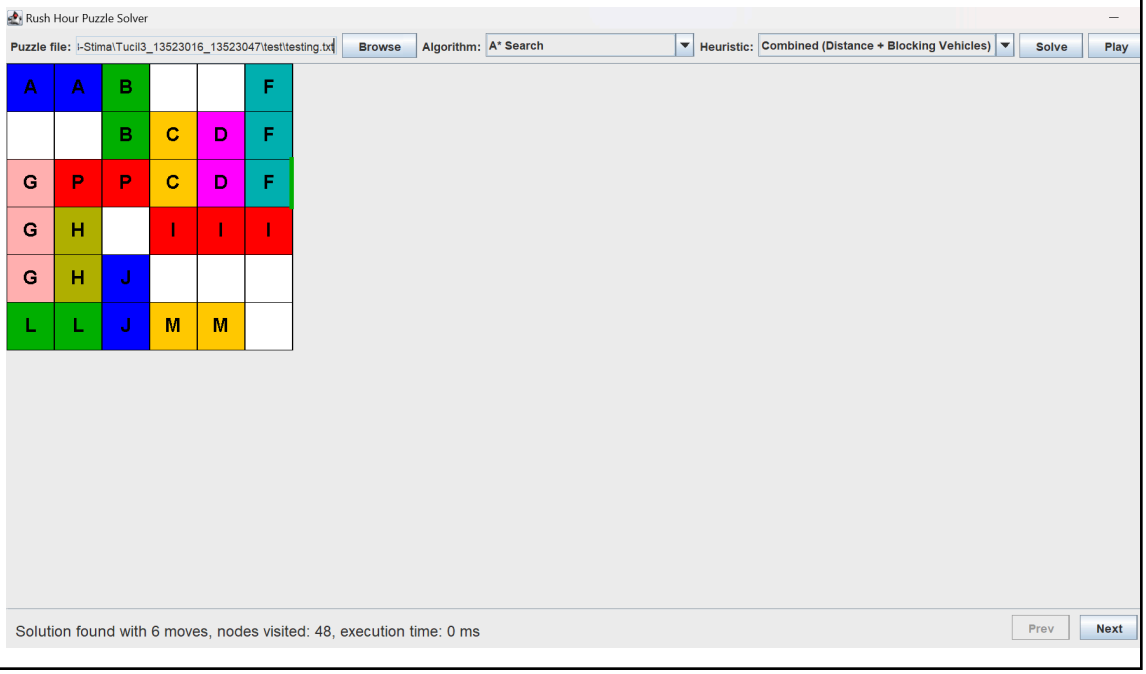


4.4. Test Case 1 - A* Heuristik Combined

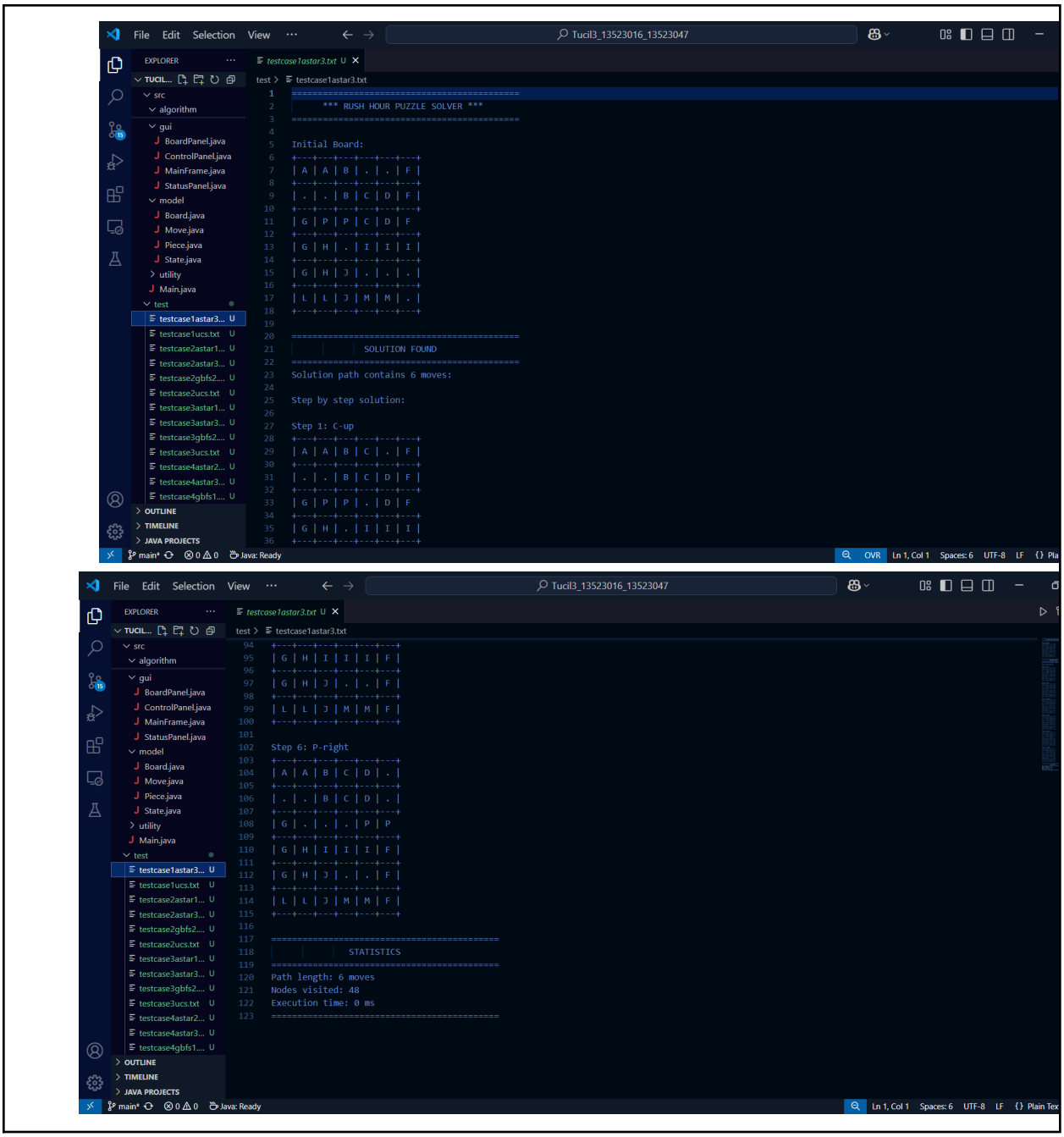
Input : test/testing.txt
6 6 11 AAB..F ..BCDF GPPCDFK

GH.III
GHJ...
LLJMM.

Output GUI



Output Simpan di File

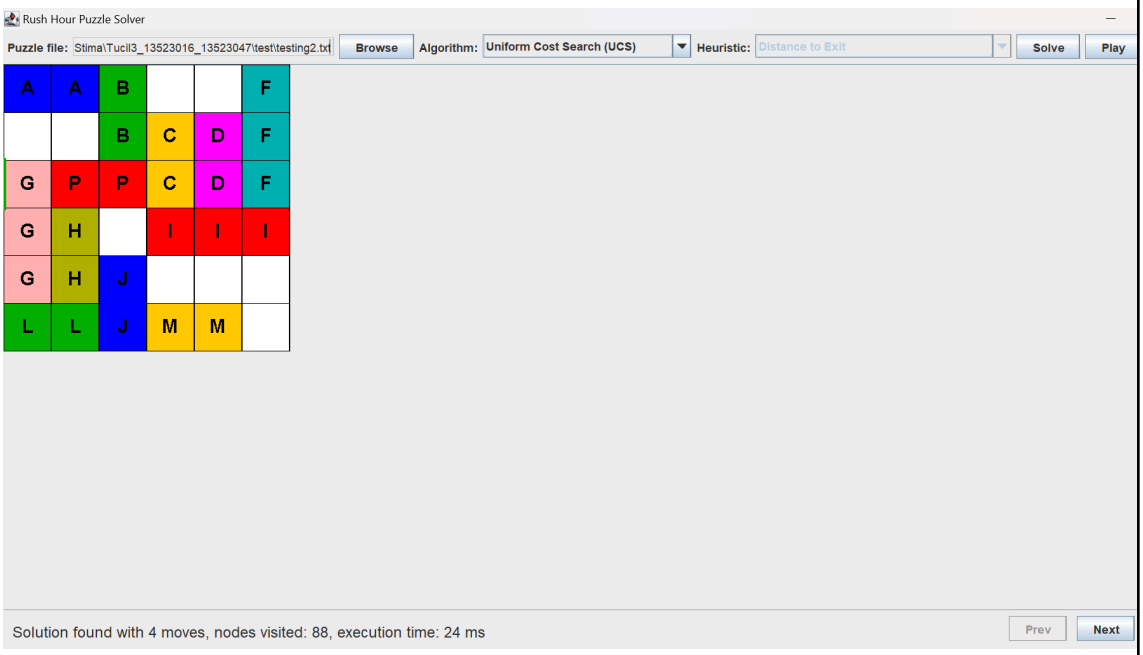


4.5. Test Case 2 - UCS

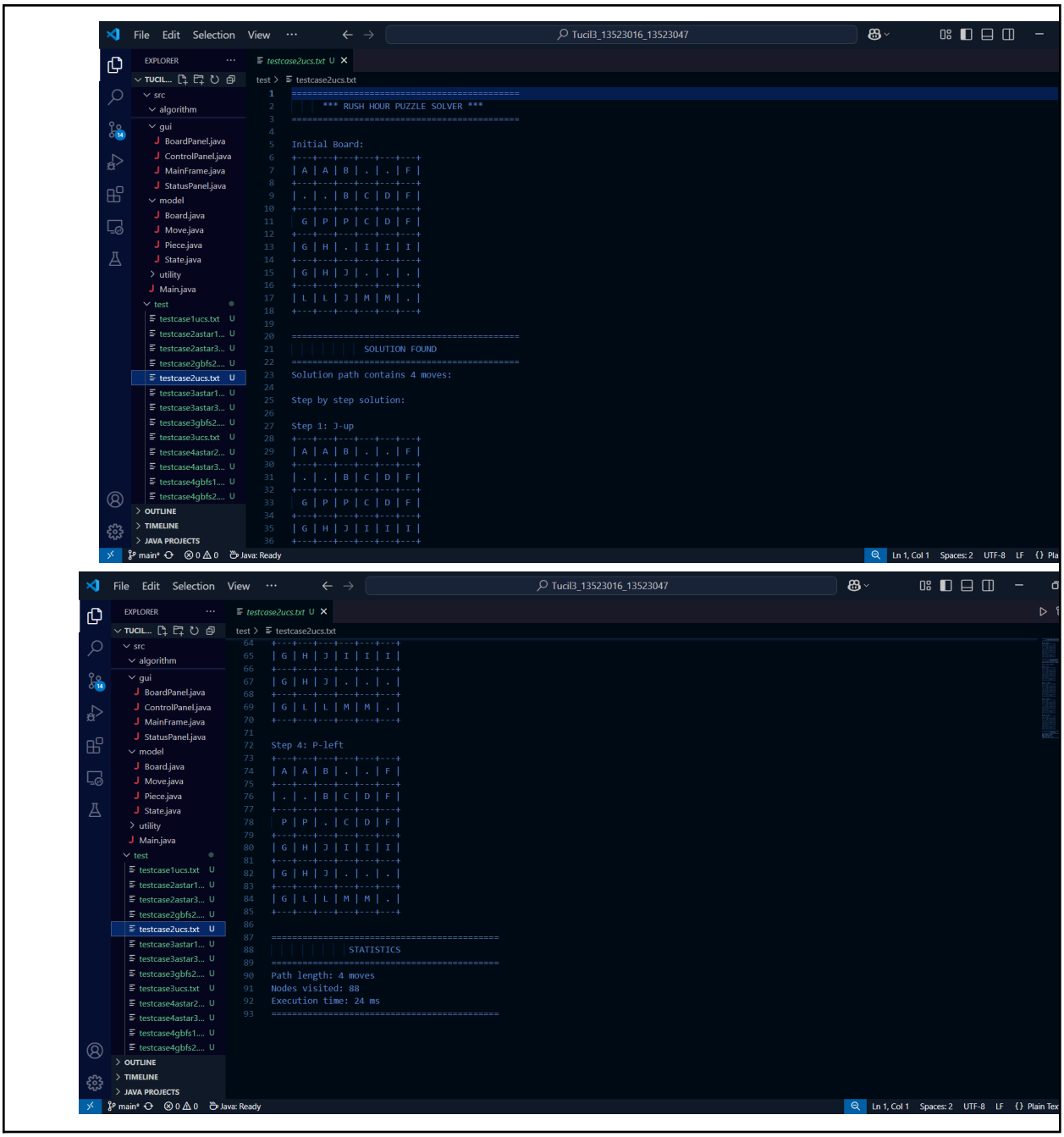
Input : test/testing2.txt
6 6 11 AAB..F ..BCDF

KGPPCDF
GH.III
GHJ...
LLJMM.

Output GUI



Output Simpan di File

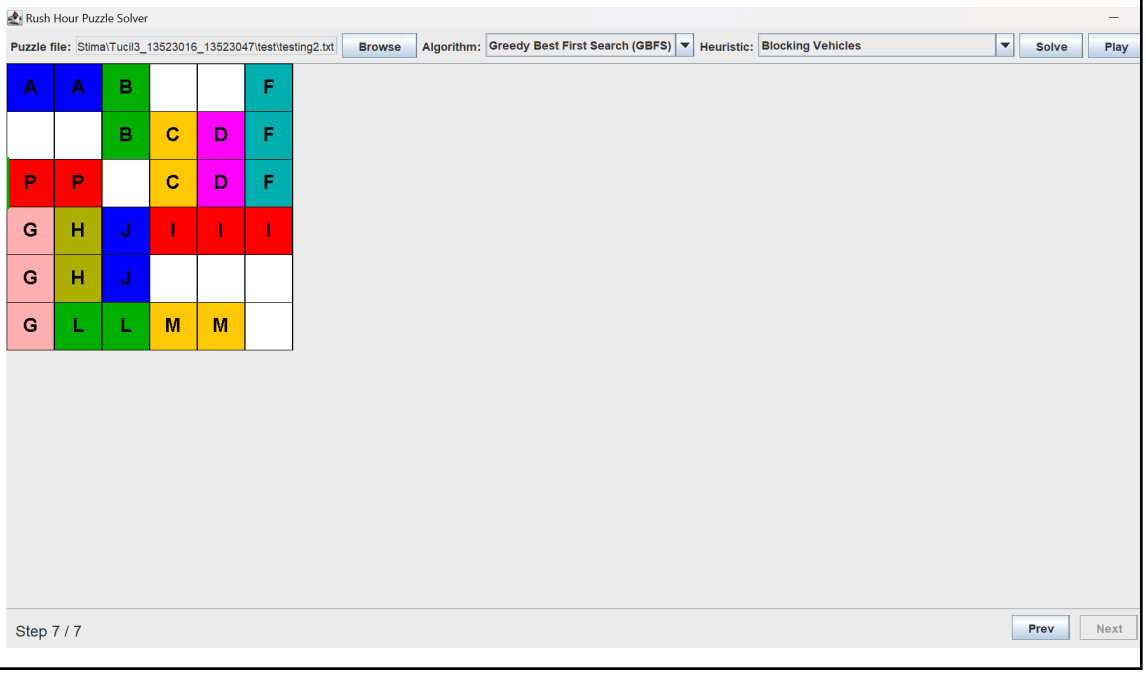


4.6. Test Case 2 - GBFS Heuristik Blocked Vehicles

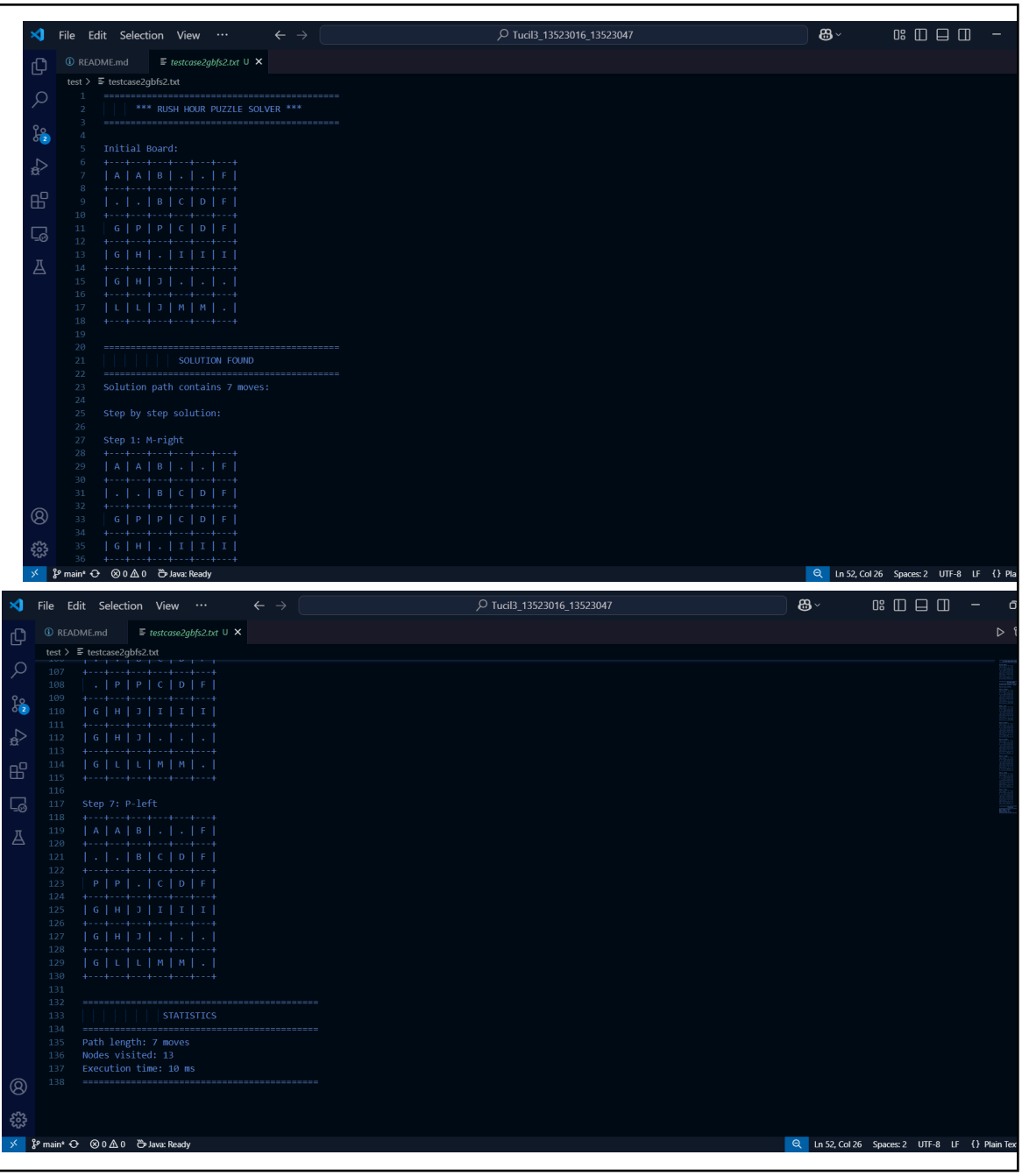
Input : test/testing2.txt
6 6 11 AAB..F ..BCDF KGPPCDF

GH.III
GHJ...
LLJMM.

Output GUI



Output Simpan di File



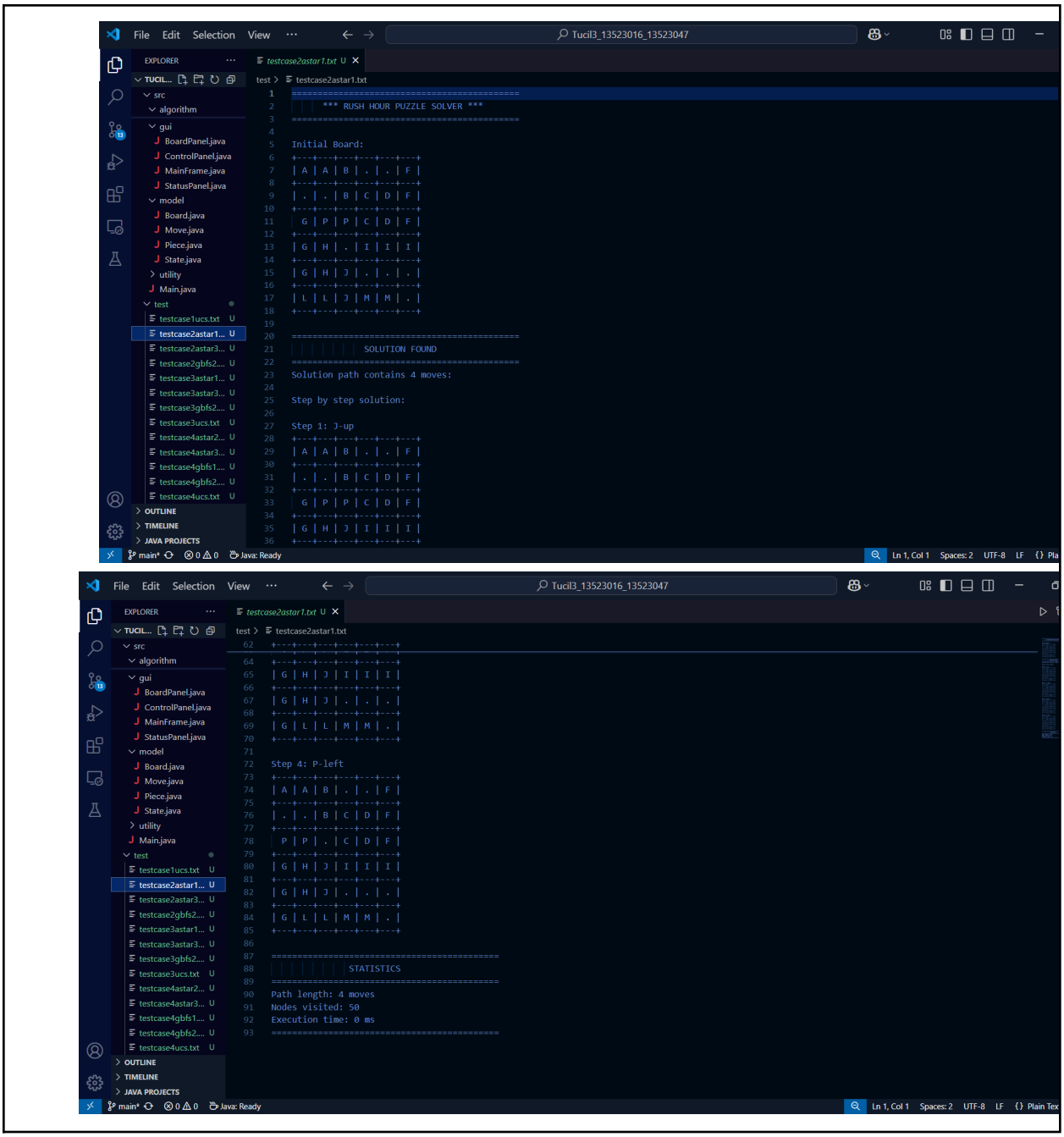
4.7. Test Case 2 - A* Heuristik Distance to Exit

Input : test/testing2.txt
6 6 11 AAB..F ..BCDF KGPPCDF

GH.III
GHJ...
LLJMM.

Output GUI

Output Simpan di File

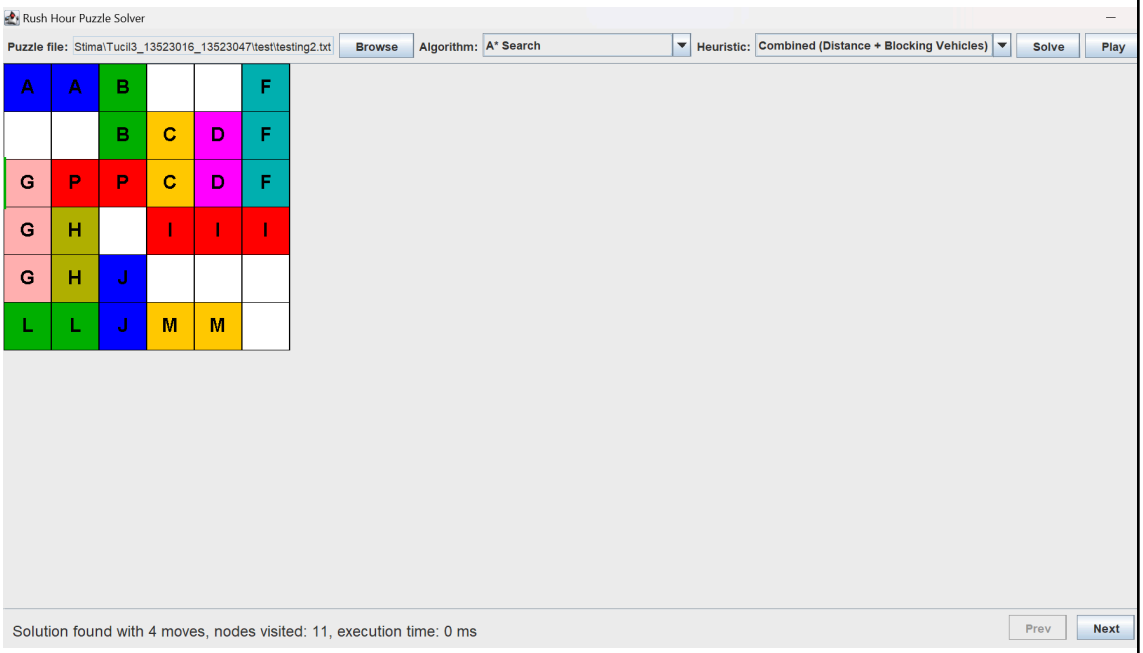


4.8. Test Case 2 - A* Heuristik Combined

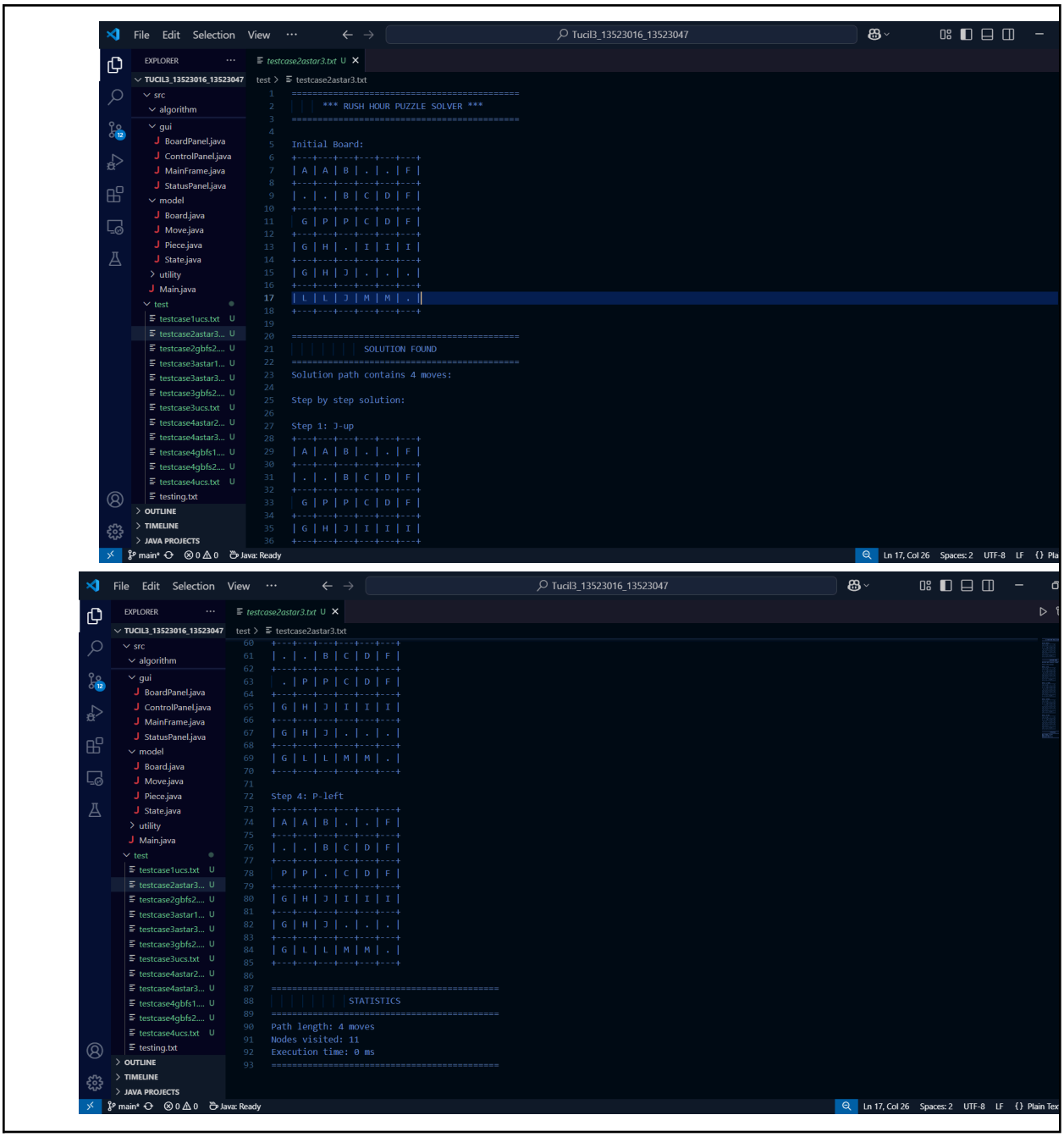
Input : test/testing2.txt
6 6 11 AAB..F ..BCDF KGPPCDF

GH.III
GHJ...
LLJMM.

Output GUI



Output Simpan di File

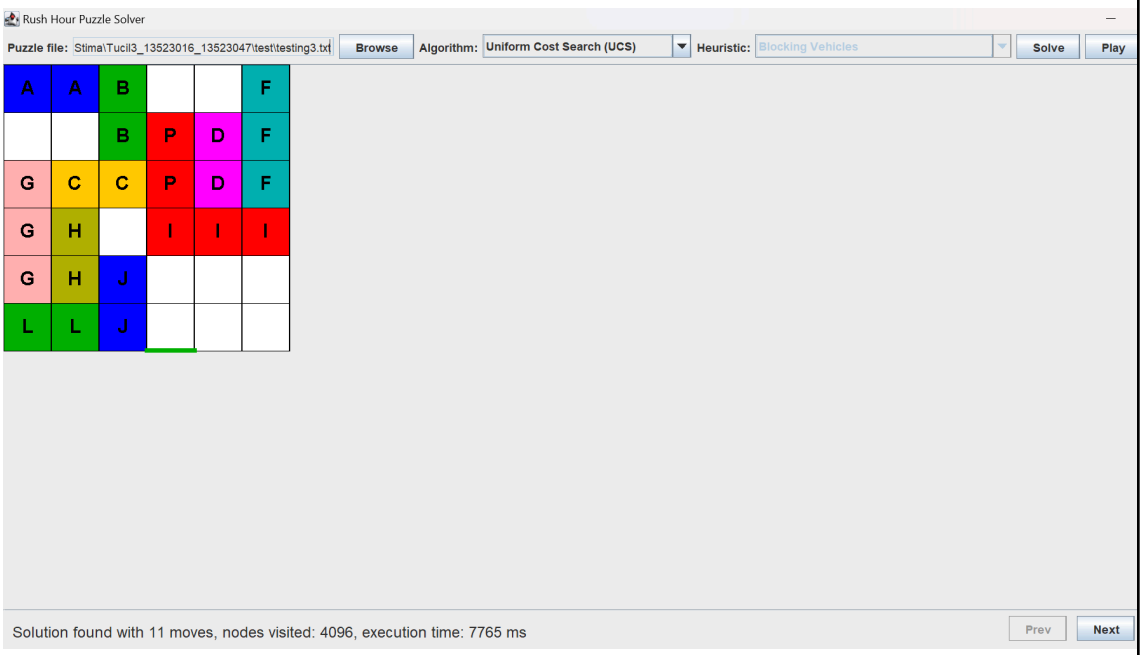


4.9. Test Case 3 - UCS

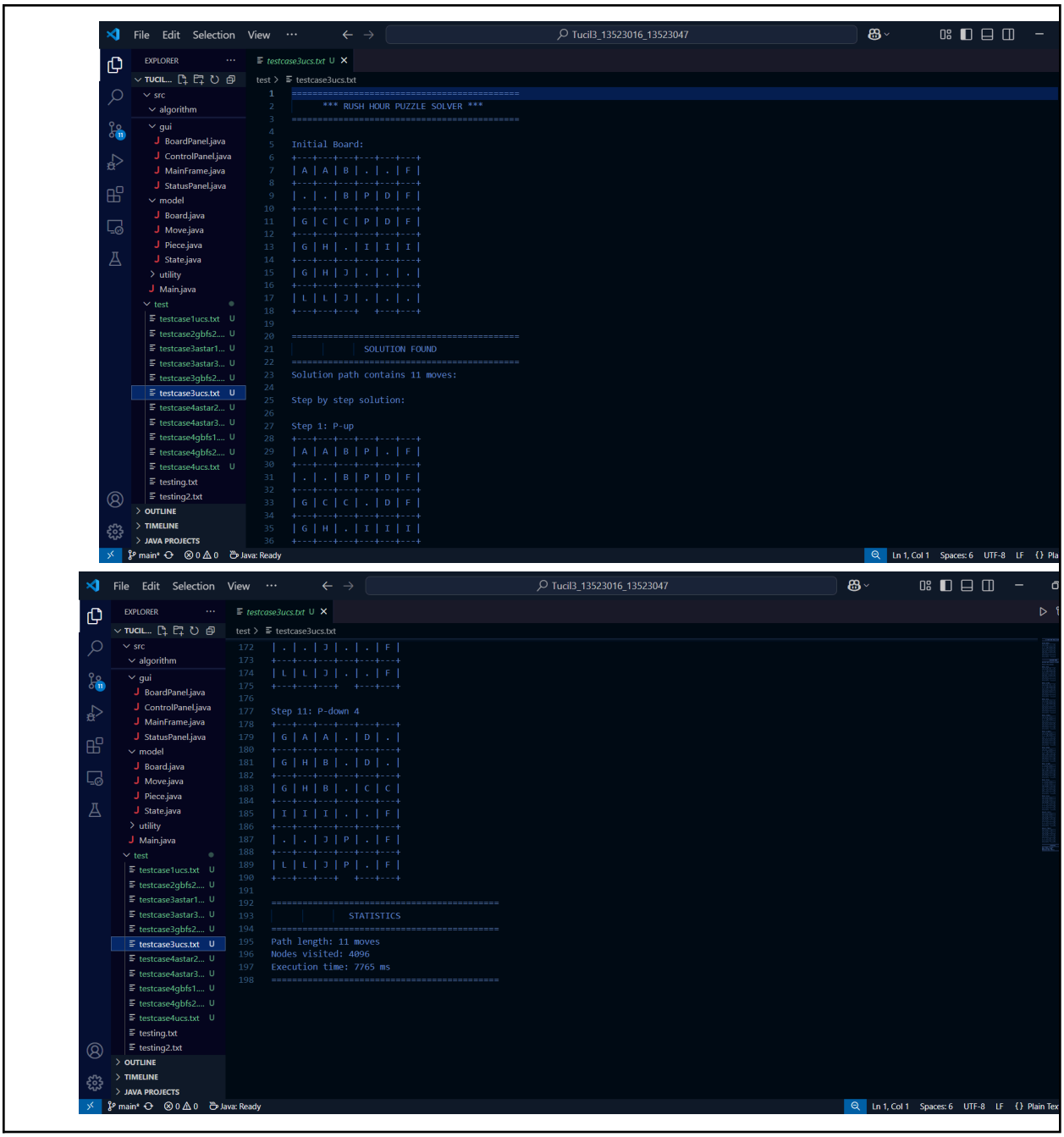
Input : test/testing3.txt
6 6 10 AAB..F ..BPDF GCCPDF

GH.III
GHJ...
LLJ...
  K

Output GUI



Output Simpan di File

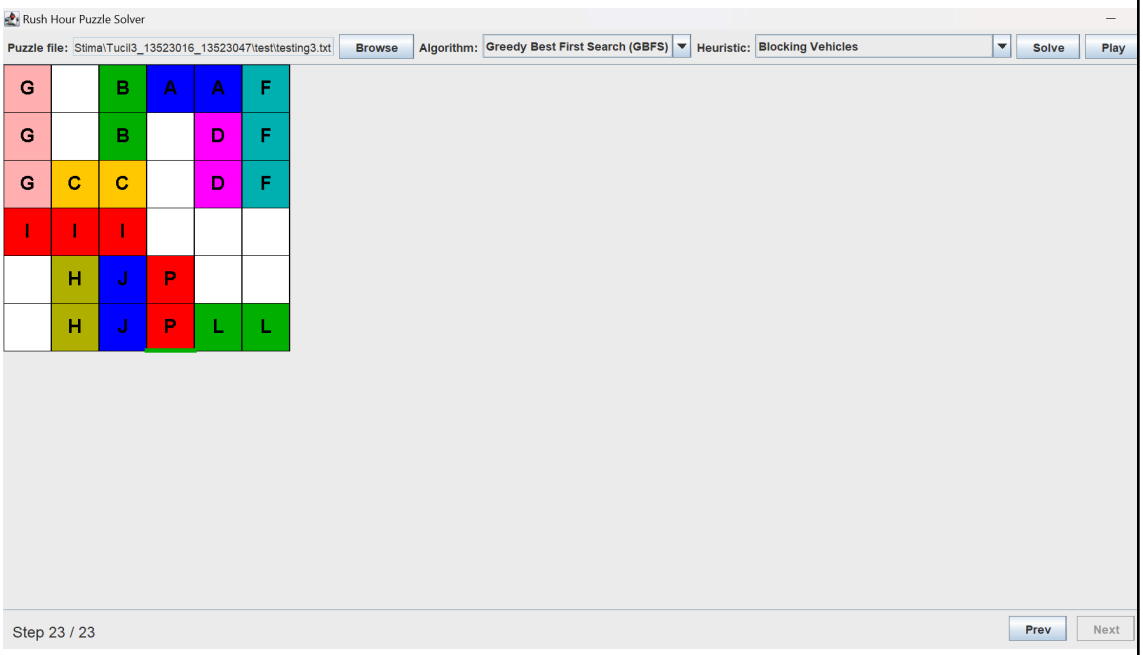


4.10. Test Case 3 - GBFS Heuristik Blocked Vehicles

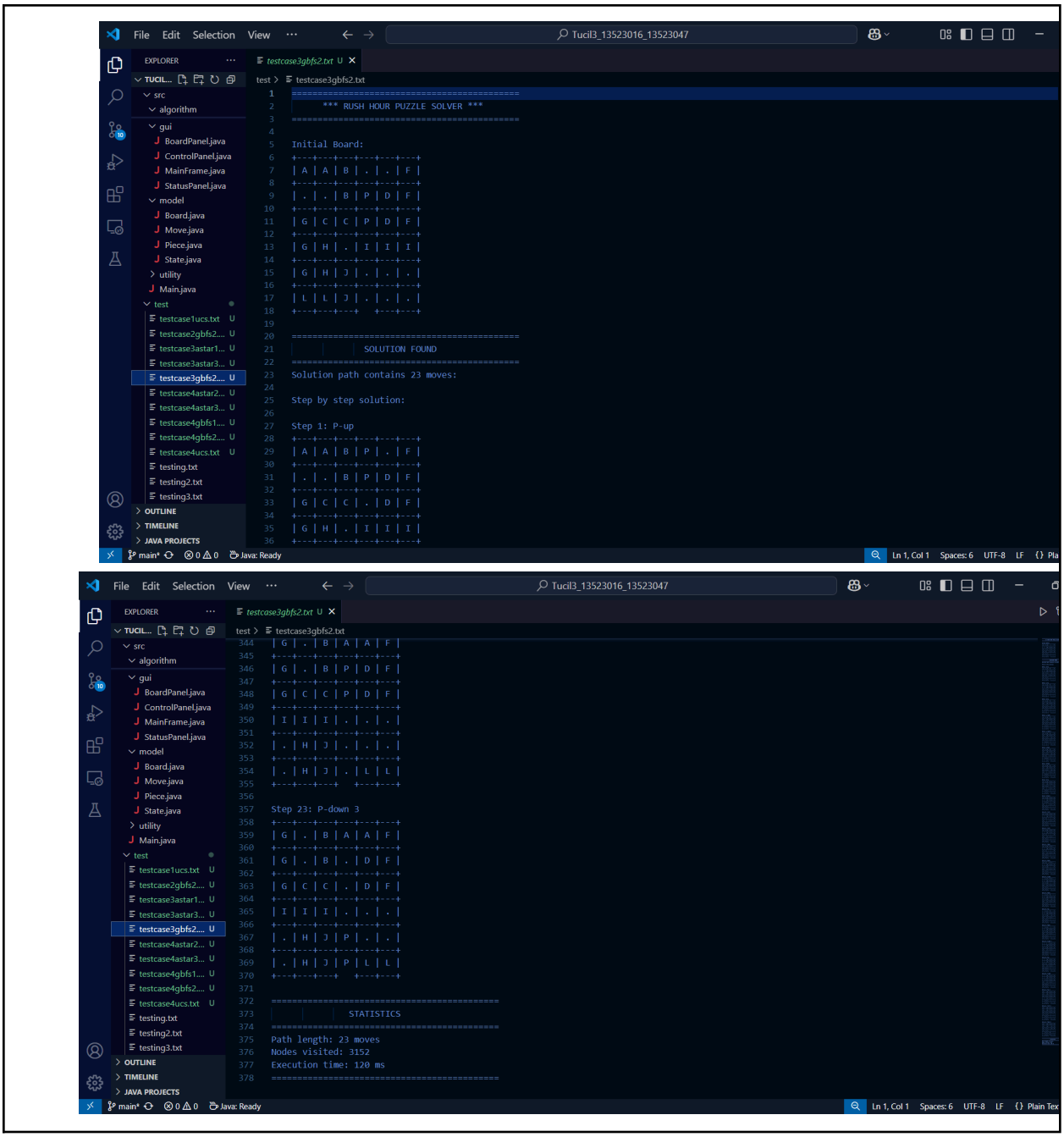
Input : test/testing3.txt
6 6 10 AAB..F ..BPDF GCCPDF

GH.III
GHJ...
LLJ...
  K

Output GUI



Output Simpan di File

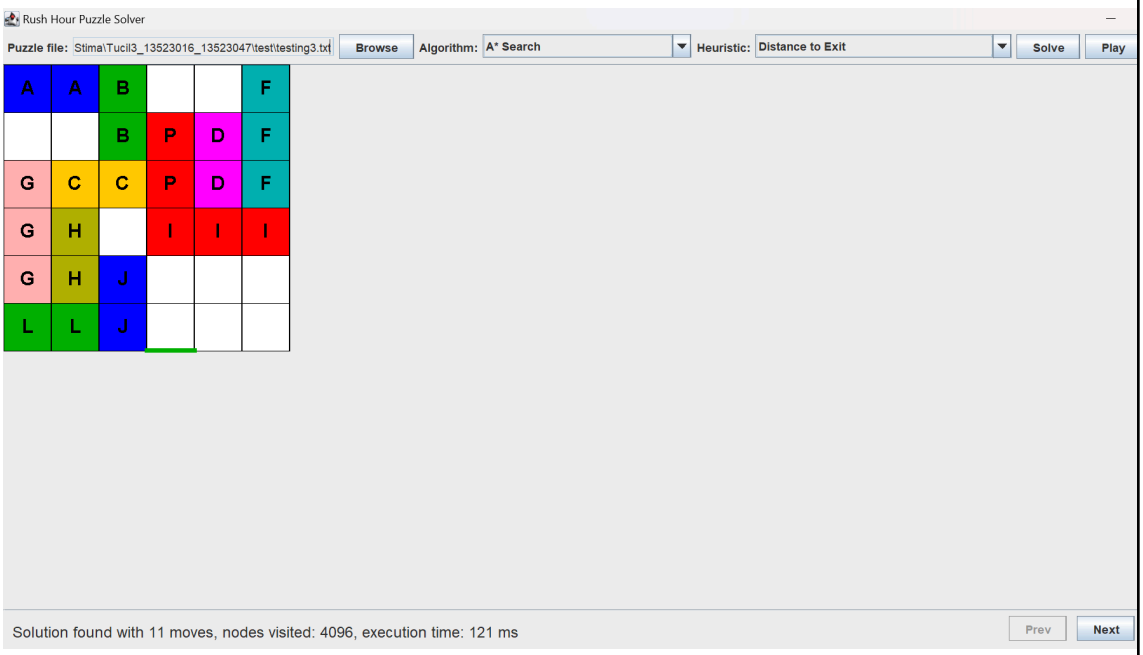


4.11. Test Case 3 - A* Heuristik Distance to Exit

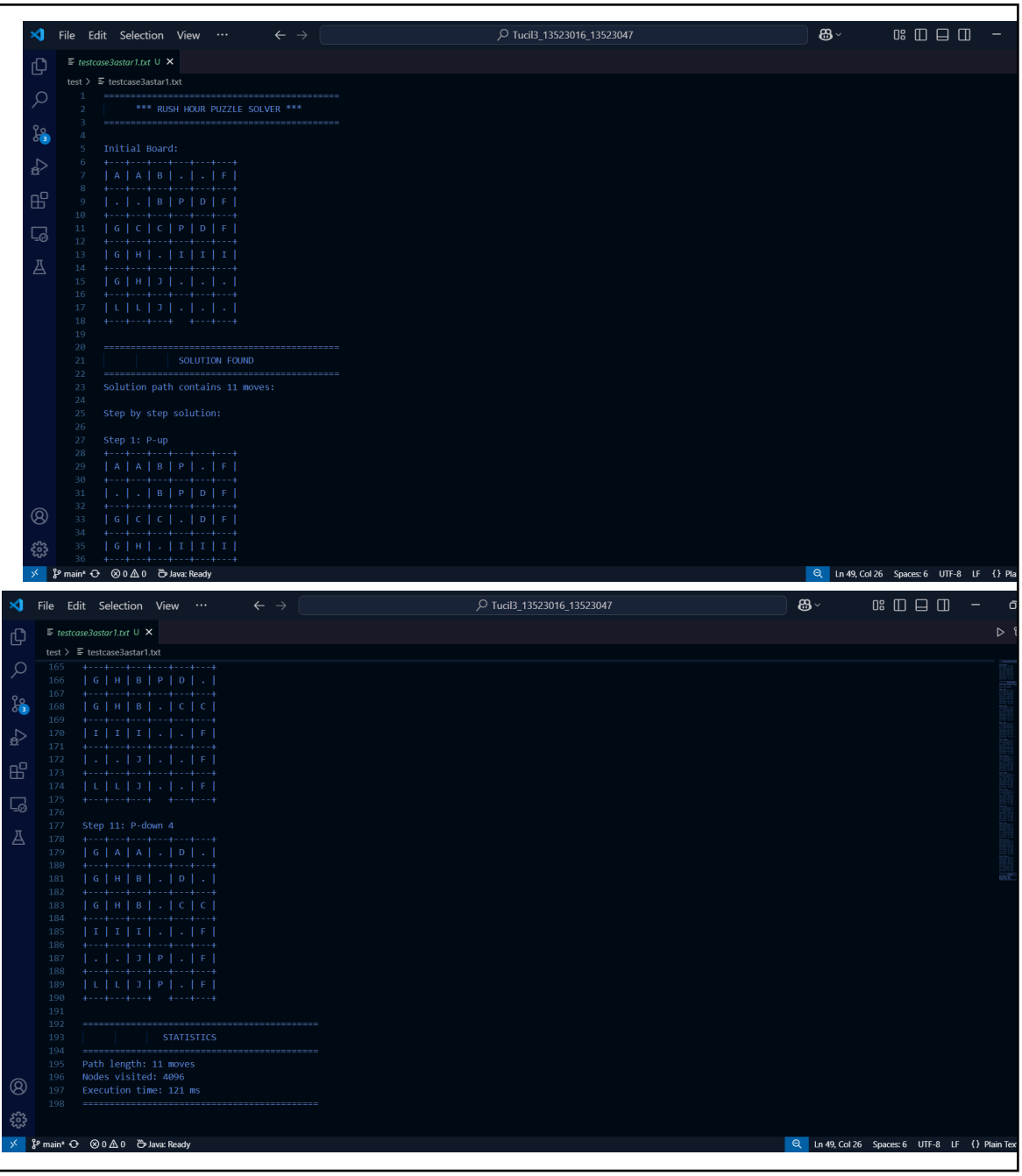
Input : test/testing3.txt
6 6 10 AAB..F ..BPDF GCCPDF

GH.III
GHJ...
LLJ...
  K

Output GUI



Output Simpan di File

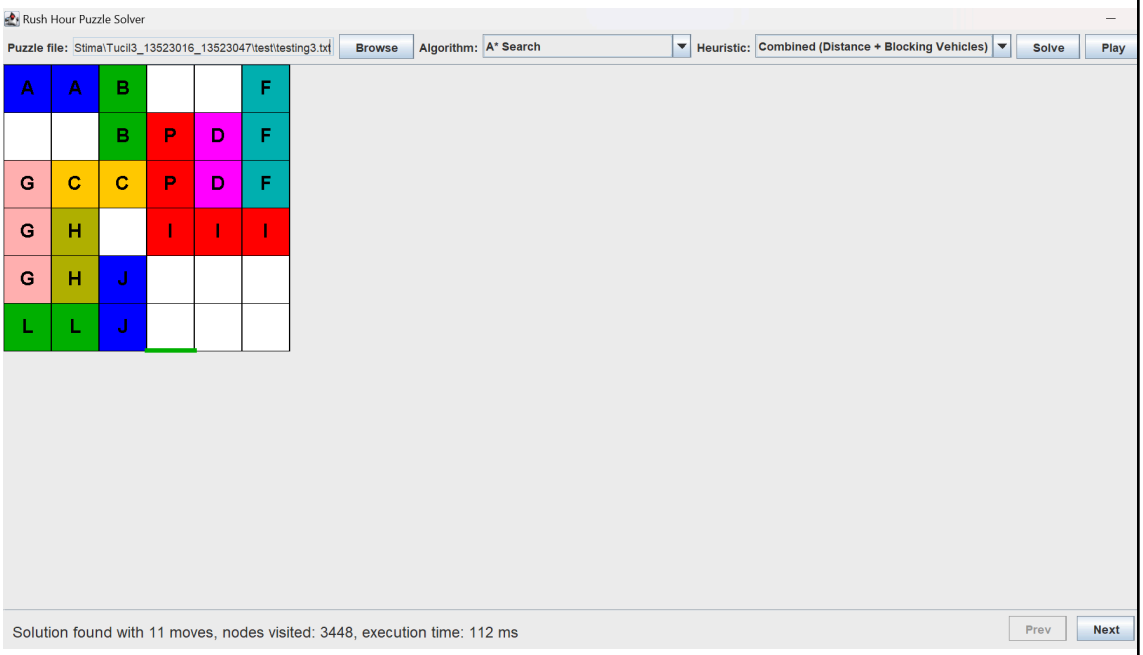


4.12. Test Case 3 - A* Heuristik Combined

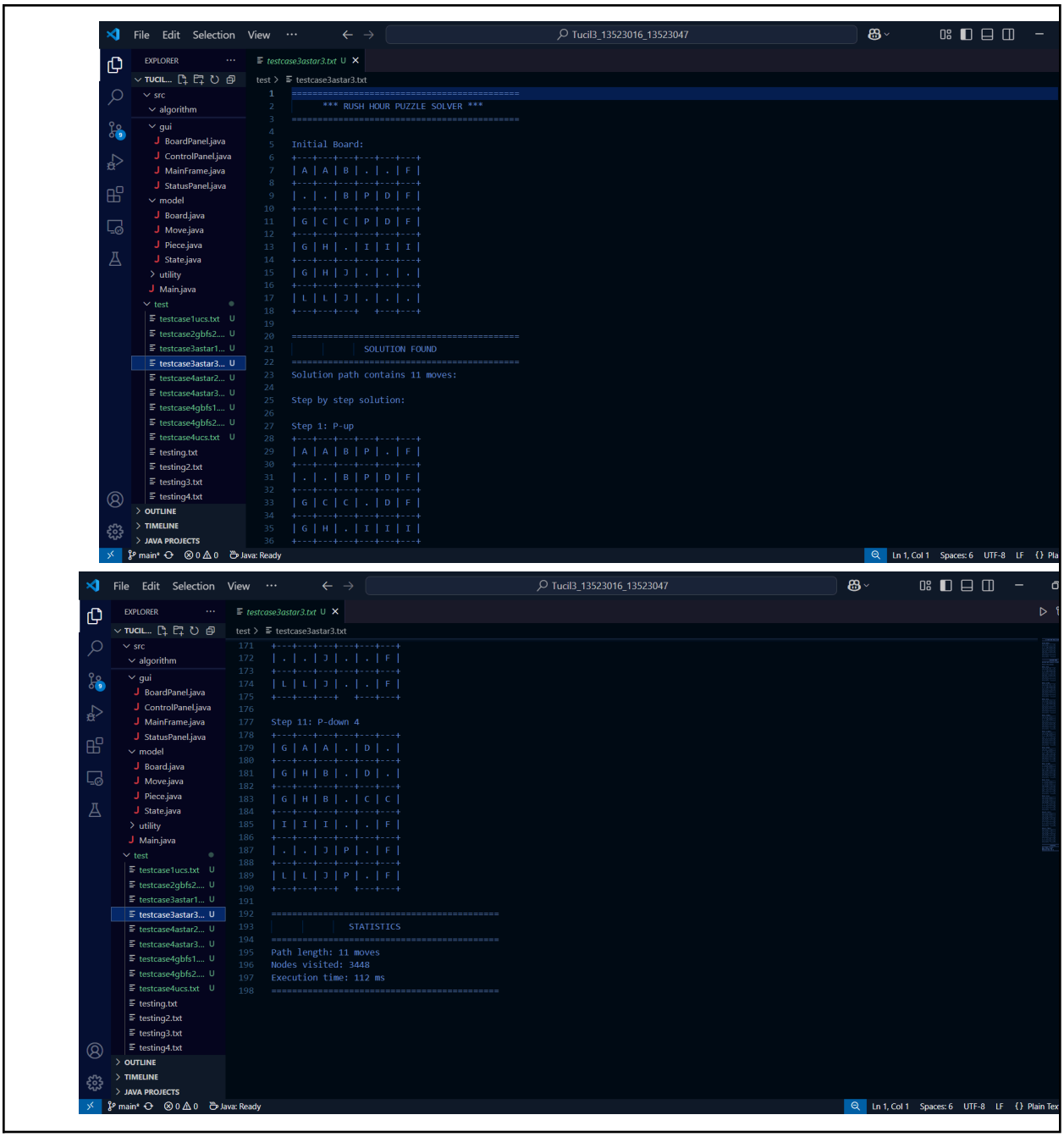
Input : test/testing3.txt
6 6 10 AAB..F ..BPDF GCCPDF

GH.III
GHJ...
LLJ...
  K

Output GUI



Output Simpan di File

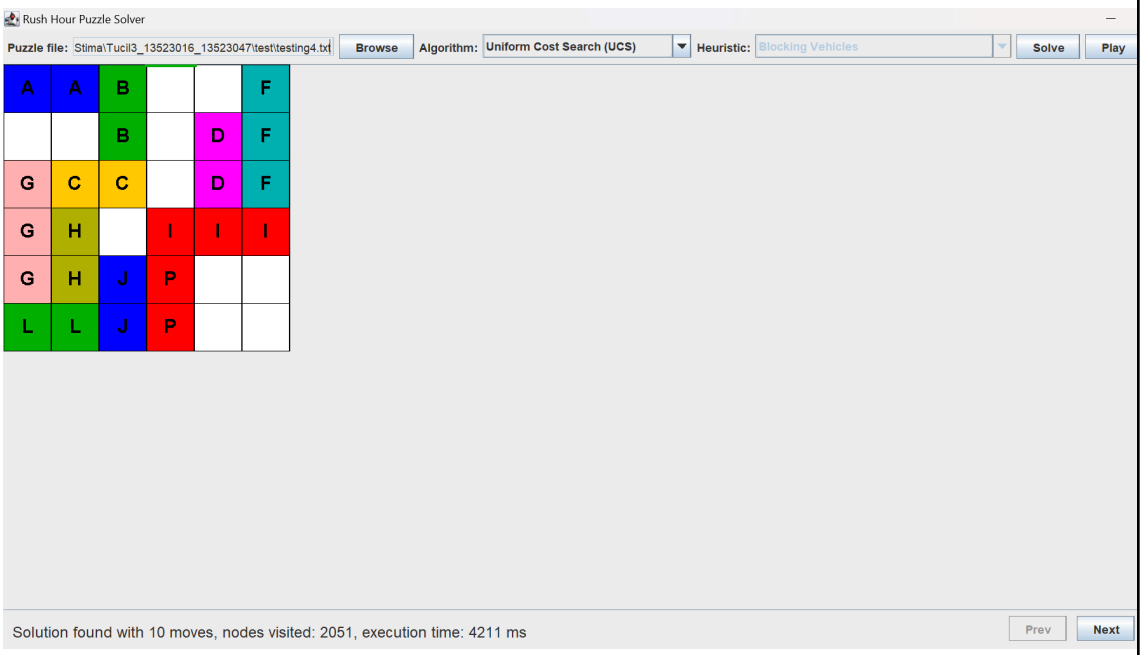


4.13. Test Case 4 - UCS

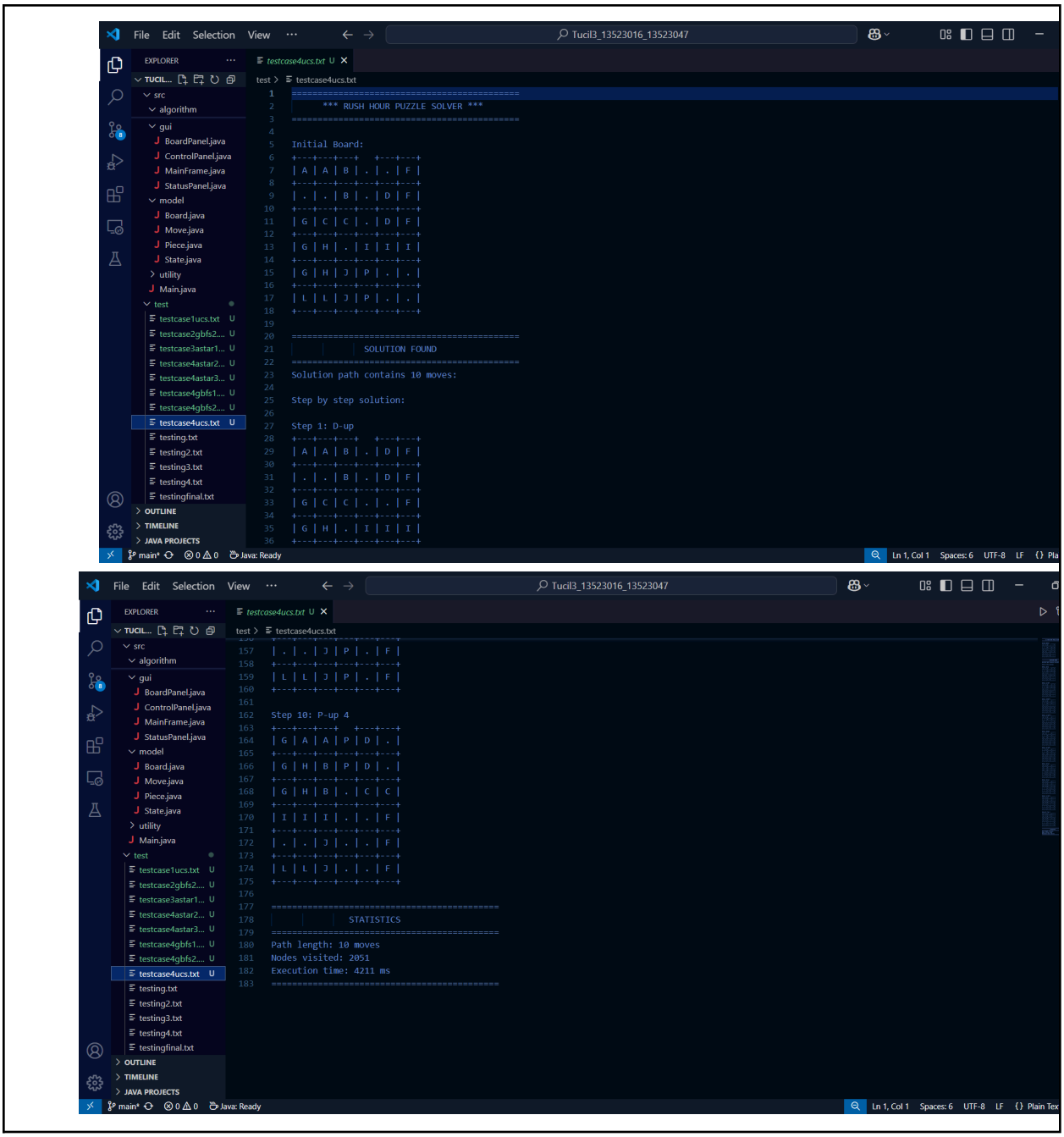
Input : test/testing4.txt
6 6 10 K AAB..F ..B.DF

GCC.DF
GH.III
GHJP..
LLJP..

Output GUI



Output Simpan di File

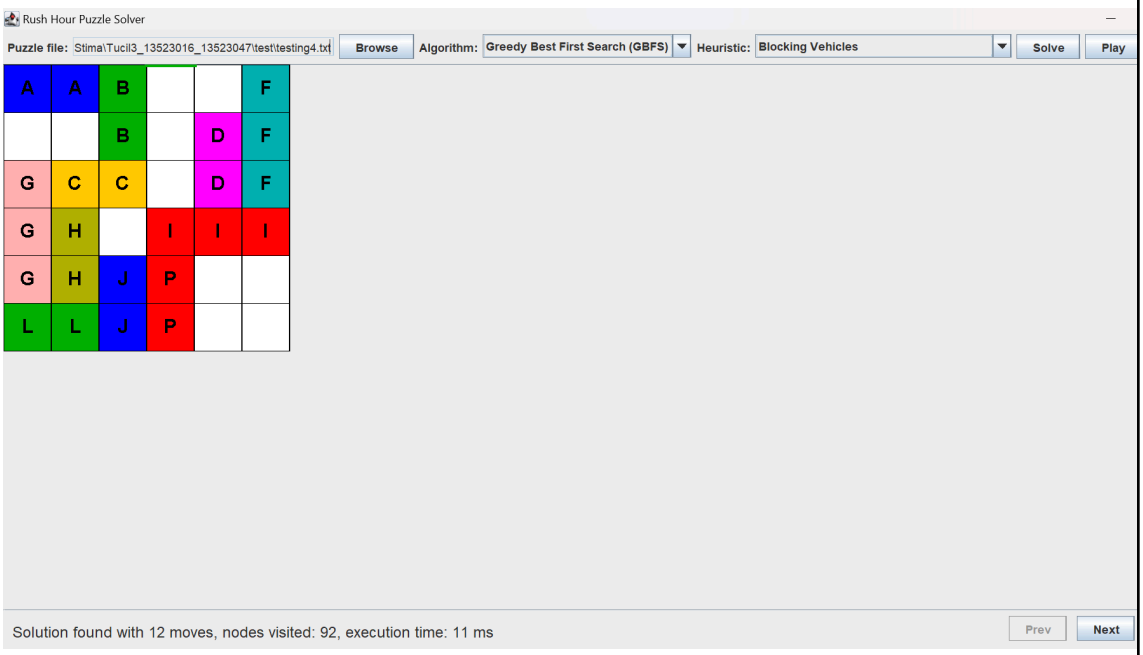


4.14. Test Case 4 - GBFS Heuristik Distance to Exit

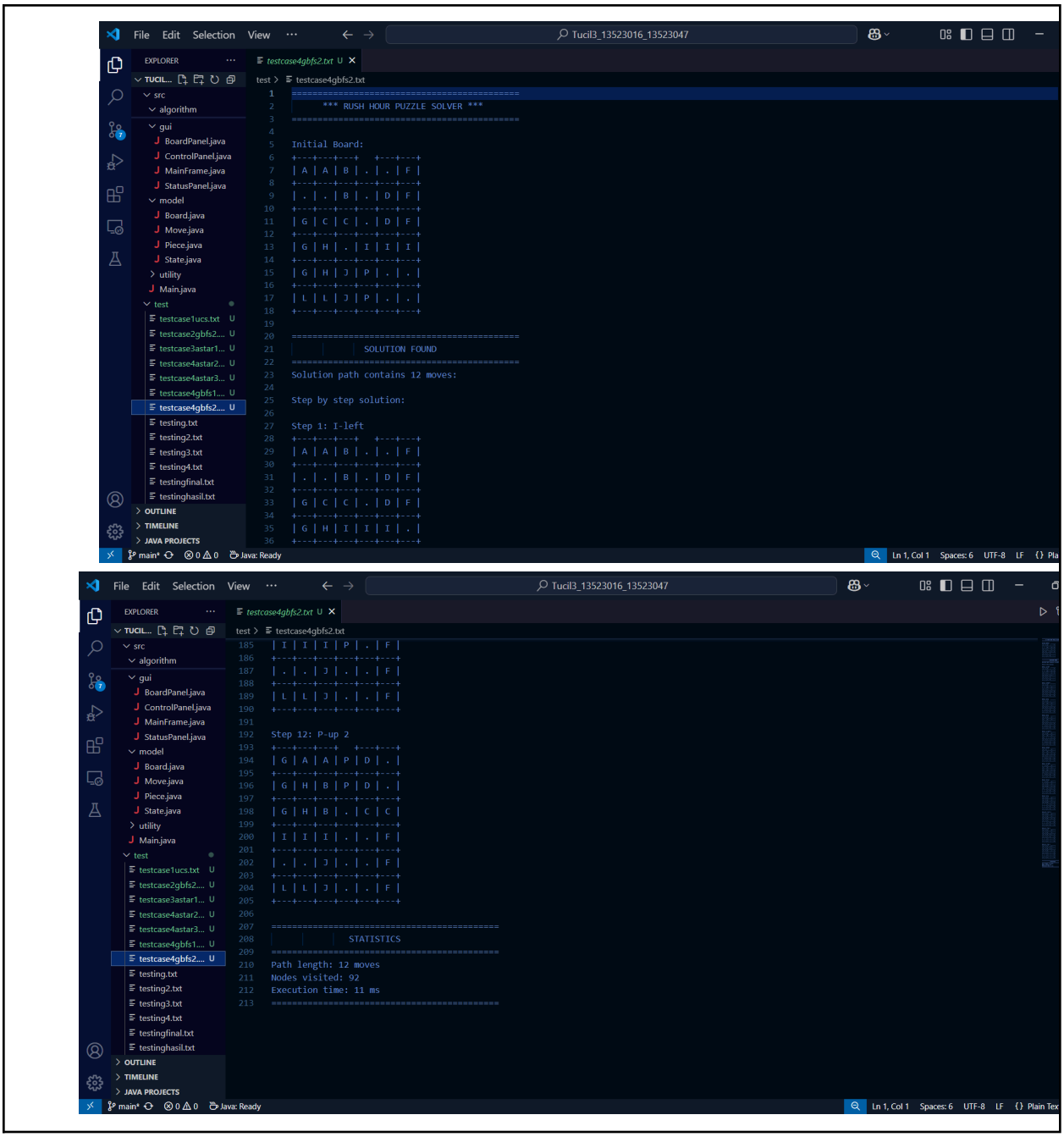
Input : test/testing4.txt
6 6 10 K AAB..F ..B.DF

GCC.DF
GH.III
GHJP..
LLJP..

Output GUI



Output Simpan di File

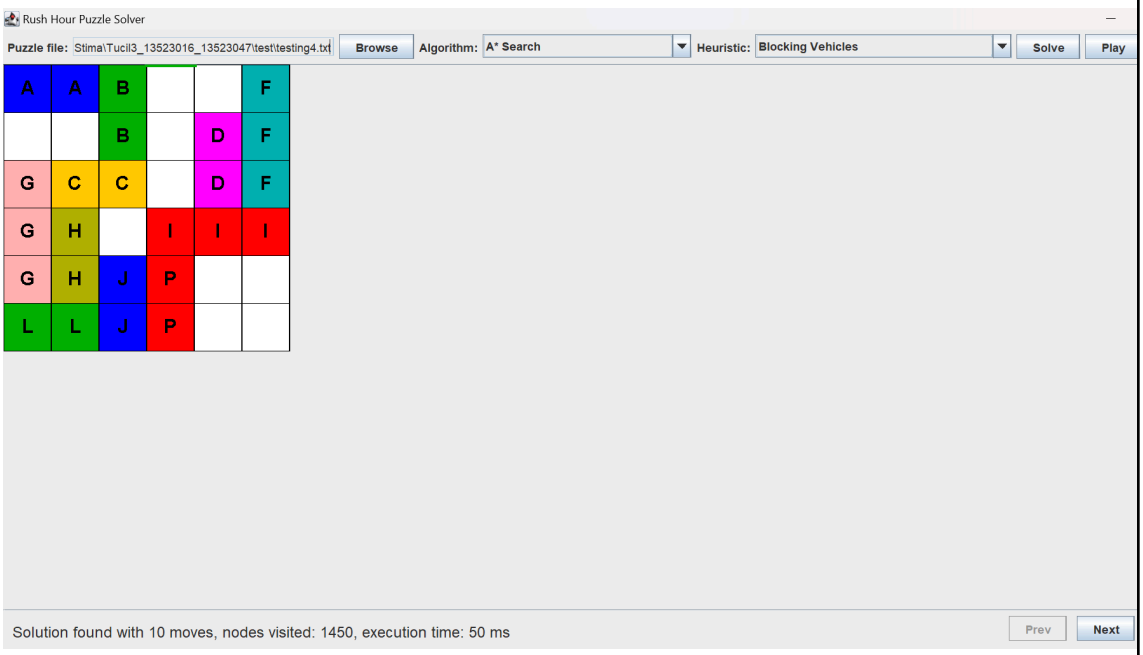


4.15. Test Case 4 - A* Heuristik Blocked Vehicles

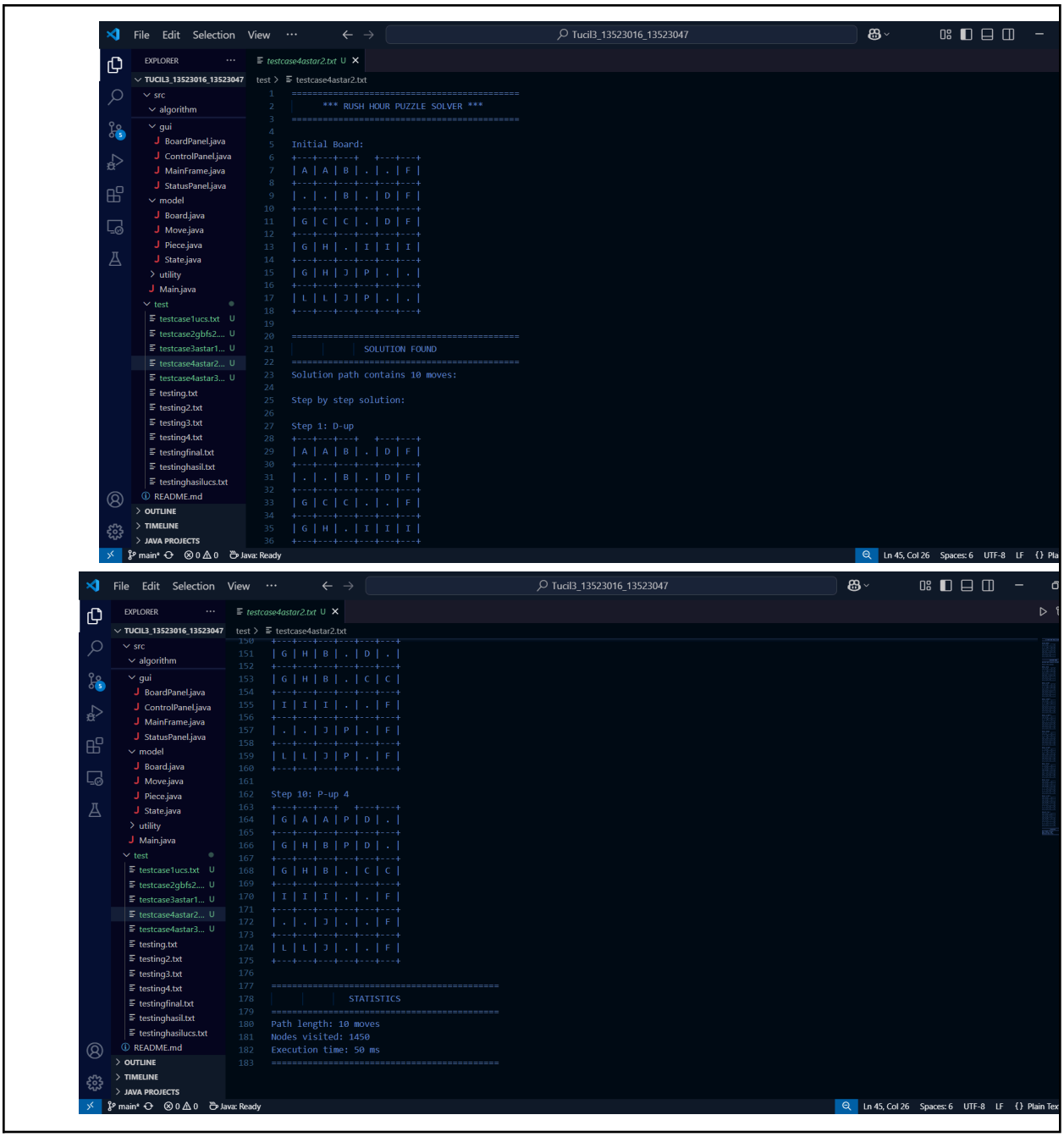
Input : test/testing4.txt
6 6 10   K AAB..F ..B.DF

GCC.DF
GH.III
GHJP..
LLJP..

Output GUI



Output Simpan di File

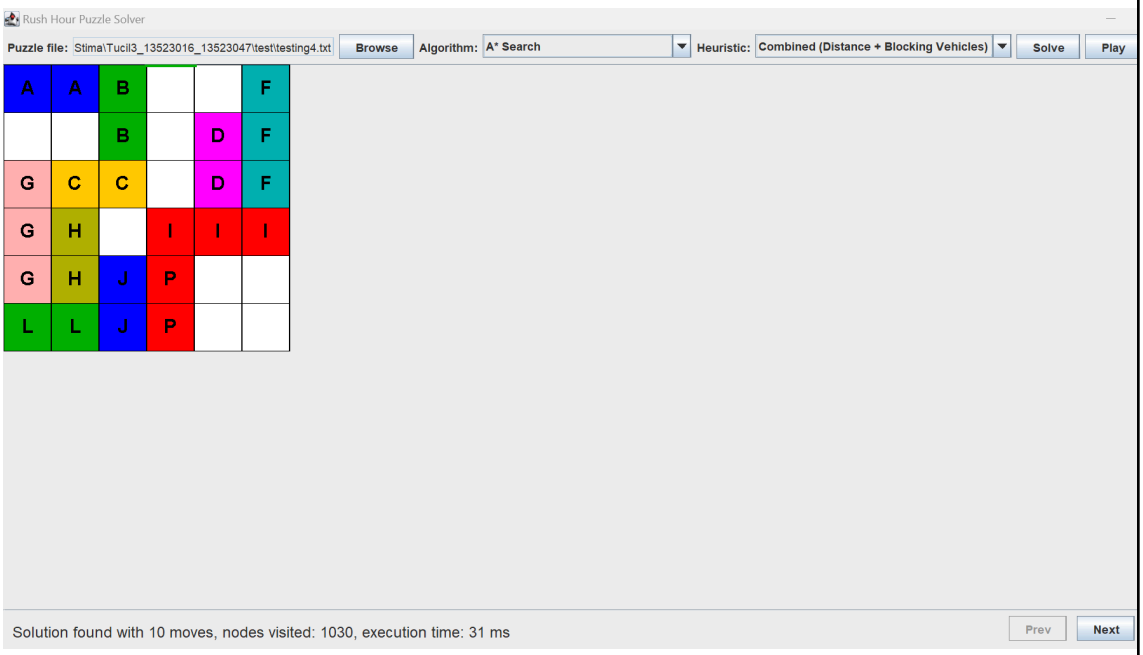


4.16. Test Case 4 - A* Heuristik Combined

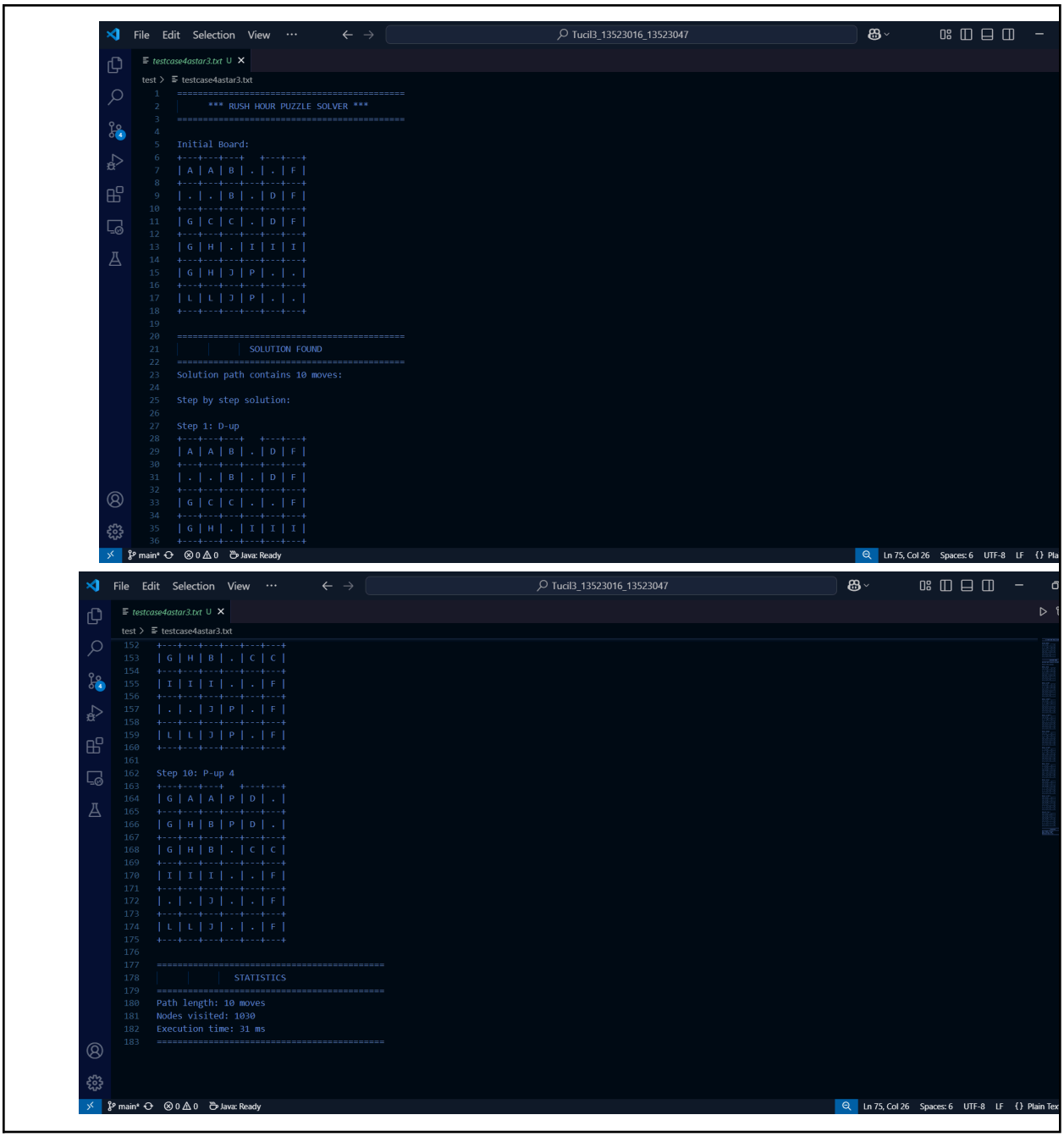
Input : test/testing4.txt
6 6 10   K AAB..F ..B.DF

GCC.DF
GH.III
GHJP..
LLJP..

Output GUI



Output Simpan di File



4.17. Analisis Percobaan Algoritma Pathfinding

Tiga algoritma pencarian yang dibandingkan adalah Uniform Cost Search (UCS), Greedy Best First Search (GBFS), dan A*. UCS memiliki keunggulan utama dalam selalu menemukan solusi yang optimal, yaitu dengan jumlah langkah minimum. Namun, kelemahannya terletak pada waktu eksekusi yang sangat lama serta jumlah node yang dikunjungi paling banyak, terutama pada test case yang kompleks. Di sisi lain, GBFS menunjukkan performa terbaik dalam hal kecepatan eksekusi dan jumlah node yang dikunjungi. Sayangnya, solusi yang dihasilkannya seringkali tidak optimal karena terlalu

mengandalkan estimasi heuristik tanpa mempertimbangkan jarak tempuh sebenarnya. A* hadir sebagai kompromi yang seimbang antara UCS dan GBFS. Algoritma ini mampu menemukan solusi optimal seperti UCS, namun dengan efisiensi waktu dan jumlah node yang jauh lebih baik. Meskipun tidak secepat GBFS, A* lebih andal dalam menghasilkan solusi yang optimal.

Tiga heuristik yang digunakan dalam eksperimen ini adalah Distance to Exit, Blocking Vehicles, dan Combined (Distance + Blocking Vehicles**)**. Heuristik Distance to Exit menunjukkan performa sedang dalam hal waktu eksekusi dan jumlah node yang dikunjungi. Ia cukup efektif untuk menyelesaikan puzzle sederhana, namun kurang mampu mengatasi kasus kompleks. Heuristik Blocking Vehicles memperlihatkan kinerja yang lebih baik dibanding Distance to Exit karena mampu mendeteksi kemacetan yang disebabkan oleh kendaraan penghalang. Heuristik gabungan (Combined) terbukti menjadi yang paling unggul. Ia secara konsisten menunjukkan performa terbaik, baik dari sisi waktu eksekusi maupun jumlah node yang dikunjungi. Bahkan pada algoritma GBFS yang biasanya menghasilkan solusi suboptimal, heuristik Combined mampu memberikan solusi yang lebih mendekati optimal dibandingkan dua heuristik lainnya.

Dalam hal efisiensi dan kualitas solusi, terdapat trade-off yang jelas antara ketiga algoritma. UCS, meskipun menjamin solusi optimal, memerlukan biaya komputasi tertinggi. Sebaliknya, GBFS sangat efisien secara waktu namun menghasilkan solusi dengan panjang langkah yang tidak optimal. A* menjadi pilihan terbaik di antara keduanya, karena ia mampu menemukan solusi optimal seperti UCS, tetapi dengan waktu eksekusi dan efisiensi yang jauh lebih baik. Penggunaan heuristik Combined pada A* semakin memperkuat performanya, menjadikannya metode paling seimbang dan efektif pada sebagian besar skenario yang diuji.

BAB V
KESIMPULAN DAN SARAN

5.1. Kesimpulan

Implementasi dan analisis algoritma Uniform Cost Search (UCS), Greedy Best First Search, dan A* dalam penyelesaian masalah Rush Hour menunjukkan perbedaan signifikan dalam hal efisiensi dan optimalisasi solusi. UCS yang hanya mempertimbangkan biaya jalur sejauh ini memberikan solusi optimal namun dengan eksplorasi simpul yang lebih banyak. Greedy Best First Search lebih cepat karena mengandalkan heuristik saja, tetapi tidak menjamin solusi optimal. Sementara itu, A* menggabungkan kelebihan kedua algoritma dengan memanfaatkan fungsi evaluasi f(n)=g(n)+h(n)f(n) = g(n) + h(n)f(n)=g(n)+h(n), sehingga dapat menemukan solusi optimal secara lebih efisien dengan bantuan heuristik admissible. Hasil ini menegaskan pentingnya pemilihan heuristik yang tepat untuk mempercepat pencarian tanpa mengorbankan kualitas solusi. Secara keseluruhan, A* menjadi pilihan terbaik dalam

menyelesaikan masalah pencarian jalur pada Rush Hour dengan keseimbangan antara kecepatan dan optimalitas.

5.2. Saran

Dalam pengembangan selanjutnya, program ini dapat ditingkatkan terutama pada heuristik yang dipakai dalam algoritma A* agar lebih akurat dan sesuai dengan karakteristik masalah Rush Hour, sehingga ruang pencarian bisa dipersempit dan efisiensi algoritma meningkat. Pengembangan tampilan program dalam bentuk antarmuka grafis (GUI) dapat mempermudah pengguna dalam mengoperasikan aplikasi serta memahami proses pencarian secara lebih intuitif. Selain itu, penambahan fitur visualisasi yang menampilkan jalur solusi dan proses pencarian secara interaktif akan sangat membantu dalam menganalisis hasil. Untuk mendukung keandalan program, pengujian lebih lanjut pada berbagai kondisi masalah dan skenario permainan juga perlu dilakukan agar performa algoritma tetap optimal di berbagai situasi.

Tautan repository Github : https://github.com/ClarissaNT44/Tucil3_13523016_13523047.git

DAFTAR PUSTAKA

[1]https://informatika.stei.itb.ac.id/~rinaldi.munir/Stmik/2024-2025/21-Route-Planning-(2025)-Bagian1.pdf

[2]https://informatika.stei.itb.ac.id/~rinaldi.munir/Stmik/2024-2025/22-Route-Planning-(2025)-Bagian2.pdf

LAMPIRAN

Poin	Ya	Tidak
1. Program berhasil dikompilasi tanpa kesalahan	✓	
2. Program berhasil dijalankan	✓	
3. Solusi yang diberikan program benar dan mematuhi aturan permainan	✓	
4. Program dapat membaca masukan berkas .txt dan menyimpan solusi berupa print board tahap per tahap dalam berkas .txt	✓	

5. [Bonus] Implementasi algoritma pathfinding alternatif		✓
6. [Bonus] Implementasi 2 atau lebih heuristik alternatif	✓	
7. [Bonus] Program memiliki GUI	✓	
8. Program dan laporan dibuat (kelompok) sendiri	✓	