Resolución

de problemas de búsqueda

Memoria de Prácticas de Inteligencia Artificial

Primera entrega

20 de febrero de 2013

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Resumen. Se desea obtener el menor numero de movimientos para que la pieza de un caballo de ajedrez se mueva por el tablero desde una casilla de inicio hasta una casilla de fin. El objetivo de esta práctica consiste en utilizar la inteligencia artificial para tratar de obtener una solución a este planteamiento, formulándolo como un problema de búsqueda. Para ello se implementarán distintos algoritmos de búsqueda (ciega e informada) de los cuales se evaluarán y se extraerán las conclusiones.

Índice

1. Resultados

En esta sección se hablará de los resultados obtenidos con el programa desarrollado en el cual están implementadas las siguientes estrategias

- Búsqueda ciega

    - Búsqueda en profundidad

    - Búsqueda en anchura

- Búsqueda informada

    - Algoritmo A*

en las cuales se ha implementado la búsqueda de la exploración de estados tanto en árbol como en grafo.

Debido a que el enunciado de la práctica solamente exige documentar uno de los métodos de búsqueda ciega se ha escogido mostrar los resultados obtenidos para la búsqueda en anchura debido a que la búsqueda en profundidad se limita en encontrar la solución de "casualidad".

1.1. Ejemplos de ejecución

En este apartado se muestra la traza completa para dos de las estrategias de búsqueda implementadas (búsqueda en anchura y A*), mostrando además, a la finalización de ambos, el camino obtenido. El tablero que se emplea es de tamaño 10x10 y se escoge como casilla de inicio la *(2, 2)* mientras que la posición *(4, 6)* es la casilla a la que se quiere llegar. En la figura 1 se puede ver esta situación, donde la casilla con el caballo es la de comienzo y la que tiene la bandera a cuadros es la de finalización.

Para recordar las heurísticas empleadas son las que aparecen en las ecuaciones 1, 2 y 3 donde *(x_i, y_i)* es la posición donde se encuentra el caballo y *(x_m, y_m)* es la casilla a la que se quiere llegar.

$$h_0(n) = 0 \tag{1}$$

$$h_1(n) = \lfloor \frac{|x_i - x_m| + |y_i - y_m|}{3} \rfloor \tag{2}$$

$$h_2(n) = \{ \begin{array}{cc} 0 & si \quad x_m = x_i \wedge y_m = y_i \\ max\left(\frac{||x_i - x_m|-1|}{2}, \frac{||y_i - y_m|-1|}{2}\right) & en\,otro\,caso \end{array} \tag{3}$$

1.1.1. Búsqueda empleando árboles

Búsqueda en anchura

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Empezando la busqueda. En anchura

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3) (7, 4) (7, 6) (6, 7) (4, 7) (3, 6) (3, 4)]

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Busqueda: Arbol

Estrategia: Anchura

Nodos generados: 227

Nodos expandidos: 34

Factor de ramificacion: 14.541607856750488

Profun: 2

Coste: 2

Solucion: (2,2) (3,4) (4,6)

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Algoritmo A* con la heurística $h_0(n)$ (ecuación 1)

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Empezando la busqueda. Con la heurística 0

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Fringe: [((2, 2), 0, 0)]

Node selected: ((2, 2), 0, 0) Path: [((2, 2), 0, 0)] Successors: [((0, 1), 1, 0) ((0, 3), 1, 0) ((1, 4), 1, 0) ((3, 4), 1, 0) ((4, 3), 1, 0) ((4, 1), 1, 0) ((3, 0), 1, 0) ((1, 0), 1, 0)]

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Fringe: [((1, 0), 1, 0) ((3, 0), 1, 0) ((4, 1), 1, 0) ((4, 3), 1, 0) ((3, 4), 1, 0) ((1, 4), 1, 0) ((0, 3), 1, 0) ((0, 1), 1, 0)]

Node selected: ((1, 0), 1, 0) Path: [((2, 2), 0, 0) ((1, 0), 1, 0)] Successors: [((0, 2), 2, 0) ((2, 2), 2, 0) ((3, 1), 2, 0)]

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Fringe: [((3, 0), 1, 0) ((4, 1), 1, 0) ((4, 3), 1, 0) ((3, 4), 1, 0) ((1, 4), 1, 0) ((0, 3), 1, 0) ((0, 1), 1, 0) ((3, 1), 2, 0) ((2, 2), 2, 0) ((0, 2), 2, 0)]

Node selected: ((3, 0), 1, 0) Path: [((2, 2), 0, 0) ((3, 0), 1, 0)] Successors: [((1, 1), 2, 0) ((2, 2), 2, 0) ((4, 2), 2, 0) ((5, 1), 2, 0)]

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Fringe: [((4, 1), 1, 0) ((4, 3), 1, 0) ((3, 4), 1, 0) ((1, 4), 1, 0) ((0, 3), 1, 0) ((0, 1), 1, 0) ((3, 1), 2, 0) ((2, 2), 2, 0) ((0, 2), 2, 0) ((5, 1), 2, 0) ((4, 2), 2, 0) ((2, 2), 2, 0) ((1, 1), 2, 0)]

Node selected: ((4, 1), 1, 0) Path: [((2, 2), 0, 0) ((4, 1), 1, 0)] Successors: [((2, 0), 2, 0) ((2, 2), 2, 0) ((3, 3), 2, 0) ((5, 3), 2, 0) ((6, 2), 2, 0) ((6, 0), 2, 0)]

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Fringe: [((4, 3), 1, 0) ((3, 4), 1, 0) ((1, 4), 1, 0) ((0, 3), 1, 0) ((0, 1), 1, 0) ((3, 1), 2, 0) ((2, 2), 2, 0) ((0, 2), 2, 0) ((5, 1), 2, 0) ((4, 2), 2, 0) ((2, 2), 2, 0) ((1, 1), 2, 0) ((6, 0), 2, 0) ((6, 2), 2, 0) ((5, 3), 2, 0) ((3, 3), 2, 0) ((2, 2), 2, 0) ((2, 0), 2, 0)]

Node selected: ((4, 3), 1, 0) Path: [((2, 2), 0, 0) ((4, 3), 1, 0)] Successors: [((2, 2), 2, 0) ((2, 4), 2, 0) ((3, 5), 2, 0) ((5, 5), 2, 0) ((6, 4), 2, 0) ((6, 2), 2, 0) ((5, 1), 2, 0) ((3, 1), 2, 0)]

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Node selected: ((3, 4), 1, 0) Path: [((2, 2), 0, 0) ((3, 4), 1, 0)] Successors: [((1, 3), 2, 0) ((1, 5), 2, 0) ((2, 6), 2, 0) ((4, 6), 2, 0) ((5, 5), 2, 0) ((5, 3), 2, 0) ((4, 2), 2, 0) ((2, 2), 2, 0)]

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Fringe: [((1, 4), 1, 0) ((0, 3), 1, 0) ((0, 1), 1, 0) ((3, 1), 2, 0) ((2, 2), 2, 0) ((0, 2), 2, 0) ((5, 1), 2, 0) ((4, 2), 2, 0) ((2, 2), 2, 0) ((1, 1), 2, 0) ((6, 0), 2, 0) ((6, 2), 2, 0) ((5, 3), 2, 0) ((3, 3), 2, 0) ((2, 2), 2, 0) ((2, 0), 2, 0) ((3, 1), 2, 0) ((5, 1), 2, 0) ((6, 2), 2, 0) ((6, 4), 2, 0) ((5, 5), 2, 0) ((3, 5), 2, 0) ((2, 4), 2, 0) ((2, 2), 2, 0) ((2, 2), 2, 0) ((4, 2), 2, 0) ((5, 3), 2, 0) ((5, 5), 2, 0) ((4, 6), 2, 0) ((2, 6), 2, 0) ((1, 5), 2, 0) ((1, 3), 2, 0)]

Node selected: ((1, 4), 1, 0) Path: [((2, 2), 0, 0) ((1, 4), 1, 0)] Successors: [((0, 6), 2, 0) ((2, 6), 2, 0) ((3, 5), 2, 0) ((3, 3), 2, 0) ((2, 2), 2, 0) ((0, 2), 2, 0)]

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Fringe: [((0, 3), 1, 0) ((0, 1), 1, 0) ((3, 1), 2, 0) ((2, 2), 2, 0) ((0, 2), 2, 0) ((5, 1), 2, 0) ((4, 2), 2, 0) ((2, 2), 2, 0) ((1, 1), 2, 0) ((6, 0), 2, 0) ((6, 2), 2, 0) ((5, 3), 2, 0) ((3, 3), 2, 0) ((2, 2), 2, 0) ((2, 0), 2, 0) ((3, 1), 2, 0) ((5, 1), 2, 0) ((6, 2), 2, 0) ((6, 4), 2, 0) ((5, 5), 2, 0) ((3, 5), 2, 0) ((2, 4), 2, 0) ((2, 2), 2, 0) ((2, 2), 2, 0) ((4, 2), 2, 0) ((5, 3), 2, 0) ((5, 5), 2, 0) ((4, 6), 2, 0) ((2, 6), 2, 0) ((1, 5), 2, 0) ((1, 3), 2, 0) ((0, 2), 2, 0) ((2, 2), 2, 0) ((3, 3), 2, 0) ((3, 5), 2, 0) ((2, 6), 2, 0) ((0, 6), 2, 0)]

Node selected: ((0, 3), 1, 0) Path: [((2, 2), 0, 0) ((0, 3), 1, 0)] Successors: [((1, 5), 2, 0) ((2, 4), 2, 0) ((2, 2), 2, 0) ((1, 1), 2, 0)]

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Node selected: ((5, 1), 2, 0) Path: [((2, 2), 0, 0) ((3, 0), 1, 0) ((5, 1), 2, 0)] Successors: [((3, 0), 3, 0) ((3, 2), 3, 0) ((4, 3), 3, 0) ((6, 3), 3, 0) ((7, 2), 3, 0) ((7, 0), 3, 0)]

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Node selected: ((5, 3), 2, 0) Path: [((2, 2), 0, 0) ((3, 4), 1, 0) ((5, 3), 2, 0)] Successors: [((3, 2), 3, 0) ((3, 4), 3, 0) ((4, 5), 3, 0) ((6, 5), 3, 0) ((7, 4), 3, 0) ((7, 2), 3, 0) ((6, 1), 3, 0) ((4, 1), 3, 0)]

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Node selected: ((5, 5), 2, 0) Path: [((2, 2), 0, 0) ((3, 4), 1, 0) ((5, 5), 2, 0)] Successors:

[((3, 4), 3, 0) ((3, 6), 3, 0) ((4, 7), 3, 0) ((6, 7), 3, 0) ((7, 6), 3, 0) ((7, 4), 3, 0) ((6, 3), 3, 0) ((4, 3), 3, 0)]

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Fringe: [((4, 6), 2, 0) ((2, 6), 2, 0) ((1, 5), 2, 0) ((1, 3), 2, 0) ((0, 2), 2, 0) ((2, 2), 2, 0) ((3, 3), 2, 0) ((3, 5), 2, 0) ((2, 6), 2, 0) ((0, 6), 2, 0) ((1, 1), 2, 0) ((2, 2), 2, 0) ((2, 4), 2, 0) ((1, 5), 2, 0) ((2, 0), 2, 0) ((2, 2), 2, 0) ((1, 3), 2, 0) ((5, 0), 3, 0) ((5, 2), 3, 0) ((4, 3), 3, 0) ((2, 3), 3, 0) ((1, 2), 3, 0) ((1, 0), 3, 0) ((1, 0), 3, 0) ((3, 0), 3, 0) ((4, 1), 3, 0) ((4, 3), 3, 0) ((3, 4), 3, 0) ((1, 4), 3, 0) ((0, 3), 3, 0) ((0, 1), 3, 0) ((1, 0), 3, 0) ((2, 1), 3, 0) ((2, 3), 3, 0) ((1, 4), 3, 0) ((7, 0), 3, 0) ((7, 2), 3, 0) ((6, 3), 3, 0) ((4, 3), 3, 0) ((3, 2), 3, 0) ((3, 0), 3, 0) ((3, 0), 3, 0) ((5, 0), 3, 0) ((6, 1), 3, 0) ((6, 3), 3, 0) ((5, 4), 3, 0) ((3, 4), 3, 0) ((2, 3), 3, 0) ((2, 1), 3, 0) ((1, 0), 3, 0) ((3, 0), 3, 0) ((4, 1), 3, 0) ((4, 3), 3, 0) ((3, 4), 3, 0) ((1, 4), 3, 0) ((0, 3), 3, 0) ((0, 1), 3, 0) ((3, 0), 3, 0) ((3, 2), 3, 0) ((2, 3), 3, 0) ((0, 3), 3, 0) ((8, 1), 3, 0) ((7, 2), 3, 0) ((5, 2), 3, 0) ((4, 1), 3, 0) ((5, 0), 3, 0) ((7, 0), 3, 0) ((8, 1), 3, 0) ((8, 3), 3, 0) ((7, 4), 3, 0) ((5, 4), 3, 0) ((4, 3), 3, 0) ((4, 1), 3, 0) ((4, 1), 3, 0) ((6, 1), 3, 0) ((7, 2), 3, 0) ((7, 4), 3, 0) ((6, 5), 3, 0) ((4, 5), 3, 0) ((3, 4), 3, 0) ((3, 2), 3, 0) ((2, 1), 3, 0) ((4, 1), 3, 0) ((5, 2), 3, 0) ((5, 4), 3, 0) ((4, 5), 3, 0) ((2, 5), 3, 0) ((1, 4), 3, 0) ((1, 2), 3, 0) ((1, 0), 3, 0) ((3, 0), 3, 0) ((4, 1), 3, 0) ((4, 3), 3, 0) ((3, 4), 3, 0) ((1, 4), 3, 0) ((0, 3), 3, 0) ((0, 1), 3, 0) ((4, 1), 3, 0) ((3, 2), 3, 0) ((1, 2), 3, 0) ((0, 1), 3, 0) ((5, 0), 3, 0) ((5, 2), 3, 0) ((4, 3), 3, 0) ((2, 3), 3, 0) ((1, 2), 3, 0) ((1, 0), 3, 0) ((7, 0), 3, 0) ((7, 2), 3, 0) ((6, 3), 3, 0) ((4, 3), 3, 0) ((3, 2), 3, 0) ((3, 0), 3, 0) ((5, 0), 3, 0) ((7, 0), 3, 0) ((8, 1), 3, 0) ((8, 3), 3, 0) ((7, 4), 3, 0) ((5, 4), 3, 0) ((4, 3), 3, 0) ((4, 1), 3, 0) ((5, 2), 3, 0) ((7, 2), 3, 0) ((8, 3), 3, 0) ((8, 5), 3, 0) ((7, 6), 3, 0) ((5, 6), 3, 0) ((4, 5), 3, 0) ((4, 3), 3, 0) ((4, 3), 3, 0) ((6, 3), 3, 0) ((7, 4), 3, 0) ((7, 6), 3, 0) ((6, 7), 3, 0) ((4, 7), 3, 0) ((3, 6), 3, 0) ((3, 4), 3, 0) ((2, 3), 3, 0) ((4, 3), 3, 0) ((5, 4), 3, 0) ((5, 6), 3, 0) ((4, 7), 3, 0) ((2, 7), 3, 0) ((1, 6), 3, 0) ((1, 4), 3, 0) ((1, 2), 3, 0) ((3, 2), 3, 0) ((4, 3), 3, 0) ((4, 5), 3, 0) ((3, 6), 3, 0) ((1, 6), 3, 0) ((0, 5), 3, 0) ((0, 3), 3, 0) ((1, 0), 3, 0) ((3, 0), 3, 0) ((4, 1), 3, 0) ((4, 3), 3, 0) ((3, 4), 3, 0) ((1, 4), 3, 0) ((0, 3), 3, 0) ((0, 1), 3, 0) ((1, 0), 3, 0) ((3, 0), 3, 0) ((4, 1), 3, 0) ((4, 3), 3, 0) ((3, 4), 3, 0) ((1, 4), 3, 0) ((0, 3), 3, 0) ((0, 1), 3, 0) ((3, 0), 3, 0) ((5, 0), 3, 0) ((6, 1), 3, 0) ((6, 3), 3, 0) ((5, 4), 3, 0) ((3, 4), 3, 0) ((2, 3), 3, 0) ((2, 1), 3, 0) ((4, 1), 3, 0) ((6, 1), 3, 0) ((7, 2), 3, 0) ((7, 4), 3, 0) ((6, 5), 3, 0) ((4, 5), 3, 0) ((3, 4), 3, 0) ((3, 2), 3, 0) ((4, 3), 3, 0) ((6, 3), 3, 0) ((7, 4), 3, 0) ((7, 6), 3, 0) ((6, 7), 3, 0) ((4, 7), 3, 0) ((3, 6), 3, 0) ((3, 4), 3, 0)]

Node selected: ((4, 6), 2, 0) Path: [((2, 2), 0, 0) ((3, 4), 1, 0) ((4, 6), 2, 0)]

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Busqueda: Arbol

Estrategia: A*

Nodos generados: 227

Nodos expandidos: 34

Factor de ramificacion: 14.541607856750488

Profun: 2

Coste: 2

Solucion: (2,2) (3,4) (4,6)

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Algoritmo A* con la heurística $h_1(n)$ (ecuación 2)

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Empezando la busqueda.

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Fringe: [((2, 2), 0, 2)]

Node selected: ((2, 2), 0, 2) Path: [((2, 2), 0, 2)] Successors: [((0, 1), 1, 3) ((0, 3), 1, 2) ((1, 4), 1, 1) ((3, 4), 1, 1) ((4, 3), 1, 1) ((4, 1), 1, 1) ((3, 0), 1, 2) ((1, 0), 1, 3)]

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Fringe: [((4, 1), 1, 1) ((4, 3), 1, 1) ((3, 4), 1, 1) ((1, 4), 1, 1) ((3, 0), 1, 2) ((0, 3), 1, 2) ((1, 0), 1, 3) ((0, 1), 1, 3)]

Node selected: ((4, 1), 1, 1) Path: [((2, 2), 0, 2) ((4, 1), 1, 1)] Successors: [((2, 0), 2, 2) ((2, 2), 2, 2) ((3, 3), 2, 1) ((5, 3), 2, 1) ((6, 2), 2, 2) ((6, 0), 2, 2)]

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Fringe: [((4, 3), 1, 1) ((3, 4), 1, 1) ((1, 4), 1, 1) ((3, 0), 1, 2) ((0, 3), 1, 2) ((5, 3), 2, 1) ((3, 3), 2, 1) ((1, 0), 1, 3) ((0, 1), 1, 3) ((6, 0), 2, 2) ((6, 2), 2, 2) ((2, 2), 2, 2) ((2, 0), 2, 2)]

Node selected: ((4, 3), 1, 1) Path: [((2, 2), 0, 2) ((4, 3), 1, 1)] Successors: [((2, 2), 2, 2) ((2, 4), 2, 1) ((3, 5), 2, 0) ((5, 5), 2, 0) ((6, 4), 2, 1) ((6, 2), 2, 2) ((5, 1), 2, 2) ((3, 1), 2, 2)]

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Node selected: ((3, 4), 1, 1) Path: [((2, 2), 0, 2) ((3, 4), 1, 1)] Successors: [((1, 3), 2, 2) ((1, 5), 2, 1) ((2, 6), 2, 0) ((4, 6), 2, 0) ((5, 5), 2, 0) ((5, 3), 2, 1) ((4, 2), 2, 1) ((2, 2), 2, 2)]

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Fringe: [((1, 4), 1, 1) ((5, 5), 2, 0) ((3, 5), 2, 0) ((5, 5), 2, 0) ((4, 6), 2, 0) ((2, 6), 2, 0) ((3, 0), 1, 2) ((0, 3), 1, 2) ((5, 3), 2, 1) ((3, 3), 2, 1) ((6, 4), 2, 1) ((2, 4), 2, 1) ((4, 2), 2, 1) ((5, 3), 2, 1) ((1, 5), 2, 1) ((1, 0), 1, 3) ((0, 1), 1, 3) ((6, 0), 2, 2) ((6, 2), 2, 2) ((2, 2), 2, 2) ((2, 0), 2, 2) ((3, 1), 2, 2) ((5, 1), 2, 2) ((6, 2), 2, 2) ((2, 2), 2, 2) ((2, 2), 2, 2) ((1, 3), 2, 2)]

Node selected: ((1, 4), 1, 1) Path: [((2, 2), 0, 2) ((1, 4), 1, 1)] Successors: [((0, 6), 2, 1) ((2, 6), 2, 0) ((3, 5), 2, 0) ((3, 3), 2, 1) ((2, 2), 2, 2) ((0, 2), 2, 2)]

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Fringe: [((5, 5), 2, 0) ((3, 5), 2, 0) ((5, 5), 2, 0) ((4, 6), 2, 0) ((2, 6), 2, 0) ((3, 5), 2, 0) ((2, 6), 2, 0) ((3, 0), 1, 2) ((0, 3), 1, 2) ((5, 3), 2, 1) ((3, 3), 2, 1) ((6, 4), 2, 1) ((2, 4), 2, 1) ((4, 2), 2, 1) ((5, 3), 2, 1) ((1, 5), 2, 1) ((3, 3), 2, 1) ((0, 6), 2, 1) ((1, 0), 1, 3) ((0, 1), 1, 3) ((6, 0), 2, 2) ((6, 2), 2, 2) ((2, 2), 2, 2) ((2, 0), 2, 2) ((3, 1), 2, 2) ((5, 1), 2, 2) ((6, 2), 2, 2) ((2, 2), 2, 2) ((2, 2), 2, 2) ((1, 3), 2, 2) ((0, 2), 2, 2) ((2, 2), 2, 2)]

Node selected: ((5, 5), 2, 0) Path: [((2, 2), 0, 2) ((4, 3), 1, 1) ((5, 5), 2, 0)] Successors: [((3, 4), 3, 1) ((3, 6), 3, 0) ((4, 7), 3, 0) ((6, 7), 3, 1) ((7, 6), 3, 1) ((7, 4), 3, 1) ((6, 3), 3, 1) ((4, 3), 3, 1)]

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Node selected: ((3, 5), 2, 0) Path: [((2, 2), 0, 2) ((4, 3), 1, 1) ((3, 5), 2, 0)] Successors: [((1, 4), 3, 1) ((1, 6), 3, 1) ((2, 7), 3, 1) ((4, 7), 3, 0) ((5, 6), 3, 0) ((5, 4), 3, 1) ((4, 3), 3, 1) ((2, 3), 3, 1)]

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Node selected: ((5, 5), 2, 0) Path: [((2, 2), 0, 2) ((3, 4), 1, 1) ((5, 5), 2, 0)] Successors: [((3, 4), 3, 1) ((3, 6), 3, 0) ((4, 7), 3, 0) ((6, 7), 3, 1) ((7, 6), 3, 1) ((7, 4), 3, 1) ((6, 3), 3, 1) ((4, 3), 3, 1)]

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Fringe: [((4, 6), 2, 0) ((2, 6), 2, 0) ((3, 5), 2, 0) ((2, 6), 2, 0) ((3, 0), 1, 2) ((0, 3), 1, 2) ((5, 3), 2, 1) ((3, 3), 2, 1) ((6, 4), 2, 1) ((2, 4), 2, 1) ((4, 2), 2, 1) ((5, 3), 2, 1) ((1, 5), 2, 1) ((3, 3), 2, 1) ((0, 6), 2, 1) ((4, 7), 3, 0) ((3, 6), 3, 0) ((5, 6), 3, 0) ((4, 7), 3, 0) ((4, 7), 3, 0) ((3, 6), 3, 0) ((1, 0), 1, 3) ((0, 1), 1, 3) ((6, 0), 2, 2) ((6, 2), 2, 2) ((2, 2), 2, 2) ((2, 0), 2, 2) ((3, 1), 2, 2) ((5, 1), 2, 2) ((6, 2), 2, 2) ((2, 2), 2, 2) ((2, 2), 2, 2) ((1, 3), 2, 2) ((0, 2), 2, 2) ((2, 2), 2, 2) ((4, 3), 3, 1) ((6, 3), 3, 1) ((7, 4), 3, 1) ((7, 6), 3, 1) ((6, 7), 3, 1) ((3, 4), 3, 1) ((2, 3), 3, 1) ((4, 3), 3, 1) ((5, 4), 3, 1) ((2, 7), 3, 1) ((1, 6), 3, 1) ((1, 4), 3, 1) ((4, 3), 3, 1) ((6, 3), 3, 1) ((7, 4), 3, 1) ((7, 6), 3, 1) ((6, 7), 3, 1) ((3, 4), 3, 1)]

Node selected: ((4, 6), 2, 0) Path: [((2, 2), 0, 2) ((3, 4), 1, 1) ((4, 6), 2, 0)]

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Busqueda: Arbol

Estrategia: A*

Nodos generados: 61

Nodos expandidos: 8

Factor de ramificacion: 7.262085914611816

Profun: 2

Coste: 2

Solucion: (2,2) (3,4) (4,6)

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Algoritmo A* con la heurística $h_2(n)$ (ecuación 3)

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Empezando la busqueda.

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Fringe: [((2, 2), 0, 2)]

Node selected: ((2, 2), 0, 2) Path: [((2, 2), 0, 2)] Successors: [((0, 1), 1, 3) ((0, 3), 1, 2) ((1, 4), 1, 2) ((3, 4), 1, 1) ((4, 3), 1, 2) ((4, 1), 1, 3) ((3, 0), 1, 3) ((1, 0), 1, 3)]

===

Fringe: [((3, 4), 1, 1) ((4, 3), 1, 2) ((1, 4), 1, 2) ((0, 3), 1, 2) ((1, 0), 1, 3) ((3, 0), 1, 3) ((4, 1), 1, 3) ((0, 1), 1, 3)]

Node selected: ((3, 4), 1, 1) Path: [((2, 2), 0, 2) ((3, 4), 1, 1)] Successors: [((1, 3), 2, 2) ((1, 5), 2, 2) ((2, 6), 2, 1) ((4, 6), 2, 0) ((5, 5), 2, 1) ((5, 3), 2, 2) ((4, 2), 2, 2) ((2, 2), 2, 2)]

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Fringe: [((4, 6), 2, 0) ((4, 3), 1, 2) ((1, 4), 1, 2) ((0, 3), 1, 2) ((5, 5), 2, 1) ((2, 6), 2, 1) ((1, 0), 1, 3) ((3, 0), 1, 3) ((4, 1), 1, 3) ((0, 1), 1, 3) ((2, 2), 2, 2) ((4, 2), 2, 2) ((5, 3), 2, 2) ((1, 5), 2, 2) ((1, 3), 2, 2)]

Node selected: ((4, 6), 2, 0) Path: [((2, 2), 0, 2) ((3, 4), 1, 1) ((4, 6), 2, 0)]

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Busqueda: Arbol

Estrategia: A*

Nodos generados: 17

Nodos expandidos: 2

Factor de ramificacion: 3.5311241149902344

Profun: 2

Coste: 2

Solucion: (2,2) (3,4) (4,6)

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1.1.2. Búsqueda empleando grafos

Búsqueda en anchura

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Empezando la busqueda.

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Fringe: [(2, 2)]

===
Fringe: [(1, 0) (3, 0) (4, 1) (4, 3) (3, 4) (1, 4) (0, 3) (0, 1)]

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Fringe: [(3, 0) (4, 1) (4, 3) (3, 4) (1, 4) (0, 3) (0, 1) (3, 1) (2, 2) (0, 2)]

===
Fringe: [(4, 1) (4, 3) (3, 4) (1, 4) (0, 3) (0, 1) (3, 1) (2, 2) (0, 2) (5, 1) (4, 2) (2, 2) (1, 1)]

===
Fringe: [(4, 3) (3, 4) (1, 4) (0, 3) (0, 1) (3, 1) (2, 2) (0, 2) (5, 1) (4, 2) (2, 2) (1, 1) (6, 0)
(6, 2) (5, 3) (3, 3) (2, 2) (2, 0)]

===
Fringe: [(3, 4) (1, 4) (0, 3) (0, 1) (3, 1) (2, 2) (0, 2) (5, 1) (4, 2) (2, 2) (1, 1) (6, 0) (6, 2)
(5, 3) (3, 3) (2, 2) (2, 0) (3, 1) (5, 1) (6, 2) (6, 4) (5, 5) (3, 5) (2, 4) (2, 2)]

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Fringe: [(1, 4) (0, 3) (0, 1) (3, 1) (2, 2) (0, 2) (5, 1) (4, 2) (2, 2) (1, 1) (6, 0) (6, 2) (5, 3)
(3, 3) (2, 2) (2, 0) (3, 1) (5, 1) (6, 2) (6, 4) (5, 5) (3, 5) (2, 4) (2, 2) (2, 2) (4, 2) (5, 3) (5,
5) (4, 6) (2, 6) (1, 5) (1, 3)]

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Fringe: [(0, 3) (0, 1) (3, 1) (2, 2) (0, 2) (5, 1) (4, 2) (2, 2) (1, 1) (6, 0) (6, 2) (5, 3) (3, 3)
(2, 2) (2, 0) (3, 1) (5, 1) (6, 2) (6, 4) (5, 5) (3, 5) (2, 4) (2, 2) (2, 2) (4, 2) (5, 3) (5, 5) (4,
6) (2, 6) (1, 5) (1, 3) (0, 2) (2, 2) (3, 3) (3, 5) (2, 6) (0, 6)]

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Fringe: [(0, 1) (3, 1) (2, 2) (0, 2) (5, 1) (4, 2) (2, 2) (1, 1) (6, 0) (6, 2) (5, 3) (3, 3) (2, 2)
(2, 0) (3, 1) (5, 1) (6, 2) (6, 4) (5, 5) (3, 5) (2, 4) (2, 2) (2, 2) (4, 2) (5, 3) (5, 5) (4, 6) (2,
6) (1, 5) (1, 3) (0, 2) (2, 2) (3, 3) (3, 5) (2, 6) (0, 6) (1, 1) (2, 2) (2, 4) (1, 5)]

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Fringe: [(3, 1) (2, 2) (0, 2) (5, 1) (4, 2) (2, 2) (1, 1) (6, 0) (6, 2) (5, 3) (3, 3) (2, 2) (2, 0)
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5) (1, 3) (0, 2) (2, 2) (3, 3) (3, 5) (2, 6) (0, 6) (1, 1) (2, 2) (2, 4) (1, 5) (2, 0) (2, 2) (1, 3)]

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Fringe: [(2, 2) (0, 2) (5, 1) (4, 2) (2, 2) (1, 1) (6, 0) (6, 2) (5, 3) (3, 3) (2, 2) (2, 0) (3, 1)
(5, 1) (6, 2) (6, 4) (5, 5) (3, 5) (2, 4) (2, 2) (2, 2) (4, 2) (5, 3) (5, 5) (4, 6) (2, 6) (1, 5) (1,
3) (0, 2) (2, 2) (3, 3) (3, 5) (2, 6) (0, 6) (1, 1) (2, 2) (2, 4) (1, 5) (2, 0) (2, 2) (1, 3) (5, 0)
(5, 2) (4, 3) (2, 3) (1, 2) (1, 0)]

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Fringe: [(0, 2) (5, 1) (4, 2) (2, 2) (1, 1) (6, 0) (6, 2) (5, 3) (3, 3) (2, 2) (2, 0) (3, 1) (5, 1)
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(4, 3) (2, 3) (1, 2) (1, 0)]

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Fringe: [(5, 1) (4, 2) (2, 2) (1, 1) (6, 0) (6, 2) (5, 3) (3, 3) (2, 2) (2, 0) (3, 1) (5, 1) (6, 2) (6, 4) (5, 5) (3, 5) (2, 4) (2, 2) (2, 2) (4, 2) (5, 3) (5, 5) (4, 6) (2, 6) (1, 5) (1, 3) (0, 2) (2, 2) (3, 3) (3, 5) (2, 6) (0, 6) (1, 1) (2, 2) (2, 4) (1, 5) (2, 0) (2, 2) (1, 3) (5, 0) (5, 2) (4, 3) (2, 3) (1, 2) (1, 0) (1, 0) (2, 1) (2, 3) (1, 4)]

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Fringe: [(4, 2) (2, 2) (1, 1) (6, 0) (6, 2) (5, 3) (3, 3) (2, 2) (2, 0) (3, 1) (5, 1) (6, 2) (6, 4) (5, 5) (3, 5) (2, 4) (2, 2) (2, 2) (4, 2) (5, 3) (5, 5) (4, 6) (2, 6) (1, 5) (1, 3) (0, 2) (2, 2) (3, 3) (3, 5) (2, 6) (0, 6) (1, 1) (2, 2) (2, 4) (1, 5) (2, 0) (2, 2) (1, 3) (5, 0) (5, 2) (4, 3) (2, 3) (1, 2) (1, 0) (1, 0) (2, 1) (2, 3) (1, 4) (7, 0) (7, 2) (6, 3) (4, 3) (3, 2) (3, 0)]

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Fringe: [(2, 2) (1, 1) (6, 0) (6, 2) (5, 3) (3, 3) (2, 2) (2, 0) (3, 1) (5, 1) (6, 2) (6, 4) (5, 5) (3, 5) (2, 4) (2, 2) (2, 2) (4, 2) (5, 3) (5, 5) (4, 6) (2, 6) (1, 5) (1, 3) (0, 2) (2, 2) (3, 3) (3, 5) (2, 6) (0, 6) (1, 1) (2, 2) (2, 4) (1, 5) (2, 0) (2, 2) (1, 3) (5, 0) (5, 2) (4, 3) (2, 3) (1, 2) (1, 0) (1, 0) (2, 1) (2, 3) (1, 4) (7, 0) (7, 2) (6, 3) (4, 3) (3, 2) (3, 0) (3, 0) (5, 0) (6, 1) (6, 3) (5, 4) (3, 4) (2, 3) (2, 1)]

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Fringe: [(6, 0) (6, 2) (5, 3) (3, 3) (2, 2) (2, 0) (3, 1) (5, 1) (6, 2) (6, 4) (5, 5) (3, 5) (2, 4) (2, 2) (2, 2) (4, 2) (5, 3) (5, 5) (4, 6) (2, 6) (1, 5) (1, 3) (0, 2) (2, 2) (3, 3) (3, 5) (2, 6) (0, 6) (1, 1) (2, 2) (2, 4) (1, 5) (2, 0) (2, 2) (1, 3) (5, 0) (5, 2) (4, 3) (2, 3) (1, 2) (1, 0) (1, 0) (2, 1) (2, 3) (1, 4) (7, 0) (7, 2) (6, 3) (4, 3) (3, 2) (3, 0) (3, 0) (5, 0) (6, 1) (6, 3) (5, 4) (3, 4) (2, 3) (2, 1) (3, 0) (3, 2) (2, 3) (0, 3)]

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(7, 0) (7, 2) (6, 3) (4, 3) (3, 2) (3, 0) (3, 0) (5, 0) (6, 1) (6, 3) (5, 4) (3, 4) (2, 3) (2, 1) (3, 0) (3, 2) (2, 3) (0, 3) (8, 1) (7, 2) (5, 2) (4, 1) (5, 0) (7, 0) (8, 1) (8, 3) (7, 4) (5, 4) (4, 3) (4, 1) (4, 1) (6, 1) (7, 2) (7, 4) (6, 5) (4, 5) (3, 4) (3, 2)]

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Fringe: [(3, 1) (5, 1) (6, 2) (6, 4) (5, 5) (3, 5) (2, 4) (2, 2) (2, 2) (4, 2) (5, 3) (5, 5) (4, 6) (2, 6) (1, 5) (1, 3) (0, 2) (2, 2) (3, 3) (3, 5) (2, 6) (0, 6) (1, 1) (2, 2) (2, 4) (1, 5) (2, 0) (2, 2) (1, 3) (5, 0) (5, 2) (4, 3) (2, 3) (1, 2) (1, 0) (1, 0) (2, 1) (2, 3) (1, 4) (7, 0) (7, 2) (6, 3) (4, 3) (3, 2) (3, 0) (3, 0) (5, 0) (6, 1) (6, 3) (5, 4) (3, 4) (2, 3) (2, 1) (3, 0) (3, 2) (2, 3) (0, 3) (8, 1) (7, 2) (5, 2) (4, 1) (5, 0) (7, 0) (8, 1) (8, 3) (7, 4) (5, 4) (4, 3) (4, 1) (4, 1) (6, 1) (7, 2) (7, 4) (6, 5) (4, 5) (3, 4) (3, 2) (2, 1) (4, 1) (5, 2) (5, 4) (4, 5) (2, 5) (1, 4) (1, 2) (4, 1) (3, 2) (1, 2) (0, 1)]

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Fringe: [(5, 1) (6, 2) (6, 4) (5, 5) (3, 5) (2, 4) (2, 2) (2, 2) (4, 2) (5, 3) (5, 5) (4, 6) (2, 6) (1, 5) (1, 3) (0, 2) (2, 2) (3, 3) (3, 5) (2, 6) (0, 6) (1, 1) (2, 2) (2, 4) (1, 5) (2, 0) (2, 2) (1, 3) (5, 0) (5, 2) (4, 3) (2, 3) (1, 2) (1, 0) (1, 0) (2, 1) (2, 3) (1, 4) (7, 0) (7, 2) (6, 3) (4, 3) (3, 2) (3, 0) (3, 0) (5, 0) (6, 1) (6, 3) (5, 4) (3, 4) (2, 3) (2, 1) (3, 0) (3, 2) (2, 3) (0, 3) (8, 1) (7, 2) (5, 2) (4, 1) (5, 0) (7, 0) (8, 1) (8, 3) (7, 4) (5, 4) (4, 3) (4, 1) (4, 1) (6, 1) (7, 2) (7, 4) (6, 5) (4, 5) (3, 4) (3, 2) (2, 1) (4, 1) (5, 2) (5, 4) (4, 5) (2, 5) (1, 4) (1, 2) (4, 1) (3, 2) (1, 2) (0, 1) (5, 0) (5, 2) (4, 3) (2, 3) (1, 2) (1, 0)]

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Busqueda: Grafo

Estrategia: Anchura

Nodos generados: 179

Nodos expandidos: 28

Factor de ramificacion: 12.851029396057129

Profun: 2

Coste: 2

Solucion: (2,2) (3,4) (4,6)

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Algoritmo A* con la heurística $h_0(n)$ (ecuación 1)

————————————————————————

Empezando la busqueda.

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Fringe: [((2, 2), 0, 0)]

Node selected: ((2, 2), 0, 0)

Path: [((2, 2), 0, 0)]

Successors: [((0, 1), 1, 0) ((0, 3), 1, 0) ((1, 4), 1, 0) ((3, 4), 1, 0) ((4, 3), 1, 0) ((4, 1), 1, 0) ((3, 0), 1, 0) ((1, 0), 1, 0)]

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Fringe: [((1, 0), 1, 0) ((3, 0), 1, 0) ((4, 1), 1, 0) ((4, 3), 1, 0) ((3, 4), 1, 0) ((1, 4), 1, 0) ((0, 3), 1, 0) ((0, 1), 1, 0)]

Node selected: ((1, 0), 1, 0)

Path: [((2, 2), 0, 0) ((1, 0), 1, 0)]

Successors: [((0, 2), 2, 0) ((2, 2), 2, 0) ((3, 1), 2, 0)]

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Fringe: [((3, 0), 1, 0) ((4, 1), 1, 0) ((4, 3), 1, 0) ((3, 4), 1, 0) ((1, 4), 1, 0) ((0, 3), 1, 0) ((0, 1), 1, 0) ((3, 1), 2, 0) ((2, 2), 2, 0) ((0, 2), 2, 0)]

Node selected: ((3, 0), 1, 0)

Path: [((2, 2), 0, 0) ((3, 0), 1, 0)]

Successors: [((1, 1), 2, 0) ((2, 2), 2, 0) ((4, 2), 2, 0) ((5, 1), 2, 0)]

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Fringe: [((4, 1), 1, 0) ((4, 3), 1, 0) ((3, 4), 1, 0) ((1, 4), 1, 0) ((0, 3), 1, 0) ((0, 1), 1, 0) ((3, 1), 2, 0) ((2, 2), 2, 0) ((0, 2), 2, 0) ((5, 1), 2, 0) ((4, 2), 2, 0) ((2, 2), 2, 0) ((1, 1), 2, 0)]

Node selected: ((4, 1), 1, 0)

Path: [((2, 2), 0, 0) ((4, 1), 1, 0)]

Successors: [((2, 0), 2, 0) ((2, 2), 2, 0) ((3, 3), 2, 0) ((5, 3), 2, 0) ((6, 2), 2, 0) ((6, 0), 2, 0)]

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Fringe: [((4, 3), 1, 0) ((3, 4), 1, 0) ((1, 4), 1, 0) ((0, 3), 1, 0) ((0, 1), 1, 0) ((3, 1), 2, 0) ((2, 2), 2, 0) ((0, 2), 2, 0) ((5, 1), 2, 0) ((4, 2), 2, 0) ((2, 2), 2, 0) ((1, 1), 2, 0) ((6, 0), 2, 0) ((6, 2), 2, 0) ((5, 3), 2, 0) ((3, 3), 2, 0) ((2, 2), 2, 0) ((2, 0), 2, 0)]

Node selected: ((4, 3), 1, 0)

Path: [((2, 2), 0, 0) ((4, 3), 1, 0)]

Successors: [((2, 2), 2, 0) ((2, 4), 2, 0) ((3, 5), 2, 0) ((5, 5), 2, 0) ((6, 4), 2, 0) ((6, 2), 2, 0) ((5, 1), 2, 0) ((3, 1), 2, 0)]

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Fringe: [((3, 4), 1, 0) ((1, 4), 1, 0) ((0, 3), 1, 0) ((0, 1), 1, 0) ((3, 1), 2, 0) ((2, 2), 2, 0) ((0, 2), 2, 0) ((5, 1), 2, 0) ((4, 2), 2, 0) ((2, 2), 2, 0) ((1, 1), 2, 0) ((6, 0), 2, 0) ((6, 2), 2, 0) ((5, 3), 2, 0) ((3, 3), 2, 0) ((2, 2), 2, 0) ((2, 0), 2, 0) ((3, 1), 2, 0) ((5, 1), 2, 0) ((6, 2), 2, 0) ((6, 4), 2, 0) ((5, 5), 2, 0) ((3, 5), 2, 0) ((2, 4), 2, 0) ((2, 2), 2, 0)]

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Path: [((2, 2), 0, 0) ((3, 4), 1, 0)]

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Path: [((2, 2), 0, 0) ((1, 4), 1, 0)]

Successors: [((0, 6), 2, 0) ((2, 6), 2, 0) ((3, 5), 2, 0) ((3, 3), 2, 0) ((2, 2), 2, 0) ((0, 2), 2, 0)]

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Node selected: ((0, 3), 1, 0)

Path: [((2, 2), 0, 0) ((0, 3), 1, 0)]

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Node selected: ((0, 1), 1, 0)

Path: [((2, 2), 0, 0) ((0, 1), 1, 0)]

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Path: [((2, 2), 0, 0) ((1, 0), 1, 0) ((3, 1), 2, 0)]

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Node selected: ((2, 2), 2, 0)

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Successors: []

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Path: [((2, 2), 0, 0) ((1, 0), 1, 0) ((0, 2), 2, 0)]

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Node selected: ((2, 2), 2, 0)

Path: [((2, 2), 0, 0) ((3, 0), 1, 0) ((2, 2), 2, 0)]

Successors: []

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Path: [((2, 2), 0, 0) ((4, 3), 1, 0) ((5, 1), 2, 0)]

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Successors: [((3, 2), 3, 0) ((3, 4), 3, 0) ((4, 5), 3, 0) ((6, 5), 3, 0) ((7, 4), 3, 0) ((7, 2), 3, 0) ((6, 1), 3, 0) ((4, 1), 3, 0)]

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Fringe: [((5, 5), 2, 0) ((4, 6), 2, 0) ((2, 6), 2, 0) ((1, 5), 2, 0) ((1, 3), 2, 0) ((0, 2), 2, 0) ((2, 2), 2, 0) ((3, 3), 2, 0) ((3, 5), 2, 0) ((2, 6), 2, 0) ((0, 6), 2, 0) ((1, 1), 2, 0) ((2, 2), 2, 0) ((2, 4), 2, 0) ((1, 5), 2, 0) ((2, 0), 2, 0) ((2, 2), 2, 0) ((1, 3), 2, 0) ((5, 0), 3, 0) ((5, 2), 3, 0) ((4, 3), 3, 0) ((2, 3), 3, 0) ((1, 2), 3, 0) ((1, 0), 3, 0) ((1, 0), 3, 0) ((2, 1), 3, 0) ((2, 3), 3, 0) ((1, 4), 3, 0) ((7, 0), 3, 0) ((7, 2), 3, 0) ((6, 3), 3, 0) ((4, 3), 3, 0) ((3, 2), 3, 0) ((3, 0), 3, 0) ((3, 0), 3, 0) ((5, 0), 3, 0) ((6, 1), 3, 0) ((6, 3), 3, 0) ((5, 4), 3, 0) ((3, 4), 3, 0) ((2, 3), 3, 0) ((2, 1), 3, 0) ((3, 0), 3, 0) ((3, 2), 3, 0) ((2, 3), 3, 0) ((0, 3), 3, 0) ((8, 1),

3, 0) ((7, 2), 3, 0) ((5, 2), 3, 0) ((4, 1), 3, 0) ((5, 0), 3, 0) ((7, 0), 3, 0) ((8, 1), 3, 0) ((8, 3), 3, 0) ((7, 4), 3, 0) ((5, 4), 3, 0) ((4, 3), 3, 0) ((4, 1), 3, 0) ((4, 1), 3, 0) ((6, 1), 3, 0) ((7, 2), 3, 0) ((7, 4), 3, 0) ((6, 5), 3, 0) ((4, 5), 3, 0) ((3, 4), 3, 0) ((3, 2), 3, 0) ((2, 1), 3, 0) ((4, 1), 3, 0) ((5, 2), 3, 0) ((5, 4), 3, 0) ((4, 5), 3, 0) ((2, 5), 3, 0) ((1, 4), 3, 0) ((1, 2), 3, 0) ((4, 1), 3, 0) ((3, 2), 3, 0) ((1, 2), 3, 0) ((0, 1), 3, 0) ((5, 0), 3, 0) ((5, 2), 3, 0) ((4, 3), 3, 0) ((2, 3), 3, 0) ((1, 2), 3, 0) ((1, 0), 3, 0) ((7, 0), 3, 0) ((7, 2), 3, 0) ((6, 3), 3, 0) ((4, 3), 3, 0) ((3, 2), 3, 0) ((3, 0), 3, 0) ((5, 0), 3, 0) ((7, 0), 3, 0) ((8, 1), 3, 0) ((8, 3), 3, 0) ((7, 4), 3, 0) ((5, 4), 3, 0) ((4, 3), 3, 0) ((4, 1), 3, 0) ((5, 2), 3, 0) ((7, 2), 3, 0) ((8, 3), 3, 0) ((8, 5), 3, 0) ((7, 6), 3, 0) ((5, 6), 3, 0) ((4, 5), 3, 0) ((4, 3), 3, 0) ((4, 3), 3, 0) ((6, 3), 3, 0) ((7, 4), 3, 0) ((7, 6), 3, 0) ((6, 7), 3, 0) ((4, 7), 3, 0) ((3, 6), 3, 0) ((3, 4), 3, 0) ((2, 3), 3, 0) ((4, 3), 3, 0) ((5, 4), 3, 0) ((5, 6), 3, 0) ((4, 7), 3, 0) ((2, 7), 3, 0) ((1, 6), 3, 0) ((1, 4), 3, 0) ((1, 2), 3, 0) ((3, 2), 3, 0) ((4, 3), 3, 0) ((4, 5), 3, 0) ((3, 6), 3, 0) ((1, 6), 3, 0) ((0, 5), 3, 0) ((0, 3), 3, 0) ((3, 0), 3, 0) ((5, 0), 3, 0) ((6, 1), 3, 0) ((6, 3), 3, 0) ((5, 4), 3, 0) ((3, 4), 3, 0) ((2, 3), 3, 0) ((2, 1), 3, 0) ((4, 1), 3, 0) ((6, 1), 3, 0) ((7, 2), 3, 0) ((7, 4), 3, 0) ((6, 5), 3, 0) ((4, 5), 3, 0) ((3, 4), 3, 0) ((3, 2), 3, 0)]

Node selected: ((5, 5), 2, 0)

Path: [((2, 2), 0, 0) ((3, 4), 1, 0) ((5, 5), 2, 0)]

Successors: []

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Fringe: [((4, 6), 2, 0) ((2, 6), 2, 0) ((1, 5), 2, 0) ((1, 3), 2, 0) ((0, 2), 2, 0) ((2, 2), 2, 0) ((3, 3), 2, 0) ((3, 5), 2, 0) ((2, 6), 2, 0) ((0, 6), 2, 0) ((1, 1), 2, 0) ((2, 2), 2, 0) ((2, 4), 2, 0) ((1, 5), 2, 0) ((2, 0), 2, 0) ((2, 2), 2, 0) ((1, 3), 2, 0) ((5, 0), 3, 0) ((5, 2), 3, 0) ((4, 3), 3, 0) ((2, 3), 3, 0) ((1, 2), 3, 0) ((1, 0), 3, 0) ((1, 0), 3, 0) ((2, 1), 3, 0) ((2, 3), 3, 0) ((1, 4), 3, 0) ((7, 0), 3, 0) ((7, 2), 3, 0) ((6, 3), 3, 0) ((4, 3), 3, 0) ((3, 2), 3, 0) ((3, 0), 3, 0) ((3, 0), 3, 0) ((5, 0), 3, 0) ((6, 1), 3, 0) ((6, 3), 3, 0) ((5, 4), 3, 0) ((3, 4), 3, 0) ((2, 3), 3, 0) ((2, 1), 3, 0) ((3, 0), 3, 0) ((3, 2), 3, 0) ((2, 3), 3, 0) ((0, 3), 3, 0) ((8, 1), 3, 0) ((7, 2), 3, 0) ((5, 2), 3, 0) ((4, 1), 3, 0) ((5, 0), 3, 0) ((7, 0), 3, 0) ((8, 1), 3, 0) ((8, 3), 3, 0) ((7, 4), 3, 0) ((5, 4), 3, 0) ((4, 3), 3, 0) ((4, 1), 3, 0) ((4, 1), 3, 0) ((6, 1), 3, 0) ((7, 2), 3, 0) ((7, 4), 3, 0) ((6, 5), 3, 0) ((4, 5), 3, 0) ((3, 4), 3, 0) ((3, 2), 3, 0) ((2, 1), 3, 0) ((4, 1), 3, 0) ((5, 2), 3, 0) ((5, 4), 3, 0) ((4, 5), 3, 0) ((2, 5), 3, 0) ((1, 4), 3, 0) ((1, 2), 3, 0) ((4, 1), 3, 0) ((3, 2), 3, 0) ((1, 2), 3, 0) ((0, 1), 3, 0) ((5, 0), 3, 0) ((5, 2), 3, 0) ((4, 3), 3, 0) ((2, 3), 3, 0) ((1, 2), 3, 0) ((1, 0), 3, 0) ((7, 0), 3, 0) ((7, 2), 3, 0) ((6, 3), 3, 0) ((4, 3), 3, 0) ((3, 2), 3, 0) ((3, 0), 3, 0) ((5, 0), 3, 0) ((7, 0), 3, 0) ((8, 1), 3, 0) ((8, 3), 3, 0) ((7, 4), 3, 0) ((5, 4), 3, 0) ((4, 3), 3, 0) ((4, 1), 3, 0) ((5, 2), 3, 0) ((7, 2), 3, 0) ((8, 3), 3, 0) ((8, 5), 3, 0) ((7, 6), 3, 0) ((5, 6), 3, 0) ((4, 5), 3, 0) ((4, 3), 3, 0) ((4, 3), 3, 0) ((6, 3), 3, 0) ((7, 4), 3, 0) ((7, 6), 3, 0) ((6, 7), 3, 0) ((4, 7), 3, 0) ((3, 6), 3, 0) ((3, 4), 3, 0) ((2, 3), 3, 0) ((4, 3), 3, 0) ((5, 4), 3, 0) ((5, 6), 3, 0) ((4, 7), 3, 0) ((2, 7), 3, 0) ((1, 6), 3, 0) ((1, 4), 3, 0) ((1, 2), 3, 0) ((3, 2), 3, 0) ((4, 3), 3, 0) ((4, 5), 3, 0) ((3, 6), 3, 0) ((1, 6), 3, 0) ((0, 5), 3, 0) ((0, 3), 3, 0) ((3, 0), 3, 0) ((5, 0), 3, 0) ((6, 1), 3, 0) ((6, 3), 3, 0) ((5, 4), 3, 0) ((3, 4), 3, 0) ((2, 3), 3, 0) ((2, 1), 3, 0) ((4, 1), 3, 0) ((6, 1), 3, 0) ((7, 2), 3, 0) ((7, 4), 3, 0) ((6, 5), 3, 0) ((4, 5), 3, 0) ((3, 4), 3, 0) ((3, 2), 3, 0)]

Node selected: ((4, 6), 2, 0)

Path: [((2, 2), 0, 0) ((3, 4), 1, 0) ((4, 6), 2, 0)]

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Busqueda: Grafo

Estrategia: A*

Nodos generados: 179

Nodos expandidos: 28

Factor de ramificacion: 12.851029396057129

Profun: 2

Coste: 2

Solucion: (2,2) (3,4) (4,6)

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Algoritmo A* con la heurística $h_1(n)$ (ecuación 2)

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Empezando la busqueda.

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Fringe: [((2, 2), 0, 2)]

Node selected: ((2, 2), 0, 2)

Path: [((2, 2), 0, 2)]

Successors: [((0, 1), 1, 3) ((0, 3), 1, 2) ((1, 4), 1, 1) ((3, 4), 1, 1) ((4, 3), 1, 1) ((4, 1), 1, 1) ((3, 0), 1, 2) ((1, 0), 1, 3)]

==

Fringe: [((4, 1), 1, 1) ((4, 3), 1, 1) ((3, 4), 1, 1) ((1, 4), 1, 1) ((3, 0), 1, 2) ((0, 3), 1, 2) ((1, 0), 1, 3) ((0, 1), 1, 3)]

Node selected: ((4, 1), 1, 1)

Path: [((2, 2), 0, 2) ((4, 1), 1, 1)]

Successors: [((2, 0), 2, 2) ((2, 2), 2, 2) ((3, 3), 2, 1) ((5, 3), 2, 1) ((6, 2), 2, 2) ((6, 0), 2, 2)]

==

Fringe: [((4, 3), 1, 1) ((3, 4), 1, 1) ((1, 4), 1, 1) ((3, 0), 1, 2) ((0, 3), 1, 2) ((5, 3), 2, 1) ((3, 3), 2, 1) ((1, 0), 1, 3) ((0, 1), 1, 3) ((6, 0), 2, 2) ((6, 2), 2, 2) ((2, 2), 2, 2) ((2, 0), 2, 2)]

Node selected: ((4, 3), 1, 1)

Path: [((2, 2), 0, 2) ((4, 3), 1, 1)]

Successors: [((2, 2), 2, 2) ((2, 4), 2, 1) ((3, 5), 2, 0) ((5, 5), 2, 0) ((6, 4), 2, 1) ((6, 2), 2, 2) ((5, 1), 2, 2) ((3, 1), 2, 2)]

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Fringe: [((3, 4), 1, 1) ((1, 4), 1, 1) ((5, 5), 2, 0) ((3, 5), 2, 0) ((3, 0), 1, 2) ((0, 3), 1, 2) ((5, 3), 2, 1) ((3, 3), 2, 1) ((6, 4), 2, 1) ((2, 4), 2, 1) ((1, 0), 1, 3) ((0, 1), 1, 3) ((6, 0), 2, 2) ((6, 2), 2, 2) ((2, 2), 2, 2) ((2, 0), 2, 2) ((3, 1), 2, 2) ((5, 1), 2, 2) ((6, 2), 2, 2) ((2, 2), 2, 2)]

Node selected: ((3, 4), 1, 1)

Path: [((2, 2), 0, 2) ((3, 4), 1, 1)]

Successors: [((1, 3), 2, 2) ((1, 5), 2, 1) ((2, 6), 2, 0) ((4, 6), 2, 0) ((5, 5), 2, 0) ((5, 3), 2, 1) ((4, 2), 2, 1) ((2, 2), 2, 2)]

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Fringe: [((1, 4), 1, 1) ((5, 5), 2, 0) ((3, 5), 2, 0) ((5, 5), 2, 0) ((4, 6), 2, 0) ((2, 6), 2, 0) ((3, 0), 1, 2) ((0, 3), 1, 2) ((5, 3), 2, 1) ((3, 3), 2, 1) ((6, 4), 2, 1) ((2, 4), 2, 1) ((4, 2), 2, 1) ((5, 3), 2, 1) ((1, 5), 2, 1) ((1, 0), 1, 3) ((0, 1), 1, 3) ((6, 0), 2, 2) ((6, 2), 2, 2) ((2, 2), 2, 2) ((2, 0), 2, 2) ((3, 1), 2, 2) ((5, 1), 2, 2) ((6, 2), 2, 2) ((2, 2), 2, 2) ((2, 2), 2, 2) ((1, 3), 2, 2)]

Node selected: ((1, 4), 1, 1)

Path: [((2, 2), 0, 2) ((1, 4), 1, 1)]

Successors: [((0, 6), 2, 1) ((2, 6), 2, 0) ((3, 5), 2, 0) ((3, 3), 2, 1) ((2, 2), 2, 2) ((0, 2), 2, 2)]

==

Fringe: [((5, 5), 2, 0) ((3, 5), 2, 0) ((5, 5), 2, 0) ((4, 6), 2, 0) ((2, 6), 2, 0) ((3, 5), 2, 0) ((2, 6), 2, 0) ((3, 0), 1, 2) ((0, 3), 1, 2) ((5, 3), 2, 1) ((3, 3), 2, 1) ((6, 4), 2, 1) ((2, 4), 2, 1) ((4, 2), 2, 1) ((5, 3), 2, 1) ((1, 5), 2, 1) ((3, 3), 2, 1) ((0, 6), 2, 1) ((1, 0), 1, 3) ((0, 1), 1, 3) ((6, 0), 2, 2) ((6, 2), 2, 2) ((2, 2), 2, 2) ((2, 0), 2, 2) ((3, 1), 2, 2) ((5, 1), 2, 2) ((6, 2), 2, 2) ((2, 2), 2, 2) ((2, 2), 2, 2) ((1, 3), 2, 2) ((0, 2), 2, 2) ((2, 2), 2, 2)]

Node selected: ((5, 5), 2, 0)

Path: [((2, 2), 0, 2) ((4, 3), 1, 1) ((5, 5), 2, 0)]

Successors: [((3, 4), 3, 1) ((3, 6), 3, 0) ((4, 7), 3, 0) ((6, 7), 3, 1) ((7, 6), 3, 1) ((7, 4), 3, 1) ((6, 3), 3, 1) ((4, 3), 3, 1)]

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Fringe: [((3, 5), 2, 0) ((5, 5), 2, 0) ((4, 6), 2, 0) ((2, 6), 2, 0) ((3, 5), 2, 0) ((2, 6), 2, 0) ((3, 0), 1, 2) ((0, 3), 1, 2) ((5, 3), 2, 1) ((3, 3), 2, 1) ((6, 4), 2, 1) ((2, 4), 2, 1) ((4, 2), 2, 1) ((5, 3), 2, 1) ((1, 5), 2, 1) ((3, 3), 2, 1) ((0, 6), 2, 1) ((4, 7), 3, 0) ((3, 6), 3, 0) ((1, 0), 1, 3) ((0, 1), 1, 3) ((6, 0), 2, 2) ((6, 2), 2, 2) ((2, 2), 2, 2) ((2, 0), 2, 2) ((3, 1), 2, 2) ((5, 1), 2, 2) ((6, 2), 2, 2) ((2, 2), 2, 2) ((2, 2), 2, 2) ((1, 3), 2, 2) ((0, 2), 2, 2) ((2, 2), 2, 2) ((4, 3), 3, 1) ((6, 3), 3, 1) ((7, 4), 3, 1) ((7, 6), 3, 1) ((6, 7), 3, 1) ((3, 4), 3, 1)]

Node selected: ((3, 5), 2, 0)

Path: [((2, 2), 0, 2) ((4, 3), 1, 1) ((3, 5), 2, 0)]

Successors: [((1, 4), 3, 1) ((1, 6), 3, 1) ((2, 7), 3, 1) ((4, 7), 3, 0) ((5, 6), 3, 0) ((5, 4), 3, 1) ((4, 3), 3, 1) ((2, 3), 3, 1)]

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Fringe: [((5, 5), 2, 0) ((4, 6), 2, 0) ((2, 6), 2, 0) ((3, 5), 2, 0) ((2, 6), 2, 0) ((3, 0), 1, 2) ((0, 3), 1, 2) ((5, 3), 2, 1) ((3, 3), 2, 1) ((6, 4), 2, 1) ((2, 4), 2, 1) ((4, 2), 2, 1) ((5, 3), 2, 1) ((1, 5), 2, 1) ((3, 3), 2, 1) ((0, 6), 2, 1) ((4, 7), 3, 0) ((3, 6), 3, 0) ((5, 6), 3, 0) ((4, 7), 3, 0) ((1, 0), 1, 3) ((0, 1), 1, 3) ((6, 0), 2, 2) ((6, 2), 2, 2) ((2, 2), 2, 2) ((2, 0), 2, 2) ((3, 1), 2, 2) ((5, 1), 2, 2) ((6, 2), 2, 2) ((2, 2), 2, 2) ((2, 2), 2, 2) ((1, 3), 2, 2) ((0, 2), 2, 2) ((2, 2), 2, 2) ((4, 3), 3, 1) ((6, 3), 3, 1) ((7, 4), 3, 1) ((7, 6), 3, 1) ((6, 7), 3, 1) ((3, 4), 3, 1) ((2, 3), 3, 1) ((4, 3), 3, 1) ((5, 4), 3, 1) ((2, 7), 3, 1) ((1, 6), 3, 1) ((1, 4), 3, 1)]

Node selected: ((5, 5), 2, 0)

Path: [((2, 2), 0, 2) ((3, 4), 1, 1) ((5, 5), 2, 0)]

Successors: []

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Fringe: [((4, 6), 2, 0) ((2, 6), 2, 0) ((3, 5), 2, 0) ((2, 6), 2, 0) ((3, 0), 1, 2) ((0, 3), 1, 2) ((5, 3), 2, 1) ((3, 3), 2, 1) ((6, 4), 2, 1) ((2, 4), 2, 1) ((4, 2), 2, 1) ((5, 3), 2, 1) ((1, 5), 2, 1) ((3, 3), 2, 1) ((0, 6), 2, 1) ((4, 7), 3, 0) ((3, 6), 3, 0) ((5, 6), 3, 0) ((4, 7), 3, 0) ((1, 0), 1, 3) ((0, 1), 1, 3) ((6, 0), 2, 2) ((6, 2), 2, 2) ((2, 2), 2, 2) ((2, 0), 2, 2) ((3, 1), 2, 2) ((5, 1), 2, 2) ((6, 2), 2, 2) ((2, 2), 2, 2) ((2, 2), 2, 2) ((1, 3), 2, 2) ((0, 2), 2, 2) ((2, 2), 2, 2) ((4, 3), 3, 1) ((6, 3), 3, 1) ((7, 4), 3, 1) ((7, 6), 3, 1) ((6, 7), 3, 1) ((3, 4), 3, 1) ((2, 3), 3, 1) ((4, 3), 3, 1) ((5, 4), 3, 1) ((2, 7), 3, 1) ((1, 6), 3, 1) ((1, 4), 3, 1)]

Node selected: ((4, 6), 2, 0)

Path: [((2, 2), 0, 2) ((3, 4), 1, 1) ((4, 6), 2, 0)]

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Busqueda: Grafo

Estrategia: A*

Nodos generados: 53

Nodos expandidos: 7

Factor de ramificacion: 6.728415489196777

Profun: 2

Coste: 2

Solucion: (2,2) (3,4) (4,6)

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Algoritmo A* con la heurística $h_2(n)$ (ecuación 3)

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Empezando la busqueda. Con la heurística 2

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Fringe: [((2, 2), 0, 2)]

Node selected: ((2, 2), 0, 2)

Path: [((2, 2), 0, 2)]

Successors: [((0, 1), 1, 3) ((0, 3), 1, 2) ((1, 4), 1, 2) ((3, 4), 1, 1) ((4, 3), 1, 2) ((4, 1), 1, 3) ((3, 0), 1, 3) ((1, 0), 1, 3)]

==

Fringe: [((3, 4), 1, 1) ((4, 3), 1, 2) ((1, 4), 1, 2) ((0, 3), 1, 2) ((1, 0), 1, 3) ((3, 0), 1, 3) ((4, 1), 1, 3) ((0, 1), 1, 3)]

Node selected: ((3, 4), 1, 1)

Path: [((2, 2), 0, 2) ((3, 4), 1, 1)]

Successors: [((1, 3), 2, 2) ((1, 5), 2, 2) ((2, 6), 2, 1) ((4, 6), 2, 0) ((5, 5), 2, 1) ((5, 3), 2, 2) ((4, 2), 2, 2) ((2, 2), 2, 2)]

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Fringe: [((4, 6), 2, 0) ((4, 3), 1, 2) ((1, 4), 1, 2) ((0, 3), 1, 2) ((5, 5), 2, 1) ((2, 6), 2, 1) ((1, 0), 1, 3) ((3, 0), 1, 3) ((4, 1), 1, 3) ((0, 1), 1, 3) ((2, 2), 2, 2) ((4, 2), 2, 2) ((5, 3), 2, 2) ((1, 5), 2, 2) ((1, 3), 2, 2)]

Node selected: ((4, 6), 2, 0)

Path: [((2, 2), 0, 2) ((3, 4), 1, 1) ((4, 6), 2, 0)]

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Busqueda: Grafo

Estrategia: A*

Nodos generados: 17

Nodos expandidos: 2

Factor de ramificacion: 3.5311241149902344

Profun: 2

Coste: 2

Solucion: (2,2) (3,4) (4,6)

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1.2. Caracterización de la calidad de las heurísticas empleadas

A continuación se expone la calidad de las heurísticas empleadas en función de la longitud del camino de solución óptimo. en la tabla 1 se muestran los resultados obtenidos para las distintas heurísticas empleando una estructura de grafo donde la posición final es *(5, 5)*.

1.3. Comparación del rendimiento de los distintos métodos de búsqueda implementados

En este apartado se muestra en la tabla 2 el rendimiento de los distintos métodos de búsqueda implementados (los resultados fueron obtenidos empleando la búsqueda con estructura de grafo) donde la búsqueda ciega usa una estrategia de exploración en anchura mientras que A*(h_0), A*(h_1) y A*(h_2) se corresponden con las ecuaciones 1, 2 y 3 respectivamente.

2. Discusión

2.1. Comparativa entre heurísticas

En este apartado se realiza una breve discusión sobre los resultados obtenidos por las heurísticas para los ejemplos planteados en relación a h*(n) (función de coste óptimo) haciendo que, la calidad (y la precisión) de una heurística aumente según se acercan los resultados a los obtenidos por h*(n).

Tabla 1: Tabla comparativa del rendimiento de las heurísticas

Estado	$h_0(s)$	$h_1(s)$	$h_2(s)$	h*(s)
(3, 4)	0	1	1	1
(3, 5)	0	0	1	2
(4, 0)	0	2	3	4
(0, 0)	0	3	3	4
(4, 5)	0	0	1	3
(0, 5)	0	1	3	3
(1, 5)	0	1	2	2
(8, 1)	0	2	2	3
(1, 0)	0	3	3	3
(7, 7)	0	1	1	4
(3, 9)	0	2	2	2
(0, 9)	0	3	3	3
(0, 8)	0	2	3	4
(5, 4)	0	0	1	2
(9, 0)	0	3	3	3
Promedio	0	1,6	2,13	2,86

Tal y como se ha demostrado en la primera parte de la memoria, las heurísticas nunca sobreestiman el coste real y eso se puede observar en la tabla 1. Como se puede ver en la heurística $h_0(n)$ siempre devuelve el valor 0 porque no tiene en cuenta el estado en el que está, y como es de esperar es una mala heurística porque es la que más se aleja de h*(n). Sin embargo, las heurísticas $h_1(n)$ y $h_2(n)$ se acercan a la función de coste óptimo h*(n) lo que hará que tengan que explorar la misma o menor cantidad de estados que la heurística $h_0(n)$ y la búsqueda primero en anchura.

2.2. Ventajas e inconvenientes de los métodos de búsqueda

La principal diferencia es que los métodos de búsqueda ciega con respecto a los informados es que los primeros no usan para nada la información del estado del problema buscando la solución de manera sistemática teniendo en cuenta de como se van explorando los nodos en la estructura búsqueda. Para los dos tipos de búsqueda ciega hay distintos puntos a tener en cuenta:

1. En la búsqueda primero en profundidad, el algoritmo de búsqueda puede no encon-

Tabla 2: Tabla comparativa de rendimiento de los métodos de búsqueda

		Coste de la búsqueda			Factor Ramificación Efectivo			
d	Ciega	A*(h_0)	A*(h_1)	A*(h_2)	Ciega	A*(h_0)	A*(h_1)	A*(h_2)
0	0	0	0	0	1.00	1.00	1.00	1.00
1	2	2	2	1	7.99	7.99	7.99	1.99
2	10	10	5	2	6.86	6.86	4.81	2.37
3	28	28	13	5	5.21	5.21	3,96	2,71
4	153	153	33	9	5.31	5.31	3.62	2.45
5	907	907	76	17	5.44	5.44	3.29	2.32
6	3267	3267	117	34	5.06	5.06	3.01	2.26
4	424	424	518	143	6.99	6.99	7.54	5.46
3	86	86	69	21	7.95	7.95	7.60	5.50
4	481	481	78	27	7.22	7.22	4.36	3.30
2	9	9	5	2	7.99	7.99	5.84	3.53
5	587	587	135	58	4.97	4.97	3.58	3.01
5	2100	2100	211	62	6.48	6.48	3.94	3.07
4	75	75	89	36	4.36	4.36	4.70	3.71
4	160	160	44	15	5.39	5.39	3.79	2.78

trar la solución debido a que se pone a explorar la profundidad de las ramas dando como consecuencia:

- el algoritmo se encuentre atrapado en una rama infinita donde no hay la solución

- o que el algoritmo este en un bucle infinito dentro de una rama

por estas razones se dice que el algoritmo primero en profundidad si encuentra la solución la encuentra por casualidad y la cual no tiene porque ser la búsqueda óptima.

2. En la búsqueda primero en anchura, el algoritmo de búsqueda se basa en explorar todas las posibilidades que hay en las ramas de la misma profundidad antes de proceder a buscar en las ramas descendientes. La búsqueda en anchura se basa en la exploración de todo el espacio de estados desde los que se puede llegar desde un estado inicial S_0, con lo que siempre encuentra una solución (si el factor de ramificación no es infinito y existe una solución), además esta solución que encuentra es óptima si los costes asociados a las operaciones son iguales (y valores constantes).

Sin embargo en la búsqueda informada se usa la información de un estado para compararla con otros para poder decidir si un estado está más cerca que otro para así poder generar menos nodos.

Como podemos ver el número de nodos que genera la profundidad en anchura es exponencial (tal y como se explicó en la primera parte de la memoria), mientras que las heurísticas en el algoritmo A* tratan de minimizar el número de nodos que hay que examinar para encontrar la solución, lo que supone que la generación de nuevos nodos, aunque crece también de manera exponencial no lo hace de una manera tan exhaustiva como la búsqueda en anchura.

2.3. Heurística no admisible

Lo primordial a la hora de tratar de encontrar la solución a este es el mero hecho de poder hallarla, pero en la mayoría de las ocasiones se quiere que está sea óptima, para ello al que minimizar los costes de esta, para ello las estrategias de búsqueda que ordenan la frontera (*fringe*) se basan en examinar los estados que se estima que van a tener un coste menor y para ello la función que estima ese coste tiene que ser admisible (es decir no sobreestimar el verdadero coste que va a tener) y así se logra encontrar una solución que es óptima. El hecho de no usar heurísticas no admisibles es que están pueden hallar soluciones subóptimas, aunque no siempre dado a que cualquier heurística admisible que se le sume una constante k distinta de cero deja de ser admisible (al dar en el estado que es solución una estimación de coste k en lugar de cero) y encuentra soluciones óptimas.

Para ello se propone la siguiente heurística:

$$h_4(n) = h_1(n) * 2^{dx} \tag{4}$$

donde dx = | x_i - x_m |. Esta heurística lo que hace es penalizar los movimientos en un eje haciendo que intente moverse primero por el eje contrario.

Con la heurística mostrada en la ecuación 4 podemos ver que el proceso de búsqueda nos da un camino no óptimo para ir desde la posición *(0, 0)* a la *(9, 9)* cuya salida de ejecución se muestra a continuación (aunque se puede ver en la figura 2 que aparece el tablero con la posición inicial y final donde en color azul aparece uno de los caminos óptimos mientras que con el camino rojo aparece las posiciones que ha utilizado la h_4).

Empezando la busqueda.

==
Fringe: [((0, 0), 0, 3072)]
Node selected: ((0, 0), 0, 3072)
Path: [((0, 0), 0, 3072)]
Successors: [((1, 2), 1, 1280) ((2, 1), 1, 640)]
==
Fringe: [((2, 1), 1, 640) ((1, 2), 1, 1280)]
Node selected: ((2, 1), 1, 640)
Path: [((0, 0), 0, 3072) ((2, 1), 1, 640)]

Successors: [((0, 0), 2, 3072) ((0, 2), 2, 2560) ((1, 3), 2, 1024) ((3, 3), 2, 256) ((4, 2), 2, 128) ((4, 0), 2, 128)]

===

Fringe: [((4, 0), 2, 128) ((4, 2), 2, 128) ((3, 3), 2, 256) ((1, 3), 2, 1024) ((1, 2), 1, 1280) ((0, 2), 2, 2560) ((0, 0), 2, 3072)]

Node selected: ((4, 0), 2, 128)

Path: [((0, 0), 0, 3072) ((2, 1), 1, 640) ((4, 0), 2, 128)]

Successors: [((2, 1), 3, 640) ((3, 2), 3, 256) ((5, 2), 3, 48) ((6, 1), 3, 24)]

===

Fringe: [((6, 1), 3, 24) ((5, 2), 3, 48) ((4, 2), 2, 128) ((3, 3), 2, 256) ((3, 2), 3, 256) ((2, 1), 3, 640) ((1, 3), 2, 1024) ((1, 2), 1, 1280) ((0, 2), 2, 2560) ((0, 0), 2, 3072)]

Node selected: ((6, 1), 3, 24)

Path: [((0, 0), 0, 3072) ((2, 1), 1, 640) ((4, 0), 2, 128) ((6, 1), 3, 24)]

Successors: [((4, 0), 4, 128) ((4, 2), 4, 128) ((5, 3), 4, 48) ((7, 3), 4, 8) ((8, 2), 4, 4) ((8, 0), 4, 6)]

===

Fringe: [((8, 2), 4, 4) ((8, 0), 4, 6) ((7, 3), 4, 8) ((5, 2), 3, 48) ((5, 3), 4, 48) ((4, 2), 2, 128) ((4, 2), 4, 128) ((4, 0), 4, 128) ((3, 3), 2, 256) ((3, 2), 3, 256) ((2, 1), 3, 640) ((1, 3), 2, 1024) ((1, 2), 1, 1280) ((0, 2), 2, 2560) ((0, 0), 2, 3072)]

Node selected: ((8, 2), 4, 4)

Path: [((0, 0), 0, 3072) ((2, 1), 1, 640) ((4, 0), 2, 128) ((6, 1), 3, 24) ((8, 2), 4, 4)]

Successors: [((6, 1), 5, 24) ((6, 3), 5, 24) ((7, 4), 5, 8) ((9, 4), 5, 1) ((9, 0), 5, 3) ((7, 0), 5, 12)]

===

Fringe: [((9, 4), 5, 1) ((9, 0), 5, 3) ((8, 0), 4, 6) ((7, 3), 4, 8) ((7, 4), 5, 8) ((7, 0), 5, 12) ((6, 3), 5, 24) ((6, 1), 5, 24) ((5, 2), 3, 48) ((5, 3), 4, 48) ((4, 2), 2, 128) ((4, 2), 4, 128) ((4, 0), 4, 128) ((3, 3), 2, 256) ((3, 2), 3, 256) ((2, 1), 3, 640) ((1, 3), 2, 1024) ((1, 2), 1, 1280) ((0, 2), 2, 2560) ((0, 0), 2, 3072)]

Node selected: ((9, 4), 5, 1)

Path: [((0, 0), 0, 3072) ((2, 1), 1, 640) ((4, 0), 2, 128) ((6, 1), 3, 24) ((8, 2), 4, 4) ((9, 4), 5, 1)]

Successors: [((7, 3), 6, 8) ((7, 5), 6, 8) ((8, 6), 6, 2) ((8, 2), 6, 4)]

===

Fringe: [((9, 0), 5, 3) ((8, 6), 6, 2) ((8, 0), 4, 6) ((8, 2), 6, 4) ((7, 3), 4, 8) ((7, 4), 5, 8) ((7, 5), 6, 8) ((7, 3), 6, 8) ((7, 0), 5, 12) ((6, 3), 5, 24) ((6, 1), 5, 24) ((5, 2), 3, 48) ((5, 3), 4, 48) ((4, 2), 2, 128) ((4, 2), 4, 128) ((4, 0), 4, 128) ((3, 3), 2, 256) ((3, 2), 3, 256) ((2, 1), 3, 640) ((1, 3), 2, 1024) ((1, 2), 1, 1280) ((0, 2), 2, 2560) ((0, 0), 2, 3072)]

Node selected: ((9, 0), 5, 3)

Path: [((0, 0), 0, 3072) ((2, 1), 1, 640) ((4, 0), 2, 128) ((6, 1), 3, 24) ((8, 2), 4, 4) ((9, 0), 5, 3)]

Successors: [((7, 1), 6, 12) ((8, 2), 6, 4)]

===

Fringe: [((8, 6), 6, 2) ((8, 0), 4, 6) ((8, 2), 6, 4) ((8, 2), 6, 4) ((7, 3), 4, 8) ((7, 4), 5, 8) ((7, 5), 6, 8) ((7, 3), 6, 8) ((7, 0), 5, 12) ((7, 1), 6, 12) ((6, 3), 5, 24) ((6, 1), 5, 24) ((5, 2), 3, 48) ((5, 3), 4, 48) ((4, 2), 2, 128) ((4, 2), 4, 128) ((4, 0), 4, 128) ((3, 3), 2, 256) ((3, 2), 3, 256) ((2, 1), 3, 640) ((1, 3), 2, 1024) ((1, 2), 1, 1280) ((0, 2), 2, 2560) ((0, 0), 2, 3072)]

Node selected: ((8, 6), 6, 2)

Path: [((0, 0), 0, 3072) ((2, 1), 1, 640) ((4, 0), 2, 128) ((6, 1), 3, 24) ((8, 2), 4, 4) ((9, 4), 5, 1) ((8, 6), 6, 2)]

Successors: [((6, 5), 7, 16) ((6, 7), 7, 8) ((7, 8), 7, 4) ((9, 8), 7, 0) ((9, 4), 7, 1) ((7, 4), 7, 8)]

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Fringe: [((9, 8), 7, 0) ((9, 4), 7, 1) ((8, 0), 4, 6) ((8, 2), 6, 4) ((8, 2), 6, 4) ((7, 8), 7, 4) ((7, 3), 4, 8) ((7, 4), 5, 8) ((7, 5), 6, 8) ((7, 3), 6, 8) ((7, 4), 7, 8) ((6, 7), 7, 8) ((7, 0), 5, 12) ((7, 1), 6, 12) ((6, 5), 7, 16) ((6, 3), 5, 24) ((6, 1), 5, 24) ((5, 2), 3, 48) ((5, 3), 4, 48) ((4, 2), 2, 128) ((4, 2), 4, 128) ((4, 0), 4, 128) ((3, 3), 2, 256) ((3, 2), 3, 256) ((2, 1), 3, 640) ((1, 3), 2, 1024) ((1, 2), 1, 1280) ((0, 2), 2, 2560) ((0, 0), 2, 3072)]

Node selected: ((9, 8), 7, 0)

Path: [((0, 0), 0, 3072) ((2, 1), 1, 640) ((4, 0), 2, 128) ((6, 1), 3, 24) ((8, 2), 4, 4) ((9, 4), 5, 1) ((8, 6), 6, 2) ((9, 8), 7, 0)]

Successors: [((7, 7), 8, 4) ((7, 9), 8, 0) ((8, 6), 8, 2)]

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Fringe: [((9, 4), 7, 1) ((7, 9), 8, 0) ((8, 0), 4, 6) ((8, 2), 6, 4) ((8, 2), 6, 4) ((8, 6), 8, 2) ((7, 8), 7, 4) ((7, 3), 4, 8) ((7, 7), 8, 4) ((7, 4), 5, 8) ((7, 5), 6, 8) ((7, 3), 6, 8) ((7, 4), 7, 8) ((6, 7), 7, 8) ((7, 0), 5, 12) ((7, 1), 6, 12) ((6, 5), 7, 16) ((6, 3), 5, 24) ((6, 1), 5, 24) ((5, 2), 3, 48) ((5, 3), 4, 48) ((4, 2), 2, 128) ((4, 2), 4, 128) ((4, 0), 4, 128) ((3, 3), 2, 256) ((3, 2), 3, 256) ((2, 1), 3, 640) ((1, 3), 2, 1024) ((1, 2), 1, 1280) ((0, 2), 2, 2560) ((0, 0), 2, 3072)]

Node selected: ((9, 4), 7, 1)

Path: [((0, 0), 0, 3072) ((2, 1), 1, 640) ((4, 0), 2, 128) ((6, 1), 3, 24) ((8, 2), 4, 4) ((9, 4), 5, 1) ((8, 6), 6, 2) ((9, 4), 7, 1)]

Successors: [((7, 3), 8, 8) ((7, 5), 8, 8) ((8, 6), 8, 2) ((8, 2), 8, 4)]

==

Fringe: [((7, 9), 8, 0) ((8, 0), 4, 6) ((8, 2), 6, 4) ((8, 2), 6, 4) ((8, 6), 8, 2) ((8, 6), 8, 2) ((7, 8), 7, 4) ((7, 3), 4, 8) ((7, 7), 8, 4) ((8, 2), 8, 4) ((7, 4), 5, 8) ((7, 5), 6, 8) ((7, 3), 6, 8) ((7, 4), 7, 8) ((6, 7), 7, 8) ((7, 5), 8, 8) ((7, 3), 8, 8) ((7, 0), 5, 12) ((7, 1), 6, 12) ((6, 5), 7, 16) ((6, 3), 5, 24) ((6, 1), 5, 24) ((5, 2), 3, 48) ((5, 3), 4, 48) ((4, 2), 2, 128) ((4, 2), 4, 128) ((4, 0), 4, 128) ((3, 3), 2, 256) ((3, 2), 3, 256) ((2, 1), 3, 640) ((1, 3), 2, 1024) ((1, 2), 1, 1280) ((0, 2), 2, 2560) ((0, 0), 2, 3072)]

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Successors: [((5, 8), 9, 16) ((9, 8), 9, 0) ((8, 7), 9, 2) ((6, 7), 9, 8)]

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Fringe: [((9, 8), 9, 0) ((8, 0), 4, 6) ((8, 2), 6, 4) ((8, 2), 6, 4) ((8, 6), 8, 2) ((8, 6), 8,

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Node selected: ((9, 2), 5, 2)

Path: [((0, 0), 0, 3072) ((2, 1), 1, 640) ((4, 0), 2, 128) ((6, 1), 3, 24) ((8, 0), 4, 6) ((9, 2), 5, 2)]

Successors: [((7, 1), 6, 12) ((7, 3), 6, 8) ((8, 4), 6, 4) ((8, 0), 6, 6)]

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Fringe: [((8, 2), 6, 4) ((8, 2), 6, 4) ((8, 6), 8, 2) ((8, 6), 8, 2) ((7, 9), 10, 0) ((8, 4), 6, 4) ((7, 8), 7, 4) ((8, 7), 9, 2) ((7, 3), 4, 8) ((7, 7), 8, 4) ((8, 2), 8, 4) ((8, 6), 10, 2) ((8, 0), 6, 6) ((7, 4), 5, 8) ((7, 5), 6, 8) ((7, 3), 6, 8) ((7, 7), 10, 4) ((7, 3), 6, 8) ((7, 4), 7, 8) ((6, 7), 7, 8) ((7, 5), 8, 8) ((7, 3), 8, 8) ((7, 0), 5, 12) ((6, 7), 9, 8) ((7, 2), 5, 12) ((7, 1), 6, 12) ((7, 1), 6, 12) ((6, 5), 7, 16) ((5, 8), 9, 16) ((6, 3), 5, 24) ((6, 1), 5, 24) ((6, 1), 5, 24) ((5, 2), 3, 48) ((5, 3), 4, 48) ((4, 2), 2, 128) ((4, 2), 4, 128) ((4, 0), 4, 128) ((3, 3), 2, 256) ((3, 2), 3, 256) ((2, 1), 3, 640) ((1, 3), 2, 1024) ((1, 2), 1, 1280) ((0, 2), 2, 2560) ((0, 0), 2, 3072)]

Node selected: ((8, 2), 6, 4)

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Successors: [((6, 1), 7, 24) ((6, 3), 7, 24) ((7, 4), 7, 8) ((9, 4), 7, 1) ((9, 0), 7, 3) ((7, 0), 7, 12)]

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Fringe: [((9, 4), 7, 1) ((8, 2), 6, 4) ((8, 6), 8, 2) ((8, 6), 8, 2) ((7, 9), 10, 0) ((8, 4), 6, 4) ((9, 0), 7, 3) ((7, 8), 7, 4) ((8, 7), 9, 2) ((7, 3), 4, 8) ((7, 7), 8, 4) ((8, 2), 8, 4) ((8, 6), 10, 2) ((8, 0), 6, 6) ((7, 4), 5, 8) ((7, 5), 6, 8) ((7, 3), 6, 8) ((7, 7), 10, 4) ((7, 3), 6, 8) ((7, 4), 7, 8) ((6, 7), 7, 8) ((7, 4), 7, 8) ((7, 5), 8, 8) ((7, 3), 8, 8) ((7, 0), 5, 12) ((6, 7), 9, 8) ((7, 2), 5, 12) ((7, 1), 6, 12) ((7, 1), 6, 12) ((7, 0), 7, 12) ((6, 5), 7, 16) ((5, 8), 9, 16) ((6, 3), 5, 24) ((6, 1), 5, 24) ((6, 1), 5, 24) ((6, 3), 7, 24) ((6, 1), 7, 24) ((5, 2), 3, 48) ((5, 3), 4, 48) ((4, 2), 2, 128) ((4, 2), 4, 128) ((4, 0), 4, 128) ((3, 3), 2, 256) ((3, 2), 3, 256) ((2, 1), 3, 640) ((1, 3), 2, 1024) ((1, 2), 1, 1280) ((0, 2), 2, 2560) ((0, 0), 2, 3072)]

Node selected: ((9, 4), 7, 1)

Path: [((0, 0), 0, 3072) ((2, 1), 1, 640) ((4, 0), 2, 128) ((6, 1), 3, 24) ((8, 2), 4, 4) ((9, 4), 5, 1) ((8, 2), 6, 4) ((9, 4), 7, 1)]

Successors: [((7, 3), 8, 8) ((7, 5), 8, 8) ((8, 6), 8, 2) ((8, 2), 8, 4)]

==

Fringe: [((8, 2), 6, 4) ((8, 6), 8, 2) ((8, 6), 8, 2) ((7, 9), 10, 0) ((8, 4), 6, 4) ((9, 0), 7, 3) ((8, 6), 8, 2) ((7, 8), 7, 4) ((8, 7), 9, 2) ((7, 3), 4, 8) ((7, 7), 8, 4) ((8, 2), 8, 4) ((8, 6), 10, 2) ((8, 0), 6, 6) ((8, 2), 8, 4) ((7, 4), 5, 8) ((7, 5), 6, 8) ((7, 3), 6, 8) ((7, 7), 10, 4) ((7, 3), 6, 8) ((7, 4), 7, 8) ((6, 7), 7, 8) ((7, 4), 7, 8) ((7, 5), 8, 8) ((7, 3), 8, 8) ((7, 5), 8, 8) ((7, 3), 8, 8) ((7, 0), 5, 12) ((6, 7), 9, 8) ((7, 2), 5, 12) ((7, 1), 6, 12) ((7, 1), 6, 12) ((7, 0), 7, 12) ((6, 5), 7, 16) ((5, 8), 9, 16) ((6, 3), 5, 24) ((6, 1), 5, 24) ((6, 1), 5, 24) ((6, 3), 7, 24) ((6, 1), 7, 24) ((5, 2), 3, 48) ((5, 3), 4, 48) ((4, 2), 2, 128) ((4, 2), 4, 128) ((4, 0), 4, 128) ((3, 3), 2, 256) ((3, 2), 3, 256) ((2, 1), 3, 640) ((1, 3), 2, 1024) ((1, 2), 1, 1280) ((0, 2), 2, 2560) ((0, 0), 2, 3072)]

Node selected: ((8, 2), 6, 4)

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Successors: [((6, 1), 7, 24) ((6, 3), 7, 24) ((7, 4), 7, 8) ((9, 4), 7, 1) ((9, 0), 7, 3) ((7, 0), 7, 12)]

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Node selected: ((9, 4), 7, 1)

Path: [((0, 0), 0, 3072) ((2, 1), 1, 640) ((4, 0), 2, 128) ((6, 1), 3, 24) ((8, 2), 4, 4) ((9, 0), 5, 3) ((8, 2), 6, 4) ((9, 4), 7, 1)]

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Busqueda: Grafo

Estrategia: A*

Nodos generados: 186

Nodos expandidos: 44

Factor de ramificacion: 1.726165771484375

Profun: 8

Coste: 8

Solucion: (0,0) (2,1) (4,0) (6,1) (8,2) (9,4) (8,6) (7,8) (9,9)

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3. Apendices

3.1. Diagrama de clases

Para poder entender como está estructura la lógica del programa se muestra un diagrama básico de ello que se puede ver en la figura 3.

3.2. Ejecución

El programa se entrega en un archivo *.jar* autoejecutable, para ello basta con entregar abrir una terminal y escribir la siguiente línea de código

$$java - jar\, IA\_p1.jar$$

lo que arrancará una interfaz gráfica para la configuración de los parámetros del programa, mientras que en la terminal se imprimirá los mensajes que se solicita en el boletín de prácticas.

Referencias

[1] Moret, Alonso, Cabrero, Guijarro, Mosqueira. *Fundamentos de Inteligencia Artificial.* Servicio de Publicaciones UDC. 2004

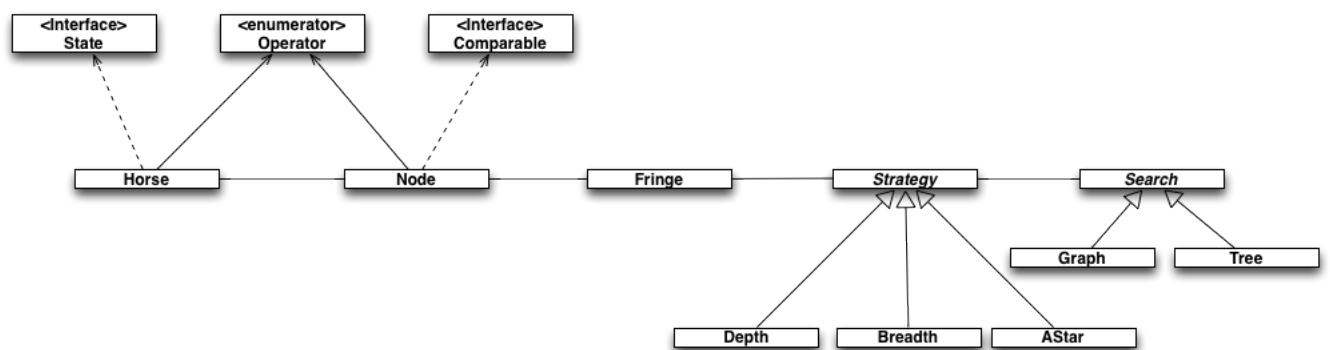[2] Russell, Norvig. *Inteligencia Artificial: Un Enfoque Moderno.* Pearson Prentice Hall. 2004
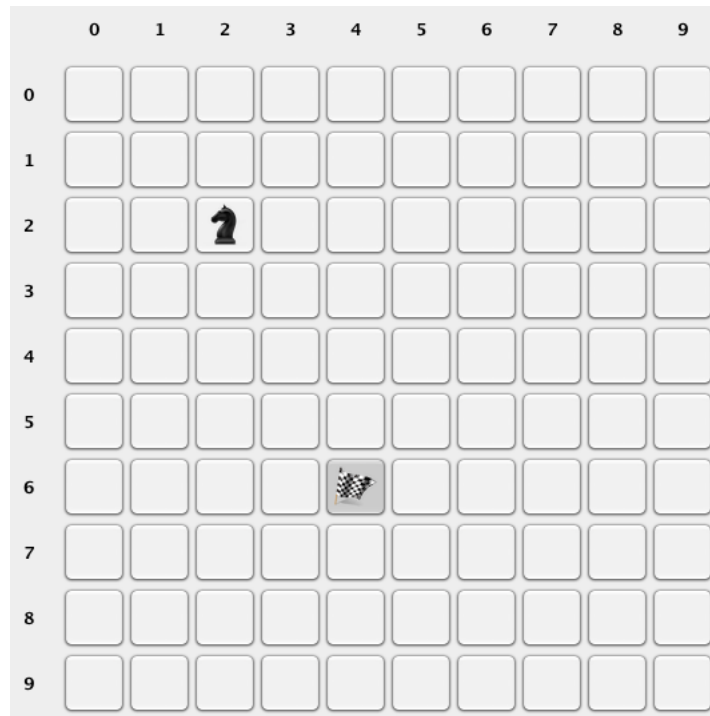
Figura 1: Situación empleada para los ejemplos de ejecución
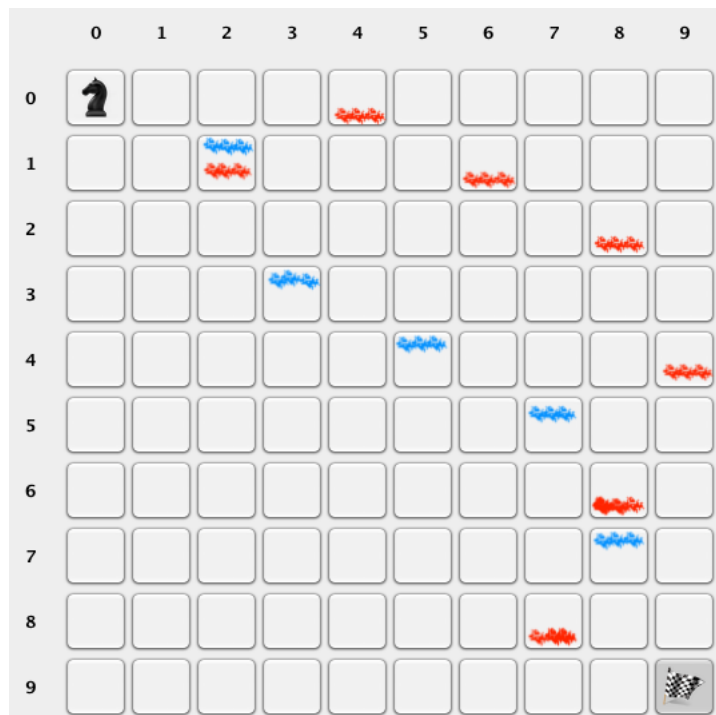
Figura 2: Situación empleada para usar en con la heurística $h_4(n)$ donde las casillas intermedias que emplea están marcadas con rojo mientras que un camino óptimo está marcado en color azul

Figura 3: Diagrama de clases diseñado para realizar el programa