

JULY 2021 UNIVERSITY OF SCIENCE, VNU - HCM

A\* Algorithm

**Shortest pathfinding algorithm**

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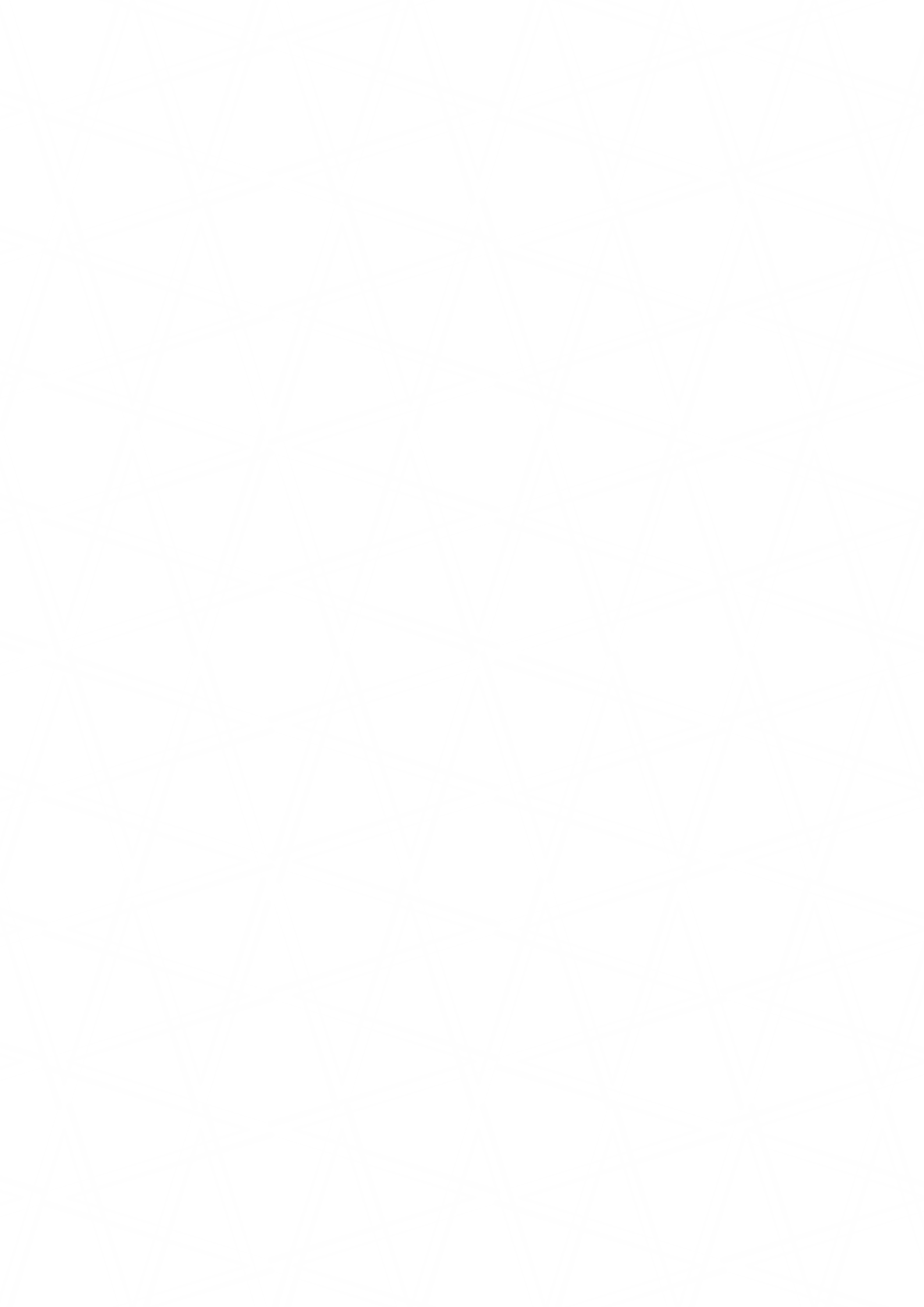
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# Table of Content



[Introduction 3](#_Toc78624584)

[History 4](#_Toc78624585)

[Application 5](#_Toc78624587)

[Data Structure 6](#_Toc78624588)

[Implement Algorithm 7](#_Toc78624590)

[Terminology 8](#_Toc78624592)

[Complexity 8](#_Toc78624594)

[Graph Example 9](#_Toc78624596)

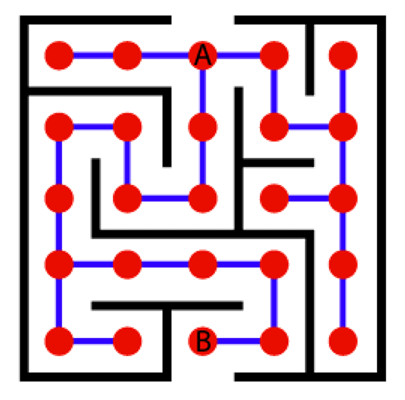
[List of questions for Quiz 10](#_Toc78624598)

[Work Assignments 12](#_Toc78624601)

[References 13](#_Toc78624604)

**A STAR ALGORITHM / PAGE 02**

# Introduction



The maze has become a classic game in the gaming world. There are thousands of games inspired by the maze. And the main task in which is probably mostly the player finding the way out of the maze in the shortest amount of time. There are many ways to complete this game. Many people choose to move forward without pre-calculating the path. However, in this way, when encountering an obstacle, the player will have to waste time to return and find a new path. Some people use pre-calculation of steps to find the most optimal path to the destination. Although pre-calculation can take quite a while, it will help players avoid obstacles.

From the 2 to play above we can see that it is important to make a plan before we move. Although they are usually time-consuming initially they are not trapped whereas moving first can be faster but fall into a trap.

The A\* algorithm was born for that reason. In games, we often want to find paths from one location to another. We’re not only trying to find the shortest distance; we also want save as much time as possible.

**A STAR ALGORITHM / PAGE 03**

# History

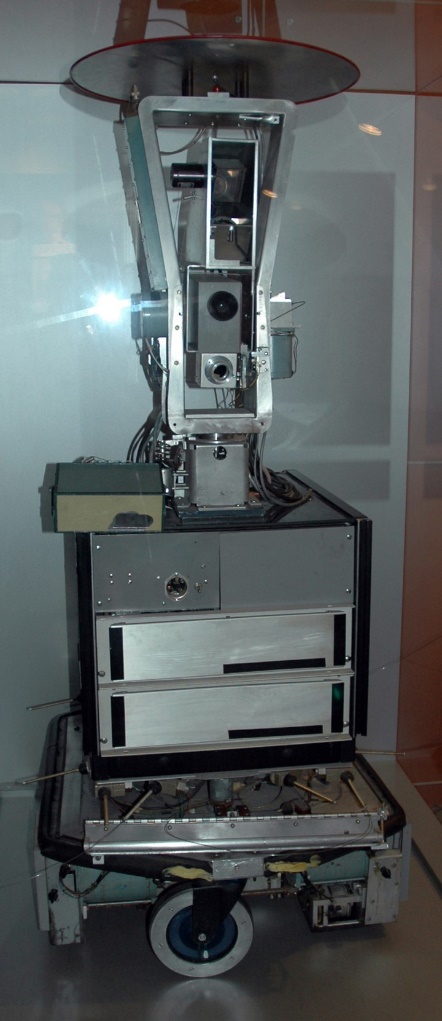
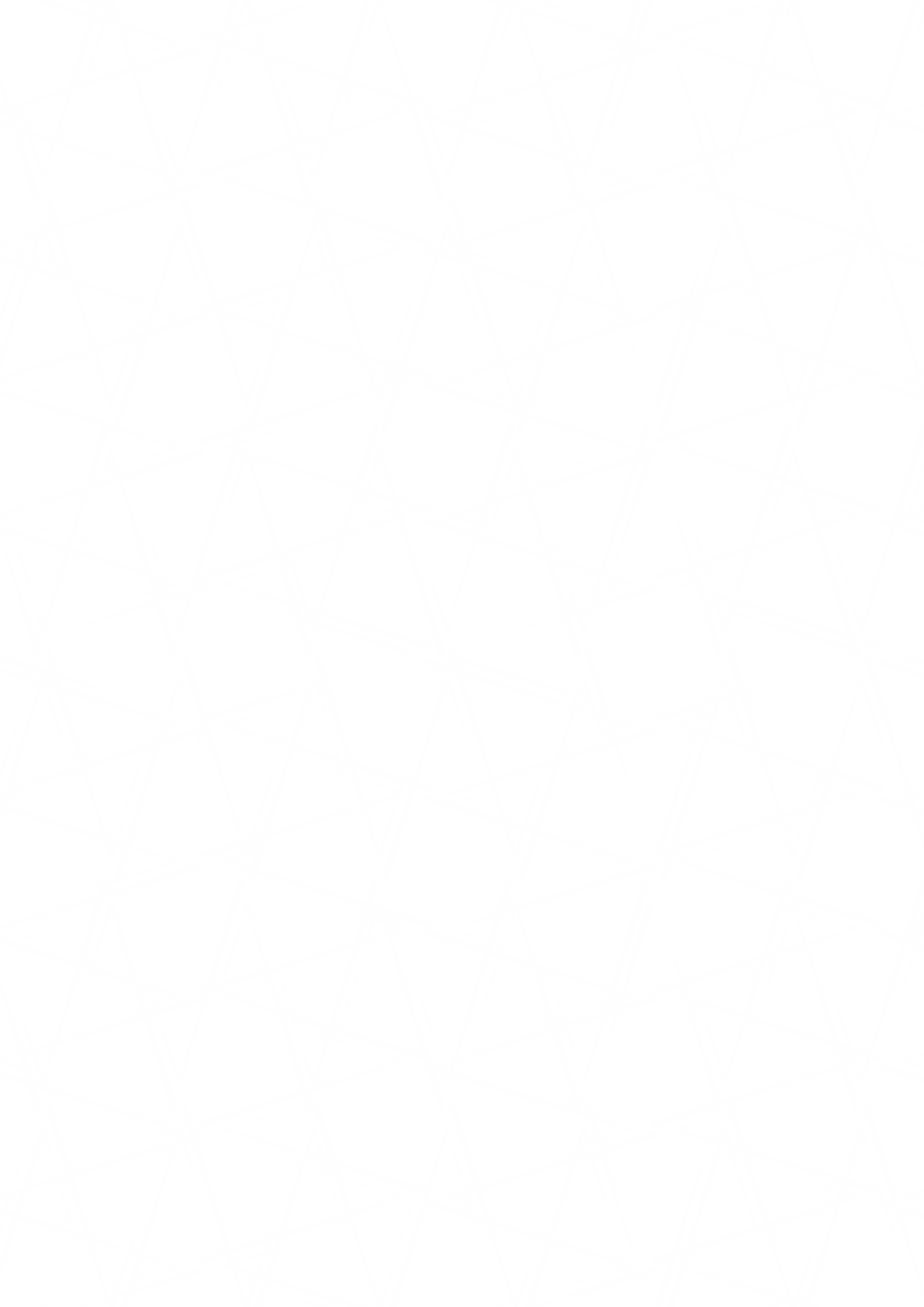
### A\* achieves better performance by using [heuristics](https://en.wikipedia.org/wiki/Heuristic_(computer_science)) to guide its search.

Created as part of the Shakey project aimed to build a mobile robot that has artificial intelligence to plan its actions, A\* was initially designed as a general graph traversal algorithm. Originally Nills Nilsson suggested using the Graph Traverser algorithm for Shakey's path planning. Graph Traverser is guided by a heuristic function h(n), the estimated distance from node n to the goal node: it entirely ignores g(n), the distance from the start node to n. Different from Nills Nilsson, Raphael suggested using the sum, g(n) + h(n). Peter Hart invented the concepts we now call admissibility and consistency of heuristic functions. A\* was originally designed for finding least-cost paths when the cost of a path is the sum of its costs, but it has been shown that A\* can be used to find optimal paths for any problem satisfying the conditions of a cost algebra. Because of its flexibility and versatility, it can be used in a wide range of contexts.

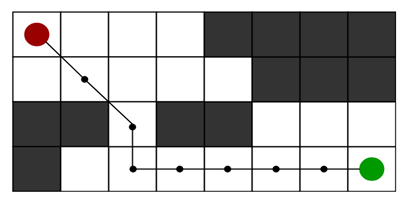
A\* was developed in 1968 to combine heuristic approaches like Greedy Best- First-Search and formal approaches like Dijkstra's Algorithm. It’s a little unusual in that heuristic approaches usually give you an approximate way to solve problems without guaranteeing that you get the best answer. However, A\* is built on top of the heuristic, and although the heuristic itself does not give you a guarantee, A\* can guarantee the shortest path.

Shakey the Robot in its [display case](https://en.wikipedia.org/wiki/Display_case) at the [Computer History Museum](https://en.wikipedia.org/wiki/Computer_History_Museum).

**A STAR ALGORITHM / PAGE 04**



# Application



* A\* algorithm is an advanced BFS algorithm that searches for shorter paths first rather than longer paths. A\* is optimal as well as a complete algorithm.
* A\* Algorithm is one of the best and popular techniques used for pathfinding and graph traversals.
* A lot of games and web-based maps use this algorithm for finding the shortest path efficiently. One example of this is the very popular game- Warcraft III.
* It finds applications in diverse problems, including the problem of [parsing](https://en.wikipedia.org/wiki/Parsing) using [stochastic grammars](https://en.wikipedia.org/wiki/Stochastic_context-free_grammar) in [NLP](https://en.wikipedia.org/wiki/Natural_language_processing).

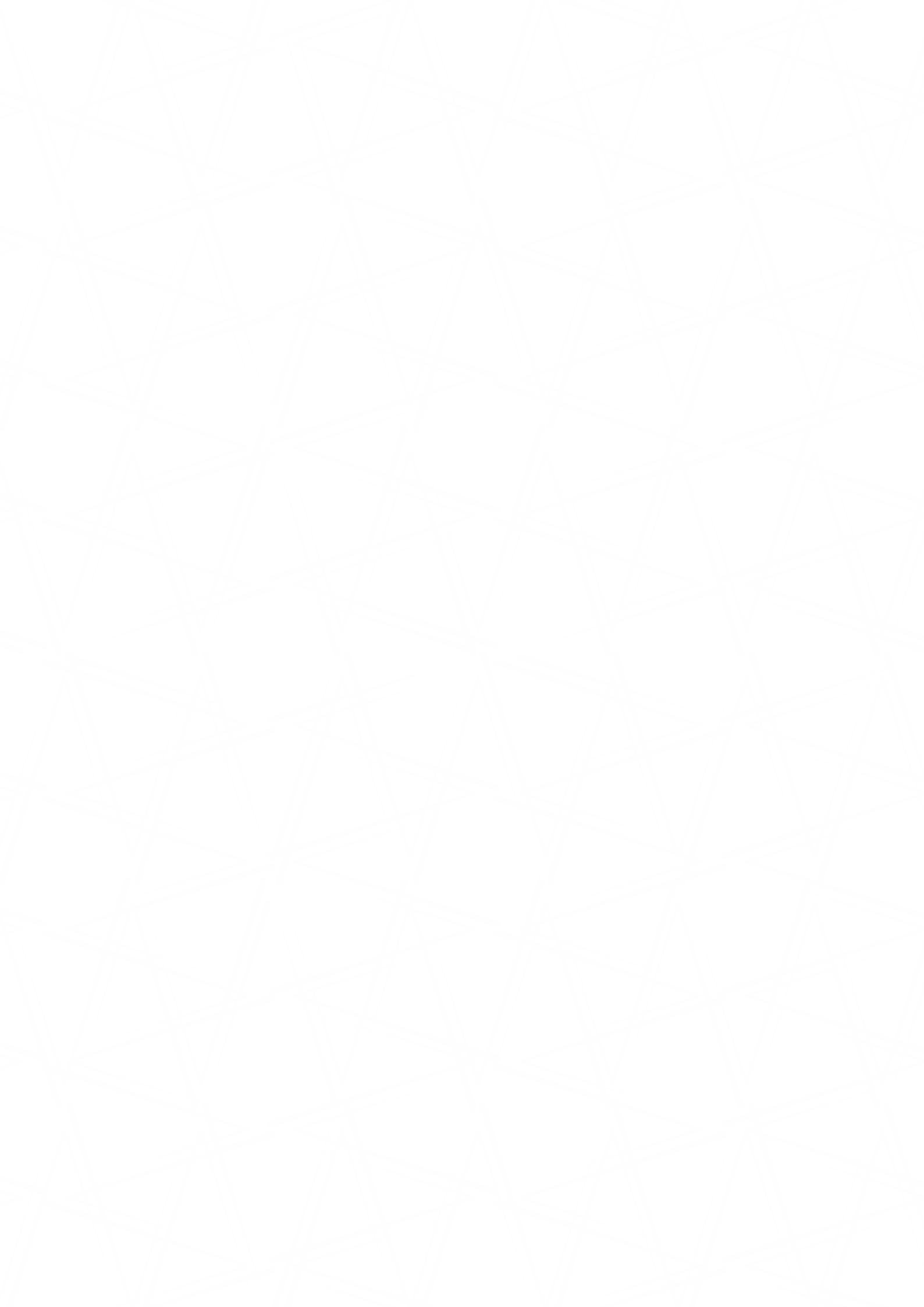
The Pathfinder: GameplayKit Pathfinding Basics

This game automatically creates mazes then uses GameplayKit to solve them, highlighting the shortest path through each maze.

2D Grid having several obstacles and we start from the source red cell to reach towards a goal green cell

**A STAR ALGORITHM / PAGE 05**

# Data Structure



### I decided to approach this algorithm by using frontier.

This frontier is a min-heap for a priority queue - it keeps the smallest value at the top. It is suitable for the frontier to keep track of the node that may be traversed in the next steps.

This min-heap priority queue uses the min-heap data structure which supports operations such as insert, minimum, extract-min, decrease-key. In this implementation, the [weight](https://en.wikipedia.org/wiki/Weighted_graph) of the edges is used to decide the priority of the [vertices](https://en.wikipedia.org/wiki/Vertex_(graph_theory)). Lower the weight, higher the priority and higher the weight, lower the priority.

A\* uses the heuristic to reorder the nodes so that it’s more likely that the goal node will be encountered sooner. And the priority queue will rearrange that to get the best node that we can visit next.

**A STAR ALGORITHM / PAGE 06**

# Implement Algorithm



*The main technique for this algorithm is using frontier as a priority queue to put the nodes while waiting. Then get the smallest cost of a path from that and put in the visited to mark up what has been visited. When we catch the goal, we start to reverse the path (the parents of visited nodes) that we saved in the frontier. Then, we return the path. If that node is not goal, we traverse all the children of that node and put these in the frontier with the formula .*

visited = [ ] //save the visited node in this, some other paper could mention it as exp anded states

path = [ ] // the p ath will return

parents = [ ] // save the p arents of the child node every time it find the path frontier = <priority\_queue> // p riority queue which has the smallest on the top push [ heuristics[START], START, -1 ] // the f value, the state, its parent

while frontier: // loop until the frontier is NOT empty

heuristic, node, parent = top of frontier //get the smallest value f(node) pop the top

if node not in visited: visited add node parents [node] = parent

if node is GOAL: // if goal is reached, get the path and return while parents [node] ≠ 1:

path add node

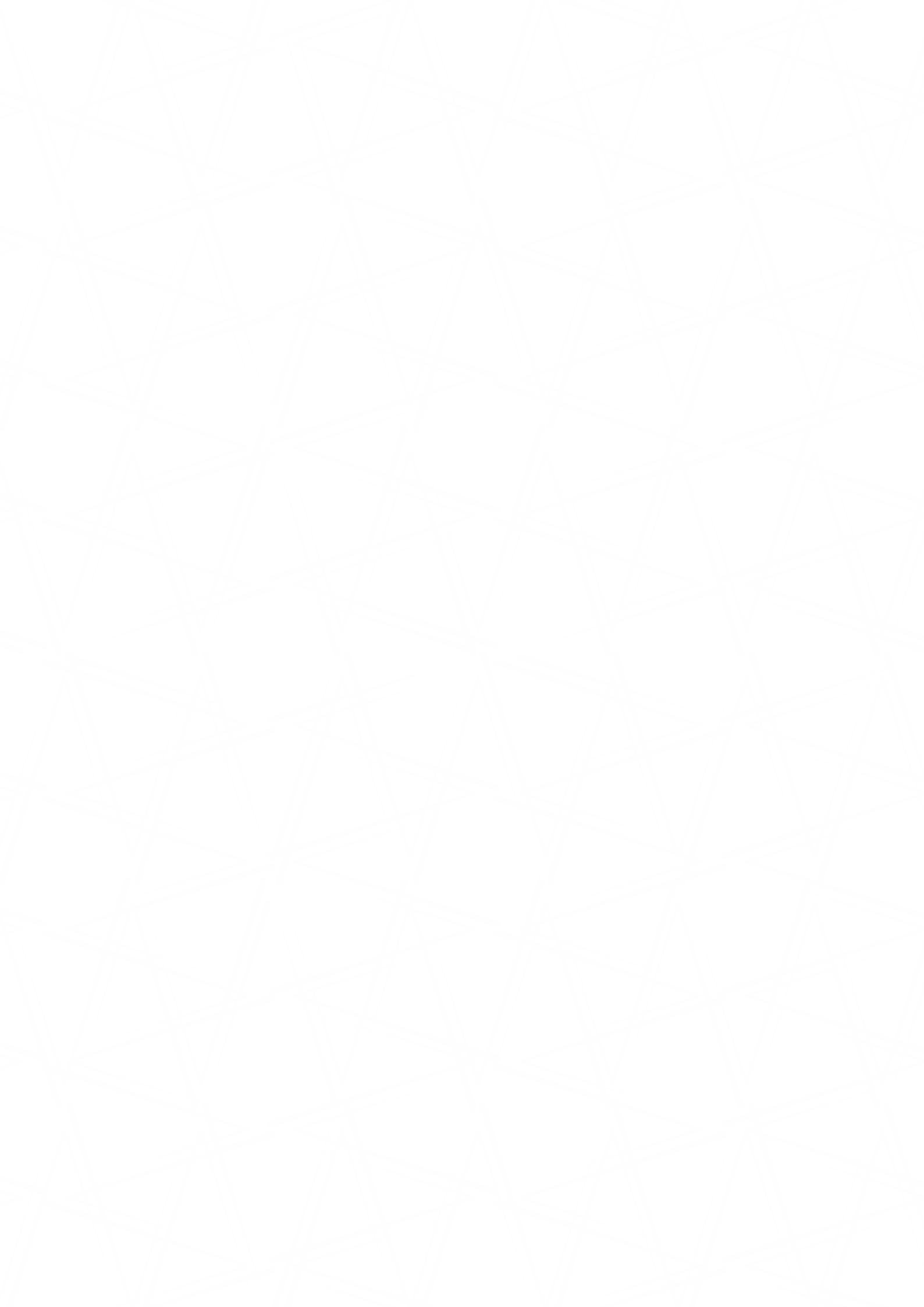
node = parents [node] path add start

reverse the path return path

traverse all the child of the node using for calculate the f(child) = g(child) + h(child) frontier push [ f(child), child, node ]

**A STAR ALGORITHM / PAGE 07**

# Terminology



*A\* is a best-first search starting from a specific starting node of a graph, it aims to find a path to the given goal having the smallest cost.*

Heuristic value is the estimated cost of moving from the current state to the goal state.

f is the parameter of A\* which is the sum of the other parameters G and H and is the least cost from one node to the next node. This parameter is responsible for helping us find the most optimal path from our source to destination. f = g + h

+ g is the cost of moving from one node to the other node. This parameter changes for every node as we move up to find the most optimal path.

+ h is the heuristic/estimated path between the current code to the destination node. This cost is not actual but is, in reality, a guess cost that we use to find which could be the most optimal path between our source and destination.

# Complexity

#### *One major practical draw back is its space complexity, as it stores all generated nodes in memory.*

#### Time Complexity

The time complexity of A\* depends on the heuristic. In the worst case of an unbounded search space, the number of nodes expanded is exponential in the depth of the solution (the shortest path) d: , where b is the branching factor (the average number of successors per state).

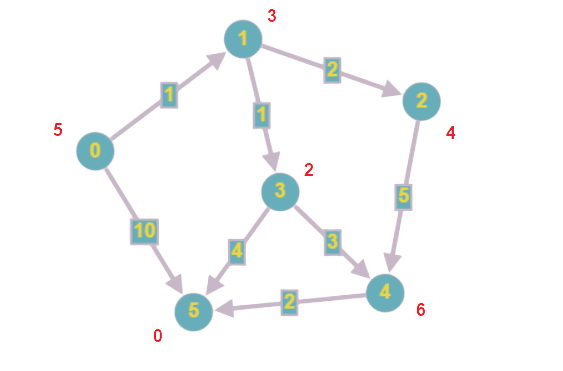
#### Space Complexity

The space complexity of A\* is roughly the same as that of all other graph search algorithms, as it keeps all generated nodes in memory.

, V is the number of vertices in a graph. The worst case is traversing all of the vertices in the graph.

**A STAR ALGORITHM / PAGE 08**

# Graph Example



### We start from 0 to 5 as a goal.

The formula is f(n) = g(n) + h(n), then we apply to the source: f(0) = 5 + 0 and put it to the frontier.

Next, there are 2 ways from 0, we put 0 to the visited and the frontier is 1 5.

0 -> 1 is f(1) = 1 + 3 = 4

0 -> 5 is f(5) = 10 + 0 = 10

Because 1 is on the top of the frontier, we put it in visited, then check the children of 1 because 1 is not the goal, the frontier will be 3 2 5.

1 -> 2 is f(2) = (cost from 0 to 2) 3 + 4 = 7

1 -> 3 is f(3) = (cost from 0 to 2) 2 + 2 = 4

Next, 3 is the top of the frontier, we put it in visited, then check the children because 3 is not the goal, the frontier now will be 5 (0 -> 1 -> 3 -> 5), 2, 5 (0 ->

5), 4.

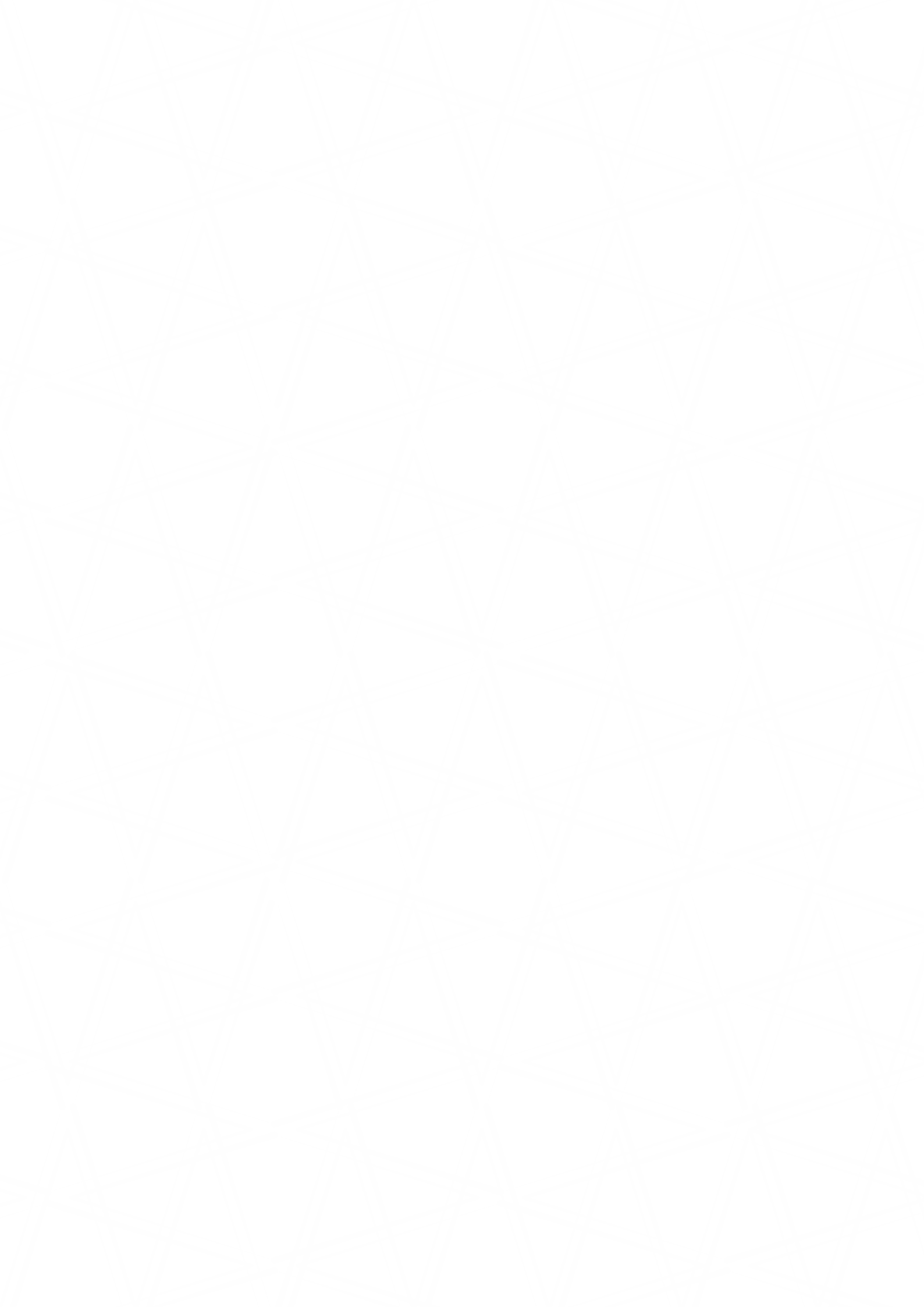
3 -> 4 is f(4) = (cost from 0 to 4) 5 + 6 = 11

3 -> 5 is f(5) = (cost from 0 to 5) 6 + 0 = 6

Now, goal 5 is on the top of the frontier, we reverse the path after getting the parents of the nodes when we approach goal 5. Then we have the path which is **0, 1, 3, 5**.

**A STAR ALGORITHM / PAGE 09**

# List of questions for Quiz



1. A\* Algorithm does ...

#### a. path-finding and graph traversals, calculate from heuristics and path cost

b. finds shortest paths in a directed weighted graph with positive or negative edge weights (Floyd–Warshall Algorithm)

c. finds the least-cost path from a given initial node to any goal node (B\* Algorithm)

d. explores as far as possible along each branch before backtracking (BFS)

1. In which project and in what year was the A\* Algorithm first published?

#### a. Shakey project (1968)

b. Plankalkül programming language (1945) - BFS

c. Richard Korf (1985) - IDA\*

d. Harpy Speech Recognition System (1976) - Beam

1. What is heuristic value?

#### a. the estimated cost from the current vertex to the goal vertex

b. the smallest cost from the start vertex to the goal vertex

c. the cost from the root node to the current node

d. the value for the best solution to a given problem

1. The A\* Algorithm is developed based on:

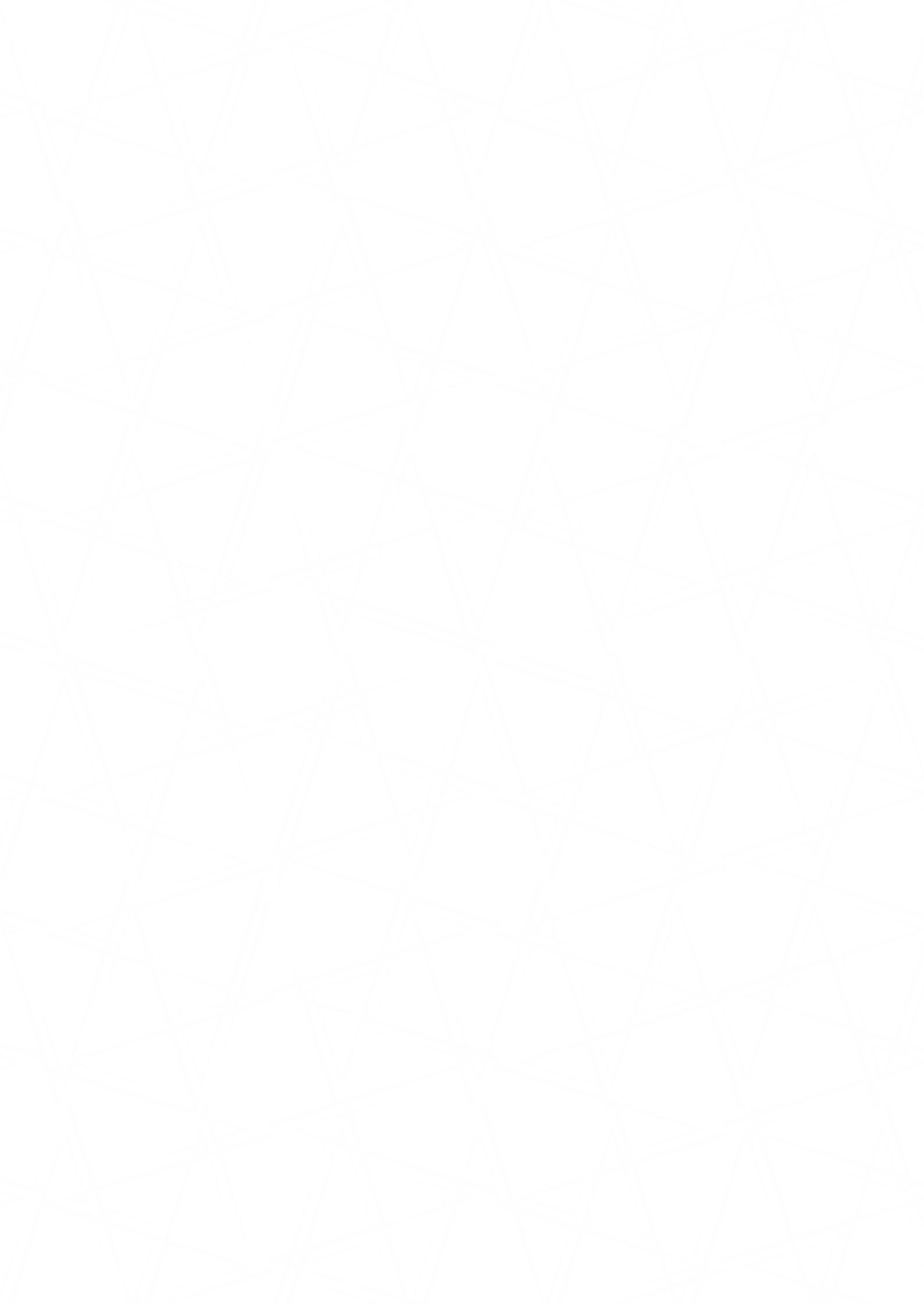
#### Dijkstra's Algorithm

* 1. BFS Algorithm
  2. IDA\* Algorithm

d. Floyd–Warshall Algorithm

**A STAR ALGORITHM / PAGE 10**

# L1ist of questions for Quiz



2. T

1. What is the TIME and SPACE complexity of A\* Algorithm?

a. **O(b^d)**

b. O(h)

c. O(h) - O(|V|)

d. O(V) - O(h)

1. What is NOT an application of A\* Algorithm?

a. **Google Maps**

b. Warcraft III

c. Graph Traversal

d. n-puzzle Solving

1. What formula does the A\* Algorithm calculate the path to the next node?

#### a. f(n) = g(n) + h(n)

b. f(n) = g(n) / h(n)

c. g(n) = f(n) + h(n)

d. h(n) = g(n) + g(n)

**A STAR ALGORITHM / PAGE 11**

# Work Assignments

Find out the introduction (history...) Some terminologies (heuristic...) Application

## Quang Tú

Notes for implementation, time/ space complexity

Write source code (Graph) Graph demo (draw -> result)

Find the questions for Quiz and put the questions on Kahoot

Report composer and PowerPoint arranger

Template for PowerPoint and report

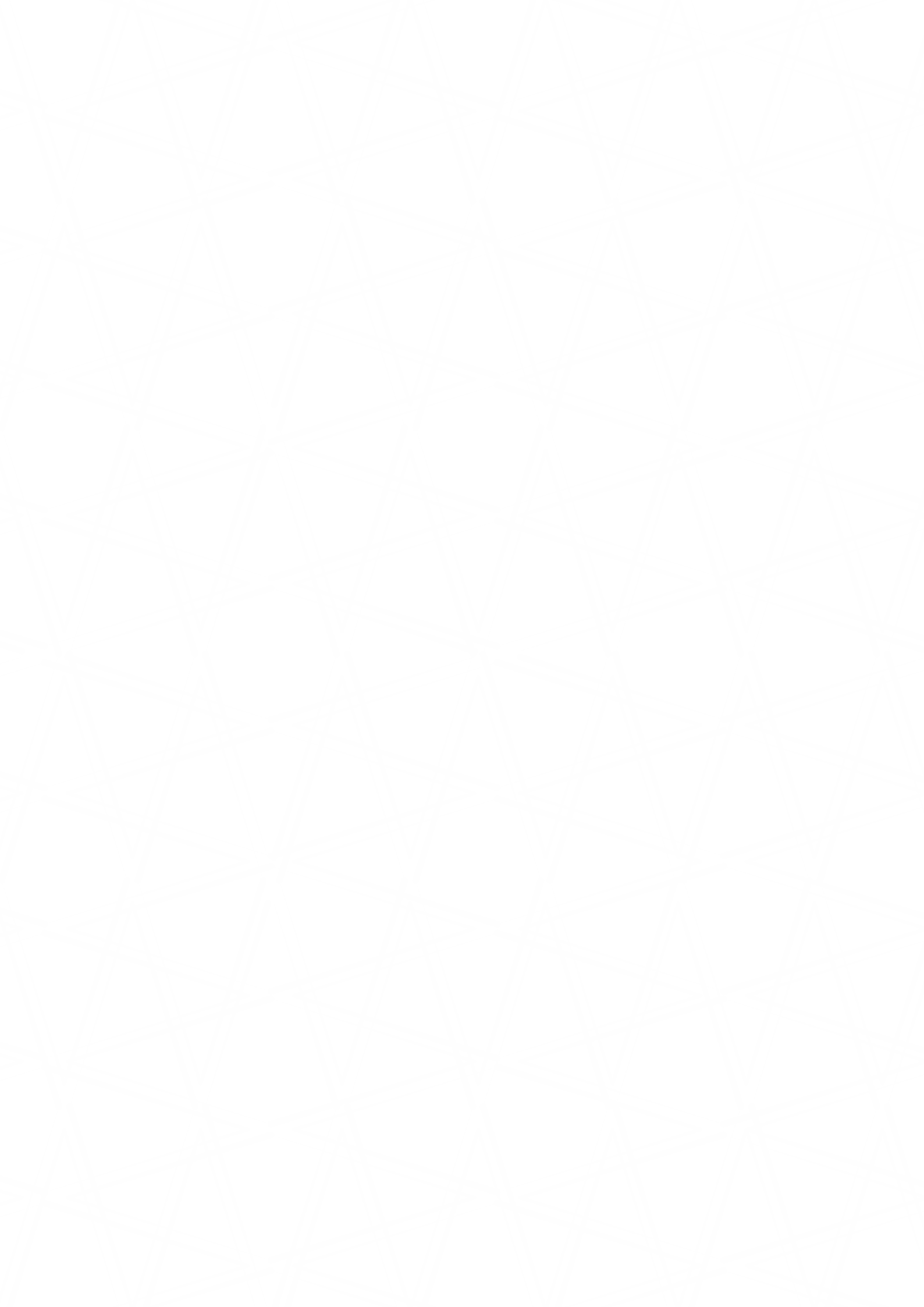
## Hoàn Mỹ

Hoài Tâm



**A STAR ALGORITHM / PAGE 12**

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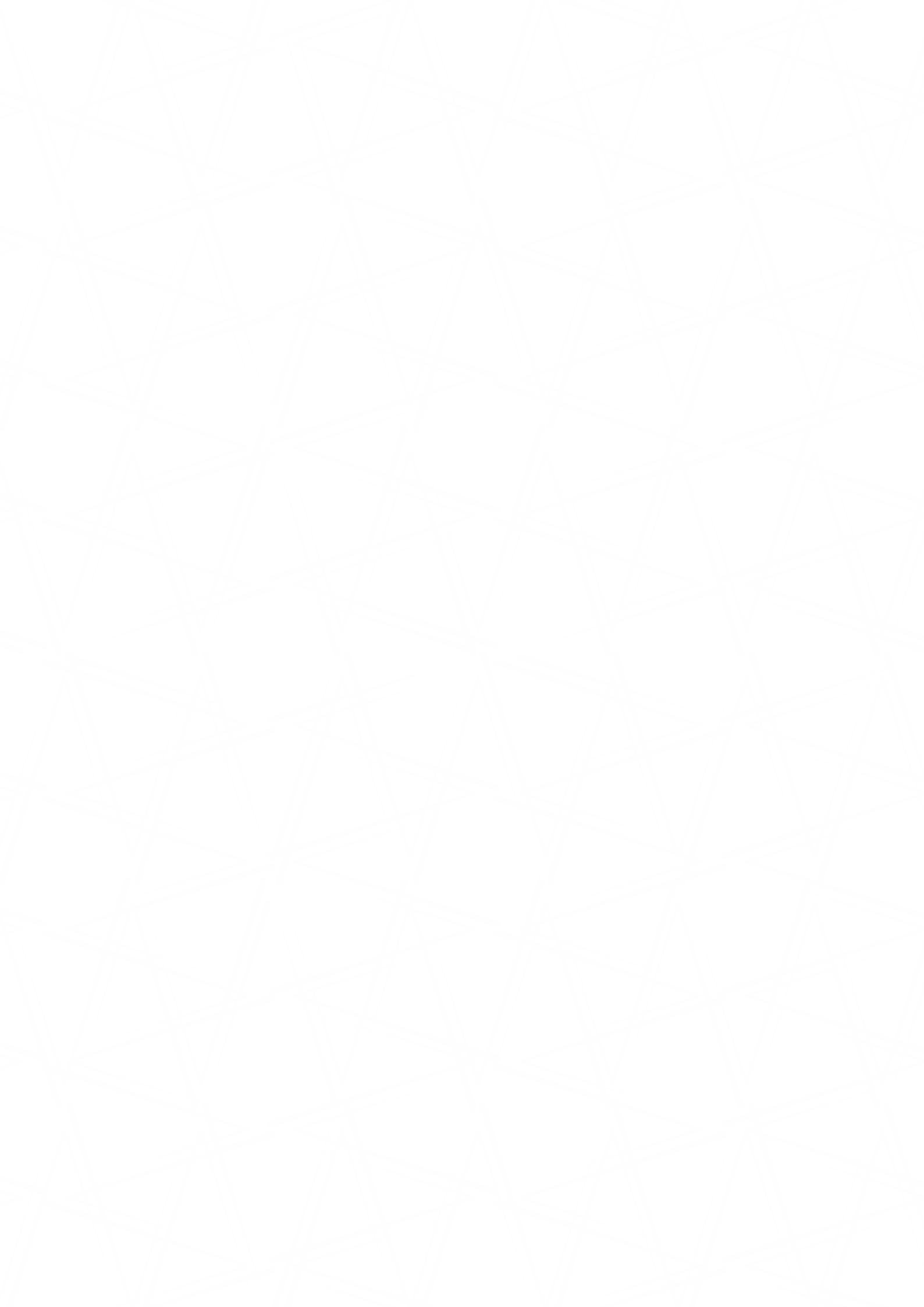
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**A STAR ALGORITHM / PAGE 13**

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**A STAR ALGORITHM / PAGE 14**