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A*Grid2D: Optimized Grid-Based A* Pathfinding for 2D Game Environments

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Abstract. In recent years, the complexity of 2D game environments has increased, requiring more sophisticated AI-driven solutions to ensure seamless and immersive game-play experiences. Traditional pathfinding algorithms often struggle to adapt in real time to dynamic obstacles and multi-agent interactions, making advancements like A*Grid2D crucial for modern game development. This study significantly im-pacts modern 2D game development by refining NPC pathfinding and enhancing gameplay immersion, efficiency, and realism. A*Grid2D addresses key challenges—dynamic obstacles, multiple agents, goal shifts, and smooth movement—ensuring seamless navigation in complex environments. Its optimized performance benefits developers by enabling more responsive AI behaviors without compromising computational efficiency. In today's 2D games, this results in smarter NPCs, faster decision-making, and more dynamic interactions, ultimately improving the player's experience. By providing a tailored pathfinding solution, A*Grid2D contributes to the evolution of AI-driven mechanics in 2D games, ensuring fluid movement, realistic behavior, and strategic gameplay while shaping the future of NPC navigation.

Keywords: Pathfinding Optimization, NPC Realism, Dynamic Adaptability, Game Development Impact.

1. Introduction

In 2D game development, seamless NPC navigation is essential for delivering immersive and dynamic gameplay. The ability of non-player characters to traverse complex environments intelligently and efficiently is a cornerstone of game design, directly influencing player engagement and interaction [1]. Pathfinding algorithms play a central role in this process, enabling characters to determine the shortest or most optimal route between two points while adapting to obstacles and evolving conditions [2]. Traditionally used across various fields—including video games, robotics, and logistics—these algorithms ensure fluid movement within interactive spaces.

While modern 2D games require intelligent NPC behavior, existing pathfinding solutions often struggle with real-time responsiveness, obstacle adaptation, and smooth character movement. A*Grid2D addresses these challenges by integrating discrete path computation, specialized heuristics, and adaptive obstacle tracking, ensuring that NPCs react realistically to dynamic environments. This enhances immersion and overall game

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mechanics. This study introduces A*Grid2D, a grid-based adaptation of the A* algorithm, specifically tailored for tile-based 2D game environments.

The primary objective of this research is to develop, refine, and evaluate A*Grid2D—an optimized A* pathfinding algorithm designed for NPC navigation in 2D games. By integrating cardinal and diagonal movement, heuristic-driven path calculations, and dynamic obstacle handling, A*Grid2D aims to enhance efficiency, accuracy, and realism in AI-driven character movement. This study explores A*Grid2D's adaptability across multiple genres—Lost Cat (platformer), Antivirus (top-down shooter), and Dungeon Escape (point-and-click dungeon crawler)—assessing its ability to improve NPC responsiveness in diverse gameplay scenarios. Through extensive testing and comparative analysis against traditional A* pathfinding methods, this research evaluates A*Grid2D's impact on gameplay fluidity and AI behavior, providing a scalable and versatile solution for developers.

As modern 2D games increasingly demand dynamic and intelligent AI, existing pathfinding solutions often struggle with real-time responsiveness, obstacle adaptation, and smooth NPC movement. A*Grid2D tackles these challenges by integrating discrete path computation, specialized heuristics, and adaptive obstacle tracking, ensuring that characters react realistically to shifting environmental conditions. The findings of this study will contribute to game AI development, offering an innovative approach to pathfinding optimization in interactive 2D worlds. By demonstrating A*Grid2D's scalability and effectiveness, this research establishes a foundation for future advancements in NPC behavior simulation.

2. Methodology

The study used the Waterfall Model to systematically develop precise NPC movement AI in 2D platformers. Refinements were applied to create advanced pathfinding algorithms. Three different games were designed to test the adaptability of A*Grid2D pathfinding across various scenarios, supported by a literature review of previous implementations.

Once integrated into the game engine, the algorithm underwent refinements to enhance NPC behavior and mechanics. QA testing was conducted to identify bugs and performance issues, ensuring smooth functionality. The improved pathfinding system was then applied across all three games, each presenting unique environmental challenges.

During deployment, the enhanced A* algorithm was fully integrated and tested for performance limitations across different gameplay styles. Beta feedback was analyzed to refine the games, with reported issues addressed through iterative improvements. Using the Godot game engine, the study successfully demonstrated the reliability of A*Grid2D in diverse 2D environments.

Figure 1 illustrates the structure of the games, each designed as simple 2D platformers featuring structured environments and char-acters. However, the core focus of this research lies in Non-Player Character (NPC) pathfinding—the ability of entities to navigate their surroundings efficiently, which is fundamental to both player movement and NPC behavior.

Figure 1. Game Menu Selection

This study conducts a comparative analysis of pathfinding performance across three games in different genres. Through systematic testing, researchers aim to identify bottlenecks, dependencies, and bugs affecting movement efficiency and responsiveness. By assessing the computational constraints and behavioral patterns of NPCs within each game type, this study seeks to refine pathfinding algorithms, enhance navigation realism, and improve overall gameplay fluidity.

Ultimately, these findings contribute to a broader understanding of AI-driven movement in interactive digital environments, offering valuable insights for game development, robotics, and intelligent agent simulations.

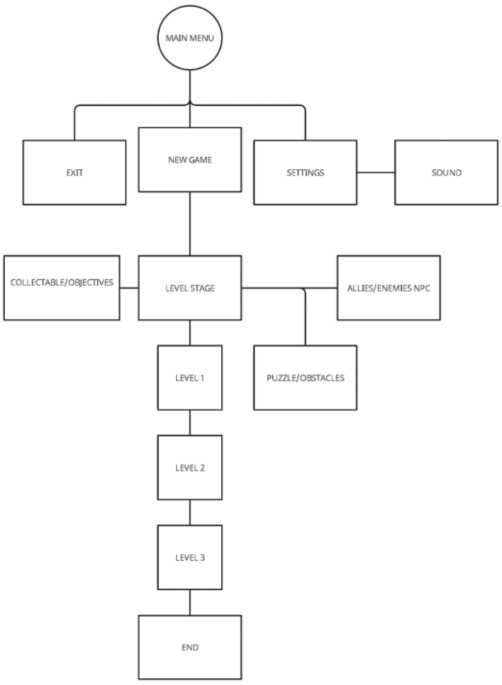

Figure 2. Fishbone Diagram

Figure 2 illustrates the game's main menu, serving as the central hub for player interaction. The design is simple and intuitive, featuring five distinct sections—Exit, New Game, Settings, Sound, and Level Stage—that allow players to quickly select an action. This streamlined layout reduces cognitive load, ensuring effortless navigation, even for new players.

While options like Exit and New Game are immediately accessible, the Level Stage branch introduces deeper gameplay elements, including collectibles, objectives, puzzle challenges, multiple levels, and a final section. This layered approach keeps core actions uncluttered while encouraging exploration, ultimately enhancing the overall user experience and facilitating a seamless transition into gameplay.

3. Results and Discussions

3.1 A*Grid2D Pathfinding Efficiency and Structural Advantages

A*Grid2D pathfinding builds upon the classic A algorithm by implementing a structured grid-based system that optimizes navigation efficiency. Unlike traditional methods requiring manually placed nodes, A*Grid2D utilizes a predefined 2D grid, ensuring consistent connectivity and reducing computational complexity. This approach simplifies pathfinding setup and improves fluid movement across the game environment, making it an effective solution for diverse gaming applications.

Recent improvements in 2D pathfinding, including cyclic dependency management [3][4], optimized grid-based methods such as Theta* and Jump Point Search [5], and specialized algorithms for computational efficiency [6], have significantly enhanced A*Grid2D's adaptability. These refinements allow real-time path recalibration, improving responsiveness in dynamic environments and making the system more reliable for simulations and interactive scenarios.

3.2 Game Map Design: Structured Navigation and Immersion

Figure 3 illustrates a structured 2D game map that employs a grid-based layout to ensure clear spatial organization and smooth navigation. Terrain elements—such as grass, water, and pathways—are visually distinct through textures and color variations, enhancing environmental recognition. Each grid cell, uniquely identified by coordinate pairs (x, y), facilitates precise placement and movement, allowing for seamless interaction within the game world.

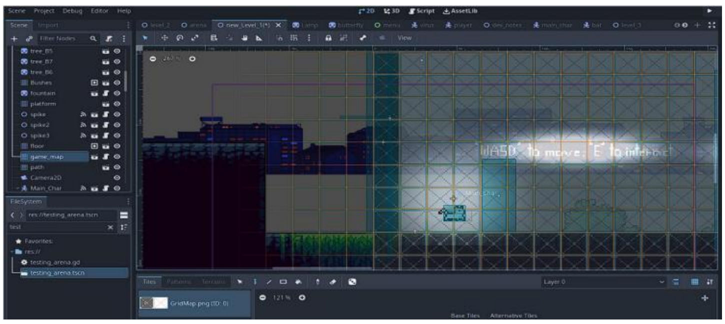

Figure 3. Game Map Design Using a 2D Grid

Beyond navigation, visual depth is achieved through layered foreground and background elements such as trees, cliffs, and buildings, making the environment more immersive. Atmospheric effects, including dynamic lighting and weather transitions, contribute to realism, while landmarks and directional markers enhance exploration.

Animated terrain features like flowing water and rustling grass further enrich the experience, ensuring an engaging visual and interactive journey for players.

3.3 Algorithmic Flow: Adaptive Pathfinding Operations

The A*Grid2D algorithm begins with grid initialization to collect spatial data necessary for path calculations. By identifying the current location of the pathfinding entity and its destination, the system computes the optimal route using heuristic analysis and stores the results in an array. This structured approach ensures accurate and efficient navigation, particularly in complex game environments with interactive movement.

A*Grid2D dynamically adjusts paths in response to environmental changes. If the target moves or obstacles emerge, the algorithm recalculates the shortest route without disrupting movement. Path recalculations also occur when certain conditions are met, such as when a player enters an entity's aggro range (*e.g.*, the "Bat" NPC in Lost Cat). If the entity successfully reaches its target, the process terminates; otherwise, iterative recalculations maintain efficient and fluid navigation.

3.4 Performance Metrics and Computational Analysis

Performance evaluation focuses on key factors, including path length efficiency, real-time adaptability, grid scalability, and concurrent entity management. Shorter paths enhance navigation speed by minimizing CPU workload, while real-time responsiveness ensures uninterrupted movement despite dynamic obstacles. A*Grid2D excels in these areas by leveraging heuristic functions to optimize route computation.

Grid size and entity count directly affect processing speed and computational load. While smaller grids facilitate rapid calculations, larger grids introduce complexity due to increased cell evaluations. Similarly, higher entity populations can cause latency, impacting FPS output. Performance testing confirms A*Grid2D's strengths in adaptive navigation but highlights challenges in dense environments, suggesting areas for further refinement to maximize scalability and efficiency.

4. Conclusion

This study confirms that A*Grid2D is a groundbreaking advancement in 2D game AI, transforming conventional pathfinding by reimagining the classic A* path-finding algorithm within a grid-based framework. By integrating both cardinal and diagonal movements with dynamic, adaptive heuristics, the algorithm eliminates the cumbersome need for manually positioning irregular nodes in tile-based environments. Extensive testing across diverse game genres—from platformers to top-down and point-and-click adventures—demonstrates its precision, responsiveness, and ability to swiftly recalculate optimal paths in real time, even as obstacles continuously change. This functionality not only enhances NPC navigation but also significantly boosts player immersion in dynamic and complex game worlds.

Moreover, the structured grid system of A*Grid2D enhances computational efficiency by discretizing the game environment into uniquely identifiable cells, reducing processing overhead regardless of the map's complexity. This efficiency enables developers to effectively manage both confined and expansive landscapes, paving the way for future integrations with advanced techniques like machine learning to predict environmental changes and player behaviors. Looking ahead, the potential to extend this approach into three-dimensional or hybrid navigation systems broadens its applicability to robotics and simulation training. In sum, A*Grid2D represents an evolutionary leap in game AI—merging adaptive performance with simplified development and setting a robust foundation for next-generation navigation systems that will redefine interactive digital entertainment.

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