CAPSTONE PROJECT 1
Planning Document

Evaluation of Nature-inspired Optimisation Algorithms in Solving Versus Tetris

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Abstract

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1 Introduction

Tetris is a popular video game created in 1984 by computer programmer Alexey Pajitnov [1]. It is a puzzle game that requires players to strategically place sequences of pieces known as "Tetriminos" into a rectangular Matrix (refer to Figure 1.1). In the classic game, players attempt to clear as many lines as possible by completely filling horizontal rows of blocks, but if the Tetriminos surpass the top of the Matrix, the game ends.

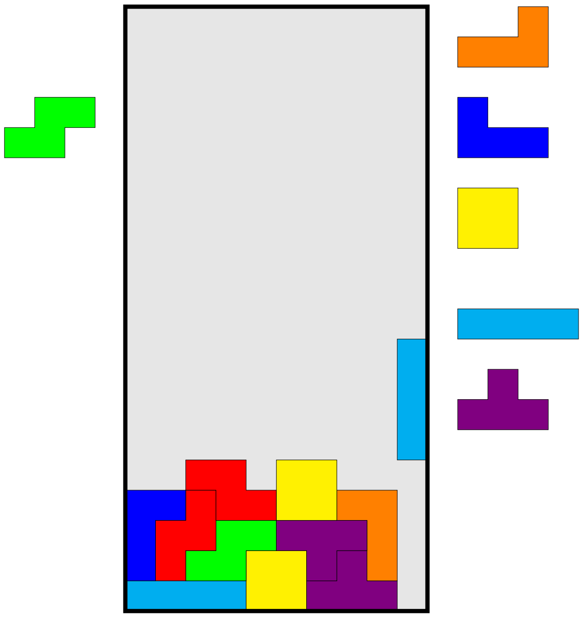

Figure 1.1: A typical modern Tetris game where four lines are about to be cleared. The Tetrimino on the left of the matrix is the *Hold* piece and the pieces to the right of the matrix are collectively known as the *Queue*.

Since its release, mathematicians and computer scientists have been intrigued by the game of Tetris, leading to a diverse array of research endeavours exploring the various facets of the game, including its computational complexity [2], and its possibility of being won [3] [4].

1.1 Motivation

In their paper, Demaine, Hohenberger, and Liben-Nowell showed that it is NP-complete to optimise several natural objective functions of Tetris [2]. NP-completeness poses a significant challenge in computational problem-solving, as it denotes the absence of polynomial-time algorithms for efficient solutions [5]. Moreover, the discovery of a polynomial-time algorithm for any NP-complete problem implies that any problem in the set of NP, encompassing efficiently verifiable but potentially difficult problems, could be solved in

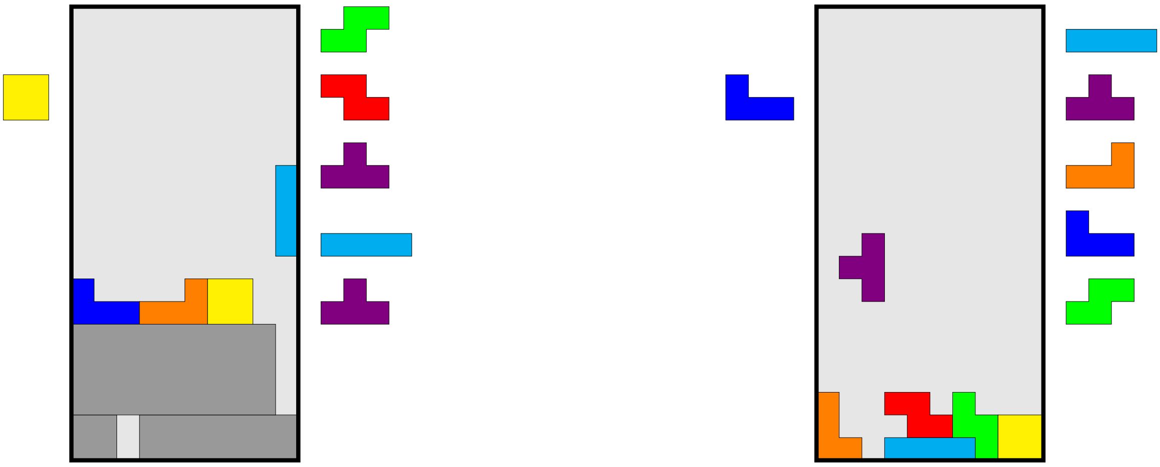

Figure 1.2: A typical game of Versus Tetris. Both players are trying to send lines to each other. The grey blocks are *Garbage Lines* sent from Player 2 (right) to Player 1 (left).

polynomial time [5]. NP-completeness extends beyond Tetris, with real-life instances of NP-complete arising in diverse fields such as route optimisation [6], job scheduling [7], and medicine [8].

To address these challenges, researchers have explored alternative approaches to tackle NP-complete problems, including the use of nature-inspired algorithms [9]. Although they might fail at finding optimal solutions, nature-inspired algorithms are able to return acceptable solutions in shorter running times [10]. In the context of optimising Tetris gameplay, studies have shown the effectiveness of using nature-inspired algorithms in playing the classic single-player game [11] [12]. However, there remains limited research on the effectiveness of nature-inspired optimisation algorithms in the multiplayer versus variant of the game.

1.2 Problem Statement

Versus Tetris (refer to Figure 1.2) presents a unique challenge in computational gaming due to its complex dynamics and real-time competitive nature. While previous research regarding the use of nature-inspired algorithms for Tetris optimisation have focused on single-player scenarios, the effectiveness of these algorithms in the multiplayer context remains largely unexplored. Despite the demonstrated success of these algorithms in improving single-player Tetris gameplay, their application to the multiplayer variant poses distinct challenges due to a different rule set and differing objectives that require further investigation.

1.3 Aim

The aim of this capstone project is to assess the effectiveness of nature-inspired optimisation algorithms in solving the game of Versus Tetris. By integrating insights from nature-inspired algorithms, the project seeks to create a robust and adaptable Tetris-playing software capable of competing against human players or other Tetris-playing programs. Through this endeavour, the project aims to contribute valuable insights into the application of nature-inspired algorithms in addressing computationally complex problems.

1.4 Objectives

The objectives of this project are as follows:

1. Formulate the problem of Versus Tetris for game AI.
2. Research and implement a variety of nature-inspired optimisation algorithms to determine their suitability for optimising gameplay strategies in Versus Tetris.
3. Design a comprehensive framework for objectively evaluating and comparing the performance of the algorithms.
4. Develop a playable game of Tetris that simulates gameplay and training.
5. Using the game, do comparative analyses with the designed framework to assess the effectiveness and efficiency of each algorithm.
6. Summarize findings from the comparative analyses.
7. Share the software with Tetris players of varying aptitudes to find the level of play for each algorithm.

1.5 Project Scope

This project will focus specifically on the evaluation of nature-inspired optimisation algorithms in the context of multiplayer versus Tetris. It will entail the development of a playable Tetris game capable of simulating gameplay and the training of algorithms. This simulation environment will facilitate in the analysis and evaluation of these algorithms' performances. The scope includes the exploring of a range of nature-inspired algorithms to address the unique challenges inherent in Versus Tetris.

2 Literature Review

2.1 The Difficulty of Tetris

In their article, Demaine, Hohenberger, and Liben-Nowell proved that optimising several natural objectives of Tetris is NP-complete, even with a deterministic finite piece sequence [2]. The authors defined the natural objectives of the game as follows [2]:

1. maximising the number of rows cleared;
2. maximising the number of piece placed;
3. maximising the number of Tetrises;
4. minimising the height of the stack.

In 2020, Asif, Coulombe, Demaine, *et al.* demonstrated that playing any game of Tetris with a matrix of eight or more columns, or four or more rows, is NP-complete, further showcasing the difficulty of the game [13]. Both of these papers aim to highlight the difficulty of the game, but what does difficulty actually entail?

This section aims to elucidate some of the key concepts of computational complexity, which involves the study of intrinsic difficulties of computational problems [14], and attempt to justify the use of non-traditional algorithmic approaches to play the game.

2.1.1 Complexity Classes

The study of computational complexity asks questions about the intrinsic difficulty of computational problems [14]. Complexity classes are usually defined by referring to computation models and by putting suitable restrictions on them [15].

The class P encompasses all decision problems that are polynomial time solvable using a deterministic model of computation [16]. In this model, for any given input, the machine's computation follows a single predetermined path [5].

The complexity class *NP*, on the other hand is the class of all decision problems that can be solved in polynomial time by a nondeterministic algorithm [17]. The nondeterministic model of computation allows for guessing correct solutions out of polynomially many options in constant time [18], and solutions can be verified in deterministic polynomial time [5].

If all problems in *NP* can be reduced to some problem X, X is said to be *NP-hard* [5]. Reductions are useful in showing the relationship between computable problems, as

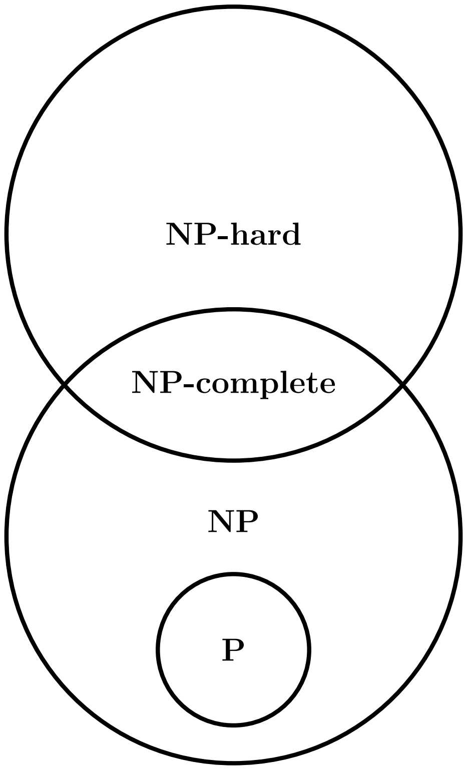

Figure 2.1: Visualisation of the sets P, NP, NP-hard and NP-complete.

a reduction from problem A to problem B tells us that problem B is at least as hard as problem A [18].

For a problem to be considered *NP-complete*, it must be a member of both the *NP* and *NP-hard* classes (refer to Figure 2.1) [18]. Therefore, *NP-complete* problems are some of the hardest problems in *NP* [16].

Since all problems in *NP* can be reduced to any *NP-complete* problem, if a deterministic polynomial time algorithm can be found for an *NP-complete* problem, it would also mean that the set *NP* is polynomial-time solvable, proving *NP* and *P* are equal sets. The question of whether $P = NP$ has famously been immortalised as one of the millennium prize problems from the Clay Institute of Mathematics [19]. Most researchers believe that $P \neq NP$ since years of effort have failed to yield efficient algorithms for *NP-complete* problems [16].

2.1.2 Abandoning Traditional Algorithmic Approaches

2.2 Addressing NP-complete Problems

2.3 Nature-inspired Algorithms

2.4 Playing Tetris with Nature-inspired Algorithms

2.5 Identifying the Research Gaps

2.6 Concluding the Review

3 Technical Plan

4 Work Plan

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