

Chapter 12

Combinatorics and Artificial Intelligence

ABSTRACT

The chapter explores the relationship between combinatorics and artificial intelligence (AI), shedding light on their historical roots and points of convergence. The historical roots are traced from Ramon Llull to deep learning, showing points of convergence and applications, such as optimization, graph theory, and natural language processing (NLP). The text also presents combinatoric problems, such as the travelling salesman problem and the knapsack problem, demonstrating how combinatorial methods are used to find efficient solutions. Furthermore, the text highlights the role of combinatorics in machine learning, optimization, and scientific discovery, underlining its importance in developing advanced AI algorithms. Finally, the text presents several promising avenues for future research, including advanced search algorithms, graph neural networks, generative models, computer defense, game theory, and the Internet of Things, underlining the potential for further integration between combinatorics and AI.

INTRODUCTION

Artificial intelligence will be the last invention made by humanity

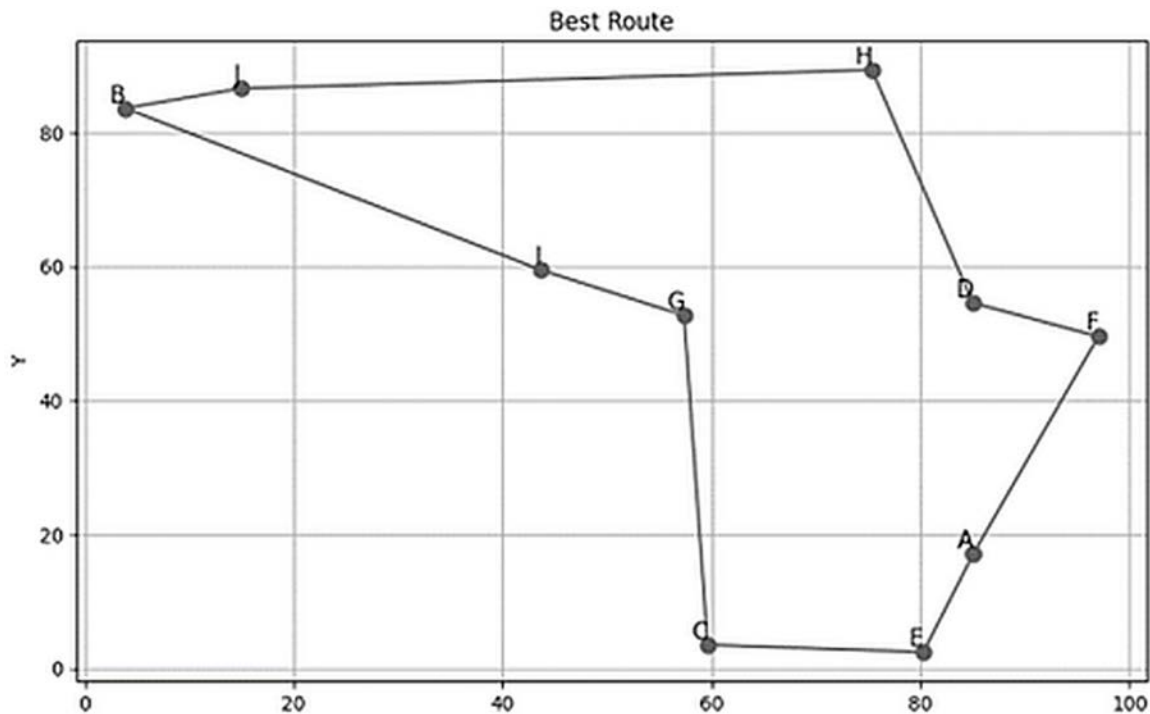
Nick Bostrom

The relationship between combinatorics and artificial intelligence (AI) is a fascinating and increasingly important area of research. Although these fields come from distinct domains, they have become closely intertwined over the years. Combinatorics provided the tools to represent and analyse search spaces, while AI developed efficient algorithms to explore such spaces.

The historical roots and points of convergence between combinatorics and artificial intelligence offer a compelling perspective on the evolution of both disciplines (Russell & Norvig, 2016); Briganti & Le Moine, 2020; Gawlikowski et al., 2023).

In this context, we could define Ramon Llull (or Ramon Llull) as a precursor of the intertwining of combinatorics and artificial intelligence. Llull, a 13th-century philosopher, theologian, and logician, developed his “Ars Magna,” a combinatorial system for generating knowledge through the manipulation of symbols and concepts. He also devised a machine to combine ideas and concepts systematically and designed a universalistic alphabet where basic elements could be mechanically combined, anticipating concepts found in modern neural networks.

Figure 1. Llull's machine



In this sense, we could consider Llull, if not a direct “progenitor”, at least a forerunner of some modes of thought that are reflected today in computational sciences and AI. It is a historical example of combinatorial thinking that, even in a quite different philosophical and religious context, anticipates some ideas of symbolic manipulation and knowledge generation that we find in AI.

The real meeting between these fields can be traced back to the dawn of AI. In the 1950s, games such as chess were used as a test bed for the development of search and reasoning algorithms (Shannon, 1950).

In the 1960s, figures such as Allen Newell and Herbert Simon developed programs, including the General Problem Solver (GPS), which employed combinatorial search techniques to tackle logical challenges. Developed in 1957, GPS was one of the first artificial intelligence systems designed to address a wide range of tasks. It introduced concepts such as problem decomposition and heuristic search.

The first concept is based on the idea that solving simpler subproblems can lead to a more comprehensive overall solution. Heuristics, on the other hand, are strategies that, while not always guaranteeing an optimal outcome, often yield acceptable results within a reasonable timeframe.

In the 1970s and 1980s, the emergence of logic programming (e.g., with the Prolog language) provided a new framework in which combinatorics intersected with AI through automatic deduction and the discovery of solutions in combinatorial spaces (Clocksin & Mellish, 1984). Based on rules and representations of knowledge, expert systems have represented an important line of research in AI in which combinatorics has played a fundamental role in the representation and manipulation of knowledge. Unfortunately, expert systems have shown limitations, including the difficulty of accurately representing knowledge and the lack of flexibility in addressing new and unforeseen problems.

In the 1990s, the introduction of genetic algorithms (Wirsansky, 2020) and other techniques revolutionized the approach to solving combinatorial optimization problems. These methods, inspired by natural evolutionary processes, have proved remarkably effective.

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