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Mapping the evolution of GPT-4o innovations: An analytical exploration of progress, applications, and horizons

Mapeo de la evolución de las innovaciones de GPT-4o: una exploración analítica del progreso, las aplicaciones y los horizontes

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ABSTRACT

Artificial intelligence is transforming various sectors, with OpenAI's GPT-4o as a key innovation in natural language processing. Its impact on healthcare, education, and business makes understanding its use essential. Clear references will guide its development and application, maximizing its transformative potential. This research employs bibliometric tools to analyze the adoption and evolution of GPT-4o. By examining published literature, citation networks, and keyword co-occurrence patterns, it identifies key application domains, emerging trends, and collaborative networks driving innovation. The study highlights GPT-4o's transition from theoretical research to practical implementation across disciplines. The findings contribute to knowledge on GPT-4o, offering insights into its applications and future opportunities. This perspective aids researchers, practitioners, and policymakers in leveraging GPT-4o for innovation. By addressing growth areas and challenges, the study underscores the need for strategic utilization to maximize GPT-4o's transformative potential across industries and society.

Keywords: Artificial Intelligence; Natural Language Processing; Strategic Intelligence; Technological Foresight

RESUMEN

La inteligencia artificial está transformando diversos sectores, con GPT-4o de OpenAI como una innovación clave en el procesamiento del lenguaje natural. Su impacto en salud, educación y negocios hace esencial comprender su uso. Establecer referencias claras guiará su desarrollo y aplicación, maximizando su potencial transformador. Esta investigación emplea herramientas bibliométricas para analizar la adopción y evolución de GPT-4o. Mediante el examen de literatura publicada, redes de citación y patrones de co-ocurrencia de palabras clave, se identifican dominios de aplicación clave, tendencias emergentes y redes de colaboración que impulsan la innovación. El estudio destaca la transición de GPT-4o de la investigación teórica a su implementación práctica en diversas disciplinas. Los hallazgos aportan al conocimiento sobre GPT-4o, ofreciendo perspectivas sobre sus aplicaciones y oportunidades futuras. Este enfoque ayuda a investigadores, profesionales y formuladores de políticas a aprovechar GPT-4o para la innovación. Al abordar áreas de crecimiento y desafíos, el estudio resalta la necesidad de una utilización estratégica para maximizar su potencial transformador en la industria y la sociedad.

Palabras clave: Inteligencia Artificial; Procesamiento del Lenguaje Natural; Inteligencia Estratégica; Prospectiva Tecnológica

1. INTRODUCTION

The world is experiencing an unprecedented wave of technological transformation, reshaping how societies function and interact. This rapid evolution is driven by advancements that extend across all domains, from information systems to automation and artificial intelligence. These innovations are not only enhancing productivity but also redefining the boundaries of what is possible, creating opportunities and challenges that demand a rethinking of traditional approaches. In this context, technology has become both a tool and a catalyst for systemic change, necessitating a collective effort to adapt and thrive (Álvarez-Diez & López-Robles, 2022; Linkon et al., 2024; López-Robles et al., 2019).

Emerging technologies are increasingly influencing sectors ranging from healthcare and education to finance and manufacturing. These innovations are introducing solutions that streamline processes, personalize experiences, and generate insights at an unprecedented scale. As they become more integral to daily life and organizational operations, the need for strategic alignment among stakeholders grows. Addressing the complexities of integrating these tools requires interdisciplinary collaboration, with a shared focus on maximizing benefits while mitigating risks such as inequities, ethical dilemmas, and unintended consequences (Abulibdeh et al., 2024; Furstenau et al., 2020).

This transformative era underscores the importance of developing technologies that not only advance capabilities but also align with societal goals. The convergence of technological innovation and collective intelligence has the potential to address critical challenges, from improving access to resources to enhancing decision-making processes. At the heart of this transformation are advancements in tools capable of understanding and responding to complex human needs, marking a pivotal shift in how technology interacts with society. These developments set the stage for a new paradigm, where innovative solutions foster collaboration, adaptability, and shared progress across all sectors (Smith et al., 2023).

One of the most notable advancements aligning with this technological transformation is the Generative Pre-trained Transformer (GPT) series, developed by OpenAI. Introduced as a groundbreaking innovation in natural language processing, GPT has redefined how machines interpret and generate human language. Initially designed to enhance text-based tasks, GPT quickly demonstrated its potential across a wide array of applications, from supporting customer interactions to generating creative and technical content. Its emergence marked a significant milestone in bridging the capabilities of artificial intelligence with real-world human needs (Mhlanga, 2023).

The progression of GPT models highlights the ongoing evolution of AI systems, each iteration surpassing its predecessor in complexity and performance. Starting with the foundational GPT model and evolving through GPT-2 and GPT-3, these technologies have shown remarkable improvements in contextual understanding and response generation. GPT-3, in particular, gained widespread recognition for its ability to produce coherent and contextually accurate text, setting a new standard in natural language processing. These advancements have been powered by extensive training on large datasets, enabling diverse applications across industries (Roumeliotis & Tselikas, 2023).

The latest iteration, GPT-4o, represents a significant leap forward in the capabilities of this AI technology. Building upon the robust architecture of earlier models, GPT-4o introduces enhanced features that allow for deeper contextual understanding, more nuanced responses, and broader adaptability across sectors. This latest version underscores the ongoing effort to refine AI tools to meet the growing demands of an interconnected and technologically advancing world, solidifying its role as a pivotal resource in addressing complex challenges and enabling innovation (Jan, 2025).

As with any transformative technology, the emergence of advanced models like GPT-4o brings with it a pressing need to understand their applications, uses, and potential. The novelty and versatility of these tools have led to their rapid adoption across various sectors, but their full scope of capabilities and impact remains a subject of ongoing exploration. Identifying how such technologies are being implemented is essential for maximizing their benefits, minimizing risks, and ensuring their alignment with societal and organizational goals (Khlaif et al., 2023; Wu et al., 2023).

Examining the use cases of GPT-4o offers valuable insights into its adaptability and potential across diverse domains. From automating routine processes to supporting high-level decision-making, these applications reveal the breadth of opportunities provided by this technology. However, understanding the contexts in which GPT-4o is being deployed, the challenges it addresses, and the outcomes it achieves is crucial. This knowledge not only informs best practices but also identifies gaps and emerging needs that future iterations of the technology can address (Raj et al., 2023).

By analyzing the applications and opportunities of GPT-4o, stakeholders can better position themselves to harness its transformative power. A comprehensive understanding of its use and potential enables researchers, practitioners, and policymakers to implement the technology effectively, fostering innovation and driving progress. Such insights serve as a foundation for developing strategies that amplify its benefits while addressing any limitations or ethical considerations, ensuring that GPT-4o contributes meaningfully to the advancement of industries and society as a whole (Vrontis et al., 2023).

To respond to the need for a deeper understanding of GPT-4o's applications and impact, this research undertakes a systematic analysis of existing publications indexed in the Scopus database. By leveraging bibliometric tools and constructing a co-occurrence map, this study identifies patterns, trends, and connections within the body of literature related to GPT-4o. These methods allow for a structured exploration of how this technology is being adopted, the domains in which it is most impactful, and the collaborative networks driving its advancement (Yan et al., 2023).

The bibliometric approach offers significant opportunities for uncovering insights that might otherwise remain hidden. By analyzing citation networks and keyword co-occurrence, it becomes possible to identify influential studies, emerging research clusters, and interdisciplinary applications. This structured analysis can reveal not only the current state of research but also gaps in knowledge and areas of untapped potential. Such findings are instrumental in guiding future studies and informing the strategic deployment of GPT-4o across various sectors (Javaid et al., 2023).

This process of mapping and analyzing existing literature not only provides a clearer understanding of how GPT-4o is being utilized but also highlights its broader implications. By

identifying opportunities for further research, collaboration, and innovation, this study contributes to maximizing the potential of GPT-4o. Moreover, these insights serve as a foundation for fostering partnerships between researchers, industry leaders, and policymakers, ensuring that the technology is leveraged effectively to address critical challenges and drive progress in an increasingly interconnected and technologically driven world (Baber et al., 2024; Khan et al., 2024).

In this context, the ongoing research focuses on examining the progression of applications and innovations associated with GPT-4o and its transformative potential, along with significant themes in the current literature, utilizing bibliometric methodologies, techniques, and tools. Initially, the study quantifies essential performance metrics, such as the number of published documents, citations received, prominent journals, leading authors, and the geographical distribution of publications, among others. Subsequently, by employing bibliometric analysis software based on bibliographic networks, the investigation explores the domains of scientific knowledge development related to the applications and opportunities of GPT-4o within a specified timeframe (Álvarez Diez et al., 2022; Issais Gutiérrez & Martínez Espinosa, 2024; Robles, 2022; Trejo Guardado et al., 2022).

2. METHODOLOGY

Bibliometric methodologies, tools, and techniques are indispensable for evaluating the impact and progression of knowledge domains, including cutting-edge technologies such as GPT-4o. These methods enable the assessment of academic, scientific, and productivity metrics, facilitating the identification of pivotal trends and contributors to knowledge advancement. Bibliometric analysis encompasses two core aspects: performance analysis and scientific relationship mapping. Performance analysis evaluates the impact of publications through metrics such as citations and temporal trends, while relationship mapping visualizes connections between documents, topics, and authors, revealing hidden associations and thematic interdependencies within the field (Álvarez-Diez et al., 2023; Herrera-Viedma et al., 2020; van-Eck & Waltman, 2010).

To explore the interrelations among GPT-4o-related themes, VOSviewer was employed in conjunction with an extensive search in the widely recognized Scopus database. The search query used was: TITLE-ABS-KEY ("gpt-4o") AND PUBYEAR = 2024 AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "cp")) AND (LIMIT-TO (LANGUAGE, "English")). This query yielded a dataset of 74 publications and 25 citations from 2024. The dataset was further refined by filtering for English-language documents categorized as articles, proceedings, or reviews. Additionally, citation data linked to these publications were incorporated into the analysis, with data collection extending up to December 1, 2024.

To enhance data accuracy, a de-duplication process was applied, consolidating synonymous terms and concepts into unified categories. For instance, terms such as "natural language processing," "NLP," and "language models" were grouped under a single thematic label to ensure coherence in analysis. This process enables the identification of distinct themes and emerging fields related to GPT-4o applications.

Bibliometric relationship maps, or scientific maps, are valuable tools for organizing and visualizing scientific information, facilitating the classification of complex themes. Themes appearing in at least 2 publications were grouped to identify emerging application areas, ranked by significance,

and represented with distinct visual identifiers. Relationships between themes, whether internal or external to their respective groups, highlight the influence one theme may exert on others. Evaluating these relationships based on their frequency and connectivity provides critical insights into the relevance and evolving dynamics of research in GPT-4o applications.

3. RESULTS

GPT-4o: bibliometric performance and scientific mapping

Publications, citations, and leading contributors in GPT-4o research

Although the current analysis identifies 74 publications related to GPT-4o in 2024, this number is expected to grow significantly as research into its applications and potential continues to expand. This projection is supported by the notable evolution of the GPT concept within the academic literature. Since 2019, a total of 1,708 publications have focused on GPT-related technologies, accumulating over 21,257 citations (67 h-index). These figures underscore the increasing attention that generative pre-trained transformers have garnered across various disciplines.

The exponential growth in GPT-related research highlights the transformative role these models play in artificial intelligence and their broad applicability in diverse fields. Each iteration of GPT has catalyzed new avenues of inquiry, driving the exploration of novel use cases, methodologies, and interdisciplinary applications. The substantial citation count further reflects the foundational role of GPT in advancing natural language processing and machine learning, positioning it as a cornerstone for ongoing innovation in the AI landscape.

Given this context, GPT-4o represents the latest milestone in this trajectory, and its bibliometric performance provides valuable insights into emerging research priorities and collaborative trends. By analyzing publication patterns and constructing scientific maps, it becomes possible to understand how GPT-4o is shaping academic discourse and practical applications. This exploration not only reveals the current state of research but also offers a glimpse into the potential impact of GPT-4o as its adoption continues to expand.

In this way, the analysis of GPT-4o-related research reveals a vibrant and expanding ecosystem characterized by global collaboration, interdisciplinary applications, and significant contributions from various authors, organizations, and countries (see Table 1). Among the most productive authors, Zhang, Y. stands out with 3 publications and 4 citations, highlighting their active role in the field. While several other authors, such as Liu, Z. and Zhang, T., contribute with fewer publications, the collective effort of 325 authors accounts for 158 citations, demonstrating the breadth of contributions. On the other hand, the most cited authors, including Abe, O., Gonoi, W., and others, each have 1 highly cited publication, showcasing the diversity of impactful research within this domain. Interestingly, some highly productive authors have a moderate citation impact, reflecting variations in the reach and influence of their work.

Institutions such as the University of Pittsburgh lead in productivity with 3 publications, followed by a diverse group of global organizations, including Università degli Studi di Padova, Stanford University, and the Chinese Academy of Sciences, each contributing 2 publications. This international representation underscores the global interest in GPT-4o research. Similarly, the United States dominates as the most productive country with 11 publications, followed by China

(9) and other contributors like Japan, South Korea, Italy, and Turkey, emphasizing the widespread geographical engagement in this emerging field.

The most productive publication venues include Ceur Workshop Proceedings and Electronics Switzerland, each with 4 publications, while proceedings such as those from the Association for Computational Linguistics (3 publications) highlight the field's focus on computational linguistics and AI advancements. The research spans across disciplines, with Computer Science leading (40 publications), followed by Medicine (21) and Engineering (19). Contributions from fields like Social Sciences, Mathematics, and even Health Professions highlight the interdisciplinary potential of GPT-4o applications, extending its relevance beyond traditional AI-centric domains.

This data demonstrates the dynamic and collaborative nature of GPT-4o research, driven by the involvement of global institutions, diverse subject areas, and a growing community of researchers. The findings highlight the field's capacity to address challenges and opportunities across various sectors, paving the way for further innovation and practical implementations.

Table 1. Research productivity and impact of GPT-4o in 2024 based on the Scopus database

Description	(Publications | Cites) Description [Cites | Publications]
Most productive authors	(3) Zhang, Y. [4] (2) Golik, P. [0]; Kim, G. [0]; Li, Z. [0]; Lin, Y. [0]; Liu, Y. [1]; Liu, Z. [2]; Modzelewski, A. [0]; Zhang, T. [2]; Zhang, W. [1] (1) 325 authors [158 cites]
Most cited authors	(5) Abe, O. [1]; Gonoi, W. [1]; Kanzawa, J. [1]; Kurokawa, M. [1]; Kurokawa, R. [1]; Nakamura, Y. [1]; Ohizumi, Y. [1]; Sonoda, Y. [1] (4) Öztürk, A. [1]; Günay, S. [1]; Yiğit, Y. [1]; Zhang, Y. [3] (3) Mao, Y. [1]; Song, J. [1]; Sun, Y. [1]; Wang, L. [1] (2) Liu, Z. [2]; Zhang, T. [2]; Atsukawa, N. [1]; BeÅŸler, M.S. [1]; Beeskow, A.B. [1]; Denecke, T. [1]; Ebel, S. [1]; Ehrengut, C. [1]; Gößmann, H. [1]; Ho, C.-T. [1]; Horiuchi, D. [1]; Junquero, V. [1]; Liu, C.-L. [1]; Matsushita, S. [1]; Merino, C. [1]; Miki, Y. [1]; Mitsuyama, Y. [1]; Murai, K. [1]; Oleaga, L. [1]; Oura, T. [1]; Shimono, T. [1]; Takita, H. [1]; Tanaka, R. [1]; Tatekawa, H. [1]; Ueda, D. [1]; Wu, T.-C. [1]; Yamamoto, A. [1]; Yoshida, A. [1] (1) 44 authors (0) 247 authors
Most productive organizations	(3) University of Pittsburgh (2) Università degli Studi di Padova; University of Pennsylvania; The University of Hong Kong; Stanford University; Chinese Academy of Sciences; Shanghai Jiao Tong University; Polsko-Japońska Akademia Technik Komputerowych; Shenzhen Institute of Advanced Technology
Most productive countries	(11) United States (9) China (5) Japan; South Korea (4) Italy; Turkey (3) Australia; Canada; Germany; Hong Kong; Spain; Switzerland; United Arab Emirates (2) 7 countries (1) 25 countries
Most productive sources	(4) Ceur Workshop Proceedings; Electronics Switzerland (3) Proceedings Of The Annual Meeting Of The Association For Computational Linguistics (2) Academic Radiology; Digital Health; Japanese Journal Of Radiology; Lecture Notes In Computer Science Including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics (1) 43 sources
Most productive subjects	(40) Computer Science (21) Medicine (19) Engineering (14) Social Sciences (7) Arts and Humanities; Mathematics (4) Health Professions

	(3) Multidisciplinary; Physics and Astronomy (2) Biochemistry, Genetics and Molecular Biology; Dentistry; Earth and Planetary Sciences; Environmental Science; Nursing (1) 9 subjects

Considering the performance and impact outcomes, it can be affirmed that the development and application of GPT-4o continue to expand both in quantity and quality within the scientific community. This trend reinforces its position as a pivotal reference point for driving innovation, fostering interdisciplinary collaboration, and enhancing organizational adaptability in an increasingly AI-driven world.

Main research themes related GPT-4o

Following this, a comprehensive exploration is provided concerning science mapping and the latent connections among pivotal themes within the primary research domains related to GPT-4o applications and innovations. This examination comprises two interconnected components: an in-depth analysis of the content delineated in published articles and a conceptual evolution map. The first component aids in identifying emerging themes within the realm of GPT-4o research, elucidating their core concepts and their role in shaping the field over the analyzed period. Meanwhile, the conceptual evolution map visually portrays the progression of these themes and the interconnectedness among them throughout the entire duration of analysis.

The topics covered in GPT-4o-related publications are comprehensively captured in the scientific map generated through bibliometric analysis. This map visualizes the connections between key terms, illustrating the thematic structure of the research field. All identified topics are categorized into six distinct clusters, each representing a major area of focus within the literature. These clusters provide a clear framework for understanding the distribution of research efforts and the relationships between various themes (see Table 2 and Figure 1).

The Advancements in Language Models and AI Performance Cluster (Red) is the largest, with 52 links, a total link strength of 119, and 27 occurrences of the term "language model," reflecting its central role in the literature. The AI Applications in Education, Healthcare, and Diagnostics Cluster (Green) includes topics with significant educational and medical relevance, such as "education 5.0" (23 links, 41 total link strength, and 7 occurrences). The AI-Driven Decision Making and Knowledge Management Cluster (Dark Blue) emphasizes decision-making and knowledge management, led by terms like "controlled study" (33 links, 49 total link strength, and 7 occurrences). The Foundational Concepts and Emerging AI Paradigms Cluster (Yellow) focuses on foundational AI concepts, with "artificial intelligence" standing out with 48 links, 93 total link strength, and 20 occurrences. The Natural Language Processing and Specialized AI Applications Cluster (Purple) highlights natural language processing, with "natural language processing systems" achieving 22 links, 31 total link strength, and 7 occurrences. Lastly, the Cutting-Edge Techniques in Large Language Models Cluster (Light Blue) explores advanced methodologies in large language models, with "large language model" dominating with 56 links, 118 total link strength, and 34 occurrences.

Together, these clusters provide a quantitative and qualitative understanding of the research field, illustrating its complexity and breadth. This classification serves as a foundation for exploring thematic connections and identifying emerging trends and research gaps in GPT-4o studies.

The Advancements in Language Models and AI Performance Cluster (Red) is centered on the progression and optimization of language models, which serve as the foundation of GPT-4o research. Among the key topics identified, "language model" emerges as the most prominent term, with 52 links, a total link strength of 119, and 27 occurrences, underscoring its critical role in this research domain. Supporting themes such as "fine-tuning," with 14 links and 4 occurrences, highlight the importance of optimizing these models for specific tasks. Similarly, "benchmarking" and "performance assessment," with significant link strengths and occurrences, emphasize the focus on evaluating and improving model accuracy and efficiency. Another notable theme is "open-source software," which reflects the collaborative and transparent nature of AI development, with 15 links and 4 occurrences (see Table 2).

The relationships within this cluster reveal strong interconnections between the technical advancements in language models and their evaluation methodologies. For instance, "language model" shows close ties with "benchmarking" and "performance assessment," reflecting the reliance on standardized metrics to assess and compare models effectively. Meanwhile, "fine-tuning" connects not only with language models but also with terms like "vision-language models," indicating its importance in enabling cross-modal AI applications. The inclusion of "open-source software" highlights collaborative efforts in developing and refining these models, while its connection to "translation (languages)" underscores the importance of multilingual capabilities in AI systems.

Observations from this cluster reveal the centrality of language models in GPT-4o research, with a clear focus on their optimization and evaluation. Terms like "fine-tuning" and "performance assessment" indicate a strong emphasis on improving model accuracy, adaptability, and efficiency. Additionally, the presence of topics such as "vision-language models" and "multi-modal surfaces" suggests an expanding interest in interdisciplinary applications that extend language models into fields like computer vision. Lastly, the inclusion of "open-source software" reflects the collaborative and transparent trends shaping the development of these technologies. Together, these insights demonstrate the pivotal role of language models in driving advancements in AI performance.

Table 2. Key themes and metrics in Advancements in Language Models and AI Performance Cluster (Red)

Theme	weight<Links>	weight<Total link strength>	weight<Occurrences>
benchmarking	18	26	5
computational linguistics	20	37	8
contrastive learning	17	19	4
digital elevation model	5	7	2
fine tuning	14	20	4
general knowledge	9	10	2
information classification	11	12	2
language model	52	119	27
linguistics	13	14	3
model based open platform communication	4	4	2
multi-modal surfaces	20	32	5
open-source software	15	23	4
open systems	11	15	2
performance assessment	25	36	7
resource domains	7	7	2
teaching	6	6	2

translation (languages)	9	11	2
vision-language models	12	13	2
visual languages	22	28	4

The AI Applications in Education, Healthcare, and Diagnostics Cluster (Green) focuses on the integration of AI technologies into sectors such as education and medicine, highlighting their transformative potential. Key topics in this cluster include "education 5.0," which stands out with 23 links, a total link strength of 41, and 7 occurrences, reflecting the growing interest in leveraging AI to revolutionize educational systems. Similarly, "educational measurement," with 22 links, a total link strength of 37, and 5 occurrences, underscores the emphasis on using AI to improve the evaluation and personalization of learning processes. In the healthcare domain, terms like "clinical competence" (18 links, total link strength of 29, and 4 occurrences) and "radiology" (17 links, total link strength of 24, and 3 occurrences) highlight the application of AI in enhancing diagnostic accuracy and medical training (see Table 3).

The relationships within this cluster reveal strong connections between education and healthcare applications. For instance, "education 5.0" and "educational measurement" are closely linked, reflecting the shared goal of improving learning outcomes through advanced tools and methodologies. In the healthcare context, terms like "clinical competence," "radiology," and "diagnostic imaging" exhibit interconnectedness, highlighting the role of AI in advancing diagnostic precision and medical education. These connections demonstrate how AI is fostering innovation across diverse yet interrelated fields.

This cluster reveals several key observations. First, education and healthcare emerge as prominent sectors for AI integration, with significant emphasis on enhancing personalized learning and diagnostic capabilities. Terms such as "education 5.0" and "clinical competence" indicate a focus on leveraging AI to address sector-specific challenges while also fostering interdisciplinary collaboration. Furthermore, the cluster underscores the role of AI in improving accuracy and efficiency in diagnostics, particularly through applications in radiology and imaging. Together, these insights highlight the transformative impact of AI on education and healthcare, reinforcing its importance as a tool for innovation and societal progress.

Table 3. Key themes and metrics in AI Applications in Education, Healthcare, and Diagnostics Cluster (Green)

Theme	weight<Links>	weight<Total link strength>	weight<Occurrences>
assessment tasks	11	12	2
certification tests	15	16	2
clinical competence	18	29	4
diagnostic accuracy	9	12	2
diagnostic imaging	16	20	2
diagnostic radiology	7	8	2
differential diagnosis	10	11	2
education 5.0	23	41	7
educational measurement	22	37	5
interventional radiology	9	9	2
medical education	9	12	2
physiology	10	11	2
radiology	17	24	3
reproducibility of results	13	15	2

The AI-Driven Decision Making and Knowledge Management Cluster (Dark Blue) emphasizes the role of AI in enhancing decision-making processes and managing knowledge effectively. Central to

this cluster is the term "controlled study," which stands out with 33 links, a total link strength of 49, and 7 occurrences, highlighting its significance in providing evidence-based insights across various domains. Other key terms include "decision making" and "knowledge management," each with 14 and 16 links, respectively, reflecting the integration of AI in facilitating strategic and data-driven decisions. The presence of "machine learning" with 14 links and 4 occurrences underscores its foundational role in powering these applications (see Table 4).

The relationships within this cluster highlight how AI is leveraged to optimize decision-making frameworks and manage vast repositories of knowledge. For example, "controlled study" is strongly connected to "evidence-based practice," indicating the reliance on AI to process and analyze data for informed decision-making. Similarly, "decision making" and "knowledge management" are closely linked, reflecting the role of AI in enabling organizations to derive actionable insights from complex datasets. Additionally, the inclusion of "video recording" and "social media data analysis" points to the diverse sources of data utilized to enhance decision-making processes.

Key observations from this cluster underline AI's transformative potential in decision-making and knowledge management. The focus on "controlled study" and "evidence-based practice" highlights the importance of AI in improving the reliability and precision of data analysis. Moreover, terms like "machine learning" and "knowledge management" emphasize the role of AI in extracting value from unstructured data, enabling organizations to enhance their operational and strategic capabilities. The presence of applications such as "social media data analysis" further demonstrates the growing scope of AI in harnessing non-traditional data sources for decision-making. Overall, this cluster reflects the critical role of AI in shaping informed and efficient decision-making across sectors.

Table 4. Key themes and metrics in AI-Driven Decision Making and Knowledge Management Cluster (Dark Blue)

Theme	weight<Links>	weight<Total link strength>	weight<Occurrences>
chemistry	4	4	2
controlled study	33	49	7
cost reduction	9	9	2
data analysis	9	9	2
decision making	14	16	4
emergency medicine	7	7	2
evidence based practice	7	7	2
knowledge management	16	17	3
machine learning	14	16	4
patient education as topic	6	6	2
social media data analysis	4	4	2
video recording	18	22	3

The Foundational Concepts and Emerging AI Paradigms Cluster (Yellow) centers on the core principles and innovative developments driving the evolution of AI technologies. Among the key terms in this cluster, "artificial intelligence" stands out with 48 links, a total link strength of 93, and 20 occurrences, reflecting its foundational role in the broader research landscape. Other significant terms include "generative artificial intelligence" (29 links, total link strength of 40, and 11 occurrences), highlighting the focus on AI systems capable of generating new content, and

"generative pretrained transformer" (19 links, total link strength of 21, and 2 occurrences), which underscores the specific emphasis on GPT technology (see Table 5).

The relationships within this cluster reveal strong interconnections among foundational AI concepts and their applications. For instance, "artificial intelligence" is closely linked with "generative artificial intelligence" and "data collection," indicating the integration of core AI principles with practical tools and methodologies. Additionally, terms like "comparative study" and "randomized controlled trial" demonstrate the ongoing efforts to benchmark AI technologies and evaluate their performance in various scenarios. These connections illustrate how foundational concepts are shaping emerging paradigms in AI research and application.

Key observations from this cluster underline the dual focus on theoretical foundations and practical innovations. The prominence of "artificial intelligence" and "generative artificial intelligence" highlights the balance between exploring AI's fundamental principles and leveraging its generative capabilities to solve complex problems. Furthermore, the inclusion of terms like "systematic reviews as topic" and "data accuracy" reflects the emphasis on rigorous evaluation and precision in AI systems. This cluster provides a roadmap for understanding how foundational AI concepts are evolving to address the challenges and opportunities presented by modern technological demands.

Table 5. Key themes and metrics in Foundational Concepts and Emerging AI Paradigms Cluster (Yellow)

Theme	weight<Links>	weight<Total link strength>	weight<Occurrences>
artificial intelligence	48	93	20
chatbots	4	4	2
comparative study	21	27	4
data accuracy	10	11	2
data collection	10	11	2
data extraction	12	12	2
generative artificial intelligence	29	40	11
generative pretrained transformer	19	21	2
large multimodal model	6	6	2
randomized controlled trial	12	12	2
systematic reviews as topic	11	12	2

The Natural Language Processing and Specialized AI Applications Cluster (Purple) focuses on the development and application of AI technologies in natural language processing (NLP) and domain-specific contexts. Central to this cluster is "natural language processing systems," which has 22 links, a total link strength of 31, and 7 occurrences, reflecting its significant role in advancing GPT-4o-related capabilities. Supporting terms such as "semantics" (9 links, total link strength of 10, and 2 occurrences) and "text mining" (8 links, total link strength of 9, and 2 occurrences) highlight the emphasis on extracting meaning and insights from text-based data. Additionally, terms like "mammography reports" (17 links, total link strength of 18, and 2 occurrences) point to the application of NLP in highly specialized fields such as healthcare (see Table 6).

The relationships within this cluster reveal strong interconnections between NLP methodologies and their specialized applications. For instance, "natural language processing systems" is closely connected to "semantics" and "text mining," illustrating the reliance on semantic analysis for

advanced language processing tasks. Meanwhile, terms like "mammography reports" and "virtual environment architecture" highlight the interdisciplinary application of NLP techniques in domains such as healthcare and digital simulations. These connections reflect the adaptability of NLP systems in addressing diverse challenges across industries.

Key observations from this cluster indicate a dual focus on advancing NLP technologies and tailoring them for specific applications. The prominence of "natural language processing systems" underscores the foundational role of NLP in GPT-4o research, while terms like "mammography reports" and "virtual environment architecture" emphasize the versatility of these technologies in specialized fields. Additionally, the presence of terms such as "semantics" and "text mining" highlights ongoing efforts to refine language processing techniques for extracting actionable insights from unstructured text data. Together, this cluster underscores the importance of NLP as a critical area of AI research with broad implications for both general and domain-specific applications.

Table 6. Key themes and metrics in Natural Language Processing and Specialized AI Applications Cluster (Purple)

Theme	weight<Links>	weight<Total link strength>	weight<Occurrences>
computer simulation languages	6	8	2
language processing	8	12	2
mammography reports	17	18	2
natural language processing systems	22	31	7
natural languages	8	12	2
semantics	9	10	2
text mining	8	9	2
virtual environment architecture	5	5	2

The Cutting-Edge Techniques in Large Language Models Cluster (Light Blue) highlights advanced methodologies and innovations in the development and application of large language models. At the center of this cluster is "large language model," which stands out with 56 links, a total link strength of 118, and 34 occurrences, indicating its pivotal role in GPT-4o research. Complementary terms include "modeling languages" (28 links, total link strength of 57, and 12 occurrences) and "prompt engineering" (10 links, total link strength of 14, and 4 occurrences), showcasing the focus on refining how these models are designed and interacted with. Additionally, "retrieval augmented generation" (9 links, total link strength of 10, and 2 occurrences) reflects the growing interest in integrating external data sources to enhance model outputs (see Table 7).

The relationships within this cluster reveal strong connections among methodologies and innovations that drive advancements in large language models. For instance, "large language model" is closely linked to "modeling languages" and "prompt engineering," illustrating the interplay between model architecture and optimization techniques. "Retrieval augmented generation" connects with these core terms, reflecting efforts to improve the contextual relevance and accuracy of model outputs by incorporating external knowledge.

Key observations from this cluster indicate a clear focus on advancing both the theoretical and practical aspects of large language models. The prominence of "large language model" underscores its central role in GPT-4o research, while terms like "modeling languages" and "prompt engineering" highlight the ongoing efforts to refine the design and usability of these models.

Additionally, the inclusion of "retrieval augmented generation" demonstrates the increasing emphasis on enhancing model outputs by leveraging external data, marking a significant step toward more context-aware and robust AI systems. This cluster showcases the innovative approaches being developed to push the boundaries of large language models, positioning them as transformative tools across diverse domains.

Table 7. Key themes and metrics in Cutting-Edge Techniques in Large Language Models Cluster (Light Blue)

Theme	weight<Links>	weight<Total link strength>	weight<Occurrences>
context sensitive languages	10	13	2
human computer interaction	7	10	2
knowledge graph completion	5	5	2
large language model	56	118	34
modeling languages	28	57	12
problem oriented languages	8	11	2
prompt engineering	10	14	4
retrieval augmented generation	9	10	2

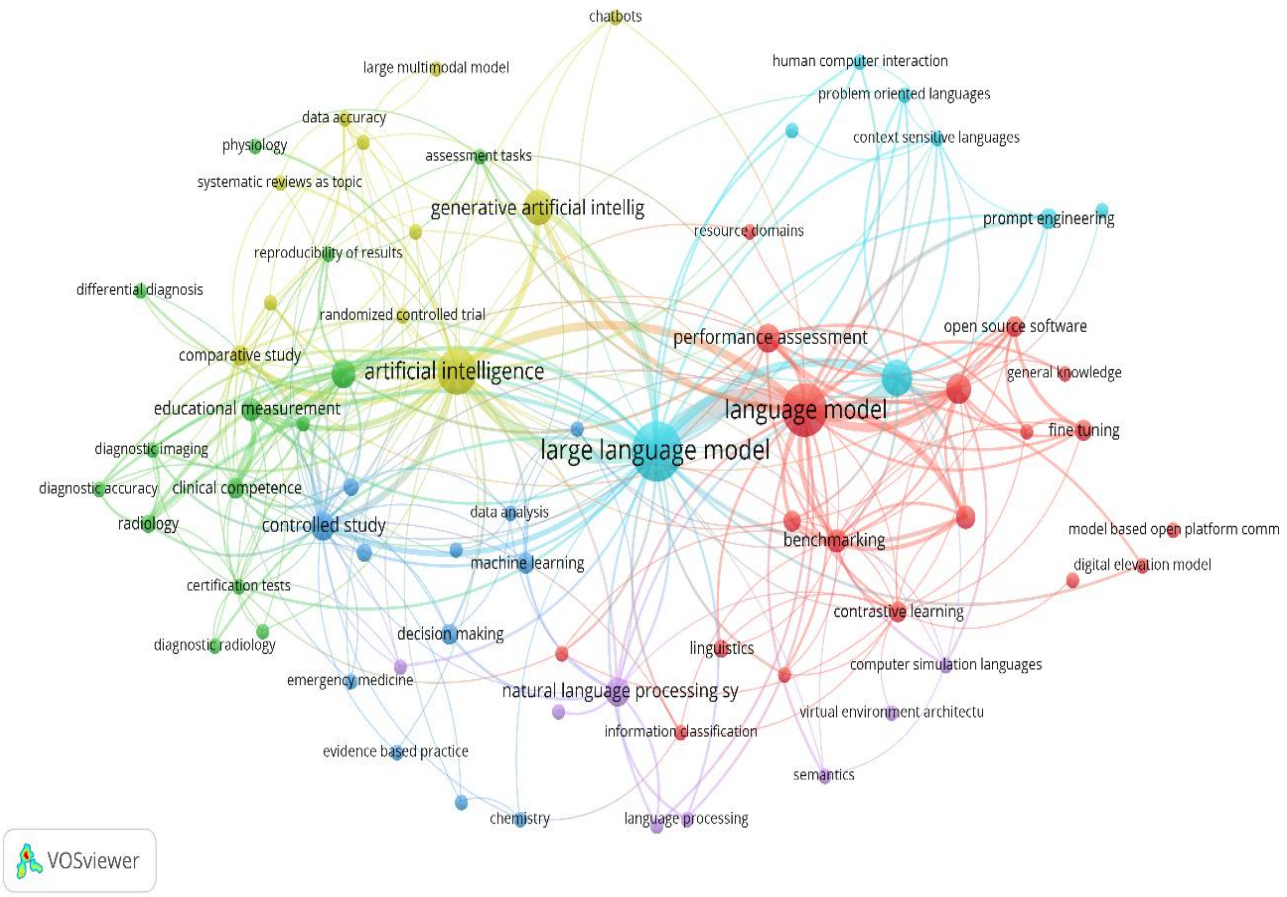

Figure 1. Scientific Co-Occurrence Map of GPT-4o Research Themes

The analysis of the identified clusters provides a comprehensive overview of the diverse themes and interconnected areas of research related to GPT-4o. From foundational advancements in language models and AI performance to specialized applications in education, healthcare, and

decision-making, each cluster highlights the transformative potential of this technology. The thematic structure reveals a balance between theoretical development and practical innovation, with significant efforts directed toward refining methodologies, enhancing interdisciplinary applications, and addressing emerging challenges. Together, these insights illustrate the dynamic and evolving landscape of GPT-4o research, offering a roadmap for future exploration and collaboration to maximize its impact across industries and society.

CONCLUSIONS

The evolution and adoption of GPT-4o have shown significant growth, as evidenced by the increase in scientific publications and the diversification of its applications across multiple sectors. Bibliometric analysis reveals that research on this technology is characterized by rapid expansion and a high degree of interdisciplinarity, with contributions from various institutions and countries. This indicates not only the immediate impact of GPT-4o on artificial intelligence but also its potential to continue transforming key industries such as education, healthcare, and knowledge management.

The findings highlight that GPT-4o research focuses on six main thematic areas, with particular emphasis on language model optimization, AI integration in education and healthcare, and data-driven decision-making improvements. The connections among these areas suggest that GPT-4o is not only advancing in technical terms but is also shaping new methodologies and approaches to solving complex problems. As techniques such as fine-tuning and prompt engineering evolve, the model is expected to further expand its applicability and accuracy in various contexts.

Despite this progress, significant challenges remain in the implementation and regulation of GPT-4o, particularly concerning ethics, transparency, and responsible use. Addressing algorithmic biases, ensuring data privacy, and developing robust regulatory frameworks are crucial for its sustainable adoption. Future studies should focus on these critical aspects while exploring new opportunities in emerging sectors. In this regard, the evolution of GPT-4o will depend not only on technical advancements but also on its alignment with principles of fairness and technological accessibility.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest related to the development of the study.

AUTHORSHIP CONTRIBUTION

Conceptualization; Data Curation; Formal Analysis; Research; Methodology; Visualization; Validation; Writing - original draft; Writing - revision and editing: Gamboa-Rosales, N. K. and López-Robles, J. R.

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