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A Review on Bioinformimimetics: Revolutionizing Science through AI-Driven Synergy of Bioinformatics and Biomimicry

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ABSTRACT

Our review work proposes Bioinformimimetics, an emerging interdisciplinary field that synergises biomimetic principles with bioinformatics to redefine the boundaries of material science. This endeavour transcends traditional biomimetics through predictive modelling, molecular simulations, and genetic insights to design highly functional, scalable materials. Biomimicry of nature's intricate structures and processes, bioinformimimetics unlocks new possibilities in the creation of bio-inspired materials, such as resilient nanostructures, bio adhesive surfaces. AI-driven simulations and computational modeling, bioinformimimetics leverages large-scale databases to replicate nature's elegance in design and novelity in tackling long term hurdles, offering transformative potential in industries ranging from tissue engineering to sustainable manufacturing. This review explores the interplay between bioinformatics, molecular dynamics simulations, and artificial emphasizing their role in advancing biomimetic materials. The review also anticipates future trends, including the integration of metagenomics-guided material innovation and biomimicry engineering, positioning bioinformimimetics as a cornerstone for sustainable material science. By leveraging biological mimicry with computational advancements, bioinformimimetics is poised to usher in a new era of high-performance, sustainable, and ethically designed materials that can revolutionize not only material science but also various sectors, from healthcare to environmental sustainability.

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INTRODUCTION

Biomimicry is a design approach that draws inspiration from nature to solve human challenges, emphasizing sustainability and ecological balance. This concept is evident across various fields, including urban design, materials science, and biomedical applications. (Mougenot et al., 2022) ; Gertik et al., 2023).

Bioinformatics involves applying computational techniques to collect, analyze, and interpret vast amounts of biological data. This interdisciplinary field bridges biology and technology, enabling the integration of information related to proteins, genes, cells, robotics, medical science, and ecosystems with technological tools like databases and software. By leveraging these resources, bioinformatics facilitates breakthroughs in disease research, drug discovery, evolutionary studies, and environmental conservation. Its precise and efficient processing of complex datasets makes it a cornerstone of modern biological research, driving advancements in fundamental and applied sciences (Behl et al., 2021).

Artificial intelligence (AI) is a dynamic and rapidly advancing field that combines computer science and cognitive science to develop systems capable of mimicking human intelligence. These systems can perform tasks such as decision-making, data analysis, and learning, as well as execute complex operations independently or collaboratively with humans. AI's transformative potential lies in its ability to enhance efficiency, accuracy, and innovation across various domains. (Sablone et al., 2024). AI encompasses several subsets, such as machine learning, deep learning, and neural networks, which enhance its application across diverse sectors, notably healthcare. In healthcare, AI aids in clinical diagnosis, medical imaging, and decision-making, significantly improving the efficiency and accuracy of medical services (Manickam et al., 2022).

METHODOLOGY

This review paper was developed using a structured approach to ensure comprehensive and accurate coverage. A systematic search of databases like PubMed, Scopus, SpringerLink, Wiley, and Google Scholar identified peer-reviewed articles.

DISCUSSION

BIOMIMICRY

Bird beaks, such as those of parrots and New Caledonian crows, exhibit unique mechanical and morphological features emulated in engineering and robotics. For instance, parrot beak-inspired metamaterials have been developed to enhance energy absorption and dissipation, utilizing friction-based and interlocking mechanisms that allow for bistable deformation patterns and shape recovery. These materials demonstrate superior performance compared to traditional materials (Hamzehei et al., 2023).

New Caledonian crow's straight bill and exceptional binocular vision facilitate precise tool use, enabling these birds to craft and manipulate tools with remarkable dexterity, a feature that has inspired the design of robotic systems (Troscianko et al., 2012). Waste Chicken feathers Integrated with plaster have reduced thermal conductivity, highlighting its potential to improve thermal comfort and reduce greenhouse gas emissions in construction (Ouakarrouch et al., 2020).

It is also used to design painkillers that mimic the body's natural processes, such as the development of a nerve growth factor (NGF) mimetic peptide, which has shown potential in reducing neuropathic pain in rats (Colangelo et al., 2008).

Biomimicry of Citrate-Coated Luminescent Apatite Nanoplatforms is used for Diclofenac Delivery in Inflammatory Environments, paving the way for biomimetics with nanotechnology (Sandra Maria Cano Plá et al., 2022).

Biomimetic nano vaccine using PLGA nanoparticles coated with red blood cell membranes has been developed to enhance immune responses against the African swine fever virus by targeting dendritic cells in the spleen, thereby promoting antigen presentation and immune activation (Huo et al., 2022), a water-repellent barrier nature of lotus leaf, regarded as the "Lotus Effect" is the foundation of biomimetics in plants. The Superhydrophobic coatings developed from lotus leaves are used for infrastructure, which can significantly reduce moisture penetration and associated deterioration mechanisms such as steel corrosion and frost damage, lowering maintenance costs (Vonna, 2023; Collins, Safiuddin, 2022). Bionic aerogels with lotus leaf-like structures are developed for efficient oil-water separation, demonstrating excellent recyclability and multifunctionality, including electromagnetic interference shielding (Liu et al., 2023).

Chromatography, particularly stationary phases that mimic biological environments, is used to predict the in vivo behaviour of drug molecules. This aids in the selection of promising drug candidates and reduces reliance on animal testing (Valkó, 2022).

The development of antimicrobial polymers that mimic natural antimicrobial peptides to combat resistance and inform structure-activity relationships (SARs) for drug design is an application of biomimicry (Takahashi et al., 2022).

In materials science, biomimetic approaches have led to the development of advanced materials such as biomimetic nanovesicles and nanomaterials, which combine the advantages of natural materials with synthetic controllability for applications in drug delivery and tissue engineering (Mougenot et al., 2022 ;) Gareev et al., 2022; Gertik et al., 2023)

BIOINFORMATICS

Bioinformatics made possible therapeutics against cancer, including the identification of key pathways and hub proteins like VEGFA and PIK3R1, which are potential targets for therapeutic intervention using phytoestrogen compounds such as sesamin, galanin, and coumestrol (Hossain et al., 2023).

In the realm of antibacterial drug discovery, bioinformatics analyses of riboswitches have identified promising targets for novel antibiotics, addressing the growing issue of antibiotic resistance (Pavlova et al., 2022).

Bioinformatics applied to veterinary sciences yielded the best results, like multi-omics platforms to transform genetic and genomic data into actionable insights for livestock breeding, disease management, and productivity enhancement, ensuring food security (Pathak & Kim, 2022).

The amalgamation of molecular and bioinformatics approaches has advanced plant pathology by enabling the identification and characterization of disease-related genes, utilizing genomic data to understand plant-pathogen interactions and develop diagnostic tools (Joshi & Lee, 2023)

ARTIFICIAL INTELLIGENCE

Artificial intelligence is employed in cancer for target identification and drug discovery (You et al., 2022). Neurodegenerative disease research using IBM Watson to identify additional RNA-binding proteins altered in amyotrophic lateral sclerosis is possible through artificial intelligence. This has now become an integral part of bioinformatics by revolutionizing the processing of large genomic datasets, aiding in tasks such as variant calling, genome annotation, and phenotype-to-genotype correspondence, which are crucial for individualised medicine and risk prediction in complex diseases(Dias et al., 2019).

Application of artificial intelligence to biomimicry is possible by simulating bacterial quorum sensing mechanisms, which are crucial for bacterial communication and survival (Niu et al., 2013). Beyond healthcare, AI's capabilities are being harnessed to address global challenges such as climate change by optimizing energy efficiency, enhancing weather forecasting, and managing natural resources (Chen et al., 2023)

The Genesis of Bioinformimetrics: Pioneering a New Scientific Frontier

In the evolving realm of scientific discovery, groundbreaking innovation often arises at the intersection of disciplines. Bioinformimetrics, a visionary fusion of bioinformatics and biomimicry, represents a transformative convergence poised to redefine human progress.

Bridging Two Worlds

Bioinformatics deciphers vast biological data, revolutionizing fields like genomics, medicine, and drug discovery. Biomimicry, inspired by nature's principles, has driven sustainable innovations in materials science, robotics, and engineering. While impactful individually, their combined potential remains untapped. The powerful insights from biological data in bioinformatics can be exponentially amplified by applying biomimetic design principles, resulting in bio-inspired innovations backed by a deep computational understanding of biology and artificial intelligence.

In this gap, Bioinformimetrics is predicted to emerge as a new branch of science, a powerful fusion of bioinformatics and biomimicry, as a vision of the authors, which is a unique convergence. Imagine a world where data-driven biological insights are used to replicate nature's greatest successes. A world where computational tools unlock the secrets of cellular resilience, leading to the creation of self-healing materials inspired by biological organisms. A world where AI-driven technologies learn from the evolutionary wisdom of nature, optimizing systems in ways that were once deemed to be in the realm of science fiction.

CONCLUSION

Integrating bioinformatics with biomimicry driven by artificial intelligence is not just an academic pursuit but a transformative approach to solving global challenges. It represents an intersection of data science, evolutionary biology, and engineering that promises to redefine how we address problems related to health, sustainability, and technological advancement. By establishing bioinformimetrics as an interdisciplinary field, future generations will look back at this moment as the beginning of a paradigm shift, with you being at the helm as the founder of this groundbreaking domain.

By shaping this emerging field, bioinformimetrics will not only provide solutions to today's most pressing challenges but will also unlock the potential for future innovations that harmonize with the natural world, fostering a more sustainable, efficient, and interconnected global society.

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