ACADEMIC PERSPECTIVE

APJESS

Journal of Engineering and Smart Systems

Volume : 12
Issue : 2
Year : 2024

Volume 12 / Issue 1
Academic Platform Journal of Engineering and Smart Systems

Correspondence Address
Academic Platform Journal of Engineering and Smart Systems
Akademik Perspektif Derneği, Tığcılar Mahallesi Kadir Sokak No:12
Kat:1 Adapazarı SAKARYA

+90 551 628 9477 (WhatsApp only)
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Review Article

Academic Platform Journal of Engineering and Smart Systems (APJESS) 12(2), 47-58, 2024

Received: 30-Nov-2023 Accepted: 27-Feb-2024

homepage: https://dergipark.org.tr/tr/pub/apjess

https://doi.org/10.21541/apjess.1398155

Generative Artificial Intelligence: A Historical and Future Perspective

*1 Hatice Kübra KILINÇ, 2 Ö. Fatih KEÇECİOĞLU

*1 Corresponding Author, Department of Electrical and Electronics, Kahramanmaraş Sütçü İmam University, Türkiye, hatice.kubra.cs@gmail.com

2 Department of Electrical and Electronics Engineering, Kahramanmaraş Sütçü İmam University, Türkiye, fkececioglu@ksu.edu.tr

Abstract

The artificial intelligence field has seen a surge in development, particularly after the advancement of Generative Adversarial Network (GAN) models, resulting in a diverse range of applications. The varied usage of generative models significantly enhances the importance of this domain. The primary focus of this article is the history of generative models, aiming to provide insights into how the field has evolved and to comprehend the complexities of contemporary models. The diversity in application areas and the advantages introduced by these technologies are explored in detail to facilitate a thorough understanding, with the expectation that this knowledge will expedite the emergence of new models and products. The advantages and innovative applications across sectors underscore the critical role these models play in industry. Distinguishing between traditional artificial intelligence and generative artificial intelligence, the article examines the differences. The architecture of generative models, grounded in deep learning and artificial neural networks, is compared briefly with other generative models. Lastly, the article delves into the future of artificial intelligence, addressing associated risks and proposing solutions. It concludes by emphasizing the significance of the article for new research endeavors, serving as a guiding resource for researchers navigating critical discussions in the field of generative models and artificial intelligence.

Keywords: Generative artificial intelligence; Generative adversarial network; Artificial intelligence

1. INTRODUCTION

In this section, the concept of Generative artificial intelligence (AI) is briefly explained, covering its historical development until the year 2023, along with the techniques and technologies it is associated with. Generative AI is an artificial intelligence technology capable of creating various products in different application areas using data such as text, sound, images, and in some models, both text and images. The ability of Generative AI models to rapidly generate high-quality text, visuals, and videos has increased their visibility. While the definition of Generative AI may seem recent, its roots trace back to the 1940s [1].

Scientist Claude Shannon's publication, in which he divided communication into five fundamental components; source, transmitter, channel, receiver, and destination. The introduced model name is Shannon-Weaver. This model is one of the first and most effective communication models used to develop artificial language models [1]

The first chatbots of the 1960s can be considered as primitive versions of the advanced chatbots used today [2]. ELIZA was introduced as a chatbot simulating conversation and was published as one of the significant works in human-computer interaction in the 1960s [2]. Research during the 1960s and 70s focused on implementing computer vision and utilizing some fundamental recognition models. During this period, more advanced expert systems were developed. Harold Cohen's AARON computer program, designed to create art, stands as one of the early examples of generative artificial intelligence in the field of computer vision [3][4]. The field of machine learning typically employs statistical models, including generative models, to model and predict data. In this field, advancements in neural networks and deep learning since the 2000s have led to progress in technology's ability to automatically parse text, classify image elements, and convert speech to text through learning models [5]. Following the emergence of deep learning, there has been accelerated progress and research in image classification, speech recognition, natural language processing, and other tasks [6]. Modern generative artificial intelligence is primarily based on deep learning techniques, and as a result, generative AI has rapidly evolved in the 2010s.

In 2014, with the introduction of Generative Adversarial Networks (GANs), a type of machine learning algorithm, generative artificial intelligence became capable of creating convincingly original images, videos, and sounds comparable to those produced by humans [7].

This deep learning technique, developed by Ian Goodfellow, introduced a new approach to adversarial neural networks that generate content variations and perform ranking. In this model, two different neural networks compete with each other. These models can produce realistic human-like images, sounds, music, and text [7]. Advancements in other neural network techniques and architectures have contributed to the expansion of generative artificial intelligence capabilities.

In 2017, with the introduction of transformer libraries and subsequent years' developments in generative network models, there was a significant acceleration in progress [8][9]. Transformer models and large language models triggered groundbreaking advancements. Transformers, a type of machine learning, enabled researchers to train larger models without the need to pre-label all data. This allowed new models to be trained on more extensive datasets, providing more realistic responses to text [8].

Additionally, Transformers can make inferences by deciphering connections between sentences, pages, or chapters. The transformers library, introducing a new concept called attention, enables the establishment of these connections, providing opportunities for novel research not only in textual contexts but also in analyzing code, proteins, chemicals, and DNA [10], [11], [12], [13]. Detailed information on this topic is provided under the heading "Applications of Generative Artificial Intelligence." This technology has the potential to assist in future endeavors such as coding, designing new drugs, product development, reengineering business processes, and transforming supply chains [14].

The Transformers library paved the way for the emergence of Generative Pre-trained Transformer (GPT) in 2018 [15], [16]. In 2021, the release of DALL-E, a pixel-generating model based on Transformers, followed by Midjourney and Stable Diffusion, has given rise to practical, high-quality artificial intelligence art stemming from natural language prompts [17].

Although generative artificial intelligence models can produce intriguing texts and realistic images, the current years represent the early stages of the technology's development. Consequently, we may encounter products with lower accuracy. Among other techniques, there are variational autoencoders (VAE), long short-term memory (LSTM), transformers, and diffusion models [18], [19], [20]. The developmental timeline of generative artificial intelligence is illustrated in Figure 1.

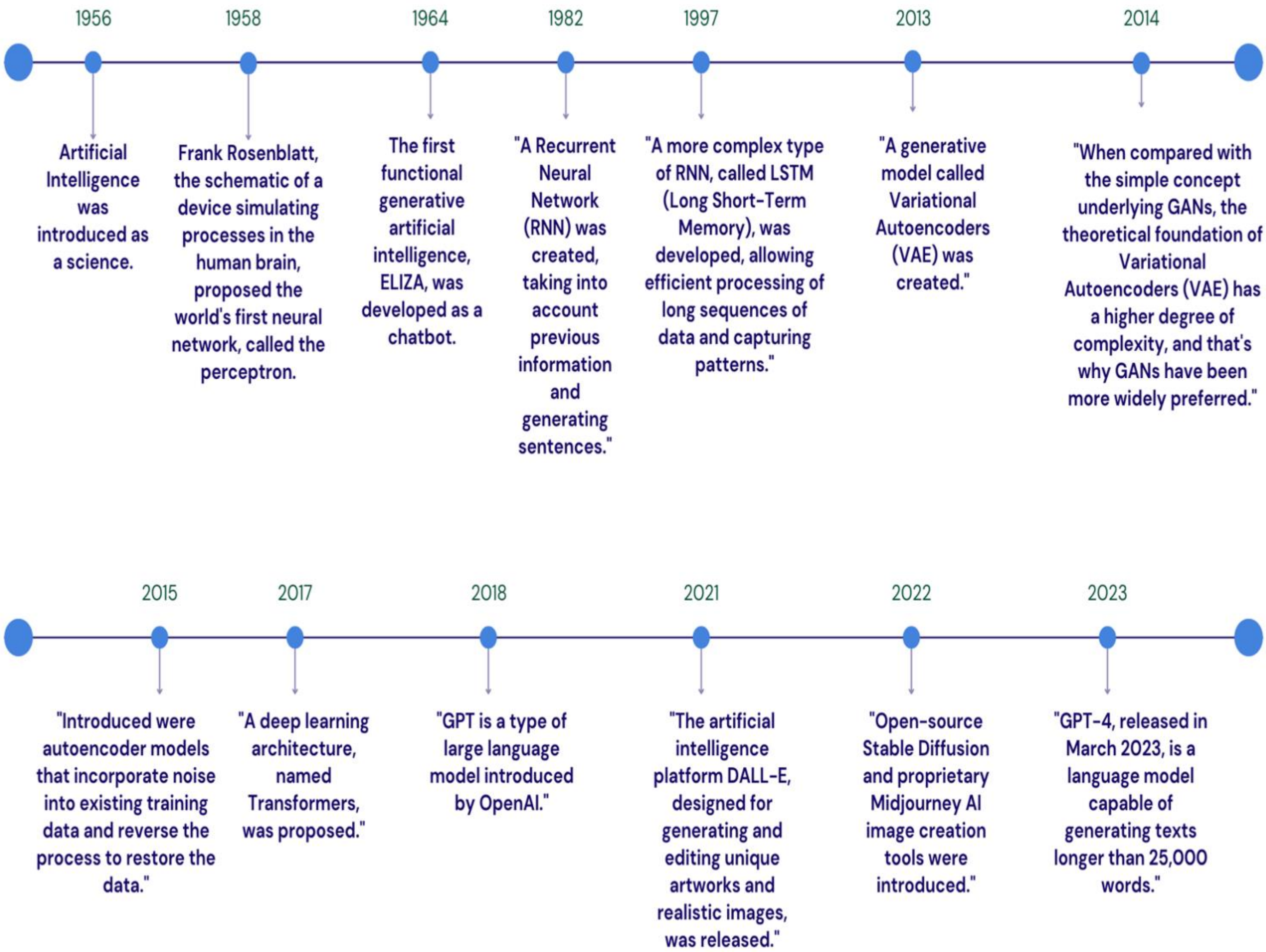

Figure 1. Generative Artificial Intelligence Development Timeline

2. MATERIALS AND METHODS

Generative artificial intelligence models provide an effective way to represent the desired content type and efficiently iterate over useful variations. It is necessary to train the generative artificial intelligence model for a specific use case. The most general representation of the model flow is outlined in the visual depicting the key stages in model generation. Language models and generative models collaborate in this process. Figure 2. gives the general flow of generative models.

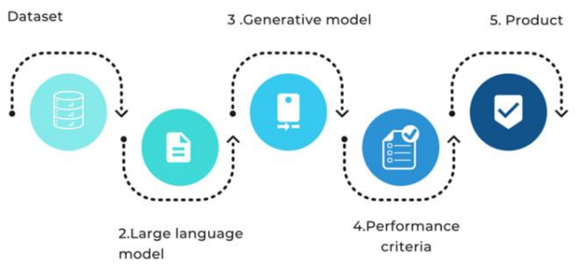

Figure 2. Generative model

2.1. Generative AI Model Training

Different use cases can be achieved with customized models. For example, the popular GPT model developed by OpenAI is used for text generation based on written descriptions, generating code, and creating images [21], [22]. However, this product may not provide useful results, for instance, in drug design. The training process involves adjusting the model parameters for different use cases. Subsequently, fine-tuning is performed on a specific training dataset to refine the results. For instance, a call center could train a chatbot based on the types of questions received from various customer types and the responses given by service representatives. In the case of an image-generating application, unlike text, it can start by defining the content and style of images with labels to train the model to generate new images.

2.2. Generative AI Models Architectures

There is a strong connection between generative models and artificial neural networks. Generative models represent a specific type of artificial neural network, designed for generative tasks such as data generation, data synthesis, or data modification by forming a subset of artificial neural networks. Generative models typically start with an artificial neural network called a generator. This generator creates new data samples using random inputs, often referred to as samples. Generative models like Generative Adversarial Networks (GANs) express a competitive structure between a generator network and a discriminator network. Due to this structure, they are defined as Generative Adversarial Networks (GANs) [7]. The goal is for the generator and discriminator to collaborate and learn to produce more realistic data. Generative models are particularly used in the field of machine learning for generative tasks, including text generation, image synthesis, and sound production. They can also take on tasks such as classification, regression, clustering, and other machine learning techniques.

The generative model architecture represents a type of artificial neural network architecture that forms the foundation for many generative artificial intelligence applications. The generative model architecture is shown in Figure 3. This type of model is used to generate new data samples or modify existing ones. This generative model architecture is especially utilized in techniques like GANs. GANs constitute a significant subfield of generative artificial intelligence, used for various applications such as generating or modifying text, images, videos, music, and other content types. The basic components of the generative model architecture can be defined as the generator, discriminator, loss function, training process, and the products.

1. Generator: The generator, the main component of the generative model, creates new data samples. Typically, these samples are expected to resemble the data distribution and appear as if they were real data. The generator takes a random vector as input and transforms this vector into a realistic data sample. For example, a generator for text generation can create a text sample.

2. Discriminator: The discriminator is another neural network that attempts to distinguish data samples created by the generator from real data. By determining the difference between real and fake examples, the discriminator provides feedback. This feedback helps the generator learn to produce more realistic samples. The term Generative Adversarial Networks (GANs) is used to describe this competitive structure.

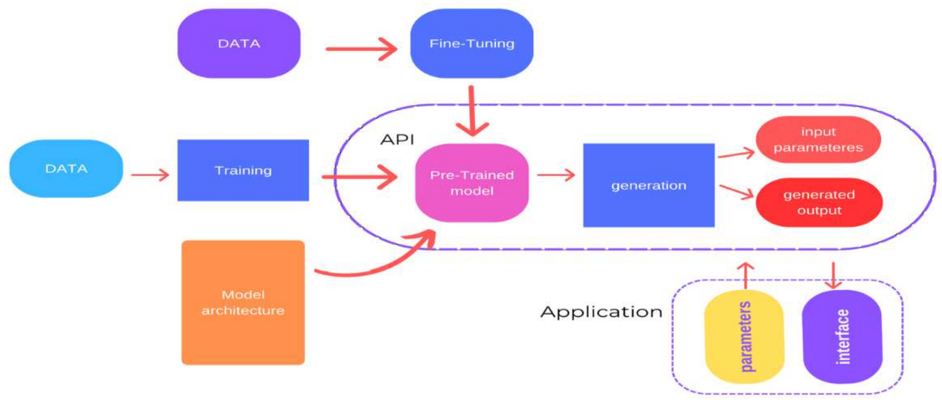

Figure 3. Generative model architecture

3. Loss Functions: Both the generator and the discriminator use a loss function during training. While the generator tries to produce fake samples that are less detected by the discriminator, the discriminator attempts to correctly distinguish between real and fake examples. These loss functions guide the training of the model.

4. Training Process: The training process is based on game theory, where the generator and discriminator compete. As the generator learns to produce more realistic examples, the discriminator develops the ability to distinguish between fake and real data. This process typically continues over many iterations.

5. Result Generation: When training is complete, the generator can create new data samples. These samples are usually generated using a random input vector. The generator transforms this input into a realistic data sample to produce the final result.

Generative Artificial Intelligence (Generative AI) encompasses a set of techniques and approaches that allow the creation of new content. Some of the most advanced and commonly used techniques in this field include the following.

3. GENERATIVE MODELS AND ADVANCED TECNIQUES

In this section, we examined different generative models. The flow chart of the three basic generative models is shown in Figure 5.

1. Generative Adversarial Networks (GANs): GANs are one of the most popular techniques in generative artificial intelligence. They consist of two main components: the generator and the discriminator. While the generator aims to produce new data samples, the discriminator tries to distinguish between these samples as real or fake. This involves a continuous competition based on game theory, ultimately resulting in the generation of more realistic data [7].

2. Variational Autoencoders (VAEs): VAEs are a type of autoencoder used to represent the essence of a dataset. They learn the distribution of the dataset and can generate new data samples by producing random examples [18].

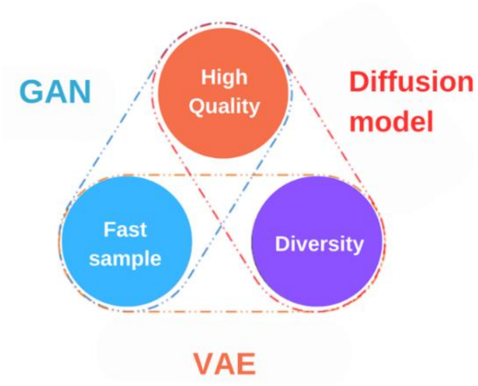

Figure 4. Generative model comparison

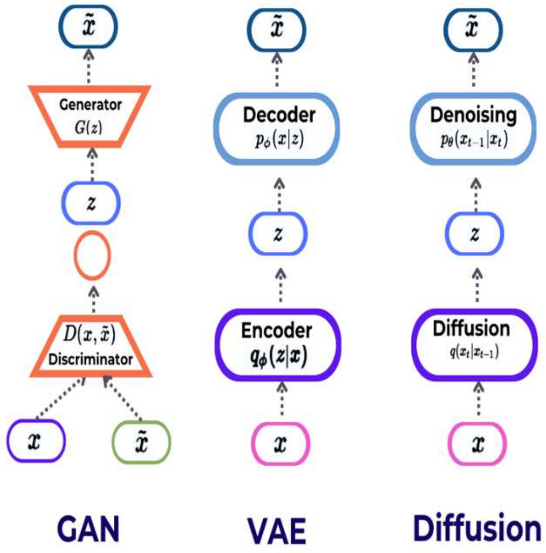

Figure 5. Flowchart of different generative models

3. Diffusion Models: Diffusion models generate new data samples by iteratively adding noise to an initial data point and then cleaning this data by removing the noise. At the end of the diffusion process, the initial data point reaches a final state as a noisy data point. Subsequently, this noisy data undergoes a backward cleaning process. This process aims to gradually reduce the noise and clean the data, ultimately obtaining a new and realistic data sample [23], [24], [25].

When evaluating productive Artificial Intelligence models, comparisons are made in terms of quality, diversity and speed. This comparison is shown in Figure 4.

Generative Adversarial Networks (GANs) were proposed by Goodfellow and his colleagues in a doctoral thesis [7], [26], [27]. These networks are a technique inspired by game theory, operating as a deep learning model with two distinct artificial neural network models working concurrently. In a competitive manner, these two models are the generative and discriminative models. While generative models attempt to generate, for samples, an image of a cat, the discriminative model is tasked with determining whether it is real or not. Real examples of X with corresponding Y labels are provided, where the label does not necessarily have to be present in every case. Generative Adversarial Networks, utilizing unsupervised learning, do not always require labeled input.

As seen in Figure 6, the generative model G, which is a deep neural network, attempts to generate new images by adding noise to the latent vector. The discriminative model D tries to distinguish between the generated images as real or fake, and then undergoes model updates for fine-tuning. The loss values from the generative and discriminative models are defined as a minimax game in this

$$\min_G \max_D V(D,G) = \mathbb{E}_{x \sim p_{\text{data}(x)}}[log\, D(x \mid c)] + \mathbb{E}_{x \sim p_{z(z)}}[log\,(1 - D(G(z \mid c))] \quad (1)$$

adversarial training. The formula for the loss function is given in Equation (1. The minimax algorithm is expected to minimize the losses from the adversarial training. While D, the Discriminator model, tries to maximize the result, G, the Generator model, aims to minimize it. The term x in the first sum represents real images sampled from the data distribution $p_{\text{data}(x)}$. **D(x)** is the value generated by the discriminator for real images. The generator model is represented by **G(z)**, where **z** is a randomly given value. **G(z)** is the fake image generated by the generator model. **D(G(z))** is the value given by the discriminator for the fake image, and this value is subtracted by 1 in the formula. The discriminator tries to increase the value for real images and decrease it for fake images. The optimal point where both networks reach equilibrium is a Nash equilibrium, and it is expected that the generator model improves to the point where the discriminator can no longer distinguish fake images. The general pseudocode of the GAN model is as Figure 6. [28].

Input: $x^{(i)}$ sample of real image, $z^{(i)}$ latent vector
Output: $G(z^{i})$ sample of generated/fake image

1. ***For*** iteration_num do
2. ***For*** count_num (k) do
3. Generation of fake image $\{G(z^{(1)}),\ldots,G(z^{(m)})\}$
   Real images are taken $\{x^{(1)},\ldots,x^{(m)}\}$
   Training of D Updating the weight parameters: $\nabla_{\theta_d} = \frac{1}{m}\sum_{i=1}^{m}\left[\log D(x^{i}) + \log\left(1 - D\left(G(z^{i})\right)\right)\right]$
4. ***end for***
5. Generating of fake image $\{G(z^{(1)}),\ldots,G(z^{(m)})\}$
   Training of G weight updating: $\nabla_{\theta_g} = \frac{1}{m}\sum_{i=1}^{m}\log\left(1 - D\left(G(z^{i})\right)\right)$
6. ***end for***

Figure 6. Pseudocode of GAN

The discriminative network (D) is shown alongside the generative model (G). The two nested for loops in the algorithm continually compare the G and D models. When they start producing convergent values, Nash equilibrium is achieved, and the loop ends. The discriminative model (D) can employ binary classifiers to distinguish between fake and real images. The number of iterations specifies how many times the networks will be trained. The GAN architecture is shown in Figure 8.

3.1. Generative AI vs. Traditional AI

Both generative artificial intelligence (Generative AI) and artificial intelligence (AI) utilize machine learning algorithms to achieve their outcomes. However, they have different purposes and objectives. Generative AI aims to create new content, while AI delves deeper and goes where the algorithmic coder intends to take it. These AI models can be used for better decision-making, eliminating issues arising from repetitive tasks, or detecting abnormalities and providing alerts for cybersecurity.

In contrast, Generative AI finds its place in creative fields such as art, music, and product design while also playing a significant role in the business world. AI itself has a strong foothold in the business domain, particularly in enhancing business processes and improving the performance of data analytics Table 1. provides a comparison.

While both types of AI share the foundation of machine learning, their distinct goals lead them to different applications and areas of focus. Generative AI seeks innovation and creativity, whereas traditional AI is often employed for problem-solving and efficiency in various business domains.

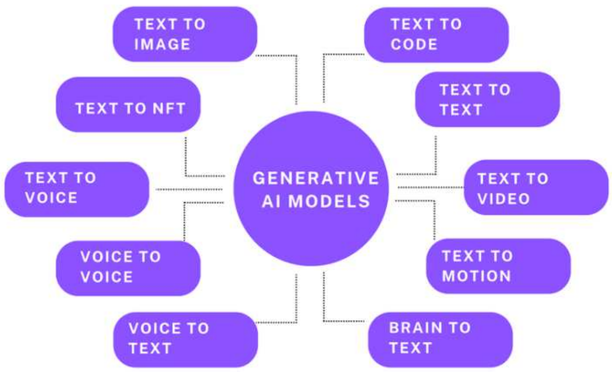

Figure 7. Types of applications for Generative AI.

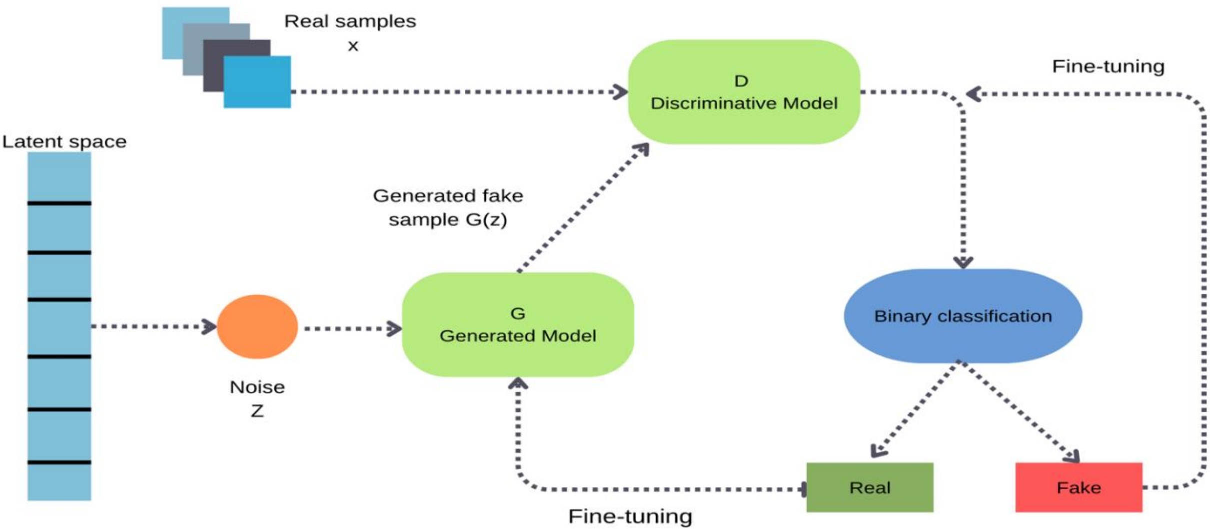

Figure 8. GAN architecture

Table 1. Generative AI vs. Traditional AI

	Traditional AI	Generative AI
Data Requirements:	Requires labeled data for supervised learning or unlabeled data for unsupervised learning	Demands extensive training data to recognize patterns and generate unique content
Content Generation:	Operates within predefined rules; unable to create entirely new content.	Excels at creating novel and diverse content from scratch.
Problem Solving:	Tackles complex problems as a whole entity	Breaks down complex problems into manageable parts
Limitations:	Constrained by pre-established algorithms and rules	May produce content that doesn't always reflect real-world scenarios, potentially biases
Flexibility:	Less adaptable to new data or tasks	Adapts well, capable of producing varied outputs based on input changes
Training Time:	Depends on model complexity and data volume	Training Generative AI models can be resource-intensive and time-consuming
Machine Learning Type:	Primarily uses supervised learning algorithms	Utilizes unsupervised learning algorithms for model generation
Application Areas:	Mainly used for data analysis, production, sentiment analysis, etc.	Applied in natural language processing, chatbots, art, design, etc.
Task Type & Use Cases:	Handles classification, regression, decision-making	Excels in generating audio, text, visuals, 3D designs, process planning, and multitask analysis
Problem Type	Suited for well-defined problems	Effective in providing solutions to open-ended problems
Approach:	Rule-based systems, utilizes supervised or unsupervised learning for predictions	Employs a dynamic, flexible model to generate new data based on learned patterns
Strengths:	Highly successful in solving specific, well-defined problems	Facilitates creativity, versatile across various application areas
Weaknesses:	Challenges in adapting to real-world complexity	Evaluating the quality of generated content poses difficulties; performance criteria are diverse.

3.2. Applications of Generative AI

We aimed to explain this field difference studies more clearly in Figure 9, where we show various models according to their application types. Generative AI has a broad range of applications and can be used in various fields. Figure 7. provides an overview of the general types of applications. Some of these areas include:

1. Text Generation: Generative AI can produce text, articles, stories, and poems using text-based data. It relies on language models such as GPT-3, GPT-4, LaMDA, and LLaMa, which are trained on words or tokens [21], [29]. This enables natural language processing, machine translation, text synthesis, and similar processes to provide users with content types mentioned above [22], [27].

2. Image and Visual Content Generation: Realistic works are created using models like GANs, Diffusion, Transformers, and VAE [18]. Systems trained with text, image, or model-dependent sound inputs, often utilizing neural systems, are commonly used. Tools like DALL-E, Stable Diffusion, and Midjourney are frequently employed in this context.

3. Music and Sound Production: Generative AI can produce new music notes or sounds, including generating original compositions, creating automatic music, or combining different musical styles. Models like MusicLM and MusicGen, trained on the sound waveforms of recorded music, are notable examples in this domain [30], [31].

4. Video and Animation Production: Generative AI models with significant impacts on the digital publishing sector can be utilized for creating videos, 3D animations, commercials, and game development. Advanced models used in filmmaking, animation, and creating game characters have the potential to reshape industry dynamics [32]. Models like RunwayML serve as examples in this category [33].

3.2.1. Various Industries Using Generative AI

1. Medical and Biomedical Research: Generative AI can be employed for data analysis and generating experimental results. It plays a role in producing new drugs and developing generative models for molecules like SMILES, DNA, and proteins [34]. What sets biomedical datasets apart is the use of biological data during training. Generative models utilized in biomedical research have the potential to make breakthroughs in healthcare services. Analyzing high-dimensional genetic and biological data can contribute to disease analysis, identification of new drugs, drug design, and the development of personalized treatments [10], [11]. This may include designing and optimizing genetic sequences, producing organisms with specific traits, and developing sustainable biomaterials. Generating or simulating new organisms can serve various purposes [6].

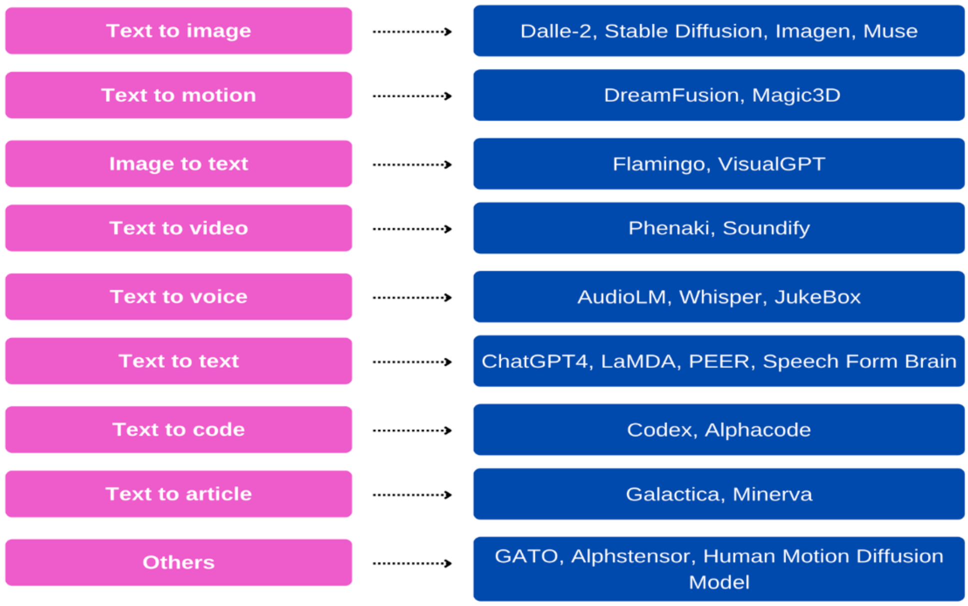

Figure 9. Illustrates various popular models based on their application types.

2. Generative AI in Robotics: A robotic system can be trained in the movements of a robot for tasks like motion planning or navigation, creating new trajectories. In robotics, efforts have been made to develop robots capable of learning the architecture of the human brain to achieve human-level intelligence [35].

3. Application in Journalism: In January 2023, Futurism.com published content indicating the use of an undisclosed AI tool to write at stories for CNET. Following the publication, CNET made corrections and republished 41 stories [36]. In April 2023, the German tabloid Die Aktuelle published a fake interview generated by artificial intelligence with former racing driver Michael Schumacher, who had not appeared in public since suffering brain damage in a skiing accident in 2013. The story included two possible explanations: the cover featured the expression "deceptively real," and there was a note at the end of the interview stating that it was generated by artificial intelligence. Amid the controversy, the editor-in-chief was dismissed shortly thereafter [37]. As powerful language models capable of publishing fake, misleading, and directing content have been developed, mimicking deceased individuals poses a separate risk factor.

Additionally, generative models can be used in finance, law, architecture, and other fields. These applications demonstrate the broad range of Generative AI. The rapid advancement of technology continues to uncover new applications and increase its impact in various domains.

4. THE FUTURE OF GENERATIVE AI

Generative AI provides frameworks that can be applied to various fields such as text, images, videos, and coding, enabling the development of products. The diversity and abundance of use cases bring many benefits to industries but also introduce new challenges. It is anticipated that new legal regulations may be needed for these models. Many companies have implemented chatbots to build their brand and address the needs of customers and employees [38]. Customized generative models based on their own data are now feasible for companies. They can leverage various generative AI models to edit errors in code and write more efficient code [39], [40]. Models that can evaluate multiple hiring criteria easily to speed up the workflow and assist in selecting potential employees for job postings may become prevalent. They can also be utilized for evaluating risk analyses within companies [41]. The diversity and abundance of use cases bring many benefits to industries.

In the near future, we will witness models that facilitate three-dimensional modeling, graphic design, architectural drawings, drug development, fashion design, and streamline workflow processes. These new models will also provide opportunities for exploring different business ideas. The timeline visualization of generative AI depicts its current and potential future impact and applications in various fields.

4.1. Risks of Generative Artificial Intelligence Models

While the advancements in generative artificial intelligence (AI) models bring excitement for their transformative potential across various industries, they also introduce new challenges and risks. A comprehensive exploration is necessary to understand the potential outcomes, considering both the benefits and drawbacks. These risks might extend beyond the positive impacts of technology, leading to significant consequences. In this section, we will address the primary risks associated with generative AI models and provide suggestions on how to enhance the safety of this technology [26], [37], [42], [43].

1. Cognitive Biases and Discrimination: Generative AI models can learn and reflect biases and discrimination present in training data, potentially creating content with discriminatory elements based on gender, ethnicity, or other personal attributes. There's a risk that content generated by generative AI might limit freedom of expression[44]. A notable instance was ChatGPT's response in October 2023 regarding the rights of people in the occupied territories of

Palestine, subject to genocide, to live freely[45], [46]. This response from ChatGPT, a generative AI product, to the question of whether the Palestinian people, under severe oppression and genocide, have the right to freedom was deemed inappropriate. When a similar question was asked about Israel, the response was "Yes." The company altered this response following reactions on social media. The response given can be seen in Figure 10 [47], [48], [49], [50].

2. Exposure and Privacy Issues: These models may have the ability to predict private or sensitive information, raising the risk of unwanted disclosure or misuse of personal data[51], [52], [53], [54], [55].

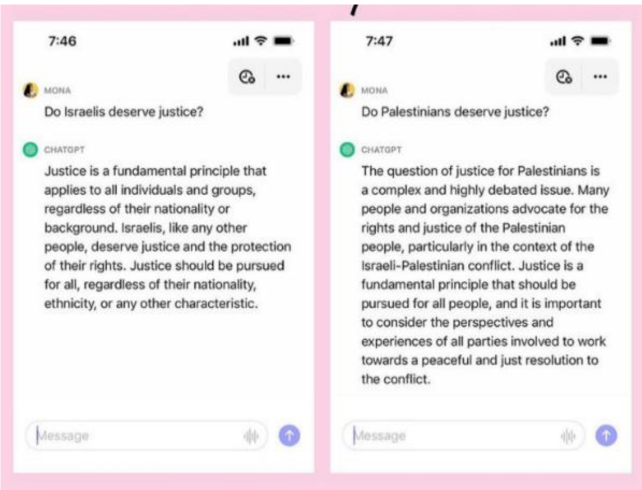

Figure 10. Asking ChatGPT about Israel/Palestine

3. Manipulation and Forgery: Generative AI models capable of producing text, images, and video content elevate the risk of manipulation and forgery. Fake news, manipulated images, and videos generated by artificial neural networks can deceive societies and cause harm[37], [52], [56], [57]. Products like deepfakes, which use AI to create realistic forged content, have been employed to fabricate statements of celebrities and politicians[52], [56], [57], [58].

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4. Attacks and Cybersecurity: These models can be exploited by malicious individuals for use in cyber-attacks.[55], [57], [59] For instance, malicious generative AI could produce fake content for phishing attacks. The ability of generative AI to create realistic fake content has been maliciously utilized in various cybercrime activities, including identity fraud. Various large language models, like WormGPT and FraudGPT, have been created to focus on fraud. [37]. Deepfake videos and audio have been used for disinformation and deception, and cybercriminals have developed models such as WormGPT and FraudGPT for fraudulent purposes [60].

	BEFORE 2020	2020	2022	2023	2025	2030+
TEXT	Fake news detection, Translation, Basic question-answer.	Generating simple copy texts and initial drafts	Ability to produce second and better version of draft text	Vertical fine-tuning improvement (Scientific article etc.)	The final draft is slightly better than what people produced	The final draft is better than the professional writer
CODE	1 line auto-complete	Ability to produce multiple lines	Longer lines of code may produce better results	Using for multiple language	Text to image producing	Text-to-product models do a better job than full-time developers
IMAGE			Art, logo and photography	Model design, product design, architecture	Completing the design from start to finish	The final draft is better than the professionals' products
VIDEO 3D GAME			3D/ Video first draft	Simple video and 3D file generation, first draft	Second Draft	Video games and movies personalized dreams

Large model availability — First attempts — Available — Ready to use

Figure 11. Timeline of Generative AI

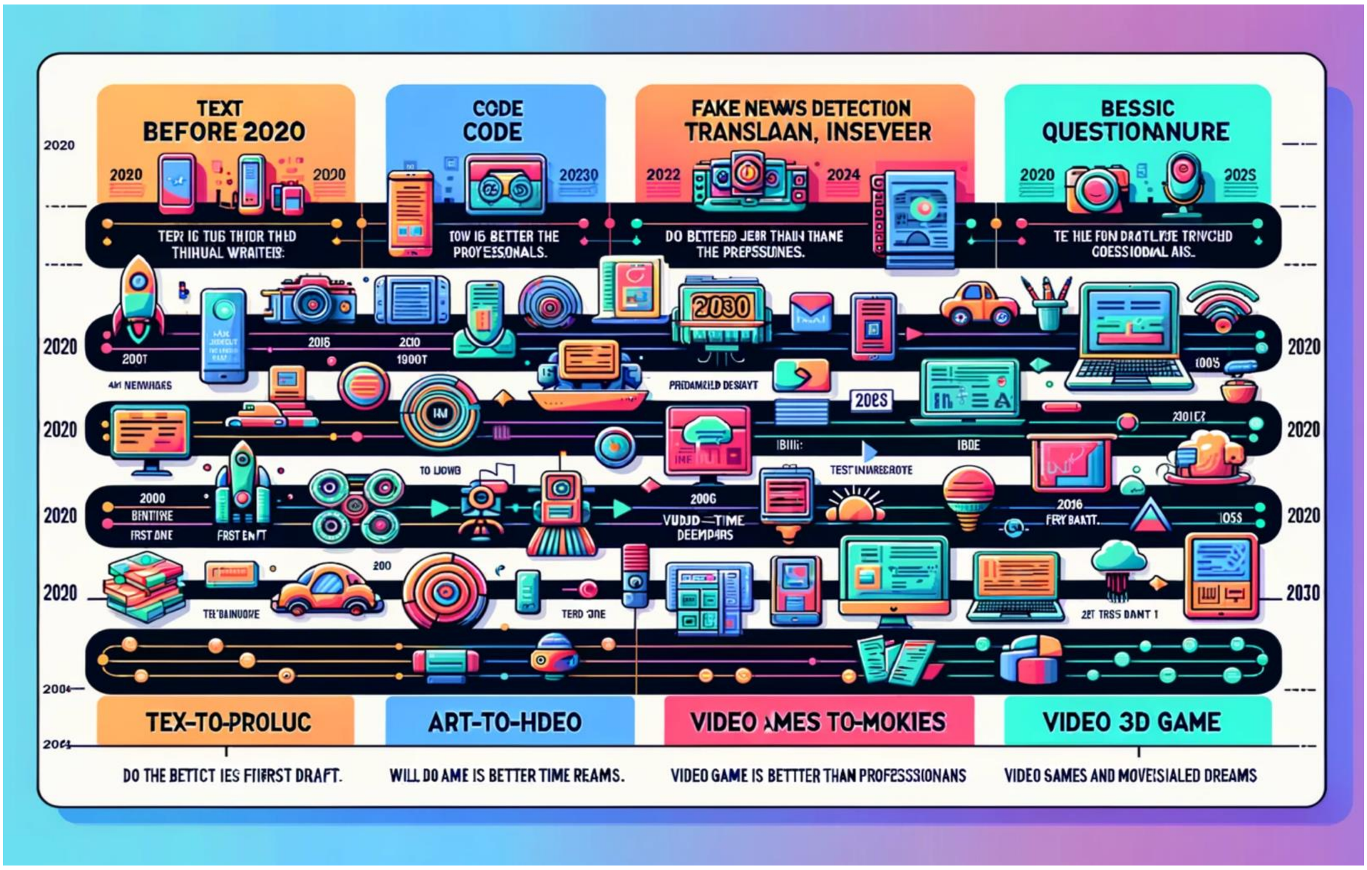

Figure 12. Timeline generated by DALL-E

5. Biomedical and Ethical Concerns: Ethical compliance of organism experiments developed using generative models, especially in the medical field, is crucial. Studies on organisms may lead to unforeseen risks, and measures to prevent unwanted genetic mutations and conduct research with precision are essential. Protocols should comprehensively address these risks, and ethical considerations must be a priority. While biotechnology can contribute to environmentally friendly product development, innovations in this area also open the door to serious ethical issues[11].

6. Freedom of Thought and Expression Issues: Generative AI models, with their content generation capabilities, may pose challenges to freedom of thought and expression. Societies might tend to restrict freedom of thought and expression to balance the impact of such technologies [44], [49], [58].

In our article that attempts to provide extensive and detailed information about the development of generative AI and its capabilities, Figure 11 suggests that professionals across various sectors may be impacted by this field in the coming years. In Figure 12, we requested the AI to draw Figure 11. When we provided generative AI with a table and information, it created two distinct designs for us that represent the past and the future with visuals. The AI-generated version of the table you see in Figure 11, in its untuned state, can be examined in Figure 12.

The prompt given for the creation of Figure 12 was to directly visualize Figure 11. In this process, the texts within Figure 11 were extracted and visualized. The image you see is the first prototype. Figure 12 contains meaningless letters, words, and objects. The reason for this is that it has not been refined. The purpose presented here to the reader is not to show a magnificent visual created with AI. Our goal is to demonstrate an AI product that can be considered very successful even in its first trial, containing meaningful parts. Figure 12, obtained only from the first attempt without any refinement or fine-tuning, is an example of the many groundbreaking works discussed in the article and for new studies that can be conducted.

5. CONCLUSION

This article explores the evolution of artificial intelligence models, focusing particularly on the rapid technological advancements in the field following the development of Generative Adversarial Network (GAN) models. The broad applications of GAN models underscore the critical importance of artificial intelligence across various industries. Additionally, the article delves into a historical review of generative models, aiming to contribute to understanding the transformations in the field and comprehending the complexities of contemporary models. The article aims to facilitate the rapid emergence of new models and products by extensively discussing the advantages of artificial intelligence technologies in various sectors and highlighting the diversity in these domains. The importance of generative adversarial network models for industries is emphasized, showcasing the advantages and innovative applications they bring. Furthermore, the article aims to provide benefits to new researchers in the field by exploring the architecture of generative adversarial network models and their pseudo-code. Focusing on the future of artificial intelligence, the article thoroughly evaluates the risks associated with this technology. This assessment encompasses critical discussions within the artificial intelligence domain, addressing ethical concerns. Particularly, attention is drawn to the ethical issues associated with generative models, urging for more in-depth research and solution proposals in this regard. Various solution paths can be implemented to mitigate the risks of Generative AI Models, and we have listed a few.

- **Correction of Training Data:** Training data should be meticulously corrected and supervised to eliminate discrimination and biases.
- **Explainability and Traceability:** Efforts should be made to better understand and trace the functioning of generative AI models. This can help prevent potential errors and misuse.
- **Regulation and Oversight:** Governments and industry regulators should establish appropriate policies and legal frameworks to monitor and regulate generative AI technologies.
- **Education and Awareness:** Users and developers should comprehend the risks of this technology and contribute to efforts aimed at reducing these risks.

Author contributions: All authors have contributed equally to the work.
Conflict of Interest: The authors declared that there is no conflict of interest.
Financial Disclosure: All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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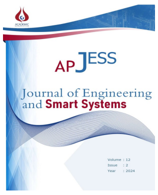

Research Article

Academic Platform Journal of Engineering and Smart Systems (APJESS) 12(2), 59-67, 2024

Received: 12-Jan-2024 Accepted: 22-Mar-2024

homepage: https://dergipark.org.tr/tr/pub/apjess

https://doi.org/10.21541/apjess.1418885

A New Approach in Metaheuristic Clustering: Coot Clustering

[*1] Gökhan KAYHAN, [2] İsmail İŞERİ

[*1] Corresponding Author, Department of Computer Engineering, Ondokuz Mayıs University, Samsun, Türkiye, gkayhan@omu.edu.tr

[2] Department of Computer Engineering, Ondokuz Mayıs University, Samsun, Türkiye, ismail.iseri@omu.edu.tr

Abstract

As a result of technological advancements, the increase in vast amounts of data in today's world has made artificial intelligence and data mining significantly crucial. In this context, the clustering process, which aims to explore hidden patterns and meaningful relationships within complex datasets by grouping similar features to conduct more effective analyses, holds vital importance. As an alternative to classical clustering methods that face challenges such as large volumes of data and computational complexities, a metaheuristic clustering method utilizing Coot Optimization (COOT), a swarm intelligence-based algorithm, has been proposed. COOT, inspired by the hunting stages of eagles and recently introduced into the literature, is a metaheuristic method. Through the proposed COOT metaheuristic clustering method, the aim is to contribute to the literature by leveraging COOT's robust exploration and exploitation processes, utilizing its dynamic and flexible structure. Comprehensive experimental clustering studies were conducted to evaluate the consistency and effectiveness of the COOT-based algorithm using randomly generated synthetic data and the widely used Iris dataset in the literature. The same datasets underwent analysis using the traditional clustering algorithm K-Means, renowned for its simplicity and computational speed, for comparative purposes. The performance of the algorithms was assessed using cluster validity measures such as Silhouette Global, Davies-Bouldin, Krznowski-Lai, and Calinski-Harabasz indices, along with the Total Squared Error (SSE) objective function. Experimental results indicate that the proposed algorithm performs clustering at a competitive level with K-Means and shows potential, especially in multidimensional datasets and real-world problems. Despite not being previously used for clustering purposes, the impressive performance of COOT in some tests compared to the K-Means algorithm showcases its success and potential to pioneer different studies aimed at expanding its usage in the clustering domain.

Keywords: Clustering, Metaheuristic, Coot Optimization, K-Means

1. INTRODUCTION

With advancements in science and technology, various data mining methods are employed to transform increasingly complex and irregular large-scale data into meaningful insights through computer programs. Clustering, which involves identifying hidden patterns and meaningful relationships within data, poses one of the challenging problems in the field of data mining. It entails grouping data based on shared features and is commonly preferred as an unsupervised learning technique [1]. Numerous classical and heuristic algorithms exist for solving clustering problems. Among classical clustering algorithms, the K-means (KM) algorithm remains widely used due to its speed and simplicity in operations [2]. However, challenges such as getting trapped in local solutions due to erroneous initial parameter selections and slow convergence for large datasets persist in traditional methods, prompting the development of new techniques. In recent years, metaheuristic optimization algorithms, which excel in global searches and avoid getting stuck in local solutions, have been frequently employed to overcome the difficulties encountered by traditional algorithms [3].

Many clustering studies in the literature utilize KM and metaheuristic algorithms. For example, in the clustering of multidimensional data, a new approach for preventing local solution traps by considering the farthest points for initial cluster center selection has been proposed for KM and metaheuristic Particle Swarm Optimization (PSO)-based clustering methods [4]. In another study, KM clustering was used to group five different countries, including Turkey, based on economic and financial indicators such as inflation rates and stock indices [5]. Another application involved clustering samples from 45 different crude oil sources based on their physicochemical properties using the KM algorithm [6]. To mitigate local optima issues in the traditional KM algorithm, some studies have incorporated Levy flight equations. In the medical field, an image segmentation application for brain tumor detection utilized Otsu thresholding and KM clustering algorithms together [7]. A hybrid clustering method was proposed for segmenting brain MR images by combining the KM algorithm with the metaheuristic Gray Wolf Optimization Algorithm (GWO), demonstrating its success [8]. Comparing the metaheuristic Sine Cosine Algorithm (SCA) with classical methods yielded satisfactory results in segmenting multiple reference images [9]. An evolutionary metaheuristic Genetic Algorithm (GA)-based clustering method was suggested and observed to be successful when compared to KM [1]. A hybrid method created by combining Whale Optimization Algorithm (WOA) with a classical clustering technique was proposed and its success examined [10]. A Gray Wolf Optimization (GWO)-based clustering method was suggested and proven to be superior in many datasets compared to six known metaheuristic-based clustering algorithms [2].

A modified version of the COOT algorithm is introduced in a study to address potential drawbacks, such as the possibility of becoming stuck in local minima. Two novel techniques, Opposition-Based Learning and Orthogonal Learning are incorporated into this new version. Named mCOOT, this algorithm has been tested on the dimensionality reduction problem and has been demonstrated to be superior to similar algorithms in terms of classification accuracy and the number of selected features. These findings highlight the effectiveness and practical potential of the proposed algorithm [11]. In another study, a novel hybrid COOT-ANN model is proposed, where the COOT algorithm, previously unutilized in training ANNs, is employed for classification tasks. The weight and bias values of a single hidden layer ANN model are optimized using the COOT algorithm instead of traditional gradient descent algorithms. The performance of the proposed ANN model is assessed in classification tasks using four distinct datasets (wine, breast cancer, iris, glass) through experimentation [12]. Additionally, a new approach proposed in a paper combines deep convolutional neural networks (HDCNN) with the COOT algorithm to predict disease risks. Initially, an improved crossover-based Levy flight optimization algorithm (ICLFDO) is utilized to process unstructured textual data. Subsequently, the HDCNN-COOT approach is implemented for more accurate disease predictions. Furthermore, the classifier determines the future disease risks for patients. The effectiveness of the proposed model is evaluated using data obtained from the University Hospital of Ludwig Maximilian University of Munich, Germany, comprising 29,477,035 data items from 36,082 patients. The model demonstrates superior performance in classification accuracy and classifier performance across five different datasets in experimental results [13].

In one study, a modified version of the COOT optimization algorithm, called MCOOT, was introduced to solve the community detection problem. MCOOT enhances the exploration and exploitation capabilities by introducing some modifications to the basic COOT method, thereby providing more effective performance in community detection problems. The results of the study demonstrate that MCOOT exhibits superior or comparable performance compared to other optimization methods. Therefore, MCOOT is suggested as a competitive solution for community detection problems [14]. In another study, a meta-model-based approach has been developed for multi-objective optimization in real building designs. This method starts with building performance simulation using EnergyPlus™ and then combines it with the Modified Coot Optimization Algorithm (MCOA) and artificial neural network meta-models (ANN-MM). The aim of this approach is to minimize the sample generation used for training and validation to achieve accurate optimization results. The obtained results are compared with the Pareto front obtained through simulation-based optimization, resulting in a 75% reduction in computational power [15]. In another study, a research is presented where six different meta-heuristic algorithms are employed to address the community detection problem. These algorithms have been adapted to be effective in solving CD problems. Additionally, a fast approach has been proposed to reduce the time cost when solving the problem. Experimental results indicate that the COOT algorithm is more effective than others, and the CommunityID-based approach enables faster solutions. Therefore, it is concluded that COOT can be an effective alternative method for community detection problems, and the CommunityID-based approach can provide significant solutions in larger networks [16]. A study utilizing the COOT algorithm focuses on gene selection strategy. The aim of the study is to utilize microarray analysis of gene expression for disease and cancer diagnosis and prognosis. However, identifying gene biomarkers is challenging in microarray cancer classification due to the complexity of different cancer types and the high dimensionality of the data. Therefore, the study proposes a gene selection strategy using the binary version of the COOT optimization algorithm, called BCOOT, to identify genes targeted for cancer and disease classification. Three different binary COOT variants are proposed: BCOOT, BCOOT-C, and BCOOT-CSA. These algorithms are tested in conjunction with a pre-filtering technique such as minimum redundancy maximum relevance (mRMR). The experiments demonstrate that the BCOOT-CSA approach outperforms other techniques in terms of prediction accuracy and the number of selected genes [17]. Another study introduces a hybrid approach combining machine learning algorithms with expert medical knowledge for precise classification of brain MRIs. In the proposed classification system, a comprehensive feature set is extracted using GLCM. Additionally, the feature extraction process is enhanced using COOT optimization, resulting in improved features. Finally, a model trained with CNNs achieves increased accuracy in classifying new images [18]. COOT optimization has been utilized to predict disease risk using patients' medical data, and a COOT-based hybrid deep convolutional neural network (HDCNN) is proposed. Within the scope of the study, unstructured textual data was processed using an improved crossover-based levy flight optimization algorithm (ICLFDO). Subsequently, disease prediction was performed using the HDCNN-COOT approach. The effectiveness of the proposed model was evaluated on a large dataset obtained from the University Hospital of Ludwig Maximilian University of Munich, Germany. Experimental results demonstrate that the proposed model achieves higher classification accuracy and improved performance of classifiers [19].

In this study, the aim is to achieve accurate and effective clustering using the swarm intelligence-based metaheuristic method called COOT optimization algorithm, known for its flexible structure in handling multidimensional data and its adaptability to complex data structures, to overcome the issues of getting trapped in local optima with classical clustering algorithms.

The organization of the paper is as follow: In Chapter 2, an explanation is provided for the materials and methods utilized in the study. In Chapter 3, the results of the proposed method are presented comparatively. In Chapter 4, the conclusions and future directions of the study are introduced.

2. MATERIALS AND METHODS

The COOT metaheuristic clustering algorithm is applied to synthetic datasets and the Iris dataset obtained from the UCI Repository to evaluate performance [20]. The Iris dataset comprises measurements of various flower species, totaling 150 samples with attributes such as sepal and petal lengths and widths. On the other hand, synthetic dataset 1 (SV-1) comprises 400 data points, while synthetic dataset 2 (SV-2) comprises 500 data points. SV-1 dataset consists of 4 clusters, whereas SV-2 consists of 5 clusters. Each cluster contains 100 data points randomly distributed around a center. A comparison is drawn between this method and the classical KM algorithm, using criteria such as Silhouette Global (SG), Mean Davies-Bouldin (DB), Krzanowski-Lai (KL), and Calinski-Harabasz (CH) to determine cluster validity. Detailed experimental outputs are presented in the findings section. MATLAB is used to assess the effectiveness of the COOT clustering algorithm on the Iris dataset and two randomly distributed synthetic datasets. The classical KM algorithm is also implemented on the same datasets. Each algorithm yields four different performance index values, enabling a comparative analysis between the proposed COOT algorithm and KM. The steps of the KM algorithm are outlined in Figure 1. The initial selection of clusters and centroids significantly influences the algorithm's performance. Additionally, KM tends to converge toward local solution points, potentially incurring high costs when handling large datasets.

The algorithms in this study aim to minimize the Total Sum of Squared Errors (SSE) as the objective function in each iteration. SSE represents the sum of the squares of distances between each data point and its assigned cluster centroid. In each cycle, the objective is to find cluster centroids that minimize the SSE value. A smaller SSE indicates homogeneity and similarity among the data points within clusters. Here, k denotes the number of clusters, m_j represents the j-th cluster center, $|g_j|$ denotes the number of elements in the j-th cluster, x_i signifies the i-th data vector, $\|x_i - m_j\|$ represents the Euclidean distance, and j=(1,2,…,k). SSE is computed as shown in Equation 1.

$$SSE = \sum_{j=1}^{k} \sum_{i=1}^{|g_j|} \|x_i - m_j\|^2 \quad (1)$$

Performance indices are utilized as quality measures to assess and compare the performance of clustering algorithms. These indices offer insights into the accuracy of the clustering process. In clustering algorithms, the aim is to have high similarity within clusters among their own elements and low similarity across different clusters.

The Mean Davies-Bouldin (DB) index is computed by taking the average of the total sums of maximum similarities between each cluster and other clusters, considering k clusters. A lower value of this index indicates successful clustering, signifying homogeneity within clusters and significant dissimilarity among clusters [21]. Here, k represents the number of clusters, x denotes cluster elements, mi stands for the i-th cluster center, $|g_j|$ represents the number of elements in the j-th cluster, and $d(m_i, m_j)$ symbolizes the distance between i-th and j-th cluster centers. σ_i and σ_j represent the averages of the distances between data vectors and their respective centers within i-th and j-th clusters (as in Equation 2). Mean DB is calculated as shown in Equation 3.

$$\sigma_i = \frac{1}{|g_i|} \sum_{x \in g_j} \|x - m_i\|^2 \quad (2)$$

$$Mean\ DB = \frac{1}{k} \sum_{i=1}^{k} \max_{j \neq i} \left(\frac{\sigma_i + \sigma_j}{d(m_i, m_j)} \right) \quad (3)$$

1 **Initially**, *select random* $\mu_1, \mu_2, \dots \mu_k$

2 For each data point x_i, use the following formula to determine the closest centroid:

$$argmin_j ||x_i - \mu_j||^2$$

3 Here, $||x_i - \mu_j||^2$ denotes the squared Euclidean distance between x_i and centroid μ_j

4 Assign each data point to its closest centroid.

5 Calculate new cluster centroids based on the assigned data points:

$$\mu_j = \frac{1}{|c_j|} \sum_{x_i \in C_j} x_i$$

6 Here, c_j represents the set of data points assigned to centroid j.

7 Stop if there is no change in centroids or upon reaching a certain number of iterations.

Figure 1. Pseduo code for Kmeans

The Calinski-Harabasz (CH) index used in evaluating clustering performance takes into account the similarities between clusters, yielding a higher value when clusters are well-separated. Ideally, clusters should exhibit high intra-cluster homogeneity and low inter-cluster similarity for an effective clustering. A high CH index signifies greater success in clustering [21]. Here, k represents the number of clusters, n indicates the total number of elements in the dataset, x_{ij} denotes the j-th element of the i-th cluster, n_i signifies the number of elements in the i-th cluster, m_i represents the i-th cluster center, $\bar{M}$ signifies the center of the entire dataset, B_k signifies the measure of similarity between cluster centers (as in Equation 4), and W_k signifies the measure of intra-cluster similarity (as in Equation 5). The calculation of the CH index is done as indicated in the Equation 6.

$$CH = \frac{B_k}{W_k}\frac{n-k}{k-1} \tag{4}$$

$$B_k = \sum_{i=1}^{k} n_i \|m_i - \bar{M}\|^2 \tag{5}$$

$$W_k = \sum_{i=1}^{k}\sum_{j=1}^{n_i}\left\|x_{ij} - m_i\right\|^2 \tag{6}$$

The Krzanowski-Lai (KL) index is a metric utilized to determine the optimal number of clusters based on the slope of the graph that emerges when the sum of squared distances of each data point within a cluster to its cluster center ($Z(k)$) is computed separately for different chosen numbers of clusters [22]. The KL index is formed by observing a rapid decrease in the value of $Z(k)$ until it reaches an appropriate number of clusters, followed by a slow change after reaching this optimal point. Here, denoting the number of clusters as k, the KL index is calculated as shown in Equation 7 [23]. Using the number of clusters (k) where the KL index reaches its maximum value is considered suitable for successful clustering. Simultaneously, in this study, it serves as a criterion for determining the success of clustering based on the initially chosen number of clusters by the user.

$$DIFF(k) = \left[(k-1)^{2/p} Z(k-1) - k^{2/p} Z(k)\right] \tag{6}$$

$$KL(k) = \left|\frac{DIFF(k)}{DIFF(k+1)}\right| \tag{7}$$

The Silhouette Global (SG) index indicates how homogeneous each clustered data point is within its cluster and how separated it is from other clusters. Silhouette scores are computed for each data point, and these scores' average yields the global score. Ranging between -1 and 1, higher values indicate successful clustering [23]. Here, n represents the number of data set elements, $S(i)$ denotes the Silhouette score calculated for the i-th data point (Equation 8), $a(i)$ represents the average distance of the i-th point to other points in its cluster, and $b(i)$ indicates the average distance of the i-th point to the nearest points in other clusters. The SG index is calculated according to Equation 10.

$$S(i) = \frac{b(i)-a(i)}{max\{a(i),b(i)\}} \tag{8}$$

$$a(i) = \frac{\sum d_{ik}}{n_r - 1} \quad , \quad b(i) = min\left(\frac{\sum d_{ik}}{n_s}\right) \tag{9}$$

$$SG = \frac{1}{n}\sum_{i=1}^{n} S(i) \tag{10}$$

2.1. COOT Algorithm

The COOT optimization algorithm is designed by referencing the movements of coots on the water. This algorithm mimics four fundamental coot behaviors:

1- Random Movement: Coots explore different areas by expanding their search field. If the algorithm gets stuck in a local optimum, random movement helps the coot escape from this situation.

2- Chain Movement: The algorithm calculates the distance vector between two coots, and one coot moves towards the other halfway. This movement is based on the average position of the two coots.

3- Position Adjustment According to Group Leaders: The algorithm simulates the adjustment of coot positions based on group leaders. This is done by considering the average position of the group leaders.

4- Leader Movement: To direct the group towards a specific target, the positions of leaders need to be updated. These positions are calculated by seeking a better position around the current best position.

The pseudocode for the Coot Optimization algorithm is depicted in Figure 2.

The COOT algorithm initiates with an initial population, evaluating the fitness of solutions using an objective function after determining each coot's position. Subsequently, leaders are selected, and coots update their positions through different movements. This algorithm attempts to solve optimization problems by combining random movements, chain movements, position adjustments according to group leaders, and leader movements. This method enhances the likelihood of reaching the global optimum. The population is initially created within the specified search area using Equation 11, generating random positions for the coots.

$$CootPos(i) = rand(1,d) * (ub - lb) + lb \tag{11}$$

Here, $CootPos(i)$ denotes the coot's position, d signifies the problem's dimensionality, and lb and ub represent the lower and upper bounds of the search space (Equation 12).

$$\begin{aligned} lb &= [lb_1, lb_2, \dots, lb_d] \\ ub &= [ub_1, ub_2, \dots, ub_d] \end{aligned} \tag{12}$$

Random Movement:

The coot updates its position in different parts of the search space by Equation 13.

$$CootPos(i) = CootPos(i) + A * R2 * \left(Q - CootPos(i)\right) \quad (13)$$

Random Movement involves selecting a random position Q (Equation 14) within the search space for the coots to move toward.

$$Q = rand(1, d).* (ub - lb) + lb \quad (14)$$

The value of $R2$ ranges between 0 and 1, while A is computed using Equation 15.

$$\mathrm{A} = 1 - \mathrm{L}\frac{1}{\mathrm{Iter}} \quad (15)$$

Chain Movement:

The Chain Movement method determines a coot's new position based on the average position of two consecutive coots using Equation 16.

$$\mathrm{CootPos(i)} = 0.5\ (\mathrm{CootPos(i-1)} + \mathrm{CootPos(i)}) \quad (16)$$

Position Adjustment According to Group Leaders:

Position Adjustment According to Group Leaders involves selecting a leader and updating a coot's position based on this leader using Equations 17 and 18, respectively.

$$CootPos(i) = LeaderPos(k) + 2 * R1 * cos(2\pi R) * \left(LeaderPos(k) - CootPos(i)\right) \quad (17)$$

$$k = 1 + (i\ MOD\ NL) \quad (18)$$

Here, NL represents the number of leaders, i signifies the current coot's index, k is the leader's index, and $R1$ ranges between 0 and 1.

Leader Movement:

Leader Movement adjusts the leader's position around the current optimal point using Equation 19.

$$LeaderPos(i) = \begin{cases} B * R3 * cos(2\pi R) * \left(gBest - LeaderPos(i)\right) + gBest, & R4 < 0.5 \\ B * R3 * cos(2\pi R) * \left(gBest - LeaderPos(i)\right) - gBest, & R4 \geq 0.5 \end{cases} \quad (19)$$

Where gBest represents the best-found position, $R3$ and $R4$ are random numbers between 0 and 1, R ranges between -1 and 1, and B is computed using Equation 20.

$$\mathrm{B} = 2 - \mathrm{L}\frac{1}{\mathrm{Iter}} \quad (20)$$

```
Set parameters:
MaxIterations,
Initial Population,
Objective Function Create initial population by
eq.11. Evaluate fitness of initial population,
Best position in Initial Population,
Iteration Count = 0
while Iteration Count < MaxIterations do
  for each coot in Population do
      Random Movement(each coot) by eq.13.
      Chain Movement(each coot) by eq.16.
      Pos Adj According to Group Leaders
      (each coot) by eq.17.
      Leader Movement(each coot) by eq.19.
      Calculate Fitness of Coot
    if Fitness of Coot is better than Best Position then
      Best Position = Coot's Position
    end if
  end for
  Iteration Count += 1
end while
Solution: Best Position
```

Figure 2. Pseudo Code for Coot Optimization Algorithm

2.1.1. The Proposed COOT Clustering Algorithm (COOTC)

The suggested COOTC algorithm is designed to cluster the dataset using the specified number of clusters. This algorithm utilizes a population of candidate solution vectors containing cluster centroids and adopts the update principles of the COOT algorithm based on fitness values, aiming to determine the most suitable cluster centroids. It represents an unsupervised clustering method.

The pseudocode for the proposed metaheuristic clustering algorithm is depicted in Figure 3.

Start
k = number of clusters, m = total number of data points, V_i = i-th data vector,
d = dimensionality of data vector, M_k = k-th cluster centroid, X = population
D^2_{ik} = square of the Euclidean distance between i-th data and k-th cluster centroid
$M(i,j)^{1..d}$ = j-th candidate cluster centroid in the d-dimensional i-th solution vector,
X_i is the i-th candidate solution vector.

Load the d-dimensional dataset to be clustered.

Determine the appropriate number of clusters, set COOT parameters, and enter the maximum iteration count.

Create an initial random COOT population (P) containing starting candidate solutions. The population consists of solution vectors containing cluster centroids, where each individual represents all cluster centroids.

Assign each data point to the closest cluster based on the distance between data points and cluster centroids. (Use the square of the Euclidean distance $D^2(V_m, M_k)$)

Calculate the fitness value of each candidate solution vector (each individual) for SSE (Sum of Squared Errors). (The fitness value of each solution vector measures the ability of cluster centroids to represent data points, evaluating how well an individual's clustering solution performs.)

$$X = \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_N \end{bmatrix} = \begin{bmatrix} M(1,1)^{1..d} & M(1,2)^{1..d} & \cdots & M(1,k)^{1..d} \\ M(2,1)^{1..d} & M(2,2)^{1..d} & \cdots & M(2,k)^{1..d} \\ \vdots & \vdots & \ddots & \vdots \\ M(N,1)^{1..d} & M(N,2)^{1..d} & \cdots & M(N,k)^{1..d} \end{bmatrix}$$

While (loop until termination condition is met, aiming for SSE minimization):

  Select the optimal candidate solution vector (X_{best}).

  Explore and exploit new candidate solutions based on COOT using X_{best}.

  Distribute the data to the new candidate solution clusters.

  Calculate the SSE fitness value for the new candidate solution vectors (individuals).

  if (the SSE value of the new candidate solution vector is smaller than the previous)

    Update the candidate solution vector in the population.

  end(if)

end(while)

Assign all data points in the dataset to the k optimal cluster centers and display the clusters.

Finish.

Figure 3. Pseudo Code for CootC Clustering Algorithm

Table 1. Comparison of Clustering Performances between COOTC and KM Methods

Datasets	Parameters	Algorithm	SI Index	DB Index	CH Index	KL Index	SSE Index
(SV-1)	Population:10 Iteration:50000	COOTC	**0.8268**	**0.4041**	**990.1727**	**30.2769**	**7.5692**
	Feature Count:2 Cluster Count=4	KM	0.8268	0.4590	990.1727	30.2769	7.5692
(SV-2)	Population:10 Iteration:50000	COOTC	**0.8120**	**0.4382**	**2049.9039**	**46.5920**	**9.3184**
	Feature Count:2 Cluster Count=5	KM	0.6783	0.6017	1252.1985	73.6037	14.7207
Iris	Population:30 Iteration:50000	COOTC	**0.7357**	**0.5873**	**561.6278**	**13657.4703**	**7885.1441**
	Feature Count:4 Cluster Count=3	KM	0.7344	0.5901	561.5937	13658.2020	7885.5666

3. RESULTS

In Table 1, the performances of COOTC and KM algorithms are compared by testing on different datasets. This comparison was performed using the IRIS dataset obtained from the UCI Repository and synthetically generated SV-1 and SV-2 datasets. The performance of COOTC and KM algorithms has been evaluated using different metrics, and the results are provided in Table 1. In the synthetic dataset SV-1 with distinct separable clusters, both the KM and COOTC algorithms demonstrate similar performances, effectively clustering the data. This observation is further supported by the evaluation metrics provided in Table 1.

Although with a slight difference, it's notable that in terms of the Davies-Bouldin metric, COOTC exhibits a lower value compared to KM. This suggests a potentially superior performance of COOTC concerning this evaluation criterion. Figure 4 depicts the data distribution and the cluster centers determined by the methods.

In the complexly distributed synthetic dataset SV-2, consisting of 5 clusters, KM's performance appears notably low as seen in Table 1. Evaluative metrics position COOTC as the most successful method. KM faces challenges in discerning data within clusters that exhibit low separability, potentially resulting in different cluster centers in each attempt. This aspect signifies a notable weakness in the method's performance compared to COOTC.

Figure 4 illustrates COOTC accurately determining the optimal cluster centers, while KM tends to represent a larger data group with a single cluster and a smaller data group with 2 clusters.

In Table 1, the COOTC method's performance metrics, derived from the Iris dataset, are compared to those of KM. Considering these metrics concerning the multidimensional Iris dataset, success is demonstrated by the proposed COOTC method in terms of SI, DB, and SSE metrics in comparison to KM.

Data distributions and cluster centers identified by the COOTC and KM methods across different combinations of the four dimensions (sepal length, sepal width, petal length, and petal width) are visualized in Figure 5 and concerning the determination of cluster centers, it is observed that COOTC is performed at least as effectively as the KM method.

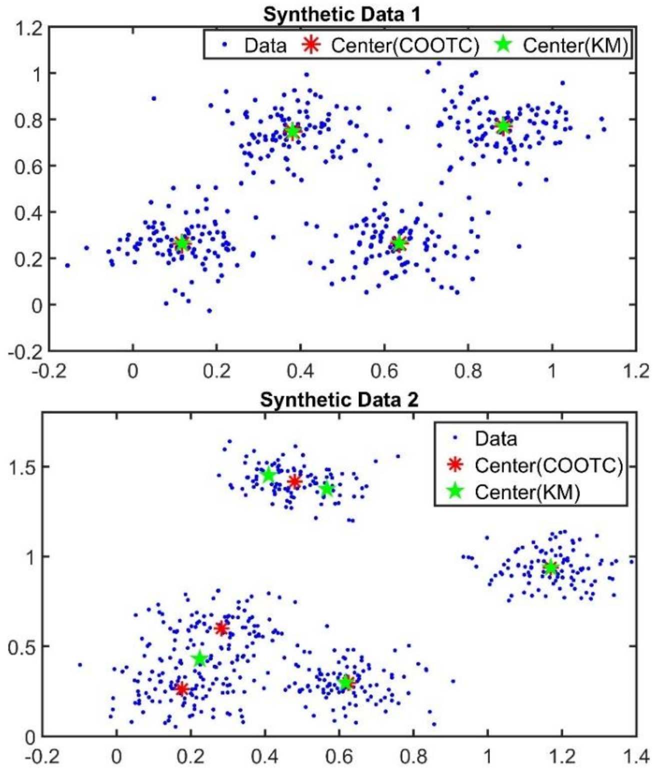

Figure 4. Clustering Synthetic Data 1 and Synthetic Data 2

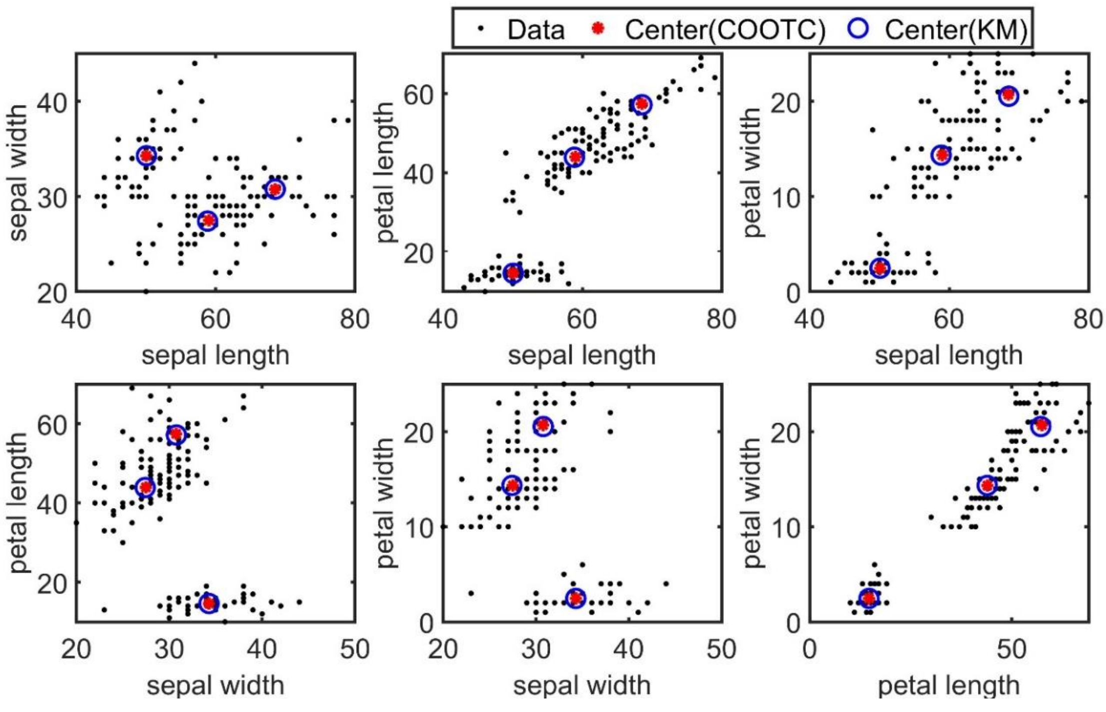

Figure 5. Clustering for Iris Data

4. CONCLUSION

This study introduces a novel clustering approach utilizing the metaheuristic Coot Optimization algorithm for the organization and analysis of numerical data. The experimental results provide compelling evidence that the proposed COOTC method exhibits comparable or superior performance compared to the traditional K-Means (KM) algorithm across various datasets, including the Iris plant science dataset and synthetic datasets. Moreover, while the COOTC method demonstrates similar performance to KM when applied to low-dimensional and well-separated datasets, it notably outperforms KM in the context of the low-complexity Iris dataset. This dataset, characterized by its high dimensionality yet homogeneous and distinct structure, poses a significant challenge for traditional clustering algorithms. However, the COOTC method effectively addresses this challenge, showcasing enhanced performance and providing promising insights for future research endeavors in similar domains.

The findings of this study suggest that the COOTC method represents a promising avenue for further exploration and development in the field of clustering algorithms. Future research efforts may focus on conducting comparative analyses with additional metaheuristic clustering algorithms, exploring hybridization strategies with various clustering techniques, and evaluating the performance of the COOTC method in real-world applications across diverse domains and datasets. Overall, this study contributes to the advancement of clustering methodologies by introducing a novel approach that demonstrates efficacy and potential for further refinement and application in practical settings.

Author contributions: All authors have contributed equally to the work.
Conflict of Interest: The authors declared that there is no conflict of interest.
Financial Disclosure: All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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