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# Modern Neural Network Technologies Text-to-Image

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**Abstract**

This paper discusses state-of-the-art graphical text-to-image neural networks and methods for text-to-image conversion, analyzing the results achieved and samples created to date for text-to-image conversion tasks. Ways of applying neural network approaches to text-to-image transformation for environmental monitoring, infrastructure and medical data analysis tasks are proposed. In this paper the results of neural network generation and its correlation with the user input linguistic constructions of text queries are reviewed, and the typical flaws and artifacts typical of the neural network generated images are identified and classified. The rapid development of neural network technologies in this field could have a significant impact on society, the professional market and the media, which makes the task of studying neural network images and identifying them among other graphic content particularly relevant.

**Keywords**: Machine Learning, Computer Vision and Pattern Recognition, Neural network, Computer graphics, Text-to-image.

## 1. Introduction

The field of neural network technology is currently undergoing rapid development, becoming more sophisticated every day and gaining more and more skills and capabilities. In particular, neural networks that can process images in a variety of ways, from animating photos to automatically creating full-fledged images based on a user's text request, are becoming particularly popular these days.

The task of such a neural network is to form plausible images for a variety of sentences that explore the compositional structure of language. Another task becomes the simultaneous management of multiple objects, their attributes and their spatial relations. In order to correctly interpret a query sentence, the algorithm must not only correctly compose each object attribute, but also correctly form associations. For example, to visualize the sentence "hedgehog in red hat, yellow gloves, blue shirt and green trousers", the neural network needs to recognize in the text and generate object images in a given combination of features and object (hat, red), (gloves, yellow), (shirt, blue) and (trousers, green) without mixing them [1].

It should also be noted that the user of this type of neural network cannot yet predict in advance the visual result that the neural network will produce for the entered textual query. The correlation between the original query text and the resulting visual image is a separate class of problems, which is currently being actively studied and solved by the developers of the largest text-to-image neural networks, such as Midjourney.

### 1.1 Text-to-image graphical neural networks

2022 is a pivotal year for many creative professions. In March 2022, the Midjourney image generation neural network opened to the public and quickly gained a large following, not least due to the fact that it became publicly available before the likes of DALL-E and Stable Diffusion. With a distinctive and already recognisable style, it's rapidly evolving and improving, allowing users to recreate more and more complex queries in graphical form.

Also in 2022, USA-based machine learning technology licensing and development company OpenAI unveiled DALL-E 2, an updated version of the neural network first shown in January 2021. The new version generates even better and more realistic images from the description in English.

One of the major events in the world of AI image generators was the public release of Stable Diffusion neural network, because unlike DALL-E and Midjourney, Stable Diffusion model source code is open and allows users to conduct their own experiments to improve the neural network. Stable Diffusion has become the basis for a dozen new projects, the number of which is now only growing.

## 1.2 Field of application

Nowadays the main area of application of such neural networks is in the media and entertainment industry, although in potential applications the field is almost limitless: from illustrations for presentations to logos, sketches for films and official covers for glossy magazines.

Manufacturers in the fashion world are also turning their attention to the potential of neural network graphics. The rapid and high-quality development of unique designs (Figure 1) to suit individual user requirements can become closely linked to production and be in demand in society.

Figure 1. A unique design for sneakers generated by Midjourney's neural network using the query "nike sneakers in khokhloma style" [2].

It can be assumed that the use of neural networks will evolve in the future as a tool for one of the most sought-after scenarios for businesses - personalizing content to suit individual user needs.

However, the ability of neural networks to quickly and automatically generate an infinite number of different images from a given textual description opens up opportunities for scientific work as well.

With the ability to train off-the-shelf algorithms on thematically selected material (prepared image database), it is possible to create specialized neural networks adapted to domain-specific terms and queries.

For example, the use of text-to-image neural networks is possible in areas such as environmental monitoring or biomedical technology.

In order to organize environmental monitoring, it is first necessary to collect data. As the data from different sources are analyzed in order to monitor the processes taking place in the environment: images, heterogeneous sensor data, textual data and others, the collected data is heterogeneous [3]. After analyzing the data and identifying the main components that have the most impact on the overall situation, it becomes possible to summarize what is happening in textual form. It is then possible to generate an appropriate textual query and model a visual image from the linguistic data.

A complex analysis allows to get the most effective picture of the processes taking place and draw adequate conclusions.

The use of neural network graphics for rapid generation of illustrative images of the processes under study allows one to get the most complete impression of what is happening.

With the availability of textual eyewitness testimonies, it becomes possible to quickly reconstruct the visual picture of the events and visualize the overall situation for further analysis.

The aggregate of various data can be transformed into a visual form without the need to use human imagination, but with the possibility of online expert corrections to bring the final representation to the desired form that most accurately reflects the phenomenon being described. Figure 2 shows a visualization of a rather general query (query text: "crimson sky, high waves, a storm is approaching"). Nevertheless, the image is already highly detailed and presented in four versions, from which the user can choose the one most suitable for his needs and make the necessary adjustments until a satisfying result is achieved.

Figure 2. Example of a visual image reconstructed from a textual description.

For more specialized tasks, such as manufacturing or medicine, specially trained neural networks are needed, capable of understanding certain jargon or science-based linguistic phrases without allowing ambiguous interpretations.

Given the vast amount of accumulated material, and the existence of specialized archives for many fields, it may be a matter of time before specifically oriented graphical neural networks are developed.

Potentially, their application gives ample opportunities for analysis of various types of data, combining them and displaying in a clear and understandable way. They can also be used extensively in teaching and learning tools.

For example, a neural network can represent a typical condition of some organ, tissues at a certain set of symptoms listed in a query. In case a textual description contains an indication of some pathology, a visual representation can help to highlight it and make the right decision.

Neural networks are already widely used in different fields of science.

For example, tasks that are performed by an inpainting function (removing objects and then shading empty areas of an image so that the fact of such shading is unnoticeable), are in demand in archeology in the case when it is necessary to recreate a building of which only ruins are left. A neural network can generate an image based on data about similar buildings and styles in architecture.

# 2. TEXT-TO-IMAGE GRAPHICAL NEURAL NETWORKS

This section presents brief descriptions of the most popular and large commercial text-to-image neural networks that have become widely known in the last year. These include Midjourney, which opened in March 2022, an updated version of DALL-E 2, first demonstrated in January 2021; Stable Diffusion, an open-source neural network that has become the basis for dozens of new projects; and ruDALL-E, a Russian neural network based on generative models from SberDevices and Sber AI.

## 2.1 Midjourney

Midjourney [4] is proprietary software that creates images from text descriptions. The project was founded in February 2022 by scientist and entrepreneur David Holtz. The Midjourney team has positioned itself as an independent research laboratory dedicated to expanding humanity's creative abilities.

Midjourney's work is enabled by two relatively recent technological breakthroughs in artificial intelligence: the ability of neural networks to understand human speech and create images.

The neural network is trained to match textual descriptions with visual images across hundreds of millions of examples, using specially compiled collections that contain billions of images gathered in the network, as well as matched image-text pairs. Such datasets can be commercial or open source, such as LAION [5], on which the famous Stable Diffusion neural network was trained. The results of such training allow solving various cross-modal tasks - generation of pictures based on text descriptions, generation of text descriptions based on pictures, regeneration or rendering of image parts, etc. This makes it possible to advance in solving such topical tasks as visualization of incomplete data and their replenishment.

Midjourney, like most neural networks of this type, is well capable of making explicit queries, without getting specific. For example, if you give it a query to generate "red car on the road", it will generate quite satisfactory options. You can experiment with car colour, size, background - these are quite general queries.

Problems may arise with more specific queries. For example, a car model may already cause problems for a neural network. The rarer this model occurs in the network space, the less chance that a neural network will be able to draw it.

However, graphical neural networks at this point in time are an extremely fast developing and progressing area of computer graphics, so versions of Midjourney are constantly being updated and improved. The paper [6] provides a comparative review of Midjourney versions v3 and v4, looking at the key differences and features of the updated version. In March 2023, an update to Midjourney version v5 was released and its features are only being explored.

## 2.2 DALL-E 2

DALL-E 2 [7] is one of the most popular neural network graphics systems, developed by OpenAI with 12 billion parameters based on GPT-3 (Generative Pre-trained Transformer 3 - the largest and most advanced language model in the world from OpenAI), trained to generate images from text descriptions using the text-image pair data set. It is able to generate original images from textual descriptions and allows users to upload images and edit them, for example by adding elements. Furthermore DALL-E can not only generate an image from scratch, it can also regenerate any rectangular area of an existing image,

According to the developers, "DALL-E 2 is an artificial intelligence system that can create realistic images and drawings from a natural language description".

DALL-E 2 started as a research project and is primarily of interest due to the publications of the developers, who have done a lot of work in creating algorithms and studying the behavior and capabilities of the developed neural network [1, 8, 9].

A neural network can create images in a wide variety of drawing styles and techniques. It can be an image that looks like a frame from a cartoon, or the image will look like a real photograph.

DALL-E 2 was trained on image pairs and their respective captions. According to the developers, the pairs were taken from a combination of publicly available and licensed sources [10].

The software is now available to a limited number of people, only by subscription. This is due to both limited server infrastructure capacity and the developers' desire to control the development and self-learning of the neural network through user testing. In particular, due to concerns about the misuse of the neural network, the developers carefully filter content for its training and incoming requests for prohibited topics (violence, adult content, etc.).

Among the features provided in the latest updates are such as:

- higher resolution of images
- query processing in more than 107 languages, including Russian
- high request recognition accuracy
- possibility of setting colour filters and image style
- can take an existing image as an input and create a creative variation of it
- possibility to refine the uploaded image.

## 2.3 Stable Diffusion

On 22 August, Stability AI released its open-source image generation model that could compete with DALL-E 2 in terms of quality.

Stable Diffusion (SD) stands out from similar neural networks primarily due to its open source code under the Creative ML OpenRail-M license [11]. This makes it possible to run SD on your own computer, rather than via the cloud, which is accessed via a website or API.

For decent results, the developers recommend an NVIDIA 3xxx series GPU with at least 6GB of RAM.

Stable Diffusion is a system made up of many components and models that are responsible for different parts of the system. These include a text understanding component, which converts textual information into digital form, and an image information space creation component, from which the image itself is subsequently drawn using an image decoder. This is done only once at the end of the process and produces a finished pixel image. Such an algorithm speeds up the process compared to previous diffusion models operating in pixel space (Figure 3).

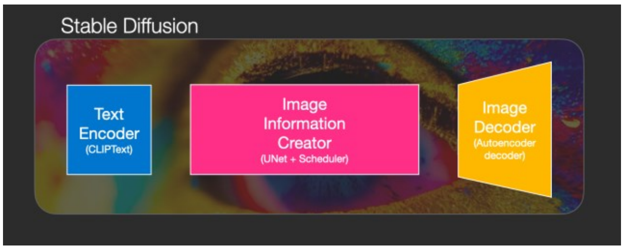


Figure 3. The main components of Stable Diffusion.

For more on the work of Stable Diffusion, see [12].

## 2.4 ruDALL-E

ruDALL-E [13] is a family of generative models from SberDevices and Sber AI. The neural network was developed and trained by Sber AI researchers with the partner support of scientists from AIRI Institute of Artificial Intelligence on a combined Sber AI and SberDevices dataset of 1 billion text-image pairs. Teams from Sber AI, SberDevices, Samara University, AIRI and SberCloud actively participated in the project.

Specialists created and trained two versions of the model, named after two great Russian abstractionists, Vasily Kandinsky and Kazimir Malevich:

- ruDALL-E Kandinsky (XXL) with 12 billion parameters;
- ruDALL-E Malevich (XL) with 1.3 billion parameters.

Both models are capable of generating colourful images on a variety of topics from a short textual description. According to the developers, Kandinsky uses backward diffusion and can process queries in 101 languages, without any loss in quality or speed. Among those languages are both common languages such as Russian and English, as well as rarer languages such as Mongolian. The system will understand even if a query contains words in different languages.

Training the ruDALL-E neural network on a Christofari cluster was the biggest computational challenge in Russia. It involved 196 NVIDIA A100 cards, each with 80 GB of memory. The whole training took 14 days or 65,856 GPU-hours. It was first trained for 5 days at 256x256 resolution, then 6 days at 512x512 resolution and 3 days at maximum clean data.

The ruDALL-E Kandinsky 2.0 system is claimed to be the first multilingual diffusion neural network capable not only of accepting requests in different languages, but also of forming linguistic-visual shifts in language cultures.

This statement is supported by a number of experiments [14]. In particular, such queries as "national dish" or "person with higher education" are tested (Figures 4 and 5). For the Russian-language query, the neural network produces predominantly white males, while for the same query in French, the results are more varied. For the query in Chinese, the results have more stylized images, but in most cases they also reflect the national component.


Figure 4. Testing the query "photo of a person with higher education" in Russian, French and Chinese.


Figure 5. Testing the query "national dish" in Russian, Japanese and Hindi.

The author also conducted an experiment (Figure 6) on the FusionBrain platform [15], which confirmed the orientation of this neural network to different language environments. The query "national dish", performed in several languages, produced completely different results.

Figure 6. Testing the query "national dish" in Russian, Hindi and Italian (rows across).

It is worth noting that queries in different languages make sense to test either on the above-mentioned platform or by interacting with developers' repositories directly. The rudalle.ru platform is not adapted to such queries; it is capable of perceiving a foreign language, identifying it, translating the query into Russian, and then generating a visual image.

Such experiments open up a separate area for research, as preliminary studies suggest that neural networks of different language groups will have their own distortions and differences in the interpretation of the same phenomenon, depending on the mass culture belonging to one or another language group.

# 3. FEATURES OF GRAPHICAL NEURAL NETWORKS

## 3.1 Human-Network interaction using natural language

This rapid development of neural network technologies' capabilities in the field of graphics and photorealistic images brings to the forefront the task of interaction between humans and neural network technologies using natural language. The linguistic construct that a human uses to formulate a task often contains much more meaning and historical context than a neural network, which focuses on a specific set of parameters and phrases, can understand. [16, 17].

For example, since most neural networks can only understand queries in a certain language (English being the most common), the linguistic context and subtleties of translation must be taken into account when dealing with them. This issue also needs research.

So, popular on the web experiments on visualization of well-known proverbs and sayings in Russian are of dubious effectiveness, because such experiments are most often carried out in Midjourney neural network, which specializes in queries in English and understands requests in other languages poorly. Accordingly, the cultural layer, on which it relies, refers rather to the English-language space and reflects its specificity.

Thus, in Figure 7 the user asked the neural network a query in the form of the Russian proverb "волки ноги кормят".

Figure 7. Neural network's attempt to generate an image using the Russian phrase "волка ноги кормят".

Unfortunately, the original article [18] does not provide the exact text of the query, but judging from the result, we can conclude that there was a direct literal translation of "wolf feet fed", and the neural network reproduced this query quite literally. Meanwhile, this proverb has the full English analogue of the semantic idiom "The dog that trots about finds a bone" or the translation offered by the online translator DeepL, "the wolf feeds the wolf", which implies absolutely different visual images, but has the same meaning. Therefore, when giving a neural network a query, you should take into account the difference between the semantic translation and the direct translation, because the results can be drastically different. Thus, making the right query becomes, in a sense, a profession. People who have learned to get the intended and high-quality result are already called "prompt-engineers", and more and more offers to form a precise query for a neural network are appearing on freelance exchanges.

## 3.2 Typical artefacts

In addition to poor correlation between linguistic query and graphical representation of the result, when a neural network does not understand the query or recognizes and visualizes only part of the meaning put into the query text by the user, a number of artifacts typical of neural networks are revealed.

These artifacts are widespread and typical for neural network generated images. In particular, their presence can be used to identify an image generated by a neural network.

Conventionally a common set of artifacts can be divided into three main groups:

1. "Chimeras". The case when a neural net cannot correctly reflect the requested object or mixes given objects with each other, generating surreal and sometimes frightening images. Such things can also be planned by the user, but in this case the query text itself implies combining incompatible notions.

One of the most famous examples is the human hand, or more precisely the position of the fingers. The most common artifact in the generation of human images - distorted hands, where there are either missing or six or more fingers, or they are intertwined and bent at an anatomically inconceivable angle. There is speculation that the neural network combines multiple hand arrangements, but does not filter out minor details like extra fingers.

2. Distorted composition. Neural networks in the majority of cases cannot create fully realistic or stylized images with a lot of details. Objects merge with one another, there are under-drawn or mis-matched objects.

This phenomenon differs from "chimeras" in that the overall structure of the generated picture at first glance is not violated and seems natural, but upon closer examination it appears that some objects are not completed, located relative to each other with a distorted perspective or flowing one into another.

Figure 8 shows one example of this problem. According to the request (man waiting in line at Mcdonald's in Thailand, detailed facial features, full body, fuji color film, 2005 -v 4) the picture shows a young man standing in a line at Mcdonald's with the appropriate entourage and appropriate appearance. There is a high degree of photorealism and detail in the image, but a closer look at the background reveals a number of clear signs that the image belongs to the neural network. The people blend into each other: for example, one man's face is sunken into another man's T-shirt, his head has no neck, and another man's arm is disproportionately thin and merges with the edge of his blue sleeve, blurring around the edges and seeming to shine through.

Figure 8. Image generated using Midjourney v4 [6].

Another artefact that occurs quite often in Midjourney is the bent spoons in the food pictures (Figures 9-10).

Figure 9. Presence of artefact - deformed spoon in the generated image [19].

Figure 10. Presence of artefact - deformed spoon in the generated image [20].

Texture artefacts. In this case, the artifacts do not affect the overall image and occur in places where the neural network cannot adequately process some highly detailed area or recreate the desired structure. This could be hair, clothing fabric, or skin.

Such artifacts are inherent to neural networks that can reconstruct part of the image, enhance the quality, or generate the image from scratch.

More often than not, at the location of the artefact, when zoomed in you can see a visible difference between the damaged area and the rest of the image. In Figure 11, for example, you can see an odd ripple in one section of hair, unlike the rest of the hair. A neural network often produces this pixel grid effect, but in most cases it is only visible when it is greatly exaggerated.

Figure 11. An example of the presence of artefacts in hair texture [21].

## 3.3 Developments in graphical networks and emerging issues

*3.3.1 Copyright*

Neural network technologies are currently in their heyday. From individual artists creating jewellery to large companies such as Adobe, the fruits of their work are beginning to be used en masse for their own purposes. Such a leap is generating quite a few social phenomena. Some companies are already banning on their site the uploading and selling of illustrations created with AI and tools such as DALL-E, Midjourney and Stable Diffusion. The reason Getty Images (the US photo agency that owns one of the world's largest image banks) is rejecting AI creativity is because of possible copyright issues.

Content creation tools are predominantly trained on images taken from the internet and protected by copyright. These sources may include personal art blogs, news sites and stock sites (stock is a photo image on a particular subject which is sold on publicly available marketplaces and can be used as an illustration or advertisement for photographs). Scraping (extracting data from web pages) is recognized as legal in the US and falls under the category of 'fair use'. A number of artists whose work has been copied or imitated by neural network image generators have called for this area to be regulated by law, as a neural network is able to copy a particular style very precisely and reproduce it on its own content (Figure 12).

Figure 12. Original photo by photographer Richard Avedon (left) and a portrait in the same style generated in the photorealistic model of the Stable Diffusion dreamlike-photoreal-2.0 algorithm (right). [22].

### *3.3.2 Spreading fake information*

Another emerging issue is the possibility for users to train ready-made neural network algorithms on their own data, given the appropriate technical capabilities. While most other paid neural networks have certain markers set by the developers that limit a number of user requests, and the system bans the account in case of abuse (such requests include 18+ topics, shocking content and violence), open-source neural networks like Stable Diffusion allow users to experiment relatively freely and train their own neural networks, targeting certain areas.

This can cause uncontrolled spew of unfiltered graphic content into the online information space, including photorealistic images that, if misused, can trigger meaningful social movements and spread unconfirmed fake information.

In February 2023, a precedent of the use of images generated by graphic neural networks was first reported in the media [23]. Fraudsters used neural network images to cash in on the earthquakes in Turkey and Syria by distributing generated disaster images on Twitter along with addresses to cryptocurrency wallets asking for charitable donations (Figure 13).


Figure 13. Fake photo generated in a neural network.

Thanks to visible artefacts (distortions of the child's face and fingers on the hands), the fraudulent scheme was quickly uncovered, but this case risks being only the first of many. Neural networks are rapidly improving and being updated, and neural network images are becoming increasingly dense in everyday life. It is quite possible that their use will soon be aimed not only at creative activities, but also at fraudulent and provocative ones. An instantaneous mass of fake images of current political events or shocking content, generated at high speed and in large quantities, can mislead unprepared people and lead to negative social reactions.

Photorealistic neural networks carry the potential risk of discretizing and destroying the legal value of photographic or video evidence and distorting and falsifying historical sources.

Such perspectives bring to the fore the need to address the task of verification and identification of generated or processed photorealistic images in order to effectively counteract their malicious use.

The first measures proposed are to identify and classify the main features of neural network images and typical artefacts (as described in section 3.2).

Currently, in most cases neural network images can be identified by a set of direct and indirect features, but for a number of images this becomes a difficult task. For example, these could be single portraits of people with no hands or complex poses, realistic 'photographs' of animals, abstract landscapes or paintings. In these cases, the neural network has been trained on a huge database and produces almost no artefacts.

This in turn raises the challenge of developing algorithms to distinguish the work of the neural network and identify computer "fakes" among the original photos.

# CONCLUSIONS

In this paper, state-of-the-art text-to-image graphical neural networks and methods of text-to-image transformation have been examined and the results achieved have been analyzed.

A number of problems generated by these systems were considered. Ways of applying neural network approaches to text-to-image transformation for environmental monitoring, infrastructure and medical data analysis tasks were proposed.

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