AI in design

for AMRC / AMRC Partners / AMRC Partners and ADG Sponsoring Company / AS Sponsoring Company / AI Project Consortium

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The University Of Sheffield. /AMRC

Executive summary

This report aims to provide clarification of how artificial intelligence (AI) can be applied in design with a detailed definition, use-case and case studies. At the same time, the report will highlight the value that AI can deliver to businesses in the prototyping of new products.

The author presents a simplified overview of AI and its uses in the design industry. Some examples of AI are given, both simple and complex. Examples of how AI is currently used in the design workflow are given and explained in detail. Research papers applicable to design are also discussed, such as using generative AI to directly create computer-aided designs (CAD) in 2D, as well as more abstract applications such as using AI for urban planning. The generative design research cited is limited in its applications as only 2D designs were shown, however, extending the functionality to 3D CAD data is discussed. The less directly applicable tools, such as AI enhancements to existing workflows, are preferred over using AI to directly automate design work due to the current limitations of generative AI. Some existing generative design tools in certain CAD programs are mentioned, but available information on these tools shows a lack of AI implementation beyond topology optimisation that could only loosely be considered AI.

AI applied to machine vision is explained in detail as it is one of the most prevalent applications of the technology. Some concerns with the use of AI in industry are explained, adversarial attacks on AI systems, and how the chain of responsibility should work. The paper then goes on to discuss how AI can specifically be applied to a past AMRC project and how it can uniquely enhance the outcomes.

Finally the future of AI, specifically with regards to the design process, is discussed. It is concluded that current design workflows can potentially be enhanced by AI tools, but there are few currently available. However, the prominence of AI will continue to grow in all fields, fuelled by the increasing availability of data and computational power.

Contents

1. Introduction to AI

Artificial intelligence (AI) focusses on intelligent tools and technologies capable of performing creative or complex tasks in ways traditional programming methodology cannot. In industry, AI is often applied in the form of automating a process or repetitive task. Typical tasks or processes where AI is used can include visual perception, speech recognition, decision-making, and translation between languages, which can be found in technologies such as defect detection, face and voice detection, smart assistants, and search engines.

AI allows for automation of complex tasks that could previously only be performed by a human, or provides a mechanism for a single person to do the work of many. The current demand in AI technology has allowed developers and researchers to create tools and solve problems that were previously too difficult for automation. As these AI technologies become more common in everyday applications, it is crucial to understand their limitations and function.

AI systems range in complexity from simple mathematical clustering models used to group data, like k-nearest neighbours, to complex multi-neural network systems capable of super human-level performance in specific tasks [1, 2, 3]. A system being classed as AI does not necessarily make it a cutting-edge system, simple neural networks and dynamic programming algorithms conceived as early as the 1950s can also be considered AI [4], demonstrating some 70 years of artificial intelligence research.

This report will focus on how AI is applied in the design space and how it could be used in the future to help designers. The main areas of interest for the design space are AI tools that can augment and improve a designer's workflow making their work easier, or allowing them to be more creative.

2. What is AI in design?

There are several areas of AI research that are of particular interest to the design sector; these include generative networks capable of creating designs based on prompts or reference material. Generative Adversarial Networks (GANs) have been used to generate images of people [5] and have been applied to some engineering problems in 2D [6]. Generative design is already a well-used term referring to topology optimisation techniques potentially enhanced by AI algorithms. Generative design and generative AI are cutting-edge technologies undergoing constant development, as these technologies progress they will be integrated further into the design workflow. Tools such as topology optimisation are well established but are usually not considered AI as their iterative approach to material removal is typically done through straightforward computation.

Any machine learning (ML) technology that can support the creation of a design, through generating aspects of the design directly, or supporting the creator indirectly, can be considered AI in design. This can be through automating certain tasks, such as localisation translations or design validation; it can be through augmenting their workflow with smart tools, for example Adobe Photoshop's content-aware cropping and fill tools which can seamlessly erase objects from photos; or automatic background blurring of webcam video in teleconferencing tools.

The technical challenges designers face typically require human participation and are not well suited to classical automation. Designing a part involves considering multiple interrelated factors, including the functionality, producibility, manufacturing costs, material properties, and the aesthetics of the part. The latter of which is a concept that can be hard to quantify and optimise with an algorithm.

The most effective way to support designers is to automate and enhance small tasks rather than automate entire designs. These tasks that designers currently perform can be well suited to AI automation, even when traditional programming is not. The goal of this AI-enabled design automation is to allow designers to focus on value-added creative processes rather than losing time to repetitive tasks. The creative and human elements of design are much harder to automate.

3. How is AI applied to design within industry?

Within the engineering sector, AI can be used for generative design in more intelligent ways than standard topology optimisation. Where topology optimisation of designs uses classical modelling to determine where material can be subtracted or added to a constrained reference part, AI-powered generative design can be used to generate more creative designs, not just designs solely driven by meeting requirements and constraints to the letter. These generative tools will create numerous designs, and the designer will down-select or reiterate the generation process. The tools offered by CAD vendors are often supported by cloud computing to handle the high computational load. Marketing material for these features within the CAD software can be intentionally vague and confuse standard topology optimisation and AI-powered generative design, making it difficult to determine if AI is actually applied. Research has shown that generative AI models can create a large number of conforming and aesthetically unique designs in 2D space using a small number of reference designs [7]. In theory, this technique can generalise to 3D designs using voxel data rather than pixel data.

AI has also been shown to work well in planning urban city designs [8]. In this report, the author proposes an AI-aided design process using AI techniques such as genetic algorithms. Genetic algorithms are well suited to problems where an organically grown solution can be optimal, such as city planning or system control. Genetic algorithms have been used extensively in teaching AI agents to control animation rigs for humanoid locomotion, or even robots and drones [9, 10].

3.1 How can AI be applied to the design process?

There is room in the design process, from initiation to finalisation, for AI tools to be implemented. Figure 1 shows a flow chart summary of a typical design process. In this breakdown of the design process the generative tools discussed above fall into the design section as they directly apply to assistance in generating the drawings and models. The urban planning tool mentioned above could fit into the concept or design sections depending on its use. Tools that apply to the design workflow are most obviously applicable, but tools that assist in research, concept generation, or testing and validation could also save large amounts of time in their respective sections of the design process.

An example of AI being used to streamline the concept stage of design is AirBnB's custom AI sketch to web design tool [11]. This tool allows designers to hand draw their concepts for web layouts quickly on paper and use an AI-powered machine vision system to quickly convert it to a web layout. This process could also fall into the design stage of the process outlined in Figure 1, however, its speed allows for excellent fast concept design and prototyping before further custom refinement.

AI tools are already used in the initiation stage in the form of search engines. Modern day search engines make heavy use of AI algorithms to optimise search results and often personalise them using collected user data.

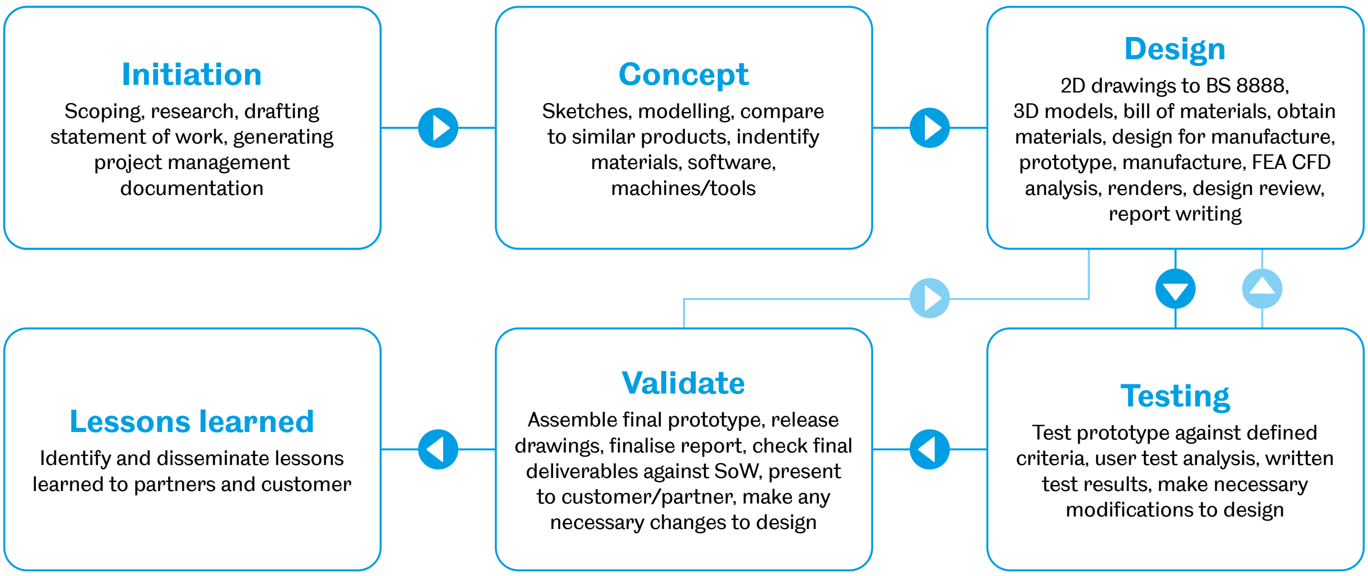


Figure 1: A flow chart summary of a generic design process from initiation to lessons learned review.

3.2 AI for machine vision

Another common use of AI within industry is AI machine vision. AI can be applied to machine vision for visual detection of objects or advanced image processing. Not all machine vision uses AI, but it is often applied when the task is too complex for traditional image processing techniques. AI-augmented camera systems can be used for production line monitoring or defect detection. Where classical image processing would require significant tuning and consistent lighting conditions, a machine learning algorithm can be trained to be resistant to those variations. Often these environments provide a wealth of data to perfect the training; this makes AI well suited to these tasks.

As large amounts of data are required to sufficiently train an object detection algorithm, its implementation into the design space can prove challenging. There will not be large volumes of training data for novel designs or prototypes and generating it is time-consuming, especially if the design is subject to changes throughout its development.

The digital design team has developed a prototype solution to this problem for image-based object detection models. The solution, CAD to ML (CAML), is capable of generating virtual images of objects with pixel-perfect labelling ready for training. The solution uses 3D models of the items and background images for context to generate renders of the object in random poses with a randomly selected background. It can generate hundreds of labelled examples in a fraction of the time it would take to capture and label real photographs and with a much wider range of backgrounds, which could be used during the design process to increase the uptake in AI technology. A summary of the process flow for this tool is shown in Figure 2.

This tool has been shown to successfully train object detection models alone, and also to bulk out an existing dataset for increased accuracy. The tool requires model files for the object and relevant background images. The speed of the tool depends on the complexity of the CAD design, as more complex 3D models require more time to render.

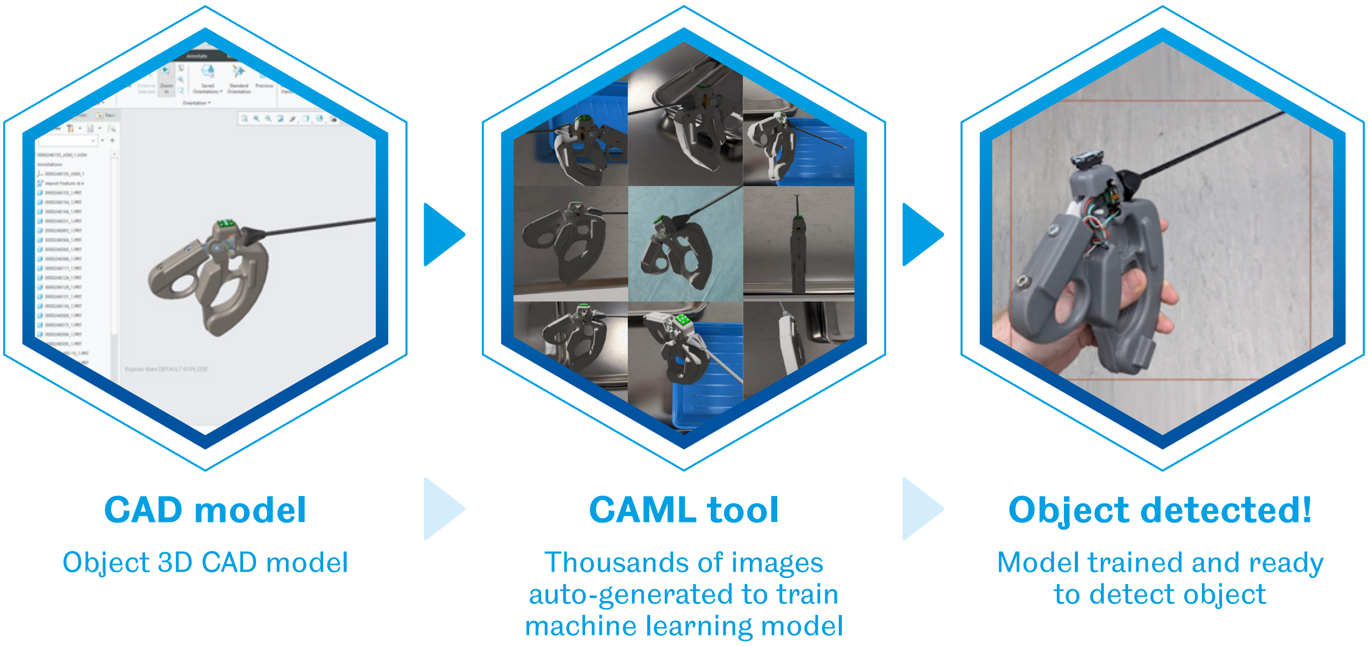
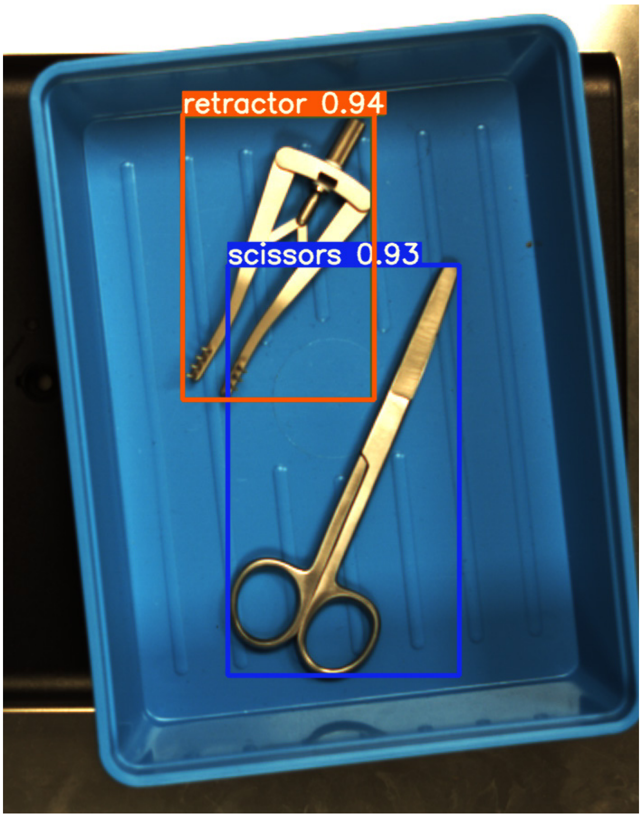


Figure 2: Process flow diagram showing the CAD to ML tool workflow.

4. Concerns with AI

When incorporated into the design process, AI could pose a risk to the design process if AI-generated designs are not inspected thoroughly and rigorously. Failures in the design that aren't identified can potentially cause much larger issues with the product in the future, an AI-generated design can further confuse the line of traceability and accountability. Therefore, a more rigorous validation process specific to AI-generated designs should be implemented to mitigate the risk that non-human generated designs pose. The accountability of AI-generated designs should then fall to the designer who oversaw the generation process or someone specialised in assessing the suitability of generated designs. In a traditional process this is the responsibility of the designer who created or signed off the design.

The use of AI for industrial applications is limited by doubts surrounding its reliability and accountability. If an AI algorithm makes a mistake, who is accountable for it? AI-powered tools can be challenging to validate as they can behave in unpredictable ways when subject to unfamiliar data. Data can be manipulated to trick AI algorithms into making mistakes while looking entirely unchanged for a human; this is known as an adversarial attack [12]. These examples shown by OpenAI illustrate how even a tiny change to an image can cause a classifier to make a mistake. Proper care must be taken when training a model to expose the algorithm to a wide variety of inputs that could be seen in later applications.



Surgical instrument classification.

5. How AI could be applied to a past AMRC project

In the current technological landscape there are no viable tools to replace a designer completely at any stage of the process, however, there are numerous tools capable of augmenting the designer's workflow to save time or improve the quality of their output. Tools such as AirBnB's sketch to web design AI, or Photoshop's content aware crop tool save the designer time by automating small tasks. We have identified certain tools capable of generating novel designs from reference designs [7, 6], however, from the research these do not seem to be currently viable for large-scale implementation. CAD vendors offer various generative design tools, however, it is unclear to what extent AI is involved as most of their functionality can be attributed to topology optimisation or similar classical algorithms. That is not to say these tools could not be applied to benefit the AMRC. AI is an extremely powerful tool when the use case is suitable; however, frequently, a classical solution is simpler and more reliable. In this section, some projects that could be augmented with AI tools are highlighted.

The Design and Prototyping Group (DPG) digital team's Digital Theatre is a good example of how AI can be integrated to augment existing processes and add entirely new functionality [13]. The digital theatre is a collection of technologies integrated into a prototype operating theatre to demonstrate how operating theatres can be enhanced with digital tools. Some examples of the tools integrated are a live digital twin that can be viewed in virtual reality (VR), a tracked projection system, Internet of Things (IoT) patient monitoring, and radio frequency identification (RFID) and AI tool tracking.

The AI tool tracking system augments a workflow that already exists, making it easier for the operating team to know what tools they have on hand and what is needed. The system has a digital checklist created in advance and that is checked against a camera feed of the tool tray. The AI object detection system updates the checklist in real time to show what tools are there and what are missing. This is extremely helpful if many tools are needed as it reduces both the time taken to check them and the chance of human error.

An example of implementing AI to add new functionality to the project is the addition of voice control to the digital systems powered by natural language processing

(NLP). NLP models have been the subject of AI research and have reached a stage of maturity where they are considered the best option. OpenAI has developed an advanced NLP model capable of generating entire documents from simple prompts, and even images from text prompts [14, 15, 16]. An AI voice control feature would enable the surgical team to interface with the technology without worrying about hygiene when coming into contact with digital tools. AI assistants are already popular amongst smart device users and extending this to a bespoke set of tools could help save time and resources in a surgical setting.

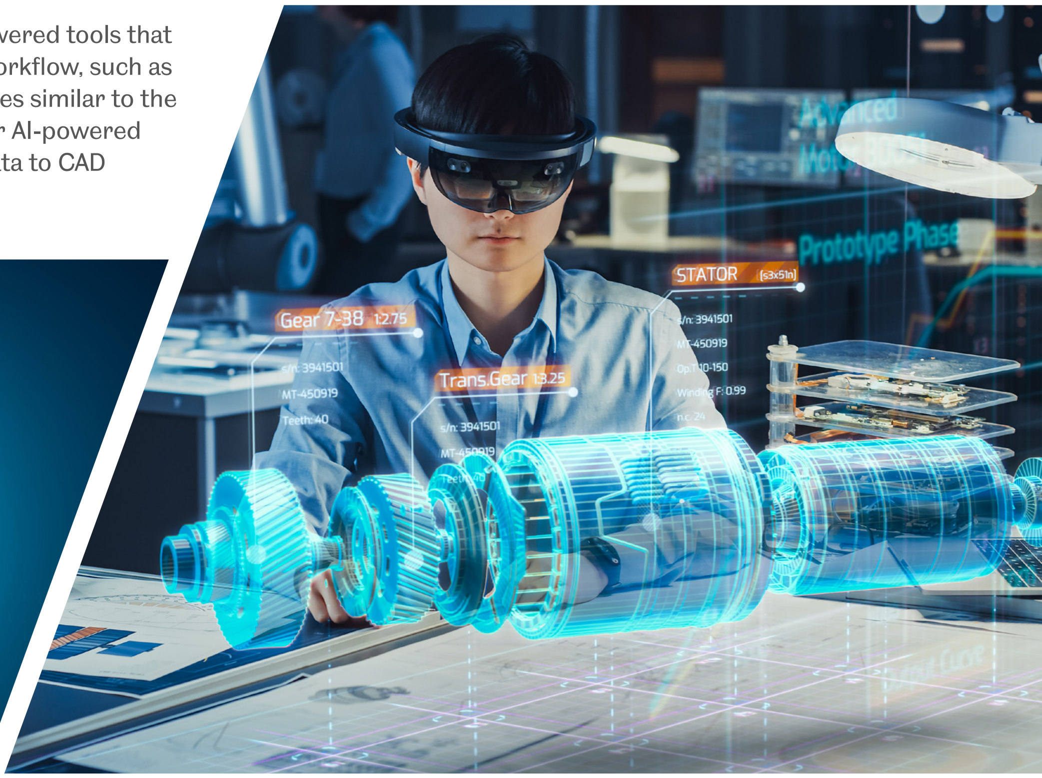
6. Where could AI in design be in the next few years?

The field of AI is continuously evolving, and it can be hard to know what the next state-of-the-art will be. However, we can make predictions based on the current limitations and demands. As discussed above, generative AI models have been shown in research to work in 2D using pixel data, raising the question of how well they would perform on 3D voxel data. There is a steep jump in computation cost when moving from 2D pixel data to 3D voxel data. As models become more efficient and available computing power grows, this will become less of an issue. For now, 3D generation is costly; many CAD vendors host their topology optimisation generative design functions on powerful cloud servers for the same reason.

There is room for more specific AI-powered tools that focus on specific tasks in the design workflow, such as generating design data from 2D sketches similar to the AirBnB tool discussed (AirBnB 2017), or AI-powered upscaling and smoothing of 3D scan data to CAD models. Tools that fast-track the design process like this will become even more capable and easy to use, making them more appealing to designers. AI-assisted model optimisation is also a possibility, however, the implementation of AI for improvement of existing solutions is not a given. AI is not the only way to improve existing technologies.

As language models evolve in the coming years, the possibility of advanced AI assistants becomes more realistic. An AI assistant to manage assets, or project files, could be a quality of life improvement for many designers and other industry roles. A context-aware AI that can make available relevant information on request could provide time-saving benefits. This can manifest as a simple assistant that is integrated into the various file systems in place, saving the designer time managing them.

One of the significant difficulties in implementing an AI solution is the training data needed to get the AI to perform as expected. A poorly trained AI solution could do more harm than good, and difficulty gathering the training data required can deter people from moving away from their current solution. With that being said, the rise of AI is sure to continue into the future as all of the factors supporting AI development continue to grow as well. Data availability, computing power, and an increasingly digital world full of new opportunities for integration mean the future is bright for AI.



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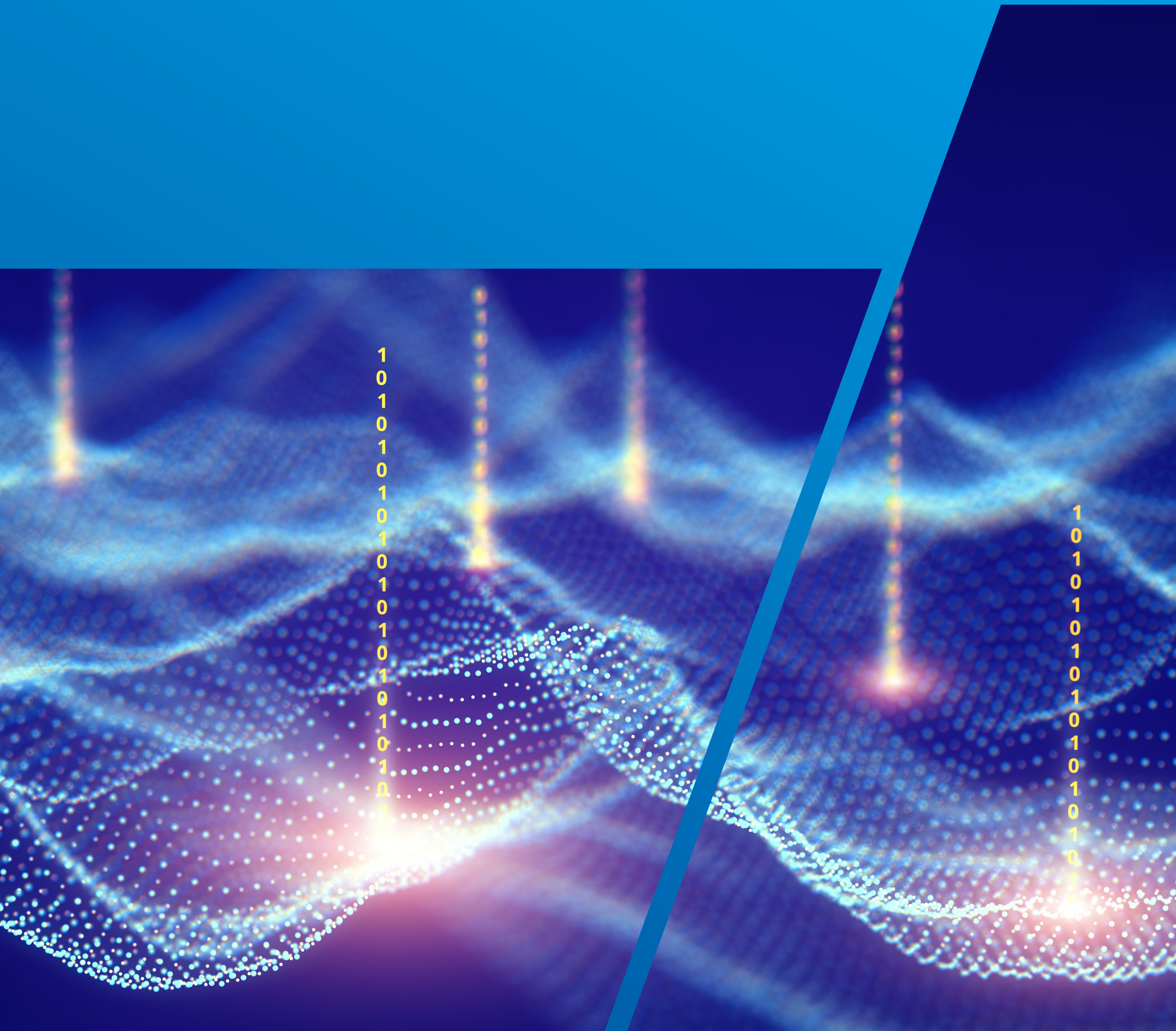

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