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Forecasts on Future Evolution of Artificial Intelligence and Intelligent Systems

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ABSTRACT The field of artificial intelligence has gained a significant attention in the media. Some countries claim to be the leaders in the field, other countries claim to be winning in the race for leadership in artificial intelligence. This article conducts a statistical (i.e., bibliometric) analysis of research data records on artificial intelligence by year, country, language, and organisation. The results are clearly in favour of the USA on a national level, and English is clearly the dominant language for disseminating results. But in terms of leading organisation in the field of artificial intelligence creates more confusing result – e.g., between the Chinese Academy of Sciences and the University of California - in the leadership race. The forecasts from this study on future evolution of artificial intelligence is that it is unlikely that (in the next 60 years) AI ‘superintelligence’ would trigger a catastrophic event for humanity.

INDEX TERMS Artificial intelligence, intelligent systems, future evolution, Covid-19.

I. INTRODUCTION

Artificial intelligence has been a topic for discussion in our society since ancient times, as proven from the ‘didrachma’ illustrating ‘Talos’, an ‘ancient mythical automaton with artificial intelligence’.¹ In more recent times, artificial intelligence is becoming involved in many aspects of our lives - e.g., education [1], healthcare [2], operations [3] - and some countries are already seeking to limit use of AI in our society.² There are also the endless debates on which countries and organisations are leading the race in creating better artificial intelligence. This article uses qualitative (i.e., literature review) and quantitative bibliometrics (i.e., statistical methods) to analyse research records from Google Scholar and Web of Science on the topic of artificial intelligence in books, articles, and other publications. Some of the results are what we would expect, other results present a glimpse on how things might change in the near-term future.

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¹https://en.wikipedia.org/wiki/Artificial_intelligence

²<https://www.bbc.co.uk/news/technology-56745730>

II. LITERATURE REVIEW – CURRENT STATE-OF-THE-ART – BACKGROUND AND HISTORY

The qualitative literature review in this article is predominated by research records from 2021. Since the field of artificial intelligence is changing rapidly, we wanted to review the current state-of-the-art in this field. Given that 2020 and 2021 have been predominated by the Covid-19 pandemic, it was not surprising to discover that most research records on Google Scholar are associated to medical and healthcare related discoveries. We have tried however to review a variety of topics covered in 2021 in the field of artificial intelligence. Some of the topics we reviewed include artificial intelligence and Covid-19, future trends, neuromorphic computing, innovation management, policy, ethics and regulation, parallel computing and swarm intelligence and ethnographic artificial intelligence.

Artificial intelligence has assisted in managing the Covid-19 pandemic in ‘..epidemiology, molecular research and drug development, medical diagnosis and treatment, and socioeconomics.’ [4]. Given our experiences with Covid-19, we could argue that one of the main values for using artificial intelligence in managing future global pandemics (i.e., Disease X) is the early detection. However, we can see that artificial intelligence has been used during Covid-19

for diagnosis with hospital records (e.g., X-ray, ultrasound images, CT, electronic medical records). There are some interesting research studies on the application of artificial intelligence with different types of data, including real-time data from hospitals. This could prevent the repeat of human errors in detecting a future pandemic, but it is unlikely to serve as early detection system, because the system will only analyse the data that is made available, and this leaves room for bias. More reliable early detection system based on artificial intelligence would be to use connected systems (e.g., internet of things, personal wearables). For example, connected thermal cameras in busy areas (e.g., train and bus stations, marketplaces, airports) can use unbiased data and produce early warning signals based on real-time updated current spread of new pandemics.

Although this might seem like developing a ‘big brother’ society, but this technology has already been used in construction engineering and management. One recent study [5] reviewed scientometric and qualitative analysis of 4,473 journal articles published in 1997–2020. This review study discovered that artificial intelligence is mostly used in construction engineering for pattern detection, predictive forecasts, creating conceptual models and optimisation for decision making. The application of artificial intelligence brings new perspectives from the traditional human-centered, conventional approaches to innovation management. Such approaches are limited by the human ability to capture and process big data and lack the ability to analyse modern streams of big data in low latency, hindering the ability of current systems to cope with complexity. In other words, artificial intelligence can ‘..generating completely novel ideas.’ [6] and automation can be used in combination with augmentation, where humans collaborate with intelligent machines [7]. Similar approach has been developed for forecasting climate change affected water resources and power systems – supported with parallel computing and swarm intelligence based on time series collected from two hydropower stations in China [8]. This approach was proven in this study to improve the forecasting ability and convergence speed of metaheuristic algorithms and can be used to improve the selection of suitable model parameters (for artificial intelligence methods) in the complex time series forecasting issues.

Since 2017, China released a strategy entitled ‘New Generation Artificial Intelligence Development Plan’ presenting the China’s aims to become the world leader in AI by 2030, to harness the value of artificial Intelligence (estimating a value of 150 billion dollars) for industry. The most interesting aspect of this strategy was the goal to become the leader in creating ethical norms and standards for artificial Intelligence. Given that other countries have much stricter ethical norms surrounding the standards for artificial Intelligence (e.g., EU proposed ban of artificial Intelligence in facial recognition software), this could be interpreted as a leader in more open ethical norms on the use of artificial Intelligence. Another major concern with the increased adoption of new

technologies is the risk from militarised artificial Intelligence, which can ignite the next arms race between old rivals [9].

Looking at this from a global perspective, the adoption of artificial Intelligence has triggered some significant advancements in photonic and neuromorphic computing, enabling a ‘new class of information processing machines’ based on ultrafast artificial neural networks – extending the domain of artificial intelligence [10]. This advancement of artificial Intelligence and neuromorphic computing brings new forms of intelligence, which in time, can result with a lot more effective and compact algorithms, similar to how our human brains operate. This in turn requires a more philosophical consideration, because such technological integration could make the Turing Test a simple positivist experiment for the new form of artificial Intelligence. Such artificial Intelligence might be able to ‘explore information-theoretic concepts such as attention, expectation, likelihood, evidence, and observation through the ways that they are interpreted in other cultural contexts – including their implications for labour, attribution, agency, and the imagination of engineers, entrepreneurs, managers, policymakers, and other actors involved in the social construction of information processing systems’ [11].

There is also a leap towards integrating artificial Intelligence and the internet of things [12], but such solutions are predominated with the use of cloud computing technology. This turns the internet of things into a technology for data collection, where data is sent from individual devices in the cloud, where artificial Intelligence is run on powerful computers. There is very little research on running artificial Intelligence on the internet of things devices themselves, because such internet of things endpoints have very low memory and artificial Intelligence requires high computing power. This is where the future research can make a real impact, running artificial Intelligence on real-time data on edge devices and sending the analytical results (e.g., forecasts) and not the data for performing the analytics in the cloud. While some ethical and privacy concerns seem impossible to resolve, by running the analytics on the edge, and sending the anonymised forecasts – derived from a large pool of data, could prove a valid solution for much of the current ethical concerns, while preserving privacy. Similar solutions emerge in recent literature on the Earth observation system - Hyperspectral images, by ‘pruning’ the inter-subspace connection [13].

Until present, internet of things predictive maintenance refers to predicting failures before they happen, in other words, using sensors to gather large data – sometimes in real time, and use machine learning to predict failures in production and manufacturing lines [14]. Most of the recent articles make incremental steps in reviewing existing studies on predictive decision making [15], reviewing challenges are opportunities for artificial Intelligence application in Industry 4.0 [16]. If we could run artificial Intelligence analytics on the edge, we could also make autonomous maintenance, effectively allowing machines to run the production and manufacturing lines and let humans build and

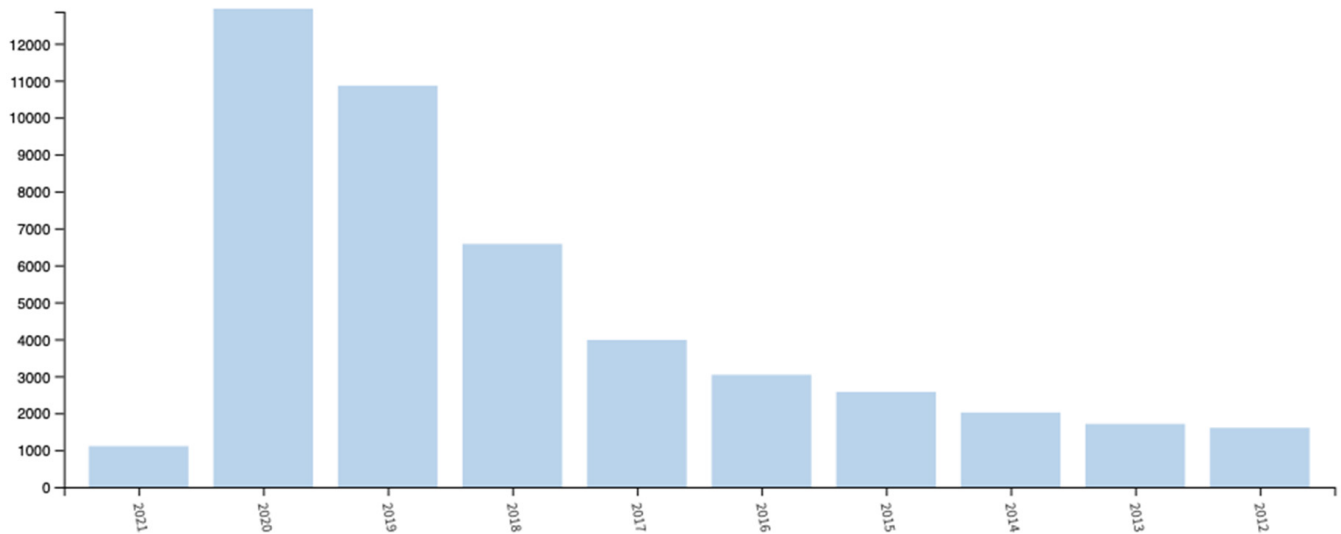


FIGURE 1. Bar graph of research data records on AI classified by year.

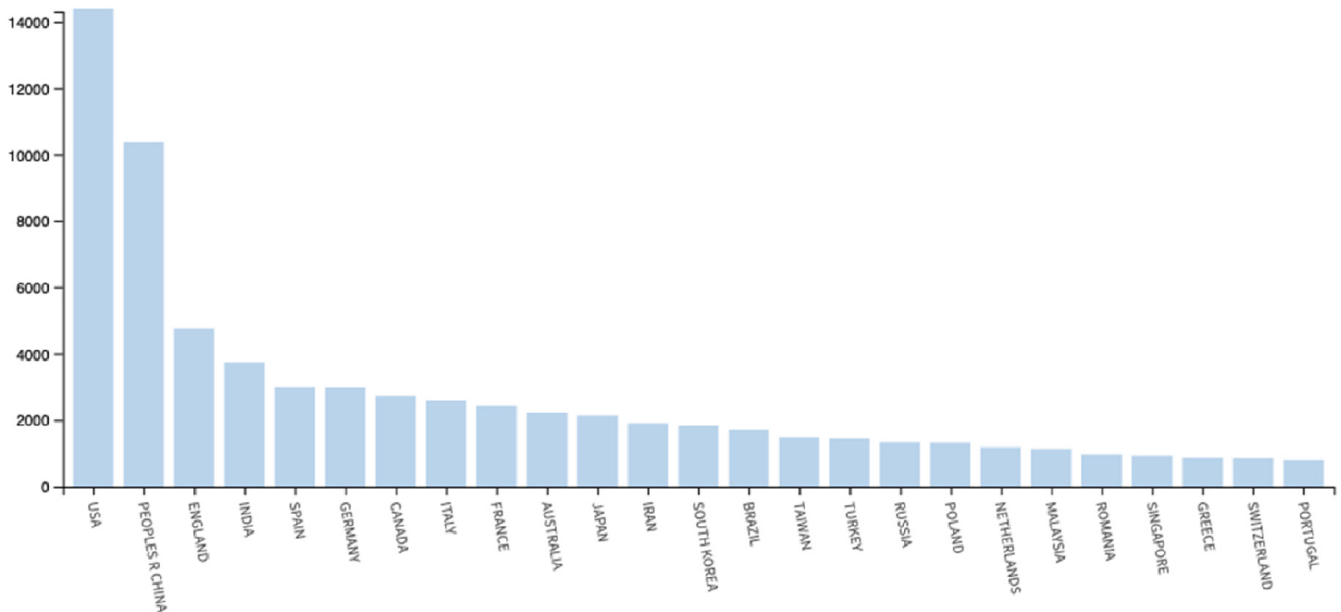


FIGURE 2. Bar graph of research data records on AI classified by country.

maintain the machines or compete with artificial Intelligence in the innovation process. It is likely that in the future, machines will become autonomous and better at building new machines than humans. While some sceptics would fear allowing machines to build themselves and contemplate a the ‘technological singularity’ scenario, where machines become advanced and turn on humans, a counter argument for this is that we already allow the security of machines to be performed by machine learning algorithms [17]. Another argument is the current use of artificial intelligence in healthcare systems, which are considered as critical infrastructure.

It seems like the trend in research on Covid-19 has triggered a wave of articles on technology related solutions for healthcare. For example, we have new articles on internet of things perspective in healthcare, investigating the correlation of tension-type headache and diabetes [18]. Or internet of things for tackling healthcare challenges caused by Covid-19 [19], that can be used for monitoring calorific intake and treatment like asthma, diabetes, and arthritis. Although not all solutions would prove practical after Covid-19 has gone, it is highly likely that some of the practical solutions will remain. Some of the new solutions, are fairly

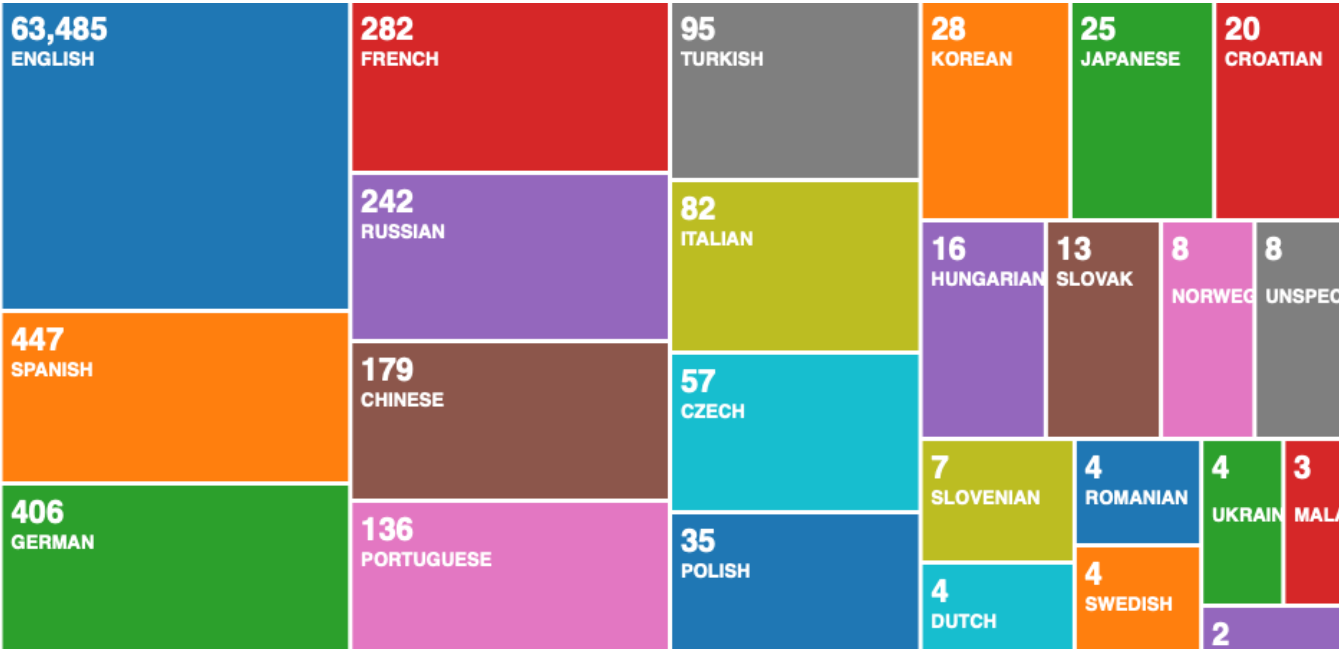


FIGURE 3. Treemap of research data records on AI classified by language.

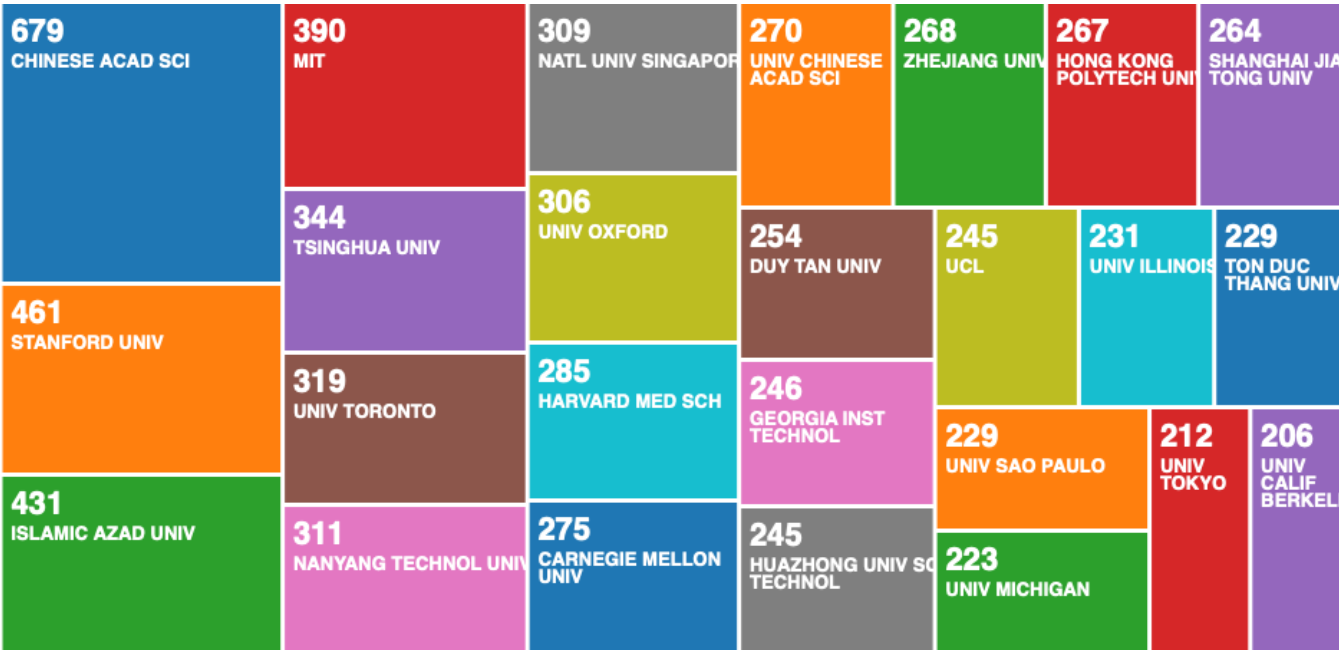


FIGURE 4. Treemap of research data records on AI classified by individual organisations.

old solutions, like ‘telemedicine’. But the adoption was very low, and because of the Covid-19 pandemic lasting over a year, patients have adopted these new technologies. The concept of patients and healthcare providers getting used to using the technological solutions, by default promotes the development of improvements (i.e., updates and upgrades), which again brings the focus back on artificial intelligence in healthcare systems. Covid-19 has caused much deeper

adoption of new technologies that we described. For example internet of things and agricultural drones have been used to advance the food supply chains in anticipation of more technologically evolved - post Covid-19 data management for smart farming [20]. Other studies investigated the use of constrained internet of things edges and Tiny ML, in combination with geolocations and e-commerce to ‘democratize AI for farmers and create (ing) sustainable food future’ [21].

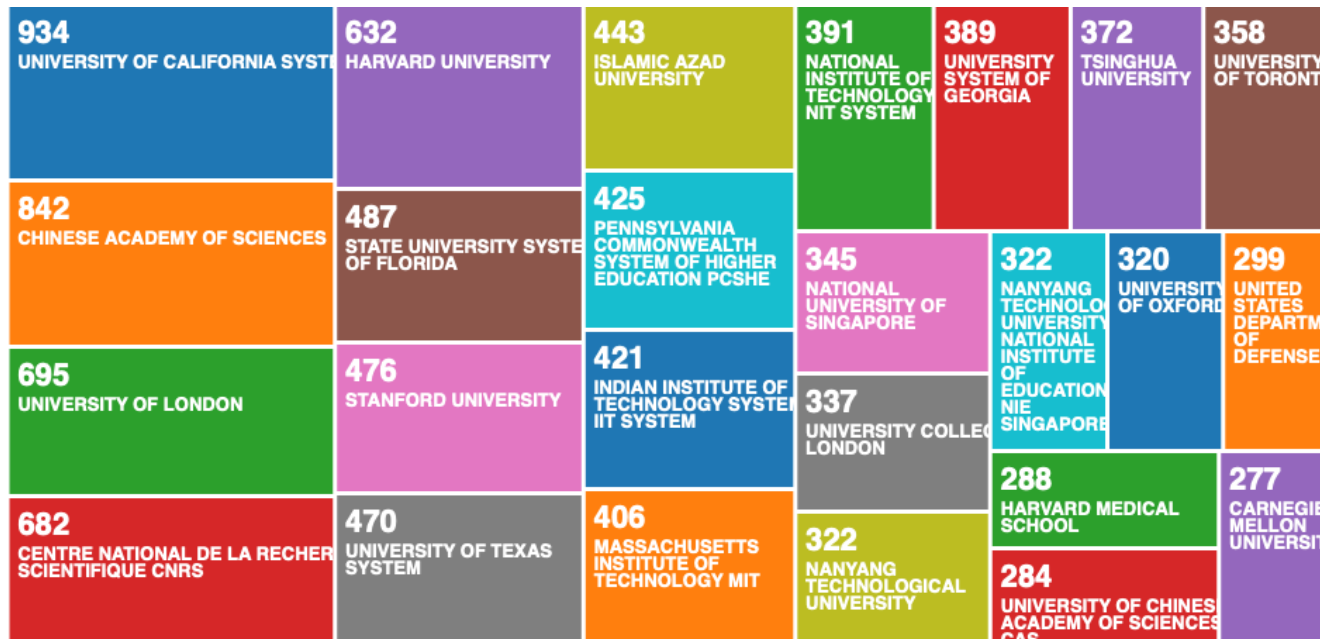


FIGURE 5. Treemap of research data records on AI classified by individual organisations - enhanced.

This means that the process of running artificial Intelligence on low memory edge devices, is becoming a reality. This is not necessarily happening in one isolated area, but we can see similar solutions appearing in many different industries and sectors.

III. TAXONOMIC ANALYSIS EMERGING FROM THE STATE-OF-THE-ART LITERATURE REVIEW

One of the key objectives of this article was to synthesise existing knowledge and forecast the future steps towards achieving a more evolved artificial intelligence. In Table 1 we categorise existing literature sources, with open-source code (from GitHub) into a pipeline that can be used with new and emerging sources of data (NEFD), to build future AI algorithms. While these are forecasts on future developments, the categorisations in Table 1 are based on existing code, that is available in public access and can be used by anyone by simply downloading the code from GitHub. The combinations in the pipeline present a new methodology for using existing knowledge. Hence, these forecasts are grounded on existing knowledge, which increase the likelihood of the AI evolving in the directions forecasted.

The taxonomic classifications outline the concerns present in the state-of-the-art literature review on scientific research. Even if the direction was not influenced by Covid-19, the future evolution of AI systems would have been in a similar pipeline. The forecasts in Table 1 are somewhat influenced by the current events, but the open-source code is a result of many decades of research on AI. Hence, the application for resolving Covid-19 and Disease X issues is just a result of the current events. If we had a different problem, the AI would have evolved in a similar fashion. This brings a very

interesting conclusion; it seems that the current events are not directing the evolution of AI as much as some predict. It appears that the evolution of AI is based on the human abilities to create AI, not on the current needs of the humanity.

On a different level, we can see that Covid-19 and the global pandemic is predominating in the research studies, with the focus shifting from tracking and monitoring, and into vaccine production and supply chain bottlenecks and risks. This brings risk from cyber-attacks in the state-of-the-art literature review on artificial intelligence. The main topic the predominates in scientific research is the automation, and compactness of future artificial intelligence. Two topics predominate the artificial intelligence research scene in 2021 – the potential from a self-procreating artificial intelligence and algorithms that can run on low memory IoT endpoints at the edge.

IV. BIBLIOMETRIC ANALYSIS

The bibliometric analysis we conducted started with data mining for research records on the Web of Science. We identified 65,601 records for TOPIC: (artificial intelligence), and we analysed the records with ‘Treemaps’ and ‘Bar graphs’. We firstly categorised the records by year – in Figure 1 (data collected on 14th of February 2021), and secondly by country - in Figure 2.

As we can see from the Figure 1, the USA is leading the global research efforts on AI, with China taking the second place. Before we continue the analysis with a more focused investigation on the US and China, it is worth mentioning that England is categorised on its own accord, without Scotland, Wales, and Northern Ireland. The actual records for England, which is one of the states in the United Kingdom, stands at

TABLE 1. Forecasting the future evolution of artificial intelligence in scientific research.

Scientific research forecasts (F _x) on the future evolution of artificial intelligence	
A self-evolving AI based on compact representations.	
F _x	A self-evolving AI needs to be based on novel algorithms founded on compact representations.
F _x 1.1	Scientific research needs to focus on ‘Deep compression’ ‘Pruning’, ‘Quantization reaching’, and ‘Huffman Encoding reaching’. Followed by ‘HashedNets’ to reduce model sizes, use vector quantization to compress deep convnets, and replace layers with global average pooling e.g., ‘GoogLenet’.
F _x 1.2	The first method that can be applied for designing a more efficient and compact AI is the ‘Adaptive Fastfood’ method for transforming and reparametising convolutional networks. This approach enables parameter reduction without affecting the accuracy.
F _x 1.3	Second method to be considered is the ‘Baseline Caffemodel’ enhanced with use of sparsity-inducing regularisers. The methods can be tested in combination with manipulating the linear structure in the convolutional filters to derive approximations and reduce the required computation.
F _x 1.4	To advance the concept of looping, scientific research can use neuromorphic computing using asynchronous spiking neural network - to design event-driven algorithm that can store and process information inside individual units, neurons, and their synapses.
A self-procreating automated AI (AutoAI).	
F _x	A self-evolving AI needs to be advanced with self-procreating automated AI (AutoAI) design for training new and self-improved algorithms with new and emerging sources of data (NEFD).
F _x 2.1	Two methodological approaches can be applied for the automation of feature engineering: (1) multi-relational decision tree learning - supervised algorithm based on decision tree and (2) Deep Feature Synthesis - open-source library (i.e., ‘Featuretools’).
F _x 2.2	Binary classification can be applied to integrate the autonomous data preparation with ‘dichotomization’ for transferring continuous functions, variables, and equations into discrete counterparts, making them suitable for numerical evaluation though discrete mathematics (discretization). Then integrate the autonomous data preparation and the automated feature engineering with the statistical binary classification methods (i.e., decision trees, random forests, Bayesian networks, support vector machines, neural networks, logistic regression and a ‘probit’ model).
F _x 2.3	Automation scenario can be designed based on particle swarm optimisation, evolutionary algorithms and Bayesian optimisation. Edge devices are characterised by a large number of data points, and new and emerging forms of data are characterised by large configuration space and dimensionality. These factors in combination could create a longer than adequate time requirement for finding the optimal hyperparameters. Alternative method to be considered is a combined algorithm selection and hyperparameter optimisation. The method selection will include testing for the most effective approach, starting from Bandit Search, Evolutionary Algorithms, Hierarchical Task Networks, Probabilistic Matrix Factorisation, Reinforcement Learning and Monte Carlo Tree Search.
F _x 2.4	The first model to test for pipeline optimisation is Auto-WEKA, second model to use is Auto-sklearn, the third model to use is the Tree-based Pipeline Optimisation Tool (TPOT). The WP2 will provide insights on how to combine the Auto-WEKA, Auto-sklearn and TPOT models for creating an efficient automated pipeline optimisation on edge devices. If these scenarios do not result with sufficient insights, additional scenarios will be created with the TuPAQ system using a bandit search for optimisation based on the data and the computational budget.
Construct training scenarios and apply the novel AutoAI.	
F _x	Training scenarios need to be constructed to test the new algorithms with different sets of training data and make iterative improvements based on the results.
F _x 3.1	The first scenario can be designed to forecast the points of failure from data collected on the edge of the network - by applying the novel AutoAI for self-optimising risk analytics of failures in healthcare systems during a Disease X event. Low-cost IoT devices and systems are increasing and as a result the risk surface is increasing on the edge of the digital healthcare network. The first scenario can forecast such cyber risk by shifting the cyber-risk analytics to the edge of the network. Integrating AI algorithms on edge devices is an important scientific milestone, because the levels of digital healthcare services will continue to increase, from a digital front door and telehealth, to augmented reality and robotic surgery.
F _x 3.2	A second scenario can be designed to optimise edge health care systems’ ability to rapidly adapt to huge external changes - self-adaptive medical production and supply chain bottlenecks during future pandemics (e.g., vaccines, protective equipment) during global pandemics i.e., Disease X. Test how the algorithm can adapt modern technologies to help with resolving shortages of supplies in critical times e.g., 3D printing, drones, autonomous vehicles, robots.

4,664 compared to 14,308 combined records for all 50 US States, and it is also higher than all other countries e.g., India 3,642; Spain 2,917; Germany 2,910; Canada 2,631. This contradicts some of the earliest studies that investigated a selected much fewer research data records, and show the distribution of publications by country of origin of the corresponding authors [22].

Second analysis that we conducted was in relations to languages used in the research data records. Although China is on the second place in the research data records, the Chinese language is on the 6th place, behind Spanish, German, French, and Russian. A surprisingly small percentage of the Chinese research output – only 179 data records (see Figure 3), is on one of the Chinese languages, while the majority of data records are written on English language – 63,485 data records. It seems that Chinese researchers are determined to share their knowledge and discoveries on a global and not on a regional level.

In the next analysis, we wanted to determine the leading universities and organisations that have produced most research on artificial intelligence. This classification is divided on two categories: a. stand-alone organisations – Figure 4, and b. combined records from organisations that operate under the umbrella of larger organisations – Figure 5. In Figure 4, we can see that the Chinese Academy of Sciences takes the leading position. Although we have seen in Figure 2 that USA leads on a country level, it seems that research on AI in China is strongly centred in one institution, while in the USA it seems a lot more decentralised.

The organisation – enhanced method that produced the Figure 5, presents a different approach for categorising the data records, and incorporates records that include the organisation name, and name variants e.g., associated organisations. This changes the order of the results, and presents a very different leadership classifications, because some organisations e.g., University of London, have many associated organisations that operate under the umbrella of one organisation. This classification brings the University of California System on the leading position, and the Chinese Academy of Sciences on the second position, while Stanford University drops to the 7th place.

V. DISCUSSION ON RESEARCH FINDINGS

The emerging key findings from the qualitative analysis in this article are outlined a taxonomic classification (Table 2). The quantitative analysis is visualised through a set of figures. In this section, we discuss the key findings, and we present our forecasts on how artificial intelligence will evolve in the next decade. The forecasts are based on the qualitative and quantitative analysis of scientific research records from the 2021 (qualitative) and from the past decade (qualitative).

The emerging question from the forecasts in Table 2 and this review study is: would artificial super intelligence become a metaphysical possibility in the next decade? Or remain a philosophical jargon as it has in the past. The related questions that emerge are can artificial intelligence surpass

human intelligence? Can machines become autonomous and evolve in functionality to become socially identical to humans and builds other machines independently without the intervention of human intelligence. Can artificial machines think like humans? Can there be a technological singularity caused by artificial intelligence in the next decade? Considering people hypothesised for such scenarios since the 60s, would this become the reality in the next decade and can artificial intelligence become a threat to humanity in the near future. Although this can be seen as a very hypothetical and sci-fi discussion, in the discussion we need to be aware that if we think about domain-specific tasks (e.g., chess playing or mathematical computing), then we already have artificial intelligence that exceeds human intelligence – immensely. The questions we ask in the discussion are more related to whether artificial intelligence will surpass human intelligence in all areas – in the next decade. We can agree that even more extraordinary artificial concepts will emerge in the next decade – maybe beyond what we can currently imagine. From a metaphysical view, artificial intelligence surpassing human intelligence is possible. But from an epistemological viewpoint, we really doubt that superintelligence will ever become something that's more advanced than human intelligence. We make this argument because artificial intelligence is comparable to mathematical universal power of logic but lacks in history and culture. Metaphysics are transferred through historical and cultural legacy that defines humanity, and there can be no metaphysics without hermeneutics, or in other words without knowledge about traditions (e.g., European, Asian) and religions (e.g., Christianity, Islam, Hinduism, Buddhism). It is more likely that artificial intelligence and robotics will be seen as digital technologies will affect substantially the human development in the next decade. Artificial intelligence has already triggered existential questions about what we should do with systems that can outperform humans, what tasks would be worthy for artificial intelligence of the future, what cyber risks will emerge from such technologies and algorithms, and how can humans control cyber and physical risks from artificial intelligence. Building upon these arguments, we need to consider that a future artificial super intelligence would also require artificial consciousness, because for artificial intelligence to be considered autonomous and independent, from a philosophical view – it would require the key attributes for interoperability and transference of automation and autonomy to interdisciplinary areas of knowledge. Since humans possess diachronic and synchronic dimensions, humans can understand rationality and existence. While at present, artificial intelligence doesn't and it's unlikely that such understanding will be acquired in the next decade. For artificial intelligence to become aware of its existence, firstly we need to enable autonomy and self-procreations. Secondly, we need to enable artificial intelligence to operate on low memory devices, so it can learn and grow from new and emerging forms of data in unclassified and uncategorised fashion. Finally, to end this discussion, there will always be the view that regardless of how much intelligence machines

TABLE 2. Forecasting the evolution of artificial intelligence.

Forecasting the evolution of artificial intelligence in the next decade.
Ordered pipeline method will be designed for energy efficient inference on a compressed deep neural network.
Event-driven algorithm will be designed that can store and process information inside individual units, neurons, and their synapses.
Automated feature engineering will be constructed for analysing NEFD.
Autonomous data preparation and automated feature engineering will become a norm.
Automatic hyperparameter optimisation will be integrated in edge devices.
Autonomous pipeline optimisers will be used on edge devices.
Artificial intelligence will be used for forecasting cyber failures in healthcare systems - in future Disease X events.
Artificial intelligence will be used for forecasting production and supply chain bottlenecks - in future Disease X events.
Tools and mechanisms will be advanced for preventing gender and race bias in AI algorithms: use of less biased/more inclusive multi-ethics, multi-gender data.

acquire, if machines and systems do not understand God, then such machines would not understand wisdom – and would not be considered alive. This belief triggers a different debate, are humans responsible for the effects from artificial intelligence? If a machine decides to destroy the world, and it cannot be considered intelligent in the true sense of the world, then ethically – who is responsible? And if such machine succeeds and destroys the humanity, or at least extinguishes all men, leaving few women for reproduction, when there is no human left on the planet, would artificial intelligence create a new form of human civilisation? Or would humans be considered unnecessary?

VI. CONCLUSION

The statistical analysis in this article is based on Web of Science data records, and the analysis of individual sources can be seen in the categorisations and taxonomies - described in the article. Worth mentioning that the bibliometric analysis is based on output as a quantitative unit, without any consideration on the qualitative aspects of the records. It is entirely possible that one research output can produce higher impact on our society than many less impactful outputs. This argument is not portrayed in the statistical analysis. The aim of this short article was to present a bibliometric analysis of all data records that are recognised as valuable and to derive forecasts based on existing knowledge. The measure of value was their inclusion in the Web of Science collection. The results show strong dominance of research output on artificial intelligence from the USA. While there is a significant output from non-English speaking countries, the representation of English language is clearly visible, with very small number of publications written in non-English languages. In terms of leading organisation on research output, the results are more confusing. It appears that some of the leading research organisations in this field³ are not leading the race in terms

of quantitative level of outputs. The umbrella organisation of the University of California appears to lead the race, but the Chinese Academy of Sciences takes the leading position when measured as single institutions. The article engages in taxonomic classification of the emerging concepts from the qualitative review of state-of-the-art literature. Then a philosophical review is conducted to synthesise the qualitative and quantitative results emerging from this study. The main results and findings are presented as a set of taxonomic categorisations and forecasts for the future evolution of AI in our society. The most intriguing finding from the study is that AI is evolving based on the human capabilities, not based on the human needs and desires. This means that future value of AI will be limited to the human creative capabilities, and lower investments in human-AI capabilities with inevitably result with lower value of the future AI systems. Considering that defence has been one of the main sectors investing in AI, this can result with some dangerous future AI systems for humanity. But it also means that the development of ‘superintelligence’ is hindered by the human abilities and limitations. In other words, the predictions from the early 60s in terms of super intelligent AI never materialised and given the current limitations of human-AI systems, it is quite likely that in the next 60 years, we won’t see the evolution of AI into ‘superintelligence’ that can trigger a catastrophic event for humanity.

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