Khazar Journal of Humanities and Social Sciences

Volume 28 | Issue 2 Article 1

2025

The Research University, Industry and Artificial Intelligence

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KHAZAR JOURNAL OF HUMANITIES AND SOCIAL SCIENCES 2025;28:72–100

ORIGINAL STUDY

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ABSTRACT

Scientific research in cooperation between science and industry occurs mainly in research universities. This article begins with a brief history of research universities, a discussion of their nature and form. Their evolution and development in Europe, the USA and China are recalled; the special importance of Graduate Schools is underlined. Cooperation between the worlds of university and industry is studied using the example in the USA of Silicon Valley, a world leader in its field and initiated by Stanford University. Presented alongside the positive American experience, is the rather negative experience of the "Russian syndrome". The development of semiconductor, transistor and microchip technology has a decisive role in competition between modern states. The development of electrical engineering and electronics led to the creation of computers and the internet. Computers were able to conduct some operations more accurately and quickly than humans: eg. completing large calculations and playing chess. Humans (natural intelligence) began by creating artificial intelligence first as an assistant, then colleague and, now, even teacher. Artificial intelligence, currently in popular focus, has significant application in all areas of human activity.The emergence of big data, an advance of immeasurable value, and studies including neuroscience have been vital to the study of Artificial Intelligence.The article discusses machine learning, deep learning based on artificial neural networks, natural language processing, generative artificial intelligence and other issues related to AI.

Keywords: Research university, Graduate school, Computer science, Semiconductor, Artificial intelligence, Machine learning, Deep learning, Robotics

Introduction

Universities are diverse; some may be similar to varying extents – close or in some way – while others may differ somewhat, substantially, or even fundamentally. Universities differ in their geographical location (country, region etc.) or date of establishment – that is, the length of the institution's history (e.g. the Middle Ages, the 19th, 20th or 21st centuries; 1636; 1991 etc.) Universities can also vary greatly in their academic subjects

Received 3 January 2025; revised 30 March 2025; accepted 25 April 2025.
Available online 30 June 2025

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https://doi.org/10.5782/2223-2621.1004

and specializations. Some higher education institutions focus primarily on a single field: in Medicine, Economics, as Pedagogical or Engineering universities, or institutions that specialize in Music, Art, Theology, Sports or Military Studies. Comprehensive universities – characterized by a multi-profile structure, versatility and broad range of academic disciplines – are also widespread. There are higher education institutions that are single-gender, admitting exclusively either female or male students. For minorities within a country's population that for various reasons cannot keep up with the broader competition, it is sometimes necessary to establish special higher education institutions (for example, historically Black and Tribal colleges and universities in the USA, Canada, India and several other countries, Hispanic Institutions in the USA…). Two-year colleges (technical colleges, vocational schools, professional higher colleges, meslek yüksek okullarıin Türkiye, community colleges in the United States) are scattered around the world. There are universities that mainly provide a bachelor's education, or both bachelor's and master's education, or that seriously offer master's and doctoral studies. State, public, private (non-profit or for-profit) and foundation-based universities are also known. And finally, on the one hand, there are research universities that prioritize scientific research and, on the other hand, there are universities that focus on teaching.

Universities are important institutions for the country and state in which they are based. In the modern world, competition between countries is determined not so much by the economy, but by the development of science and technology; the economy being a derivative of science and technology. Universities, it seems, are institutions that develop science and technology. Is this true? Can every higher education institution boast of scientific and technological discoveries? No, such successes are mostly the outcomes of strong universities. Then what is a strong university?!

People often speak of "World-Class Higher Education Institutions" (Altbach & Salmi, 2011). "World-class" is not a precise concept, but when people think of world-class higher education institutions, they think of famous institutions like: Harvard, MIT, the California Institute of Technology, Yale, Stanford, Princeton, Oxford, Cambridge, Imperial College, ETH Zurich, Tsinghua, Peking University…

There is also ambiguity in the expression "strong university." What is the measure of a university's strength? What does it mean for one higher education institution to be stronger than another? This is clearer with the concept of a research university. Such a university prioritizes scientific research, creates new knowledge, is a knowledge-producing institution, contributes to the development of technology, trains high-level specialists…

When and where were higher education institutions founded? How have they progressed from their foundation to the present day? How have universities developed in different regions of the world, and what role was played by interregional relations in their strengthening? How have the research university and the world surrounding it influenced each other? What trends are apparent in the university world today? It is quite a substantial task to provide clear and complete answers to these and similar questions. Experts dealing with issues of higher education and the history of education, have posed similar questions and tried to answer them. This article will trace the evolution of the concept of a research university, albeit from a bird's-eye view.

The technopark is a bridge between a research university and industry, bringing them closer together. Silicon Valley, which has flourished in the USA, became the brightest and greatest success in the history of university-industry relations and, moreover, as an example of this form of cooperation, it had a serious impact on subsequent development. There are also negative experiences. Why did Russia, a country with quite sufficient intellectual power, lag behind in the development of modern technology? The reasons for the weak application of scientific discoveries will be touched upon using the example of the ‘Russian Syndrome’.

Natural intelligence began to create Artificial Intelligence (AI) to do the work that it could not do itself. How, when, and in what ways did this happen? The semiconductor-microchip revolution was one factor key to technological competition between states. The creation of computers, which began in the mid-1940s, may also be regarded as the beginning of the AI era. Large networks such as the Internet, the emergence of large databases, the successes of computer science and engineering, as well as neuroscience, enriched the science and technology of AI. Robotics, Machine Learning and Deep Learning built via artificial neural networks, Natural Language Processing, Generative Artificial Intelligence, and other concepts of AI are reviewed briefly here.

In the first half of 2025, the author of these lines delivered several lectures to people of science, art and business under the headings, “What kind of university do we want?”, “Research university and industry: in history and today” and “Research university, industry and artificial intelligence” (Khazar University, Azerbaijan Technical University and Institute of Mathematics and Mechanics, Baku, Azerbaijan), and endeavoured to align the audience’s interests and his thoughts. This article is based on those lectures.

The concept of a research university

A research university is a higher education institution that distributes, creates (produces) and applies creative knowledge. It is a centre for the conduct of high-quality scientific research and education, not of the mass, but of the elite, best, leading minds. It is known for its high-level scholars. A university with such scholar-educators attracts the most talented young people – bachelor’s, master’s and doctoral students. Its reputation is determined mainly by the power of its research. A research university creates the conditions for conducting high-level research – it spends a lot of money, builds powerful research centres and state of the art laboratories. It is a place where academic freedom, an objective competitive spirit and a creative environment reign. A research university should be a centre of innovation in which science and technology meet industry and economy, in which inventions are achieved and patents obtained.

The path to becoming a “world-class university” lies in becoming a research university. A developing university’s principal goal is usually to become a research university, and often not “just any research university”, but a “strong research university”. A strong country should have strong universities. A strong university strengthens a country. Competition between countries is based mainly on science and technology. A research university is a country’s brain centre.

A brief look at the history of the university: The Islamic period

Let’s take a look at history. How, and in what way, did the world’s best universities make their way to the present? Or how did today’s powerful universities become stronger?

There were no universities before the Islamic era, nor even in Islam’s early days. Plato’s Academy, Aristotle’s Lyceum, Epicurus’ Garden, the Library of Alexandria, al-Ma’mun’s translation centre known as Bayt-al-Hikma (House of Wisdom), large observatories and other places all attracted thinkers who would gather to listen to someone’s lectures, read books, translate and/or discuss issues of scientific and philosophical interest. But there was no systematic education in those places, no one was given a document – a certificate or diploma – to confirm what and how well they learned.

During the Islamic era, a broad educational network was established, mosques were built everywhere touched by Islam, the Quran and Hadith were taught; and this was impossible without learning to read and write well. Arithmetic, geography, grammar, calligraphy, history and some natural history (botany etc.) could also be taught. Lessons were held in the teacher's home and in palaces, and it is correct to describe this educational activity as elementary school. In both small and large mosques – masjids (large mosques were called "Cami" in Türkiye), the halqa (ring/circle) teaching method was widespread. A well-educated teacher, a sheikh, would speak and teach, and the listeners – his students – would sit before him in a semicircle, listen and write. This may be regarded as secondary education and, in some cases, in large cities, under prominent scholars – higher education. Each well-known scholar had his own halqa. A student could go to various halqa, and take lessons from each teacher in his field of expertise.

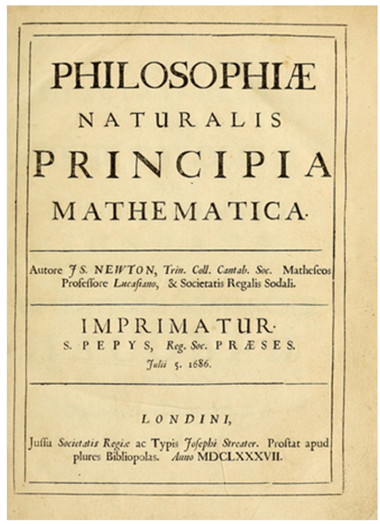
However, in the Islamic world, strong, systematic higher education institutions emerged mainly in the second half of the 11th century. Earlier, there were some institutions that provided a higher religious education, these included al-Azhar, which operated in Cairo from 970–972. Although there were educational institutions, called madrasahs, in separate centres that provided secondary or higher-education-like courses, a strong, systematic network of higher education institutions was created with the Nizamiye madrasahs founded by the celebrated Nizam al-Mulk (1018–1092) vizier to the Seljuk state leaders, Sultan Alp Arslan and Sultan Malik Shah. The madrasahs' principal purpose was to teach and propagate the religious sects (madhhab) to which their founders belonged. The Nizamiyya madrasah, founded in Baghdad from 1065–1067 and opened with an official ceremony, may be considered the first in this line. Al-Ghazali was for a time appointed head (principal scholar or rector) of the Nizamiyya Madrasa in Baghdad; the great poet Saadi Shirazi and the great philosopher Ibn Arabi are said to have studied there.

Madrasahs were higher education institutions established through a charitable foundation – a waqf, where the founder's (waqif) ownership passed to his heirs; this was not the case with mosques and associated educational institutions – the founder could not pass on anything to anyone.

Well-known, selected madrasahs created every condition necessary for successful operation: teachers and employees received salaries, students enjoyed scholarships, free dormitories, often food and sometimes clothing. A rich library would be established there. There were two main areas (faculties) of study: theology (the foundations of the Islamic religion, the Quran, hadith, kalam) and Islamic law – fiqh. Doctors were trained in medical madrasahs connected to hospitals. Mathematics, philosophy, engineering and natural sciences were mainly taught in observatories, such as the large observatories headed by Nasir al-Din Tusi in Maragha and Ulugh Beg in Samarkand, as well as in classes organized by scholars (Ibn Sina, for example) at home. A student who studied law and theology for four years became an assistant to the teacher. He worked on the teacher's lectures, commented on them and, if desired, expressed objections, made additions and turned them into a scientific work – a taligha (from the word al-alaqha – to write a report) – a dissertation, and prepared a book (by himself or with his teacher). As a result, the student received a certificate of permission to engage in work, to teach, signed by the teacher. A student who received this permission gained the right to teach and pass on what he had learned to others. One who gained this right was called bi-haqq al-riwaya (one who has the right to tell): this is where the word "bachelor" comes from! (Ebied & Young, 1974). Later, history, natural science, mathematics and even music were taught in madrasas to some extent (Massialas & Jarrar, 1987). Madrasas did not develop continuously and did not survive to our time (one of the reasons will be explained below, when discussing later European universities).

A brief look at the history of the university: Europe – the middle ages

Islamic Andalusia (Iberia or the Iberian Peninsula) and Sicily, as well as Italian cities that were centres of trade and culture, were closely connected with the Islamic world. The Crusades, wars between Islam and Christianity, also had a role in Europe's understanding and study of that world. Most of the Greek scientific and philosophical works that were widespread across Islam were translated from Arabic into Latin, as well as the works of Islamic scholars expounding their mathematical, astronomical, chemical, philosophical, medical and technological knowledge, and were reflected in the development of science, medicine and philosophy in Europe, and in higher education programmes. The universities of Bologna and Paris are usually accepted to be the first universities in Europe. Both were active in the second half of the 12th century, the 1170s–80s, although it is claimed that the University of Bologna appeared earlier (in 1088). European scholars at that time mainly taught (including to the children of the wealthy), research being a hobby pursued in their free time.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IMPRIMATUR.
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Universities had faculties of law and theology, with some also having faculties of medicine. European universities did something that was an important difference from the madrasahs of the Islamic era – they began to issue a single, unified diploma of graduation from the university, rather than a document signed by the individual teacher with whom the student had studied. This probably turned European universities into monolithic institutions and paved the way for their continuity, many of them surviving to this day. Universities awarded medical graduates the degree Medical Doctor (M.D.), law graduates the degree Juris Doctor (J.D.), and theology graduates the degree Doctor of Theology (ThD). Eventually, a preparatory faculty was formed for those wishing to enter university, and it became necessary to study other fields: languages (Latin, Greek), literature, history, philosophy, mathematics and natural science. The words art or philosophy were sometimes used to encompass these fields. The term philosophy seemed more comprehensive, since from ancient times a philosopher was interested in all existing fields of knowledge in order to express his opinion. Gradually, natural sciences became known as natural philosophy; for example, Isaac Newton named his famous work, "Mathematical Principles of Natural Philosophy" (Philosophiæ Naturalis Principia Mathematica). Over time, this faculty became independent, as it had become important to train specialists in relevant fields. The Faculty of Philosophy had bachelor's and master's degrees and, in the 19th century, like other faculties, this faculty began to award the degree-diploma Doctor of Philosophy (Philosophie Doctor, PhD). In the middle and second half of that century, the Faculty of Philosophy (i.e., the faculty for studies of scientific fields other than law, theology and medicine) reached a level of prestige comparable to the other three faculties.

Towards a research university

In medieval Europe, there were prestigious universities like the University of Leiden (1575+) and the University of Edinburgh (1583+, then 1707+) that sought to pursue research not only in theology but also in the natural sciences, as well as in medicine, and they became intellectual centres. German universities became increasingly distinguished, with the emergence and advance of the University of Halle (1694+) and the University of Göttingen (1737+). In emphasizing the importance of research and academic freedom within higher education, the roles of these two universities and, in general, German (Prussian) higher education of the late 18th and early 19th centuries, is widely recognized. The work of the University of Berlin, founded in 1809–10 by Wilhelm von Humboldt and other German intellectuals, is particularly noted. In some views, the establishment of the University of Berlin is celebrated as a remarkable event, a magnificent landmark in the development of the world of higher education. The 19th century German university was highly regarded throughout the world and was seen as a model for the creation of powerful new higher education institutions in the United States and elsewhere. Recently, while Humboldt's philosophy of education and ideas for reform continue to be appreciated, there has been an increasing number in those who view the role played by the University of Berlin as having been exaggerated (Johan, 2018). Kant, Schleiermacher, and other German philosophers are said to have expressed ideas about academic freedom and the establishment of a university in Berlin before Humboldt. On the other side, it is argued that modern research universities existed as an idea at the time but did not become a reality until emerging in the 1870s and 1880s.

Wilhelm von Humboldt
1767-1835

Immanuel Kant
1724-1804

Friedrich Schleiermacher
1768-1834

These debates and Humboldt's ideas are discussed in higher education, and their decisive power is noted. Three of Humboldt's ideas are underlined: 1) the unity of research and education, 2) academic freedom (autonomy), and 3) the student's right to choose. What do they mean? Strong scientists and artists should be invited to teach. They, in addition to disseminating existing, known information, create new knowledge, produce knowledge, and discuss it in class, involving students in the process of creating new knowledge. The student sees the process of creating new knowledge and, in some cases, may participate in it. Scholars in the sciences and arts working in the university should have academic freedom; there should be no restrictions on their areas of research, they should be able to choose their own research topics, and there should be no prohibitions or pressures. Even if the university is state funded, the government should not interfere in its scientific and educational activities. Of course, the government may appeal to the university and ask it to investigate certain issues of interest. But the university should have the freedom to respond to changes in the environment in a timely and appropriate manner, and the ability to respond effectively. Students should have the right to choose their specialization, as well as certain courses and teachers; the student should be able, to a certain extent, to have their wishes taken into account in their educational trajectory.

The research path in US universities – the faculty of graduate studies

The first real research university was the relatively recently (1876) established private Johns Hopkins University (JHU). This is regarded as the first modern university in the United States. Harvard University, founded in 1636, and later the College of William and Mary (1693), Yale College (1701) and others applied the English and Scottish university models that dominated in the United States, basing their teaching on Latin and Greek classics and theology. Powerful people who were somehow unconvinced by the existing university system considered connecting with another university or establishing their own. For example, conservative Puritan figures (ministers), who did not like Harvard University's liberal theology, brought Yale College to Connecticut to implement their orthodox teachings (1716). The first PhD in the United States was awarded by Yale College in 1861; this higher degree was awarded by the University of Pennsylvania in 1871 and Harvard University in 1873. The best PhD graduates were those who graduated from Johns Hopkins University. Johns Hopkins graduates who achieved doctorates were teaching at most good universities in the United States. JHU incorporated the German research model, prioritising fields such as the natural sciences, engineering and agricultural work in its teaching and research. The first president of JHU, Daniel Coit Gilman, argued that universities' most important work was in graduate education and the cultivation of high-level talent. US universities such as Harvard and Columbia followed JHU's path, that is, the German research university model, and newly established universities also followed this path.

Homewood Campus of Johns Hopkins University. Gilman Hall

The model of an independent faculty engaged in master's and doctoral studies – graduate school and research university in general – spread through the United States from JHU. This was a new path, a new form, with new content; a leap forward. Since then, the US has become the country with the world's strongest research universities. However, there was for a while a great desire to study in traditional European universities of higher quality than those in the United States. During this period, the US also had many 'diploma-mill' universities with low standards.

In 1900, the presidents of five powerful US universities – Harvard, Chicago, California, Columbia, and Johns Hopkins, invited the presidents of nine other universities (Yale, Stanford, Princeton, Cornell etc.) to form an organization that expressed their common interest in developing graduate study. Thus, the presidents of 14 universities founded the American Association of Universities (AAU) and set about raising the standards of educational degrees. (This association today has 71 members – research universities – including two from Canada; membership is by invitation.) There are also a small number of elite universities – the well-known Ivy League, founded in 1954 by eight private universities in the north-eastern United States: Brown University, Columbia University, Cornell University, Dartmouth College, Harvard University, the University of

Pennsylvania, Princeton University and Yale University. Graduate study – master's and doctoral (PhD) education – developed so much in America that the world flocked there, including from Germany!

Note. The USSR, which engaged in competition with the capitalist world, realized that it could not develop without raising science and industry to a high level and it created the Academy of Sciences, which, along with universities, united scientific research institutes in various fields. The USSR also tried to be different in its system of scientific degrees – in 1934, a two-tier system of scientific degrees was introduced: Candidate of Sciences and Doctor of Sciences. In fact, this innovation appeared by revising the structure of the single PhD degree that existed in the Western world; in Europe and America, a PhD programme was in two parts – after successfully passing all the necessary exams, a student in doctoral studies was a candidate for a doctorate and from then he or she was engaged only in writing a dissertation. The USSR introduced the candidate for a doctorate as a primary scientific degree under the name "Candidate of Sciences"(*Кандидат наук*); if a candidate of sciences wanted (or could), he or she could write a new dissertation and receive a higher scientific degree called Doctor of Sciences (*Доктор наук*). Some of the former Soviet republics (Estonia, Lithuania, Latvia and Georgia) returned to a single PhD scientific degree that was in line with the developed world.

Technological progress and research university

The complex technological foundations of industry and the incredibly rapid development of technology once again emphasize the importance of higher education and the need for a good higher education on the path to success. Moreover, initial higher education – a bachelor's degree – is not enough to understand and apply scientific and technological progress. A research university prefers to admit and train students of master's and doctoral level, that is for graduate studies. The number of people awarded a doctorate in a year is a most important reflection on a research university (the other being published scientific works). At the same time, undergraduate education at a research university is enriched with elements of research, the tendency toward research-based teaching is strengthened, and research and teaching are combined as far as possible as a preparatory stage for master's and doctoral studies in developing research and writing skills, and implementing certain scientific and practical projects. A research university is also distinguished by its ability to introduce new disciplines and specializations; only those operating at the forefront of higher education, science and technology are able to see and introduce these innovations. A research university is more internationally oriented than others; its attractions are visible from afar. It has a greater opportunity to succeed in university-industry collaboration and in fundraising.

It is possible to study, describe, and interpret changes in the world in economic, scientific-technological and cultural terms. The history of the world's welfare can be written in the language of successive economic periods, eg. the Agricultural, then the Industrial, and the Knowledge economies. Industrial development and the invention and application of powerful technologies drastically altered the global landscape – it is also possible to talk of successive revolutionary periods: the Steam Era, the Electric Era, the Atomic Era, and the so-far indescribable New Technological Era (biotechnology, nanotechnology, genetic engineering, microelectronics, the Internet, artificial intelligence…). Science and technology are decisive and fundamental for the modern world, with innovations in the economy and everyday life as derivatives. University and technological development progress hand in hand; the commercialization and industrialization of knowledge are very important forces. Technological transfer connects the university with the business world and industry. Science and technology also have significant impact on culture. Personal, administrative, and academic cultures are intertwined. A research university creates new knowledge, so it has a more creative and cultural environment, and it encourages the discovery and development of student talent. There, academic strength is to the fore, strongly influencing administrative strength.

How is research power measured?! The American experience

What characteristics clearly distinguish one research university from another? The direct result and manifestation of research are articles published in prestigious journals, and the quantity and quality of such articles (the number of high-quality articles citing these papers). On the other hand, a research university is engaged in teaching and training high-level, elite personnel. In this work, doctoral studies are the focus, and master's studies are also strengthened. Graduate studies, especially doctoral studies, are based on research and are completed by the defence of a dissertation, a completed scientific work, and the awarding of a scientific degree.

What are world-class universities in the USA, and how do they differ? How can universities be compared with each other, how can similar ones be identified and grouped – that is, how may universities be classified? On what basis may the strongest universities, those in the highest class, be identified? Although scientific and technological progress began in Europe, the 20th century saw the USA achieve leadership in most areas; most new ideas and their implementation occurred there. Higher education institutions, which are the driving force of scientific and technological progress, also developed more rapidly in the USA (and, broadening the scope, in the Anglo-Saxon countries).

Steel magnate Andrew Carnegie founded the Carnegie Foundation for the Advancement of Teaching (1905) and this, in turn, established the Carnegie Commission on Higher Education. The Commission began working on the idea of classifying higher education institutions in 1970 and announced its first classification in 1973 – the Carnegie Classification of Higher Education Institutions. Research universities were at the top of this classification, ranked not by the number and quality of articles published in good scientific journals, but by the annual number of doctoral students defending their dissertations. The highest level included universities awarding 50 or more PhD degrees annually; they were ranked "Research I universities." There were then 59 such universities in the United States. Corresponding classifications, with certain changes, were subsequently announced in 1976, 1987, 1994, 2000, 2005, 2010, 2015, 2018 and 2021 (https://carnegieclassifications.acenet.edu/).

For 2015–2018 (and continuing for 2019–2021), universities that awarded doctoral degrees (Doctoral Universities – DU) were divided into three categories:

R1 – Doctoral universities with Very High research activity. In 2021, there were 146 such institutions of higher education.

R2 – Doctoral universities with High research activity. In 2021, there were 133 such institutions of higher education.

D/PU – Doctoral/Professional universities. In 2021, there were 187 such institutions of higher education.

R1 and R2 – Universities that conferred at least 20 research-scholarship doctorates in the years 2019–2020 and reported at least $5 million in total research expenditure.

As may be seen, it was considered important that some of the doctoral degree holders received a scholarship (research scholarship) from some source.

But how are R1 and R2 distinguished from each other? According to the special "Research activity index"; see: (https://carnegieclassifications.acenet.edu/).

D/PU category – Universities that conferred fewer than 20 research-scholarship doctoral degrees and at least 30 professional practice doctoral degrees in at least 2 programmes.

In the academic year 2022–23, there were 3,722 higher education institutions in the United States, of which 2,488 ran courses that were four years or longer (716 public, 1,772 private), and 1,234 colleges running two-year courses (854 public, 380 private) (https://nces.ed.gov/programs/digest/d23/tables/dt23_317.20.asp).

In 2025, R1 required: a) $50 million in research expenditure, b) at least 70 research doctorates awarded annually.

There are many who suggest that the much-praised US universities, are not so good. There is some discussion about US research universities experiencing a certain crisis, Anxiety prevails, with focus on the reduced funding allocated to higher education by the federal government and, especially, the states, as well as skyrocketing tuition fees, with seemingly no solution to the problems in sight (Fenwick *et al.* (2012).

What about the numbers of US research doctorates? (not including the numerous professional doctorates – J.D., M.D., D. Mgt, D.B.A., Ed.D., Psy.D, D.M., D.M.E., D.S.W. etc.) In 2022, a total of 57,596 research doctorates were awarded there (compared with 40,031 in 2002). Thus, over 20 years the number of doctorate recipients in science and engineering had increased by 74%, while the corresponding number in non-scientific fields had fallen by 13%. Thus, in 2002, science and engineering doctorates accounted for 65% of all doctorates, while in 2022 they accounted for 79%. In 2022, the numbers of research doctorate recipients in the top three and several subsequent US universities were as follows: 1. University of Michigan – 861; 2. Stanford University – 836; 3. University of California at Berkeley – 830; 11. Harvard – 753; 14. MIT – 735; 28. Cornell – 509; 29. Johns Hopkins – 507. 457 higher education institutions award doctoral degrees, averaging 126 awarded annually. In general, in 2022, those included in the R1 category awarded 45,592, those included in R2 – 7,466, and those in the DPU category awarded 2,101 doctorates. How many research doctorate degrees did citizens of other countries achieve in the US in 2022? The top 4 places: China – 6,664 (in total, 33% of all foreign students in the US), India – 2,671, South Korea – 1,071, Iran – 859. The figures for several other countries: 5. Bangladesh – 551, 6. Saudi Arabia – 493, 9. Türkiye – 354, and then Nigeria – 295, Pakistan – 166, Egypt – 143 (https://www.nsf.gov/statistics/doctorates/).

How to catch up?! Research university in the People's Republic of China

What should universities do to strengthen and join the ranks of strong research universities? As the laggard moves forward, don't those who are far ahead advance even faster? In this case, how can the laggard succeed relatively quickly? Nothing serious can be achieved in small, slow steps in easy-going fashion. Leapfrog Development!? In Soviet times, the Russian slogan *Догнать-перегнать* (Reach and Surpass) expressed the drive to catch up and overtake the advancing United States. This was believed to be possible under Communism, and poems with the repeated line “We are moving towards Communism” were written in this mood. Sometime later, realizing that this would not be possible, Soviet people, in this case Azerbaijanis, came up with jokes and parodies of the situation.

Əlimizdə zorba çomaq
Başımızda motal papaq
Ağ şalvarda qara yamaq
Kommunizmə gedirik biz…

We have a stick in our hands
A felt/hairy hat on our heads
A black patch on white pants
We’re moving towards communism

(or offered by Ian Peart)
With big thick stick in hand
Woolly sheep’s hat on head
White pants patched with black thread
The path to communism we tread…

Is it possible to build a strategy on the idea of a leap? Considering reality, the possible and advancing on this basis, as well as thinking about the future ideal and the path towards it – without a leap, there is no development. The need is to select research areas and evaluate them: very important; important; or average. It is impossible to be very strong across the broadest spectrum, covering many areas. To become a high-level research university, every member, every department, must make their contribution, everyone must be a mover along the way to the highest goal.

China’s experience is instructive. In the late 1970s, the Chinese government introduced a policy of reform and opening up. In the 1980s, Western-style educational and scientific (academic) degrees were adopted. Who could be a scientific supervisor for someone entering a doctoral programme? This right became a token of prestige; a scientific supervisor of doctoral students became a title that was noted on business cards: Doctoral Supervisor (*博士生尒师*).

“Most of the world’s best universities are in the United States” – since this was then the dominant conception in China, in order to improve higher education at home, it was decided to analyse the American experience and to benefit from it by following a similar path, but establishing higher state education institutions with a ‘Chinese face’, a ‘Socialist face’. It was stressed that the way was to build research universities, some of which could, and should, become world-class. The idea of having world-class universities as a long-term goal, and the establishment of high-level research universities as a prerequisite, was activated.

In 1995, the Chinese government announced “Project 211” focused on developing higher education. The project was a reform and investment plan to raise 100 Chinese universities to the level of the world’s strongest institutions in the 21st century. The number “211” is a juxtaposition of “21” (for the century) and “1”, the first digit of “100”. Ultimately, “Project 211” involved 116 of China’s universities. It continued until 2016.

The idea for “Project 985” was born on 4 May 1998, at the celebration of Peking University’s centenary; it was launched in 1999. 39 good universities were selected for development into “world-class universities.” The number “985” is a juxtaposition of numbers indicating the 5th month of the year ’98. Investments were made to provide selected universities with laboratories and other resources essential for science and education, to establish research centres, organize international conferences, invite well-known foreign scientists, and help Chinese scientists travel to conferences. This project continued until 2016.

On the same day (4 May 1998), nine strong universities (Beijing, Tsinghua, Fudan etc.) formed a formal group called the "C9 League". This 'select' or 'elite' group was created by imitating the high-league university groups in many developed countries. The most well-known being: the American Association of Universities (AAU) in the USA and the Ivy League, which unites eight universities; the Russell Group in the UK (17 members in 1994, 24 members in 2012); the U15 in Germany (2012); the Group of Eight in Australia (1999); the League of European Research Universities (12 members in 2002, 24 members in 2024); the RU 11 in Japan (2009: nine public, two private); the U15 in Canada (10 members in 1991, 15 members in 2011); and the Association of East Asian Research Universities, with 19 universities operating in China, Hong Kong, Macau, Taiwan, Japan, S Korea. (1996).

In 2003, experts on higher education reforms noted once more that Chinese universities lagged behind the research universities in developed countries: "There is a big gap between China's research universities and foreign counterparts" (Zhanjun, 2010).

The Chinese government has continued unceasingly its policy of strengthening universities. In 2015, the "Double-First-Class Construction" programme to have 140 Chinese universities on the list of 1st class, i.e., the strongest, universities in the world by 2050, was proposed, and was underway by 2016. In addition to first-class universities, this project also included the creation of "First-class Academic Subjects"; thus the "Double" in its title. In 2022, another seven universities were added to the list (in China then there were 3012 higher education institutions.) At the time, 15 of the 140 higher education institutions were warned that their work was not good enough.

China's leap

In 2000, there were 18,289 doctoral students in science, technology, engineering, and mathematics (STEM) in the United States, in China there were about half that number, 9,038. The number of doctoral students in these fields, assuming good quality, is usually seen as a very important indicator of the level of science in a country and at the university concerned (as we saw above, especially in the United States). In 2007, when the number of people awarded a doctorate (PhD) in the same STEM field in China exceeded the corresponding number in the United States (forever! (Zwetsloot *et al.*, 2021)), this was viewed as an "American Tragedy" within the US science and education community. In 2019, the difference in these numbers increased: 33,759 in the United States, 49,498 in China., And the difference has grown rapidly in China's favour over recent years; the corresponding numbers for 2025 look like this: 39,959 and 77,179.

In the 2009 "Times Higher Education" ranking of universities, there were two Chinese universities – Peking and Tsinghua universities – in the top 100 universities; they ranked 49th and 52nd, respectively. In 2015, they improved seven and five places – to 42nd and 47th. In the latest 2025 ranking, seven of China's "C9 League" nine members entered the top hundred (the top 65!), Moreover, Tsinghua was 12th and Peking was 13th, sitting among the world's most famous – leaving behind such notables as the University of Chicago, Johns Hopkins University, Columbia University, the University of California, Los Angeles and Cornell University! Another six Chinese universities were placed in the second hundred. Further, four universities from Hong Kong entered the top one hundred, and one university each from Taiwan and Macao entered the 2nd one hundred. As an example for comparison: Lomonosov Moscow State University, once ranked among the most famous in the world, had to settle for 107th place. For more information on the Chinese higher education system, see the specialist literature (Yang, 2012; China Education and Research Betwork, China

Education and Research Network; Frezghi & Tsegay, 2019; Li, 2018; Ministry of Education of the People's Republic of China, 2018; Rhoads *et al.*, 2014; World Education News and Reviews, 2019; Xu & Mei, 2018; Zhou & Zhou, 2019; Hu & Ni, 2019; Welch, 2018).

One of the most important factors in strengthening China's science, education and technology, making it a world leader, is the Chinese government's university development programmes; another is the Chinese people's discipline and hard work. Chinese students studying in America and Europe are usually regarded as the best students; they develop their abilities to the maximum by working hard. The question arises (for non-Chinese, for example Azerbaijani students, and of course, universities): how to teach students to be hardworking? I believe that this is related to the university's seriousness and strength. A scientist working, teaching and conducting research at a strong university should provide serious knowledge and require students to assimilate that knowledge creatively! Unfortunately, there are teachers-scholars who think they are doing students a favour by giving them light study material.

Research university and industry. American experience

The higher education institution is in constant contact with the surrounding world. Science knows no borders, scholars study the works of specialists scattered around the world in the field they are researching; they are familiar with some of them, and may be co-authors with them. Inter-university relations are the most widespread phenomenon in the world of science and education. Institutions of higher education that conduct research and train specialists in the natural sciences, life sciences, engineering, economics and other areas of applied science strive to do work related to industry and technology, to bridge theory and practice.

A technopark (or science and technology park) is an institution that brings universities and industry closer together; it is engaged in research and development-oriented business, a "house of companies" in need of innovative ideas. This is a place of cooperation between scientists, engineers, businessmen and investors engaged in applied fields, and is distinguished by its establishment of companies to implement new ideas. It is a centre of applied knowledge, a place where ideas on paper come to life. It is usually the product of private initiative, but it is also strengthened by appropriate government policy and support. A technopark is a triumph of both market economy and science and technology.

Silicon Valley was the world's first, and most famous, university technology park. In 1951, in order to resolve financial problems while providing its graduates with promising jobs, Stanford University laid the foundation for Silicon Valley by renting out a vast area of land (267 ha) to technology companies. Frederick Terman, Dean of the Stanford University Engineering School, told teachers and students to "build a company" and invited in only high-tech companies. Start-ups began! Moreover, an agreement was signed between the university and the companies: full-time employees of the companies could enter master's and doctoral programmes at Stanford University without leaving their jobs (part-time); the company would pay such students twice the tuition fee so they could afford to live!

Companies began arriving there in 1953. It can be said that the history of the technopark began there and then. In fact, Hewlett-Packard, founded in 1939, may be considered the first high-tech company on the site that would later become Silicon Valley. Two Stanford electrical engineering graduates – William R. Hewlett and David Packard – developed the first audio oscillator in 1938, in Packard's garage in Palo Alto (San Francisco Bay Area); this is a device that produces, transmits and measures electrical, sound signals of certain characteristics. They also founded there the giant information and communication company of the future, that would be called HP from their names (HP or PH? – they decided that by drawing lots). That garage has since been declared a historical site – the birthplace of Silicon Valley! For the record, I note that giant companies like Disney, Apple, Google and Amazon also began their work in garages.

Silicon Valley (Palo Alto)

William Shockley, one of the three men to invent the transistor (a device that regulates electrical currents) and win the Nobel Prize in 1956, took his Shockley Semiconductor Laboratory company to Silicon Valley in that same year. Frederick Terman and William Shockley are regarded as the two fathers of the now famed Silicon Valley. However, it is said that the authoritarian style of management, and racism, as well as a reluctance to deal with silicon-based semiconductors, led to the departure of eight talented members of company staff. Those eight founded the Fairchild Semiconductor Company, with W. Shockley calling them the "Traitorous Eight". The germanium (atomic number – 32) first used as a semiconductor was soon replaced by high-purity silicon (atomic number -14). Silicon, obtained from commonly found sand and quartz, is cheaper than germanium. Two of the eight, together with an investor, went on to found the technology giant Intel (1968).

Semiconductors (Germanium, Silicon, Selenium, S-Sulfur, C-Carbon, B-Boron, Te-Tellurium, I-Iodine,. . .) become insulators (dielectrics) when the temperature is close to absolute zero, and as the temperature increases, their conductivity increases (on the contrary, it decreases in metals).

This microelectronics revolution changed the face and spirit of the time. The steam engine developed physical power, semiconductor technology developed intellectual power. Silicon Valley, a large area south of San Francisco, employs about half a million people. Intel, Yahoo! and Oracle were founded there. General Electric and Kodak went there. Xerox, Cisco Systems, Apple (Macintosh, iPod, iPhone, iPad, iTunes) and Microsoft became hugely popular there. In 1998, two Stanford PhD students founded Google, a company that would provide a technologically more efficient Internet search engine than its predecessors; now a giant, it currently has 182,502 full-time employees (https://explodingtopics.com/blog/how-many-people-work-at-google). Having achieved great success in the semiconductor industry, Silicon Valley has also become a world centre for software and the Internet. About 33% of the US's venture capital (that which builds start-ups and finances them) is in Silicon Valley (2021 data). Taxes in this area are low, and the California government has introduced additional incentives. About 3 million people live in the Valley, which covers approximately 4,800 km^2. Silicon Valley is world leader in the number of millionaires and billionaires per capita: 163,000 millionaires, 85 billionaires! Along with Stanford University, the University of California, Berkeley, is also an important brain centre within Silicon Valley.

Another major university-industry association was established at Boston Route 128, with MIT business start-ups playing a decisive role. Biomedical technology, information technology and other fields developed in this high-tech park. The revenue of around 4,000 companies originating from MIT and operating in various parts of the world amounts to $232 billion! Harvard and Boston Universities also invested in 128 Boston Road with their intellectual and technology strengths.

Far from America. 'Russian syndrome'

Technoparks established in the USA, Europe, Japan, China, India, Israel, Taiwan, Singapore, Japan, South Korea, Hong Kong and other places have been very successful. India has become a leading country in the field of high technology and electronics, especially information technology. "An elephant has learned to dance, and better than anyone else" – this unattributed statement reflects a truth. Bangalore Electronic City has been called the Silicon Valley of India, the "2nd Silicon Valley". But there is great competition for that second place.

Referring back to the bitter, negative experience of Russia in technological development, the 'Russian Syndrome', is also of interest to an understanding of the former Soviet countries. The opinions and observations expressed by MIT professor Loren Graham on that negative experience are illuminating (Graham, 2013). I try here to summarize some of the professor's thoughts. Russia or, more broadly, the USSR, achieved great success in music and literature, art and the fundamental (theoretical) sciences, computer programming (software), that is, their strengths are in the products of mind and intelligence. An important reason for this is the possibility of achieving success in these areas without large investment or extensive teamwork, and without corruption. But is there a special "Made in Russia" brand of technology? Not at all. Why is Russia so distant from applied high technologies, why does Russia have advanced science, but no Russian computer, no Russian mobile phone...?! There is science, but the country is totally dependent on foreign technology. This is why sanctions imposed on Russia have a serious impact. The Russian economy is not built on high technology; it depends on oil and gas. Although Russia (and the USSR) led the way in the invention of weapons, railways, the electrical industry, the electric telegraph, the aviation industry, the semiconductor industry, genetics, biotechnology, computers and lasers, the practical implementation of relevant ideas happened in the Western world. Although the Kalashnikov assault rifle (*Автомат Калашникова*) was very popular, the poor inventor did not personally profit much from his invention. "He lives very modestly, on the third floor of a house without an elevator with a woman who looks after him. The country itself did not receive much, what it needed, because it sold the licence to produce the Kalashnikov assault rifle for nothing, very cheaply" (Сафронов, 2011).

In the 1950s and 1960s, laser technology developed mainly thanks to the work of Russian scientists Nikolai Basov and Alexander Prokhorov and the American Charles Townes, and in 1964 all three scientists were awarded the Nobel Prize for this discovery. Townes quickly obtained and sold a patent, as a result of which American companies did great work on laser applications. What did the Russians do? They did not even attempt to commercialize the laser. Another example is the deep drilling system, now called "fracking" or hydraulic fracturing; this work is based on pumping water, sand and chemicals into deep layers of the Earth at high pressure. The Russians wrote about this in scientific journals before anyone else, but it was companies like BP, Chevron and Exxon that implemented it; now they are teaching the Russians (and the world) a lesson.

Ukrainian mathematicians Alexey G. Ivakhnenko and Valentin G. Lapa created the Deep Learning algorithm – the "Group Method of Data Handling" in 1965. Ivakhnenko and his co-authors improved the method in following years (Schmidhuber, 2015). However, ultimately, Soviet and Russian science lagged far behind in the development of the field of Deep Learning and, in general, Artificial Intelligence.

For Russian scientists and inventors, business means corruption, dirt, and a scholar does not want to, or cannot, get near it. In America, a successful businessman is a national hero (Edison, Bill Gates, Steve Jobs,..) In Russia, however, society does not value the inventor, the state sees big business as a competitor. The economic system does not help or encourage investment opportunities. The legal system is weak in protecting intellectual property. Corruption hinders work, the political and social environment does not support work. In general, this mentality hinders private work. The central state Skolkovo technopark being built in Russia, is a state, not a business, initiative, not a private investment, and it is doubtful that great results will be achieved there.

Natural intelligence and computers

Humans are not the most superior of living beings in terms of physical capabilities; there are animals that are bigger in body, physically stronger, faster runners, with sharper eyesight, hearing and smell. Unlike humans, many creatures can live under water or fly in the air. However, their power of intelligence makes humans incomparably more powerful than any other living creature. Humans have survived, evolved, learned about the world, and begun to change it. By inventing the telescope and the microscope, humans have been able to see vast distances and into the very small realms that the naked eye cannot see – they have observed the universe, molecules and cells. With inventions like the steam engine, electricity and the internal combustion engine, humans have created much more powerful machines – vehicles that move at speed across land, sky and water. That have illuminated the darkness, heated homes, and provided new sources of energy. In ancient times, people measured time by natural means, such as the Sun's shadow, and the flow of water or sand. Since the Middle Ages, life has been organized to an unprecedented degree with the inventions of mechanical, electric, quartz and atomic clocks; the value of time has increased, and every minute has become important. Humans have studied the world more carefully by inventing devices that can measure important physical quantities and determine geographical direction. With the discovery of electricity, electronics and atomic physics, humans invented means of long-distance communication; as a result, the telegraph, telephone, radio and television were created, capable of transmitting words, sounds and images in sequence from one place to another, both through wires and wirelessly.

Technological development increasingly focused on 'intelligent' machines. In the 1940s computers began to emerge that could perform calculations beyond the capacity of the human brain – or that would take a very long time for a person to complete. John von Neumann defined the operating principle and architectural structure of a computer: the Memory Unit and the Central Processing Unit, which are interconnected. The Memory Unit stores data and programs. The Central Processing Unit 'opens' and 'reads' the program, breaks it down into individual instructions, executes them and sends the results both to the Memory Unit and to the user via an Output Device (such as a monitor or printer).

John von Neumann

A computer consists of ‘hardware’ and ‘software’, that is, an intelligence program. The so-called intelligence program consists of binary code, written in two symbols. There is a tradition of using the numbers 0 and 1 as these two symbols. It is possible to express any idea through these two digits. The mathematical logic or algebra that is based on two symbols (‘true’ and ‘false, or 1 and 0) and is called Boolean algebra, is the basis of digital electronics and programming. To solve a problem under consideration, it is necessary to write a finite number of instructions – an algorithm, in code; that is, to write and compile a program. For the information (instruction, program, software) written in binary code to be read by a computer, 1 is set to the ‘on’ state of the electric current, and 0 is set to the ‘off’ state. This is the soul of modern electronics: the transistor turns on or off, opens or closes the electric current; a closed switch does not emit an electric signal, while an open switch does; that is, the instructions 1 and 0 are fulfilled. Thus, the digital world is based on these two numbers or rather, it is expressed through these two numbers. As for materiality, these numbers are in thought, in imagination; what exists is the electric current that the electric switch opens and closes.

Semiconductor – microchip technology

An *Integrated Circuit* (IC) or *Microchip* or *Computer chip* or, simply, a *chip* is a digital system consisting of connections between various electronic components (transistor, resistor, capacitor, inductor, diode) with conductive wires: this circuit is placed within a flat semiconductor (mainly silicon). “Chip” in English means thin plate. Within a modern microchip, a small piece of silicon the size of a fingernail can contain millions, even billions of transistors. This means that the computer can execute millions of commands very quickly. The microchip’s small size ensures that little electricity is consumed. However, it is very expensive to design and produce chips in a factory. Jack Kilby, who realized the idea of an integrated circuit in germanium in 1957–59, was awarded the Nobel Prize in 2000 for this work. Robert Noyce, one of the founders of Fairchild Semiconductor, improved the integrated circuit by replacing germanium with silicon, making it a complete monolith (Kilby had one external connection). Silicon is one of the most abundant elements in the Earth’s crust (second only to oxygen).

In the 1970s, the average transistor size was around 10 microns (1mk $= 10^{--6}$ m, i.e. one hundredth of 1mm); in 2021 this size was reduced to 5 nanometers (1nm $= 10^{--9}$ m). By applying Artificial Intelligence to chip design, it is possible to save time and improve quality. Depending on their purpose, different types of microchips are produced: logic microchips are for computing work like microprocessors, memory microchips store and save information. It is possible to talk about discrete, analogue and mixed microchips, sensors that convert physical effects or quantities into electrical signals, photon microchips and others. Special EDA software is used to design the transistor in the microchip.

The world is built on microchips – this idea is widely accepted, the microchip is the soul of electronic devices, the building block of modern technology. Although a new world war has not yet begun, wars between states occasionally break out, and semiconductor technology and artificial intelligence play a decisive role in these wars, with nuclear weapons, although they exist, not being used – with the exception of the nuclear bombings of Japan by the United States in 1945 that caused the tragedies of Hiroshima (6 August) and Nagasaki (9 August). One of the great measures of power in the modern world is the development of a national semiconductor industry, the production of high-quality chips! Europe and the United States, which were the world leaders in chip production in 1990 – 44% and 37%, respectively – (Zhu, 2025) are now far behind Asia.

Information on the semiconductor and microchip industry is somewhat mixed and volatile, with volume and price figures fluctuating, rising and falling. The confusion arises from the fact that circular semiconductors, or wafers, are manufactured in different sizes, and the volatility is due to the fact that the situation can change very quickly. The information for 300 mm wafer manufacturing as of 2022 is as follows: South Korea – 25%, China – 22%, Taiwan – 22%, and Japan – 13%. The order changes for 200 mm wafers: China, Japan, and Taiwan (Zandt, 2023). The 300 mm wafer is more affordable, because more chips can be placed on it. The top five countries in semiconductor manufacturing in 2025 are: Taiwan, S. Korea, Japan, the US, China (https://worldpopulationreview.com/country-rankings/semiconductor-manufacturing-by-country#what-country-produces-the-most-semiconductors). The Taiwan Semiconductor Manufacturing Company controls more than 90% of the world's production of the most advanced chips (Arthadeswa, 2025). Producing and selling chips is a hard but profitable business. These countries, as well as Germany, the UK, the Netherlands, Israel, Singapore and Malaysia, are investing significant financial and intellectual capital in the development of semiconductor technology. "China now spends more money each year importing chips than it spends on oil" (Miller, 2022a). The most obvious example of the relentless competition between China and the US is the struggle over Taiwan, and in particular for chips. "The interconnections between the chip industries in the U.S., China and Taiwan are dizzyingly complex" (Miller, 2022b).

From natural intelligence to artificial intelligence

The Internet, a network for transferring data between computers, originated in 1969, and led to the establishment of the www, i.e. world-wide-web network, 20 years later. Although personal computers were useful devices in the 1970s and 1980s, only the Internet gave computers a revolutionary technological power. The computer and its applications have created two converging currents. At first, the direction called "Expert Systems" gained momentum: facts and rules are given, new facts are extracted by applying the rules to known facts, a conclusion is drawn from the reasoning, that is, a decision is made. This is a system that works according to the rule of software written by a human. Expert systems were applied in medical diagnostics for their ability to respond to queries. Then a self-adjusting system with the ability to work autonomously, i.e. 'intelligent machine', or artificial intelligence, emerged and became the main direction, the leading current. The trinity of Computer Science, Networking and Artificial Intelligence has become a world-changing superpower.

Human intelligence (Natural Intelligence), which had the idea of changing the world, was looking for a companion, a colleague, and it began to create artificial intelligence! Isn't it possible to create an artificial intelligence, a non-biological intelligence, a smart machine that can think like a human, learn, become more accurate step by step, and make decisions, solve problems and take action?! The science of Artificial Intelligence or Artificial Intelligence engineering began to take shape! Psychologists have tried to create many models of intelligence, but it cannot be said that they have achieved great success in this way, nor have they paved the way for serious applications. When computers surpassed natural human intelligence as a tool that can calculate faster and more accurately than humans, it became natural for humans to think about creating powerful artificial intelligence in other areas as well. A number of mathematicians and engineers-technologists including Alan Turing, J. von Neumann, N. Wiener and C. Shannon, have said that intelligent machines can be created,and have taken steps towards realizing this idea (Carthy, 2007). In 1950, Turing proposed an experiment to test Artificial Intelligence (the "Turing Test" or "Imitation Game") (Turing, 1950). The Turing test in simple form is as follows: if artificial intelligence and human-natural intelligence are placed in two different rooms and enter into a dialogue without knowing each other's identity, and if the person does not doubt that the other individual, that is, the machine, is a person by questioning in every way, then it seems natural to accept that the artificial intelligence has human intelligence.


Alan Turing

While noting that a machine cannot be happy or sad like a human, and does not have a will, or the love between men and women, Turing expressed his hope that intelligent machines would be created in the future: "We may hope that machines will eventually compete with men in all purely intellectual fields" (Turing, 1950, p. 460). If we work hard, we will achieve much – the last sentence of the article says: "We can only see a short distance ahead, but we can see plenty there that needs to be done" (Turing, 1950, p. 460). Turing originally proposed the idea of a step-by-step creation of intelligent machines, first simulating a relatively simple mind, in this case a child's mind, and then training it: "Instead of trying to produce a programme to simulate the adult mind, why not rather try to produce one which simulates the child's? If this were then subjected to an appropriate course of education one would obtain the adult brain… Our hope is that there is so little mechanism in a child's brain that something like it can be easily programmed" (Turing, 1950, p. 442).

At the same time as A. Turing, Norbert Wiener (Wiener, 1948) compared a machine to a brain, saying that a computer could play chess based on a minimax search algorithm. American mathematician and electrical engineer Claude Shannon made significant progress in this area in 1950 (Shannon, 1950). He presented the computer playing chess as a solution to a specific mathematical minimax problem: one should imagine a chess game as a tree, the current state of the board as the trunk, and the possible moves as the branches. It is necessary to limit the length (depth) of the possible moves to a single number (10, 15, etc.). The concept of each move's strength includes a numerical value; factors such as the relative strength and position of the pieces, control of the centre and open lines, the position of the pawns, and the safety of the king are taken into account. The move with the maximum value is chosen as the best move from all possible moves. In 1974, the world championship involving 13 participating chess computer programs was won by the Soviet program "Kaissa". However, the true power of artificial intelligence in chess became clear in 1997: IBM's Deep Blue supercomputer defeated world chess champion Gary Kasparov: 3.5–2.5. (İsaxanlı, 2024). Much later, in 2016, DeepMind's deep neural network-based AlphaGo program defeated world champion Lee Sodol in the complex game of Go. One of the founders of this program, Demis Hassabis, together with John M. Jumper, succeeded in predicting the 3D structure of proteins based on their amino acid sequence in 2024 using artificial intelligence (Deep Learning!) and was awarded the Nobel Prize in Chemistry.

John McCarthy coined the term "Artificial Intelligence" in 1956, at the Dartmouth Conference, the first conference devoted to artificial intelligence, and also gave a now often-remembered definition of artificial intelligence: "…Every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to stimulate it." This is called "artificial intelligence"; this term, which has acquired a universal meaning, has replaced terms such as "thinking machines", "cybernetics", "automata theory", and "information processing" that were previously used.

Robotics

Electronic people with artificial intelligence – robots – began to appear from the 1960s onwards. The word "robot" was first encountered in the play "R.U.R." written by the Czech writer Karel Čapek in 1920 (at the suggestion of his brother Josef); "robot" is derived from the Slavic word "rab", which means slave; the word "rabota" (labour) is from the same root. The word "Robotics", used in the sense of robot work, robot art, was introduced by Isaac Asimov, author of science fiction and popular science works, in his short story "Runabout" (1942). The history of robotics is a long one, so I will limit myself to a few words here. In Japan, Waseda University became known for its work on making human-like robots that could see, hear and talk, and it released its first product in 1972 thereby playing a role in popularizing the work. Intelligent robots were made to resemble humans in appearance – with a head on top of a body, two hands, arms and two legs and were called "Humanoid robots". Robots that sense the environment, see, hear, plan each subsequent movement and can operate to a plan became widespread. The robot called "Kismet", which can communicate with humans using facial expressions, body language and speech, was considered a triumph of artificial intelligence (1998, MIT); it was equipped with a variety of sensors. In general, perception in robotics is handled by sensors and cameras. The integration of mechanical, computer, electrical and electronic engineering has greatly developed the making of robots in various ways. In many factories nowadays, robots rather than people perform manual work; this is made possible by the fact that robots have very good vision and touch.

Experts from the College of Artificial Intelligence at Nankai University in Tianjin, China, used robots to clone pigs. All stages of this cloning process were automated, without human intervention, and seven piglets were obtained from March–May 2022. By the Somatic Cell Nuclear Transfer (SCNT) technique, the nucleus is removed from the egg cell of the surrogate animal and replaced with a (somatic) nucleus taken from the cell of the cloned animal. This embryo is implanted into the surrogate for development. The success rate of such work that required much time and attention from someone with a microscope, was 10%, while for the robotic project, the success rate was much higher: 27.5%. I should note that in 1996, the creation of a clone sheep named Dolly succeeded only at the 277th attempt. China is the country that breeds and consumes most pigs in the world. During the severe Covid-19 pandemic, pigs were slaughtered in China, causing a meat crisis. China has restored its pig stock by cloning and now it is said that there is no need for foreign imports. China has generally made great progress in cloning; a monkey was cloned, and two long-tailed macaques were born in 2017.

Along with robots, the creation of autonomous vehicles, drones and watercraft is popular. Attempts were made from 2018 to construct a robotic car or robo-car, i.e. self-driving cars, and in the 2020s self-driving cars hit the streets in the United States and other places (question: if such a car crashes, who will be held responsible?!).

Artificial intelligence techniques: Machine learning and deep learning

At the centre of the science of Artificial Intelligence is the technical, mathematical-statistical approach called Machine Learning, the term itself being coined by Arthur Samuel (1901–1980) in 1959. Machine Learning is based on the technique of examining a very large database, in other words, drawing conclusions from known experience and strengthening the ability to think, plan, make decisions and take action. On the one hand, machine learning learns from labelled data, predicts the label of unseen data, finds patterns and creates groups for unlabelled data, while also learning from contact with the environment – doing reinforcement learning by correcting and reinforcing errors. Following the era of formal logic and programming languages – the era of classical computer science, came the era of Artificial Intelligence and Data Mining, built on data and statistics. In the classical case, there was no room for probability and uncertainty. It can be very difficult to create an algorithm and write a computer program for very complex problems, for example, to understand speech or recognize faces. In this case, Machine Learning, which studies statistical data and predicts what may happen, comes to the rescue, providing not an exact solution to the problem, but an approximate solution that is very close to it; in practice, this is enough. A simple example: as a result of machine learning, emails that we consider to be spoiled, unwanted, spam, are divided into two parts – "spam" and "nonspam".

The huge amount of varied data, the "data explosion", has become the treasure and weapon of companies and organizations, and it has begun to play an extraordinary role in determining target customers and marketing strategies. In the era of Artificial Intelligence, data is the oil of the modern era – so the word goes in the world of science and business. Data Mining intersects with Machine Learning, using the same methods, but adding the finding and discovering of unknown data instead of prediction.

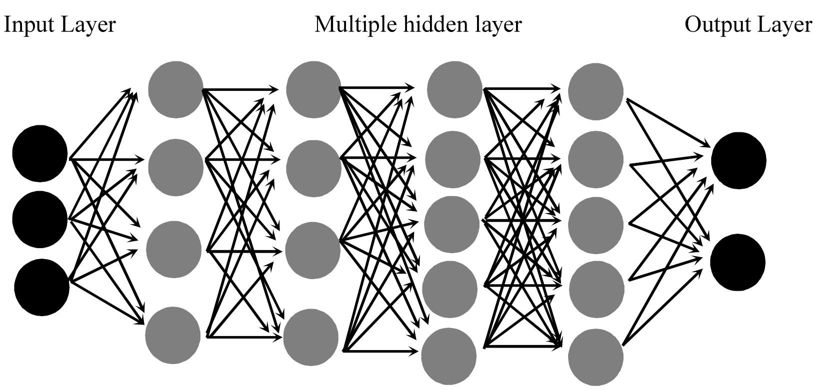
The increasing power of computers and processors, the existence of large databases, sensor networks, cloud technology and the development of fields like neuroscience have led to the great scientific and technological power of artificial intelligence. Artificial intelligence consists of effective software or effective hardware, or a combination of both – as in the case of robots or self-driving cars. It has surpassed human capabilities in several areas – in games like chess and go, or in image recognition and classification. However, it cannot be as universal as that of humanity; such artificial intelligence, which is typical of the current era, is called Narrow Artificial Intelligence.

Unlike expert systems, humans do not giving a program to Artificial Intelligence, we only provide this system with a database that has a training role. Everything necessary is taken from this database. That is, the machine programs itself, learns the database, and draws conclusions from the data and known patterns. The power of machine learning depends on the quantity and quality of the database (completeness, clarity, relevance, . . .). In a machine learning system, the machine is autonomous, once activated, it does its job, there is no, or minimal, human intervention; after providing the data, no explicit instructions are given. Machine learning 1) tries to see and predict the future based on the vast amount of data available; 2) selects, separates and classifies similar data (divides it into samples, clusters); 3) creates new knowledge, new content (text, image, video, artwork, problem solving strategies).

The mathematical basis of machine learning consists of calculus, statistics and linear algebra (Danka, 2025; Nelson, 2023).

In the 2010s, Deep Neural Networks filled the field with a roar like thunder and with it, the science and technology of Artificial Intelligence took a leap forward, and its amazing applications emerged. In fact, Deep Neural Networks had been introduced in 1943 (McCulloch and Pitts), but remained in isolation and were forgotten. Deep Learning is at the heart of Machine Learning and is based on a biological idea – "how does the brain work?" The neural network is regarded as the backbone of Deep Learning which is based particularly on modelling the process of converting light and sound into images and hearing respectively. The brain itself converts electro-chemical impulses flowing between neurons into sound, images and feelings.

"His Excellency, the brain, is the main organ of a person, both literally and figuratively" (Isaxanli, 2023). How does the human brain receive, store and analyze information? The brain and its nervous system are so complex that although the principles of its functioning have been studied extensively and generally to good effect, unfortunately, it is still not fully understood and cannot be fully described. The main nerve cells that make up the brain are *neurons*, while other cells, called *glia* or *neuroglia,* mainly protect neurons and ensure their proper functioning. Connections between neurons are through *synapses*. It is said that there are about 86 billion neurons and about the same number of glial cells in the human brain. Each neuron is connected to more than a thousand, or thousands of, neurons through synapses. In other words, the number of connections in the brain is enormous, a network of hundreds of trillions of synapses encodes information in the brain. Anatomically, a neuron has three parts: the cell body – *soma* or *perikaryon*; numerous *dendrite* branches (protrusions, arms) that receive signals from other neurons, that is, they collect signals like antennas; and *axon* branches that send and bring signals to and from other neurons. The vast majority of axons are covered with a fat called *myelin*; an insulator to prevents leaks of electrical charges. There is a synaptic gap – a gap between the axon of one neuron and the dendrite of another. In the transition from axon to dendrite, the electrical signal is converted into a chemical signal, a message, crosses the synaptic gap and takes the form of a neurotransmitter molecule. That is, electrical (nerve) impulses sent and received between neurons trigger chemical reactions in the synapses, and a chemical postman, messenger, the neurotransmitter, moves along the synapse. Glia are also active in the transmission of signals. The electrical impulses sent are the brain's command, determining the decisions made by the brain. (Isaxanli, 2023, pp. 169–170).



Artificial neural networks, or simply *neural networks,* are built by simulating human nerve cells. As a model or scheme, a neural network may be imagined as a set of dots and lines connecting them, the dots representing neurons, and the lines as synapses. A neural network is a set of artificial neurons that are connected to each other, they are also called *nodes*; since each affects the behaviour of the others to some extent. More precisely, each artificial neuron has its own 'weight' and 'threshold' determined by the output in the learning process (these weights and thresholds are determined by a human, the designer, programmer of the network). When the artificial neuron exceeds the limit, it 'fires', activating and sending information to the next layer of the network, otherwise the information does not travel; thus, the neuron whose strength exceeds a certain threshold affects some subsequent ones in the network, but not others. There is a biological similarity here: we are talking about neurons whose stimuli exceed a certain threshold, "able to send an electrical or chemical impulse-signal". Each artificial neuron receives a signal from the neurons connected to it, processes that signal and sends it to other neurons. The function that calculates the neuron's output value using input values and weights is called the "Activation Function." If the activation function is nonlinear, it is possible to solve a complex problem with a relatively small number of neurons.

In Deep Learning, there are multiple layers between input and output neurons, i.e. at least two hidden layers of neurons. It is as if there is a foggy box – it is known what happened at the input, and what conclusion was reached, but the processes taking place inside are unclear. Each neuron takes in many inputs from previous ones in the network, but there is only one path from that neuron to each subsequent neuron. Data is transmitted from one layer to the next. The number of neurons (nodes) in different layers may differ. Thus, in the Artificial Neural Network model, it is possible to represent the state of each neuron with a single number and the strength of each synapse also with a single number. With easy access to training data in the middle, the abundance of information allows an observer to view hundreds of layers, getting ever closer to reality. The goal is to make the difference between the actual output of the model and the expected output (cost function) of the programmer be zero, or very close to zero, as the model runs. The number of neurons in the output layer depends on the problem being solved, the number of indicators that need to be determined. Neurons connect to each other with non-linear functions, approximating them with "good" functions helps.

Artificial intelligence does not work on models that simulate a single person‘s thinking, but tries to work on models that attempt to study and imitate a common life style of organisms living together in large groups. There has been special interest in honey bees and ants (Mahawar *et al.*, 2025; Scoble & Cronin, 2025).

John Hopfield (1933), an American physicist who developed machine learning through a network of interconnected artificial neurons, and Geoffrey Hilton (1947), a specialist in computer and cognitive sciences, were awarded the 2024 Nobel Prize in Physics. Deep Learning is applied in many diverse and complex domains and for very large databases performs better than general machine learning. Numerous books have been written on General Artificial Intelligence, Machine Learning, and Deep Learning, including: (Norvig & Russell, 2021; Goodfellow *et al.*, 2016; Burkov, 2019).

What else is there?

All the successes of Artificial Intelligence listed above and mentioned below are based on Machine Learning, especially Deep Learning techniques. It is difficult to think of a field where Artificial Intelligence is not applied. In particular, Google's search algorithm, known and used by all, is built on a neural network. In the 2000s, artificial intelligence-based internet, telephone and social media celebrities emerged: Skype, Facebook, Youtube, WhatsApp and iPhone that connected everyone to these remarkable networks. Artificial Intelligence is manifest in most areas of human activity – healthcare, epidemiology, medicine (diagnostics, surgery), pharmacology, various industries, the natural sciences, technology, military work, politics, management, finance, art, transportation, education, psychology, philosophy, linguistics, various modellings and experiments, literature, press, entertainment, agriculture ('smart' farming, for example: determining with robots and drones where and when to fertilize and water plants…) and many more. Finance (e.g., investment, timing, fraud detection and prevention), healthcare, marketing and a number of other activities depend to a significant extent on good forecasting.

Artificial intelligence called *Natural Language Processing* (NLP) enables reading, understanding, writing, speech recognition, transforming speech-to-text, and text-to-speech, communications, machine translations of living human languages, and a new application found on mobile phones (smart phones) converting speech in one language into speech in another language. The field of artificial intelligence known as *Computer Vision* (CV) is for understanding, classifying and analyzing image and video data, including object detection and facial recognition. This has a crucial role in functions such as self-driving vehicles and medical imaging. *Human-Computer Interaction* (HCI) enables the recognition, interpretation and imitation of human emotions.

When most people think of Artificial Intelligence, they think of *Generative Artificial Intelligence*, especially the creative program called *ChatGPT*. Generative Artificial Intelligence, which is based on *Large Language Models* (LLMs), is very widespread and has intervened in the lives of literate people. For example, ChatGPT (Chat Generative Pre-trained Transformer), which can make plans based on patterns, gives logical, truthful and creative answers to any question asked by the user; it can also write new logical content – articles, stories, poems, compose music and take pictures. It was announced by the US artificial intelligence organization Open AI in November 2022 and gradually conquered areas of education, general and creative writing; it became widespread and popularized the concept of Artificial Intelligence. In this case, the data can be in text, drawings, audio and video material, and other forms. The initial ChatGPT systems, created from 2018, have gradually been improved; and this process continues. Chat GPT can successfully pass the Turing Test in its field of activity. It has become so popular so quickly that it has become a competitor to the Google search engine. Google was worried and tried to do something similar; currently, the Google search engine provides an Artificial Intelligence Overview ("AI Overview") at the beginning of its search results.

ChatGPT systems are penetrating deeply into education and other fields. Learning these new Artificial Intelligence systems, knowing (and teaching) their advantages, as well as disadvantages, and using them effectively in teaching are essential issues for modern education. Students can prepare homework and answer exam questions through ChatGPT, as well as working on projects; this, albeit useful, also creates ethical problems, can sometimes be confusing, and does not show the original sources used. It is necessary to know the risks when applying such artificial intelligence programs. It is possible to speak of "good artificial intelligence" and "bad artificial intelligence". Clearly visible are the problems of data security, the possibilities of creating biased opinions and discrimination, also violations of equal opportunities, inclusivity and transparency. Of course, it is also true that Artificial Intelligence creates very dangerous weapons. In any case, Artificial Intelligence has begun to play a serious role in the transfer of knowledge, experience, cultural heritage and the creation of new knowledge.

Where are natural intelligence and artificial intelligence taking us?

It is believed that Artificial Intelligence can change our society, our world, for better or worse, and the artificial intelligence revolution, like other revolutions, brings problems with it. John Hopfield compares AI to nuclear fission and the resulting nuclear weapons and nuclear energy (Taylor *et al.*, 2024). From a military perspective, following the era of nuclear weapons, the era of Artificial Intelligence may be termed the era of autonomous weapons.

Globalization has revised the concept of state sovereignty, and Artificial Intelligence has now changed it more fundamentally. First, the Internet has broken the state monopoly in the information field. Territorial sovereignty is easier to understand than digital sovereignty. State control over data, that is, a large database, is difficult, probably impossible, and there is also talk of powerful digital empires. Artificial intelligence is changing the socio-political and economic systems.

There is a battle for leadership in artificial intelligence between the United States and China (see, for example: (Özdemir, 2024)). There is a very popular (but not precisely known) phrase about China, attributed to Napoleon: "China is a sleeping giant, let her sleep, for when she wakes, she will shake the world" (Welch, 2018). China leads in the numbers of journal articles devoted to artificial intelligence – in 2023, it published almost twice as many articles in this field as the US; Turkey ranked 16th in this race (Özdemir *et al.*, 2025).

Artificial Intelligence first appeared as a student quickly and effectively completing a task, then it became the colleague of a scientist, an engineer, a teacher, and now it is itself the teacher, teaching others. Artificial Intelligence is developing, is being applied, and is becoming popular (at lightning speed!) A new type of neural network architecture contributes to the development of science and to the solution of problems it faces. This enables the solution of special differential equations approximately better than traditional methods of approximate solution (Grohs & Kutyniok, 2022). Neural networks seem to be suitable for everything. As Ali Rahimi said: "Machine Learning has become a form of alchemy" (Kutyniok, 2021). It is thought that Artificial Intelligence can play a role in slowing climate change: "Artificial Intelligence (AI) could revolutionize our ability to understand and address climate change" (Lewis *et al.*, 2024).

The extraordinary success of Artificial Intelligence has given rise to realistic opinions about its future, as well as ideas close to fantasy. What if one day (sooner or later?) a superintelligent machine is created?! There are many books for those who want stimulation along this path (Bostrom, 2016; Tegmark, 2017). There are those who are not satisfied with the idea that artificial intelligence will be able to learn like humans and reach a level to achieve a goal it has set for itself, that is, *General Artificial Intelligence*. There is talk that artificial intelligence will surpass natural human intelligence, that an *Ultraintelligent Machine* or *Superhuman Intelligence* will emerge and that it will get beyond control, such a hypothetical time has been called an "intelligence explosion" or "technological singularity" (Koch, 2015). It is possible to build another dream – if it is possible to calculate, code and algorithmize human thought, then it is possible to write a program with which the human brain can be copied, reproduced, transferred to another place, to a server, transferred to a robot, or downloaded. The creation of general and super artificial intelligence full of fantasy, and the legal, security and ethical issues may be considered the subject of the *Philosophy of Artificial Intelligence.*Will artificial intelligence be able to feel happy or unhappy? Difficult. Because artificial intelligence is a non-biological being.

Here, naturally, the question arises, "What to do?".

In countries where scientific research and technology are not so strong, it is no easy task to instill in the government the importance for the state of research, university-industry cooperation and the development of Artificial Intelligence. On the one hand, this work must not be forgotten, universities should try to enter into a dialogue with the government. On the other hand, universities that claim to be strong as research universities should work in this direction themselves, tirelessly and independently of the government, and do what is possible.

What should be done to develop a high-tech culture? It is impossible to achieve success without primary and secondary education. Starting from kindergartens, it is necessary to promote and demonstrate the idea of high technology in primary and secondary schools, and to give more attention to experimental, practically-oriented lessons (the syndrome of putting theories to the fore in education systems with a socialist past has still not completely disappeared). The Chinese government has declared its intention to become a world leader in the science, technology and application of Artificial Intelligence by 2030 and has proposed a serious program for teaching Artificial Intelligence from primary schools onwards.

It is necessary to "create with hands and brains" in engineering schools, to base classes on applied projects. Robots, electric cars, unmanned aerial vehicles (drones), self-driving cars, more extensive use of solar energy, nanotechnology, biotechnology, genetic engineering, biomedical engineering, the Internet of Things and cybersecurity, climate change and environmental engineering, artificial intelligence science and artificial intelligence engineering in a broader sense – all this would be good if it were the basis of teaching, with working cooperation between teachers, specialists and students!

Conclusion

There are various forms of higher education institution in the world. Research universities are the ones that contribute most to scientific research, industry and technology development. A research university is an institution that produces, disseminates and applies knowledge while training high-level, elite specialists in this way.

The madrasah-university movement that spread in the Islamic world found its further development in Europe. In European higher education institutions that had been based on classical languages and theology in the early Middle Ages, natural sciences gradually began to be a larger part of the studies. Eventually, German universities that made research and education an organic unity became popular throughout the 19th century. A new rise of the research university took place in the United States: on the one hand, John Hopkins University applied the German higher education model to America and, on the other hand, by establishing the School of Graduate Study, it regarded the training of Master's and, especially, Ph.D. degree holders to be crucial. Finally, through the new 21st century, China began to emerge; the China that has become the new second-placed economic, political and technological centre of the world, while aspiring to be first. Realizing the decisive role of its research university in the country's development to strengthen these universities, it began to implement programs that replace each other. China has made a leap forward on this path! Chinese universities have an undeniable role in the development of university-industry relations and artificial intelligence.

What is the strength of a research university, how to measure it? What are the research indicators of a relevant academic institution in any field, be it natural sciences, engineering, economics and management, humanities, or social sciences? History and present-day experience says that it is necessary to measure, calculate and evaluate two indicators: 1) quality articles published in reputable journals (number of, and citations from them) and 2) the number of graduates who successfully defend their PhD dissertations in a year. It is possible that, along with item 2, a slightly different item should be included: 2a) the number of those who successfully defend their master's thesis and doctoral dissertation in a year, that is, graduate degrees conferred. The idea that "the existence of master's programmes encourages the strengthening of PhD programmes in the relevant field" suggests the evident reasonableness of article 2a). There is a very important issue regarding the defence of dissertations and the awarding of scientific degrees: the existence of scholarships for graduate education, especially doctoral studies. In order to attract talented doctoral students from different parts of the world, it is vital to provide them with competitive scholarships.

The research university has played an extraordinary role in the emergence and invention of new technologies. The idea of combining semiconductors – germanium and then silicon – with a transistor that regulates electric currents was central to the Stanford University initiative in a place called Silicon Valley; it laid the foundation for the transistor industry. There is a binary code based on two signs, traditionally “1” and “0”, that is, Boolean algebra or logic in which any information can be written. Through the transistor, the computer can read this information (algorithm, command, program): if there is an electric current, “1” is written, otherwise “0” is written! By placing a large number (millions, billions!) of transistors and other electronic components on a semiconductor flat plate – wafer – interconnected by wires, a microchip or simply a chip emerged, now considered to be the lifeblood of modern technologies. The industry that designs and manufactures these chips is called the “chip industry” or “semiconductor industry”. The centre of chip production moved from Europe and America to Asia. The Soviets, with their great intellectual power, and their successor, Russia, lagged behind in the field of new technologies. The reasons for this backwardness, the poverty (absence?!) of “Made in Russia”, include the lack of government incentive policies, the unhealthy economic, political and legal environment, and the mentality that distances scientists from application (‘Russian Syndrome’).

The invention of computers gave rise to the idea of an “intelligent machine”. Can’t a machine that can calculate incomparably faster than humans, also play Chess or Go better than a human by applying a suitable algorithm?! Humans, with their natural intelligence, began to develop the idea of creating artificial intelligence. With the advent of the world-wide network – the Internet – huge databases increased even further and grew unimaginably. Data is a great treasure, just as a person makes decisions based on his own experience, a machine with artificial intelligence, can study the database, analyze it, classify it and, as a result, try to predict output, the future. The Artificial Intelligence mechanism that can do this is called Machine Learning. Machine Learning is the backbone of Artificial Intelligence, and the most important area of Machine Learning is Deep Learning. Deep Learning, which can work effectively with huge databases and solve complex problems, is based on a modelling of the human brain, its neural-synaptic network. Artificial neural networks, with their multi-layered rows and columns, are the most powerful tools of modern Artificial Intelligence science and Artificial Intelligence engineering. Robotics is the union of the hard and soft sides of Artificial Intelligence.

The part of Artificial Intelligence that can solve language-based problems such as reading, writing, speech recognition and interlanguage translation is called Natural Language Processing. Another popular area is Generative AI, which provides logical answers to questions, and its most popular product is Chat GPT. The latter is seen as a revolution in the education system (revolutions always have their downsides…). One more important field of Artificial Intelligence with various interesting applications is Computer Vision.

Where are we going in the footsteps of Artificial Intelligence? Narrow (or “Weak”) Artificial Intelligence is currently the type that exceeds human intelligence in a certain area. It is widespread, and all the achievements of Artificial Intelligence in science or engineering belong to this type. General (“Strong”) Artificial Intelligence – that thinks, analyzes and makes human-like decisions does not exist, and finally, there is much talk about whether Super Artificial Intelligence that exceeds human intelligence in general; it does not exist. General and Super Artificial Intelligence are dreams. Opinions about them vary: “it’s not real, it’s a fantasy”, “it could happen in 25 years?!”, “it could happen in 100 years?!…”

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest

The author declares no conflict of interest.

Ethics approval

Ethics approval was waived for this study because no patients' data were reported.

Data availability

No datasets were generated or analyzed during the current study.

Author contribution

The author confirms being the sole contributor of this work and has approved it for publication.

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