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Perspective

Orderliness in Mining 4.0

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Abstract: Mining of minerals is an important part of the technical sciences, for which the certainty and unambiguity of terms and the correct application of definitions is an absolute requirement. At the same time, the expansion of Industry 4.0 technologies, both in practice and in scientific discussions, brings new terms to mining that are far from the original meaning. These terms include Data Mining and Mining 4.0, which, having a common digital core, refer to fundamentally different areas of human activity, and have the opposite meaning in relation to the use of resources (digital ones—endless, and the natural ones—finite). The indiscriminate use of the term "mining" is especially dangerous in the context of Mining 4.0, in which digital technologies allow the intensification of the exploitation of natural resources. This brief Perspective paper will show the role of terminology in Mining 4.0 and offer an interpretation of its relationship with Data Mining.

Keywords: Mining 4.0; Data Mining; orderliness; disorder; Industry 4.0; Mining 5.0; Industry 5.0

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1. Introduction

Initially, mining was considered as a sphere of human activity associated with the development and use of the bowel, in practice embodied in the extraction of mineral resources in the course of a targeted impact on the earth's crust. Despite a long history (the first copper mines date back to the Copper-Stone Age—about 7000 BC), the information content of mining dates back to the High Renaissance, when scientific research related to mining technologies received a boost, giving rise to the classification of minerals, the methods of their extraction, the organization of labor and efforts to ensure the safety of mining [1,2].

Until the end of the 20th century, the information basis of mining was formed within the framework of geotechnology—the science of subsoil development, in which the processes of mineral extraction are comprehended and theoretically generalized, allowing the development of engineering solutions in the field of cost-effective and environmentally safe exploitation of the reservoirs [3]. However, with the start of the 21st century, the proclamation of the concept of Industry 4.0 [4] as a rapid change in industrial technologies and social relations associated with the expansion of the Internet of Things, artificial intelligence, smart robots and machine learning, areas of knowledge such as geotechnology, energy, transport, etc., began to develop their own concepts of the Fourth Industrial Revolution (Mining 4.0, Energy 4.0, Transport 4.0) [5]; even the term "Science 4.0—E-Science" appeared [6].

In addition to this, with the advent of cryptocurrencies at the end of 2000s, the definition of mining as an activity creating new information structures in the computing blockchain became the most widespread [7]. Finally, by the mid-2010s, the term "Data Mining" came into use as a set of methods for detecting previously unknown, non-trivial, practically useful and accessible knowledge in data [8,9]. These new phenomena can also be associated with Mining 4.0, based on their genesis during the Industry 4.0 conversion.

In relation to the analysis of Mining 4.0 terminology, we will make a reservation regarding the assessment of the impact of digital information on the extraction of minerals. We will use the term "digitization" in relation to the conversion of analog information as such into digital, and the term "digitalization" for assessing the development of various processes under the influence of digital technologies.

As a result of such disordered sense making, modern geotechnology is in a difficult position due to the confusion of terms that wander from publication to publication, blurring the original understanding of the widespread digitalization of production and social processes embodied in Industry 4.0. Mining, energy and similar terms join new concepts, giving them a new semantic load and distorting the original meaning.

Mining 4.0 is a scientific discipline (today it is gradually becoming an educational one)—a body of knowledge with strictly defined concepts, terms and rules for their interpretation [10], which, nevertheless, should be explained. At the same time, the genesis of Mining 4.0 is certainly associated with Industry 4.0, which, in turn, is due to the breakthrough of digital technologies from the sphere of circulation of poorly structured heterogeneous information into industrial cyber-physical systems.

Therefore, Mining 4.0 can be considered as a product of Internet technologies and an improvement of physical means of data processing (i.e., the development of artificial intelligence, machine vision and learning, neural networks, the Industrial Internet of Things, smart sensors, etc.). Consequently, mining, i.e., the creation of new blocks in the blockchain, and Data Mining may well take place in its technological core [11,12].

Thus, an unacceptable layering of concepts arises, and we are already talking about the "mining of mining in mining", which undermines the theoretical foundations for the development of geotechnology in the 21st century and sets off interdisciplinary research in the field of synchronous development of mineral extraction and energy production (Mining 4.0 and Energy 4.0). As a result, we see a lot of "mining" in scientific and popular science circulation. If we take into account the opinion that digitization itself can solve a number of problems in obtaining mineral resources (for example, optimize the consumption of the rare metals, reduce environmental damage from burning oil and coal), then a certain paradox arises. The reality is that the global spread of Industry 4.0 technologies does not reduce, but rather increases energy consumption in technologically advanced countries and in the world as a whole [13]. In accordance with this, the specific capacity of underground mining and quarrying equipment is growing.

One absolutely new concept (self-reproduction of information) in IT has been replaced by another new concept (mining of information) from the mining of mineral resources. This "sleight of hand" creates, among other things, a negative reputation for the mining of minerals, replacing it with the mining of data in the minds of people, thereby diverting promising applicants and students from studying mining, endowing it with anachronistic features.

The exponential development of the digital world, the processes in which are perceived as mining, has its great merits, which are not questioned here. The fact is that the self-reproduction of information, decentralized blockchain networks, are the reason that today we have cheap and wide access to many assets "on demand", as well as the ability to regulate the very course of scientific and technological progress.

Scientific and technological progress is the progressive movement of science and technology based on the knowledge and development of the forces and wealth of nature. Therefore, a priori, it is impossible to talk about accelerating progress only in the light of the development of information technology and digital mining. In modern society, two contradictory trends are developing—an increase in the excess of information and the periodic occurrence of an excess of mineral resources on the market. In the absence of effective tools for optimizing information exchange and mining, a misleading picture of the prosperity of an information society rich in natural resources emerges. The result of such self-deception in the theory and practice of mining is the crises of commodity markets, which deprive developing countries with a commodity specialization of the economy of access to markets for products of deep processing of raw materials and advanced technologies for its extraction. As a result, the growth of their energy supply is slowing down, which makes Mining 4.0 inaccessible to them.

Therefore, the phenomenon of Mining 4.0 (a set of individual phenomena of the same type constantly repeating in a complex system) needs additional theoretical justification in order to maintain an interdisciplinary “bridge” to Energy 4.0 research related to finding a balance between the provision of modern society with fossils and alternative (renewable) energy carriers.

2. Digital Maturity of Mining 4.0

Digital maturity is an indicator of the involvement of a certain system (sector, industry, individual company) in the process of introducing advanced digital technologies. It is also appropriate to talk about digital maturity in the context of assessing saturation with end-to-end digital and unmanned technologies that “penetrate” a certain process along the entire length of its chain [14].

Some confusion can also be seen here, since Data Mining can be considered an end-to-end technology that transforms the use of computational optimization models in many industries [15]. However, at the level of methodology, Data Mining and Mining 4.0 fundamentally diverge. Thus, if for Data Mining the main research method is the analysis of the possibilities of optimizing the data flow, then for Mining 4.0 the most applicable method is the synthesis of the achievements of geotechnology and the family of digital technologies of Industry 4.0.

At the same time, Mining 4.0 incorporates several end-to-end technologies of Industry 4.0, such as artificial intelligence, the Internet of Things (IoT), machine vision, etc. Its genesis is shown in Table 1.

Table 1. Relationship between the stages of industrial development, geotechnology and the evolution of Mining 4.0.

Century	Stages of Industrial Development	Key Innovations	Stages of Development of Geotechnology	Mining Innovations
First half of the 19th century	Industry 1.0	Coal and coke, steam engines	Mining 1.0	Mechanization of auxiliary processes
Second half of the 19th–early 20th centuries	Industry 2.0	Electricity, in-line production, oil and gas production, internal combustion engines	Mining 2.0	Mechanization of the main processes
Second half of the 20th century	Industry 3.0	Automation, analog computing and control systems	Mining 3.0	High capacity equipment, analog telemetry
Beginning of the 21st century	Industry 4.0	Digitization, Internet of Things, artificial intelligence, machine vision, blockchain	Mining 4.0	Unmanned technologies, remote process control, smart robots

Despite almost two hundred years of geotechnology evolution from Mining 1.0 to 4.0, its digital core has not once been formed at the beginning of the 21st century; rather, it is the result of the evolution of human competencies in the use of hardware and software, as well as an increase in the digital maturity of mineral processing and power generation (at the moment, up to the level of Processing 4.0 [16] and Energy 4.0 [17]).

At the same time, the digital maturity of existing mining enterprises is significantly lower than that of energy, processing and even metallurgical enterprises, and today it corresponds to the Digital 2.0 level, compared to the target Digital 4.0 (characteristic of Mining 4.0) (see Figure 1) [18].

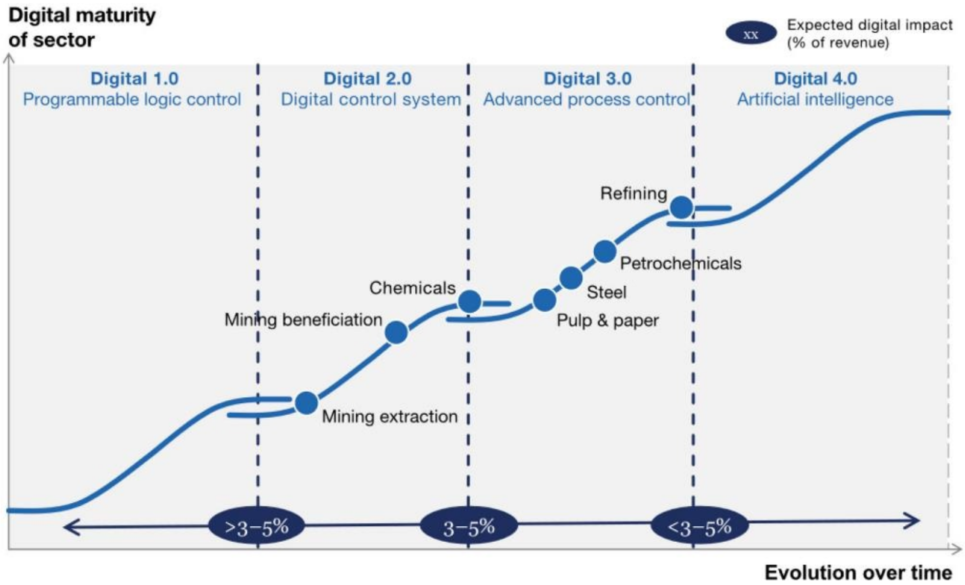

Figure 1. Digital maturity of a number of core industries.

Despite the catch-up nature of mining digitization, reflected in Figure 1, as we move from the use of programmable controllers in individual mechanisms to digital control systems, and further to artificial intelligence (AI), Mining 4.0 expands from the digitization of individual extraction of minerals to the full intellectualization of the technological chain up to its processing, taking into account market prices and demand specifics. As a result, there is a common process for the extraction and processing of minerals, as well as energy production—the exclusion of a person from production processes with an increasing complexity of the organization, which are managed at the "right time", i.e., in the required time and volume. Currently, this is gradually being determined by phenomena such as big data and Data Mining (Figure 2).

As follows from Figure 2, Data Mining is more common in Processing 4.0 and Energy 4.0, as it is more technologically mature and currently corresponds to the level of Digital 2.0 and 3.0. Accordingly, we can say with confidence that Data Mining, in relation to Mining 4.0, occupies the position of a subordinate process associated with the digitalization of geological surveys and accurate mine surveying. However, the observation of the acceleration of scientific and technological progress in the mineral resource sector suggests that, with the transition to Mining 5.0, based on the Industry 5.0 platform [19], expected in the second half of the 21st century, the terminological differentiation of minerals and Data Mining will not be so unambiguous.

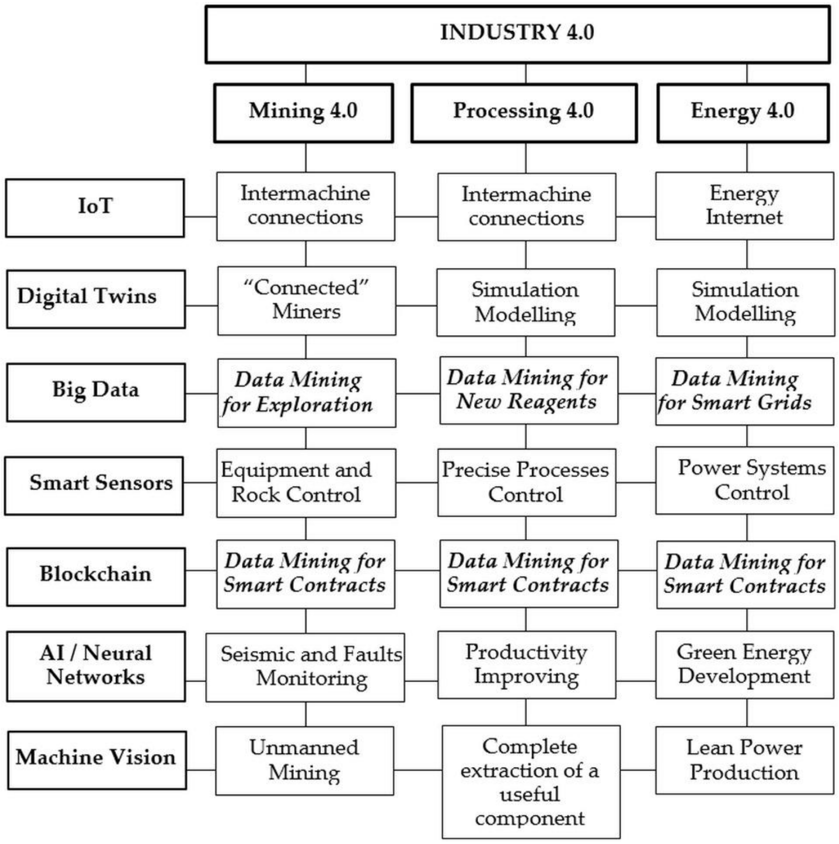

Figure 2. The place of Data Mining in the system of implementing Industry 4.0 technologies in Mining 4.0, Processing 4.0 and Energy 4.0.

3. Data Mining in Transition to Mining 5.0

The horizon of the transition to Industry 5.0 is associated both with technological convergence, which allows the radical increase of both the productivity of mining and the processing of minerals with less environmental impact (including subsoil deposits). Industry 5.0 is also associated with a human-centric economy, in which the priority of life and health of workers is ensured by the use of collaborative robots (co-bots) [20]. At the same time, the Mining 5.0 technological platform, as it is considered today, will also be a logical continuation of the development of the Internet of Things, which allows the collection and analysis of data on energy consumption in real time to increase the load on the mining sector [21]. The global nature of this data inevitably implies the use of artificial intelligence in their analysis, and Data Mining in decision making. Moreover, big data mining allows the implementation of a strategy for the transition to Green Mining by analyzing data on the intensity of consumption of raw materials and energy by other industries [22].

Machine vision and learning of collaborative robots is also expected to become a bridge to Mining 5.0, when more advanced systems with powerful artificial intelligence will completely displace humans from underground mining, dangerous and harmful areas of open pit mining and processing plants [23]. Data Mining will fill the intuition of a person in making engineering and organizational decisions in the unpredictable conditions of mining enterprises. In addition, fluctuations in commodity markets can be smoothed out using Smart Contracts in the blockchain, in which Data Mining is also a part of the core (Table 2).

Table 2. Data Mining in Mining 5.0 Innovations.

Stages of Industrial Development	Description	Key Innovations	Stages of Development of Geotechnology	Mining Innovations
Industry 5.0	Synergy of humans and autonomous machines	Ubiquitous machine learning, self-educating collaborative robots, integration of the physical and virtual world into big data, Data Mining by machines	Mining 5.0	Complete replacement of people by collaborative robots in mines, smart contracts in the raw materials market, machine vision, artificial intelligence, digital twins based on Data Mining

It follows from Table 2 that the role of Data Mining in the innovative development of the mineral resource sector will increase significantly with the transition to Mining 5.0. That is, in the second half of the 21st century, a close connection of these phenomena that can become inseparable is expected. This means that the extraction of mineral resources (mining) will gradually converge with digital tools for managing production and organizational systems.

Under such conditions, the phenomenon of Data Mining, as well as other technologies of Industry 4.0 and 5.0, in terms of importance in the development of mining science, can surpass innovations in geotechnology, despite the fact that a number of scientific papers state the opposite [24,25].

The value of the idea of the primacy of studies of the material aspects and physical processes of mining was proved by those authors [26–28], who showed that no matter what level the digitalization of the processes of extraction and primary processing of mineral resources had reached, understanding of mining should be associated with ensuring modern economy and society with metal ores, energy carriers and building materials. In our opinion, confusion arises due to the fact that when studying the formation of Mining 4.0, as well as the prospects for the transition to Mining 5.0, the achievements of Industry 4.0 and modern geotechnology are considered non-systemically, and a single consistent commonality of definitions has not yet been developed. Some recent works in the field of Mining 4.0 reproduce its digital core but say nothing about the future horizons for the development of geotechnology [29–31].

Thus, Data Mining and Mining 4.0 remain not completely distinguished at the level of phenomena.

Mining 4.0 teaches that digital technologies can significantly change and transform geotechnology, but cannot replace it. All real mining is “tied” to geotechnology, and this process is irreversible as scientific and technological progress accelerates. Mining that does not exist is a digital substitution of geotechnology, rather than its convergence.

4. Conclusions

The importance for science and education of the accuracy of definitions regarding mining—geotechnology and advanced information technology—is explained by the fact that the ordering of terms allows analysis of the development of these areas based on objective criteria. In the future, the advanced ideas and developments of Mining 4.0, which incorporate both mineral resource and digital innovations, are synthesized in fundamentally new ways and methods of processing minerals and generating energy. Terminological certainty here is the key to the objectivity of research, during which new substances should not unnecessarily multiply [32].

The fact that words matter makes it necessary to separate the meaning given to mining as the extraction of fossil resources and the creation of new information. This is required, first of all, to correctly explain to students the meaning of saving non-renewable resources, especially in the face of growing demand for electricity in the new "digitized" world. The distinctions in mining terminology and in scientific discussions regarding the prospects of Mining 4.0 must be clearly followed in order to eliminate the dangerous misconception about the ease and infinity of the disposal of wealth created by nature, which is often associated with the endless self-reproducing world of digital information.

At the same time, the combination of digital and mining technologies in Mining 4.0 is an objective reality, which, based on the achievements of the Fourth Industrial Revolution, brings to the world a sustainable supply of minerals with the minimization of environmental damage, and safe work for those employed in subsoil extraction. Therefore, today we foresee an increase in the number of attempts to connect at the level of the convergent terms of digital technologies and geotechnology, without which the movement towards Mining 5.0 would be difficult.

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