ОБЩИЕ ПРОБЛЕМЫ МЕХАНИКИ

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SMART MECHANICS — A NEW DIRECTION IN MODERN MECHANICS

The article considers a new direction in modern mechanics, which our collaborative research group is actively developing — it is "Smart Mechanics" or "Development of smart (intelligent in future) systems for modeling and engineering calculations in mechanics". The scope questions concerning development of modern highly effective "smart" systems and algorithms of mechanical-mathematical modeling and computer simulation of various physical processes and phenomena are discussed. Notions of "Smart mechanics" and "Smart (Intelligent in future) modeling systems in mechanics" are introduced. The main strategic directions for building new type of modeling systems (new class of systems of computer modeling and engineering calculations) are given. Difference between artificial intelligence technologies and traditional mathematical modeling in the current period of technology development is discussed. The characteristic of the specific application areas of smart systems for modeling and engineering calculations in mechanics is given.

Keywords: *fundamental and applied mechanics, artificial intelligence technologies, mathematical modeling, computer simulation, CAD and CAE technologies, digital twin, intelligent knowledge bases*

Introduction. There is currently an increased interest in artificial intelligence (AI) and even an unusual amount of hype around the subject. In fact, the situation with AI resembles what it was during the beginning of the mass penetration of personal computers into all spheres of human life.

The number of publications, special reports, interviews where various aspects of AI are touched upon is growing exponentially. It seems that everything that humans produce today, from technology to finished products, already has some degree of AI. Even expert professionals are often in doubt when it comes to issuing an opinion on whether an object has AI elements or not.

About the titles "Smart Mechanics" and "Smart (Intelligent in future) modeling systems". The essence of mathematical modeling, building mathematical models not only for problems of mechanics, but in general for various physical processes, from the point of view of a "common man", in my opinion, is well reflected by the picture presented on the Figure 1. On the other hand, this picture also essentially reflects the state of affairs of artificial intelligent technologies with respect to the consideration of various processes.

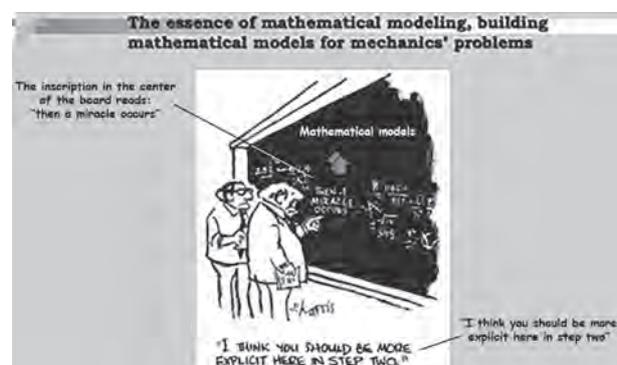The basis of modern mechanical research and calculations nowadays is mathematical modeling

Figure 1 — The essence of mathematical modeling

and computer modeling and simulation. At the same time, the question is: "Will AI technologies replace traditional methods of mathematical and numerical modeling in the near future?" At least, today there is a tendency of active introduction of AI elements into "standard" technologies of mathematical and especially numerical modeling.

In mathematical modeling, we strive to ensure that the mathematical models used are not only reasonable and correct, but also sufficiently understandable and "transparent (clear)" for the user and the customer and inspire their "full confidence". Basically, the same requirements are being placed on AI technologies.

If we talk about systems for modeling physical (mechanical) processes using AI technologies, then in this case the necessary requirement for such systems is that the AI elements should not "work" as "black boxes" that "just produce a solution". AI elements should not only present a credible toolkit for solving a problem, but also demonstrate a clear and efficient algorithm for obtaining a solution.

At first glance, since we are talking about mathematical modeling and AI, perhaps it would be more appropriate to use the name "mathematical and computer modeling systems with AI elements". However, I would like to emphasize that the use of the abbreviation "smart (intelligent) systems" is not accidental.

Under *"smart systems"* we understand systems of analysis and study of physical (mechanical) processes on the basis of coupled technologies including:
- mathematical, computer modeling;
- AI technologies;
- active participation (presence) of a human (operator).

At that, the role of each of the three factors is important.

What are intelligent and smart systems? An intelligent system is not the same thing as AI, although the terms are sometimes used interchangeably. With AI, computers and other machines attempt to simulate human intelligence, but its presence does not automatically imply an intelligent system.

While smart (intellect) and intelligence are related, they are not the same thing. A person can be highly intelligent but lack intellectual curiosity or the ability to think deeply about abstract ideas. Conversely, a person can have a high intellect but struggle with practical problem-solving or learning new skills.

It may be said that: "Intelligent" is a quick learner of any task and "Smart" ("Intellectual") is knowledgeable and would offer great solutions to an issue.

Therefore, let's assume that in decision-making technologies, an intelligent system is an information-computing system with intelligent support that solves problems mainly without human involvement, as opposed to a smart (intellectual) system in which an operator is present.

About AI technologies and Mathematical modeling. Why AI technologies are promising for the development of a new class (type) of computer modeling systems for various classes of mechanics' problems?

1. Progress in mechanics is mainly determined by the elaboration, development and improvement of methods and models of mathematical and computer modeling of mechanical and coupled physical processes.

Therefore, *today one of the important tasks is to elaborate, develop and adapt modern advanced approaches and methods of mathematical and computer modeling in combination with other technologies for different classes of problems in mechanics.*

2. Mathematical modeling is used to study processes, phenomena and objects when the researcher can "build" mathematical models, and in such a way that the constructed model mathematical problem is solvable.

But ... And what to do if it is not possible to build/select a mathematical model that satisfies qualitative and quantitative requirements for describing the object under study?

What is the situation if we consider the behavior of complex new objects? How can we assess that the chosen basic mathematical model is correct?

One of the promising approaches to "cope" with this situation is the development of technologies and methods for solving problems in mechanics in the direction of developing technologies for building coupled computational schemes and algorithms based on "classical methods" of mechanical-mathematical modeling, numerical modeling and artificial intelligence methods.

It should be noted that this statement is fully consistent not only with the actual tasks of modern mathematical modeling in mechanics, but also with the important tasks of the development of AI technologies. Thus, among the actual directions of AI methods development is indicated "development of modeling, analysis and decision support systems". AI methods play an increasing role in the development of computer technologies for mathematical modeling of the state and behavior of physical and engineering objects of different nature and purpose.

The use of tools based on AI methods in solving problems of mechanics opens wide opportunities for the development of new approaches in theoretical studies, methods of mathematical and numerical modeling of complex real mechanical and related processes.

In turn, the application of AI methods in mechanics, physics and other natural science disciplines, engineering, is a source for further development of AI methods and technologies proper.

It can be stated that a new direction in mechanics — *"Smart Mechanics"* — is being formed, which is a symbiosis of classical and modern mechanics, applied mathematics and computer science and, of course, AI as a fundamental and applied science.

Note that when developing smart (intelligent) modeling systems, it is necessary to proceed from

the "classical definition" of notion of "Intelligence", namely: "understanding", "insight", "discernment", "recognition", "information gathering and processing".

Therefore, *modern systems of smart (intelligent) modeling in mechanics are systems whose algorithms implement such qualities as "processing, recognition and interpretation", "analysis and prediction", "understanding and insight". At the same time, such systems are based on laws, methods and approaches primarily of mathematics, mechanics and computer science.*

Systems of smart computer modeling on the basis of processing of the whole set of primary information and data should "be able" to give recommendations for setting model mathematical problems, be able to build and correct computational algorithms, analyses and interpret the results of calculations.

So, modern modeling technologies in mechanics (it can be said essentially about all physical and industrial processes) are: *"high-performance computing + knowledge and 'Big data' + mathematical and computer (numerical) models + artificial intelligence technologies".*

What is the difference between artificial intelligence technologies and traditional mathematical modeling in the current period of technology development?

Let us summarize the responses of chat-bots (in particular ChatGPT). The main points are as follows:

1. Mathematical modeling is an important aspect of many fields, including AI. But it is not generally considered part of the Artificial Intelligence area by itself.

2. AI is the development of algorithms and models that allow machines to perform tasks that normally require human expertise and intuition, inference logic, generalizations and conclusions. It does this by using techniques that allow machines to perceive, reason, and learn. *These methods are generally not used in mathematical modeling based on physical principles and laws.* Mathematical modeling relies on mathematical equations and physical laws to describe and predict the behavior of physical objects.

3. Naturally, there are areas where AI and mathematical modeling overlap and complement each other effectively. For example, AI techniques can be used to optimize and improve the accuracy of mathematical models or to extract information from large data sets generated by physical systems.

4. It should be noted that chat-bots provide information based on the processing of a large data set. And there is no "hint" of any connection with "classical approaches" of mathematical modeling in their answers.

Mathematical modeling is not primarily based on "human capabilities, intuition and experience" but on physical principles and laws. It allows us to learn objectively about the mechanical state and behavior of the object being examined, something that humans, relying on intuition alone, are often unable to do.

This is particularly evident when examining the behavior of new complex objects. How to evaluate that the chosen basic mathematical model is correct in such a situation? Our knowledge in any field of knowledge is always relative. At the same time, "learning", the acquisition of new knowledge usually takes place within certain boundaries of observation, experiment and experience. Importantly, a single observation can overturn an axiom derived over several millennia.

Let's emphasize it again. One of the essential requirements for smart (intelligent) computer modeling technologies is that they should not "work" as "black boxes" issuing a solution. Such systems should present not only a credible toolkit for solving a problem, but also demonstrate a clear and efficient way to obtain a solution. It should be noted that at the current stage of AI technology development we are talking about automated systems, i.e. systems with human participation in the control of the modeling process supported by AI.

At the present stage in the general problem of developing coupled methods and technologies for the study of physical (mechanical) processes and solving complex applied problems based on approaches and methods of mathematical and computer modeling and AI technologies, the following directions are important strategic directions:
- development of mathematical foundations for methods of processing and intelligent analysis of large volumes of data for various applied areas and directions;
- development of mathematical foundations for smart systems of computer modelling, calculations and analysis of physical processes;
- transition to new intelligent CAD, CAE and CAM technologies.

But, in my opinion, the most difficult, but, at the same time, the most promising, in the direction of building a new class of systems of computer modelling and engineering calculations (intelligent CAE systems), are the following tasks:
- elaboration of recommendations for setting model mathematical and computer tasks for the processes and phenomena under study;
- smart (intelligent) interpretation and analysis of modelling and simulation results.

In order to develop highly efficient systems for smart modeling and engineering calculations in mechanics, it is necessary to first focus on solving the following groups of strategic problems:
- methods of intelligent processing and analysis of primary information and data;
- technologies for choice and construction of mechanical-mathematical models of the processes under study, solution of applied problems;
- technologies for building numerical models and calculation schemes;
- technologies for building coupled calculation schemes and algorithms based on AI methods and

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"classical" methods of mechanical and mathematical modelling;

- smart interpretation and analysis of modelling results;
- methods and technologies of new intelligent CAD, CAE and CAM systems.

Thus, smart (intelligent) computer modeling systems based on the processing of the primary information and data sets should "be able" to give recommendations for the formulation of model mathematical problems, be able to build and adjust computational algorithms, analyze and interpret the results of calculations, etc.

The general scheme of the technology for solving problems in mechanics using AI methods, can be presented in the form of the following block-diagram (Figure 2).

It is interesting that "according to chatbots" the most promising directions of combining artificial intelligence and mathematical modeling are:
- optimization;
- simulation;
- data analysis;
- algorithms for controlling mechatronic systems.

Let us give our interpretation of this answer.

Optimization. Different kinds (types) of Machine Learning (ML) methods, such as reinforcement learning, ensemble methods, neural networks and others, can be used to optimize mathematical models or to select one of several. This involves finding the best set of model parameters that fit a given data set or minimize some objective function.

Simulation. Mathematical models are used as a baseline for numerical simulation of the behavior/ state of complex objects. Artificial intelligence techniques, in turn, are applied to improve the accuracy and efficiency of numerical simulations by optimizing computational models, reducing computational complexity or managing uncertainty in the input data.

Data Analysis. Mathematical modeling is a basis for analysis and interpretation of data describing the state/behavior of physical objects of systems, obtained as a result of in-situ and/or experimental studies, measurements, gauges for selection of a mathematical model. ML algorithms are used to "extract" patterns from large datasets.
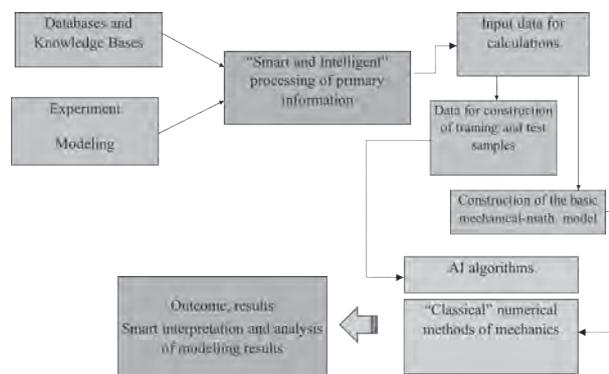

Figure 2 — Block diagram of the technology for solving mechanics problems using AI methods

Algorithms for controlling mechatronic systems. Mathematical modeling is used, for example, for the design, construction and optimization of various mechanical/mechatronic systems (robots, manipulators, autonomous vehicles, etc.). Machine learning is applied to improve the resilience and adaptability of these systems.

The principle of AI algorithms is the intelligent processing of huge amounts of data with automatic identification of patterns and features contained in the data, which allows programs to automatically learn and, most importantly, to model and predict "new events" and generate new data.

When realizing attempts to implement ML methods and, in particular, artificial neural networks (ANNs) in such fields as mechanics, physics, researchers are faced with significant problems. An important point in this case is that developers have not only knowledge and skills in the field of AI, but also deep specialized knowledge in the relevant subject area.

For example, when applying AI methods in the problems of deformable solid mechanics (SM), first of all, fundamental knowledge in the field of continuum and discrete media mechanics, mechanics of materials, mathematical models of SM, strength and fracture mechanics and a large number of other special disciplines is required. In addition, of course, knowledge of applied mathematics, computer science is required.

But still, since approximate 2017–2018 there has been a sharp jump in the number of scientific publications related to the applications of machine learning methods, in particular, artificial neural networks for solving applied problems of various sections of mechanics.

Analysis of works devoted to the use of ANN methods in mechanics shows that ANNs have good prospects for solving the following types of problems in mechanics:

1) the modeling of the response of a mechanical system to an external influence by input physical and mechanical parameters;

2) identification of a mechanical system parameters by the response of the system to an external influence;

3) identification of external system exciters by target parameters and system response;

4) integrated evaluation of external excitations and system response for all relevant physical and mechanical parameters and system operating conditions.

Interestingly, the highlighted directions correlate with the suggestions that were formulated based on the chatbots' responses.

To date, there are already a sufficient number of publications that consider examples of using different implementations of neural network algorithms to solve a wide range of applied problems in geotechnics, the study of plastic behavior and fracture of materials, the study of strength properties of building materials and structures, computational aspects of the interac-

tion of neural network algorithms and the finite element method in the analysis of the stress-strain state of deformable solid bodies.

Some remarks on specific application areas of smart systems for modeling and engineering calculations in mechanics.

Area of development: elaboration of applied computer systems for design and engineering computations (calculations) with elements of intelligent analysis on the basis of CAD & CAE technologies.

As it was indicated earlier, among the actual directions of development of applied systems with elements of smart analysis, a special role is played by the development of modern CAD/CAE systems in the direction of introduction of AI elements into such systems to build real smart systems.

This direction can be interpreted as the development of modern engineering solutions, development of specialized software based on the knowledge of mechanics, mathematical modeling, informatics and AI.

A few comments concerning this direction.

Currently, Continuous Acquisition and Life Cycle Support (CALS) technologies are being actively introduced into the technological processes of development and production of industrial products for various purposes.

Remark. CALS technologies — information technologies used in the management of product or system life cycle processes, mainly for complex (high-tech and knowledge-intensive) engineering products and other engineering objects.

In CALS systems there are subsystems supporting storage, processing and transfer of information, operational access to data. The efficiency of CALS technologies is essentially based on the use of various CAD/CAE/CAM/PDM systems.

The modules included in CALS systems allow project management (PDM system), two- and three-dimensional design of engineering products (parts, assemblies) (CAD systems), engineering calculations, analysis, modelling and optimization of design solutions (CAE systems), development of technological processes, synthesis of control programs for robotic complexes and technological equipment with numerical control, modeling of machining processes, including construction of trajectories of relative motion of tool and workpiece during machining, calculation of machining time standards (CAM systems).

CAD/CAE systems represent one of the basic elements of modern CALS technologies and in general systems of automated smart support of production and technological processes.

Area of development: construction of digital twins.

The introduction of artificial intelligence technologies nowadays seems to be very promising and relevant in computer modelling and simulation of life activity of technical objects in order to create their digital twins and in controlling such objects in the process of their operation.

A *digital twin* (DT) of some object can be defined as a digital (virtual, computer) dynamic smart model of this object with a large set of information and data from various sensors, devices and experts. In this case, the term object means any process, phenomenon, system, physical, technological or production object.

The structure, features and specificity of prototypes are taken into account by building digital base models based on CAD and CAE technologies. CAD systems allow obtaining an exact copy of the object topology, and the use of CAE technologies makes it possible to carry out computer simulations and calculations of physical and technological processes that constitute the essence of the object.

It is assumed, that DT reproduces the form, characteristic features and properties, behavior and state of "its" physical prototype (object) according to a set of specified parameters, properties and criteria. It is obvious that the greater the number of determining parameters and properties of the object that its DT takes into account, the more adequate the latter is and closer to the original.

The ideology of DT creation requires inclusion of a large set of information and data from various sensors, devices and experts into the virtual model in addition to the original information.

According to the main goals and objectives, the DT is required for imitation modeling and computer simulation of the state and behavior of the physical original under various conditions of acting on it.

The increased interest in digital twin technologies and the strong push to perform research in this direction is currently driven by the development of artificial intelligence (AI). Digital twin technologies are becoming increasingly advanced through integration with AI technologies, developments in virtual and augmented reality, the development of 3D and 4D printing, and computer vision technologies.

So, today digital twins are paired with AI technologies. This combination of technologies allows to capture an unprecedented amount of data about their systems and processes, and evaluate the information collected without investing in additional human resources. What's more, utilizing AI to evaluate the data collected can eliminate human error and ensure that managers can make better operational decisions based on accurate, real-time insights.

It should be emphasized that digital twins are not static, conservative, but represent a whole system of conjugate (interconnected) dynamic digital twins that model an object at different stages of its life (birth (design), growth (manufacturing, construction), active life cycle (operation).

There are three important components to creating a DT:
- complex modeling and computer simulation tools (mathematical and computer imitation models);
- means and tools of collecting data, combining them, processing them, converting them into the necessary

information to transmit a digital model; means of communication between different parts of the DT;
- ML tools.

To create a DT of a complex real object it is necessary to build a DT of separate structural elements of the object, which can be not only hundreds, but also thousands of them. Therefore, it is possible to distinguish different levels of functioning of digital twins.

The following *types of DTs* can be distinguished according to their intended purpose in relation to such an object as a modern production enterprise:
- CAD–DT is a conjugated general CAD project of a real object, which contains all components and systems of its life support;
- CAE & Simulation–DT is virtual coupled model of the object, allowing to perform mathematical modeling and computer simulation of physical and technological processes accompanying the whole complex of production and technological processes;
- CAM–DT is intelligent computer-aided system of the whole set of DT of separate structural elements of the object, monitoring system for the state of the structural elements of the object (sensors, observations), computer-based workplaces (CBWP) of specialists and services to manage the life of the object as a whole.

As can be seen from the introduced typification of digital twins, the name of types is "consonant" with the widely used abbreviations CAD, CAE, CAM. But DT has significant differences from traditional CAD models or computational CAE models.

When constructing a DT, it is effective to develop *DTs of different levels*:
- pre-digital twin (level 1) — traditional (classic) virtual prototype;
- digital twin (level 2) — a DT in which a virtual model of a physical object is able to combine a lot of data of different nature about the "physical twin". In this case, it is possible to collect data from physical sensors and specialized equipment;
- adaptive digital twin (level 3) — a DT with the presence of an adaptive user interface (AI elements) for both physical and virtual twins. DTs include ML algorithms. The models used in such a digital twin are constantly updated based on real-time data from the physical twin (prototype);
- smart digital twin (level 4) — a DT that has all the capabilities of the third-level DT, but in addition has "machine unsupervised learning" features. At this level, the DT has a high degree of independence.

Obviously, the costs of creating a DT are quite significant, but the prospects of their use at a modern enterprise recoup all the invested funds.

An important component of the enterprise DT is the *"Imitation and simulation computer modeling"* module.

Remark. Imitation is the act of imitating; that which is made or produced as a copy; that which is made to resemble something else; likeness; resemblance. Simulation is the act of simulating, or assuming an appearance which is feigned.

In order to predict how the physical prototype will work in real conditions when implementing the proposed technical solutions, it is very effective to use the technologies of imitation and simulation modeling based on DT and special mathematical models of imitation and simulation modeling. At the same time, several models can be built for the same component of a physical object, depending on the purpose for which it is used.

The DT is augmented by data from the "physical twin" input to the databases, which in turn is used in performing simulations. Data obtained under operational conditions are used to modify the parameters of mathematical and computer models (for verification, "calibration", refinement of parameters and characteristics). DT monitors critical situations and failures of various physical prototype systems and, based on modeling, proposes criteria for limit states, strength and durability, life and operation (in the broad sense of the term) assessment of various systems.

Computer vision is an important and very large section of AI that includes pattern recognition and image processing. Computer vision is a section of computer science and artificial intelligence that develops principles, methods, technologies of identification and classification of objects, phenomena, processes, signals, images and situations. It involves a set of techniques that give a computer the ability to "see" and extract information from what it sees.

The range of practical applications of computer vision technology means that it has become a central component of many modern innovations and solutions. There are great prospects for the application of computer vision technologies in the development of digital twins of various production processes and objects.

Area of development: expert systems, Knowledge Engineering.

An important element of smart modeling systems are Knowledge and Data Bases in conjunction with Knowledge Acquisition and Solution Acquisition systems.

The creation of smart modeling systems requires first of all the development of intelligent knowledge bases.

The main tasks in the construction of the "Knowledge and Data Base" system are to identify and clearly formulate not only general, but also special knowledge, as well as the rules of entering and actually entering this knowledge into the computer.

The knowledge acquisition system is built on the basis of processing data obtained:
- in the course of dialog with an expert (in the general sense of the word);
- in the process of accumulating practical experience of system operation;
- as a result of analyzing new achievements in the fundamental and applied spheres of the problem area under consideration and related areas.

Knowledge is a key factor in solving complex problems. Therefore, it justifies the high costs associated with its extraction and require a well-established and efficient technology to make it "marketable".

Knowledge Bases are the main part of expert systems. When applied to an expert system in a certain subject area, Knowledge Bases represent a set of data, facts and rules of logical inference that allow formulating correct conclusions, findings, suggestions and recommendations.

The main tasks in the construction of the "Knowledge and Data Bases" system consist in the identification and clear formulation not only a "general" knowledge, but also the special knowledge, as well as the rules of entering and actually entering this knowledge into the computer.

One of the reasons for failures in building intelligent modeling systems in application domains is the underestimation of the role of tacit knowledge.

Area of development: artificial neural networks in computer modeling and simulation systems.

When implementing ML methods and, in particular, artificial neural networks in such fields as mechanics, physics, it is important for developers to have not only knowledge and skills in the AI but also deep specialised knowledge in the relevant subject area. For example, when applying AI methods in the problems of deformable SM, first of all, fundamental knowledge in the field of continuum and discrete media mechanics, mechanics of materials, mathematical models of SM and coupled problems, strength and fracture mechanics and a large number of other special disciplines is required.

Neural network models allow for much better extrapolation of experimental data than traditional approaches (e.g. polynomial approximation).

However, based only on numerical data, training a neural network may lead to incorrect results, which will contradict the physical laws of behavior of a real medium (e.g. a deformable solid body).

An example is the development of a specialized software module for solving the problem "Calculation of Earth Surface Displacements and Deformations".

In the case of developing an algorithm based on the use of only ANN models, the constructed dependencies for displacements, deformations and inclinations are independent of each other. At the same time, these quantities are known to be related to each other. If as a base model to use mechanical-mathematical model of rock massif behavior with underground geotechnical structures, and ANN to use for "selection" of determining coefficients, then in this case the constructed dependencies are correct from the physical point of view. That is, this case is about model verification, but not model validation.

Today our collaborative research group (representatives from Department of Theoretical and Applied Mechanics & Applied Mechanics Laboratory, BSU; "ProTechLab" (Belarus, Minsk – Russia,
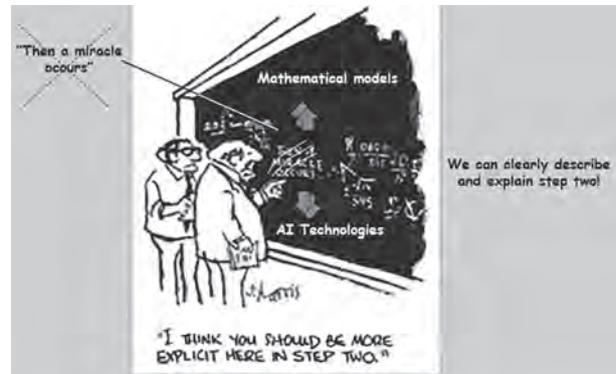

Figure 3 — The main essence of "smart mechanics"

Skolkovo); School of Mechanics and Mechatronics, Harbin University of Technology (HIT); Chongqing Research Institute of HIT; Department of Engineering Mechanics & State Key Laboratory of Structural Analysis for Industrial Equipment, Dalian University of Technology) actively works in the direction of creating smart computer systems for modeling, simulation and engineering computations in geomechanics, biomechanics and technics (see, for example, [1–30]).

Conclusion. Let us return again to the picture that was presented at the beginning. Taking into account what was discussed in the article, in the picture we need to add Artificial Intelligence technologies to mathematical modelling, but we already have a clear idea of how the "miracle occurs" (Figure 3).

Taking into account all potential possibilities, today it seems realistic to develop "smart" and "intelligent" systems of numerical modeling and computer simulation, which implies the "ability" of such systems to give recommendations to the formulation of model problems, to adjust computational algorithms, to perform intelligent processing and interpretation of computational results.

AI technologies are increasingly becoming full-fledged "co-authors" of algorithms of mechanical-mathematical modeling and computer simulation of various physical processes and phenomena.

Therefore, the formulated new definition of computer modeling on the basis of mathematical modeling: computer technologies of mechanical-mathematical modeling are: high-performance computing + knowledge and "Big Data" + mathematical and computer (numerical) models + artificial intelligence technologies, is correct and can be accepted as a basic one.

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ИНТЕЛЛЕКТУАЛЬНАЯ МЕХАНИКА — НОВОЕ НАПРАВЛЕНИЕ В СОВРЕМЕННОЙ МЕХАНИКЕ

В работе рассматривается новое направление в современной механике, которое активно развивает наш объединенный исследовательский коллектив — «Интеллектуальная механика» или «Разработка интеллектуальных систем моделирования и инженерных расчетов в механике». Рассматриваются вопросы, касающиеся разработки современных высокоэффективных «умных» систем и алгоритмов механико-математического и компьютерного моделирования различных физических процессов и явлений. Вводятся понятия «интеллектуальная механика» и «интеллектуальные системы моделирования в механике». Приводятся основные стратегические направления для построения систем моделирования нового типа (нового класса систем компьютерного моделирования инженерных расчетов). Обсуждается разница между технологиями искусственного интеллекта и технологиями традиционного математического моделирования на текущий период развития технологий. Дана характеристика определенных областей приложения интеллектуальных систем моделирования и инженерных расчетов в механике.

Ключевые слова: *фундаментальная и прикладная механика, технологии искусственного интеллекта, математическое моделирование, компьютерное моделирование, CAD- и CAE-технологии, цифровой двойник, интеллектуальные базы знаний*

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