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On the Growing Impact of Artificial Intelligence

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ABSTRACT

We discuss the two-layer structure of scientific research. The NATURE-LAYER defines the particular field (of Nature) which is analyzed by conducting experiments. The MODEL-LAYER hosts all our understanding of a particular research-field through qualitative and, subsequently, quantitative models. The evolving field of artificial intelligence allows us to interrelate the different models of this layer, potentially leading to new fundamental insights. Physics is used to make these ideas transparent.

Physics is concerned with the understanding of experimental results, which are described by a few basic notions such as charge, mass, momentum, and time. The interrelations among these entities are given by mathematical equations thus specifying a (theoretical) "model" of the behaviour of nature. This model leads to predictions which subsequently are checked with other results in order to verify its correctness. Three important aspects can be identified: First, our system must be specified using the basic notions and the system rules. The system is not nature itself, but a simple picture of what we "understand" about the sometimes quite complex behaviour of nature. Second, the system's behaviour is described with mathematical functions and statistical quantities. We automatically assume that the set, algebra, and group-theory axioms plus their derived theorems are valid. Third, a complex physical system is in most cases built-up from (our understanding of) simple physical systems. Scientific research thus proceeds on the NATURE-LAYER where the experiments are carried out, and on the MODEL-LAYER which hosts our understanding in the form of models (Fig.1). This same pattern applies to the other research-fields such as biology, medicine, and geology, as well as economics, law, sociology, psychology, etc. [1].

Let us now focus on the MODEL-LAYER. Obviously, the behaviour of nature in its full complexity cannot be described and analyzed by our limited abilities for comprehension. We have, for instance, no "feeling" for the behaviour of a system depending on many variables - our intuition and memory capabilities are too limited. In order to overcome these limitations, clear and simple situations ("models") are analyzed. The actual behaviour of Nature is then described by modifying and/or combining these models. The model-layer thus involves three basic activities: MODEL-SPECIFICATION (Qualitative), MODEL-BEHAVIOUR (Quantitative), COMPLEX MODELLING. The first one gives a qualitative description of simple model-systems (e.g. massive particle in a gravitation field) which tell us, for instance, that no multiply-charged elementary particles have sofar been found. Using the basic notions of physics the second basic activity focuses on the quantitative description of the models. The third activity is concerned with the combination of several simple model-systems in order to arrive at the description of a more complex physical situation such as for instance a charged massive particle in an electromagnetic and gravitation field.

The specification of the model-systems involves KNOWLEDGE and DEDUCTION because they are built up by notions of the particular field, by facts, and by their (logical) interrelations. Computer-systems with such capabilities do exist, allowing us to analyze the combined action of several model-systems with the hope to gain new insights into the behaviour of nature. Since computers do not (yet) have invention capabilities, one however should limit ones expectations; at best, one may expect to see discrepancies. We add here the remark that mathematics offers in the model-layer the most clear situation because it is predominantly concerned with thinking-constructs and does not have to accommodate the complexity of nature.

In the majority of our model-layer activities we use LOGIC [2] as the basic reasoning tool to arrive at new insights. This means that the model-layer knowledge can be encoded as a succession of many elementary logic steps; the more involved reasoning processes are carried out by powerful logical inference mechanisms. Artificial intelligence is to a considerable degree concerned with these two aspects.

The encoding, analysis and processing of knowledge by so called KNOWLEDGE-BASED SYSTEMS has in the recent past received a lot of attention since these techniques allow for the storage of complex (logical) interrelations between different pieces of information. There exists a large number of such systems for diagnosis, interpretation, monitoring, prediction, planning, design, etc., in a wide variety of fields. We mention as examples the diagnosis of a patient's illness, the elucidation of a chemical compound from given laboratory information, or the determination of a financial investment-plan according to customer specifications [4]. In physics, these techniques have timidly been used to model the behaviour of highly complex instruments [5], to assemble all experimental information on the known semi-conductor materials in order to arrive at significant new insights [6], and for the modelling of complex fluid dynamics problems using "Qualitative Physics" techniques [7]. Generally speaking, expert-systems are most useful for the analysis of problems which escape a systematic analysis and treatment or where highly complex interrelations govern the behaviour of a system composed of many sub- and sub-sub-systems.

One of the most popular methods for complex LOGICAL DEDUCTIONS [8] is a proof technique called RESOLUTION [2]. To apply resolution, one must first convert a statement to be proved into the logical formalism of the predicate calculus. The statement is then negated, and the negation is "resolved" with a series of axioms: statements known to be true for the particular problem area. If the inferences drawn by combining the negation with the axioms yield a contradiction, the negation must be false and the original statement therefore must be true. In 1964 J.A.Robinson showed that the resolution method is "complete": in every case it will eventually generate a contradiction if the original theorem is true. If the theorem is false, the series of inferences produced by resolution is not guaranteed to end. Robinson's work touched off a decade-long surge of activity in applying resolution and other closely-related formal methods to automatic theorem proving. It turns out that computer programs are capable of proving statements of a considerable degree of difficulty and that the resolution method also can be applied to a whole variety of problems such as, for instance, the analysis of communication protocols, the design and verification of logical circuits, the analysis of an assembly-language problem [9].

The use of AI-techniques in physics opens the possibility to analyze problems which indicate some systematic features; they however might be difficult to recognize due to a seemingly non-systematic component such as in stochastic-type problems. These new AI-techniques allow for a step forward into the unknowns of nature and have sofar barely been recognized.

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Fig. 1 : Layered structure of scientific research.

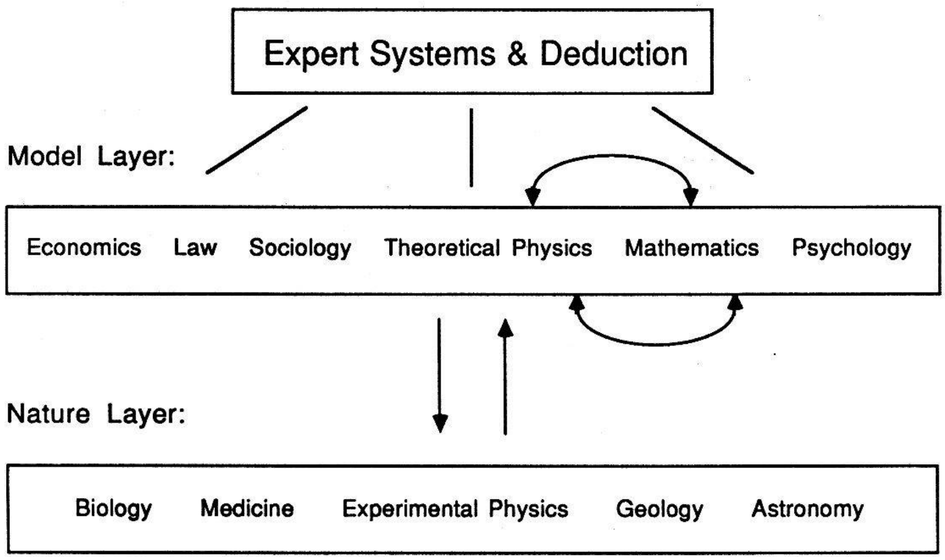

Fig. 1