Applications of Knowledge Engineering to Fluids Engineering

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In this paper, first of all, we present philosophical issues around artificial intelligence related to an AI system which is designed to solve problems of fluids engineering. Although these issues are rather philosophical and not restricted to only fluids engineering application, but we consider some discussions must be given on these topics in order to clarify our research objects. Brief comment will be given on an automatic FORTRAN code generator devised by us for most general parabolic partial differential equations. Any student of fluids engineering must learn dimensional analysis. We developed a program written in a symbolic manipulation language to help human who is not an expert of fluids engineering to solve dimensional problems. A system that can solve various problems about fluids properties that students of fluids engineering have to learn at the first step will be discussed. In the course of this research we found the importance of common sense even in this "elementary problem". Equations are most valuable tool in order to solve quantitative problems in any field of mechanics, a system was devised to make equations of fluids engineering which use concepts of information flow. Difficulty of fluids engineering problems unveiled in this research. Finally, from ontological point of view, we will give some discussions on the qualitative description of flow field using the concept of vortex.

***Key Words*:** Fluids Engineering, Artificial Intelligence, Dimensional Analysis, Automatic Problem Solver.

1. Introduction

Since the question "what is knowledge?" has very long history, any book treating the history of philosophy contains many names of philosophers who considered the essential nature of our knowledge. One of the most important philosophers concerned this question is ,without no doubt, Plato. Also he deeply considered the nature of "technee" which is a Greece word and is the origin of the technology, Technologie, and so on.

Then it is natural so many philosopher have interest on the technology of artificial intelligence, AI, which has two connections with issues of philosophy that are knowledge and technology. They gives very sharp critique on recent, so called strong AI technology(1). In the course of research AI-technologists themselves realize the fantasy of the AI's ability which at first had a exaggerated Commercial Message that AI can do every human intelligent act even as love! Now AI has humility and is trying to solve clear problems in a restricted world and obtained concrete results.

In this paper, mainly we present our researches done during last years, and also discuss some problems about qualitative reasoning in fluids engineering, which are investigated by us.

First of all, we present issues philosophical aspects of AI system. Although these issues are rather philosophical and not restricted to only fluids engineering application, but we consider some discussions must be given on these topics in order to clarify our research objects. Through this consideration, we find how deep and plenty of knowledge is required to construct an AI system which can solve elementary fluids engineering problems. Brief comment will be given on an automatic FORTRAN code generator devised by us for most general parabolic partial differential equation. Any student of fluids engineering must learn dimensional analysis which has an extraordinary power as proved by Kolmogorov to obtain the first exact prediction on the nature of turbulence, whose celebrated paper is cited as K41 since it appeared in 1941. Already in 1985, we developed a program written in a symbolic manipulation language to help human who is not an expert of

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fluids engineering to solve dimensional problems. Then we proceeded to construct a system that can solve various problems about fluids properties that students of fluids engineering have to learn at the first step. In the course of this research we found the importance of common sense even in this "elementary problem". Equations are most valuable tool in order to solve quantitative problems in any field of mechanics, a system was devised to make equations of fluids engineering which use concepts of information flow. Difficulty of fluids engineering problems unveiled in this research. Finally, from ontological point of view, we will give some discussions on the qualitative description of flow field using the concept of vortex.

2. Cognitive or Philosophical Discussions

Our final goal is to construct a program which command a computer to solve real problem of fluids engineering, so we must understand the process of cognition of fluid flow. The problem of cognition, the relationship among the objects, the subject and the recognized idea is important for AI in terms of the question about the correspondence between the seen object and visualizing machine and judgment and thought obtained from the output of the machine. For example, this situation appears symbolically using a microscope by increasing the magnification of the instrument, the thinking about the micro-universe changes, and such an idea forms a strong motivation to improve the instrument. Also, in case of a computerized visualization, we should ask the meaning of a color produced by computer. In spite of many critique on the dualism, we stand the position of dualism, since we use a computer and it is not a flow. As a tool, computer exhibited many aspects as numerical method need not to mention CFD, visualizing software as a tool, and as symbol manipulator. Milton van Dyke, an excellent theoretician of fluid mechanics pursued a computer extended series solution of various fluid mechanical equations[2]. Perry et al. uses computer to generate automatically Taylor series solutions of Navier-Stokes equations in order to study a singular point of separated flow[3]. With this respect, we must cite a comment of logician Takeuchi (Univ. Illinois)that is, present logic is very suitable to the problems which have small number of cases amenable to check each variation or have an infinite or a very large number of cases amenable to be taken a limit, he suggested, when we can treat the medium cases by computer, which have too many cases intractable to the human being directly, and there is a possibility to our thinking method will change[4].

We consider that symbolic computation of fluids engineering is the one of the examples in the line of Takeuchi's suggestion. Schlechtendahl's work using REDUCE is interesting research[5]. He asserts that the theory of turbulence and multiphase fluid should be able to treat the concept which allows a difference between the local physical value at a point and the average value over the region including that point, and then derives new momentum equations. Recent Oberlack's work used a special symbol manipulating software package for MACSYMA for Lie analysis for partial differential equations and obtained new exact scaling-laws for inhomogeneous turbulent shear flows[6],[7]. In these cases, computer is not only a "tool" but also an essential act for "technee". In this direction we constructed an automatic numerical cord of FORTRAN for human friendly input style, that is almost common mathematical symbols (see chp.3).

As a conventional machine, an AI computer's ability is twofold. First,

(a): simulation of the intelligent act of a human being.

Second,

(b): expansion of the intelligent act of human being as an airplane can give us flying ability.

In both cases, the judgment of the achievement of their goal is a problem. A proposed standard for such a judgment for the first case is Turing test. However, it neglects completely the ability of vision, the ability of the sense of touch etc. Disregard for the ability of vision on the part of intelligence is a common imperfection of the present discussions on AI. Many medieval and Renaissance pictures were painted in order to express a world view, and an AI computer, which can realize such pictures, should have a vision ability. If we can construct such a machine system, the following questions still remain. What kind of output should be given by an AI computer which can process the picture as does the brain-vision system of a human being?

Assume that such a machine processes a picture. If the output of the machine is the same one as the picture, machine does not perform any process in the meaning of human intelligence. Of course if the picture is random in the sense of Kolmogorov Complexity[8], the computer's response is to make a completely the same picture as it saw. But the impression produced by a picture in the human brain is not a simple conditioned reflex, but a synthesized thing forming one's own life experience and the stimulus from the picture and the atmosphere at that time. For example, consider to see Da Vinci in Louvre or in some kitchen wall.

We consider more simple case of flow visualization as shown in Fig.1, of course this is a most famous vortex in fluid mechanics, Karman vortex street.

By seeing this picture, the impression of it obtained by a man is individual and he or she makes an individual mental act and sometimes expresses some particular output corresponding to each person. If he or she has knowledge of Karman vortex,

Fig.1 Karman vortex (Prof. Miyata, Yamanashi Uni.)

the person says that I see a Karman vortex street. This is evidently the expression of compressing and symbolizing the world. In contrast, a person having no knowledge of a Karman vortex can not compress his or her impression and only can indicate the figure and says: " I see this ". This communication method is the one to transfer the information of a random phenomena totally (Kolmogorov[9]).

Conversely, a person having knowledge of Karman vortex can construct an image like Fig.1 even by hearing the words, while a person having no knowledge of it can get no idea from the words. Thus the former can restore the world from the symbol, whereas the latter can not.

L. Prandtl who was one of the greatest fluid dynamicist in the last century, began to use these visualization technique as an effective method to study various flows. But at that time, fluid dynamics did not developed to realize completely the differences of meaning of the various lines photographed on such a picture. It seems that the differences between streamline, particle path and streak line were not apparent even for Prandtl. If Karman vortex street is symbolized using these concepts of various lines, Prandtl might struggle to understand the output code. Here the problem arises with respect to the second problem (b), that is,

(c): An AI computer should have the ability to explain its output to human beings.

This ability is required to an e-learning assistant computer. Usually human being considers that firm belief about the truth of some results is obtained when he or she can follow the reasoning step by step as in the case of mathematical proof. However, one of the goals given in (b) of AI is to perform the extraordinarily lengthy and complex reasoning very quickly which can not be checked by a man. When a man can follow such a reasoning of an AI computer step by step, such an AI computer performs (a) and has no function as (b). If we can implement the function (c) completely to some AI computer, it does not perform the function (b) completely, since a man can understand the every output.

In what follows a proposition or a working hypothesis for general AI system will be discussed. In order for a person A to perform communication with an other person B about something, there must be some common ens or being for A and B. Our first assumption is,

(i) The idea, in the sense of Plato, of a thing exists as the ens which is recognized commonly both A and B about the thing.

It is permitted for both A and B to be the thoughts of a person. So we assume a duality of self in some sense. Another hypothesis is the proposal of Fujisawa for the theory of ideas[10]. According to his expression, the following mode can be formulated for the idea:

(ii) The idea of desk is projected on this place in the real world now.

The other expression may be,

" The idea of desk or vortex makes a thing a desk or a vortex when the idea is mapped on the thing existing here in the space at now"

This means that the idea is an abstract thing which makes something a thing by mapping in the space and time. The space, in these sentences, may be an abstract one.

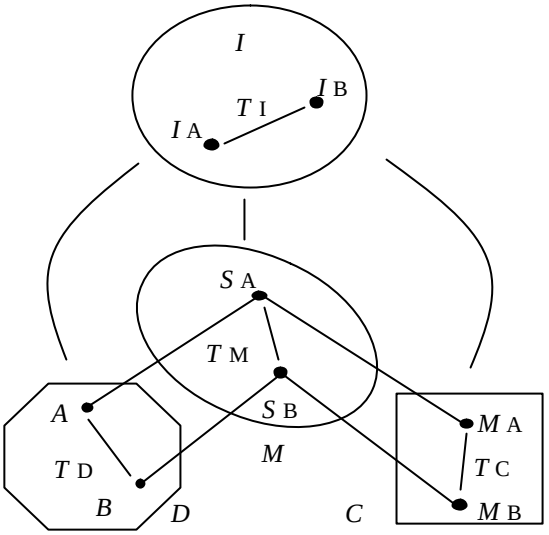


Fig.2 A scheme of he process of AI. D : domain of discourse. M : human being's world. C : AI computer. I : world of idea.

In Fig.2, a picture expressing the AI system according to the above consideration is shown. Individual A which means a concrete thing like a desk or a vortex but also abstract things like proposition and strings of symbols, exists in the domain of discourse D and has an image of idea I_A in the world of idea I. In the human being's world, that is the world of representation M, I_A is projected on representation S_A and I_A is related to symbol M_A in the world of AI computer C.

When M_A is transformed into by some transformation T_C in the AI computer, representation of S_B having M_B is related to representation S_A through the operation of T_M in the world of representation where T_M has symbol T_C . Similarly, in D, there are individual B and action T_D which have images S_B and T_M in M. Changes in D, M and C can be connected through these schema. The assumptions (i) and (ii) guarantee the existence of the idea of a thing and possibility of restoration of a thing from the idea respectively.

Also T_C ,T_M and T_D should be considered as images of an idea in I. At this point Aporia arises as the third man discussed in Parmenides, which is the question about the relationship between the three worlds D,M and C and the world of idea I.

This question may be considered to lead endless retroaction. Here, we avoid this classical aporia to assume simply that in this case the real world consists of D, M and C and the relationship between them, and everything and mapping in the world are

such thing since they are the image of the idea.

The assumed schema given above is an axiom to establish the realizability of AI computer and the meanings of output from it. Without this assumption, we consider that the relationship between the domain of discourse—the representation in human being—and AI computer is lost.

3. Automatic Partial Differential Equation Solver

Since fluid flow is principally continuous phenomena, partial differential equations are inevitably necessary to describe them. In order to solve them numerically we must construct a program for difference form of them, but it has usually complicated form. In 1986 we considered it is desirable to prepare an automatic cord generator which can accept inputs written in human friendly notation that has a form as one can easily realize a usual mathematical partial differential equation. Parabolic type was selected, since its physical importance as it describe boundary layer, diffusion and heat transfer and it needs open boundary conditions. Keller's box method was chosen for difference form of them. The program was written by LISP and moves as shown in Fig.3.

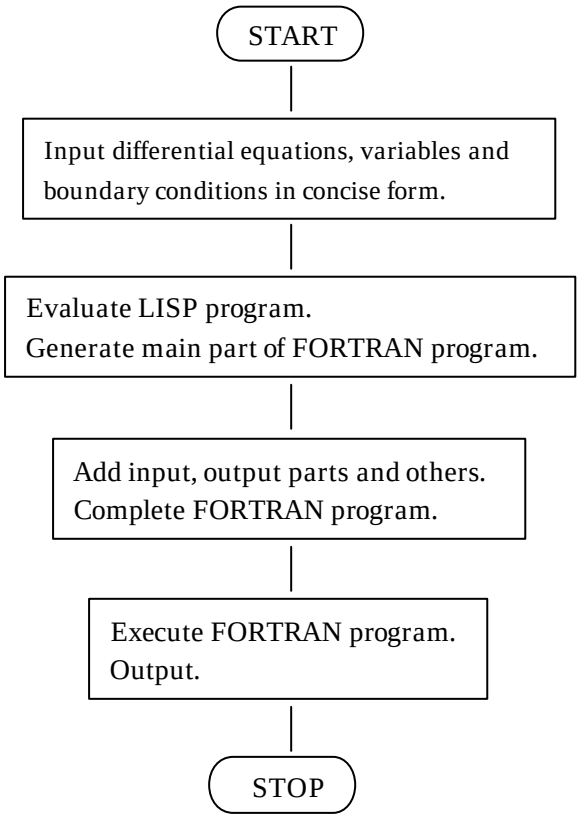


Fig.3 The procedure solving pde

Complete details are presented in our summary (11).

4. Automatic Dimensional Analysis System

Usually fluid flow problems have similarity and it must be investigated various methods[12]. The most powerful and elementally method is dimensional analysis which can be effective even the fundamental equation is not known but in practice it requires rather much experience and insight of the problem in hand[13]. We wanted to construct a program in 1985 which have a structure as shown in Fig.4 (see next page).

Dimensional analysis using the p-theorem is written in list processing language LISP and a computer aided support system is developed. The overall system is composed of functional modules.

While it is not a difficult problem for experts in fluid mechanics to carry out dimensional analysis on fluid mechanical problems if the correct variables are selected but the analysis of problems in thermodynamics seems to be unfamiliar territory for them. The present support system facilitates this kind of situation. Physical variables used frequently are stored in the data base with their dimensions and when they are used the system consults with it and refers to their dimensions. This functions useful to prevent input errors. Analyzed non-dimensional variables are rearranged by using the well known variables and suggestions to understand the physical meaning of results will be offered. More details refer to reference[11].

5. Mechanism for Solving Fluid Property Problems

Fluids are one of the three material forms, and have physical properties like density, viscosity, at some pressure and temperature. Students in fluids engineering course must learn various properties of various fluids, air, water, oil and so on. Consider the simple problem of obtaining a specific volume of fluid, in which we follow the process of a student in solving this problem and then try to create some human models. Confronted with a problem, students have some representation about the problem: given quantities, wanted quantities, constraints and so on. This makes a set whose elements are various kinds of understood concepts.

A rough out line of the process for solving a fluid property problem is shown in Fig.5 (next page). Space X is a set of unknown and data in problems. Each of the quantities to be obtained in a problem makes set in X, whose element is unknown itself. Consider one of these sets, S_0. In Fig.5, P is a set of given quantities in problem and Q is quantities prescribed by the general decision and default knowledge. It is difficult to

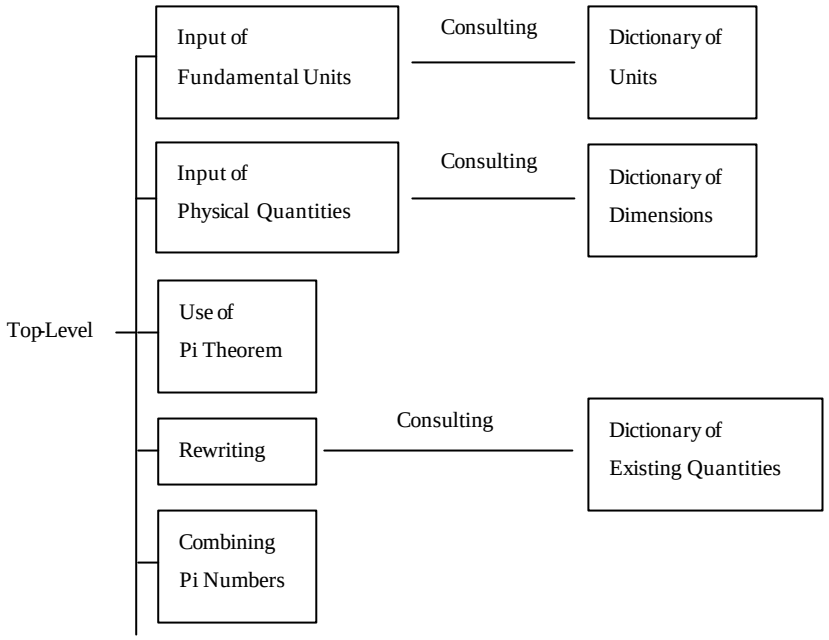


Fig.4 Architecture of dimensional analyzing system

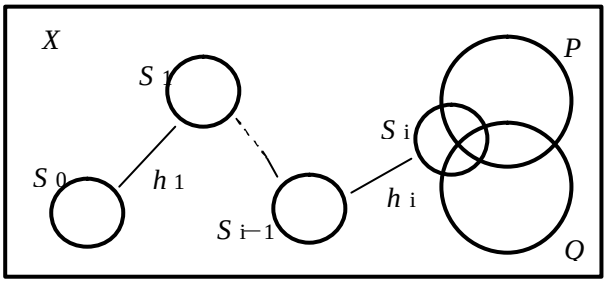


Fig.5 Rough sketch of solving process using relations

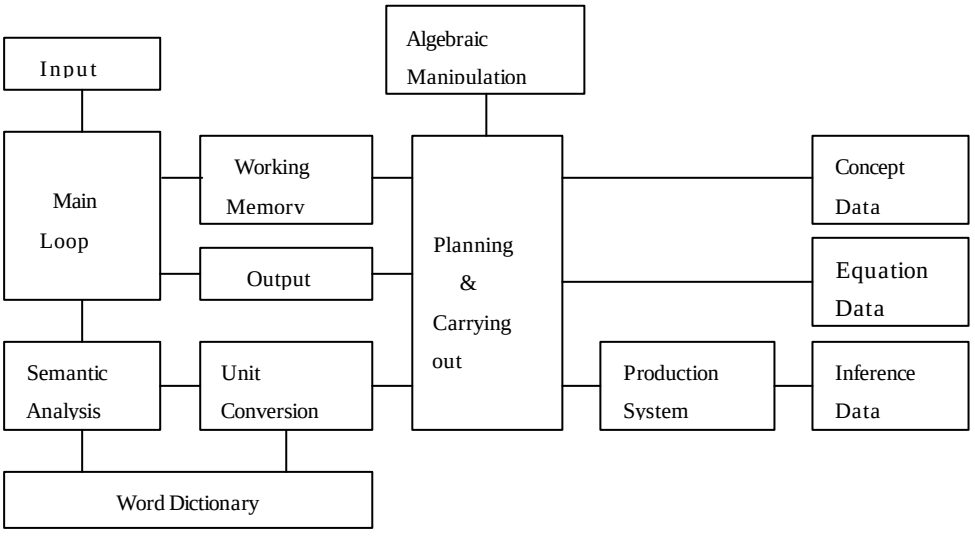


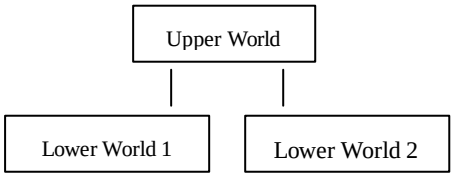
Fig.6 Architecture of the solving system

clarify the ways to define set Q and it seems that experienced teachers have more excellent ability for it than students. From set S_0 transformation h_i is applied to the set of unknowns, and a set of unknowns in sub-problems is formed, in this figure, if all the quantities in S_i are known, the quantities in S_{i-1} can be obtained.

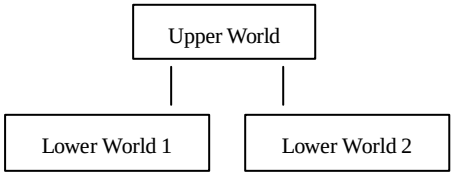
The transformation which uses quantities replaced by previous transformations is never applied. When all elements set S_i are included in set P and/ orQ, The problem can be solved by a general decision, default knowledge and given values. On the other hand, if no transformation is found to make S_i contained in P and/ or Q, it is concluded that the problem cannot be solved. In problem solving, transformations, general decision and default knowledge depend on the characteristics of the problem areas. The architecture is shown in Fig. 6 on the previous page. In terms of the above considerations, a soling system was coded[11].

6. Engineering Problem Model and Equations

In this chapter, an investigation of the possibility of a problem-solving mechanism in practical engineering problems will be presented. At first, a description will be given about a production system to problems with changing conditions. This system analyzes the input Japanese sentences syntactic and semantically. It is based on the extended Japanese LINGOL[14]. The system can treat multiple problems. Consider the problems with changing conditions such as are the energy conservation problems and problems of expansion and contraction of gases.



(a) Processing Form of Type 1



(b) Processing Form of Type 2

Fig.7(a),(b) Problem processing in multiple worlds

One of the typical problems is that of momentum, which requires the force resulting from momentums of a water jet before and after collision with a plate. The local problems before and after the collision may have different quantities but they can be assumed to have the same kinds of properties in the working memory and the same rule base. While the result of the local problems are obtained at a lower level, the resultant force found by combining these results and by using the rules for the momentum at the higher level. An outline of this process is presented in Fig.7(a)(b)[11]. The upper world gets the results from the lower worlds and obtains the final consequences. Another typical problem is the one which requires the state of a water jet before or after the collision and can be solved by using some other state and momentum theory. A solution process for this sort of problems is shown in Fig.7(b). The upper world gets the known result from one of the lower worlds and transfers the information to the other lower world which obtains the final result.

We have considered to construct a program which can derive governing equations from the input of graphical problem representation. Problems can be considered that they are composed of two classes of elements. The element in one class is defined as information flow, and the element in other class is termed as a device. The information flow has static constraints on the relations in a state observed at one measuring point. The device has multiple constraints which describe relations between states. The information flow and the device have local problem-independent abilities which represent sub-problems and their solutions. Problems are formulated by a graph in which an information flow and a device are adjacent to each other. The system of equations which governs the given problem is derived by using the fact that one physical parameter, the value obtained by static constraints must be equal to the value deduced from multiple constraints in devices[14].

7. "Vortex" as a Tool Explaining Flow

Not only for students learning fluids engineering, but also an expert of fluid mechanics, vortex is a central concept to realize fluid flow. When we explain to people, we say "Please see the vortex in the flow in this machine which makes trouble". Usually people can understand the meaning of this phrase. Our question is that what kinds of knowledge is required to construct a program which can be said that realize the phrase cited above. We have examined how the word vortex, in Japanese "Uzu" and tried to extract ontological nature of the word[16].

8. Concluding Remarks

In this paper, we investigated at first the philosophical issues which is required as a foundation to construct a program that can simulate some intelligent ability of human being. The nature of knowledge with respect to the relationship between computer and human being must be assumed. We take a position as a Platonic idea theory of knowledge. Fluid mechanics have very many type of partial differential equations and it is important to

solve them numerically. Described is a program which can code a difference scheme automatically.

Dimensional analysis is one of most fundamental exact method. A program was developed to perform the problem automatically and support the user providing various known non-dimensional numbers.

The process solving the problem which impose to obtain some physical properties of fluids, such as density, viscosity. The problem of using the common implicit knowledge was analyzed.

Engineering problem model and equations were investigated and a program to treat problems with changing conditions using production system. Also a system was investigated to derive equations given statements and graphs. It uses concept of information flow. Some considerations on ontological nature of "Uzu" (Japanese word of vortex) is mentioned.

References

(1) Searl, J., Minds, Brains and Programs, with Peer Commentaries: The Behavioral and Brain Sciences, Vol.3, (1980)., see The Mind ans the Machine ed. Torrance, S., Ells Hovwood Ltd. (1984), trans. into Japanese by Yohichiro, M. et al., Sangyo Tosho (1985).

(2) van Dyke, M., Computer-extended series, Ann. Rev. Fluid Mech., Vol.16 (1984), p.287.

(3) Perry, A. F., and Chong, M. S., J. Fluid Mech., Vol.13 (1986), p.207.

(4) Takeuti, G., "*The Mathematical World View*", (in Japanese), Iwanami (1982).

(5) Schlechtendahl, E. G., A theory of fractal fluids, Kernforshungzentrum, Karlsruhe, KfK4070 (1986).

(6) Oberlack, M., Symmetries, invariance and scaling-laws in inhomogeneous turbulent shear flows, Flow Turbulence and Combustion, Vol.62 (1999), p.111.

(7) Oberlack, M., A unified approach for symmetries in plane parallel turbulent shear flows, J. Fluid Mech., Vol.427 (2001), p.299.

(8) Li, M., and Vitanyi, P., "*An Introduction to Kolmogorov Complexity and Its Applications*" 2nd ed., Springer, (1997).

(9) American Mathematical Society and London Mathematical Society, "*Kolmogorov in Perspective*" (2000), p.67.

(10) Fujisawa, N., "*Idea and the World*" (in Japanese), Iwanami, (1980), p.54.

(11) Nakamura, I., and Watnabe, T., "Fundamental study of the problem solver for fluids engineering", Memoirs of the Faculty of Engineering, Nagoya Uni., Vol.42, No.2 (1990), p.183.

(12) Barenblatt, G I., "*Scaling, Self-Similarity and Intermediate Asymptotics*", Cambridge, (1996).

(13) Panton, R. L., "*Incompressible Flow*", 2nd ed.. Wiley (1996), p.175.

(14) Tanaka, H., Mototoshi, H. and Yamanashi, M., Cognitive Psychology Learned by LISP 3 (in Japanese), (1983), Univ. Tokyo Press.

(15) to be published elsewhere

(16) Nakamura, I., Watanabe, T. and Yamada, Y., A qualitative physical approach of fluids engineering (classification of vortex and explanation of flow using vortex) (in Japanese), Proc. JSME Congress 2001, Vol.2 (2001), p.335.