Developing Students' Skill to Identify Properties of Cognitive Control Systems

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Abstract—Scientific and technological progress has significantly changed the very process of developing technical devices and significantly complicated their principles. Many modern systems are designed with using knowledge-cognitive systems, and they themselves use hard-formalized and fuzzy rules, often based on big data. Accordingly, there is an urgent task of adapting the modern education system to these changes. Soon, knowledge can't be transferred to trained engineers within the framework of existing teaching technologies; the skills of using, extracting and transforming knowledge become the basis for promising technologies of continuous self-education. This article suggests a model of the structure of cognitive management systems based on control levels. The levels of this model reflect the procedures for transforming of knowledge forms. As practical steps to introduce such an educational approach for engineers, it is proposed to increase the amount of research work of students of technical specialties. The article contains examples of the formulation of problems requiring research in the study of physics, electrical engineering, signal processing and other disciplines. The most simple to implement is the use of a "black box" to conceal the structure of the object for investigation or use non-standard modes and settings of well-known devices, for example, ADCs. Also, approaches are considered for assessing quality of knowledge that obtained under the cognitive control system.

Keywords—cognitive control systems, models of cognitive control systems, research assignments, engineering education

1 Introduction

The necessity of changing the existing engineering educational system is discussing nowadays from different points of view. The main cause of these discussions is a fact that the pace of technological innovations continues to increase rapidly in the twenty-first century. And there are no doubts that the educational system should give new generations of engineers the opportunity to thrive in modern professional environment [2].

In general, the main components of engineering education can be described as knowledge, skills, and attitudes that dictate the goals toward which skills and

knowledge are directed [14]. The process of transformation the educational system influences all these components.

In this paper, predominant attention is paid to one of skills which can be described as ability to identify the system's emergent properties, capabilities, behaviours, and functions without looking inside the system and its parts/components/details [5]. This skill seems to be crucial so far as the Fourth Industrial Revolution is expected [15], and a person will be surrounded by artificial intellectual systems that will continuously explore an object of control, themselves and environment.

For building these so called cognitive systems, future engineers should have some knowledge about methods of their processing, and be able to extract and use new data and rules. It is necessary to emphasize that an approach to teaching engineering courses is changing: since the volume of information is increasing far more rapidly than the ability of engineering curricula to "cover" it, the focus shifts away from the simple presentation of knowledge toward the integration of knowledge [14]. For instance, in [6] was reported about teaching mathematics within electrical engineering courses; authors of [17] informed of a multidisciplinary course "Engineering Discovery" for first-year students; a model curriculum proposed in [2] merges the disciplines of mathematics, science, engineering, and computing.

The way of organizing the studying cognitive control systems and development students' skill to identify the system's properties without looking inside the system is considered below.

2   State of the art

It cannot be said that these issues are not given attention in the modern system of engineering education — research projects are present in university programs for graduated students. For example, students of Electrical Engineering Department of Zaporizhzhya National Technical University study a course "Automation and Informatization of Scientific Research" [1]. According to the framework of this curriculum, such methods of changing knowledge forms as signal processing, fuzzy logic, neural networks, cluster analysis, genetic algorithms, logical programming and others are considered.

However, a lot of study time is spent on learning principles of systems' component operation, and confirming operability and effectiveness of a certain method. This leads to an undesirable situation when research potential of the future engineers does not accumulate, students do not develop skills to determine and choose a method for investigating an object of unknown structure.

The literature analysis allowed us to reveal some reassuring empirical results about teaching students to deal with such objects, so-called "black boxes". For instance, in [9] the author described her experience of using black box method both in the classroom and in the education of future physics teachers. The author also noted that although the experiments with black box foster the creativity of students many teachers don't seem to be familiar with it.

In [7] was reported about a laboratory course of Electrical & Electronics where a black box has been provided to each student during final exams. The authors claimed that in this way a student's best creativity is highlighted. It is also worth to mention that results of educational researches in another field — a Computer Science/Software Engineering indicate in favour of this approach. In [3] was noted that software testing principles and techniques have been identified as one of the areas that should be integrated early in the curriculum.

We would like to emphasize that time is definitely an important factor for developing students' research skills. There is no hope that it is possible to ensure appreciable changes during one-semester course at the end of university education. Therefore, it is necessary to create a specially constructed series of task which could be integrated in different courses starting with basic curricula such as Physics and Electrical Engineering.

Another important factor that should not be forgotten is the psychological atmosphere, the style of teacher-student interaction. It is doubtful that first students' attempts to solve a problem of unfamiliar type will be successful, thus a teacher has to be able to encourage and inspire them.

This work is aimed at presenting a way of purposeful training for students to identify properties of cognitive control systems through several curricula. Certainly, the approach used for forming this skill must be linked to a structure of corresponding systems [10]. Since models of such structure are currently under formation, it was necessary to begin our study from elaboration a model of a cognitive control system.

3   Model of a cognitive control system

The proposed structural model of a cognitive control system is shown in Figure 1. This model describes a cognitive control system in the form of a hierarchy of control levels(from the target to the direct)where subsystems of a corresponding level are located.Describing cognitive systems, it is necessary to determine a knowledge base in a form which is typical for a given level; rules for converting this knowledge into a form of the next level of the knowledge pyramid [13]; goals of management in categories of activities and management functions at a given level.

An activity of a subsystem is formed by a finite-state machine (FSM) of this level and aimed at managing knowledge converters at this level, managing downstream levels and informing a higher level about the results of their activities.

The principle of knowledge homogeneity is applicable to subsystems of each level. According to this principle, both knowledge about a control object which is stored in a knowledge base, and knowledge which is underlying control algorithms can be processed. On the level of computing systems, this principle is known as the Von Neumann principle of memory homogeneity. Application of this principle allows to build hierarchies of controls in which the control device on the i-th level becomes the control object on the higher $(i + 1)$ level.

An example of the described model possible application to a system which controls cooling of an oil-filled power transformer is shown in Fig. 2 and Fig. 3.
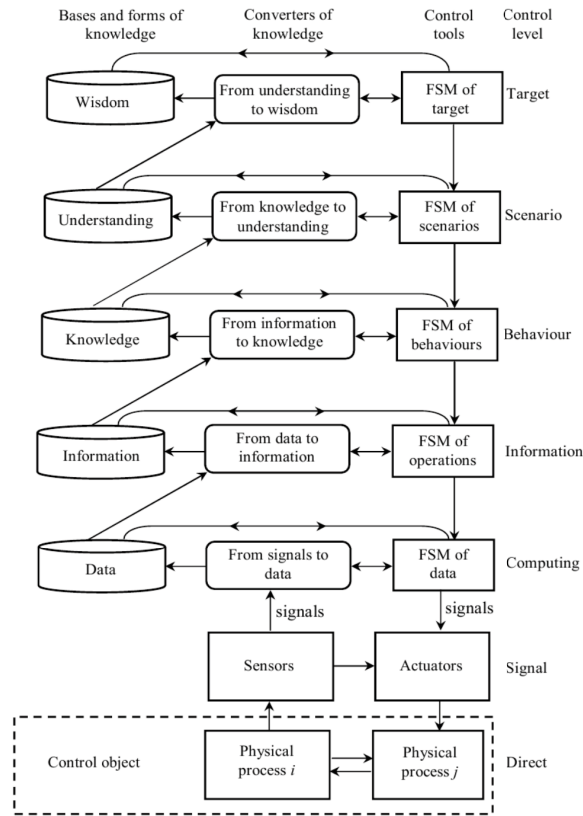
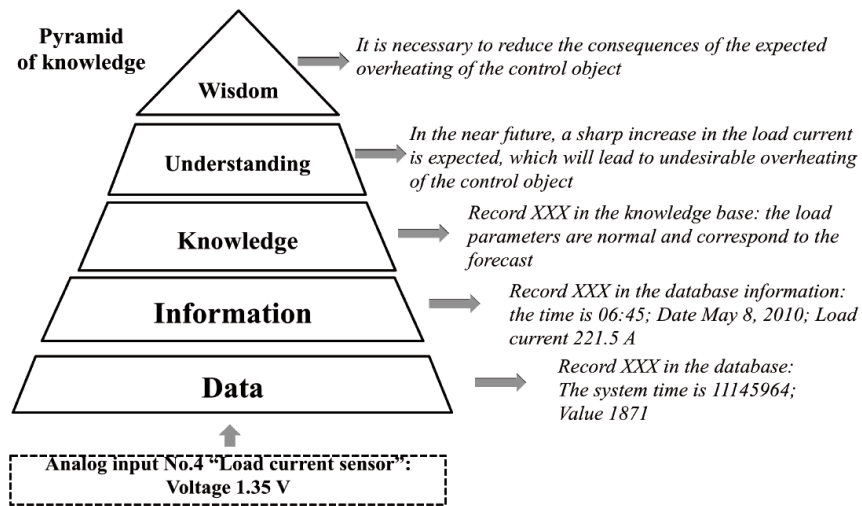**Fig. 1.** Model of a cognitive control system

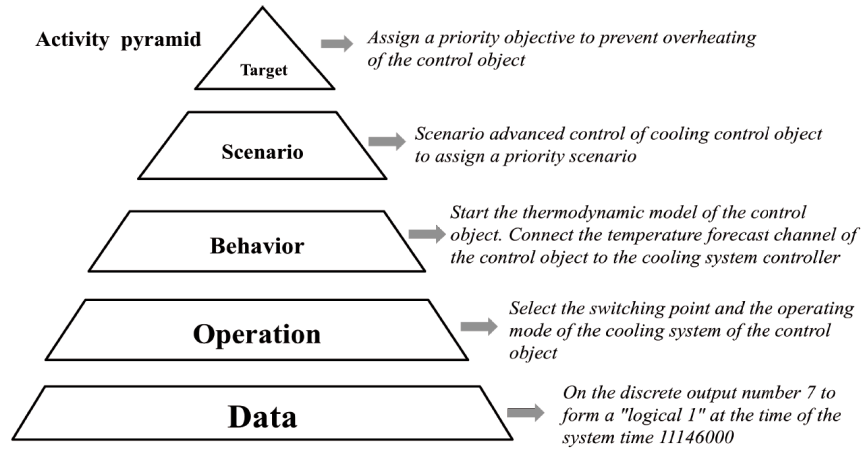**Fig. 2.** Elements of a cognitive cooling control systembased on pyramid of knowledge

Fig. 3. Elements of a cognitive cooling control systembased on activity pyramid

The proposed structural model of a cognitive control system allows to decompose it into simpler subsystems, to identify typical elements, to detail their interfaces and, ultimately, to organize appropriate learning process for students.

Research assignments for students have to include objects with unknown to them structure. A trainee should investigate them by examining signals, data, information, knowledge, understanding, and wisdom. Methods of extracting knowledge of higher forms from knowledge in lower forms must also be studied: data from signals, information from data, etc.

4 Research tasks on the study of a cognitive control systems

In this part of the paper we present a series of assignment examples which might favour the development such important skills for future engineers as commitment to self-education, and ability to work with unknown structure systems.

Example 1 (Physics).A three-pole "black box" with no more than three resistors inside is offered to students. They have to propose possible versions of these resistors connecting, and find their values. Electrical resistance between terminals A, B, and C of a "black box" is known. For carrying out experiments, both real ABC circuits and their software emulators with generators of random resistance values and topology of ABC circuits could be used.

An unexpected but crucial gap in our students' knowledge was found by one of the authors at the beginning of the semester when trainees could not solve this problem. It was quickly elucidated that the difficulty did not connect with knowing corresponding physics formulas. When students had to calculate the resistance between the external outputs of circuits (see Fig.4) almost all of them correctly identified these resistances using formulas for serial and parallel connection of conductors.However, when the group was assigned to research option with a "black box", most of students could not fulfil the task, and needed a clue. After that the trainees carried out all possible exper-

iments, compiled and solved systems of linear equations for each of the possible configurations of the scheme under study.
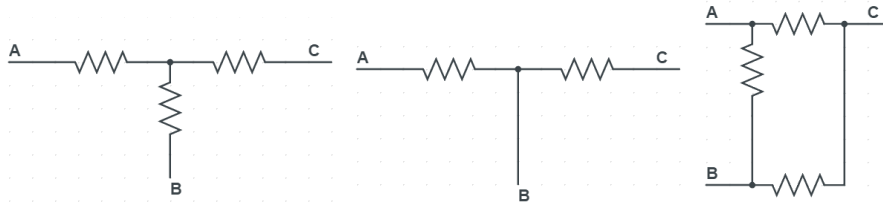

Fig. 4. ABC circuit options

This situation strikingly shows the need to expand the scope of research assignments, and include them in curricula learned from the firstdays of study at university.

Example 2 (Electrical Engineering). Students have to determine if there are reactive elements or p-n junctions in a circuit.

Such tasks could be used with the purpose of complicating the experiments from the previous example. Semiconductor diodes connected in series or in parallel to the resistors are inserted in the ABC circuit. Students have to diagnose the presence of diodes by differences in measurement results obtained in forward and reverse directions of a circuit.

This assignment could be extended by asking students to measure resistors in the ABC circuit which were connected in parallel to the p-n junctions as it showed on Fig. 5. For fulfilling this task students have to measure resistances at voltages less than 0.3 V when the p-n junctions of the diodes have a high electrical resistance both in reverse and forward directions.
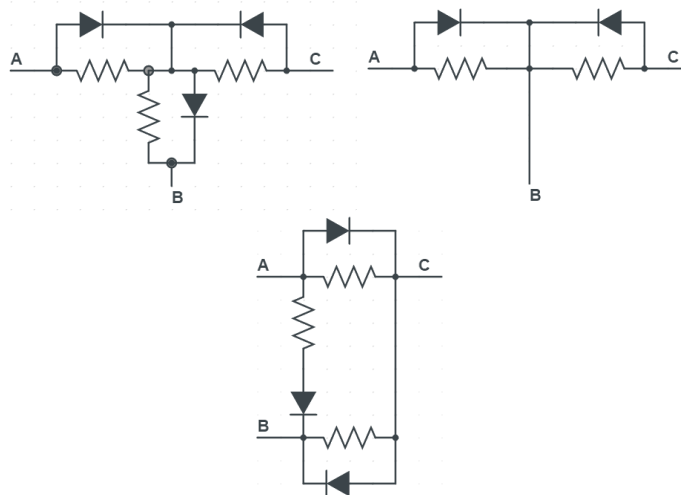

Fig. 5. ABC R-Diode circuit options

Example 3 (Electrical Engineering). Students have to measure a frequency of a harmonic signalusing information obtained from digital readings during analog to digital conversion (Fig.6).
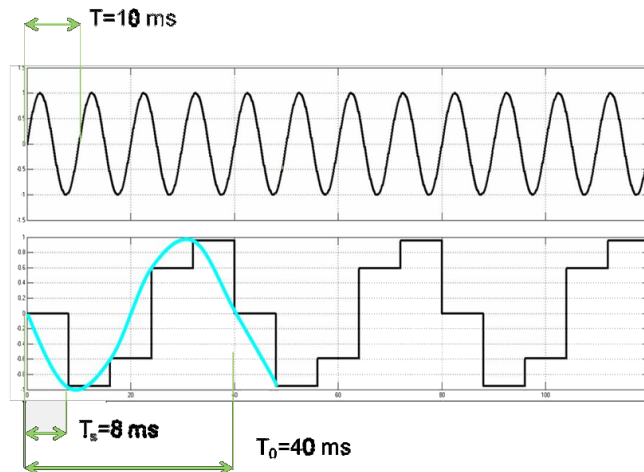

Fig. 6. Definition: T – period of signal; T_s – sampling time; T_0 – period of recognized signal

The standard logic of researchers in this situation is to adjust the analog to digital convertor (ADC) to the maximum sampling rate and get the maximum number of samples. For instance, let a trainee use an ADC at a maximum sampling cy$f_s = f_{smax} = 175$ Hz. As a result of measurements, a number of values are obtained, and on the basis of these values a student's concludes that the original signal had the frequency $f_{01} = 75$ Hz (Fig.7).
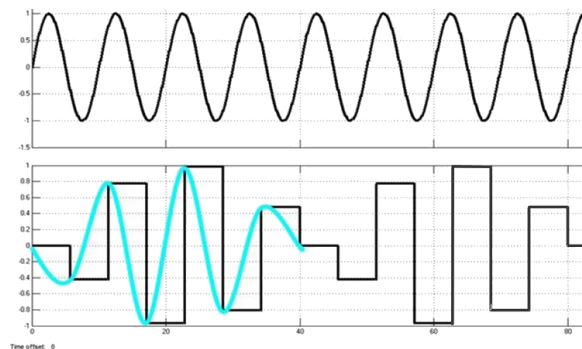

Fig. 7. The results of experiments at a maximum sampling frequency$f_s = f_{smax} = 175$ Hz

However, it is useful to show students that sometimes this statement is not true. An additional experiment with a frequency $f_s < f_{smax}$ should be performed. Fig.8 shows a number of values obtained at a sampling frequency $f_{01} = 125$ Hz. The signal reconstructed from these values has a frequency $f_{02} = 25$ Hz.
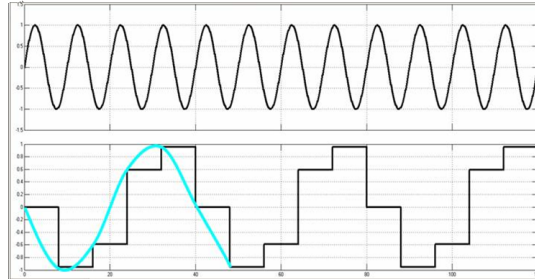
Fig. 8. The results of experiments at a maximum sampling frequency 125 Hz

Example 4 (Automation and Informatization of Scientific Research). As is generally known, information of daily and weekly cycles which is received as a result of processing a power system are used for obtaining knowledge about the load parameters in a forecast horizon. The forecast are given to students and they have to implement a strategy of advanced control and optimize operating modes of power system equipment.

The stages of forecast transformation into power system control parameters are shown in Fig. 9. The transformation procedure involves several steps, each from them is a separate cognitive stage and uses own methods. It all begins with the accumulation of energy consumption monitoring data, which are used to train the cognitive system for building forecasting model. On the other hand, a power system model which built using conventional methods for calculating power electronics will be used.
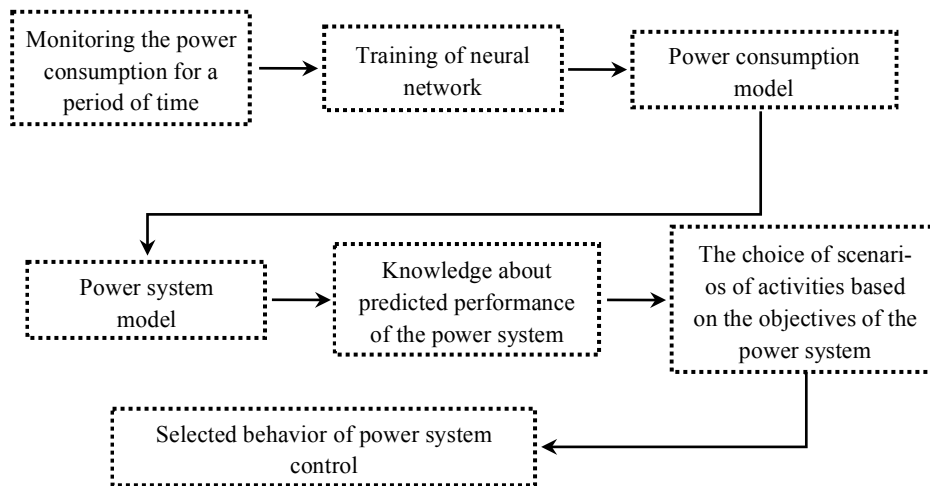

Fig. 9. Using a forecast about power consumption for choosing the behavior of power system control

Using both models, students can select the optimal scenario for controlling the power system based on certain limitations, for example, optimizing the cost or load on the power network.

Example 5 (Automation and Informatization of Scientific Research).The Cyber Physical System of a remote laboratory can include false knowledge into the knowledge base of an investigated object. Models that provide such possibilities are considered in [11]. Studentshave todiscover these contradictions by the methods of logical programming.

Consider an assignment about assessing completeness and consistency of available knowledge obtained from a cognitive control system of powertransformer cooling. Parameters of the transformer control system are the load current L, the cooling system operating time T, the thermal resistance between a transformer and external environment R, and oil or a transformer winding temperature θ.

These parameters are described by ternary variables and can take values from a set ("−", "0", "+") which means "decreases", "does not change", and "increases". For example, if L is equal "+"this is corresponded to a situation in which the load current of a transformer increases with time.

The result of assessing the quality of knowledge is also described by the ternary variable. A result Q can take values from a set ("−", "0", "+") which means "contradictory", "incomplete", and "consistent" respectively.

Students should develop a logical scheme for assessing the quality of knowledge. An example of such a scheme is shown in Figure 10.
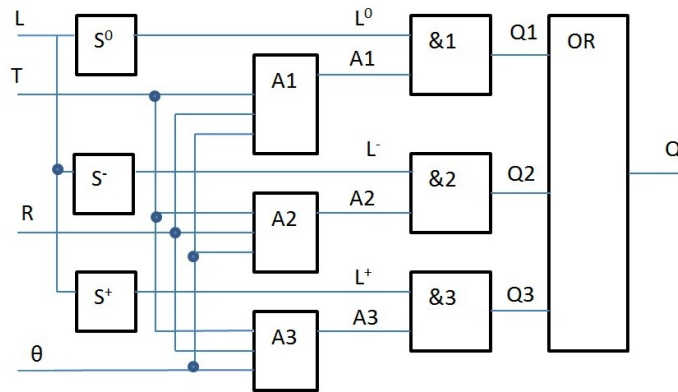

Fig. 10. Logical scheme for assessing the quality of knowledge

All elements of the circuit in Figure 10, except A1, A2, A3, are described by known truth tables. For example, the table for S^0 element is shown in Table 1.

Table 1. Truth table for S^0 element

Input	−	0	+
Output	−	+	−

Elements A1, A2, A3 should take into account specifics of a subject area. For instance, the table for element A1 is shown in Table 2.

Table 2. Truth table for a ternary logical element A1

T	–	–	–	–	–	–	–	–	–	0	0	0	0	0	0	0	0	0	+	+	+	+	+	+	+	+	+
R	–	–	–	0	0	0	+	+	+	–	–	–	0	0	0	+	+	+	–	–	–	0	0	0	+	+	+
θ	–	0	+	–	0	+	–	0	+	–	0	+	–	0	+	–	0	+	–	0	+	–	0	+	–	0	+
A1	0	+	0	–	–	+	–	–	+	+	–	–	–	+	–	–	–	+	+	0	–	+	–	–	–	+	0

It is expected that students carry out the analysis of the circuit (Figure10) by using the programming language Prolog [12].A fragment of the Prolog program is shown in Figure11.This fragment contains the description of `Q_logic(L, T, R, θ, Q)` of the circuit, and the specification of the ternary logic element S^0.

Prolog can create a list of situations as an answer to a question. Students may use:
`? Q_logic (L, T, R, θ, "-")` –for a question "at what value of the variables L, T, R, and θ is the result should be considered as contradictory?" or
`? Q_logic (L, T, R, θ, "0")` – for aquestion "at what values of the variables L, T, R, and θ is the result should be considered as incomplete?"

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  Q_logic(L, T, R, θ, Q)⇐OR(Q1, Q2, Q3, Q), AND1(L0, A1,
Q1), AND2(L-, A2, Q2), AND(L+, A3, Q3), A1(T, R, θ, A1),
A2(T, R, θ, A2), A3(T, R, θ, A3), S0(L, L0), S-(L, L-),
S+(L, L+).
  So("-","-").
  So("0","+").
  So("+","-").
  ....
```

Fig. 11. Fragment of the Prolog program for the logical conclusion about the quality of given information

An example of a contradictory set of knowledge is the set L = "0", T = "–", R = "+", θ = "+" that is determined by the thermodynamic model of a transformer. If its thermal resistance R increases, and the load L is constant, than the oil temperature θ and the cooling time T must increase. However, in presented knowledge T = "–", that is the reason for the final answer Q ="–".

5 Conclusion

Development the ability to work with cognitive control systems and to research them has to be in the focus of learning process for future engineers. Corresponding training, studying models of such systems, methods of obtaining and transforming knowledge could be realized in different courses of engineering curriculum by organizing students' researches and practical works with objects of unknown structure

("black box"). The examples of assignments which can be used for studying elements and components of complex cognitive control systems are described in the article.

The presented approach for engineering training is expected to be implemented in curriculum that are being developed at the Zaporizhzhya National Technical University according to the framework of the projects of the European Commission within the program Tempus "DesIRE" and "ALIOT".

6 Acknowledgment

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