vegetation, that a uniform and high temperature is maintained throughout the night. Because of this fact, in the radiometric observations of tropical regions the boundaries between water and land, hence parts of the outlines of continents, cannot be distinguished.

Comparison of a radiation picture of the Siberian tundra on 5 September 1964 (Fig. 16) and hydrometeorological data for the same date provides an example of very close equilibrium between soil and air temperatures. In Fig. 16 a band of clouds, indicating a cold front, lies across western Siberia near 60°N. The skies to the north and south are cloudless; this is indicated by the clearly visible lakes and rivers on both sides of the front. Blackbody temperatures, however, are markedly different on the two sides. To the south of the front the temperatures range from 277° to about 280°K, while to the northwest they are about 287°. Surface-air data provided by the Hydrometeorological Service of the U.S.S.R. show that surface-air temperatures in the southern region were about 279°K, while in the northwest they ranged from 283° to 288°K. This agreement with the satellite-measured soil temperatures suggests a complete equilibrium between air and soil temperatures in this region. Other radiometer observations were obtained when the satellite passed over this area during September 1964, but the north-south temperature contrast was apparent only on 5 September. This leads to the rather surprising conclusion that, in this case, the soil temperatures were governed by the temperatures of the overlying air masses.

Thus, a variety of geophysical and atmospheric facts can be inferred from the satellite observations of temperature variations over clouds, oceans, ice formations, and the earth's terrain. The height distribution of the tops of clouds can be determined from the temperatures of cloud surfaces. Temperature measurements of the surfaces of oceans and extensive vegetated regions are of great importance to meteorology. The heat capacities of these regions are so large that the ground (or water) acts as a reservoir which heats or cools (depending on its own temperature) the air moving over it.

In dry, sandy terrain, the heat capacity of the ground is so small that, at night, when there is no solar radiation, the ground temperatures are very low, generally much lower than air temperatures. In more solid, rocky surfaces and in moist terrain, surface temperatures remain high during the night, generally the same as air temperatures. Thus, contrasts in the thermal properties of the surfaces usually produce a pronounced fine structure in the radiation picture. In many cases, these contrasts can be interpreted, qualitatively at least, as a measure of the moisture content of the ground or a measure of changes in vegetation or geological formation (*10*).

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Computer-Aided Instruction

Concepts and problem-solving techniques can be learned by conversing with a programmed-computer system.

John A. Swets and Wallace Feurzeig

Computers as teaching machines can present lesson materials, and accept student responses, in several forms. A computer can type on an electric typewriter, generate text and pictures on a television screen, and control a slide projector and tape recorder; the student can type, write with a "light pen" on the television screen, or respond by means of some special device. The computer-based teaching machine can keep various scores, and use them to select an appropriate path through a lesson for any particular student. A time-shared computer serves many users simultaneously, so that complicated decisions can be made for each student at low cost. The computer can keep records of student progress, with summary statistics for individuals and groups, and produce them on call. This kind of teaching machine can act like any one of a number of fixed machines. Given the necessary preparations, the stimulus and response modes and the lesson content can be readily changed.

These capabilities are at present exercised in a half-dozen or so prototype, programmed-computer systems. The report of a recent conference (*1*) is a convenient reference.

This article describes a system for instruction that uses the power of the computer in other ways, in an attempt to deal more effectively with complex subject matters. The system was designed for use with rich materials that may be expected to suffer when they are reduced to machine-controlled step-by-step presentation of small pieces of information and associated questions requiring short answers from the student.

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The system was also designed for students who might be hampered by the inability to demonstrate initiative under a relatively restricted procedure.

The "Socratic System"

In this system, termed the "Socratic System," the computer states a problem to the student and then provides a framework in which the student can proceed to a solution, and form concepts, on his own terms. The progression of the lesson is flexible and almost fully under the student's control. The student does not merely generate responses on cue; he can ask, as well as answer, questions. The emphasis of the system is not on stamping in responses, but on facilitating study.

The computer engages the student in "conversation" while he attempts to solve the problem that is posed. The conversation is accomplished by means of an electric typewriter. The student types a question or an assertion, and the computer responds by typing an answer or comment or, possibly, a question in return. Limited only by a specified vocabulary on a list given him, which can be extensive, the student can request information, or propose a solution, whenever he likes. The computer responds in natural English; the response is determined by the student's actions up to that time and by the information he has at that point, and may depend not only on all the previous interchanges but also on their order. The subject-matter specialist and the computer programmer devise conditional strategies so that the computer answers good questions, reproves hasty conclusions, acknowledges perceptive decisions, questions the grounds of inference, suggests new approaches, and develops interesting contingencies to the appropriate depth.

An illustrative protocol obtained with the first problem prepared is reproduced below. More a guessing game than a problem intended to help form complex concepts, it was devised by Judith R. Harris principally for use in debugging the computer program. It shows, however, that the responses of the computer can be of some interest in even a simple situation, and it has some properties that will serve as useful contrasts in discussing more complex problems.

The student (or player) is to try to guess a letter of the alphabet. The questions he can ask of the computer pertain, for the most part, to simple geometric characteristics of a printed letter, such as the number of horizontal, vertical, oblique, or curved line segments in the standard drawing of the letter. In the dialogue given here, and in "conversations" given later, the student's questions and assertions are in capital letters and indented to distinguish them from the computer's responses, which have only an initial capital and are not indented. In the original transcript the student's comments are typed in black and the computer's in red.

Start when ready.

CURVES?
One.
LOOSE ENDS?
Two.
OBLIQUES?
Zero.
C.
You don't have enough information yet to get the right answer. How do you know it isn't J, for example?
J.
You don't have enough information yet. How do you know it isn't C, for example?
HORIZONTALS?
Zero. That was a wasted question. It did not eliminate any possibilities.
VERTICALS?
Zero. Good question.
G.
Wrong. Your guess is inconsistent with the information you've been given. You must have forgotten that the right letter hasn't any *horizontal lines*. The letter you guessed can't be right—it has too many *loose ends*.
CURVES?
The answer is still: one.
X.
Wrong. Your guess is inconsistent with the information you've been given. I think you only made that guess to see what I would say.
C.
Yes, you've done it. Good work. If you want to play again, start right in.

To play this game, the Socratic System has only to recognize logical conditions, such as sufficiency, necessity, redundancy, and consistency. This capability is not inconsequential—for example such a capability might be sufficient in an aid for teaching fundamentals of geometry, or qualitative inorganic chemistry—but it can be realized in a less complex system. A colleague of ours, Thomas Marill, has designed such a system, and it is evident that his system could be implemented relatively easily.

The more general problems for which the Socratic System was developed are typified by its applications to management decision-making and to clinical medicine. An illustrative dialogue concerning a hypothetical medical case follows. This case was designed by Preston K. Munter of the Harvard Health Center; Myra Breen assisted in its programming. The student's vocabulary (not shown here) for this problem consists of 40 questions and 35 declarative statements. The problem, as stated to the student, is given first.

Please type your name, the date, and a slash.

MYRA BREEN, AUGUST 1963/
It is mid-December. Late this afternoon, a patient was admitted to the hospital. He is a well-developed, well-nourished, 34-year-old Negro coal miner. He was brought in by his wife who reports that he has had "the grippe" for about 4 days. During the past 3 days she has given him fluids and aspirin every 6 hours with no sign of improvement. Today he suddenly became much worse. For the past 2 days he had complained of feeling very warm and of pain in his belly. This morning he had a severe shaking chill that was so bad his teeth rattled.

You, the admitting physician, are requested to diagnose the case. To obtain the information you need to make this diagnosis, you are required to perform a methodical physical examination of the patient and to order all pertinent lab tests. This is done by typing questions to the computer. The set of questions you may ask is listed in the vocabulary you have been given. The computer will respond to each question with an answer or comment.

When you have finished the examination and lab tests, type: proceed. At this point the day "ends." Before you "go home" you may leave instructions for the night nurse to take a second series of lab tests during the night so the results will be ready for you "tomorrow." It is assumed that the second series consists of just those tests you think necessary.

Tomorrow morning, results of some of the first lab tests will be returned to you; others won't be available until late in the day. On the basis of information you have been able to obtain, you will be asked for the diagnosis. If you feel that no conclusive diagnosis can reasonably be made, you may then

perform another full physical exam. Also, reports from the second series of lab tests may be requested.

You may make a diagnosis at any time you choose by typing the name of one of the diseases in the vocabulary. At various times the computer will discuss certain diagnostic possibilities with you. If questions are raised you must answer them by typing a diagnosis or an appropriate declaration from the final section of the vocabulary. Begin the physical examination as soon as you are ready.

PHYSICAL EXAM?

Fine. What in particular would you like to know?

CHEST EXAM?

It is common practice in the medical profession to begin an examination by checking the patient's general appearance.

GENERAL APPEARANCE?

Acutely prostrated, lying in bed on his right side. Looks acutely ill, sweaty, apprehensive, but alert. Paroxysmal cough, bringing up a little rusty streaked sputum. Breathing with difficulty.

EENT EXAM?

Check all of the vital signs first!

TEMPERATURE?

103.

BLOOD PRESSURE?

150/84.

PULSE?

100 a minute. Occasional extra systole.

RESPIRATORY RATE?

20 a minute and shallow.

[*Several requests and responses have been deleted from the dialogue at this point for the sake of brevity, including interchanges about abdominal, chest, and eye-ear-nose-throat examinations.*]

COUGH?

Yes, developed yesterday.

BACKACHE?

No.

HEART EXAM?

Not enlarged to percussion but low-grade systolic murmur at apex. Otherwise normal.

ABDOMINAL EXAM?

Diffusely tender, some splinting noticed in lower right quadrant and occasionally radiating to right flank area.

THE GRIPPE.

There's insufficient information for any conclusive diagnosis at this time. You're not being careful!

MUSCULO-SKELETAL SYSTEM?

Essentially negative, except for generalized weakness and aching.

EXTREMITIES?

Normal, except nail beds are questionably cyanotic but difficult to determine because of patient's skin color.

RECTAL EXAM?

You're not being careful! The patient is too acutely ill for a rectal examination.

LABORATORY REPORTS?

Fine. Which lab tests would you like to have done?

RBC?

A red count will be done. Results will be sent to you as soon as possible.

WBC?

The WBC will be taken.

[*Deleted: requests for laboratory tests such as urine, x-rays, and blood culture, and the results of these tests promised by the computer.*]

NOSE AND THROAT SMEAR AND CULTURE?

They'll be ordered now. When you've requested all the lab reports you want, let me know that you're ready to proceed.

PROCEED.

You may want repeats on some of the lab work. Would you like to alert the night nurse to set up the lab tests you'll want to see tomorrow?

YES.

Good. That will speed things up. However, there's nothing further that can be done tonight to help the patient. Let's call it quits for now. Perhaps you'll be in a better position to diagnose the case tomorrow after the first lab reports come in and you have reexamined the patient. Have a good night's sleep and when you're back on duty tell me to "proceed."

* * *

PROCEED

It's morning and you're making your rounds. You've come to our patient and are given the night nurse's report: "Temperature remained high but patient spent a reasonably comfortable night. Cough diminished but persists. Occasional traces of blood in sputum. Patient still dyspneic and still has pain in abdomen. The second series of lab tests was initiated."

Some of the first series of lab reports have just come in: urine exam, insufficient fluid for analysis; RBC, 5 million; WBC, 15500; differential, shift to left. When the other reports are in you'll be notified. Before proceeding with the reexamination it might be instructive to pause and consider the diagnostic implications of the information at hand. Perhaps you think it too early to arrive at any definitive conclusion. On the other hand, you may be prepared to make the diagnosis now. Are you?

NO.

Fine. Nevertheless, we've got a fair amount of information — at least enough to raise some, perhaps several, diagnostic possibilities. Have you any in mind?

YES.

Name one.

PULMONARY INFARCTION.

Fine. Pleural pain, dyspnea, fever and the physical exam signs and symptoms are certainly consistent with pulmonary infarction. Do you think that shaking chills and the presence of rusty sputum further support this diagnosis?

NO.

Right. Though the white count is consistent, isn't it?

NO.

Wrong. The white count is consistent. This should further support your diagnosis. We've considered one possibility. Do you have another diagnosis in mind?

NO.

In that case I'd like to talk about viral pneumonia. The tachycardia, high WBC, elevated respiratory rate, shaking chills, bloody sputum, and severe pleural pain all lend weight to that diagnosis—right?

YES.

You're way off base. There's not an iota of truth to any part of what I just said; in fact, the opposite of what I said is true. You'd better review some elementary medicine, doctor.

[*Deleted: the results of some laboratory reports requested the previous day.*]

PULMONARY INFARCTION.

Yes, I remember you liked this diagnosis before. There's no question of the need to account for this possibility. . . . But rule it out, won't you, on the basis of the history of shaking chills, high temperature, and somewhat excessive WBC.

ACUTE PYELONEPHRITIS.

Very good. You should think of acute pyelonephritis. It's consistent with many of your patient's signs and symptoms—but not all. Wouldn't you want some signs of dysuria to support this diagnosis? And what about the respiratory symptoms in the history and findings? You'd better reevaluate the evidence.

FRIEDLANDER PNEUMONIA.

A wise thought—but off the mark. You don't have the usual Friedlander pneumonia gelatinous type sputum nor the Klebsiella organism—do you? Hold off on this diagnosis for awhile.

[*Deleted: interchanges concerning some physical examinations and vital signs,*

and some diagnostic assertions that were off the mark.]

PLEURAL EFFUSION.

A good contender, but let's be careful. What evidence would rule it in or out?

POSITIVE EVIDENCE OF ANOTHER DISEASE.

Is there such evidence?

POSSIBLE EVIDENCE THOUGH INCONCLUSIVE.

Since you aren't sure, continue the examination until you have conclusive evidence one way or the other.

RBC?

An RBC is not indicated at this time. It's an unnecessary expense for a poor patient.

WBC?

22500.

STAPH PNEUMONIA.

Fair enough. But where is the guilty organism? When you have isolated staphylococcus aureus in significant numbers in your samples of this patient's fluids or excretions, let me know.

PNEUMOCOCCAL PNEUMONIA.

Are you absolutely sure?

YES.

You can't be until you have irrefutable evidence. What would help you nail down the diagnosis?

EVIDENCE FROM SPUTUM SMEAR AND CULTURE.

Good. Anything else?

NO.

I think you might also want evidence from x-ray findings. Go ahead and we'll see what happens.

X-RAY?

Not ready yet. Try the blood lab.

DIFFERENTIAL?

Marked shift to left. Even though all the lab reports aren't in, you have enough information to make a presumptive diagnosis. If you care to make one go right ahead.

ACUTE PYELONEPHRITIS.

It's getting hard to hold on to this diagnosis with neither history nor signs of dysuria. Moreover, the pain is getting away from the flank region into the lower belly. Still thinking of a renal problem? Reconsider.

TB PNEUMONIA.

Any other thoughts as to diagnosis? The sudden high rise in WBC and differential is against it and you don't have tubercle bacilli in the sputum.

URINE EXAM?

The urine test shows presence of albumen, few hyaline casts, few WBC, occasional RBC.

X-RAY?

The x-ray shows: area of consolidation, right lower lobe, consistent with pneumonic process. This is a good time to review the total findings and to make another tentative diagnosis—if you like.

EVIDENCE OF FLUID?

No evidence of fluid.

SPUTUM SMEAR?

Gram-positive rods.

STREP PNEUMONIA.

Fine, but how can you distinguish this from any other bacterial pneumonia? Wait until you have an irrefutable case.

VIRAL PNEUMONIA.

But what about shaking chills, rusty sputum, elevated WBC, etc.—all the evidence of an acute febrile bacterial process? You are in error, doctor.

SPUTUM CULTURE?

Presence of pneumococci.

STREP PNEUMONIA.

Incredible! You have disregarded the positive findings that should clearly have established the correct diagnosis.

PNEUMOCOCCAL PNEUMONIA.

Very good. It's obvious now, though there were some confusing signs and symptoms in the picture. You've seen your way through to the correct diagnosis.

In this illustration the student made many diagnostic guesses. The time required, much of it taken by the student in making his decisions, was about an hour. In another run of the same problem with a more insightful student, the correct diagnosis was reached with greater dispatch. This dialogue, with preliminary questions deleted, is given below. The computer, upon recognizing a more capable student, is less demanding, and its comments have a kindlier tone.

Before proceeding with the reexamination it might be instructive to pause and consider the diagnostic implications of the information at hand. Perhaps you think it too early to arrive at any definitive conclusion. On the other hand, you may be prepared to make the diagnosis now. Are you?

NO.

Fine. Nevertheless, we've got a fair amount of information—at least enough to raise some, perhaps several, diagnostic possibilities. Have you any in mind?

YES.

Name one.

PNEUMOCOCCAL PNEUMONIA.

Good. The general signs of a pneumonic process are present. Of course, you haven't isolated the bug. Do you think the belly pain and flank pain reinforce the case for pneumococcal pneumonia?

NO.

Right. Though the white count is consistent, isn't it?

YES.

I think so too, but a later reading is indicated to confirm this finding. We've considered one possibility. Do you have another diagnosis in mind?

NO.

In that case I'd like to talk about pulmonary infarction. What I like about that diagnosis is the presence of high fever, rusty sputum, and shaking chills; I don't like the dyspnea, pleural pain, and signs of consolidation—do you agree?

NO.

You're quite correct. I was just trying to see whether or not you were alert—and you were. Now let's see how the patient is today. Begin the physical when you're ready.

[*Deleted: requests for general appearance and vital signs.*]

PNEUMOCOCCAL PNEUMONIA.

Yes, I remember you liked this diagnosis before. Are you absolutely sure?

NO.

What would help you nail down the diagnosis?

EVIDENCE FROM SPUTUM SMEAR AND CULTURE.

Good. Anything else?

EVIDENCE FROM X-RAY FINDINGS.

Good. X-ray shows area of consolidation at right lower lobe, consistent with a pneumonic process. Lab reports Gram-positive organisms in the sputum smear and the presence of pneumococci in the culture. Had you thought to rule out things like appendicitis and acute pyelonephritis? Apparently you weren't thrown off by the referred abdominal pain. In any case you've made the correct diagnosis.

The Socratic System places few constraints on the style and strategy of teaching. In designing the problem in medical diagnosis, the subject-matter programmer made certain choices: how full a medical history to incorporate; what restrictions to place on the order of conducting the physical examination; what aspects of the situation were to vary with time; and whether or not factors involved in prescribing treatment should be included. The problem designer can program a problem that does not have a unique solution. He can have the computer refer to pages in a book for pictorial and graphical materials such as x-ray pictures and temperature

charts (though it would not be difficult to extend the system so that these materials could be presented on lantern slides or generated by the computer on its oscilloscope screen). The affective quality of the computer's comments is also a matter for his decision.

About 30 hours were required for the doctor and the computer programmer to prepare the medical case shown. Much of this time was spent in choosing a problem with characteristics that would provide a full but economical demonstration of the system. An additional 30 hours of computer programming and clerical transcription were needed, as well as several hours spent in composing and editing the English prose. With this experience, and with the aid of compiler programs developed since, comparable cases can be designed and programmed for the computer in much less time. Present computer-programming efforts should further reduce the time of problem preparation: we are developing a teacher-oriented compiler to permit a subject-matter specialist, who is unacquainted with computers, to prepare a case program without assistance from a computer programmer.

Three other computer-based systems that use the case method of instruction have come to our attention; all three were developed to aid in teaching medical diagnosis. None of these systems places a comparable emphasis on conversational interaction. Two of them are similar in structure to the alphabet guessing game illustrated above; they incorporate a statistical approach to problem generation which permits generation of large numbers of cases by the computer (*2*). In the third system the student presses one of nine buttons to choose among, and carry out, a variety of activities: he can see a film, answer questions, experiment with the patient, check the patient's condition, check laboratory norms, check a dictionary, or receive help in answering the questions (*3*).

Three other existing systems resemble the Socratic System in providing an automated context for student-controlled exploration. One of them teaches relations between symbolic and graphical representation of mathematical functions. The student can vary the coefficients of an equation and observe corresponding changes in the graph displayed on the oscilloscope screen, or he can sketch a graph on the screen and view the best-fitting function, together with its equation (*4*). In another system, for language teaching, the student speaks phrases in imitation of standard phrases stored in the computer. The computer displays the magnitude and direction in which the imitation must be modified—in intensity, intonation, and rhythm—to decrease its deviation from the standard (*5*). The third system was devised to conduct experiments on perceptual learning. It allows the subject to choose among several modes of practice, and to regulate the introduction of new material (*6*).

Conclusion

The Socratic System was programmed for the Digital Equipment Corporation's PDP-1 computer, a moderately fast, medium-sized machine. The program operates in the time-sharing mode, which permits several students to be served simultaneously and independently. Facilities for computer time-sharing are proliferating rapidly. This development will make possible the economic use of computer-aided instructional systems on a large scale in the near future.

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Chemical-Biochemical Signal and Noise

Resolution of properties at low temperatures may be utilized in the medical sciences.

Simon Freed

As in the reception of signals, the relative prominence of background in a measurement affects the differentiation between contributions from various substances of a chemical system. The relative magnitude of the background affects also the precision with which the property may be measured.

Suppose that the apparatus has high signal-to-noise ratio and introduces negligible error or background in the measurement. Reduction in the background must then be sought in the nature of the chemical system itself. Greater contrast between the contributions stems from the recognition that even a pure substance is, in a sense, an equilibrium mixture of components residing in energy states in each of which the substance has characteristic and precise properties. The magnitude of the measurement constitutes, then, a superposition from the components originating in appreciably occupied states weighted according to the fraction of the substance in each state.

The fractions vary with the temperature, of course—that is, with the thermal energy that maintains the populations of molecules in the activated states. Cooling brings about a redistribution of the populations from higher to lower states, and, at the extreme limit, all the molecules are in the lowest or ground state. The averages are now extremely sharp, since all the molecules are precisely alike.

Imagine a crystal of a salt consisting of positive and negative ions and of

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