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On the possibility of "smart" perceptual mechanisms

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what does "advanced" mean?

Abstract.—A basic feature of some modern theories of perception is the notion of complex or higher order variables which are considered basic for perception. A distinction between "rote" and "smart" mechanisms is introduced and it is suggested that perception consists of smart mechanisms which directly register complex variables. A model of a perceiver, based on the smart polar planimeter, is constructed and used to illustrate the possible consequences of smart perceptual mechanisms for research in areas such as psychophysics, cognition, attention, and perceptual development and learning.

A fundamental idea in Johansson's work on event perception (e.g. 1950, 1964, 1974*a*, 1974*b*) is that perception is based on certain advanced properties of the input available to the visual system. It is borne out also in his empirical studies, where percepts are constantly found to correspond to vectorial properties or projective invariants of the whole set of moving stimulus elements, rather than to their individual absolute motion properties.

Related conceptions have a central role in Gibson's (1950) theory of perception, in which ordinal stimulation or higher order variables are proposed as the basis for perception. In his second book (1966), Gibson treats the information about the environment available in the array of ambient light, in particular in transformations of the array. According to Gibson, the perceptual systems "resonate to" such information (1966; pp. 5; 267), and there is no need for "analysis", "synthesis", "assumptions", "inference", "knowledge", etc. which are traditionally invoked to explain perception.

Opposition to such approaches often takes the form of an argument that basic physical variables *by logical necessity* must be registered first, and extraction of array- or vector-properties must therefore be a secondary process. Depending on whether or not the notion of "complex" variables is recognized, approaches of this kind are regarded either as erroneous or as implying nothing new.

At the root of this controversy there seems to be an ontological issue. The traditional approaches rest upon an implicit ontological standpoint according to which only the basic variables of physics are given primary reality status.

However, a different ontological standpoint is possible. The concepts of physics are regarded as *nothing but* a set of concepts, i.e. developed to satisfy the intellectual and technological needs of a simple and useful theory to cover observations relevant to physics. (For a similar refutation of the hypostatizing of scientific concepts, see Naess, 1974, e.g. p. 35.) In other fields of study different sets of concepts must often be developed in order to make theories *manageable*, even if, as is often the case, the concepts used in physics can, in principle, cover the same phenomena. Providing that standard requirements of logical coherence and empirical support are fulfilled, the primacy of such concepts cannot be challenged by concepts taken from other disciplines. In other words, array- and vector-properties could be just as real within the psychology of perception as light energy is within physics.

Given this possibility, we may ask whether there is really a need for a special set of concepts for the study of perception. The answer seems to be yes for at least two reasons. The first is that one half of the problem of perception, that of available information, has not previously been studied very much. The study of available information for visual perception is called "Ecological Optics" by Gibson (1961). It is a difficult enterprise indeed, since appropriate geometrical and optical concepts are not readily available (see also Lee, 1974, pp. 250–267).

The second reason is that through the refinement of instruments, the observations which the concepts of physics have been developed to account for, have become more and more alien to what is biologically relevant in a natural environment. Therefore, when we go back and describe our immediate environment—that which perception is about—the concepts of physics are often not very

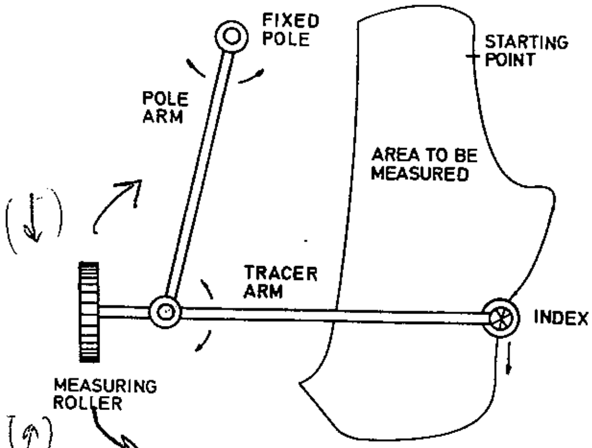

Fig. 1. The principal parts of a polar planimeter.

convenient. For instance, in mechanics simple events are motions in empty space with constant forces. Typical ecological events will therefore require complex, multi-concept descriptions, since they always occur in or on friction media and with nonconstant forces. However, it should be possible to select concepts in such a way as to include in their definitions the common characteristics of natural events. It would allow natural occurrences (virtually everything that we perceive on earth with the possible exception of some technological creations) to be described more conveniently, whereas the simplicity of events in outer space would perhaps disappear—a small sacrifice indeed (Runeson, 1974, 1977).

Now, if the theory of physics cannot be claimed to have monopoly on descriptions of "what is really there", there is no longer any reason to assume that the perceptual systems must necessarily begin by registering what is basic to physics. On the contrary, we should expect perceptual mechanisms which *directly* register variables of high informational value to the perceiver.

The polar planimeter

The idea of a mechanism which directly registers a physically "complex" variable is often somewhat contrary to common sense. A pedagogic device which demonstrates the possibility of such a mechanism would therefore be valuable. Many instruments that technology has provided might be used for this purpose; the one chosen here is the ingenious polar planimeter. It was invented in 1854 by the German mechanic Jacob Amsler, and is used to measure the area of irregular shapes like pieces of land on a map. It has three basic parts (see Fig. 1), the *pole arm* pinned to the surface at the pole, the *tracer arm* with an index and the *measuring roller* at the opposite end of the tracer arm.

After marking a starting point, the boundary line of the figure is traced carefully by the index until it again reaches the starting point. The measuring wheel has then rotated an angle which is directly proportional to the area of the figure. By choosing a suitable length of the tracer arm, the angular units of the measuring wheel will correspond to a convenient unit area, e.g. cm².

Thus, the planimeter is an instrument built for *direct* measurement of a "complex" variable: the area of a plane figure, irrespective of shape.

The instrument is surprisingly simple. No strange mechanical parts, two arms, hinges, and a wheel. No peculiar scales, just a linear one. No calculations, no inferences! The operation of the planimeter follows certain mathematical principles (Klein, 1925/1939, pp. 11–15), which can be understood by means of a not quite commonplace type of geometry, in which one, for instance, discriminates between positive and negative areas, depending on which way they are encircled.

The instrument works because these mathematical principles happen to be translateable into simple mechanical functions, of which the combined rolling and skidding of the roller is perhaps the most crucial. Since this possibility *exists*, we can both construct and use planimeters without any knowledge of the principles as such. The only thing we need is some simple know-how. (It is not known to the author whether the inventor knew the mathematical principle.)

"Smart" vs. "rote" instruments

The planimeter can be said to be a "smart" instrument. It is to be distinguished from "rote" instruments, of which a digital data acquisition system could be an example. The distinction between rote and smart instruments is meant to have heuristic value only and need not be very sharp:

Rote instruments consist of large numbers of a few types of basic components, each of which performs a rather simple task. The accomplishment of complex tasks is possible through intricate interconnections (programming) between the components. The important principles of operation reside in the program, and by changing the program the instrument can be put to different uses. New problems can be approached in a straightforward, intellectual, bureaucratic, "systems", manner. The solutions will be elementaristic and often a bit clumsy.

Smart instruments are specialized on a particular (type of) task in a particular (type of) situation and *capitalize on the peculiarities of the situation and the task*, i.e. use shortcuts, etc. They consist of few but specialized components. For solving problems which are repeated very often, smart instruments, if they exist, are more efficient and more economical. They are also likely to be more reliable and durable. Solution of a new problem requires the *invention* of a new instrument. A straightforward and bureaucratic procedure is not likely to achieve that, since the task is creative and just as much intuitive as intellectual.

It should be noted that the essence of the rote–smart distinction concerns quite delicate aspects of instruments. Although there might be a positive correlation, rote instruments are therefore not necessarily digital and smart instruments are not necessarily analog.

What if perception consists of smart mechanisms?

Given the distinction between rote and smart mechanisms, we may ask to what extent perception could consist of smart mechanisms or processes. It seems that traditional theorizing about perception has tended to imply rote mechanisms, most clearly, perhaps, when an "information processing" approach is taken (e.g. Reitman, 1965) and it is considered a virtue to employ the same conceptual structure for perception as for thinking, learning, etc. (An exception is Miller, Galanter, and Pribram's, 1960, chap. 6, treatment of motor skills, in which it is admitted that perceptual and certain low-level motor functions may be "analog" as opposed to the "digital" functioning of the rest of the mind. Their meaning of "analog" does not seem to correspond to the present meaning of "smart", however.)

For at least two reasons the likelihood of smart mechanisms in perception should be considerable. One is that the basic tasks of perception, and the information available for them, are stable properties of the organisms and the environment, respectively. It therefore seems appropriate that they have been solved through "invention" (evolution) of smart mechanisms. Many of the tasks require more or less continuous operation, which also favors smart solutions.

The second reason has to do with the principle that when designing something one does not normally make it more complex than necessary. The perceptual mechanisms were not designed by a human mind, however, and are therefore not subordinate to the same complexity scale(s) as man-made devices. Biological evolution might have arrived quite easily at solutions which require the utmost of capacity and sophistication of a human mind for their basic principles of operation to be understood. In other words, we should not necessarily prefer one theory of perception over another because it uses less complicated geometrical, logical, etc., principles. Or to quote Bernstein (1967, p. 56):

> "To set up simplicity as a criterion ... would be to affirm in principle that the categories of logic ... dominate the categories of objective reality and determine them, and we have no authority for apriorities of this type."

Given that smart perceptual mechanisms are both possible and likely, it is important that research on perception is not, as it often seems to be, prejudiced against such mechanisms. To prevent that, it is necessary to discuss the possible consequences of smart perceptual systems, and for that purpose a model of a perceiver with such systems will be constructed. The model will then be confronted with some typical approaches and topics in research on perception and related areas.

A PLANIMETER-BASED MODEL OF A PERCEIVER

In analogy with the planimeter and its user, our perceptual systems will be considered as a set of smart *instruments* which are (more or less actively) *used by our intellect* to get information about the environment.

The study of perception would then be the study of the perceptual instruments. This may be subdivided into the search for the *principles* behind the function of the instruments, and the discovery of the *physical realizations* of these principles, i.e. how these instruments are actually built. The former would be the psychological part of the enterprise and the latter would be the physiological part.

The relation between perception and cognition is modelled by the relation between the planimeter and its user. However, it is only the non-perceptual functions of the user which are relevant to the model. Thus, our model does not contain a complete homunculus—only a cognitive, emotional, etc., homunculus. This should be a proper procedure when the focus of interest is on perception.

Sensory psychophysics

The study of relations between simple physical variables and experience is based on the implicit or explicit assumption that such relations are fundamental for the apprehension of "secondary" properties like causality and depth. Even when one finds the latter properties more interesting, one feels obliged to study the "primary" ones first. Mostly, such studies indicate that we are very bad at judging simple variables. This seems paradoxical when confronted with the delicate perceptual tasks we repeatedly perform in normal life.

Consider for instance the tennis player watching an approaching ball. If we somehow combine the uncertainties of judging distance, speed, acceleration, direction, position of hand and tool in hand, etc., it seems impossible that he would be able to hit the ball except by chance. Nevertheless he usually does, so something must be wrong with this analysis. (Bernstein, 1967, pp. 50–57, uses similar arguments in a discussion of motion coordination issues and presents a "principle of equal simplicity" according to which it is possible to reach conclusions about the principles of operation of a system under study by comparing the degree of simplicity (speed, accuracy, variance) with which the system handles tasks of different types.)

Now suppose that a Sensory PsychoPhysicist (SPP) encounters a Person With Planimeter (PWP), who claims himself to be able to measure the area of irregular shapes with good precision. To test this claim, SPP gives PWP the task of measuring the *length* of a line, since he considers this to be basic to area measurement. Having nothing but the planimeter at hand, PWP is very confused, but since he is not allowed to talk during the test he tries it anyway. He draws a crude circle with the given line as radius and measures the area. Then he mentally divides this measure by 3, which is a manageable approximation of π and takes an approximate square root out of it. Thus he arrives at the length of the line.

SPP correctly observes that the answer is of very low precision. Varying the test conditions, SPP finds out that the judgments are also influenced by practice, emotions, set, fatigue, and rewards. He concludes that the planimeter is a crude and unreliable instrument! He reasons further that if PWP happens to make good measurements of area (SPP never thinks of testing that), it could not be based on the planimeter alone. He probably uses other cues (like comparing the area with the size of his hand) and has a miraculous ability to combine cues in a way that makes all uncertainties even out. Or he is a cheater who somehow knows the answers in advance!

Moral. From this can be seen that the fact that subjects *do* judge a certain variable does not prove that they possess perceptual mechanisms of an appropriate kind. When the task does not fit the perceptual mechanisms we must expect the subject to try to compensate by using intellectual abilities, and such results will not be relevant to the study of perception (cf. Sjöberg, 1968).

What indications are there to help us differentiate true perceptual reports from pseudo-perceptual judgments? Since the latter are the results of multistage elaborations on output from perceptual mechanisms, precision is likely to be low, and factors known to influence cognition should have an influence here too. Basic perceptual phenomena, on the other hand, should be stable, striking, and hard to change at will, to an extent which corresponds reasonably well to normal perception.

A more direct distinction between perception and cognition can often be made phenomenologically (see Michotte, 1955). It is usually possible to explain to an observer the difference between "to see" and "to know", between a "direct impression" and what he can "figure out"—at least if we explain to him why it is of interest to study the former.

The task of the observer in a perception experiment is nevertheless to a large extent a cognitive one—to describe or judge what he perceives (Michotte, 1959). Therefore it must be made very clear to the observer that his cognitive efforts should be directed towards *communicating*, in the most faithful way, his percepts—not towards elaborating and supplementing them. This could sometimes be a delicate task, since we must in principle leave it to the observer to decide what dimensions and categories are relevant to the percepts (Runeson, 1974, 1977). Both experimenter and observer must also be alert to the possibility that the stimulus arrangement may not give rise to any clear percept at all.

The methods suggested do not, of course, allow for clearcut distinctions between perception and cognition in all cases. Although foolproof scientific methods are desirable, they are in fact rare, and existence of an unclear borderline zone does not necessarily invalidate a distinction. There are enough cases where the distinction is unproblematic for fruitful research to be carried on, and sometimes the distinguishing between perceptual and cognitive components could be a valid research problem in itself.

As an example of the dangers inherent in conventional analysis of perceptual tasks into "basic" components, consider the case of a perceiver moving towards an object or an object moving towards a perceiver. The task of judging how much time is left before collision, might seem to consist of picking up the present distance and speed of approach, and dividing the latter into the former. Since both speed and distance occur in depth, information about these must in turn be based on proximal information properties or cues, such as size and expansion rate of the projected object. A complex task indeed, it would seem!

As has been shown by Lee (1974; see also Hoyle, 1957) the situation contains certain invariants (or "peculiarities", as it was called above) which a smart perceptual mechanism could make use of and solve the task in a much simpler way, however. It turns out that "time-to-collision" (Lee, 1974, p. 263) is uniquely determined by the *rate of expansion of the image* of the object approaching or being approached. Thus, a highly relevant type of information for such activities as controlling locomotion, avoiding looming dangers, and catching or hitting missiles, is available as a quite simple property of the optic array. The abovementioned tennis-player would be much better off if his perceptual systems were smart enough to make use of this geometrical invariant.

A related example concerns the case of running towards a fence and jumping over it. It would seem that an efficient jump must be initiated at a certain distance from the fence. This distance, in turn, must depend in a rather complicated way on a number of variables such as speed of approach and height of fence, both of which are distal properties. Even in this case certain invariants have been shown to exist, however, which make the above analysis of the task inappropriate, and allow for a much smarter solution (Lee, 1974, p. 263). Quite surprisingly, speed of approach is not necessary to know, nor is it necessary to determine *where* to jump. The only thing that needs to be determined is *when* to jump, or more precisely how long in advance of colliding with the fence the jump should be initiated. And that happens to be a simple function of the height of the fence only!

The two examples above rest on quite simple and universal invariants of geometry and mechanics, and ought to have been brought into perceptual research long ago. Since the process of discovering smart possibilities is by no means straightforward, but rather a matter of the researcher's creativity, there is no way of excluding the possibility of perceptual mechanisms which are smarter than the ones we can presently think of. This is all the more so because we must expect perceptual mechanisms to make use of invariants which are much less universal than those of scientific geometry and mechanics, namely those of the normal biological environment, or even of the particular ecological niche in which the animal has evolved. It seems that our knowledge about such invariants is rather meager. (The issue is to be treated in a forthcoming book by J. J. Gibson.)

The argument above might suggest to some readers that perception is based on "assumptions" about the world. It would be a misleading idea for many reasons. For instance, to work by assuming something implies that one knows about or can imagine a more general situation which for the present purpose needs to be narrowed down. However, there is no reason why evolution (nor the resulting animal) should "know" anything about more general conditions. For the evolving animal its ecological niche *is* the universe. If a perceptual mechanism can pick up useful information in and about this universe, it is there to stay. The difficulties that we as scientists, trained in abstract geometry and theoretical physics, encounter in our attempts at understanding the preconditions for perception should not be ascribed to the perceptual system under study.

Cognitive psychology

Feeling that he had not been treated justly, our PWP leaves SPP and goes to a Cognitive Psychologist (CP), who gives him a problem-solving task—to determine the area of an irregular shape. "At last", PWP thinks, measures the area and reports the result, knowing that his abilities will now be fully appreciated.

CP, however, does not seem very interested in the result. He quickly proceeds to the question, "Now please tell me how you did that!"

"Oh, I just measured it", says PWP.

"Of course you did, but what did you think when you did it?"

"Well, I thought I'd better be careful, to make a good impression on you."

"Very well" says CP, "but how did you argue?"

"I'm afraid I didn't argue at all", answers PWP, who is by now a bit puzzled by the questions.

"Now, tell me step by step exactly how you did it!"

"You see", says PWP, "first I mark a starting point. Then I trace the contour ..."

"Well, well, thank you for your cooperation", interrupts CP, "the test is finished."

Afterwards CP is first puzzled, then delighted by the discrepancy between the paucity of conscious content and the correctness of results, and he starts writing a thesis on "unconscious thinking" and "irrational rationality". Two years later he has thrown out consciousness and thinking altogether and become a behaviorist.

(The story about PWP and CP is modelled on Boring's 1950, pp. 402–410, and Humphrey's, 1951, pp. 34–36, accounts of an old weight-judgment experiment by the Würzburg-school member Marbe, the result of which is said to have had a crucial impact on the course of the science of psychology.)

Moral. The possibility of smart perceptual mechanisms creates pitfalls for the cognitivist, too. No task can a priori be classified as cognitive, no matter how complex it might seem. The amount and kind of thinking needed to solve a particular problem depends, of course, on the quality of the input to the thinking process. And that input, the "data of sense", consists of the conscious output from the perceptual processes. Since there is theoretically no limit to the complexity of sense data, we again end up in a situation where it must be determined empirically what is perceptual and what is cognitive in each task.

Although Marbe's subjects (and PWP) resisted, there is always a risk that subjects surrender to demands from the experimenter (or themselves) and give false ad hoc rationalizations as accounts of how they arrive at judgments which are in fact obtained through direct perception. Since the processes of perception are unconscious, such rationalizations well be based on the subjects' intellectual ideas about how judgments ought to be arrived at. The results will therefore be particularly alluring to experimenters with a cognitivist bent.

Perceptual development

If a person discovers that he has a planimeter he usually cannot use it immediately. He has to find out how to use it, a procedure which is often aided in a crucial way by having someone else to show him. After that he has to try it for a while before he can handle it safely and conveniently. And the instrument may need some calibration and running in.

Moral. Many results on perceptual development could probably be understood in learning-to-use terms (Gibson, 1966, p. 5). The analogy reminds us that when we observe the gradual emergence of a perceptual function, it does not prove that a perceptual mechanism is being built or acquired through experience. The central principles behind its function might be genetically given in certain preprogrammed neural structures. Once fully developed, the mechanism must only be discovered and put to use.

Inhibited practice

If a person is not allowed to use his planimeter for a number of years, he may be unable to use it afterwards. Either the planimeter has deteriorated through corrosion or the user has grown too old to relearn its use.

Moral. The problems encountered by blind people who get their vision back through operation could be of the above kind. The same might be true for the practical blindness exhibited by kittens who have been moved around passively for a long time.

Practice effects

Prolonged experience will often lead to increased precision and flexibility in the use of a planimeter. The improvement could consist both of a general increase of proficiency and of the adoption of certain tricks. For instance, making a double measurement, one forwards and one backwards, will eliminate certain instrument errors. "Islands" inside the area can be subtracted directly by tracing them backwards, and large areas can be measured with the pole inside the area if a constant is added to the result, etc. It is also possible to correct for a mistracking by making another mistracking on the

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opposite side of the line, and to change the length of the tracer arm for convenient measurement on maps of varying scales. None of these tricks entail any changes in the instrument nor do they require any knowledge of the theory of the planimeter.

Moral. The increased precision and differentiation of perception with practice need not entail any changes in the basic principles of operation of the perceptual mechanisms but could be due to changes in the way they are put to use.

Adaptation to distortion

If the planimeter is "hurt", for instance if the pole arm is bent or the calibration chart is lost, recalibration is possible by means of a simple device which is supplied with the instrument. Thus, it is in a way self calibrating.

Moral. Adaptation to prismatic and other distortions of the visual input might perhaps be understood as recalibration processes which do not alter the basic perceptual mechanisms.

Attention

Let us now equip our model of a perceiver with many instruments. Some of them, like the planimeter, operate only when actively used by him, and thus only one of these can be in operation at a time. But he also has instruments of a different kind which are parts of systems in which they are connected on-line to executive devices and operate more or less continuously. Thermostats and autopilots are systems of this kind. Their autonomy is conditional, however. The user can interrupt an on-line connection and take command of a system any time he wishes. He will thus be able to exercise a more critical evaluation of the information coming from the instruments (although he will usually *not* be able to interfere with their information-getting procedures), and he can supplement or replace it by relying on some of the off-line instruments. He can also select actions more carefully. The user must be cautious in taking command of a system, however. Although his intellectual powers are good for many purposes such as handling unusual situations, they may be very clumsy when breaking into a smart on-line system, and the effect might be bad or even disastrous.

Even if the user can take command any time, he is likely to do so only in the following types of situations:

(*a*) when he wants to make a routine check on what is going on,

(*b*) when he wants something special to be done,

(*c*) when the record of ongoing activities indicates something peculiar,

(*d*) when a system calls on him because it has encountered something which it is programmed to call on him for,

(*e*) when there is an alarm signal from one of the on-line systems.

The user could, of course, stay in command all the time, but the on-line systems will relieve him of a lot of routine and allow him to devote himself to more qualified, creative, and interesting activities. The existence of attention and alarm signals will allow him to do so, or to relax, without taking too many risks.

Some of the on-line systems might have been given from the beginning to our perceiver model, but he may also build new ones. He may thus take an off-line instrument, such as the planimeter, and equip it with gadgets like automatic zero setting and an automatic line tracer. Finally, the measuring roller could be connected to some of the executive devices, and the system could be left to run with less and less intervention of the user. After some time the user might even have forgotten how to use the planimeter off-line and will get problems if he tries to intervene. He will neither be a good teacher of planimeter use nor of how to build new on-line systems.

Moral. The analogy to attention phenomena should be obvious. "To attend to" something corresponds to the "taking command of" a particular system, checking the information and/or directing other instruments to it.

Among the five reasons for taking command, *a* and *b* and to a certain extent *c* represent cognitive ("active", "inner") control of attention, whereas *d* and *e* represent perceptual ("passive", "stimulus") control. Note that "control of attention" refers to the initiation ("catching") of attention only, and that sustained attention is always a cognitive process (PWP himself decides how long he should stay in command).

The building of new on-line systems corresponds to the acquisition of perceptuo-motor skills. Typically, these are mastered first in an intellectual way with much attention devoted to details of the perceptual input and/or the motor output. This slow and tiresome procedure gradually gives way to more or less automatic functioning in the sense that attention is required only for the more global or intentional aspects of the skill (see Miller et al., 1960, chap. 6). The planimeter analogy suggests that acquisition of skills need not entail learning of anything fundamentally new, but could more probably consist of the establishment of new connections between existing perceptual and motor mechanisms.

FINAL REMARKS

The model illustrates the possible nature of smart perceptual mechanisms and its consequences for theorizing about perception and cognition. It suggests a sharp distinction between perceptual and intellectual processes by specifying a relation between them and some specific types of interaction. It is implied that perceptual mechanisms in general are responsible for more advanced information processing than commonly assumed.

This may help to settle the conflict in our image of man between stable "mechanical" and flexible "human" functioning. It could release theories of cognition from the burden of explaining perceptual functions, and let theories of perception deal with all perceptual phenomena irrespective of complexity, instead of confining them to the leftovers between physiology and cognition.

More generally, the technology of instruments can provide us with a number of useful concepts. If the objection is raised that the complexity of the human mind is too great to be represented by such concepts, be it remarked that it would be a great step forward if we could grant to the concepts of psychology the degree of sophistication commonly assigned to instruments.

Note. To prevent a possible misunderstanding: The planimeter is *not* intended to be a model of how we perceive area. Nor is area meant to be a basic perceptual variable.

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