Parallel versus serial processes in multidimensional stimulus discrimination¹

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Although considerable effort has been devoted to the description of processes underlying discriminations along single dimensions, there have been few attempts to determine whether or how these elementary processes are combined when discrimination requires the consideration of more than one stimulus dimension. In the present experiment, Ss were required to indicate whether two simultaneously presented multidimensional visual stimuli were identical or different. The response measure was reaction time, and Ss had a monetary incentive to respond both quickly and accurately. It was concluded that the most appropriate model for this task is one that assumes that dimensions are compared serially, and that the order in which dimensions are compared varies from trial-to-trial. Further, when a pair differs along several dimensions, Ss do not necessarily examine every dimension before initiating the response "Different."

Although considerable effort has been devoted to the description of processes underlying discrimination along single dimensions, there have been few attempts to determine how these elementary processes may be combined when discrimination requires the consideration of more than one stimulus dimension. Despite the fact that they have not been amply studied by psychologists, discriminations among complex stimuli are far more common and important in our daily lives than simple discriminations. The present study is an effort to increase our understanding of complex discriminations by investigating in detail the fundamental task of deciding if two simultaneously presented multidimensional stimuli are identical or different when Ss have an incentive to respond both quickly and accurately.

The specific question which is dealt with in the present investigation is whether humans discriminate between multidimensional objects by comparing them one dimension after the other (serial mode), or by comparing them on several dimensions simultaneously (parallel mode), or by comparing unitary representations of them without regard to their component dimensions (template mode). These three modes of information processing are of particular interest since there have been several recent attempts to assess their applicability to the task of pattern recognition as performed by both humans and computers (e.g., Uhr, 1963; Neisser, 1964; Sternberg, 1963). Each of these modes provides the basis for a class of models of the stimulus comparison process. Specific instances from these classes are discussed and, for each, behavioral predictions are made which may be tested against obtained data. In particular, the predictions which are made by each

model regarding two important relations are stated to give a basis for comparison among the models. These relations are: (a) the function relating the time taken to determine that two objects are identical, i.e., "Same" reaction time (RT), to the number of relevant dimensions, and (b) the relation, for any given number of relevant dimensions, between the time required to determine that two objects are different ("Different" RT) and the number of relevant dimensions along which there are differences.

To facilitate the description of these models and their behavioral predictions, a set of three hypothetical two-valued dimensions (X, Y, Z) will be referred to occasionally. This set of independent dimensions, which may be used in constructing pairs of stimuli, has the characteristic that the two levels of X can be more quickly discriminated from one another than can the two levels of Y, which are, in turn, more discriminable than the values chosen for Z. The identical ordering of dimensions for "Same" RT also obtains.

In deriving predictions from all of the following models it is assumed that Ss are uninfluenced by the presence of irrelevant information. That is, it has been assumed that if a set of complex stimuli contains a dimension which is irrelevant to the judgment of "Same" vs. "Different," then Ss are capable of completely filtering it. Although it is a simple matter to find instances in which irrelevant information (noise) cannot be ignored, there is evidence that, in reaction time experiments similar to the present one, Ss may filter irrelevant information. This evidence and the validity of the filtering assumption for the present experimental task are both treated in the discussion of the present experiment.

Serial models. Serial models are characterized by the assumption that in determining whether two simultaneously presented multidimensional stimuli are the same or different, the two stimuli are compared dimension by dimension, one comparison after another. This assumption, in conjunction with the assumption that the comparison processes are independent, leads to the prediction that "Same" RT should increase with the number of relevant dimensions since a pair of stimuli must be found identical along every relevant dimension before a "Same" response can be made. Thus when all three dimensions (X, Y, Z) are relevant "Same" RT ought to be slower than the average of those three conditions in which two dimensions are relevant (X & Y, X & Z, Y & Z), and that average ought to be slower than the average of those three conditions in which only one dimension is relevant (X, Y, Z).

In fact, it is a simple matter to show that as long as the same dimensions are used at each level of dimensionality (as in this example) the function relating mean "Same" RT to the number of relevant dimensions must be linear.

There are two attributes of serial models which are considered here, for the sake of simplicity, to be dichotomous. One attribute is concerned with whether "Different" judgments are made as soon as the two objects are found to differ on one relevant dimension (self-terminating comparisons), or whether every relevant dimension is examined on every trial regardless of the outcome of any comparison (exhaustive comparisons). The other attribute of serial models has to do with the order in which dimensions are compared. The two extreme cases considered here require Ss to use either a fixed order on every trial or a random order over a series of trials. Taken in combination, these two attributes result in four possible sub-classifications of serial models.

Since all serial models yield the identical prediction that "Same" RT must increase linearly with the number of relevant dimensions, only predictions concerning "Different" RTs are stated for each particular model. Serial/Exhaustive/Fixed order and Serial/Exhaustive/Random order both predict that for any given number of relevant dimensions, "Different" RT will be the same regardless of the number of relevant dimensions along which there are differences, since all dimensions are always compared. Thus, when Ss are dealing with two-dimensional stimuli, they ought to respond "Different" no faster when the pair of objects differs on both dimensions than when they differ on either one alone. These two models cannot be distinguished by the experiment proposed in this paper.

Serial/Self-Terminating/Fixed order and Serial/Self-Terminating/Random order both predict that for any given number of relevant dimensions, the greater the number which differ between two objects, the faster will be the average "Different" RT. This prediction is based simply upon the self-terminating assumption; on the average, the larger the number of dimensions which differ between two stimuli, the earlier will one of these differences be detected, whether the order of examination is fixed or random. These two models may be distinguished on the basis of another prediction about "Different" RTs. For example, when there are three relevant dimensions, an experiment can be arranged so that on certain trials there will be only one dimension along which there is a difference. Over a series of such trials, we can establish the mean "Different" RT separately for each dimension when it alone is different between the two stimuli. Assuming a fixed order of examination, the fastest of these RTs indicates the dimension which is interrogated first. This dimension is not necessarily the most discriminable one, it is simply examined before the others. (The fastest of the observed "Different" RTs will

indicate the dimension that is interrogated first as long as the time required to judge that two stimuli are different is not substantially greater than the time required to judge that they are the same.)³ With this RT as a standard, we may now inquire into the effect of having differences along one or more other dimensions in addition to the one that is interrogated first. If the process takes place in a fixed order, then adding more differences cannot reduce RT below the "standard," since, of course, none of the additional differences will be detected after the first one. In terms of the hypothetical set of dimensions introduced earlier, when X, Y, and Z are all relevant, if the "Different" RT when X alone differs between the two stimuli is shorter than the "Different" RTs when either Y or Z is alone different, then X must be interrogated first. Further, if Y and X, or Z and X, or even Y, Z, and X differ within a pair of stimuli, "Different" RT can be no faster than when X alone is different. However, assumption of a random order of comparisons from trial-to-trial leads to quite a different interpretation of the finding that differences along one of the dimensions (X) yield faster "Different" RTs than differences along either of the other two (Y or Z). The assumption of random order of comparisons obviously precludes the conclusion that X is consistently interrogated first, and implies that the observed mean "Different" RT when X alone is different is based in part on trials on which Y, or Z, or Y and Z are interrogated first. Thus, if Y and/or Z differ in addition to X, then the mean "Different" RT can be faster than when X alone is different since on those trials on which Y or Z happens to be examined first, the comparison process can terminate without having to reach X.

Parallel models. Parallel models are characterized by the assumption that several comparisons may be made simultaneously. To make this presentation specific, the further assumptions are added here that these tests commence simultaneously and that irrelevant information is ignored. As with serial models there are two important dichotomous attributes of parallel models. First, parallel comparison processes may be either exhaustive or self-terminating. Secondly, the time required to make a comparison along a single dimension may be either constant over all trials or it may fluctuate somewhat from trial-to-trial, as would be the case if comparison times were distributed like a random variable. A word of explanation must be given concerning the implications of the assumption that comparison times are statistically distributed (for a more complete discussion see Rapoport, 1959). For example, consider a "Same" judgment; a correct decision hinges upon the outcome of as many tests as there are relevant dimensions. Therefore, a correct decision takes at least as long as the longest component. However, the mean of the longest time in a sample of statistically distributed times increases as the size of the sample increases, if there is any overlap at all

among their respective distributions. Thus, the greater the number of relevant dimensions, the longer will be the mean time required to judge that two stimuli are "Same." Note that in the case of serial models it was not important to specify whether a comparison was of a fixed or a statistically distributed duration since predictions were based simply on expected values of a series (sum) of such processes.

In the section on serial models, it was important to know which single dimension gave rise to the fastest "Different" RT on those trials when, among several relevant dimensions, it alone was different. The same information is important for testing predictions from the parallel models. In addition, it is crucial to find out which dimension yields the slowest "Same" RTs. Of course, Ss can correctly respond "Same" on the basis of a single dimension only when there are no other relevant dimensions. Thus, for each dimension which is used in the conditions requiring multidimensional judgments, a separate condition must be run in which it is the only relevant dimension. From the results of these conditions, it is possible to determine how long it takes to judge that two stimuli are the same with respect to any given dimension. Predictions from the four sub-classes of parallel models follow.

Parallel/Exhaustive/Constant: For any number of relevant dimensions, "Same" RT should be equal to the "Same" RT when the single worst component is judged in isolation. Thus, if Z leads to a slower average "Same" RT than either X or Y when tested in isolation, then the mean "Same" judgments involving X and Z, Y and Z, or X, Y, and Z should be equal to the mean "Same" RT when Z is judged alone. Since the testing is assumed to be exhaustive, "Different" RT when several (but not necessarily all) relevant dimensions are different depends upon the relevant dimension which yields the slowest RTs: for those trials on which that dimension is "Same," the correct response ("Different") is limited by the "Same" RT obtained for that dimension; for those trials on which the "slowest" dimension happens to be "Different," the correct response is limited by the "Different" RT obtained for that dimension.

Parallel/Exhaustive/Distributed: Both "Same" and "Different" RTs will increase with the number of relevant dimensions. Differences along several relevant dimensions will not result in shorter RTs than a difference along the most discriminable of the relevant dimensions.

Parallel/Self-Terminating/Constant: For any given number of relevant dimensions, "Same" RT ought to be equal to "Same" RT for the least discriminable relevant component. Multiple differences will not result in faster RTs than a difference along only the most discriminable component dimension.

Parallel/Self-Terminating/Distributed: "Same" RT for complex stimuli ought to be longer than to the least discriminable component dimension. However, "Dif-

ferent" RT will be faster when there are differences along several dimensions (including the most discriminable one) than when there is a difference along only the most discriminable single dimension.

Template models. The term "template" usually refers to a stored replica of a stimulus object. However, in the present context of comparing simultaneously presented stimuli it is probably worthwhile to ignore the notion that a template must be in memory. Rather, one might conceive of some process which replicates each of the two stimuli in a pair, and then makes an overall comparison between these two replicas. If there is a complete point-for-point match, then a "Same" response is made; if there is any mismatch at all, a "Different" response is made. This hypothesis leads to the prediction that "Different" responses should be equally fast regardless of the number of dimensions which actually are different. Furthermore, since tests are made on the basis of an overall comparison rather than from the combination of elementary tests on separate dimensions, it seems reasonable to predict that "Same" RT for multidimensional stimuli would never be slower than the "Same" RT to the single worst dimension. On the basis of these predictions, template matching seems very similar to the Parallel/Exhaustive/Constant model. Although the experiment reported in this paper cannot distinguish between these two models, they may be distinguishable on other grounds; they are both described here for completeness. (Of course, if they are both rejected on the basis of their common predictions, then it will not be necessary to find their distinguishing features.)

Previous Research

There have been several well conceived studies on the role of dimensionality in stimulus comparison. However, most of them have not used latency as a response measure, and thus offer little help in choosing among the models just presented (e.g., Shepard, 1964; and see Garner, 1962, for a review of the literature on absolute judgments of multidimensional stimuli).

METHOD

Subjects

Six students at The University of Michigan were chosen from a large pool of persons who had volunteered to serve in psychological experiments for pay.

Apparatus

The S sat at a table and looked directly into a Gerbrands two-field mirror tachistoscope which had a uniform light-gray background field. On the table in front of S was a panel with two response keys side-by-side labeled "Same" and "Different." The E gave a verbal "Ready" signal approximately 1 sec. before he initiated the stimulus presentation which was terminated by the depression of one of the two response keys. A printing timer made a record, accurate to the nearest

millisecond, of the time between the onset of the stimulus and the depression of the response key.

Task and Stimulus Materials

There were seven conditions in the present experiment. Each was defined by the dimensions which were relevant to the "Same" or "Different" decision. These conditions were: Color (C), Form (F), Tilt (T), Color & Form (CF), Color & Tilt (CT), Form & Tilt (FT), and Color & Form & Tilt (CFT). Thus, for example, in FT, Ss were to respond "Same" whenever both stimuli were of the same form and tilt, and "Different" whenever form and/or tilt were different; color was irrelevant to the decision.

Pairs of stimuli were prepared on white index cards. A stimulus assumed one of two values on each of three dimensions: Form—square or circle; Color of form—vermillion or light blue, and Tilt of inscribed black line—45° left or right of vertical. The colors were from the Zip-a-tone Company series of adhesive papers; the other dimensions are illustrated in Fig. 1. The outside diameter of the circle was 3/4 in. and the square was 5/8 in. on a side. Since there are eight possible stimuli resulting from the combination of three independent binary dimensions, there are 64 possible pairs of such stimuli. The procedure used to keep the probabilities of "Same" and "Different" responses equal in every condition is outlined in the following three paragraphs.

One-Dimensional Stimuli. For any single dimension, half of the 64 possible pairs were "Same" and half "Different." One copy of each was made, and these, taken together, formed the deck (I) which was used for the three conditions involving single dimensions (C, F, & T).

Two-Dimensional Stimuli. Although half of the cards in Deck I can be categorized as "Same" and half as "Different" with respect to any single dimension, with respect to any pair of dimensions only one-fourth of the cards can be categorized "Same" while three-fourths are "Different." In order to keep the probabilities of the two types of responses equal in every condition, an additional deck had to be constructed for each of the three bidimensional conditions. These decks contained, in addition to the basic 64 cards of Deck I, enough replicas of cards which could be categorized "Same" with respect to the two relevant dimensions, so that half of the required responses would be "Same" and half "Different."

Fig. 1. A stimulus pair illustrating differences along the dimensions of Form and of Tilt of inscribed line.

Three-Dimensional Stimuli. Only one-eighth of the cards in Deck I were "Same" with respect to all three dimensions. In order to keep the probabilities of the two types of response equal, another deck of cards was constructed for the tridimensional condition. It contained, in addition to the basic 64 cards of Deck I, enough replicas of cards which were "Same" with respect to all three dimensions so that half of the required responses would be "Same" and half "Different." For every condition, there were more cards in the appropriate deck than there were trials; cards were selected for use by drawing at random, without replacement, from the pool of available cards.

Procedure

Design. Three Ss were instructed to press the left key to indicate "Same" and the right key to indicate "Different," while the remaining three Ss were given the opposite response-assignment. All Ss served in one practice session and three experimental sessions. In each experimental session they participated in all seven conditions.

Three different orders of presentation of the seven conditions were constructed, and one of the three Ss from each of the two response-assignment categories served in each order. Each order had the following features: (a) the three one-dimensional conditions followed one another in a block, as did the three two-dimensional conditions; (b) the order of the one-, two-, and three-dimensional blocks formed a Latin square over the three days of practice; and (c) within the one- and two-dimensional blocks the order of particular conditions formed a Latin square over the three days of practice.

Each day, Ss received 30 trials in each of the one- and two-dimensional conditions, and 90 trials in the three-dimensional condition (CFT). Thus, each day, 90 trials were given at each level of dimensionality.

Practice Session. During the 1/2-hr. practice session Ss were first apprised of the payoff scheme, described below, which was to be used in the main experiment. They were then given 75 trials in a compatible two-choice reaction time task. On each trial an arrow was presented which pointed either left or right; they were to depress the key corresponding to the direction of the arrow. After each trial Ss were informed of their errors, and their RT. Following these trials, Ss received their response-assignment instructions. A series of 100 trials judging "Same" vs. "Different" with regard to pairs of letters—AA, AB, BA, BB—were given to insure that Ss were familiar with their particular response-assignment.

Experimental Sessions. The first experimental session began with a brief description of the stimuli and of the seven experimental conditions. The payoff scheme was reiterated and Ss were reminded of their response-assignment.

Before each condition, Ss were told which dimensions

were relevant, and were given seven practice trials to insure that they understood the instructions.

There were 5-min. rest breaks between the blocks of one-, two-, and three-dimensional judgments, and 2-min. rest breaks between conditions within the one- and two-dimensional blocks. Also, there were two 2-min. breaks within the 90-trial three-dimensional condition.

Payoffs. Monetary bonuses and penalties were used to maintain fast, accurate responding. The base rate of pay was \$1.00 per session. For every correct response which was equal to or faster than the arbitrary criterion of 450 msec. S received 1¢, while for correct responses slower than 450 msec. nothing was awarded. For every incorrect response, whether fast or slow, 5¢ was deducted from S's earnings—however, Ss were not allowed to earn less than the guaranteed base rate. Speed and accuracy feedback was given after every trial during the experiment.

RESULTS AND DISCUSSION

In order to correct for an observed dependence of variance on mean in the present latency data and thus meet the assumptions of the analysis of variance model the dependent variable used was logarithm of reaction time.⁴ Errors were excluded from the analysis, as were unusually long times (RTs more than four standard deviations above the mean of a particular S's distribution of latencies in a given condition).

Different RT as a Function of the Number of Dimensions of Difference

In the tridimensional condition, CFT, there are seven possible ways in which pairs of stimuli may differ (viz., they may differ along C, F, T, C & F, C & T, F & T, and C & F & T). The data from condition CFT, averaged over three sessions, were subjected to an analysis of variance. Response-assignment was the between-groups variable and the seven categories of "Different" stimuli formed the within-Ss variable. The results of this analysis indicated that the differences among the seven categories of "Different" stimuli were statistically significant, $F=19.42$, $df=6/24$, $p<.001$. Neither response-assignment nor the interaction of response-assignments with the within-Ss variable was a significant source of variance. In Fig. 2 geometric mean "Different" RT is plotted as a function of the number of dimensions along which stimuli differed.

"Different" responses in the three bidimensional conditions were separated into those instances in which the stimuli differed along only one of the relevant dimensions and those instances in which they differed along both of the relevant dimensions. (In either case the data are averaged over series of trials in which the irrelevant dimension was "Same" or "Different" about equally often.) All six Ss had faster geometric mean "Different" RTs when there were differences along both relevant dimensions ($p<.05$).

Fig. 2. Geometric mean "Different" reaction time as a function of number of dimensions along which stimuli differ: Condition CFT. (Vertical lines represent the respective 95 per cent confidence intervals.)

Of the models considered in the introduction, only two are consistent with the data reported above, viz., Serial/Self-Terminating/Random order of interrogation and Parallel/Self-Terminating/Statistically distributed comparison times.⁵

It is possible, of course, that the use of data averaged over three days of practice may obscure changes in an S's mode of stimulus comparison which occur in that period of time. To test this possibility, data from condition CFT were analyzed in more detail.

For each S and each day of practice, "Different" responses in the tridimensional condition were classified according to the number of dimensions along which the stimuli differed (one, two, or three). The geometric mean RTs for each of these categories was calculated, and for each S on a given day, the categories were ranked according to RT. For four of the six Ss the ranks on each day of practice were identical and indicated that "Different" RT was fastest when there were differences along all three dimensions and slowest when only one dimension differed (probability of identical order of three categories over three days for any single S, $<.03$). A fifth S showed the same pattern for the first two days, but reversed his rankings for one and two dimensions of difference on the last day ($p<.2$). For the sixth S, "Different" RT was consistently fastest when there were differences along all three dimensions; however, on two days, he reversed the usual order for one and two dimensions of difference. Thus these data fail to indicate any major change in the stimulus comparison process over three days of practice. It is conceivable, of course, that Ss did switch from one of the two remaining models to the other; however, such a change presumably did not result in a different ordering of the various categories of "Different" stimuli.

"Same" RT as a Function of the Number of Relevant Dimensions

Mean log "Same" RTs were subjected to a three-way analysis of variance in which the seven conditions and three days of practice were within-S variables and response-assignment was the between-groups variable. Since the means of condition CFT were based upon three times as many observations as the means in the other conditions, a least-squares solution was required (Winer, 1962, p. 375ff). The results of this analysis indicated that the conditions were significantly different from one another, $F=9.11$, $df=6/24$, $p<.001$, and that practice led to a significant decrease in RT, $F=21.77$, $df=2/8$, $p<.001$. Response-assignment was the only other source of variance which approached significance, $F=5.83$, $df=1/4$, $.05<p<.10$. None of the interactions among the three variables was statistically significant ($p>.10$). In particular, the failure to find an interaction between days and conditions indicated that these data do not permit the conclusion that different models are appropriate at different levels of practice.

Geometric means of "Same" RTs for the tridimensional condition and the three bidimensional and the three unidimensional conditions are given in Fig. 3, along with the overall averages for the one-, two-, and three-dimensional conditions. Examination of the 95 percent confidence intervals for these overall averages indicates that the relation between "Same" RT and the number of relevant dimensions is reliably nonmonotonic, thus supporting none of the nine models proposed in the introduction.

It seems likely that the shape of the obtained function is reflecting other processes than comparisons among

Fig. 3. Geometric mean "Same" reaction time as a function of number of relevant dimensions: (Vertical lines represent the respective 95 per cent confidence intervals.) Points at the right represent the geometric mean "Same" reaction times for each of the seven conditions.

relevant dimensions. One possibility is that Ss adopted a lower "decision criterion" in condition CFT, i.e., that they were faster in this condition because they allowed themselves a higher error rate (see, e.g., Fitts, in press). In the present experiment, however, there is a *positive* correlation across conditions between speed and accuracy, and in particular the tridimensional condition had a somewhat lower error rate than any of the bidimensional conditions.

Another possible explanation of the nonmonotonic relation between "Same" RT and the number of relevant dimensions is loosely related to the Gestalt principles of perceptual organization. Since the comparison of stimuli when all three dimensions are relevant is a comparison of two whole figures, there is reason to think that such judgments ought to require less time than judgments which require the S to analyze the figures and compare components of the whole. This interpretation, although plausible, has the defect of leading to the prediction that tridimensional "Same" judgments ought to require less time than unidimensional "Same" judgments, although the opposite obtained.

A third possible explanation of the relation between "Same" RT and dimensionality lies in a more thorough analysis of the Ss' task. Specifically, it should be pointed out that in order to make a correct response in the uni- and bidimensional conditions it is necessary to disregard information from irrelevant dimensions. There is considerable evidence that Ss can effectively ignore (filter) information from irrelevant dimensions in speeded tasks (Archer, 1954; Green & Anderson, 1956; Morin, Forrin, & Archer, 1961; Fitts & Biederman, 1965; Imai & Garner, 1965). Nevertheless, there is reason to believe that in the present experiment Ss did *not* ignore irrelevant information. If Ss were "filtering" irrelevant dimensions, then whether a pair of stimuli was "Same" or "Different" on these dimensions should have had no influence on the obtained RT. This null hypothesis was tested for the "Same" RT in the uni- and bidimensional conditions. Consider first the unidimensional conditions, each of which involved two irrelevant dimensions. "Same" RTs in each condition were separated into two (nonexhaustive) classes—those obtained when pairs of stimuli were the same on both irrelevant dimensions or when they were different on both. There were 18 possible comparisons made (6 Ss by 3 conditions), all of which indicated that unidimensional "Same" judgments were shorter when the stimuli were "Same" on both irrelevant dimensions. When the bidimensional conditions were analyzed in a similar way, 16 of 18 comparisons indicated that "Same" judgments were faster when the stimuli were the same with respect to the irrelevant dimension than when they were different. It is clear that Ss did not completely ignore the irrelevant dimensions. This finding has several implications for the analysis of the "Same" RT function shown in Fig. 3. Firstly, since irrelevant di-

mensions did influence RT, then on at least some trials, Ss must have interrogated more dimensions than were logically necessary. This has the effect of making an observed uni- or bidimensional RT reflect more than the comparison times for the relevant dimensions. Secondly, since the error rate did not exceed 13% for any condition and since the function in question is based upon only correct responses, Ss must have in some way "suppressed" a tendency to respond on the basis of irrelevant dimensions, and it is plausible to think that this suppression took time. Therefore the RTs in the uni- and bidimensional conditions are not indicative of the times required to compare only relevant dimensions, and some other basis must be sought, in present data, to distinguish between the two models which still remain plausible.

Another Basis for Distinguishing Between Serial and Parallel Models

The Parallel/Self-Terminating/Distributed model leads to the following prediction: Considering "Different" judgments made in the various conditions of the present experiment, the fastest ought to be in condition CFT on those occasions when all three dimensions are in fact different. The Serial/Self-Terminating/Random model leads to the prediction that the fastest "Different" judgments ought to be obtained in the best of the uni-dimensional conditions, since the model assumes that Ss can interrogate the single relevant dimension first and then stop. According to the latter model, in condition CFT, with all dimensions different, the S, of course, detects a difference no matter which dimension he interrogates first; however, on some proportion of trials he does so by examining first one of the less discriminable dimensions. Thus in the tridimensional condition, Ss ought not to be as consistently fast as they can be (in principle) in the best of the unidimensional conditions. These predictions were compared by determining the geometric mean "Different" RTs to identical types of stimuli (viz., different along all three dimensions) in conditions C and CFT. Five of six Ss were faster in condition C than in CFT, thus lending support to the serial model.

Although we have seen that Ss do not always completely ignore irrelevant dimensions, this does not necessarily invalidate the comparison just made. It should be clear that a prediction of the condition that ought to yield the shortest "Different" RTs may be valid as long as the assumptions on which it is based are not violated too severely. Just how severely were the assumptions of the two models violated? Although a quantitative index is not available, we may answer in the following way: They were enough in error to invalidate the assessment of the relation between "Same" RT and the number of relevant dimensions; however, they were sound enough to allow a meaningful interpretation to be drawn from the relation between "Different" RT and the number of relevant dimensions

that differed between two stimuli. The crucial point in this argument is that the prediction of the condition yielding the shortest mean "Different" RT seems to require no more from the assumptions than did the prediction of the relation between "Different" RT and the number of dimensions of difference.

The results of the present experiment make it painfully clear that irrelevant dimensions of variation are not necessarily ignored at the command of the experimenter. It has already been pointed out that Ss in several previous experiments were able to filter irrelevant information. It is important to determine whether Ss in the present experimental situation could have filtered irrelevancies but chose not to do so, or whether the present conditions made filtering more difficult. Since all irrelevant dimensions were at other times relevant, it is a distinct possibility that implicit competing responses were engendered by irrelevant information (Hodge, 1959; Montague, 1965). However, Imai and Garner (1965) have demonstrated perfect filtering in a task in which irrelevant dimensions were also at other times relevant. This discrepancy is unresolved.

It seems clear that until more is known about the processing of irrelevant information it will be difficult, if not impossible, to achieve a good understanding of the processing of relevant information.

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Notes

1. The study reported here is part of a dissertation submitted to the faculty of the Department of Psychology of the University of Michigan in partial fulfillment of the requirements for the Ph.D. degree. The research was supported by the Advanced Research Projects Agency, Department of Defense, and was monitored by the Air Force Office of Scientific Research, under Contract No. AF 49 (638)-1235 with the Human Performance Center, University of Michigan. The author held a National Science Foundation Fellowship while the research was being carried out. The generous help of J. D. Birch, P. M. Fitts, J. E. K. Smith, R. S. Tikofsky, and D. J. Weintraub is gratefully acknowledged.
2. Now at the Johns Hopkins University.
3. Unfortunately, there is no direct evidence on this point in the present experiment, since the data concerning the two kinds of judgment times come from two different response systems, viz.,

the left and right hands. The task itself may impose response biases which could favor one response over the other, even though a payoff matrix was introduced to mitigate any such response preferences. It is for this same reason that no predictions were made that involved a comparison between "Same" and "Different" response times.

4. The reliability of the conclusion that "Different" RT decreases with the number of dimensions along which a pair of stimuli differ is attested to by the results of another experiment carried out by the author. Eighteen Ss made "Same" and "Different" judgments about pairs of four-dimensional stimuli. Again, the factor of number of dimensions of difference was a highly significant source of variance, $F = 24.42$, $df = 14/224$, $p < .001$. "Different" RT decreased regularly with increasing number of dimensions of difference.

5. The models developed in the introduction are based upon reaction time, not a logarithmic transformation of reaction time. Nevertheless, the general relations observed in the present experiment would be preserved by any reasonable monotonic transformation of these raw data.

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