

STUDIES IN INDIVIDUAL DIFFERENCES IN MAZE ABILITY

VII. THE SPECIFIC COMPONENTS OF MAZE ABILITY, AND A GENERAL THEORY OF PSYCHOLOGICAL COMPONENTS¹

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In attempts to develop an experimental comparative psychology of individual differences, one encounters the pervasive problem of describing the *psychological* nature of the differences between individuals. I conceive it merely necessary but not sufficient in our series of experiments to prove the purely objective facts that differences in maze ability *X* are reliable (12), are unrelated to certain obvious physical characters (13), correlate high with maze ability *Y* (14), persist over a long period of time (15), and are inherited (8, 9, 10). But we should now ask: conceptually, emotionally, motivationally, what is the bright rat doing in the maze in psychological contrast to his duller fellow?

This psychological analysis requires our examining in some detail the behavior of the animals in the actual maze situation, utilizing not only quantitative evidences of differences in performance but also, if you will, "clinical intuition," based on many hours of observation of the rats in the maze. I do not see how the comparative psychologist, if he is to be psychologist, and not sterile objectivist, can escape a heavy load of inductive inference in describing the psychological components of behavior.

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The first part of the paper is specific, being concerned initially with a statement of the criteria by which any inferred set of components may be accepted as valid, this to be followed by a detailed description from the maze data of the psychological components believed to determine individual differences in this particular maze performance. The second part deals with general comparative psychological theory. In it, using illustrative material from the first, I shall describe the general properties of psychological components and of the coalitions of these that determine individual differences in objective performance. This conception of components leads directly to a description of the general nature of learning, which is seen to be a statement of the nature of the change of a coalition under conditions of repeated experience. The second section is therefore an attempt to develop what Tolman calls a "complete psychology," aiming to integrate the normative and individual difference viewpoints.

I. THE PSYCHOLOGICAL COMPONENTS OF THIS MAZE ABILITY

Our specific task is to discover the psychological components determining the maze performance of 1,085 rats who ran 19 trials on the 17 T-unit maze called Maze X. I assume that the cognitive dispositions of the rat can be inferred, in part, from the kinds of errors he makes. If one blind alley is so easy for the rats that few go into it, another so hard that nearly all do, the inference is that the rats have "reasons" for the difference. Since one cannot ask them, one is bound to try to infer these "reasons" from a study of the configured pattern of errors made by them. The maze has a plan which must be learned by the rat if he is to get to food with the least effort, hence the configuration of errors he makes offers the clue to his "conception" of the plan, and the *change* in configuration on successive trials indicates his changing conceptions. Furthermore, the difference in configuration of errors of bright and dull rats indicates the cognitive differences between them.

A. The criteria of validity

In this paper, I shall present the pattern of errors made during learning, and from it and from subjective observation shall postu-

late the psychological determinants of the rats' performance. One may object immediately that such inferences could be performed in an infinity of ways, and who is to say that my inferences are better than anyone else's. This objection may be somewhat quieted by stating that inferences as to "what is going on in the rat's mind" are considered "valid" only if they meet certain criteria:

(1) *Internal consistency.* The logic of the components must hang together. Thus, if one postulates, for example, the component, "orientation towards the food box," it should be elicited positively by all blinds pointing towards the food box, and negatively by all blinds pointing away from it. One may further assert that the potency (i.e., weight) of this component decreases the further the rat from the box, and if so, a decrease-gradient must be systematically applied.

(2) *Goodness of fit.* The components must be shown to fit the data. Since those I shall postulate are supposed to determine the rats' performance, I must show that they do actually fit it. The procedure employed here is to set up a *theoretical* frequency of blind entrances based upon the components and then show that these values correlate approximately unity with the *experimental* frequencies.

(3) *Prediction in situ.* Internal checks of the validity of the components should be made. One form of verification is the application of them to other aspects of the behavior *in situ* which they might reasonably be expected to affect, aspects not analysed, however, at the time the components were originally inferred. Thus in our problem, retracings and speed of running in the paths are aspects of behavior in this maze situation different from error-making, and these aspects should be to some extent affected by the components inferred as determinants of error-making. These checks will be reported in a later paper.

(4) *External prediction.* By an external check, I mean the prediction of new behavior *Y* from the types of components postulated and shown to fit behavior *X*. In the present case I possessed unanalysed data on another 20 T-unit Maze *Y*, which though differing in pattern and procedure nevertheless would be expected to elicit similar types of components postulated for Maze

X. I attempted, in short, to predict the actual pattern of errors made by the rats in Maze Y at different stages of learning. The predicted values correlated surprisingly high with the found values, as I shall show in a later paper.

Internal consistency and goodness of fit are criteria necessary for validity, though not altogether sufficient. They may, however, be the only criteria that the experimenter can conveniently employ. Furthermore, prediction *in situ* and external prediction may not pan out, for the reason that the specific performance for which a set of components is inferred may be so unique that these components might not appear in any other behavior, or if so, in such a new configured weight-pattern as to preclude prediction. In such an unfortunate event, the experimenter may have to rest his case upon the first two necessary criteria, and wait for the acceptance of his inferences upon the concerted judgment of other workers experienced in his type of psychological data.

Implicit in this approach is a type of dualism. I am implying that the components are psychologically genotypic in nature, whereas the observed performance is phenotypic. From a study of the latter, the former are inferred. But it is just such a dualism that is the basis on which we, as human beings, "understand" the actions of each other. For example, when I, as teacher, try verbally and with gestures to describe "the concept of correlation" to a pupil, the words and motions I produce are the phenotypic aspects of my concept, whereas the abstract relatively stable ideational concept which determines and controls my words and movements is the genotypic basis. The pupil studies the welter of phenotypic data I present and if my words and gestures persistently show a systematic organization, he infers that these acts of mine are determined by some relatively stable and unitary genotypic concept. By careful study of my more or less organized phenotypic utterances, he may himself finally evolve a concept of correlation. Neither of us can as yet be sure that our concepts are the same, so he may *test* me to see whether his own concept is a valid representation of mine. The test is conducted entirely on the phenotypic level: he asks me questions about cor-

relation, and if I give answers which are just those he himself would give (i.e., predicts), he concludes that he has discovered my original genotypic concept.

This illustration depicts quite analogously the role of the comparative psychologist who, as pupil, seeks by inference to discover the nature of the concepts of the rat, as teacher. If the rat shows consistent and organized phenotypic tendencies, the psychologist infers the existence of genotypic components in the rat, and postulates what they may be. Then by the application of the four criteria mentioned above, he tests the validity of his inferences. If the tests come out well, he feels that he has discovered the conceptual components of the rat, and with the same assurance he experiences when he thinks he understands the concepts of another human being.

The genotype-phenotype dualism expressed here is not the mind-body variety from which psychologists recoil. The dichotomy represents a distinction familiar to biologists, indeed, the terms are borrowed from genetics. It merely implies that an observable phenomenon may have a complex causal matrix of a different order from the phenomenon itself, a matrix which, however, can only be inferred by a proper analysis of the phenomenon.

In the preceding paper of this series (16), I attempted to prove what the components differentiating bright from dull rats were *not*. I reported there a variety of experiments in which it was shown that when the stimulus field was radically disturbed, the rats proceeded in their running without much disturbance. From these data the conclusion was made that individual differences were not determined by differences in sense organ efficiencies or in sensory sign-learning capacities. What, then, are the components? In this paper, I shall proceed by inference to the assertion that the cognitive determinants are *non-sensory abstract spacial sets* or orientations of various sorts.

B. Maze, procedure, and subjects

The maze is a 17 T-unit Maze X, described previously (12). A schematic depiction of its design is shown in figure 3. The rats are automatically delivered singly into the maze from a lower

compartment and "picked up" at the end in an upper compartment by means of a revolving delivery table in which the daily ration of food is placed. The rats are given practice runs for eight days on the preliminary path (dashed line in figure 3) before starting the maze proper, and then they run one trial a day for 19 days in the maze. Their movements are electrically recorded on a moving tape from which full and partial errors, speed and retracings in each unit may be read off. Trap doors prevent retracing into preceding units. The rats whose behavior is analysed here were the animals of the P, F₁, F₂, F₃, F₄ and F₅ generations of the selective breeding experiments of the writer. The total sample is therefore somewhat more heterogeneous than a random sample because of the higher frequency of bright and dull rats in the later generation. The experimental controls are such that the differences between rats in maze errors are significantly determined by heredity (8), a fact which enables us to conclude that the psychological differences between brights and dulls described in this paper are significantly hereditary differences.

C. Blind difficulties: measurement, reliability, and change

Measurement of blind difficulty. The logic of this analysis is simply that the cognitive determinants may be inferred from the differences in difficulty of the blind alleys. Difficulty is defined as per cent of rats entering a blind. Figure 1 shows the per cent entrances of 1,085 rats into each blind for ten successive stages of learning. For simplicity the trials have been grouped in pairs as shown on the abscissa; the ordinate is per cent of the group entering the blind. Read the graph as follows: for blind 1 (see the line labelled "1") 66 per cent of the rats entered it on trial 1, 69 per cent at the stage indicated by trials 2-3, 63 per cent at the stage, trials 4-5, etc. The per cent entrances per stage were determined as the ratio of the total entrances divided by the total opportunities for entrances. Thus, the value 63 for trials 4-5 was determined as follows: as there were 1,083 rats with complete records on trial 4, and 1,085 on trial 5, there were a total of 2,168 rats who faced choice-point 1 on trials 4 and 5 and hence had the

opportunity to enter blind 1; actually 772 entered the blind on trial 4, and 720 on trial 5, making 1,492 who availed themselves of this opportunity on the two trials; hence $1,492/2,168$ equals 63 per cent for this stage of learning. For various accidental reasons, there were not exactly 1,085 complete records for each trial, but the average deviation from that number per trial was

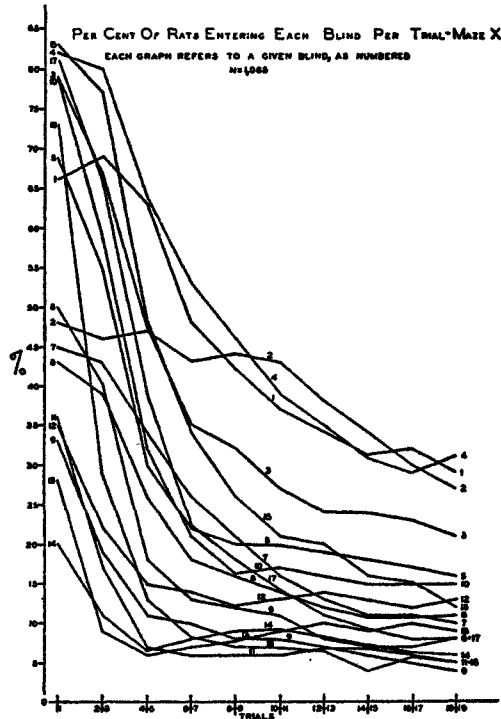


FIG. 1. PER CENT OF RATS ENTERING EACH BLIND PER TRIAL—MAZE X
Each graph refers to a given blind, as numbered. N is approximately 1,085.

only 4 rats. A major exception was trial 1, on which, after the F_2 generation, I did not record any rat's performance, and therefore was able to find percentage values for only 530 P, F_1 , F_2 and F_3 rats on this trial. The raw data separated into bright and dull subgroups are given in the Appendix.

The curves of figure 1 present a truly amazing phenomenon, for they show in dramatic fashion that the blind alleys differ widely

in difficulty at all stages of learning. Particularly surprising is trial 1 when the rats enter the maze for the first time. Note that around 80 per cent of the rats enter blinds 15, 4, 17, 3, 10 as compared with 20 per cent into blind 14. Were they reacting by chance, about 50 per cent should go into each blind. Obviously they are *not* reacting by chance, but are differentially forced into the blind alleys by orienting sets or "ideas where they should go" even on this first trial. These components obviously change as learning proceeds, for whereas the blinds continue to differ in difficulty, some blinds remain relatively difficult, others become easy, others increase in difficulty. Thus blind 4 remains very difficult throughout, blind 16 changes rapidly from being very difficult to very easy, blind 2 changes from average difficulty to very difficult.

Reliability. How much in error are the values plotted in figure 1? One way to answer this question is to figure the approximate standard error of each value by the conventional formula for the standard error of a per cent. The largest error is of a per cent of 50, which turns out to be ± 1.5 per cent. All values above and below 50 have smaller errors. Thus the error variance of each point in the graph is exceedingly small.

Another method of determining reliability is to divide the 1,085 rats into two random samples and compute the difficulty of each blind per stage for each sample. The r between the difficulties of the two samples for a given stage, corrected by the S-B formula, would express the reliability of the difficulties for that stage for the 1,085 rats. Now, as I had worked up the data for the two sexes separately, I calculated the correlations between the two sex samples *in lieu* of two random samples. The effect of a sex difference would be to give values below those of two truly random samples. For the successive 10 stages shown on the abscissa of figure 1 the uncorrected correlations between the two sex groups were:

.99, .98, .98, .98, .98, .99, .99, 1.00, .99, 1.00

The corrected reliabilities determined for two random samples would thus closely approach unity.

Change of difficulty pattern of the blinds. Visual inspection of figure 1 shows that the relative difficulty of the blinds changes as learning proceeds. This fact indicates that the components controlling performance change. We need to know the specific *degree* of this change. The measure of the degree of change can be succinctly, although rather abstractly, expressed in the form of a few simple statistics.

The shift in mean per cent entrance of all the blinds, and the change in variability among the blinds as learning proceeds can be seen from the means and sigmas of these per cents for the ten successive stages of learning:

Mean.....	.56	.44	.30	.23	.20	.18	.17	.15	.14	.13
Sigma.....	.21	.23	.19	.15	.13	.11	.10	.09	.09	.09

Read these values as follows: the mean per cent entrance in all blinds on trial 1 is .56, the standard deviation of the 17 percentage values of the 17 blind alleys on trial 1 is .21; the second set of values refers to trials 2-3, etc. The series of means shows at once the gross effects of learning. Especially it is to be noted that a plateau is rather well established by trials 12-13. The mean for this stage is .17, and the means following, italicised, do not greatly change. Furthermore, the variability amongst the blinds does not change during this plateau period. It looks as if the situation has got well stabilized by trials 12-13. Turning back to figure 1, one can see at a glance that the only note-worthy thing happening during this plateau period is that the more difficult blinds, 4, 1, 2, 3, 5, 15 gradually decrease in difficulty, whereas the remaining nine blinds remain rather constant.

A more sensitive statistical description of the change in error pattern is the table of intercorrelations between the difficulty patterns of blinds for successive stages, given in table 1. Read this table as follows: the correlation between the per cent entrances into the 17 blinds on trial 1 and those on trials 2-3 is .89, between trial 1 and trials 4-5 is .71, etc. Note that the last eight trials have been lumped into a plateau stage, trials 12-19. The reason for this grouping should be evident from the correlations given in the table, for the r between trials 10-11 and plateau

trials 12-19 is 1.00. This means that as early as trial 10 the components determining blind difficulty are the same as later. Furthermore, a general inspection of the correlation table reveals the fact that the drift of the magnitudes as one goes into the lower right corner of the table is towards unity, indicating that the pattern of errors is towards an ultimate stability in the plateau period.

The changing pattern of errors, and hence of the components which produce them, is clearly revealed by an inspection of the upper left to lower right diagonals in the table. The diagonal, just below the central, with values .89, .91, .95, etc. gives the correlations between the error patterns on adjacent stages of

TABLE 1
Intercorrelations between blind difficulties of seven successive stages of learning
Each stage consists of the trials as indicated

TRIALS	1	2-3	4-5	6-7	8-9	10-11	12-19
1		.89	.71	.58	.52	.46	.45
2-3	.89		.91	.81	.76	.69	.68
4-5	.71	.91		.95	.94	.88	.86
6-7	.58	.81	.95		.97	.95	.94
8-9	.52	.76	.94	.97		.99	.99
10-11	.46	.69	.88	.95	.99		1.00
12-19	.45	.68	.86	.94	.99	1.00	

learning. These are uniformly high except at the very beginning, where rather a fair change of determining components on adjacent stages is indicated. The next lower diagonal, with values .71, .81, etc. gives correlations between stages once removed, and here in the earlier stages a more critical change is reflected.

Possibly the most interesting value in the table is that of the bottom diagonal, .45, the r between trial 1 and the plateau stage trials 12-19. This value indicates that there is an important difference between the components determining the rats' movements on the first day in the maze and at the end when they have become fixated. But the surprising fact is that *the correlation is not zero*, which is what it should be if the rats ran in a chance fashion on their first trial. Indeed, the components determining

their movements on the first day appear, to the extent indicated by a positive r of .45, to affect to some degree their behavior in the plateau period.

Our task is simplified by a proper appraisal of the facts in this correlation table. Note that the intercorrelations between the stages from trials 6-7 on to the end are very high, all above .94. Clearly then, if we postulate components that show a rigorous fit with the blind difficulties in the plateau period, trials 12-19, these components will apply with considerable accuracy clear back to the behavior beginning with trial 6. Furthermore, the complex of components which we deduce as determinants of trial 1 will, if our fit is rigorous, apply well to trials 2-3, whose blind difficulties correlate .89 with trial 1. Thus we need only to set about the simpler task of giving a rigorous psychological analysis of the plateau period and of the first trial. This done, we will have pretty well covered the whole ground. It leaves, to be sure, the middle stage trials 4-5 unaccounted for, but not entirely so, as this stage correlates .71 with trial 1 and .86 with the plateau period. It rather looks as if there is a rapid transition from the first trial components to the plateau. This being the case, then the possibility suggests itself of a simple linear composite of these components providing a good fit with the transition stage, a matter which can be investigated.

D. The inferred components and conceptions of their internal consistency

As our task has been reduced to describing the components that control the rats' movements on trial 1 and during the plateau, we fix our attentions on the blind difficulties at these two periods. We must study these error patterns especially in connection with the maze plan, for doubtless the rats' conceptualizations which determine his movements are governed in large part by the character of the maze path. To facilitate this study, I present figure 2 which is a replica of the true path of the maze. The placement of the blind alleys is expressed by the arrows. The black arrows have a length proportionate to the *relative difficulty* of the blinds of the first trial. The relative difficulty of each blind is merely

the ratio of the total entrances in it over the total entrances in all blinds on trial 1. By following the maze design and noting the relative lengths of the black arrows, one may observe the flow, as it were, of the rats' movements through the maze on this first trial. Analogously, the white arrows, being relative plateau difficulties, depict the flow of the rats' movements during the plateau period. The lengths of the black and white arrows can be compared quite validly with each other, for the total physical length of all the black arrows is equal to that of the white, namely, 100 per cent. One should keep in mind that any noticeable

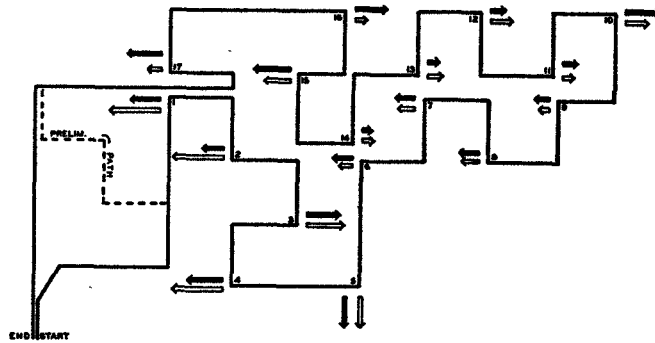


FIG. 2. RELATIVE DIFFICULTY OF EACH BLIND ON FIRST TRIAL AND ON PLATEAU STAGE

The length of arrow is proportional to the per cent of total entrances in all blinds per trial. Black arrows show relative difficulty on first trial, white, on plateau trials.

differences in lengths of arrows is significant, for the reliability of the values is nearly unity.

Several important relations immediately strike the eye. The earlier blinds are easier on the first trial than at the plateau, the end blinds easier at the plateau than on the first trial. Blinds pointing back towards the exit and towards food seem more difficult than the others, though there are exceptions. Blinds at the ends of interior lines of direction, e.g., at 3, 5, 10, 15, 17, seem difficult, other things equal. A complex pattern of errors is clearly evident, suggesting the operation of a matrix of multiple components at work. No simple set will fit the data adequately.

I list below the cognitive, emotional and motivational compo-

nents which, in my opinion, control the rats' movements on the first and plateau stages of learning. My claim for the validity of them rests on the criteria mentioned earlier. How these components specifically influence the entering of each blind alley is quantitatively represented in table 2 for the first trial, and table 3 for the plateau.

In these tables each component is represented in a column, each blind by a row. The effect of each component is to force movement into or out of each blind. These effects are represented by weights, positive values indicating the forcing of movement into blinds, negative values, out of blinds, and blank (zero) entries denoting no effects. The greater the magnitude of the weight, the greater is the effect of the component.

One may think of the logic of assigning weights as follows: Beginning with a blank table, which represents the theoretical case of all rats running the maze without errors in any blinds, we ask the question: What components can we postulate, and with what weights per blind, which will make the blinds differ in difficulty? Some of the components we think of (e.g., inertia) may generate movement into blinds and not out of them, hence they take only positive values. Others (e.g., exit gradient) create a negative tendency to enter blinds, requiring negative weights, and signifying a tendency to avoid blinds. Still others (e.g., food-pointing) may exert positive influence on some blinds, negative on others. Any weight may therefore be thought of as a quantitative statement of how the inferred component causes performance to depart from the theoretical case of all blinds being equally and perfectly learned—it is, in a sense, a "disturbance" in the perfect case of learning.

(1) *Direction-sets*. When the rat enters the maze, even on the first trial, he is immediately affected by certain abstract lines of direction inherent in the maze design. These lines of direction are depicted in figure 3 by dashed lines terminating in arrows.

Look, for example, at line *a*. This line is an abstract expression of a directed spacial configuration of units 1 to 5. My inference is that the movement of the rat through these units generates an abstract spacial set in the rat which in part controls his move-

ments and thus accounts for the errors he makes here. This set is generated in the rat, I would believe, because of the nine maze segments in these five units that are in conformity, *abstractly*, with this, shall we say, southeast direction, namely, true path of unit 1, stem of 2, true path of 2, stem of 3, blind of 3, stem of 4, true path (two segments in length) and blind of 5. Seven of

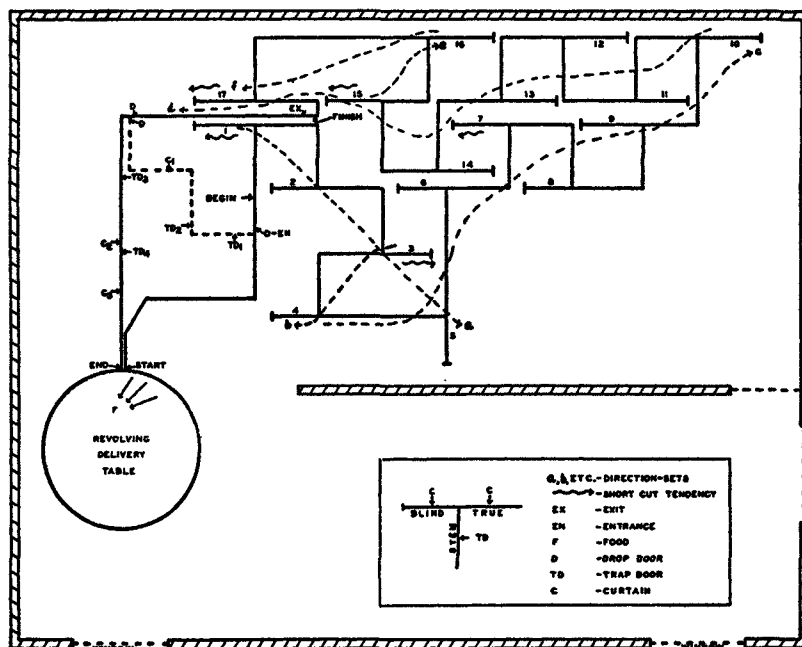


FIG. 3. SCHEMATIC PLAN OF MAZE X SHOWING INFERRED DIRECTION-SETS

The preliminary practice path begins at "Start" and turns left at "En" proceeding along dashed line and around to "End." Electric recording of maze run starts at "Begin," ends at "Finish."

these segments get the rat on into further paths. To be sure, two segments (blinds 3 and 5) block him, as they are blind alleys, but nevertheless, until the rat reaches the end of these blinds his movements are in conformity with direction-set *a*.

The effect of such a direction-set in controlling the rats' movements I conceive to be cumulative, as a *gradient*; that is, the later movements in conformity with set *a* are more strongly controlled by it. Turn now to table 2 and note that I have entered in the

form of numerical weights the effect of *set a* in producing movements into and out of the blinds on trial 1. Under "direction-sets," column "a," I have indicated that the effect of *set a* is to pull the rat out of blind 2 to the extent of -2 (or reciprocally to steer him into the true path to the extent of $+2$), to steer him into blind 3 to extent $+4$, and to steer him into blind 5 to extent

TABLE 2
Weight per blind of each component—1st trial—maze X errors

BLIND	DIRECTION-SETS							FOOD-POINT	COUNTER	CENT SWING	ADAPT	LASS	CONFLICT	THEOR. DIFF.*	EXPER. DIFF.†
	a	b	c	d	e	f	Prel.								
1							+1	+3			+2			12	7.0
2	-2						+1	+3	-2	-1	+2		+1	8	5.0
3	+4							-2		+1	+2		+3	14	8.3
4		+1						+3	+2	+1	+1		+2	16	8.6
5	+3							+2					+1	12	7.3
6								+2						8	5.3
7			-.5					+2		-1				6	4.6
8			-2					+2		-1		+ .5		6	4.5
9			-3					+1		-1		+1		4	3.5
10			+7							+1		+1.5		16	8.3
11			+1	-.5					-2	-1			+1	5	3.8
12				-1						-1				4	3.7
13				-3						-1				2	3.0
14				-5				-.5		-1		+1		1	2.1
15				+7				+1		+1		+2		17	8.7
16					+2			-1	+2	+1		+2	+1	13	7.7
17						+1		+1	+1	+1		+3	+1	16	8.5

* Theoretical difficulty is sum of weights plus 6, rounded.

† Relative difficulties.

+3. I assume that as learning proceeds the effects of *set a* becomes more *dynamically generalized*, as indicated in table 3 for the plateau. Under column *a*, the effect of the set reaches back to blind 1, pulling movement out of the blind to extent $-.5$. *Set a* affects blind 4 to the extent -1 , and even blind 6.

Consider direction-set *b* in figure 3. There are three maze segments which cause its generation, true path 3, stem 4, and blind 4. Its effect is minor, occasioning entrance into blind 4

to a mild degree on trial 1, but, being more generalized in the plateau period, affecting also blind 3 there.

The northeast direction-set *c* is a potent one, being elicited by twelve maze segments. Its quantitative evaluation in tables 2 and 3, as well as that of sets *d*, *e*, and *f* should now be more or less evident from my illustration of sets *a* and *b* above. A final word

TABLE 3
Weights per blind of each component—plateau trials 12-19—maze X errors

BLIND	DIRECTION-SETS						FOOD-POINT	SHORT-CUT	COUNTER	INERTIA	EXIT GRAD.	CONFLICT	THEOR. DIFF.*	EXPER. DIFF.†
	a	b	c	d	e	f								
1	-.5						+5	+1		+8.3	-.9	+2	19	12.5
2	-1						+5			+8.0	-1.0	+3	18	12.5
3	+3	-1.5					-4	+1		+7.5	-1.2	+3	12	9.0
4	-1	+2.0					+6		+1	+5.0	-1.3	+3	19	12.5
5	+.5		-1				+1			+4.0	-1.5	+1	8	7.0
6	-1		-2							+3.6	-1.7		3	3.1
7			-2					+1		+3.3	-1.9		4	4.3
8			-2							+3.0	-2.1		3	4.3
9			-3							+2.7	-2.3		1	2.4
10			+4	-1						+2.3	-2.7		7	5.9
11			+1	-1					-1	+2.1	-3.0		2	2.4
12			+2	-1						+1.9	-3.3		4	5.1
13			+1	-1						+1.7	-3.6		2	3.9
14				-1.5						+1.5	-4.0		0	2.7
15			+3		-1		+2	+1		+1.4	-4.5	+1	7	6.3
16			-2	+2	-1	-1	-1		+1	+1.2	-5.2	+1	0	2.4
17			+1			+2	+2	+.5		+1.0	-7.3		3	3.5

* Theoretical difficulty is sum of weights plus 4, rounded.

† Relative difficulties.

should be said for the direction-set labelled "Prel." in table 2. This set refers to the western orientation elicited by the eight days training on the preliminary path. Its effect is to occasion errors in blinds 1 and 2.

To sum up, it may be said that the following principles describe the rôle of direction-sets in determining the rat's movements.

(a) The larger the number of more or less consecutive maze segments in conformity with the direction-set, which is an ab-

stract direction orientation, the stronger absolutely will be its effect.

(b) In the series of movements in conformity with the set, the later the movements, the more strongly will they be determined by it, i.e., it operates as a gradient.

(c) The effect of experience is to make the set dynamically more general; i.e., to widen the locale of its effects.

(d) When two sets conflict, the result is to decrease their specific effects on movement in the spacial area of the conflict. To illustrate, the conflicting effect of *sets a* and *b*, reduces the weight of *set a* on blind 5; similarly, the conflict of *sets d* and *e* reduces the weight of *d* on blind 17.

(e) The effect of experience, or learning, is to occasion the integration of the various direction-sets into larger *direction-configurations*, which, in the rat who has learned the maze perfectly, consist of a perfect cognitive structure of the maze. My belief is that the rat who has learned the maze perfectly is one who has integrated the *sets a, b, c, d, e, f* into one abstract, configured whole. A drawing of this direction-configuration would be merely the connecting of the dashed direction lines of figure 3 together, erasing each dashed line beyond the point of its intersection with the first one it meets.

I would believe that the rat who learns the path perfectly possesses ultimately a hierarchy of such higher-order direction-configurations. The most generalized configuration is an integration of *sets a, c, and d*, for these define the most general design of the maze. The evidence supporting this conception is in our experiments described in the preceding paper of this series (16), in which we discovered that when we seriously disrupted sensory stimuli on the 20th trial and furthermore short-cut the rats across from unit 2 to unit 6, the rats who had learned the maze proceeded on from unit 6 with only minor disturbance. In unit 6, they seemed to know very well where they were. This fact is understandable if we impute to them a generalized unified closure, as it were, of direction-sets *a, c, and d*.

A lesser generalization of the maze design is one including the two loops occasioned by set *b* and by set *e*. As these two sets are in conflict with the more general direction-configuration described

in the preceding paragraph they create areas of special difficulty for the rat. Evidence is seen from the persisting difficulties of blinds 3 and 15 which are at the points of conflict. As further evidence, I recall that when I originally designed the maze, it did not contain blinds 4 and 5: the rats ran directly from unit 2 into unit 6. Furthermore, it did not then include units 16 and 17; the rats ran from 15 into the exit. On running a sample of rats through this shorter maze, I discovered that nearly all learned it rapidly. Evidently, the rats abstracted the simple rectangular design in a few trials and thenceforth made few errors. I then introduced the two conflicting loops, with the consequence that the maze became very difficult, at least for the dull rats.

(2) *Food-pointing*. The piling up of errors in food-pointing blinds suggests that the rats readily take a food orientation, which has also an abstract character as there are no specific cues in the maze to elicit it. The effect of this set is shown in the columns marked "Food-point" in tables 2 and 3. Note that it is assumed to be a gradient, blinds at the beginning of the maze and nearer the food, which was in the delivery table, eliciting it more strongly. Thus in table 2, it is conceived as disappearing by blind 10 but reappearing by blind 14. Had the rats been introduced "cold" into the maze on trial 1, not knowing where food was, it would not have appeared there, but our preliminary procedure served to identify its location. Food-pointing is conceived as being less generalized by the plateau period, affecting strongly only those blinds near the food.

At this point certain matters of method have doubtless disturbed the reader—matters which I could not have properly considered, however, before the presenting of several concrete examples of the components. One might validly ask: What guides the experimenter in postulating a given determiner? An obvious answer is that a thorough study of the data as presented in figures 1 to 2 suggests it. To some extent true, such leads are probably not so important as the ones provided by subjective impressions heavily affected by an anthropomorphic empathy for the performing animal. On having watched several thousand rats run, for example, from units 5 to 10 in this maze, I cannot

escape the impression that as the rats get going in this section they become more set in the general northeast direction and that this set is *determining* his movements. It is not only the spot behavior of the rats decreasingly entering blinds 6, 7, 8, 9 and piling up in blind 10 that suggests direction-set *c*—it is the whole directed organization of his movement, his increasing speed and smoothness of running, and his somewhat disorganized behavior when he lands in blind 10. Likewise with food-pointing: it is not merely the fact that, statistically, food-pointing blinds tend to receive more errors, it is the nature of his behavior in these blinds that suggests food orientation—his strugglings to get out through the top, a certain “pointingness” of his behavior, all better described by saying, “he is trying to get over there,” where “there” is the physical position of food.

Another question: How can one tell the importance to be attached to a given determiner relative to the others? Subjective impression does give a preliminary lead here, but I have found a set of statistical tricks to be of great value. Unhappily space limitations prevent a full description of these, but sufficient can be given to show the general procedure. The goal in this analysis, it must be remembered, is to set up *theoretical* difficulties of the blinds based upon the postulated components, these difficulties to correlate perfectly (or within the allowable error, which in our case is nearly zero) with the *experimentally determined* difficulties. One proceeds then as follows, taking as an example the first trial, table 2: One starts by putting into table 2 weights for the first type of component, in our case, the direction-sets, *a*, *b*, etc., these weights being decided upon quite subjectively according to their importance as conceived by the experimenter. These weights are now tested, as follows: for each blind alley, they are summed, giving thus for all the blinds a theoretical array of difficulties that would obtain *if the direction sets were the only determiners*. The theoretical values are now correlated against the experimental relative difficulties, given in the last column of table 2. The *r* is not itself calculated; only the correlation scatter is drawn up, each point entered being a blind alley and identified in the scatter by its ordinal number in the maze. Now, if the

direction-sets were the only components determining blind difficulties, all the blinds, being points in the scatter diagram, would fall on a straight line, and the correlation would be unity. Of course they do not, but the experimenter now tries to *get* them onto the straight line by juggling the weights originally entered in table 2. The important thing to remember is that *the juggling must be applied with psychological consistency*. Thus, for example, one may decide, say, that blind 3 should be made more difficult by changing its weight by *set a* from +4 to +8. Note, however, that *set a* also affects blinds 2 and 5, hence if blind 3 is increased, 2 and 5 should for consistency be increased proportionately or the gradient be altered in a reasonable fashion. But such a set of changes, though they pull 3 onto the straight line, may throw 2 or 5 or both farther off, hence none would be made. On the other hand, such changes may better the status of 2, 3, and 5 and would, therefore, be considered valid. The next component, food-pointing, is now entered in table 2 with appropriately graded weights given the blinds as subjectively decided upon by the experimenter. For each blind a new theoretical value is now found, it being the sum of the weights of the direction-sets and of food-pointing. A new correlation scatter is set up showing the relation between the new theoretical difficulties and the experimental values. Further juggling of weights may be instituted, under conditions of consistency, to improve the lie of the blinds on the straight line. The remaining components are introduced one at a time following the above procedure until they are exhausted or until an exact fit on the line is made. Far from being boring, the process is ordinarily exciting, providing a means by which an experimenter may test his preliminary speculations on psychological causation. Furthermore, it is fruitful in suggesting hypotheses which may not have been thought of at first. Thus one may have exhausted the components he originally planned to test, and still may discover in his last correlation plot some blinds well off the straight line. No reasonable juggling of weights of components already postulated will pull them onto the line. In his final plot one notes that additional components are necessary to make certain blinds more difficult, others easier.

By a study of the maze situation in the light of his observations of the animals' actual performance there, he may hit upon additional determiners which appear psychologically reasonable and provide an improved fit.

The obvious criticism of this technique is that when the number of components is large, one may make reasonable and consistent juggling of weights in many different ways all leading to an equally good fit. Such a criticism was anticipated earlier by pointing out that the two criteria of consistency and of fit are necessary but not sufficient conditions for complete validity. Sufficiency is effected only by prediction. As mentioned earlier, failure of prediction does not necessarily invalidate the postulated components. In the absence of good prediction, probably the final court of appeal will be convincingness of the determiners in the eyes of other psychologists who have had experience with analogous forms of behavior, in our case, of other rat psychologists. With this technological aside, we turn now to other determiners.

(3) *Short-cut.* After the rats have been through the maze a number of trials, they show types of behavior which look like definite attempts to short-cut the path. This behavior is particularly noticeable in blinds the blocked ends of which touch a path through which the rats must later go. The locale of this tendency is depicted by wavy arrows in figure 3. Thus in blinds 1 and 17 which are conterminous with the final exit path, in blind 3 which abuts physically on stem 6 (figure 3 is merely schematic), in blind 7 which abuts on stem 14, and in blind 15 which abuts on the exit, this behavior, characterized at times by persistent efforts of the rat to push off the lid of the blind and slip over its blocked end, is most apparent. Appropriate weights have been assigned in table 3, column "Short-cut." Here again, this tendency can be considered as an abstract set, for no locally presented stimulations can "condition" it.

(4) *Counter tendency.* When a strong determining set culminates in a blind alley which, as such, not only suddenly thwarts the movement set but requires the rat actually to take the opposite direction, the animal tends to adopt the counter set immediately after the thwart. In table 2, column "Counter," I have

indicated that the direction-set occasioned by training on the preliminary path is thwarted in blind 1, thus causing the rats to go in the opposite direction in unit 2, that is, *not* to go in blind 2, as expressed by the negative weight; blockage of *set a* in blind 3 generates the counter tendency *into* 4; blockage in 10 pulls the rats *out of* 11; blockage in 15 sends the rats *into* 16, and from thence *into* 17, though this last tendency is weak. In this maze the counter tendencies are, however, weakened by learning, as they result in more errors than correct movements, hence they do not appear in the plateau period.

(5) *Centrifugal swing*. Some writers claim that when a rat turns an elbow, momentum throws him against the opposite wall of the stem of the T-unit, and as he now comes to the choice-point along this wall, he turns in a mechanical fashion into the alley which is just around the corner. Such a component probably emerges only in the rat that aimlessly wanders. As some rats actually do show such aimlessness on earlier trials, I have introduced it as a component of minor weight in table 2, under "Cent swing." It tends to make for errors in blinds 3, 4, 10, 15, 16, 17, but to reduce errors in 2, 7, 8, 9, 11, 12, 13, 14. As the choice-points of 1, 5, 6 are not immediately preceded by elbows, the factor is of no influence there.

There are numerous other types of cognitive components (1, 6) which might be elicited in rats in mazes but the five listed above appear to be the major ones in ours. In some mazes, rats probably anticipate a final or crucial turn in choice-points just before such a turn, provided the maze units leading up to the crucial turn are homologous in configuration with it, as in a linear maze. I find no evidence of this component here, except possibly in unit 9 which is spacially homologous with 10. Another possibility is the elicitation of a generalized position habit determined by the fact that a majority of the correct turns in choice-points are, say, right turns. But this is not the case in Maze X. Indeed rats will doubtless abstract any feature of a maze, provided the design of the maze puts a premium on it, and provided it is within the rat's ken. It appears doubtful if rats are controlled in the maze by specific directive sensory cues, unless of course the design of the maze or the procedure puts emphasis upon them.

The five cognitive components deal with the rat's "knowledge" of the maze. In addition there are the following dispositions of an affective, conative sort which seem definitely to affect his behavior in the maze.

(6) *Adaptation, or emotional inurement.* When rats enter the maze on the first trial, they commonly show "upset," especially in the first units. In its extreme form this disturbance is characterized by defaecation, urination, a forward-stretching movement, and a hesitant exploration of the various parts of the unit. Such halting exploratory behavior naturally makes for entrances into the blinds. As nothing untoward really happens to the rat, after he has progressed through a few units, this behavior tends to disappear. I have therefore shown this component of significant weight only in table 2 and in units 1, 2, 3, and 4, in the column, "Adapt."

(7) *Lassitude.* The first trial in the maze is frequently characterized by a disinclination to effort as the rat proceeds, and sometimes by complete cessation of movement. Most rat-runners will, to their chagrin, confirm this observation; indeed, they find it necessary to give an occasional rat a push. In Maze X it occurs first as the animals approach blind 10. Note that this point is farthest from food, the location of which they had learned from the preliminary training. It is just as if the rats tend to some extent to give up the task and, in consequence, to wander a bit. The effect is to increase errors there, as the entries of table 2, column "Lass," indicate. The return trip from 10 tends to speed up at first but then by units 15, 16, 17 the giving-up behavior becomes especially more noticeable. Accordingly, appropriate weights are given these blinds in table 2.

(8) *Exit gradient.* Observers universally note that as rats approach the last choice-point of the maze, immediately beyond which the food is normally located, they run faster and, other things equal, learn better to avoid the blinds. The phrase used to describe this behavior and one which also implies an explanation of it is the *goal gradient*. The implication is that the anticipation of food tends in some abstract fashion to act back from the goal, but decreasingly so the farther away the choice-points. In contrast to the conditioning explanation of this phenomenon, I

will attempt below to explain it in genotypic psychological terms, bringing to notice the assumptions involved.

After a rat has traversed the maze several trials, when he later approaches the end sections, he *remembers* (i.e. reelicits) the direction-sets which control his movements there (Assumption 1), and in addition, he *remembers* their immediate consequence, food (Assumption 2). The question as to whether such memories are conscious is irrelevant. Being terminal, these direction-sets are necessarily the ones first to get the cognition of food-consequence attached to them. This anticipation of food gives extra weight to these direction-sets, to the detriment of other types of components which may affect performance there (Assumption 3). As ultimate learning of the correct path is postulated as being due to the integration of specific direction-sets into higher direction-configuration unities, integration would necessarily occur earlier in the end section of the maze, for the direction-sets elicited in the preceding sections lack at first the special weight lent by immediate anticipation of food. The essential point here is that the former independent terminal direction-sets have now become by integration caught up into a new direction-configuration unity with its remembered food-consequence. In other words, the several disparate terminal sets have by integration become collapsed or telescoped into one unity with immediate food-consequence, hence for the direction-sets elicited in the *middle* of the maze the food-consequence has now come within reach as a to-be-remembered but not-now-so-remote sequela of them. The process of integration and unification thus continues backward until the whole mass pattern is ultimately cognized as one large direction-configuration having at its end a specifically remembered food-consequence.

In Maze X the food happens not to be located just beyond the last T-unit. On leaving the 17th unit, the rats enter a long exit path (starting at "Ex" in figure 3) which goes west then south to food. This exit path doubtless early takes on a goal character because it is the first set to have food-consequence as a sequela. And it also has a release-from-the-maze goal character, for it lacks the problem-creating blind-blocking features of the pre-

ceding units. As one watches rats debouch into it from unit 17, one sees a sudden spurt of speed there, an unhibited freedom-from-load character of their movements—signs that this exit serves as a sort of major goal second only to final food.

So far as learning to avoid blind alleys is concerned, this exit appears to be *the goal*, for it provides an uninterrupted reach without blocking to food. I would believe that the facilitating effect of the goal works back from it rather than from the food-box, and have therefore termed the effect *the exit gradient*. The exit-goal's quantitative influence is exactly that postulated by the goal-gradient theorists (3, 5). I have borrowed Hull's logarithmic description of its effect, which assumes that the exit-goal has a disproportionately greater influence the closer the maze units are to the exit. As stated above, the net effect of the goal is genotypically to facilitate integration of the direction-sets, therefore the phenotypic manifestations are a reduction of errors. Hence, in table 3, the weights under "Exit grad" are all negative. Note the progressively greater influence of the gradient, which reaches finally a high value of -7.3 in unit 17. These values are calculated as follows: working back from the exit, we divide the maze into unit-segments, each segment being the length of a blind, a stem, or a true path, which in our T-units are the same length. For the beginning of each blind, we count the number of traversed segments it lies back from the exit-goal. For example, a rat entering blind 17 traverses one segment into the blind up to its end, another out of the blind, and a third through the true path of 17 to the exit goal. Hence, with the exit having an arbitrary excitatory goal value of 10, the beginning of blind 17, 3 units back, has a log excitatory value of -7.3 . From Hull's tables (3, p. 32), we may read off log values of points x segments back from a maximum of 10. Proceeding with these operations, we find that blinds 16, 15, 14, . . . have respectively distance values from the exit-goal of 7, 9, 11, . . . segments, thus earning log values of -5.2 , -4.5 , -4.0 , . . . , respectively.

(9) *Initial inertia gradient*. Another observation is of the rats' disposition to "warm up" to the task, noticeable especially in later trials. One notes a certain dilly-dallying in the first

units. It is as if the rats, cognizant that they are confronted with a difficult task, are somewhat reluctant to get started on it. It appears as if a component of *inertia* holds them back. The behavior looks objectively as if the entrance serves as a sort of brake holding them back, but with progressively less strength the farther away they get from it.

The effect of inertia is to produce more entrances into blinds (as well as into true paths) where its influence is greatest, namely, at the beginning of the maze. To give quantitative expression to it, I have conceived the entrance of unit 1 ("En" in figure 3) as a sort of reverse goal, pulling the rats back, the effect decreasing logarithmically as the rat proceeds. Giving the entrance an arbitrary inertia value 10 and counting unit-segments forward, we may assign quantitative weights to each blind alley as above, affixing however, a positive sign, for the effect is to increase errors. To illustrate, in figure 3 the choice-point of unit 1 is two segments from the entrance, earning an excitatory log value of 8.3 (from Hull's tables). Note that *both* the blind alley and the true path of unit 1 are two segments from the entrance, producing thus an equal disposition to enter them. Blind 2 is 4 segments from the entrance and should, assuming a pure logarithmic function, receive a value of 6.6. Note in table 3, column "Inertia," that the value for blind 2 is 8.0 instead of 6.6. In testing for goodness of fit the summation of the inertia component to the preceding complex, I employed some license in ascribing weights to the component for blinds 2, 3, and 4. These were given higher values than the logarithmic function denotes, whereas the remaining blinds gave empirically a good fit to the log values. The correct log values could, however, have been kept for blinds 2, 3, 4 by ascribing more weight of "conflict" to them, a change considered allowable and consistent in the section below.

(10) *Conflict*. One notes at times a distinctive pattern of a rat's movement at choice-points very like "indecision." He aggressively and rapidly weaves his head back and forth,² and

² There are other types of head-weaving in rats that should be distinguished from that appearing in conflict at choice points. One type appears in sick rats or stupid rats who come to a complete stall at any point in the maze. Another occurs in rats who are startled by a sudden novel stimulus, such as a sound or movement; it may be a visual exploratory maneuver.

makes tentative gross movements now into the blind, now into the true path. This behavior I have noted especially at difficult points in the maze, that is, points at which I believe the rat to be under the influence of conflicting sets, in Maze X especially at choice-points 2, 3, 4, and 15, 16, 17. The term given this behavior by Tolman and others (6), is VTE (vicarious trial and error). From our conception of components, we can give a precise psychological explanation of this phenomenon. On the first trial, when a rat arrives at choice-point 3, his behavior there may be weighted by *set a*, tending to push him *into* blind 3, and also simultaneously weighted by food-pointing, tending to pull him *out of* blind 3. Further trials may not relieve the conflict, for new components may appear—the short-cut tendency pushing him *into* blind 3, and the influence of *set b* tending to pull him *out of* blind 3. The effect of these counter pushes is to introduce confusion or disorganization, with a resulting *tendency* to reduce his choice of path to chance. The consequence is to increase errors in blind 3 relative to other blinds in the maze in which less opposition of components occurs.

The effect of conflict at a given choice-point I would believe to spread to choice-points which follow it. At any particular choice-point, therefore, the effects of conflict are not only noted in the particular dilemma generated by opposing cognitive sets at that point but they include effects of confusion carried over from immediately preceding conflicts. Thus in table 2, column "Conflict," on the first trial blind 2 gets a mild effect from the opposition of food-pointing and *set a*, blind 3 similarly plus a hang-over from 2, blind 4 involves no unique conflict, as *set a* has dropped out, but nevertheless, it carries a load from blinds 2 and 3, blind 5 shows some effects due to a reviving of *set a* vs. a backward pull of *set b* and food-pointing plus some carry-over from previous units. Unit 11 shows effect of conflict of *sets c* and *d*, 16 from *sets d* and food-pointing, and 17 from a carry over from 16. In the plateau, table 3, unit 1 shows its own unique effect due to the emergent influence of *set a* vs. food-pointing plus short-cut, and the effects on 4 are enhanced due to emergence of *set c*, and on 15 due to emergence of *set d*. In the later stage of learning when the integration of the various direction-sets is occurring, the conflict

is reduced, especially at the end of the maze. The componential complexity of units 2, 3, and 4 should allow us to give greater weight to conflict than table 3 shows, thus permitting the ascribing of the correct log values to them for the inertia gradient, as suggested in that section above.

Our conception of multiple psychological components requires a final statement of how the numerous components behave as a coalition in determining performance. At choice-point 4, for example, table 3 tells us that seven different components affect movement here. One might be led to believe from this table that the average rat is simultaneously affected by all seven components on a given trial at choice-point 4. The correct view, however, is that a given rat's behavior at unit 4 may be determined by a *selection* from the group of components. Thus, on a given trial, one rat's behavior may be entirely determined by *set a*, resulting in a correct choice, another rat by *set b* producing an error, another rat by *set a* and *set b*, resulting in such a conflict that if one set is not stronger for him on that trial than the other, the result would be confusion and a "chance" choice, another rat by food-pointing, resulting in an error, another by inertia resulting in chance movement—in fact, any single component or selection of them may affect different rats on a given trial, and a different selection may affect the same rat on different trials. Only when a single rat's performance is heavily determined by one component does the observer get a clue to it, and this fact explains why the observation of many animals is necessary before one can infer with assurance the existence of a component having much universality in the group. The weights in tables 2 and 3 are, like any other statistics, merely a summary statement of the degree of universality of the component. We are trying to prove that these weights, depicting the differential universality of our postulated components, fit with accuracy another set of statistics, namely, the experimental determination of actual entrances into blind alleys. These latter group statistics may not describe any particular rat's behavior on a particular trial, and neither may the theoretical weights of the components.

Doubtless I have ignored many components affecting particu-

lar rats in this analysis—components which may have affected a few rats with considerable weight, or many animals to too mild a degree, or some animals adventitiously for too short a time.

E. Goodness of fit

Assuming the above array of components to be quantitatively expressed with internal consistency, we next ask: How well does such a theoretical structure fit the experimentally determined performance of the rats?

Fit with the first trial and plateau stage. To measure the fit, we find the correlation between the summed theoretical weights of the blinds in tables 2 and 3 and the corresponding experimental difficulties. Define the variable as follows:

- x = experimental difficulty of each blind, trial 1
- x' = theoretical relative difficulty of each blind, trial 1 (table 2)
- y = experimental difficulty of each blind, plateau trials 12-19
- y_1' = theoretical relative difficulty of each blind, plateau trials 12-19 (table 3).

Note that unprimed symbols stand for experimental values, primed for theoretical. The correlations work out as follows:

$$r_{xx'} = 1.00 \qquad r_{yy_1'} = .99$$

The perfect fits are not necessarily surprising, as our statistical method of finding weights was such as to put a premium on good fit. It may, however, have turned out that, given the method, our postulated components may have been such that, when the weights were applied with psychological internal consistency, no perfect fit would have resulted.

Parsimonious components. Would fewer than our multiple set of psychological components give a good fit? In particular, would a simple set such as the goal-gradient proposed by Hull (3), or this plus food-pointing as weighted by Spence (5), or these plus centrifugal swing turn the trick? I have worked out the correlations for these components for the plateau period only. In the *first* trial the goal-gradient would not operate, and in mazes in general (though not ours in which food locale is known)

neither would food-pointing. Let us define the variables as follows:

$$\begin{aligned} y_2' &= \text{exit gradient plus food-pointing} \\ y_3' &= \text{exit gradient plus food-pointing plus centrifugal swing} \\ r_{y_2'} &= .61 & r_{y_3'} &= .69 \end{aligned}$$

The fit of these simpler sets of components is fair, but not, in fact, as good as the first power of the r 's indicates, for in this determinantal set-up where the y' values are postulated as elements of y , the percentage determination of the experimental y variance by the y' components is the square of the r 's, namely, .37 and .48 respectively (11).³ This is not good in contrast to the percentage determination from our multiple components, for the square of the r 's for them is nearly unity.

Fit with intervening stages. Do the first trial and the plateau components equally well describe performance in the intervening stages, trials 2-3, 4-5, 6-7, 8-9, 10-11? For an exact fit there, would it be necessary to infer additional components that come in after trial 1 but go out before the plateau? To answer these questions, we need to find the goodness of fit of these components with the experimental difficulty patterns on these intervening stages.

What we need is a table like tables 2 and 3 for each of these intervening stages, including in the columns only the components of tables 2 and 3, but assigning weight values possibly different from those in tables 2 and 3. In each table we would sum its weights per blind, and thus have a theoretical difficulty value defined as:

$$\begin{aligned} z_i' &= \text{theoretical difficulty of each blind on stage } i, \text{ this to be} \\ &\quad \text{correlated with} \\ z_i &= \text{experimental difficulty of each blind on stage } i. \end{aligned}$$

³ This theorem holds only on the assumption that the intercorrelations between the components is zero. We have no sure data on this matter, but on theoretical grounds, and reasoning from the lack of correlation between the weights of these components in table 3, I would expect the r 's to be very low. Were they high, however, the percentage determination would be greater than the squares of the r 's.

If $r_{zz'}$, comes to unity for every stage, then our particular set of components accounts perfectly for performance throughout.

But in any one of these tables, how are we going to find the exact weight value to put in it for each blind per component? One method would be to proceed with trial correlation plots as described earlier. The procedure is greatly simplified, however, if we set the problem a little differently and ask the question: Does any linear combination of the first trial and plateau weight-patterns provide a good fit? This is the same as asking whether on any intervening stage, i , the weight for each component per blind is some form of linear weighted average of the corresponding weights on the first trial and the plateau. Now this question can be simply answered by defining

$$z_i = (1x' + ky')/(1 + k)$$

where x' and y' are the theoretical difficulties of each blind on trial 1 and on the plateau, respectively. The variable, x' , takes the weight of unity and y' takes such a weight, k , that the correlation between z_i , the experimental difficulties, and z_i' , the theoretical, is a maximum. We need only to find k . The combination of the components will provide an exact fit for the intervening stage if, on weighting the y' values by k , then $r_{zz'}$ is 1.00. This is a simple problem in multiple correlation, in which after transforming the x' and y' values into sigma scores, then (2)

$$r_{zz'} = (r_{zz} + kr_{yy})/\sqrt{1 + k^2 + 2r_{xy}k}$$

$$k = (r_{zz}r_{xy} - r_{yy})/(r_{yy}r_{xy} - r_{zz})$$

The calculated values are given in table 4, in the two rows designated for the "total group." Looking along the row, $r_{zz'}$, we see that the components, so weighted, fit excellently throughout, for all r 's are above .94. I have entered in the third row of table 4 the correlations, or degrees of fit, $r_{zz'}$, of the first trial components only with the experimental difficulties of the stages. In the fourth row are the analogous correlations, $r_{yy'}$, with the plateau components only. Note that, for any intervening stages, the fit of a linear combination of the two types, $r_{zz'}$, is better than r_{zz} or r_{yy} , but from trials 6-7 on, the fit of the plateau components alone, $r_{yy'}$, is about as good as the combination.

The values of k have an interesting meaning, for from them we can see more succinctly the degree of similarity of the components of any intervening trial with those of the first trial and plateau stage. Recall that in estimating $r_{zz'}$, we set the weights of the first trial components, x' , always at 1.00, whereas those of the plateau take the value k . Hence when k is less than 1.00, the components of the intervening stage are more like those of the first trial, but when k is greater than 1.00 they are more like the

TABLE 4

Goodness of fit with blind difficulty, z , of the first trial components, x' , the plateau components, y' , and of a linear combination, $z = 1x' + ky'$ of these components, where k is value which makes $r_{zz'}$ a maximum, for each stage of learning of total, bright, and dull groups

		TRIALS						
		1	2-3	4-5	6-7	8-9	10-11	12-19
Total group	$r_{zz'}$	1.00	.94	.94	.96	.99	1.00	1.00
	k	.0	.5	1.7	4.3	10.3	79.7	∞
	$r_{zz'}$	1.00	.89	.71	.58	.52	.46	.45
	$r_{yy'}$	.45	.68	.86	.94	.99	1.00	1.00
Bright	$r_{zz'}$	.99	.93	.96	.97	.95	.96	.96
	k	.1	.8	8.0	13.9	7.6	9.3	18.9
	$r_{zz'}$	.99	.82	.52	.38	.33	.34	.39
	$r_{yy'}$	.51	.77	.95	.98	.97	.97	.97
Dull	$r_{zz'}$	.98	.96	.92	.92	.94	.95	.98
	k	.0	.3	.9	1.9	4.1	10.3	51.7
	$r_{zz'}$	.99	.93	.79	.68	.57	.49	.45
	$r_{yy'}$	.41	.60	.77	.87	.92	.95	.98

plateau. Note the rapid rise of the k values. Even by trials 4-5, the weight of the plateau components is nearly double ($k = 1.7$) that of the first trial, and that $r_{zz'}$ is about the same as $r_{yy'}$. On the other hand, when the weight of the first trial components is double that of the plateau, as on trials 2-3, where $k = .5$, $r_{zz'}$ is about the same as $r_{zz'}$.

To sum up, it appears that the components postulated for trial 1 and for the plateau account for performance throughout all stages of this learning, that there is a rapid transition from those

of the first trial as depicted in table 2 to those of the plateau of table 3, and that for the group as a whole, this transition occurs during trials 2 to 5.

Several final matters regarding this type of analysis should be considered. First, the failure of the $r_{xx'}$ value to reach unity may mean either that some new but minor short range components may enter in the middle stages, or that a more complex type of weighting of the components is necessary to give exact fits, namely, the ascribing of not the same k weight to all components for a given intervening stage, but of different weight values to the different components. I have not tried this latter method because of the great labor involved and because the present envisagement of uniform weights per stage gives a reasonable and satisfactory fit.⁴ Second, it must be said that *any* sets of components which fits exactly the first trial and the plateau, as do ours, would produce exactly the same values as shown in table 4, hence we have proven only that our components do in fact fit—and this is all we wish to do—but have not proven that it is the only set that does.

Fit with errors of brights and dulls. How do the components fit, separately, the performance of bright and of dull rats throughout the stages of learning? To answer the question, I split the total group into bright and dull subgroups as follows: total errors on trials 2 to 19 were summed for each rat, the median of these scores was figured and found to be 50.7, and the 530 rats above the score of 50 were then classed as bright, the 555 below classed as dull. For each subgroup, the error difficulties per blind per stage (i.e., per cent entrances) were calculated. The degrees of fit of the x' and y' components with them were then calculated. These values, $r_{xx'}$ and $r_{yy'}$, are given in table 4 in the third and fourth rows, respectively, of the bright and dull subtables. I

⁴ Actual tables, such as 2 and 3, can be worked out for each intervening stage. One would begin by setting up a new table 2 for trial 1 in which each weight there is multiplied by the constant $1/\sigma_{x'}$. Call these new weights, w_1 . Analogously, a new table 3 for the plateau, with new weights, $w_p = 1/\sigma_{y'}$ times the value in table 3 should be set up. These operations would not change the relative theoretical difficulties of the blinds. Finally, in any table for an intervening stage, x , each $w_x = (w_1 + kw_p)/(1 + k)$.

then calculated for each stage the k values which would make the correlation between actual difficulties and a combination of the two types of components a maximum, and finally worked out these maximal $r_{ss'}$ values, shown in their appropriate rows in table 4.

Note that for the bright group, the weight k of the plateau components is 8.0 by trials 4-5 and that the fit there with the plateau components alone, namely, .95, is not substantially improved by combining them with the first trial components, for the combination gives an $r_{ss'}$ value of .96. For the brights, therefore, the transition from first trial to the plateau components is extremely rapid, occurring during trials 2-3. For the dulls, the k weights of the plateau components are not as large until trials 10-11, and their transition from first trial to plateau components is slow. The important conclusion here is that on the first trial the performances of both brights and dulls are determined by the same first trial components, both of their $r_{ss'}$ values being nearly unity at this stage, but as learning proceeds the coalition of components changes much more rapidly for brights than for dulls, nevertheless, becoming the same coalition at the plateau stage, for both of their $r_{ss'}$ values are nearly unity at this stage.

The sufficiency of these components to account for the performances through all stages for both groups is shown by the $r_{ss'}$ values, which even in the transition period are .92 or higher. The failure of these values to reach unity may be due, as mentioned earlier, not necessarily to an advent in the transition stages of components other than those here postulated but to a weight-patterning of the first trial and plateau components more complex than that of uniform linear weighting.

Components of brights and dulls in the transition period. If the brights tend to elicit the plateau components earlier than do the dulls, then a detailed comparison of their blind difficulties during the transition period should illuminate the matter. Such a study might also give insight in any complex weight-patterning of the components during these stages which prevents the goodnesses of fit from being unity. In figure 4, I present a scatterplot of the blind difficulties of brights against those of the dulls

on trials 4-5. At this particular stage the brights are at the end of their transition stage, the dulls at the beginning of theirs. Read the plot as follows: the point in the plot labelled "1" stands for blind 1, entered on trials 4-5 by 55 per cent of the brights, by 70 per cent of the dulls. The best fitting line through the plot purports to be a *line of equal relative difficulty*. If all the points (blinds) were exactly on this line, the relative order of difficulty would be the same for brights and dulls irrespective of absolute difficulty, and the components considered as causes of difficulty

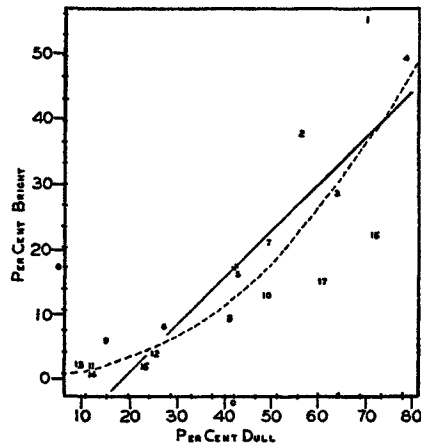


FIG. 4. RELATION BETWEEN PER CENT ERRORS IN BLINDS OF BRIGHTS AND DULLS ON TRANSITION TRIALS (4-5)

The entries are blinds; large scale units are per cent entrances; fine scale .2 sigma units with origin only shown.

would be assumed to be the same for the two groups. To explain the *divergence* of points from this line, however, requires the postulation of different components for the two groups, or differences in weight-patterning of the same components, or both. Blinds that lie above this line are relatively more difficult for the brights (or easier for the dulls), those below are relatively easier for the brights (or more difficult for the dulls).

The placement of the line of equal difficulty in the plot presents some difficulties. For a straight line, $y = mx + c$, the ordinary least squares solution is inadequate, as it *provides* two lines, de-

pending on which axis is the independent variable. But in our case both are dependent on factors which we believe to be common. We want *one* straight line, as shown in figure 4, so located in the swarm of points that the sum of squared perpendicular deviations (normals) of the points from it are a minimum.⁵ The line of equal difficulty might better be conceived as a curve, as free-handed in the figure, for the swarm of points may seem to require such a curvature. A curve indicates that for brights vs. dulls the units of measurement of difficulty, here per cent entrances, are not linearly related. Indeed, this would seem to be the case here, for there is a lower limit of difficulty, namely, zero per cent, against which, for the brights, blinds 11, 12, 13, 14, 16 are crowded, whereas for the dulls, these same blinds lie in absolute region of the scale of difficulty which permits discrimination between them. The curved line is therefore probably the best expression of equal relative difficulty, and we will, in consequence, attempt to explain psychologically the divergences of blinds from it.

Starting with the dulls, let us see what insight we can get into the components which in contrast to those of the brights affect their performance most heavily. It appears that the local direction-sets strongly affect the dulls' performance, for the blinds at the termini of the most important of these, namely, blinds 3, 10, 15, 17 at the ends of direction-sets *a*, *c*, and *d* lie in the plot below the line of equal difficulty. As these blinds are relatively easier for the brights, we would assume that these rats, by trials 4-5, have integrated to a much greater extent these specific sets into the higher direction-configurations, which pull movement out of these terminal blinds. For the dulls, *set d* is a potent determinant, for it accounts for the greater divergence of 15 and 17, and for the absolute lack of difficulty of 16, from which it pulls out movement.

The divergence of 15 and 17 below the lines may have been enhanced by the exit gradient becoming more potent for the

⁵ Reed (4) has shown that in general the slope, $m = -\cot \alpha$, is determined from $\tan 2\alpha = 2\sigma_x \sigma_y r_{xy} / (\sigma_x^2 - \sigma_y^2)$, from which α takes two orthogonal values, the one chosen having the sign of r . When the X and Y values are expressed in sigma scores, the fine scales of figure 4, α is always $\pm 45^\circ$, giving an $m = \pm 1$ of the line passing through the intersection of means.

brights at this early stage, and thus making these blinds relatively easier for them. This possibility would likewise explain the absolute easiness of 16. A further hypothesis that the brights at this stage are more definitely food-pointing would explain the greater relative difficulty for them of 1, 2 and possibly 4, 5, 6, 7, and the less difficulty of 3, which is not food-pointing. The greater difficulty of 9 for the brights may indicate an anticipation of *set d*, to be expected in their earlier efforts at integrating *set c* and *set d* into the higher direction-configuration *cd*.

These data are a bit meagre for much generalizing, but they nevertheless are consistent with the hypothesis that the brights are more potently controlled by the components of food-pointing and the exit gradient during the transition stage, and by efforts to effect the elicitation of higher direction-configurations. These are components characteristic of the plateau. But note that these components are all *highly abstract*, there being no immediately presented spacial features of the maze controlling them. The dulls, on the other hand, are relatively more controlled by components evolving from the specific spacial features of the maze, the specific direction-sets, at this early stage; the more abstract exit gradient and the higher configurations are not as significantly evident as determiners of their performance.

II. GENERAL THEORY OF PSYCHOLOGICAL COMPONENTS

With the detailed description of the psychological components of the maze performance before us in section I, let us note in this section the properties of them as radical psychological entities, their characteristics when they act together in a complex coalition, and the nature of the *change* of coalition with practice (i.e., learning). On doing this, we shall discover that these features are very general, seeming to apply, at least in outline, to most any performance, animal or human. In presenting them I shall try, by confining the content to this special case of maze performance, to avoid too great overgeneralization.

A. *The properties of components as psychological radicals*

The properties of the components may be described in a number of ways. I shall employ *faute de mieux* the analytical cap-

tions suggested elsewhere (17) for human mental test performance.

Cognitive content. By content I mean the unique unitary radical character of a given component which distinguishes it from all other components. Thus direction-set *a* is a southwest unified orientation, set *d* a different due-west orientation, food-pointing is probably one general orientation, centrifugal swing is of utterly different character from the foregoing, but the swings in different units are also different from and independent of each other. By their being *radicals*, I mean that they cannot as such be broken down into more elementary psychological components. In human thought, we would define the cognitive content of an "idea" as its meaning for the subject, referring to the unique, unified knowledge-character of the idea.

Cognitive form. Though set *a* and set *d* differ in content, they are alike in form, that is, in the respect that they are both sets in given directions. Each of the ten types of components listed earlier refers to a class of components which supposedly are alike in form. Clearly, decision as to form-character *lies with the experimenter*—on observing the objective spacial settings in which two components occur, and on noting the behavior elicited by these components, as observer I may abstract out a form-character which I believe they have in common. But whether or not the *rat* responds to this common form, I do not know.

Emergence process. The nature of the process by which a component emerges in the rat is unknown. In human beings, it is called "insight," "hypothesis formation," "the creative act," etc. One cannot deny the existence of such a process, for at one moment nothing in the subject's behavior indicates the existence of a component but in the next his behavior is controlled by it. Though the emergence process as such cannot be described, we may, however, indicate the *conditions* which must prevail for the component to appear.

The first condition is that the organism possess *knowledge of the fundamentals* of the field in which the component is to be elicited. The rat must have learned that floors, walls, and tops of the maze, which are the fundamentals, are things not to be penetrated,

but to be passed over, by, and under, respectively. These fundamentals he has had to learn previously, i.e., they have had their own conditions of emergence.

The second condition is that there must be a *critical arrangement of the fundamentals* of the field in which the component is to be elicited. This arrangement may be of the external stimulus features. For example, as a condition of the emergence of direction-set *d*, a series of maze segments, namely, the fundamentals, must be arranged all bearing off in the west direction. Again, the emergence of food-pointing requires that the animal previously physically approach food through a stimulus-defined path. The critical arrangement may be, however, not of fundamentals consisting of stimulus presentations. The fundamentals may be cognitive and non-cognitive components. Thus, the emergence of a higher direction-configuration probably requires a critical serial experience of the direction-sets from which it is evolved. Similarly, conflict emerges under conditions of a critical simultaneous experience of opposing direction-sets.

Knowledge and critical arrangement of fundamentals are two necessary conditions of the emergence process—a component will not appear unless they are fulfilled. They are to some extent independent: stimulus conditions, for example, may be critically arranged, but the rat lack knowledge of its fundamentals, or the rat may possess knowledge of the fundamentals, but the arrangement of them be not critical. In neither case will the component emerge.

There is still a third condition, namely, that the organism must possess the *process-competence*. Thus, he may possess knowledge of fundamentals and they may be critically arranged, but the component still fail to emerge because he lacks the capacity to execute the process. For example, both the bright and dull rats may possess equal knowledge of the direction-sets of the maze and may experience them in similar critical arrangement, but the bright may be competent to elicit the higher direction-configuration, but the dull may not.

The emergence of cognitive components, such as the higher direction-configurations in the rat, is doubtless also affected by

emotional or motivational components. These latter may either promote or they may disrupt the three conditions necessary for the emergence of the higher spacial sets. The goal gradient, for instance, is doubtless facilitating, as suggested earlier, the anticipation of food-consequence serving greatly to weight the local direction-sets which are the essential fundamentals to the higher configurations. On the other hand, when the noncognitive components of lassitude, inertia, and conflict strongly control movement, the rat is prevented from cognizing the essential fundamentals and their arrangement, and the process-competence is inhibited.

How do hereditary and environmental factors affect the emergence process? We can see how these two fundamental causes work by noting, I believe, their influence on the three conditions of emergence described above. Individuals differ in their readiness to evolve the concepts controlling a given performance when the requisite three conditions vary among the subjects. Such variation is of two sorts: first, the presented situation or relevant prior situations may vary for the subjects; second, hereditary genotype or trained-in differences in process-competence may occur.

Regarding variation of the first type, hereditary variance occurs when different genotypes seek out different present or prior situations that influence the emergence of components, environmental variance when such situations are varied for individuals of the same genotype. In our maze experiments, we sought to control the presented situation by providing, through extensive preliminary training and constancy of procedure, equal knowledge and arrangement of the maze fundamentals, and to control prior experience by standardizing living cage conditions. Nevertheless, it would be egregious for us to believe that all rats come to the first trial on the maze equal in knowledge of its fundamentals. Now genetic and environmental variance enters the picture through emotional and motivational components which, we noted above, influence emergence conditions. We know, from experiments to be reported later, that in the preliminary training period rats differ widely in emotional response to floors, walls, doors, and curtains, and hence we have no assurance that by the first trial

they come equal in cognizance of these maze fundamentals. Furthermore, recall that lassitude, emotional inurement, inertia, and conflict affect the performance, and that these emotional components are disruptive. The goal gradient, derived from hunger motivation, promotes the emergence of the higher configurations. Do these emotional and motivational components appear for the first time in the maze? Surely not. They doubtless have a developmental history. And any variation among rats in such development, whether genetically or environmentally produced, would affect the emergence of cognitive components in the maze. I suspect we are here describing the psychological basis of the variation we find among individuals in our bright and in our dull pure lines, and to some degree the difference between the lines.

As for individual differences in process-competence, both genetic factors and training probably produce them.⁶ Our hope originally was to bring all rats to equality in knowledge and arrangement of the maze fundamentals, and to discover that all the differences between rats were due to genetically determined difference in competence to elicit the higher configurations. We certainly provided no opportunity for differences in training of the specific process-competence required to elicit the direction-sets, for all rats lived previously in confinement. To some unknown degree, our hope has been realized. But we cannot separate out genetic variance in process-competence from variance in *performance*, which is our observable and which unfortunately includes variance in knowledge and arrangement of the maze fundamentals.

Generality. The components possess different sorts of scope.

⁶ The expression, *habits of learning*, is an ambiguous set phrase often connoting some generalized improvement in process-competence as a consequence of practice. From our analysis, it is now evident that it refers to any of three phenomena: as a result of practice (1) the improvement of a specific process-competence that is reelicited in subsequent performance, (2) the greater readiness to eliminate deleterious non-cognitive components which interfere with a specific process-competence, itself unaffected by practice, (3) the evolution of high-order cognitive components, called economical methods of learning, which as such dispose the subject, when confronting a new task, to focus on the discovery of the appropriate fundamentals of the new field and on the critical arranging of these fundamentals, to the end of evolving more readily the new cognitive components necessary for correct action in the new situation.

The *dynamic generality of content* refers to the range of related acts in a given performance covered by a given component. Thus, direction-set *a* controls action in units 1, 2, 3, 4, 5, 6; set *b* only in 3, 4; exit gradient, in all units, etc. Another form of generality refers to the extent to which a given component tends to recur in performances separated in time. Some components, such as the direction-sets, are quite generalized in time for they may recur, we assume, on 19 successive days or performances in the maze. Others, such as adaptation, short-cut, etc., appear as short-range determiners of action in a shorter period of learning. This feature I have therefore termed the *retention generality of content*. A third type is *generality of process-competence* about which our knowledge is nil. I would believe, with many psychologists, that process-competences vary in generality from those that are strictly unique, affecting emergence of a specific content only, to those that cut generously across content, determining the emergence of components differing widely in content.⁷ A final type is *generality of form*, i.e., the common form-character (q.v.) of components which differ in content and possibly in process. Generality of form is, analytically, a treacherous concept, for it refers to a property of components which is not a parameter of behavior, and it is frequently confused with general process-competence which *is*. I, the experimenter, note the generalized form which I name direction-set, but each of the sets subsumed under this name-category may be elicited by its own unique process-competence. The evil of hypostasis is no more evident than in the including in a single name-category components of like form, to the reification of which is ascribed a single general process-competence. Generalized form is a caption in

⁷ Some psychologists take a position of faith on this matter, believing that there exists an important general process-competence, called intelligence (Terman) or *g* (Spearman), or a few such faculties, called functional unities (Kelley, Thurstone), or an extensive universe of them (Thomson, Tryon). The methods which aim to discover the facts I have called correlation profile and orthometric (factor) analysis, techniques which unhappily provide findings that are always equivocal. I have elsewhere suggested the labelling of the correlational clustering of variables as *operational unities*, leaving the decision as to the psychological genesis of the clustering to further experimental tests of coalitionality (7).

the mind of the experimenter, process-competence lies in the subject.

B. The characteristics of coalitions

The above properties of content, form, process, and generality refer to attributes of each component taken as a radical. Performance in a given situation is, however, probably always determined by a coalition of components. I shall now describe the four characteristics of coalitional totalities which enable us to distinguish different performances.

Number or complexity of components. Though an axiom of the logic of the physical sciences is the describing of any measured phenomenon in terms of the fewest independent parameters possible, psychological analysis requires no such a priori restriction of "scientific parsimony." We are interested in psychological components, and only secondarily, if at all, in orthogonal mathematical axes. Our interest in stating the number of components is in describing the psychological complexity of a performance. *Complexity of content* refers to the number of radical components. In our maze performance, we find on the first trial, seven direction-sets, five counter tendencies, 14 centrifugal swings, etc. *Complexity of form* refers to the number of different types of components in each of which the components are alike in form; these are the ten types indicated by the general column heads of tables 2 and 3. *Complexity of process-competences* refers to the number of different process-competences involved; of this we know nothing from our analysis. On all counts it would appear that this maze performance is far from a simple psychological affair.

Relation between components. Each component is a psychological radical having its own special content which has emerged under its own unique time-space conditions. It is independent of other components in the sense that it preserves its own unique content at the moment it controls performance. Though independent radical entities, two components may nevertheless show a *concomitant relation* or correlation in the Pearsonian sense. We may find that rat A elicits the two unitary radicals, set *a* and set *b*, rat B elicits neither, and that such concomitant

variation occurs throughout the population. The tetrachoric r between the two components would then be unity. On the other hand, only a tendency for such concomitant relation may appear, resulting in an r less than unity. What causes this concomitant relation between any two radical components, X and Y ? The correlation, $r_{xy} > 0$, arises when the three conditions of the emergence processes (q.v.) of X and of Y are themselves correlated, and this relation can be caused in four different ways, enumerated in the following two paragraphs.

Consider first the two conditions: knowledge and arrangement of fundamentals. Those of X may be correlated with those of Y , and in two ways: (1) When the emergence conditions of X and of Y entail common (overlapping) knowledges and arrangements of fundamentals, $r_{xy} > 0$. For example, the different direction-sets of our maze involve knowledge of the same kinds of doors, curtains, walls, thus probably generating a concomitant relation between them. (2) In the absence of common fundamentals, a correlation between the disparate fundamentals of X and Y may be produced by agencies existing prior to or independent of the situation, hence $r_{xy} > 0$. A theoretical example would be the correlation between a direction-set in our alley T-maze and one elicited in an elevated circular maze. Though the knowledges and arrangements of the fundamentals of these two types of sets may be utterly different, a general component of "fear of any novel objects" would cause rats possessing this fear to fail to learn well the maze fundamentals of both direction-sets, thus eliciting neither; rats lacking the fear would cognize readily these fundamentals and thus would elicit both sets. In human mental test performances, the positive correlation between components sampled by two different tests is doubtless in large part caused by numerous emotional and motivational agencies of this sort as well as by gross differences between subjects in prior social and educational environments which cause a positive correlation between the different fundamentals basic to the components sampled by the different tests.

Consider next the two process-competences of X and Y . These also may be correlated in two ways: (3) When the process-

competences of X and of Y are determined by common (overlapping) physiological mechanisms, $r_{xy} > 0$. This source of correlation appears to be an undeterminable, since there seems at present no way to map out the sensory-neural-motor mechanics of process-competence. (4) When the two process-competences are determined genetically by gene-blocks independently assorting in gametogenesis, assortative mating of parents with respect to X and Y will cause a correlation between the two gene-blocks in the present population, and *pari passu* between the two process-competences, resulting, therefore, in $r_{xy} > 0$. Such assortative mating has occurred in our rat populations and we would therefore expect a correlation between the various process-competences utilized in the maze. Similarly, due to social and educational caste systems in human beings, assortative mating occurs, though less stringently, and doubtless accounts in part for the positive r universally noted between mental components sampled by different tests.

Our interest in the concomitant relation between components is created by the emphasis placed by some students of individual differences on the study of the correlations (*vide* factor analysis) between different behavior items within a performance (blinds in a maze or items of a test) and between different total performances (mazes or tests). These correlations are obviously determined in part by the concomitant relation between the components controlling the performances, and hence by the above four sources of correlation. But these sources, and other sources, such as the dynamic and retention generality of content, and the generality of process-competence, are singularly difficult to isolate. No one has yet shown how a mere mathematical analysis of correlations turns the trick.

Interaction between components. The multiple radical components determining a given performance may not combine in a simple additive way. The contexture of the coalition determines to some extent the weight taken by each component. For example, direction-set c would probably show a much greater weight on performance if set b were deleted by the elimination of units 4 and 5 from the maze. In our present analysis, the effects of

interaction are quantitatively expressed by the weights and their gradients in each column of table 2 and 3. Weights per blind were assigned a given component in the light of the effects upon it by other components. Thus, the tailing off of the weights of each direction-set per column results in part from the emergence of the next succeeding direction-set.

Complex interactions between radical components are doubtless numerous and difficult to estimate. We discern various types of interaction in our own data, beside that mentioned above. The component, conflict, is itself uniquely a consequence of interaction. Again, the reciprocal gradients of the exit and the inertia components may possibly be an expression of their interaction. From the point of view of learning, the most interesting effects are the change of radicals with the changing coalition at successive stages of learning. On successive trials, a component may change in content to a different radical, with only minor change in its control of performance, not sufficient to warrant a change in its name-label, but sufficient to require a change in its weight. Indeed, it may change to an entirely different radical, of such different content as to require a new descriptive label. Such a case is the change of the specific direction-sets into higher configurations. The dynamics of such a change in a radical has been described: we are merely now saying that the old radical comprises a component-as-fundament in a contexture of other components-as-fundaments which provide the emergence conditions for the elicitation of the new radical.

Individual coalition vs. average coalition of components. It would be a mistake to believe that the total coalition of components of, say, trial 1, having the weights given in table 2, represents a correct psychological analysis of each rat. The weight-pattern shown in the table merely describes the average rat, the values entered being a rough estimate of the population frequency on trial 1 of each component. Each rat should have his own table 2, and none of the N such tables might agree with table 2; in some, whole columns would be missing, in others, the weights per component would be much greater or less than those shown there, in still others, there would be columns for new universal, class, or

individual radicals not having, however, sufficient frequency to appear in the condensed table 2. The coalitions we have been describing are therefore the average of many individual coalitions.

C. The temporal coalitional change: a description of learning

The above essentially cross-sectional delineation of psychological components leaves out an adequate description of the nature of the change of the coalition through successive stages of learning. We ask: what is the nature of *learning* in terms of these components? An adequate answer to this question would require, I believe, a full description of (1) the change of the contents of the components at successive trials, (2) the progressive alteration of the emergence conditions that produce the components, and (3) the principles governing the elimination of components from, or their retention in, the coalition as trials proceed. Important in such a description is an analysis of those higher-order components which ultimately become, through integration, the determiners of the final "correct" or skilled performance.

Changing contents. The change of contents of the components of our maze task is summarily shown in the comparison of those of the first trial with those of the plateau. These have already been sufficiently described.

Changing emergence fields. Each component has its own emergence field, an adequate description of which would be a specification of its fundamentals and of the critical arrangement of them. These fields and the components elicited by them change as learning proceeds. Some components emerge in the rats prior to the regular maze run, such as the preliminary path direction-set, and food-pointing. Most of them emerge for the first time in the maze proper, some appearing early, such as those having as fundamentals the cognitions of the pattern of the maze segments (the direction-sets, centrifugal swings), others later, such as those depending on cognition of other components (conflict, the higher direction-configurations).

Modes of selection. Why do some components disappear from the coalition, others persist? How does it happen, in the rat who learns the maze perfectly, that *all* the components do in time

vanish in so far as producing movements into blind alleys is concerned? Considered in the light of the properties of the components, the answer to such questions, a *casus belli* among learning theorists, appears simple enough for this maze learning. Selection may be understood if one accepts the assumptions offered earlier under *Exit gradient* (q.v.), to wit, that on a later trial the rat remembers the components which controlled his movements on former trials (Assumption 1), and furthermore remembers their consequences (Assumption 2). It does not strain my credulity to believe, to cite several examples, that a rat may remember that food-pointing, or specific counter-tendencies resulted in being blocked in blinds, or that in unit 5 when under the influence of direction-set *c* the result was getting on rapidly in the maze and not being blocked for some distance, or that set *c* was previously succeeded by set *d*, or that set *d* had as its consequence the exit.⁸ I assume, further, that those components whose remembered consequences are the goals or sub-goals he seeks carry with them a special emotional enhancement or support which gives them greater weight at the expense of other components having goalless consequences (Assumption 3). We have thus introduced another assumption, namely, that there exist for the rat sub-goals in the maze (Assumption 4) besides the major food and exit goal. The spacial locales in the maze in which direction-sets are elicited become, I believe, sub-goals in their own right. Simply "getting on into new territory" is probably also a sub-goal, possibly in part because it has promising food-goal consequences. I would add several final assumptions, namely, that the rat remembers the amount of *effort* required by previously elicited components (Assumption 5), and that those components requiring excess effort in reaching goals or sub-goals are rejected in favor of those involving least effort (Assumption 6). These assumptions tell the story of selection, which may be summed up as follows: *On any given moment in*

⁸ The inertia-exit gradient may be due, in part, to the fact that consequences of components elicited at the beginning of the maze are, with multiple components, necessarily more numerous than those at the end, hence the consequences of the earlier components are more difficult to remember, thus occasioning more wandering at the start, but progressively less so as the rat proceeds towards the end.

any given trial, the subject may remember the components elicited in him on previous trials, the consequences of them, and the efforts they entailed. Those are selected as determiners of performance whose remembered consequences are the accomplishment with least effort of sought-after goals. When the competition between remembered components and their consequences is too great, the subject either manifests conflict and disorganization, or he elicits new components conditioned by the presented field situation.

Integration. An adequate description of the higher components which finally control performance in any learning situation requires a statement of the knowledge and arrangements of the fundamentals of their emergence fields, data on differences in process-competence, the nature of their contents, and the modes of selection which preserve them. In our maze performance these higher-order determinants are the direction-configurations, the contents of which were described earlier under *Direction-sets*. The emergence process is one in which the various radical direction-sets *a, b, c, d, e, f*, comprise the fundamentals. In the earlier trials these sets are independent radicals having unique content. With added trials, the cognitive field is laid out for integration: each of these sets, as a fundament, has as its remembered consequence the direction-set which follows. The problem for the rat is to remember, while traversing the maze, just when one set is to be dropped, the next to be elicited. It takes some practice to hit it off just right—when he overshoots or undershoots the mark, he enters blinds. In due course, however, he makes the shift correctly and we would then say that he has integrated the two sets into a higher direction-configuration. The process is the same as that described under *Exit-gradient* (q.v.) for the retrogressive integration of food-consequence into the spacial cognitive structure of the maze, but augmented here by the assumption that a subsequent direction-set is also a remembered spacial goal just as is terminal food.⁹

⁹ The phenomenon of *latent learning*, i.e., the fact that rats show evidence of having learned the maze path to some degree even though not having been given terminal food reward, is thus understandable. One would predict from the theory of direction-sets as sub-goals that in a series of mazes having the same number of units, those designed to elicit the fewest and simplest direction-sets would, other things being equal, show greatest evidence of latent learning.

The above general treatment holds, of course, only for the statistically average rat, and the statements under *Integration* hold only for the rats who learn the maze. As rats vary in their coalitions of components, the learning process may be quite different for different individuals. Only a special study of individuals or of selected subgroups will illuminate this matter. In our dullest strains of rats which show little learning there is doubtless not much change of components throughout the whole 19 trials, except, perhaps, for the reduction of strength of the first trial non-cognitive components which make for errors. In the bright line, the change is rapid, with integration appearing early. Probably the gross difference between the two strains in maze performance is in large part caused by a difference in the process-competence basic to the elicitation of the higher configurations.

This envisagement of learning suggests that it may be futile to seek *universal* laws of learning. An experimenter may describe any learning performance of rats or of men by the outline-captions of changing content, emergence fields, and the modes of selection, but the really important matter of filling in the details depends on a psychological analysis of the particular performance. The so-called laws of learning refer to the modes of selection in a changing coalitional matrix, but that these modes should be the same in radically different matrices represents again a pious faith in and urge for "scientific" parsimony.

SUMMARY

The psychological components (concepts, emotions, motivations) which determine individual differences in a given performance are conceived of as being validly inferred from performance if they satisfy the criteria of internal consistency, goodness of fit, prediction of other behavior *in situ* and in relevant other situations. The performance studied here is the relative difficulty of 17 blind alleys in a T-maze at successive stages of learning as manifested by 1,085 rats from the P to F₄ generation of a selective breeding experiment. Relative difficulties of the blinds are measured with negligible error at all stages, and they change as learning proceeds. Ten types of psychological components are inferred. The bases of inference are a study of the

TABLE 5 (Appendix)

Total entrances into each blind alley for each stage of learning for the bright and dull groups separately

Trial 1 includes rats from P to F₃ generations, later trials from P to F₅. N for each stage of two trials includes total rats that ran on the two trials; from trials 2-3 on, approximately 530 brights and 550 dulls ran the maze per single trial.

BLIND	TRIALS									
	1	2-3	4-5	6-7	8-9	10-11	12-13	14-15	16-17	18-19
Bright										
1	178	710	585	374	290	256	214	201	206	161
2	128	451	399	328	294	255	180	133	119	112
3	216	607	313	164	122	105	84	93	103	86
4	218	792	524	362	283	217	172	141	125	134
5	176	519	173	110	80	73	73	63	57	64
6	137	367	90	43	22	20	12	12	20	18
7	115	393	219	105	51	23	20	28	33	26
8	104	308	98	40	38	19	15	7	13	11
9	79	173	69	34	15	15	13	16	8	6
10	208	476	141	75	47	60	49	44	48	60
11	91	123	23	9	5	10	4	13	7	11
12	85	159	46	49	27	24	26	27	12	17
13	56	60	21	24	20	13	13	6	11	7
14	36	78	12	18	17	14	9	8	8	6
15	224	720	230	94	47	23	18	18	25	13
16	178	134	23	6	5	11	16	5	9	8
17	210	553	163	47	24	22	18	10	17	10
Σ...	2,439	6,623	3,129	1,882	1,387	1,160	936	825	821	750
N...	269	1,052	1,063	1,062	1,057	1,063	1,056	1,059	1,059	1,056
Dull										
1	173	763	774	658	610	547	531	477	496	458
2	129	528	622	610	663	676	637	604	537	474
3	201	827	704	606	572	479	443	420	391	361
4	215	932	869	787	706	635	588	544	518	535
5	188	670	475	367	356	355	338	334	318	288
6	130	484	299	244	231	209	167	138	142	147
7	121	521	545	451	399	331	265	213	214	185
8	126	521	456	355	308	281	239	227	230	228
9	98	245	163	181	161	155	134	121	103	76
10	211	796	544	384	306	304	298	281	287	269
11	100	234	131	129	129	122	141	137	122	101
12	100	318	276	256	240	258	268	252	248	254
13	91	137	104	134	146	191	203	199	197	182
14	68	165	149	159	187	187	165	147	142	118
15	216	937	800	651	519	438	406	338	310	247
16	207	463	255	162	146	146	134	92	108	105
17	219	873	677	433	361	277	222	185	159	165
Σ...	2,593	9,414	7,843	6,567	6,040	5,591	5,179	4,709	4,522	4,193
N...	261	1,095	1,105	1,109	1,110	1,108	1,110	1,104	1,107	1,099

blind difficulties and subjective judgment from observation of the rats' performances. These components are: direction-sets, food-pointing, short-cut, counter tendency, centrifugal swing, adaptation, lassitude, exit gradient, inertia, and conflict. The effects of these components are expressed quantitatively, and are shown to fit rigorously the experimental difficulties of the first trial and of the plateau stage, approximately the difficulties of the intervening stages, and in general better than a more parsimonious set, such as goal-gradient, and food-pointing alone. The performances of the bright and dull subgroups are adequately described by these components, the difference being that the brights elicit the more abstract cognitive types earlier than do the dulls.

A general theory of psychological components is presented, purporting to apply in descriptive outline to animal and human performances, but here illustrated on the rats' performance. This theory consists of a statement of (1) the properties of components: content, form, emergence process conditioned by knowledge and arrangement of fundamentals of the emergence field and process-competence, and generality of content, form and process-competence, (2) the characteristics of coalitions of components determining performance: complexity, concomitant relation, interaction, and individual coalitions and (3) the nature of learning, conceived of as the change of coalition with practice, to be described in terms of change of contents, change of emergence processes, modes of selection by the subject, and those components whose final selection accounts for "correct" performance. The selective mode postulated for this maze ability requires six assumptions: retention (memory) of components, of their consequences, of the effort they entail, existence of multiple goals, added weight through emotional support of those components having goal consequences, and selection of those involving least effort.

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