processes of perception and co-ordinated movement. The third level included memory and habit formation. The relational level involves what is generally termed reasoning ability. General intelligence is expressed throughout all levels of the hierarchy but its manifestations differ not only in degree but also in quality at the various levels.

The current British conception of the structure of intellect is probably best represented by Vernon's (1950) hierarchical model. At the top of the hierarchy is again g which sub-divides into the major group factors viz. verbal-educational (v:ed) on the one hand and spatial-perceptual-practical (k:m) on the other. The latter corresponds with what Burt called "practical", and sub-divides into the minor group factors viz. space ability, manual ability and mechanical information. The former v:ed sub-divides into verbal and numerical. The minor group factors divide further into specific factors but because of their narrow scope Vernon considers them to be of minor importance. Since first presenting this exposition Vernon (1965) has broadened the number of minor group factors to include creative abilities, mathematical abilities and scientific and technical abilities. It is characteristic of British factor analysts to extract a general factor first. This is followed by the extraction of the major group factors and then the minor group factors. The loadings for the general factor are always positive but the subsequent

factors appear in a bipolar form i.e. approximately half the loadings are positive and the rest are negative.

In America, Thurstone has probably had the most influence in terms of both theory and methodology. Indeed, in Thurstone's case, methodology and the findings are closely related. It will therefore be necessary to mention his technical innovations which led to a divergence of views between himself and his British counterparts.

In 1931 Thurstone published his centroid technique of factor analysis as a means of assessing group or multiple factors as he called them. (The centroid method is clearly admitted by Thurstone to be a computational compromise for the principle-factor solution: a procedure commonly used by factor analysts nowadays). By means of this method one factor at a time is extracted. The first centroid has the largest means of loadings and each successive factor has a mean of smaller loadings. The factor matrix, as described above, consists of a major centroid with positive loadings and the remainder appear in a bi-polar form. Among American factor analysts there is general agreement as to the arbitrariness of this centroid factor matrix. Thurstone maintained that, if the matrix being analysed was based on ability scores, it would be unreasonable to assume that a factor ability could have a negative contribution to make to performance. He therefore adopted the criterion of <u>positive manifold</u>, which is

achieved by rotating the axes in the factor space to a new position. This results in an elimination of all negative loadings in the final solution, except for a few very small ones which are, anyway, due to chance. Another important criterion Thurstone introduced was the concept of simple structure. (The criteria for simple structure are given in Thurstone, 1947, p. 335). He noticed that if two sets of centroid factor loadings were plotted against one another on a particular plane they tended to form clusters. To Thurstone this condition was highly significant and scientifically meaningful. He therefore advocated that the axes be rotated to positions close to these clusters. This has the effect of increasing the magnitude of some of the loadings and reducing others to negligible proportions. Rotations can either be performed by keeping the axes orthogonal (i.e. at right-angles to one another) or by reducing the angle between the axes to obtain an oblique solution. In the oblique solution the factors are always correlated. In some cases this solution is to be preferred as it yields a clearer simple structure.

The principle of simple structure has been the cause of much controversy. Adherents to the school of non-rotations maintain that rotations result in g being robbed of the variance that rightfully belongs to it and consequently rotated out of existence. Guilford (1941) has shown however, that if g really exists in a matrix to be factored it will still be detected by

Thurstone's methods. Thurstone on the other hand has pointed out that if sceptics try out rotations they will be convinced of the worth of the method by the clearer interpretations which result.

Thurstone applied these techniques in a number of large scale studies made on college students and school children. In one of his studies (Thurstone, 1938) he identified seven factors which he labelled "the primary mental abilities". These seven abilities were: S - spatial ability, P - perceptual speed, N - numerical ability, V - verbal meaning, M - memory, W - verbal fluency and I - inductive reasoning. Many other investigators have repeatedly confirmed the existence of these abilities. In using the criterion of simple structure Thurstone broke away from the hierarchical conceptions of intelligence and in effect returned to the oligarchic or "faculty" school of thought. A great deal of argument has been put forward in favour of either point of view. Some of these will be mentioned briefly.

Guilford (1967), as the major representative of multiple-factor analysis, has severely criticised British factor analysts on a number of points. He argues that the preference for a general intellectual factor (g) over multiple factors is due to a restricted view of the area of investigation. He maintains that any genuine pair of intellectual tests is sufficient to disprove the existence of g. He also points to the invariance of g

in hierarchical models. It changes with every battery of tests that is analysed. This is a valid criticism and a serious shortcoming in hierarchical models. Thurstone (1947) in contrast has stated his position clearly:

> "The factorial composition of a test in a set of primary factors that have been found in a complete and overdetermined simple structure remains invariant when the test is moved to another battery involving the same common factors and in which there are enough tests to make the simple structure complete and overdetermined" (p. 363).

Vernon (1950) has listed his criticisms of Thurstone's approach and at the same time attempted to reconcile the two points of view. Thurstone himself believed that it was possible to obtain g from second-order factor analyses (cf. Thurstone and Thurstone, 1941). Tyler (1965), having surveyed the literature on factor analytic studies has concluded that intelligence is neither pure g nor a combination of completely independent abilities. She seems to imply from her conclusion that a case may be made for the value of correlated factors.

During and after the second world war further research along the lines proposed by Thurstone resulted in a breaking down of the "primary" abilities into others, more homogeneous and narrower in scope. French (1954), in a survey of some 69 analyses, identified 59 factors which he believed should be regarded as distinct although some of them overlapped. In a sustained programme of research Guilford brought some order into the impending

chaos by proposing his "structure-of-intellect" model (Guilford, 1967). For present purposes it will only be necessary to describe some of the more salient features of his model. (An excellent summary of this model will be found in Guilford, 1968).

As the number of factors increased, Guilford saw that they could be related to one another in a three dimensional system analogous to the periodic table of elements in chemistry. This configuration indicates that there are three main ways or facets for classifying mental abilities. If the operations a thinker performs are examined it will be seen that there are five classes: cognition (recognition), memory (retention of what is cognized), divergent thinking (searching for different ideas or solutions to a problem), convergent thinking (processing information which leads to the correct answer) and evaluation (reaching decisions as to how correct, or adequate the result of one's thinking has been).

If the materials (tests) which are used to assess these operations are considered they may be broken down into four classes: figural (concrete material, e.g. size, colour, shape and texture); symbolic (e.g. letters, digits); semantic (verbal meanings and ideas) and behavioural (e.g. social situations).

If the kinds of answers or products that the subject is asked to produce are examined, they may be classified

into six classes: units, classes, relations, systems, transformations and implications.

Guilford's system makes provision for 120 factors of intellect since all combinations of operations, products and contents are theoretically possible (i.e. 5 x 4 x 6). Not all these abilities have emerged from factor analyses so far, but a large proportion have. The formulation of the model has made it possible to design new tests to fit vacant cells and this has led to the discovery of many abilities not suspected before.

Guilford (1967, pp. 65-66) has shown how his model accommodates some of Spearman's ideas as well as some of Vernon's. He has also linked his work to Guttman's (1965 a) facet model, Bloom's (1956) educational taxonomy and Piaget's (cf. Hunt, 1961) work. These writers all provide structural theories of intelligence, but most of them are only now being subjected to empirical verification. A few remarks pertaining to their work will be made at the end of this chapter.

If Spearman represented the extreme monarchic view Guilford represents an oligarchic view approaching an anarchic position. Humphreys (1962) has objected to Guilford's model on the grounds that the tests developed to measure the abilities in his model are too simple. His preference is for the facet kind of model in which more complex tests are used.

Along with the increase in the number of abilities

and the efforts to organize them into a meaningful system has come an increasing realization that not all the abilities uncovered are truly independent of one another. This state of affairs leads to a factor analysis of factors and the identification of what are called second-order factors. The work of Cattell (1963) characterises this trend. Cattell has argued that g is in fact two interrelated and cooperative factors. The first is fluid intelligence (G_f) defined as " ..... the major measurable outcome of the influence of biological factors on intellectual development ..... "; the second is crystallized intelligence (G_c) defined as " ..... the principal manifestation of a unitariness in the influence of experiential-educative-acculturation influences" (Horn and Cattell, 1966, p. 254). Cattell related his distinction to a number of views. He sees G_f and G_c having correspondence with Hebb's (1949) distinction between intelligence A and B, Newland's (1962) process and product and Ferguson's (1956) ability and learning set. He also regards G_f as corresponding to Spearman's (1927) "eduction of correlates" while G_c corresponds with Hunt's (1961) information processing strategies.

In order to test his theory Cattell assembled a battery comprising four IPAT culture-free subtests and five of Thurstone's Primary Mental Abilities tests as measures of G_f and G_c respectively. In his analysis he found two second-order factors which corresponded closely to the predicted factors. The first second-order factor (G_f) consisted of four of the culture-free

tests and Thurstone's spatial test. The second second-order factor (G_c) consisted of the verbal, reasoning and number subtests of Thurstone's battery and the series sub-test of the culture-free battery. A subsequent factor analysis of the second-order factors caused G_f and G_c to merge. This was regarded not as the result of some single overriding influence but as the influence of G_f on G_c. In a second study (Horn and Cattell, 1966) use was made of an older, more varied sample and the tests used were considerably different to the original battery, most of which were used to test the hypothesis that other factors, besides G_f and G_c, influenced intelligence. These other influences were predicted to be general visualization, general fluency and general speediness. The results showed that almost all the tests loaded on the various factors as predicted, and a carefulness factor was uncovered. In addition the correlation between G_f and G_c was lower than in the previous study. This supported Cattell's contention that as educational opportunities are less closely tied to capacity, G_c will be less closely tied to G_f, and the distinction will be easier to demonstrate.

Cattell's theory, amended to include general visualization, fluency, speediness and carefulness, falls somewhere between Spearman's g and the multiple-factor conceptions. However, unlike Burt and Vernon, he views his factors as general functions that are positively related to one another and work in a

cooperative manner to produce test responses.

Although Cattell's results look impressive some psychometricians are apt to be sceptical about his use of second-order factor analysis. The correlation matrix to be factored at the second-order level is obtained from oblique rotations. It is therefore somewhat indeterminate. In other words different methods of oblique rotation at the first-order level can result in different second-order factors. Another point is that the number of unknowns increases at the second-order level. In other words one has the unknowns at the first order plus those at the second order which results in an extremely complicated model about which very little is known. (M. W. Browne, personal communication).

This brings to a close the description of the major factor analytic approaches to the nature and assessment of intelligence. Many different points of view have been discussed but in making an overall assessment of these approaches a distinction may be made between British and American factor analysts. The British approach grew out of a long tradition which emphasized hereditary and evolutionary aspects. While accepting the importance of heredity, the American approach paid more attention to environmental aspects and tended to be largely influenced by the need for operational definitions. The concept of general intelligence has always been of central importance to British psychologists and their models have been of a hierarchical nature. In their

hierarchies, abilities have been conceived of as uncorrelated. Influenced by Thurstone's criterion of simple structure, American psychologists adopted a multiple-factor approach. Provision is made for both uncorrelated (orthogonal) and correlated (oblique) factors. Thurstone's techniques led to his model of "primary mental abilities", which in turn led naturally to the structure-of-intellect model propounded by Guilford. Cattell's work, based on correlated factors, is an attempt to bridge the gap between the two points of view. A basic difference between the two systems is to be found in their respective conceptions of factors. On the one hand Spearman, Burt and Vernon have regarded factors as statistical abstractions or convenient principles of classification which simplify the comparison of individuals on the basis of test performance. On the other hand Thurstone, Guilford and Cattell have regarded factors as genuine causal entities and have equated them with "real" abilities.

There is some reason to believe that both methods are basically reducible to each other (Bernyer, 1958 and Cattell, 1963) an interpretation which has not generally been accepted (Guilford, 1967). Coan (1964) has suggested that the different theoretical orientations are due simply to preferences for different modes of verbal description. If the philosophical, historical and methodological points of departure are taken into account the two orientations must be regarded as being widely disparate.

Ultimately the choice of approach lies with the investigator himself who must decide whether or not to rotate the reference axes. It should be remembered that the unrotated matrix, in which the major factor has positive loading throughout and the remainder appear in a bipolar form, is purely arbitrary. This is true whether Thurstone's centroid method or Burt's simple summation technique is used. The characteristics of the unrotated factor matrix are merely circumstances of the procedure of factor extraction. If g is extracted, the remaining factors are bi-polar. They are difficult to interpret psychologically and difficult to defend logically. One may well ask then, how an arbitrary method of extracting temporary factors can be used as a foundation for a psychological theory?

Thurstone's criterion of simple structure was an attempt to overcome the criticisms listed above, but the points to which he rotated reference axes were located on a subjective and therefore arbitrary basis. His early intuitions for determining psychologically interpretable factors led, however, to attempts to objectify the definition of simple structure (cf. Carroll, 1953 and Tucker, 1955). In these attempts the emphasis shifted away from simple structure to the "concept of parsimony" (Ferguson, 1954 a) and ultimately to the "factorial invariance criterion" which Kaiser (1958) seems to have achieved with his "varimax" rotational procedure.

In making a choice among the many possibilities that exist, the preferred types of factor solutions are determined on the basis of two general principles: (a) statistical simplicity and (b) psychological meaningfulness. If the choice is made purely on statistical grounds, the natural approach would be to represent the original correlation matrix in terms of a number of factors, determined in sequence so that at each successive stage the factor would account for a maximum of the variance. This statistically optimal solution is the method of principal axes, first proposed by Pearson (1901) and later developed by Hotelling (1933). If psychological meaningfulness is required, then the judgement of the investigator is involved. Factors do not emerge conveniently labelled "spatial ability", "verbal ability" etc. Since factor analysis is a purely classificatory technique the problem of labelling the factors uncovered remains the investigator's.

As a final assessment Kelley's (1940) observation is most apt.

> "There is no search for timeless, spaceless, populationless truth in factor analysis; rather, it represents a simple, straightforward problem of description in several dimensions of a definite group functioning in definite manners, and he who assumes to read more remote verities into the factorial outcome is certainly doomed to disappointment" (p. 120).

In order to place the investigator's search for factors on sound scientific foundations the conditions

for proper factor analyses should be observed. Since all techniques of factor analysis begin with inter-correlations, conditions affecting correlation coefficients will also influence factor loadings. Thus the use of sufficient numbers of subjects is of prime importance. The size of correlation coefficient is also affected by the heterogeneity of a sample. Groups should be as homogeneous as possible in such characteristics as age, sex, education etc. unless it can be shown that no significant mean differences exist between subgroups in the variables to be correlated. The tests used in factor analysis should be highly reliable. Unreliable tests contribute little to the identification of factors. The scores to be intercorrelated must be experimentally independent. In other words no two variables must be derived from the same set of responses. A discussion of these conditions as well as others of equal importance may be found in McNemar (1951), Guilford (1952) and Gulliksen (1959). If careful attention is paid to these points, the interpretation of the factors uncovered in terms of psychological meaningfulness should be less difficult and more valid.

4. Other Current Conceptions of Intelligence

Guttman (1965) has presented, what he calls, a "faceted" definition of intelligence. Preferring to talk about "the degree of intelligence of an act of a subject" rather than "intelligence" per se he has written:

> "An act of a subject is *intelligent* to the (extent) to which it is classified by a (tester) as (demonstrating) a *correct* perception of an unexhibited *logical* (aspect) of a (relation) intended by the tester, on the basis of another (exhibited) *logical* (aspect) of that relation that is *correctly* perceived by the subject" (p. 168).

The italicized words in the definition are peculiar constant features of the concept of intelligence while those in parentheses are sets of ideas rather than constants. The sets may also be called facets as they define a Cartesian space in which any response to any intelligence test may be classified.

It is important to note that facets are logical units, not psychological units or factors. Guttman draws attention to the manner in which tests are drawn up with special reference to the mode of communication used in tests. He suggests that the repeated finding of the verbal, spatial and numerical factors in factor analyses may be due to nothing more than the limitations of pencil-and-paper tests. He shows also that his definition leads to a clearer distinction between achievement and analytic ability. In obtaining the correct solution to an item the subject has to make use of "culling rules". According to whether the subject has no information about the sets of ideas involved or has some information, so the items will be either of the achievement type or the analytical type.

The importance of facets lies in the domain of test construction. Once a faceted definition of an ability

is arrived at, the domain of the items is well-defined. By increasing the number of facets and relations among items, complex items may be constructed and innumerable abilities defined. Guttman has argued that the three dimensions in Guilford's model may be viewed as facets. In his 1968 article Guilford apparently acknowledges this observation. It should be pointed out that the "facet" model implies a greater number of abilities than the "structure-of-intellect" model. Guttman, however, attempts to contain the proliferation of abilities by invoking laws of formation.

No review of the nature of human intelligence would be complete without some reference being made to Piaget's work. Hunt (1961) and Flavell (1963) have both presented full accounts, in English, of Piaget's work. In the present context only a brief outline of his general conceptions will be given.

Piaget regards life as a continuous creative interaction between the organism and the environment. This interaction functions outwardly as adaptive coping and inwardly as organization. (This conception is similar to Spencer's, who saw life as "the continuous adjustment of internal relations to external relations"). Piaget conceives of adaptive coping as continually reorganizing the structures of the mind. The structures change but the functions remain invariant. The adaptive interaction between organisms and the environment involve two complementary processes which correspond to inner

organization and outer adaptation. These processes are respectively assimilation and accommodation. Assimilation occurs whenever an organism utilizes something from the environment and incorporates it. Accommodation is the process of modifying an existing schema as a result of repetitively applying the schema to the environment and thereby assimilating it.

The theory which emerges then is that the development of intelligence is characterized by continuous transformations in the "structures" of intelligence. His theory also takes the form of an hierarchical model. There are three major periods of intellectual development: sensorimotor, concrete operations and formal operations. Each period is characterized by a set of substages. The periods and substages represent forms of cognitive organization, each of which is more complex than the preceding. Each evolves from the preceding stage and no stage can be skipped. They are a form of biological adaption which grows out of the adaptation of the organism to the environment.

Piaget had little interest in the measurement of individual differences. His terminology excludes the concept of "ability" and the traditional concepts of experimental psychology. His use of the term "intelligence" corresponds to "cognition" rather than to intelligence in the sense of individual differences. His assessments nevertheless have profound implications for the assessment of intelligence. By showing the complexity underlying fundamental concepts such as space, time and