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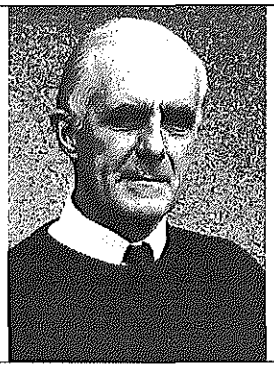
Understanding the Powerful Grouping Sense through a Unifying Classification Theory



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A unifying theory has been developed that draws together a compatible set of methods for classification, and shows why others should be rejected. The methods reveal polythetic groups and sequences, and evaluate the quality and the best identifying characters for each group. The theory defines the rules for the fuzzy uses of 40 interacting options for group studies in a new 12 000 line FORTRAN program called Uniter, available from the author. The theory and the program's options help to show the nature of the achievements and failures of humanity's powerful grouping sense. This approach offers useful understandings in an extremely wide range of fields, examples of which are given. Both research and teaching should take account of this development. (Author)

1. Introduction

The human senses provide data for a given instinct that is highly efficient at revealing groups. An example is music which gives hundreds to thousands of notes a minute to the aural sense which passes the information to the brain where is is processed at high speed to give a wealth of patterns of harmonious themes, sub-themes, chords and discords. The processing of themes is primarily grouping with past or immediately prior patterns of notes. More impressive is the visual sense which collects information through 131 million receptors in each eye. Processing of the visual field operates as rapidly as the eye can be scanned over a scene, grouping the input at high speed with associated synaptic patterns held in the brain. Inputs from the other external senses, smell, taste, touch and heat are similarly rapidly grouped. During every waking moment there are enormous data fluxes into the sensory systems and the brain's linked grouping processes. The brain is then seen as acting as a highly efficient acceptor and group-former of information. An important aspect is that the group-making process is made more sensitive by training. An experienced motor mechanic can detect subtle diagnostic sounds in an engine that are completely hidden from an untrained observer. A musician may detect far greater depths of theme-groupings in a work than a casual listener. A community ecologist may be able to detect the most subtle nuances in plant growth and habitat when passing from one area of vegetation to another. Some of the weak polythetic groups detected by taxonomists evoke admiration for their delicacy and sensitivity. The instinct involved in all this might best be seen as a metasense as it draws upon the senses for its data, but for simplicity it is termed here the grouping sense. The relevant aspects of group theory are applied to various situations as follows.

2. Examples of Groupiness

2.1 Pleasure and Displeasure

Groups dominate in the experience of many pleasurable recreational and cultural activities. Music has an intense groupiness and it ranks highly as a cultural asset. The visual arts are a further example, providing objects with patterns, colours, shapes and associations in time and space with strong groupiness. Many are highly valued, some reaching major prices in sale-rooms. Both art and music offer groupiness in contexts of a broad range of complexity. Only a specialized public can enjoy the more difficult passages of music or more abstract works of art: the group patterns are more hidden and require more training and intellect to reveal them. In contrast, the simplest music and artworks have relatively compact groups that are well isolated so that their main elements can be easily discovered by the public. In ballet, the choreographer's groupings of the dancers is supported by music with themes that have a high groupiness that is easily understood.

Sport, seen as a participant or as a viewer, has an exceptionally high, pleasurable groupiness for most people. Teams may be viewed as simple groups in competition. At a more sophisticated level, like race-horses, their performances are eagerly forecast with careful attention to the details of past achievements, de-weighted by their remoteness in time, with bets placed on their chances of winning. Games such as cricket and football have a wide appeal as their complexity can be read and enyoyed as a challenge at any level of difficulty. High levels of groupiness are seen in stadium singing, creating a great feeling of togetherness that is highly enjoyable to the participants. Very high levels of complexity are seen in some sports such as yachting, where to win, subtle inputs of evidence of weather and current must be integrated with critical elements of boat speed under various conditions. Chess provides high challenges in grouping the consequences of moves and sequencing the resulting groups in priority of tactical advantage. Many hobbies such as stamp collecting and bird watching have a high groupiness requiring various levels of grouping skill that are pleasurable to the participants.

In contrast, displeasure comes from failures of the grouping sense and its supporting systems. Some people find complex works of art or music too challenging and so may react with frustration and annoyance. Here the data are too complex so the grouping system fails. Where the data are seriously incomplete, so that there is no hope of building a reliable set of groups, disappointment and frustration may ensue. Annoyance may come from badly made groups lacking adequate data, or debased by distortions, monothetic bias and wrong weightings or dilations, as in a poorly drafted political speech. Over-hasty conclusions may be based on preliminary data that are too incomplete for adequate reliability. There are numerous ways in which group-making can fail and it is only by knowing about the structure of the process that their problems can be properly assessed and corrected. In extreme cases, the badly made groups may lead to strife and warfare as discussed below.

2.2 Promoting Alertness

Exposure to groups appears to increase alertness. Students often find that their learning ability is enhanced by studying with background music, despite the risk of being distracted by it. Music is commonly piped to shops, lifts, offices and factories where it provides a more pleasant environment. This pleasantness may be associated with the music's groupiness, and possibly a resulting greater alertness. In some buildings so-called 'white noise', a rustling sound, is held to stimulate alertness, perhaps by the mind being challenged to perceive groupiness where virtually none exists. Many find that reading a morning newspaper is stimulating at the start of a day. While this raises mental activity, it may partly do so by exercising the grouping sense with material that is very largely about groups: political parties, warfare, crime, economic developments, share movements and sport.

2.3 Maintaining and Strengthening Groupiness

In many situations it is helpful to be able to weld society together by raising the level of groupiness among people and their surroundings. A strongly unifying force is language. The mind is deeply aware of the complexities of languages and easily detects the sets of nuances in dialects that signal social groups and regions. The groupiness of nationality is deeply rooted in language and powerful social defences are sometimes erected to preserve it. An example is French where pollution by English words and phrases is of deep concern to some authorities. The signals of language are usually numerous and clear, allowing widespread use as a monothetic marker character of what are essentially polythetic groups of people. Prolonged exposure can lead to training in the nuances of local dialects to the extent that in England many speakers can be placed to county and even some towns. Groupiness is strengthened further by emblems, flags, folk-music, costumes and a host of other aspects of fashion. Tourism may lead to enhancement of this groupiness, sometimes in artificial ways such as exhibitions of indigenous traits. Initiation by completing a difficult or ridiculous task may be used to weld members of a group into a strong team which may have to face tough challenges. The initiation creates a sense of close groupiness that is vital for the high level of mutual reliability required, as in a street gang or a secret society.

2.4 Crime and its Correction

For street gangs, part of the reward of joint participation in a crime is a strong feeling of groupiness at the time, and later through recounting the pleasurable secrets of the criminal actions shared by the members. This is all the more enjoyable in a monotonous slum environment where groupiness may be boringly low. Gang crime is less frequent in the countryside where the natural environment supplies its own special polythetic intensity of groupiness, full of exceptions that are quite absent in the rigid brick and concrete of a depressed townscape. In attempting correction of crime the courts aim to curtail the criminal's range of action by fines (reducing funds to explore the world's groupiness) or by imprisonment. However, prison society generally has its own intense groupiness and the way of life there is actually preferred to 'outside' by some criminals (1). The worst form of non-violent punishment is solitary confinement where the prisoner is cut off from as much external groupiness as possible. Seen in these ways, the intensities of group patterns emerge as a major element in criminality and its correction. The best ointment to heal the wounds of crime then seems to consist of polythetic groups learned in a sequence of rising complexity. This could be found in an environment which is the complete opposite of a jail, such as a rich natural countryside where the 'warders' introduce the criminal to a more holistic life. Prison farms and community service schemes are a move in this direction.

2.5 Strife and its Antidotes

Strife is mainly caused by greed, power-seeking and opposing beliefs (often misunderstandings) about political or religious paradigms. Much of this material originates in the powerful grouping sense. It flourishes best where concepts are badly formed, giving faulty views between groups of people. The differences occur on either side of leaky communication barriers where just enough information permeates the boundary to build up erroneous views. The barrier is often language. The size of a region in conflict partly depends on the efficiency of communication within it. The scale of warfare has enlarged from the limited communication units of the city-states of ancient Greece, to the inter-continental conflicts of the present century. The 'global village' achieved with modern media may eventually become a triumph of communication over warfare.

The proximal causes of strife include stereotypic groups made inaccurately due to lack of all relevant data ('the full picture'); there may be distortion of the information due to politically inspired filters in the media; monothetic bias may exist in the perceived groupings of what are basically

polythetic, natural communities; there may be lack of dilations in the groups to take account of past and present elements that are thinly known; and weightings of some properties may be quite inappropriate for the nature of the foreign society. Seen in such light, the foreigners can seem to have extraordinary, even dangerous properties. Where different communities are involved, the target group may come to believe from what it knows from the badly made groups that a conspiracy is afoot against it (2), and so it may resort to aggression.

A power-hungry dictator can easily make use of such misconceptions. The borders close, the local media become filled with distorted information and groups, and simple slogans proclaim increasingly angry stereotypes. Militarism becomes rife, with strong signals of groupiness including the paraphenalia of flags, uniforms, special salutes, parades and martial music with simple, highly grouped themes. The society becomes increasingly ruled by monothetic paradigms so that all people are made to conform to a single outlook, the same way of life and even the same dress. Under this barrage of groupiness it is a short step to take up arms and go into battle against the 'enemy'. Part of the aim in battle is to kill as many of the enemy as possible to reduce them to a weak and terrified minority. Another is to occupy as much of the enemy's territory as a means of suppression and to serve an interest in spreading ones own kind across the world, an instinctive carry-over from natural selection during pre-historic and tribal phases of humanity's evolution.

Armaments to support these group-based ideals and to defend against them have become exceedingly costly for most countries. Instead of going to war, a more rational approach would be to find out how each ingredient of conflict arose and what paradigms should be adopted to ensure their cure. From group theory the most obvious origin lies in the badly made groups we noted above, apart from the problems of greed and supposed divine guidance. The best general antidote emerges as a strongly polythetically-based flow of accurate information between the opposing groups, coupled with debate to clarify group differences and even to promote their enjoyment. It has been difficult to establish peace tables for negotiation in the past, but today there is the 'global village' effect in which the electronic media bring pressure on leaders to behave in a more rational way about their differences. The essence of peace negotiations is to bring the combatants to a forum for communication so that differences can be ironed out and common interests enhanced to kindle a spirit of increased joint groupiness. For this to succeed, naturally high human groupiness must be accepted as the norm. A peace negotiator's message must show that for both sides the ideal is a set of stable, mature, polythetically formed communites, tolerant of exceptions and believably complex.

A future stabilizing force is to look on the diversity of humanity and its rich array of views of life as a source of pleasure. However, to get to this utopian state will require much effort in understanding other groups of people, particularly in surmounting the huge barriers of unintelligible languages, deep religious convictions and cultures with quite different outlooks, while respecting them enough not to interfere with them. Tourism is a healthy sign of peoples' curiosity about each other, their lifestyles and their countries. This interest in group diversity has strong economic underpinnings from the great profits to be made from tourism which can then be seen as another stabilizing force.

2.6 Divorce and Reconciliation

The widespread tragedy particularly in developed countries is the problem of divorce between formerly blissfully happy couples. The social destructiveness of this is gross and bears such severe scars on productive lives of parents and children that it deserves close attention. Regions with a high level of stress on ordinary people to achieve high status are particularly prone to high divorce rates: South Africa and California are examples. Any hypothesis for understanding it and its cure must take full account of the powerful forces of groupiness. When the husband and the wife both have complex and time-consuming careers, communication between them may decline. This may lead to misunderstandings through badly formed, stereotypic groups. If these are not soon corrected by a return through communication to more natural, exception-riddled, polythetic grouping of shared concepts the marriage may collapse. This solution bears a close resemblance to the corrections and antidotes noted in the two sections above.

2.7 Politics and Management

Deft political management requires a balance between the party slogans' simple messages at election time and the realities of the complex world afterwards. The slogans provide easy monothetic labels for the political parties, while the real world's complexities are polythetic groups of phenomena for management, many riddled with exceptions.

Rather like chess, the politician and manager must sequence groups of consequences of alternative pathways, using a mixture of criteria as priorities. The alternatives are often full of exceptions arising from social and economic diversity. Simplification of the groups by changing them so as to have monothetic labels is a departure from reality. This may have disastrous effects as in the case of the race-labelled policies of apartheid, where the recent return to democratic, natural and polythetic groups has been greeted with such great pleasure and relief. Great discipline is required to protect the diversity of all groups, ranging from the minorities to the majority so as to be able to continue to draw upon the broad array of their polythetic wisdoms.

Another large problem in politics and management is that most decisions have to be based on incomplete data. Where evidence is missing, the classification of alternative future pathways must be patched with local dilations. The dilations must also allow for the non-linear systems that may create chaotic fluctuations in key variables, demonstrated in chaos theory (3). As with weather predic-

tion, accurate forecasts that are needed as basic inputs to management planning may be impossible beyond a few cycles.

3. Discussion

Despite the brilliant sense for revealing groups being a major attribute of humanity it has been neglected in the literature. A partial reason may be the weaknesses of past theories and methods of classification. Cognition is defined as the action or faculty of knowing or perceiving, but it makes no claim as to how this is done. It has helped to bring pattern recognition into psychology (4). However, the pattern-seeking algorithms used in psychology lack most of the options found to be essential for classification in studies based on the unifying theory (5, 6). With this lack of depth of understanding of groups, it is not surprising that psychological and cognition texts continue to give little or no reference to the grouping sense (7-13).

With the advent of connectionist models of brain function ('neural networks') with parallel distributed processing, a fresh approach is coming to cognition. It is hoped to have a link between biological models of brain function and the phenomena of cognition, within a decade (14, 15). This will be useful for the light it may throw on the biochemical structure of the grouping sense.

4. A Unifying Theory and Options for Classification

In the course of studies to develop a broad theory for methods of classification for biological systematics (16), a very wide range of research applications has become evident (17, 18, 19, 5). The theory has been used to draw together a set of compatible methods to give a unified approach in classification studies. This has resulted in a large new grouping and group analysis program called Uniter which has 12 000 lines of FORTRAN and explanatory text. The unifying theory draws together 40 options in the program which can be set by rules to contribute to the result in a fuzzy way (20). In this paper the unifying theory is applied to understanding aspects of humanity's powerful ability to sense and use groups in all spheres of activity. An introduction is first given to the theory and Uniter's options.

The aim of the Unifying Theory is to draw together in a computer program a set of methods of classification that match a number of ideal tenets (16). In the summary that follows the term item is used for an object or concept being grouped. A property is given as a value for an item against a defined descriptor. The descriptor may include the property value's units of measurement (such as plant height in metres). The items, descriptors and property values form a data table. Classification is performed in a strict sequence: grouping the items according to their property profiles; sequencing the groups; showing their informational quality in terms of isolation and compactness; and then, finally, finding the best characters for making identifications.

The theory holds that groups must be made to be as consistent as possible. For this purpose a set of homogeneity functions has been developed (21). These are more general than similarity which can only test the relations between two items at a time. Homogeneity is seen as the 1-complement of a dispersion ratio. The ratio measures the disorder of the data compared with that of a maximally heterogeneous set. This approach, related to entropy, has numerous advantages. It can be applied to non-sequential properties, where the dispersion is measured by the number of rarer states. Such properties are uncommon: an example is whether an artifact is made of brass or silver. Most properties are sequential, showing the extent or degree of presence of some feature such as length or number of parts. For these the dispersion is measured by the standard deviation. The homogeneity value found this way for a pair of items is exactly the same as their similarity. The internal variation of a property such as height or width can be given in the data table by two or more values per item which homogeneity can use directly without the prior averaging needed with similarity (22). Homogeneity can be used with another source of grouping information: inter-item reaction tests such as hybridization between plants, or the relative successes of communication between speakers of similar dialects (16).

The theory and its options provide for exceptional cases in a number of ways. A simple case is when an item's datum is missing for a property. A deeper case is when entire items that are suspected to be close relatives are missing from the data table. To take account of these, the information space of the classification is locally dilated (23). Centroid resemblance is used for dilation and a fuzzy algorithm alters its contribution to varying degrees set by a rule as the clustering proceeds (20, 24).

A very important tenet of the theory states that one must expect groups to have up to many discordant property values. This may occur to an extent that no property is uniform enough in a group for any to be used as a clear-cut characterizer. Such groups, riddled with exceptions, are termed polythetic (many possible combinations exist for defining membership). The important contrasting kind of group is monothetic, where membership requires the presence of all of a single set of defining character states in each of the group's items (16, 25). Monothetic groups are often artificial, usually made by divisive methods for some special purpose. Polythetic groups are often called natural, peppered with changes made by nature's processes over periods of time. They are easily made by clustering, starting with the most homogeneous cores. The intensity of polytheticness varies. Most of the members of a relatively strong polythetic group possess similar property states and form a compact set at least over a broad core. On the other hand, a relatively weak polythetic group has most of its members with rather different properties, forming a hazy, core-less structure (26). The structure is weak despite the algorithm seeking the most compact possible grouping of the items. The polythetic and monothetic group theory deserves a far more central position in texts about groups

than it normally gets: indeed it is often overlooked (27, 28). This may be partly due to the incompleteness of the original definition (25). The two kinds of group are pivotal in understanding the uses and misuses of groups discussed later in this paper. In natural groups a common misuse is distorting polythetic, maximally compact structures to give some constant characters to make identification easier. This is called monothetic bias. It has no place in trying to reveal groups made by natural processes which could not care whether you or I could identify their group products or not. Monothetic bias is probably common in biological groupings where the classifier may often favour, erroneously, easy identification as an attribute of 'good' groups.

A critical issue to ensure high-quality results is to avoid unneccessary information loss or distortion (29). Such problems are regrettably common among the more than 250 algorithms proposed for computer-based grouping (17). An example of a common distortion is the use of Mean Euclidean distance as a measure of resemblance (29). A unit-long distance, when placed at 45° to the axes of a scatter diagram, has an average informational difference of 0.7, but if put parallel to an axis it is 0.5, a 41% distortion. This is highly damaging to the accuracy the user expects from computer methods. It restricts the use of graphical methods of comparison such as the widely used principal components analysis. The problem is rooted in semantics where difference is loosely equated to distance. Information is lost heavily when finely scaled observations have to be coded in only two states, 0 and 1 because the resemblance tests cannot work with greater detail. Further problems occur with some of the clustering algorithms where inappropriate linking rules distort structures (29).

Information can also be lost or distorted if the properties are used in an unbalanced way. Some properties may be very alike in nature, relative position and function. Allowing each to contribute as much to average resemblance as any other property would over-weight the information they bear. They should be de-weighted, given less weight than a 'standard property' (22). De-weighting is often needed for other reasons. Some properties such as hairiness of leaves are difficult to measure so they have to be coded by a few values such as 0 (absent), 1 (some) and 2 (dense): this is called coarse coding. Coarsely coded properties should be de-weighted to avoid distortion by the strong differences and resemblances they tend to give (6). Some properties are known to be affected by irrelevant factors. To eliminate their unwanted noise they also need to be de-weighted. Finally, it may be necessary to de-weight the contributions from smaller values which are more affected by random forces than the larger.

All this shows that group studies are rather more complex than one might expect. Many of the options noted above are absent from other computer programs, despite their general aim to be explicit, accurate and reproducible. In contrast to the unified approach, other programs mainly offer the user a set of separate methods that each give an alternative pattern of groupings (18, 30). The Uniter program's methods are more explicit than the human grouping sense. However, they have two problems. The first is that measuring and recording data are so much slower than using the senses, except for the less visual properties such as chemistry. Preparing a data table for grouping 100 species may take a week or more. The eye can scan shapes far faster than this but it takes time to learn the properties and the processing will have lower repeatability, especially in difficult material. The second problem is the vagueness of some of the rules for choosing the relative strengths of actions of the options.

For example, it is necessary to pre-treat some properties to isolate overall size variation, so as to avoid small items grouping with other small ones and large with large, where proportions are more important (22). The pre-treatment does this with the numerical data for those properties that are seen to be involved. The size extraction is done by Uniter as a separate process. The extracted joint size factor may be used as another property and be given a full weight or less. The mind does all this instinctively, integrating the results in some way with its data gathering and grouping processes. When weeding a flower-bed, small and large plants of weeds are recognized mainly by the proportions of their structures and their overall size is only partly used by the gardener. However, both the gardener and the programmer have the same problems: which properties are actually involved and how much should the overall size property be de-weighted? The difference is that the programmer has to make more explicit decisions.

The next step is to examine the grouping sense and to find where the unifying theory and its methods can be applied. A cardinal point here is that previous literature on the human instinct for sensing groups is thin. Group behaviour is well-served by texts such as those of Brown (19) and Douglas (1), but there is virtually no coverage of the topics discussed below in leading works such as those of Flanagan (7), Foster & Louw-Potgieter (8), Geen (9), Krahe (10), Morris (11), Perkins (12) and Posner (13). Surprising is the absence of a word for the intensity with which things form groups, here referred to as groupiness: this does not appear in the chief dictionaries consulted.

5. Conclusion

Important aspects of grouping theory and practice, widely missing in the literature and many computer programs, have been drawn together in the Uniter program which is available from the author. They give a valuable insight into humanity's deep involvement with groups. They show how aspects of groupiness underpin major issues across an extremely wide range of aspects of life, only a few of which are touched on in this paper. Especially important are the two major kinds of groups, monothetic (single character set, often artificial) and polythetic (properties as homogeneous as possible but may be riddled with exceptions, usually natural).

The enjoyment of groups through excercise of the grouping sense is circumstantially supported by the high groupiness of recreational pursuits and, conversely, in a

negative manner by the deprivations of crime correction, especially solitary confinement. The understanding of how cultural and natural assets are enjoyed is of fundamental importance. The high groupiness of these assets holds great potential for uplifting immense numbers of dreary lives by offering the fun and challenge of polythetic diversity. The assets may be strong antidotes to crime and antisocial behaviour, besides being a first step away from poverty. These suggest deeper reasons for strengthening support for nature conservation and for the creation of cultural works, both of which have extensive histories of financial neglect as economic externalities and are usually the first to see funding cuts in a depression. Linking culture and nature conservation by their high groupiness could give them a new strength in opposing threats of damage. To destroy permanently a portion of an important natural area would be like excising a part of an art-work or burning all copies of a movement of a major symphony.

The grouping sense and the basics of group studies noted in the early part of this paper should urgently be brought into education. Potent, sometimes dangerous forces arising from the power of the grouping sense would be more easily controlled by people trained with a proper knowledge of it. Its development might have been of great selective value in human evolution over the past hundred thousand generations. It needs to be understood better today where it has the potential for such widespread creative pleasure on the one hand and destruction on the other.

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References

(1) Douglas, T.: Groups - understanding people gathered together. London: Routledge 1988. 252p.
(2) Moscovici, S.: The conspiracy mentality. In: Graumann, C.F. & Moscovici, S. (Eds.): Changing conceptions of conspiracy. New YorK: Springer 1987. 264p.
(3) Gleick, J.: Chaos - making a new science. London: Heinemann. 352p.
(4) Reynolds, A.G. & Flagg, P.W.: Cognitive psychology. Cambridge, USA: Winthrop 1977. 457p.
(5) Duda, R.O. & Hart, P.E.: Pattern classification and scene analysis. New York: Wiley 1973. 482p.
(6) Hall, A.V.: Classification of evolutionary groups: the Uniter program's approach to greater resolving power. Taxon 42(1993) p.609-625.
(7) Flanagan, O. The science of the mind. Cambridge, USA: M.I.T. Press 1984. 424p.
(8) Foster, D. & Louw-Potgieter, J. Social Psychology in South Africa. Johannesburg: Lexicon 1991. 515p.
(9) Geen, R.G. Human aggression. Milton Keynes, GB: Open University Press 1990. 241p.
(10) Krahe, B.: Personality and social psychology, towards a synthesis. London: SAGE Publications 1992. 278p.
(11) Morris, R.G.M. (ed.): Parallel distributed processing. Oxford, GB: Clarendon 1989. 339p.
(12) Perkins, M.: Sensing the world. Indianapolis, USA: Hackett 1983. 352p.
(13) Posner, M.I. (Ed.): Foundations of cognitive science. Cambridge, USA: M.I.T. Press 1989. 888p.
(14) McLelland, J.L.: Parallel distributed processing: implications for cognition. In: Morris, R.G.M. (Ed.): Parallel distributed processing. Oxford, GB: Clarendon 1989. 339p.
(15) Sejnowski, T.J. & Churchland, P.S.: Brain and cognition. In: Posner, M.I. (Ed.): Foundations of cognitive science. Cambridge, USA: M.I.T. Press 1989. 888p.
(16) Hall, A.V.: A unifying theory for methods of systematic analysis. Biol. J. Linn. Soc. 42(1991) p.425-456.
(17) Sneath P.H.A. & Sokal, R.R.: Numerical taxonomy. San Francisco: Freeman 1973, 573p.
(18) Wishart, D.: Clustan user manual, ed. 4. Snt Andrews, GB: University of St. Andrews 1987. 250p.
(19) Brown, R.: Group processes - dynamics within and between groups. Oxford: Basil Blackwell 1988. 297p.
(20) Kosco, B.: Fuzzy thinking - the new science of fuzzy logic. London: Harper & Collins 1994. 318p.
(21) Hall, A.V.: Methods for demonstrating resemblance in taxonomy and ecology. Nature 214(1967) p.830-1.
(22) Hall, A.V.: Automatic grouping programs: the treatment of certain kinds of properties. Biol. J. Linn. Soc. 1(1969) p.321-325.
(23) Hall, A.V.: Studies in recently developed group-forming procedures in taxonomy and ecology. Jl: S. African Bot. 33(1967) p.185-196.
(24) Hall, A.V.: Evolutionary classifications: dilation control for poor sampling and extinctions. In preparation.
(25) Beckner, M.: The biological way of thought. New York: Columbia University Press 1959. 200p.
(26) Hall, A.V.: Detecting groups in dendrograms. S. African J. Sci. 87(1991) p.304-307.
(27) Ridley, M.: Evolution and classification. London: Longman 1986. 201p.
(28) Levinton, J.: Genetics, paleontology and macroevolution. Cambridge, GB: Cambridge University Press 1988. 673p.
(29) Hall, A.V.: Avoiding informational distortion in automatic grouping programs. Syst. Zool. 18(1969) p.318-29.
(30) Anderberg, M.R.: Cluster analysis for applications. New York: Academic Press 1973. 359p.

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