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Graphic Representations of Hierarchical Systems: Preliminary Study

by

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Abstract:

Graphic representations are used to explain or illustrate concepts in many contexts. This paper presents initial research into the graphic representation of hierarchical systems. In particular, the visual arguments presented in tree and circular hierarchical diagrams are described and discussed using a number of particular examples. Since the graphic display for a hierarchical system represents the relationships recognized by that system, a study of characteristic types of graphic display contributes to our knowledge of the theory that underlies the system. The extent of conceptual match between the visual and classificatory arguments represents the degree to which the graphic form depicts the theory it purports to illustrate.

Introduction

The graphic representation of concepts is of interdisciplinary concern in fields ranging from geology to advertising to statistics to medical imaging to astrophysics, and the study of non-art images has been approached both theoretically and empirically from, for example, cognitive, linguistic, educational, and aesthetic perspectives.[2] According to Stewart, graphic representations of models of linguistic theories have influenced the evolution of the theories in a way "that is neither governed nor allowed for" (1976: 3). An important consideration for classification research is the different graphic forms that may be used to represent hierarchies because these graphic forms may have influenced theory in unanticipated ways. Many bibliographic classification systems incorporate hierarchical elements. Some endeavour to be hierarchical both structurally and notationally (e.g., the *Dewey Decimal* and the *Universal Decimal* classifications), and some may be at least partially hierarchical in structure without reflexive notation (e.g., *Library of Congress Classification*). Similarly, classification systems for other purposes are often structured hierarchically. Thus, identification of types of hierarchical diagrams may be significant for the development of classification theories and systems in many fields. This paper considers only hierarchical classification systems, and other types of classifications are not discussed.

No single definition has been generally accepted for the term "hierarchy," and Arras' study of the concept found that definitions ranged from narrow and restrictive to broad and

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[2]Non-art images in disciplines outside of the fine arts and popular imagery are discussed extensively by Elkins (1995). Studies in all disciplines use varied terminology for the pictures, graphs, diagrams, and charts that are produced for differing purposes in the assorted research fields. Following Winn (1978), this paper uses the term "graphic forms" to encompass all types of graphic representations.

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inclusive (1991). Like the concept of classification, the concept of hierarchy is transdisciplinary, and different definitions have been adopted for different functions. For the purposes of this paper, we may adopt a commonly used broad definition, i.e., a hierarchy is a set of ordered levels. Since our purpose is to examine some of the different graphic forms hierarchies have taken, it is not helpful to insist on a strict definition because whatever definition is implicit in the particular graphic form is presumably the definition that is appropriate for that specific hierarchical display (regardless of whether or not it is appropriate for the theory the display presents). To discover whether or not this presumption is true is one of the goals of graphic analysis of the diagrams that purport to illustrate a certain system. Thus, a strict definition would rule out a number of possible displays of hierarchies and prove detrimental to the inquiry.

Complete treatment of the role(s) of graphic forms in the theory and practice of the development of hierarchical structures is outside the scope of this paper. Such a treatment should provide: 1) an investigation of various theories of graphics for use as analytic frameworks for the examination of graphic forms; and 2) the selection of the most appropriate theoretical framework for the purpose. The goal of the present paper is one preliminary to such a comprehensive study. That is, the purpose is to identify examples of certain kinds of graphic forms, both tree and non-tree, that have been used to represent the structures of hierarchical systems. This approach has been taken because, although previous work has been done on classificatory displays (e.g., Rolling (1965); Wille (1984)), these studies have not been cumulative, and we have no shared body of research knowledge to draw on. This absence of shared knowledge means that examples of different kinds of hierarchical displays from a number of fields need to be identified. The displays discussed in this paper do not exhaust all existing or potential displays, but they may be considered as at least preliminary data that must be accounted for in any useful theoretical work on the graphic forms of hierarchical systems.

To assess the conformity of the visual and classificatory arguments to each other, as discussed below, it is necessary to use a framework designed to make such an assessment. One potentially valuable framework was proposed by Bertin (1983: 2-14), who identified three functions for graphic representations: recording information, communicating information, and processing information. These three functions are not mutually exclusive and may all be present in a single graphic form. Ideally, the process of graphic design must be grounded in the nature of the primary questions to be put to the display. Bertin divided the process of graphic analysis into three major areas:

1) analysis of the information (i.e., the content to be presented in the graphic), including invariant information, its components, and the number, length, and level of organization of these components;
2) the properties of the graphic system (i.e., the container for the information), which is composed of eight variables (i.e., the two dimensions of the plane, size, value, texture, colour, orientation, and shape); and
3) the rules of the graphic system, which govern choices about the efficiency and legibility of the eight variables for the given purpose of a particular graphic representation.

The qualities of any specific graphic representation can thus be assessed using Bertin's system for analyzing graphic representations as systems of signs. Graphic forms for hierarchical

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systems are intended primarily for communicating information about the system, i.e., to render the classificatory argument in a visual vehicle. In this paper, the primary variables under discussion are 1) the shape of the graphic form as a container for the information it is intended to communicate, and 2) the devices by which the information is made understandable. In addition, whether or not these elements may have influenced the theory of the particular system is discussed for some examples.

Visual and Classificatory Arguments

If we take a graphic form as a "visual argument" (e.g., Winn, 1978: 156), then it follows that different graphic hierarchies may present different visual arguments and proceed from different verbal definitions and concepts. Indeed, if the graphic form adopted for a particular concept or set of concepts can influence the development of the theory of the field (as, for example, Stewart (1976) found for linguistics), then the visual argument can be assumed to be a strong and persuasive one.

Classification systems, too, can be seen as arguments about, for example, the structure of the world of knowledge. "A taxonomy is a truly conceptual and insubstantial thing. ...and...it is just where taxonomy ends that empirical reality comes into existence" (Storkerson, 1992: 403). A classification system does not exist in the world of empirical reality, but is a conceptual invention that is imposed on phenomena and that is more or less satisfactory (or not) for some particular purpose.[3] For bibliographic purposes, it is conventional to select certain conceptual abstractions of knowledge (Ranganathan's "idea plane") as phenomena and to create classification schedules as artifacts embodying those abstractions (Ranganathan's "verbal" and "notational" planes). In this view, the reasoning used by a classificationist to choose which classes and relationships are to be presented in the system are the premises of the classificatory argument.[4] According to Messaris (1994), linguistic and visual representations differ in kind, not simply in degree, and language shapes one's world-view in ways that pictures do not. Thus, the graphic representation of a classification system should display visually the classificatory argument of that system because the concepts and relationships in the system should be defined before the graphic display is designed. This decision sequence is based on the same assumptions that advocate that the notation for a bibliographic classification system

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[3]Bates and Peacock (1989) discussed the differences between classifying and modelling as intellectual strategies in sociology in terms of concepts, units of analysis, levels of scale, and causation. Their view is that "the connectedness...in models is thought of as existing in the empirical world and as only being represented symbolically in the model. ...[In classifying] the mind constructs the class on the basis of comparison and there is no object in the real world that corresponds to the class. It is a pure mental construct with no empirical referent" (1989: 569). This distinction has implications for bibliographic classification theory. Bibliographic classification systems have been traditionally created for the subjects of books. It is arguable that confusion has arisen between classifying and modelling because a book is an "object in the real world", but its subject exists only in the classification system. It may be that the problems that arise in, for example, shelving books as physical objects according to the multi-dimensional conceptual system of a classification can be helpfully understood using Bates and Peacock's distinction.

[4]A discussion of these issues for bibliographic classification systems appears in previous research (Beghtol, 1986a).

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should be the last consideration, after the concepts and relationships that will be present in the system have been fixed. The question then arises whether or not the visual argument and the classificatory argument coincide with or diverge from each other, and, if they diverge, how much and in what respects.

Tree Hierarchical Diagrams

The most frequent graphic form used for taxonomic systems is a tree (or branching) diagram or some variation on a tree form. Using a tree as a metaphor for various kinds of systems can result in various presentations of graphic forms.[5] The variety of these graphic forms may have arisen from the ingrained character of the tree metaphor. As Davis noted,

> This visual concept [of a tree] is so well internalized in so many Western belief systems that it is an almost commonplace emblem, a visible archetype accessible to the learned and illiterate alike. (1987: 116)[6]

An interesting example of the pervasive metaphoric status of the tree concept and of the kinds of objections that have been made to it in the literature of bibliographic classification appeared in Broadfield, who criticized Bliss' diagram of the discipline of biology by raising the tree metaphor to the status of an argument by analogy:

> A tree with such weighty branches and so sapless a trunk would have little survival value; but the possession of these subdivisions does not cause biology to have so poor an expectation of life. ...The only tree that could meet the requirements of logic would be the one whose trunk ended at the first ramification, and whose branches produced sub-branches only once, and so on as far as the last twig; in which also every co-ordinate set of branches or sub-branches issued from exactly the same point in the parent stem. Having a clearer idea in his mind, the classifier need not look for such a tree. (1946: 61)

Ranganathan, too, at least partially rejected the tree metaphor as a graphic form for the classification of knowledge. He considered the well-known tree of Porphyry to be "greatly oversimplified" (1965: 30). In his view, two closer approximations to the tree of knowledge were available. His drawings of one of these trees, a century old banyan tree (which has an original trunk and a large number of secondary trunks) were reproduced both right side up (1967: 368) and upside down (1965: 32) in an effort to facilitate comparison to the tree of

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[5]For example, tree diagrams of hierarchical systems may appear as drawings in two dimensions on paper (e.g., Perreault, 1969: 130-131, Fig. 6); as three-dimensional constructs for computer projection (e.g., Robertson, Mackinlay, and Card, 1991: 193); as skeletal line diagrams (e.g., Robin, 1992: 160, 162); or as depictions of relatively realistic trees (e.g., Robin, 1992: 161).

[6]The implications and problems of discussing and depicting various kinds of systems, including hierarchical classificatory ones, as trees have been widely discussed. In comparative linguistics, for example, Southworth suggested modifications (in the form of "isogloss maps" (e.g., 1964: 558)) to family-tree diagrams that would allow the metaphors of both family and tree to continue to be useful ones, and Davis (1987) described the intersections and divergences between the family metaphor and the tree metaphor during nineteenth century debates on the relationships among Indo-European languages. In the biological sciences, Sluys (1984) clarified the distinction between phylogenetic and genealogical trees that in his opinion had caused confusion in a number of areas of taxonomic research.

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Porphyry and to employ the banyan tree usefully as a graphic form for the tree of knowledge. In Ranganathan's opinion, the banyan tree was the closest the tree metaphor could come to diagramming the universe of knowledge, but even such a complex tree was not complex enough because it could not show the many ways in which knowledge proliferates. His description of this proliferation, which continued to employ the tree metaphor even after he had rejected its possible graphic forms, follows:

> For in the true Tree of Knowledge, one branch is grafted to another at many points. Twigs too get grafted in a similar way among themselves. Any branch and any twig are grafted similarly with one another. The trunks too become grafted among themselves. Even then the picture of the Tree of Knowledge is not complete. For the Tree of Knowledge grows into more than three dimensions. A two dimensional picture of it is not easily produced. There are classes studded all along all the twigs, all the branches, and all the trunks. (1965: 32)

Falling between the tree of Porphyry and the banyan tree in Ranganathan's attempt to diagram the universe of knowledge accurately was the branching diagram shown in Figures 1a and 1b.[7] Figure 1a shows an early and Figure 1b shows a later version of the same diagram. Ranganathan called both versions "Schematic Diagram of the Tree of Knowledge", the symbols used for the Personality, Energy, Space, and Time Isolates are similar in both, and the Matter Isolate is absent in both, but the two versions differ visually. Figure 1a looks more organic and tree-like and has an obvious starting point at the top. As he had done with the figure of the banyan tree, Ranganathan deliberately presented this diagram upside down "to facilitate comparison with the Tree of Porphyry" (1965: 30). Figure 1b, which is not upside down, has no obvious starting point, and the precision of the shapes in the diagram resembles a tree less than it resembles a non-organic structure such as an electronic circuit board or an electrical wiring diagram. Ranganathan found both versions inadequate for displaying the "tremendous unlimited proliferation [of possible subjects, which] can only be imagined" (1967: 365). Further research may reveal whether the increasing number of Basic Classes in different editions of the *Colon Classification* (CC), especially in the seventh edition, was influenced by the inadequacy of these various tree diagrams to express Ranganathan's thought. Thus, Ranganathan's view was that the visual arguments of tree diagrams could not be made to conform sufficiently to the classificatory arguments he wanted to make and depict.

Although he was unable to find a tree diagram that satisfactorily represented the entire universe of knowledge, Ranganathan continued to use simpler tree diagrams to illustrate concepts less complex than the whole of knowledge. Figure 2 shows three examples of these less ambitious tree diagrams, which represent three different ways in which subjects can proliferate (i.e., by linking collateral arrays, by linking basic subjects, and by linking isolate ideas). These diagrams are interesting because they combine the usual technique of subdividing a class hierarchically into a number of subclasses in a tree form with Ranganathan's technique of creating subgroups by facetting (i.e., subdividing by only one characteristic of division at a time). Thus, the subclasses in Figure 2 each represent subdivision by a different characteristic,

[7]Note: All Figures are placed after the references.

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in contrast to the conventional technique of subdivision into different "species" of a "genus". In this way, Ranganathan was able to combine traditional hierarchical classification with his idea of facetted classification in one tree diagram. The visual argument here appears to conform with the classificatory argument that Ranganathan espoused in CC in which the universe of knowledge is divided initially into a number of Basic Classes (Agriculture in Figure 2), and in which each of these is then subdivided on the basis of particular characteristics of division, (i.e., facets).

Circular Hierarchical Diagrams

A less familiar graphic form for hierarchies is a diagram that uses circles (usually, but not always, concentric) to depict hierarchical levels. According to Fenk, all non-representational "logical" pictures of the kind we are considering are "transformations of spatial metaphors into visual analogues" (1994: 43). Although this generalization does not seem to apply clearly to tree diagrams, it is useful when considering hierarchies displayed as circles, which depend on distance from the center (rather than on higher or lower levels) to show super- and subordinate relationships.

Circular hierarchical diagrams have been used in various disciplines, and in most cases a circular hierarchy can be transformed into a tree hierarchy (and vice versa). For example, Figure 3 shows Stanzel's typological circle for his theory of point of view in literature (Bonheim, 1990: [299]). Figure 3 shows three sets of binary possibilities for literary point of view, i.e., person (first or third); perspective (inner or outer); and mode (narrator or reflector). Beyond the outer ring appear examples of particular literary works that illustrate appropriate possibilities, thus adding instances to a generalized diagram of types of points of view. In addition, boundary lines are drawn to show where each possible point of view technique abuts another. Nevertheless, the diagram is somewhat hard to read because of the complexity of the subject matter combined with italic printing, and these difficulties make interpretation of the diagram demanding. A tree diagram could be constructed by using "point of view" as a highest level of the hierarchy, by subdividing into three coordinate classes at the next level by "person", "perspective" and "mode", and by subdividing these into their respective binary oppositions. In that case, boundary lines between literary techniques would not be needed. The close connections between the techniques might not be made visible in such a succinct manner, however, and an important part of Stanzel's theory would not be visually represented.

Figures 4a and 4b show two examples from the field of information studies. Figure 4a appeared in Rolling's discussion of the "circular thesaurus" display for "Publications" from the Technical Documentation Centre of the Dutch Army (TDCK). Rolling suggested that the concentric circle technique facilitated chain indexing because one could follow each arrow to construct the chain of terms for the index (1965: 307). Chain indexing was developed by Ranganathan as a semi-automatic way of creating an index for a classification system, but Rolling did not explain whether chain indexing from a circular diagram would be easier or more accurate than using the hierarchical chain derived from the schedules of the classification system or how chain indexing could be usefully applied to thesaurus construction. For those familiar with the concepts of broader and narrower terms this diagram is easy to interpret. These terms are examples of the use of the spatial metaphor, in the sense of size, in thesaurus theory, and

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may also be compared to Bertin's (1983) view of the graphic form as a container of information. It is interesting that the broadest term ("Publications") appears in the smallest circle and the narrower terms are shown in progressively bigger circles. Thus, this diagram seems to counter Fenk's view (1994) on spatial metaphors as noted above because "broader terms" are depicted as physically smaller than "narrower" ones.

Figure 4b shows a concentric circle diagram of three levels developed by W. Dahlberg (1984). The Figure is one of a series that illustrates orders of complexity in the development of the alphabet and of other systems of signs, i.e., the phenomenal level (centre ring); the instrumental level (middle ring); and the theoretical level (outer ring). It is noteworthy that Figure 4b contains two "Unfilled" slots. These would not be evident had a tree diagram been chosen. In addition, because Figure 4b does not name the highest level of the hierarchy, it would not be possible to create a tree diagram with a named superordinate class. Because it lacks some device to help the viewer "navigate" the diagram (such as the boundary lines in Figure 3 or the arrows in Figure 4a), Figure 4b seems less clear. The relationships among the various elements are not visually succinct or self-explanatory.

Silverman (1989) created non-concentric circular hierarchies that cannot be made into trees to demonstrate his model for analyzing processes and systems. Figure 5a represents the children's game Rock-Scissors-Paper in which each player chooses to be a rock, a pair of scissors, or a piece of paper without telling the others. Hand signals made simultaneously by all players show which implement a player has chosen, and a hierarchical power relationship is created by the choices made, i.e., scissors cuts paper; paper covers rock; rock breaks scissors. Each choice is superior to one of the others, but inferior to the third. The choice made by each player determines which player is allowed to rap the knuckles of another player. The circular diagram of this game is read as follows:

> Each of the three product spaces represents a process that is generated by a pair of the axes, so that, for example, XY represents a process by which X governs (limits or controls) Y by design, while Y does the same to X by precedent. Referring to the entire circuit of relations, we see that, by design, R governs X through RX, X governs Y through XY and Y in turn governs R through YR. (1989:34-35).

The diagram presenting this hierarchy

> ...must be circular. Otherwise, there would be an invulnerable top-level that would give everyone a safe choice, and therefore no player would have a chance to inflict pain. The game would then seem to be pointless. (1989:34)

The Rock-Scissors-Paper model is used as an analogy to the different roles people engage in when playing the stock market (Figure 5b). It is noteworthy that the three "players" in Figure 5b are groups (i.e., Brokers, Sellers, and Buyers), instead of individuals as in Figure 5a. The differences between the behaviour of individuals and of groups may make the analogy between Figures 5a and 5b less compelling than if the same kind of actor(s) were playing the "game" in each diagram. According to Silverman, the model in Figure 5 can also be used to give an "account of what some branch of learned discourse had contributed to the tree of common knowledge" (1989: 36).

For both Figures 5a and 5b, it is impossible to draw the hierarchy in tree form and still

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take into account the choices made by the players (whether an individual or a group) at different times because the occupant(s) of the superordinate position varies each time the game is played. In contrast, each circular diagram previously discussed had an invariable superordinate position that seemed to make tree diagrams for the most part equally useful for conveying the hierarchical argument graphically. In those cases where the hierarchical argument is not made clear in a tree diagram, those theoretically important elements that appeared in the circular diagram would need to be explained.

Tree and Circular Hierarchies in Total Descent Charts

A familiar form of hierarchy is a family tree, that is, a diagram illustrating the ancestors and descendants of a family and allowing one to move backward and forward in time. In genealogical work, a "total descent chart" shows the complete ancestry of one individual moving backward in time. Figures 6a, 6b and 6c show three relatively common methods of displaying a total descent chart. Figure 6a is a tree form on its side in which "you", the person for whom the chart is being constructed, appears at the left of the diagram, the person's father's family is shown at the top, and the person's mother's family at the bottom. Each ancestral slot is numbered for ease of reference and names the relationship of that person to the next generation. The letters B, M, D, and R allow one to fill in when and where each ancestor was born, married, died, and resided. Various assumptions are made in this chart. For example, it is assumed that a mother and father were married at the same time and resided in the same place, so that the letters M and R are omitted for the mother of the person. Potential anomalies (e.g., surrogate mothers, step-parents) cannot be accounted for. In this case, then, a particular theory of family membership is represented accurately in the chart, but does not account for possibilities not allowed for in the theory.

The total descent chart in Figure 6a is essentially self-explanatory, but that in Figure 6b, which shows the known ancestors of the mathematician Gottfried Wilhelm Leibniz, is less intuitively clear. This branching diagram, which is known as a "binary pedigree", contains two kinds of notation. The person for whom the pedigree is constructed (i.e., the "proband") is always "1", each male ancestor is "0", and each female ancestor is "1". If we take the numbers in order starting from the proband, it is then possible to create a code for each position (e.g., "110" is a maternal grandfather). The second notation is obtained from a decimal system introduced in the nineteenth century in which, for example, a maternal grandfather is "6". Like the chart in Figure 6a, Figure 6b is an abstraction in the sense that it does not include the actual names of the Leibniz's ancestors (most of which can, of course, be provided).

Figures 6a and 6b show genealogical relationships and the degrees of such relationships in branching diagrams. In contrast, the total descent chart for the Prince of Wales, which is shown in Figure 6c, provides the same information in concentric circle form. Here, the Prince's father's descent is shown on the left of the circle and his mother's descent is shown on the right. Figure 6c can be uniformly subdivided at every level to conform to the fact that each person in each preceding generation had two parents. It is also clear that if 1) a further generation were in the centre of the diagram (i.e., if a chart were made for one of the Prince's children), or 2) a seventh (and possibly preceding) generation(s) of the Prince's ancestors were added, another concentric row(s) of slots would be needed at the outer edge. In these cases, the

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slots would be only half the width of those shown in the outer ring here and would become even harder to read. Eventually, as more generations are added, the circular chart would become illegible. Nevertheless, the visual impact of Figure 6c seems greater than the visual impact of Figures 6a and 6b. The visual argument, however, is the same in all three.

Conclusion

As discussed above, Bertin (1983) suggested that graphic displays may be used to record, communicate, or process information and that each graphic display can be assessed on its use of certain visual variables that address more or less successfully the particular purpose of the display. This paper has examined tree and circular diagrams for hierarchical systems in an effort to assess the adequacy with which these different graphic forms convey the information they contain. The placement of different elements within the space of the graphic form and some of the devices that have been used to orient and inform the viewer have been discussed. In all cases, the viewer must know something about the concepts the diagram depicts before being able to interpret it. That is, the viewer must know what the diagram is "about" in order to understand the diagram, just as a reader must have an idea of what a text is "about" in order to understand the text. Thus, the concept of aboutness is one that is as valid for diagrams as it is for texts.[8] The assessment of whether a certain visual argument coincides appropriately with its intended classificatory argument thus depends upon the conjunction of the aboutnesses of the two forms of communication.

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[8]Aboutness in texts is discussed in Beghtol (1986b).

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Figure 1b
Ranganathan (1967: 367)

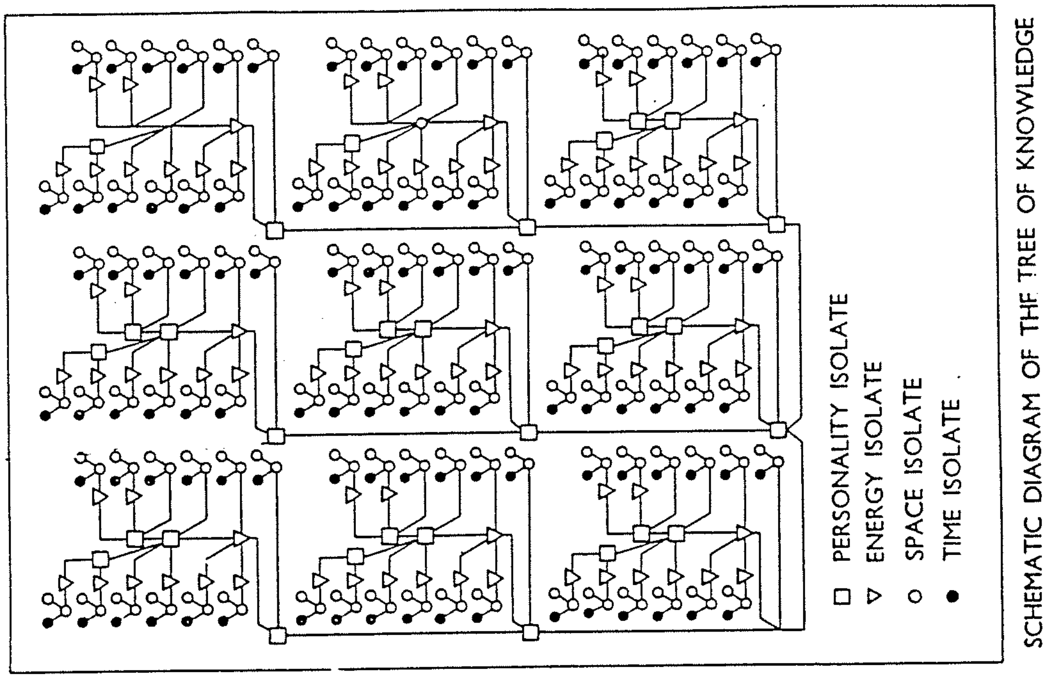

Figure 1a
Ranganathan (1965: [31])

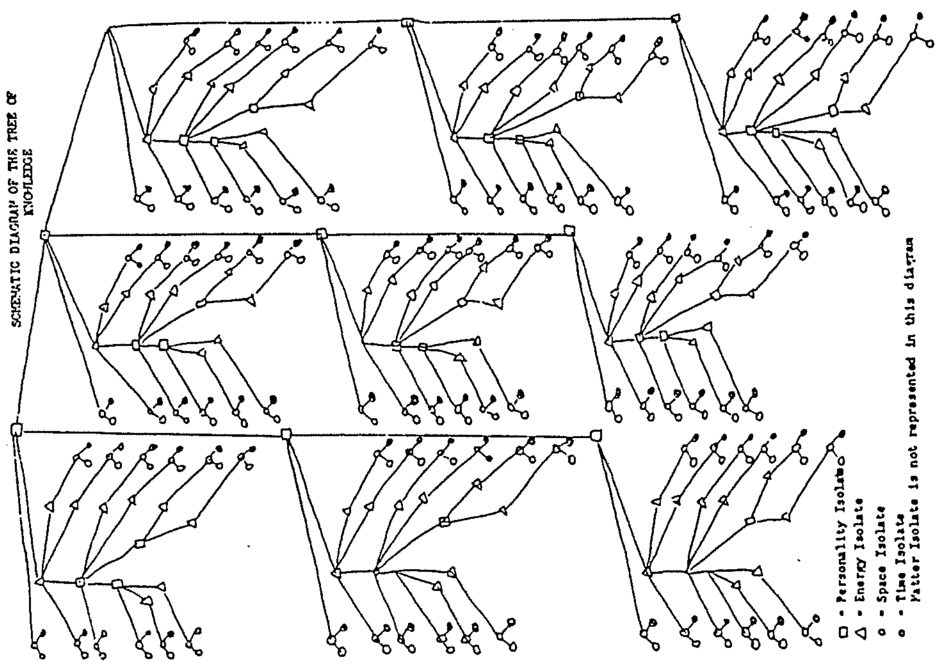

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Figure 2
Ranganathan (1967: 366)

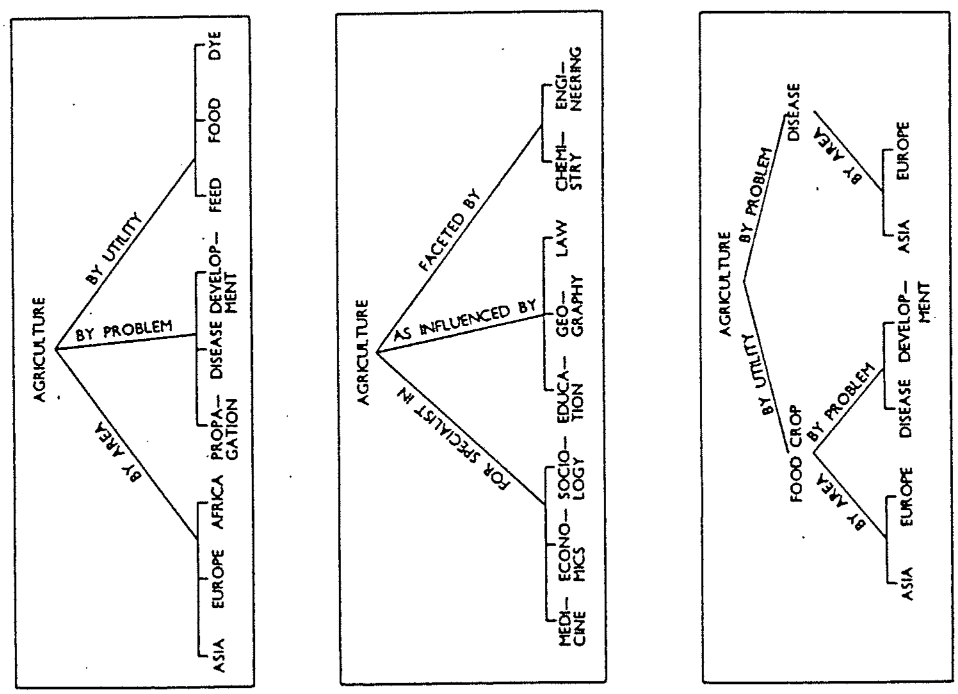

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Figure 3
Bonheim (1990: [299])

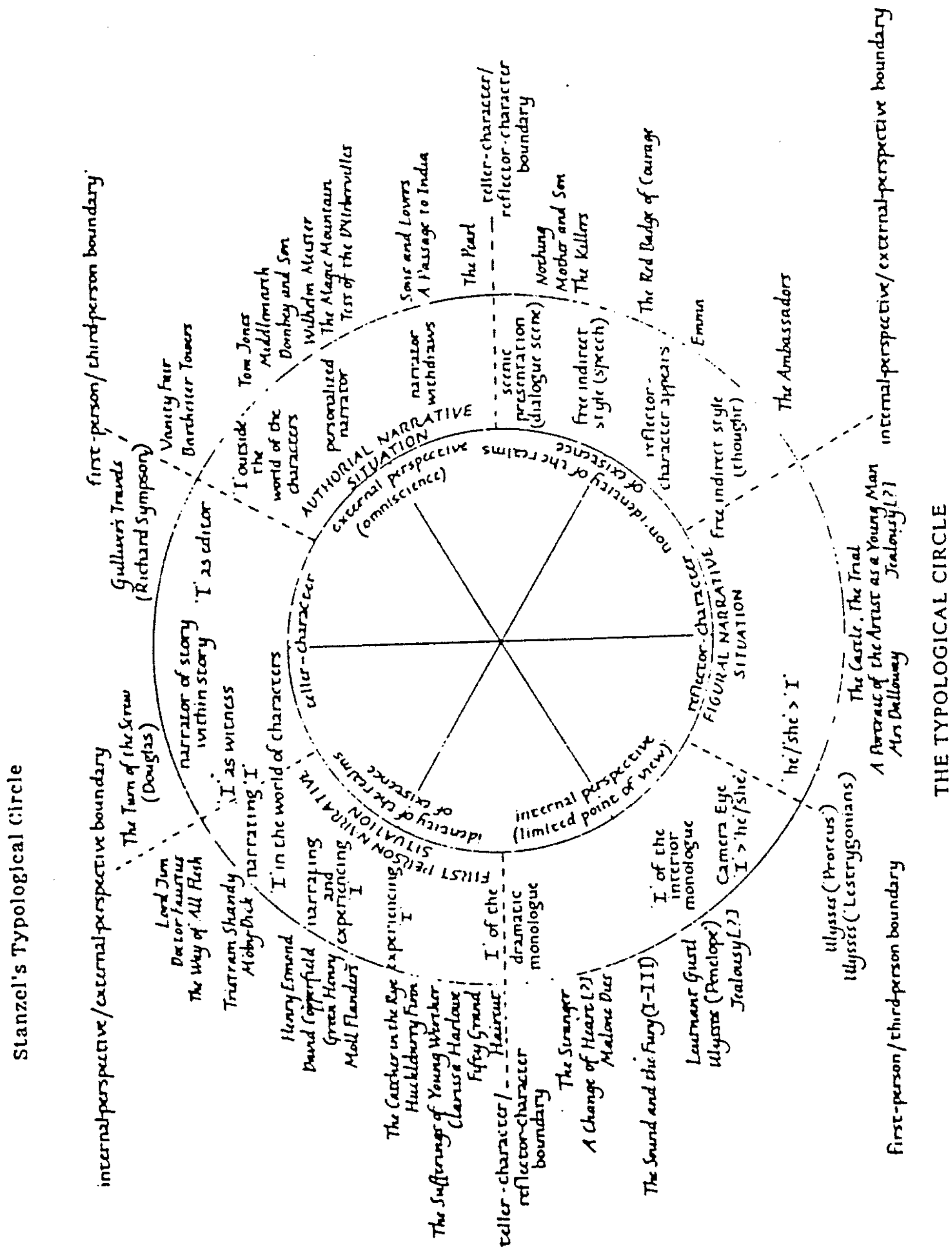

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Figure 4a
Rolling (1965: 312)

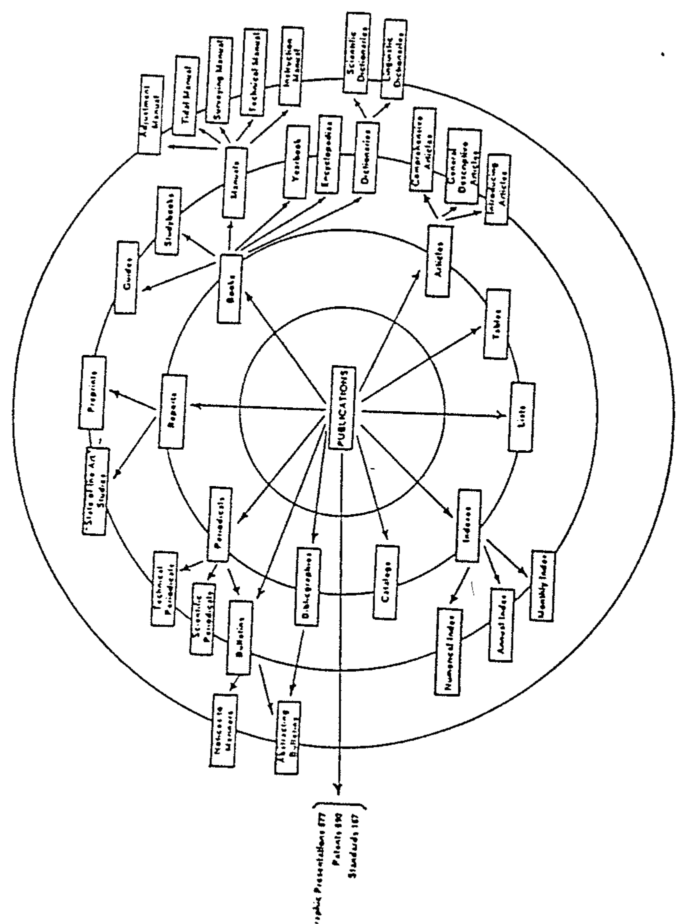
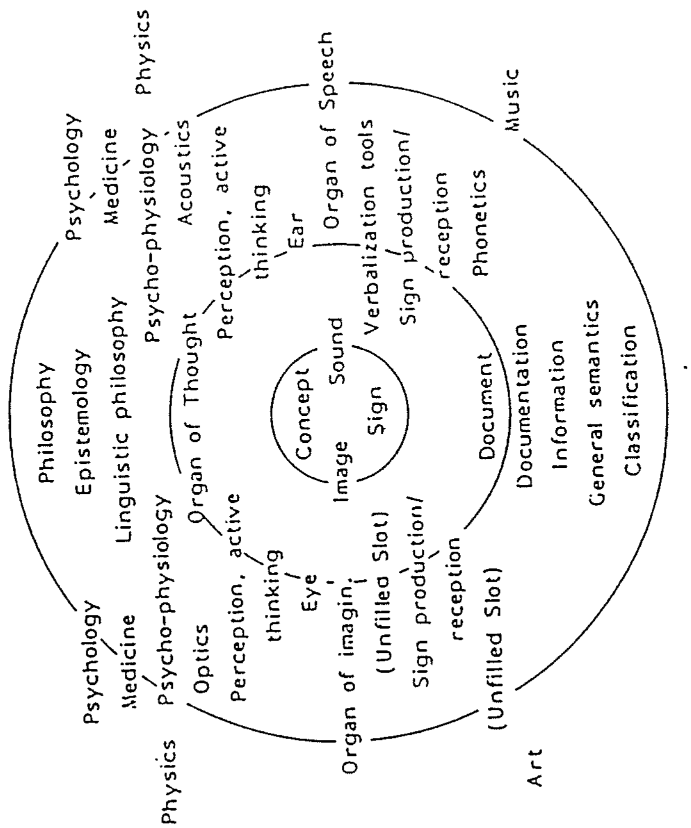


Figure 4b
Dahlberg (1984: 14)



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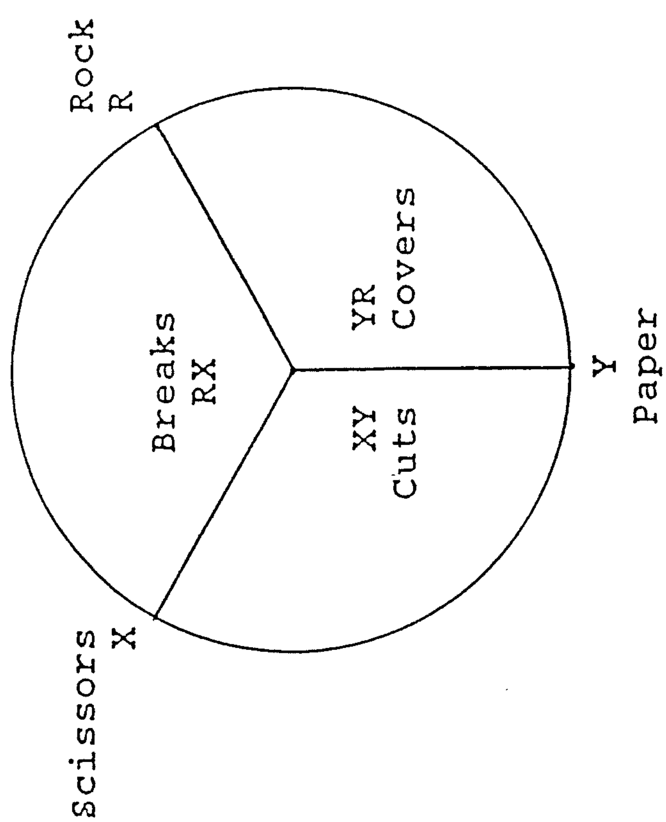

Figure 5a
Silverman (1989: 34)

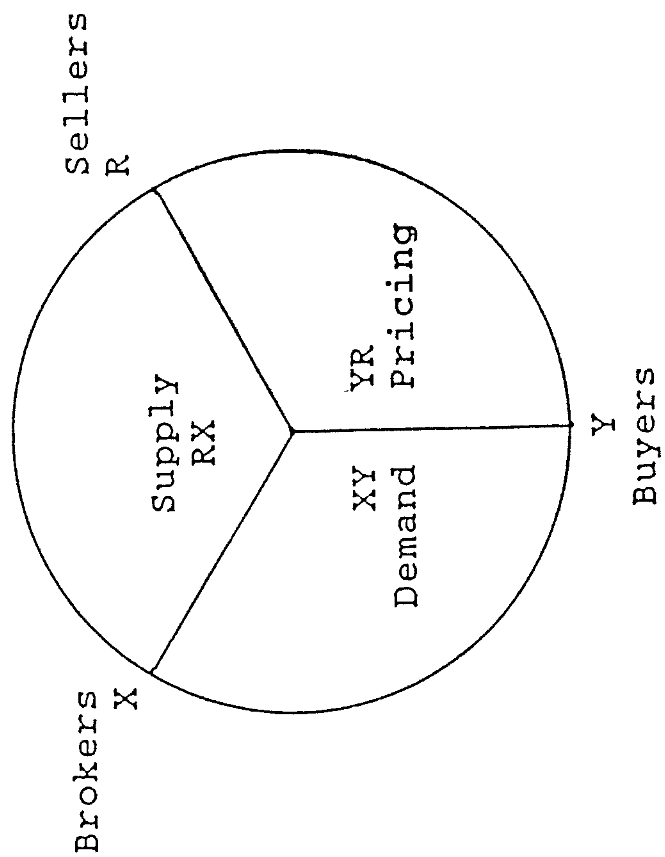

Figure 5b
Silverman (1989: 36)

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Figure 6b
Richter and Meyer (1996: 103)

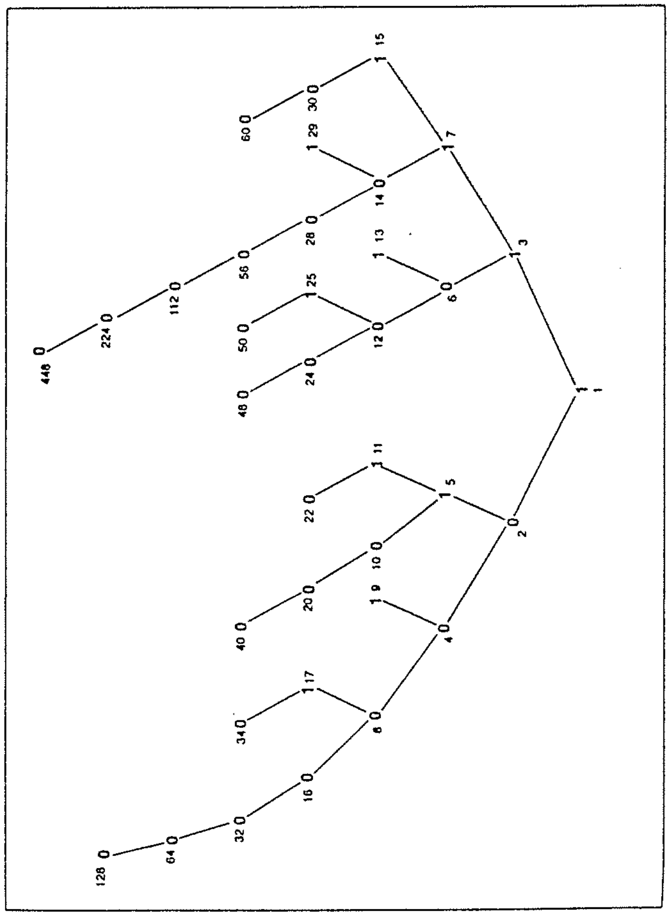

Figure 6a
Williams (1961: [32])

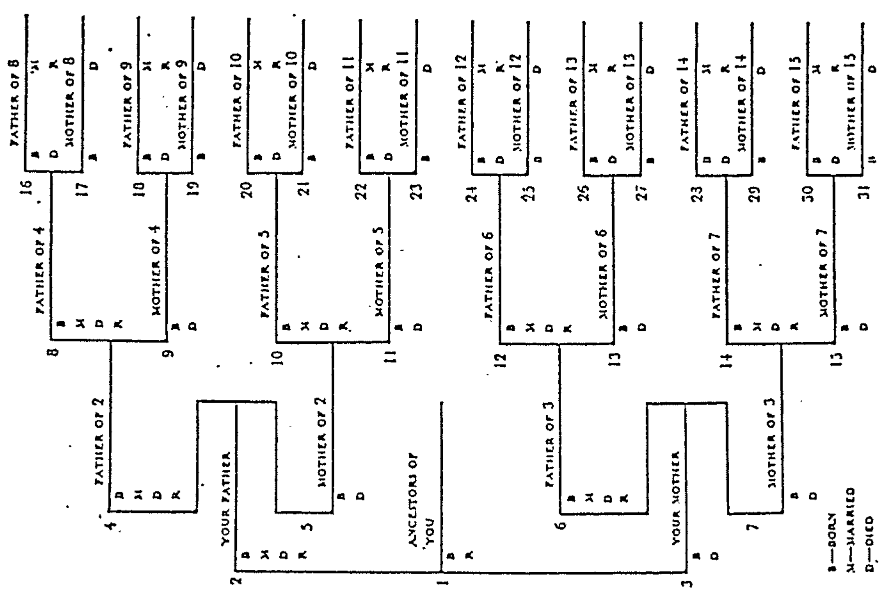

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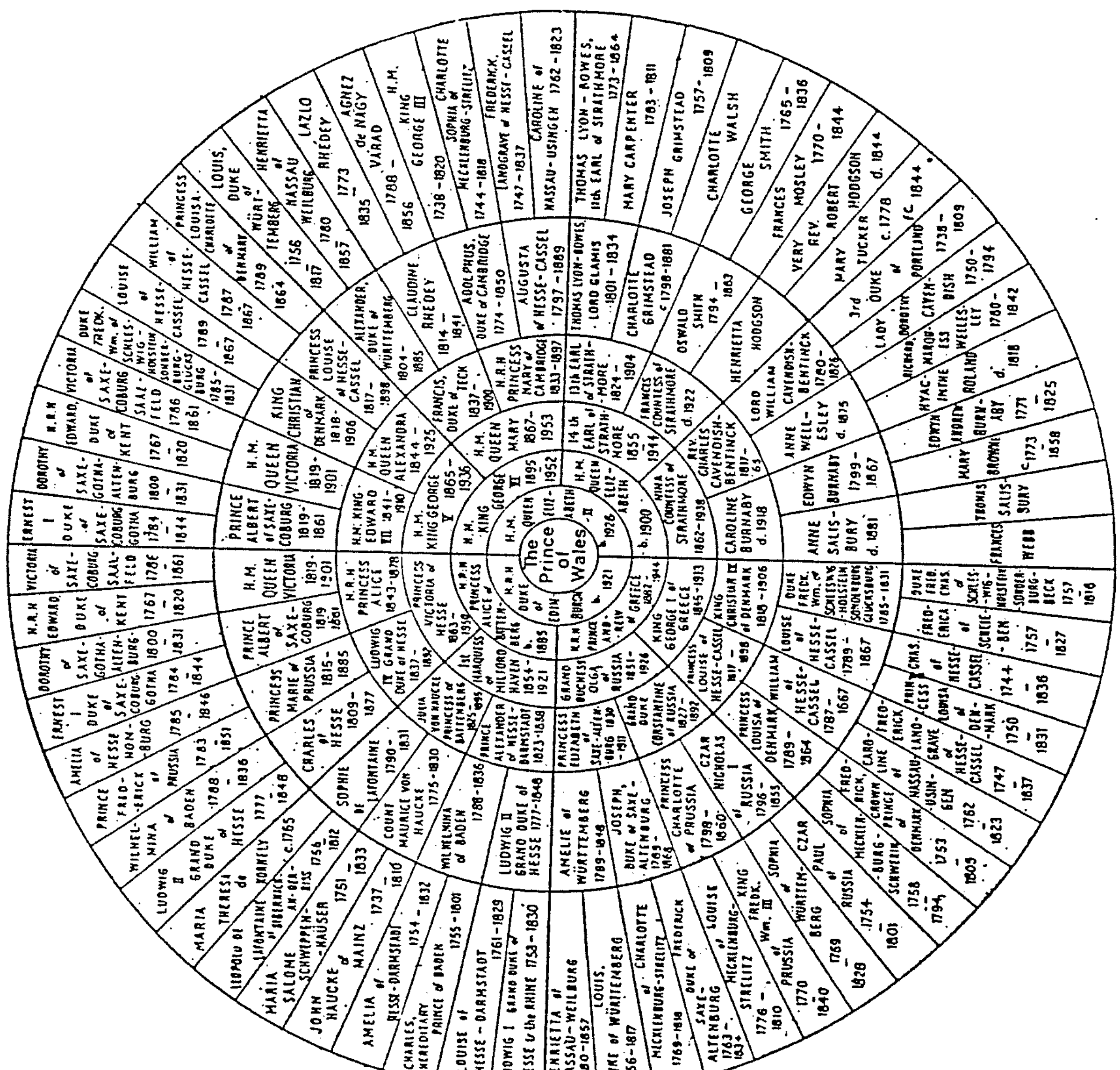
Figure 6c
Fitzhugh (1988: 287)



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