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SEEKING A COMMON THEME: A STUDY OF CERAMIC EFFIGY ARTIFACTS IN THE PRE-HISPANIC AMERICAN SOUTHWEST AND NORTHERN MEXICO USING COMPUTER IMAGE PATTERN RECOGNITION AND PHYLOGENETIC ANALYSIS

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ABSTRACT

Tallier, Lee R., Jr., Doctor of Philosophy, May 2023 Anthropology

Seeking A Common Theme: A Study of Ceramic Effigy Artifacts in The Pre-Hispanic American Southwest and Northern Mexico Using Computer Image Pattern Recognition and Phylogenetic Analysis.

Committee Chairperson: Dr. Anna Marie Prentiss

Effigy artifacts are found throughout the Pre-Hispanic American Southwest and Northern Mexico (PHASNM), as well as in other cultures around the world, with many sharing the same forms and design features. The earliest figurines within the PHASNM were partial anthropomorphic figurines made from fired clay, dating to between A.D. 287 and A.D. 312 (Morss 1954:27). They were found in a pit house village of Bluff Ruin in the Forestdale Valley of eastern Arizona, and they appeared to be associated with the Mogollon culture. The temporal range of the samples examined in this study is from approximately 200 A.D. to 1650 A.D., and the geographical range includes the Southwestern United States (Arizona, New Mexico, Texas, Colorado, and Utah) and the northcentral section of Mexico (Casas Grandes and the surrounding area).

This research looks at the similarities among the markings of ceramic effigy artifacts from the PHASNM, using computer image pattern recognition, design analysis, and phylogenetics, to determine whether their ceramic traditions share a common theme and whether the specific method of social learning responsible for the transmission of information relating to ceramic effigy decoration can be identified. Transmission is possible in one of three ways: vertical transmission, where parents/teachers distribute information by encouraging imitation and sharing learned traditions with children/students (Richerson and Boyd 2005; Shennan 2002); horizontal transmission, where information is transmitted among peers, either from within the individual's group or from interaction with peers from neighboring populations (Borgerhoff Mulder et al. 2006), and where the individual comes into contact with a wide range of attributes related to the item of interest and then adopts those that allow for the fastest, most economical methods of production and distribution (Eerkens et al 2006; Rogers 1983); and oblique transmission, where information is transmitted by adults, masters, or institutions of elite or higher social status, either internally or externally to the adopting cultural Type (Jensen 2016; Jordan 2014), and where particular traits are adopted or left out in disproportionate ways, creating patterns in localized traditions that can be empirically identified. Horizontal transmission can be broken into two types: unlimited, where contact is not confined to a particular group; and limited, where contact is restricted to a particular set of contacts.

Using criteria for each of the categories as set forth by the New Mexico Office of Archaeological Studies Pottery Typology Project (https://ceramics.nmarchaeology.org/index/the-classification-system), the samples were classified in terms of cultural area (culture), branch, tradition, ware, and type. The research group consisted of 360 photographic samples represented by 868 images that were resized to a 640x640 pixel format. The images were then examined through computer image pattern recognition (using YOLOv5) and through manual observation. This study resulted in a database representing 230 traits. These traits were assembled into groups by cultural area, branch, tradition, ware, and type, and phylogenetic analysis was applied to show how the different entities transfer information among each other.

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This study could not have been done without the help and encouragement of many people. My advisor and committee chair, Dr. Anna M. Prentiss, believed in the project and was a major factor in its completion. For that, I thank you. My thanks also go to the rest of my committee, Dr. Randall Skelton, Dr. H. Rafael Chacon, Dr. Matthew J. Walsh, and Dr. Meradeth Snow.

Dr. Prentiss and Dr. Skelton introduced me to phylogenetics, showing me a wonderful new world to explore. Dr. Chacon agreed to be on the committee to round it out, and Dr. Snow stepped in at the last moment when help was needed to fill a vacancy. Dr. Walsh has been invaluable as a sounding board, giving help and counsel when things looked dark.

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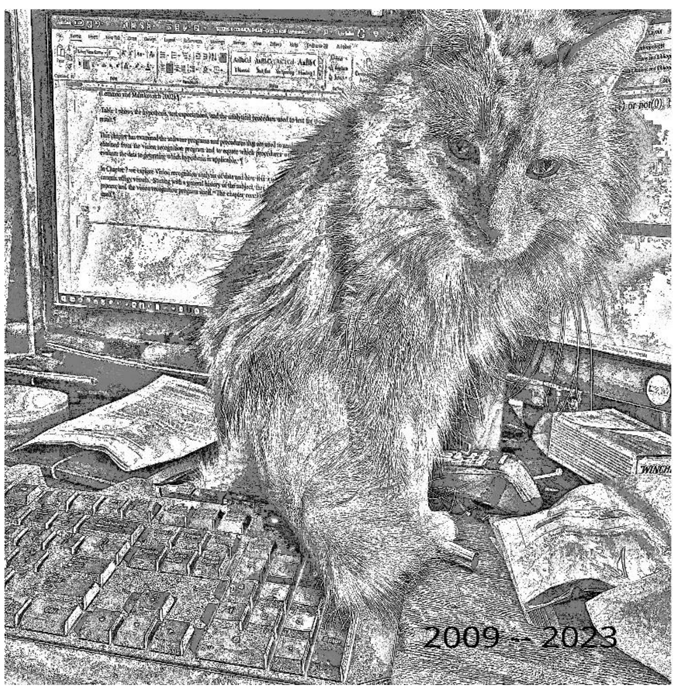

And, finally, to our cat, Droolie, one last thanks. Without her, many pages would not have had to be rewritten.

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Chapter 1: Introduction

Vast in expanse, the Pre-Hispanic American Southwest and Northern Mexico (PHASNM) covers more than 130,000 square miles and has been populated for a long time. The Ancestral Pueblo, for example, occupied what is now Utah in 6000 B.C. (Utah 2017). The Mogollon occupied central Arizona, southern New Mexico, and Northwest Chihuahua in ca. 50 B.C. (Walters and Rogers 2001); and the Chihuahuan people became sedentary and began producing pottery ca. A.D. 250 (Di Peso 1974a).

The pre- and proto-historic greater American Southwest was the home of several major cultures. These include:

- **Ancestral Pueblo:** Greater Mogollon (Jornada region in the eastern, southern, and western portions of New Mexico; western and Southwestern Arizona; the extreme western portion of Texas; and the northern part of the state of Chihuahua in Mexico) A.D. 200 – A.D. 1450[1]
- **Ancestral Pueblo:** Greater Upper Rio Grande Valley (Northern Rio Grande Valley and the Southern Colorado Plateau) A.D. 1500 – A.D. 1720)
- **Ancestral Pueblo:** Southern Colorado Plateau (Anasazi) A.D. 400 – A.D. 1750
- **The Hohokam:** (Arizona) A.D. 1 – A.D. 1450
- **The Fremont:** (Utah, Nevada, Idaho, and Colorado) A.D. 1 – A.D. 1300.
- **The Patayan:** (Arizona) A.D. 700 – A.D. 1550)

A plethora of literature about the ancient American Southwest and Northern Mexico is available. Di Peso (1974b)) alone wrote an eight-volume set on the history and excavation of Paquimé, as well as numerous journal articles on the subject. Whalen and Minnis (2001) have done extensive work in the area as well. Gladwin (1957; 1938), Haury (1976), Mills (1995), Crown and Bishop (1994), Plog (1980), Oppelt (1988) and many others (some of whom are cited in this dissertation) have researched and contributed to the understanding of the cultures and history of the PHASNM.

As cultures and civilizations develop new technologies and social and political complexity, changes occur. Although this study focuses on ceramic effigy artifact design and decoration during transitional phases, the changes that are manifested during these transitions are reflected in many ways, from architecture to agriculture to settlement planning to ceramics (Leblanc and Nelson 1976) and beyond.

By tracking the changes in design, e.g., from grayware to corrugated grayware, or from thin lines to thick lines to outline a panel, that occur because of an influx of people, changes in ideology, or political shifts, we should be able to phylogenetically map these transitions. These changes are both patterned and directional in ideas represented by traits (motifs and/or forms) and are, therefore, trackable (Lyman 2000).

Tracking such changes is one research goal of this project. By doing so, the variations or similarities that occur over time among diverse groups will be visible. And by using computer imaging software to identify the various markings, shapes/forms, and unusual components, it will be possible to determine the amount of interaction among the groups.

This interaction between groups and the methods of information transfer, and the social learning model in use is the other research goal. If the traits (markings, shapes/forms, and unusual components) are restricted to a solitary group, then it is reasonable to believe that information transmission was vertical in nature, only being transmitted between individuals within that group (Type). However, if the traits are shared among a number of groups (Types) within a larger group, either a Ware (several related Types) or within an even larger group, a Tradition (consisting of several Wares), then it appears that the transmission of information is of a horizontal nature, either restricted (within a Ware) or unrestricted (within a Tradition). If a trait is found to be shared among all Cultures, then the transmission method is hypothesized to be oblique.

By collecting the number of traits that appear within a Type using a vision recognition program, then analyzing the data in R/RStudio for Type, Ware, Tradition, Branch, and Culture, using both phylogenetics and binary heatmaps, the social learning model—either vertical, horizontal, or oblique—can be decided.

This study is important for Southwestern Prehistory and cultural evolutionary theory in that it explores cultural transmission using both phylogenetics and heatmaps to show the relationships among groups across the Southwest. The binary heatmaps produced indicate clearly whether an object is present or it is not. Because human culture is composed of various and varied beliefs, behaviors, and artifacts (Creanza et al. 2017), ideas move from individual to individual or from group to group through different processes of learning. These processes of transmission—vertical, horizontal, or oblique—determine the amount of dispersal an idea may achieve as well as the tempo or speed at which it may diffuse across a given space. By tracking these changes and determining to what degree dispersal has occurred, we can infer the amount of interaction among groups.

What to expect:

Chapter breakdown:

This study is broken down into 9 chapters and 3 appendixes.

Chapter 1. Introduction:

A brief introduction to the Cultures associated with this study and the concept of phylogenetically mapping changes in traits (motifs and/or forms) to follow social learning patterns.

Chapter 2. Social learning models

This chapter explores the social learning models used in the study, briefly describing each and introducing the related hypothesis to be tested for that model.

Chapter 3. Data

Here I discuss the difference between innovation and imitation and explain how to tell them apart. The chapter also explores the places where the data was found, and it introduces and explains the different data divisions. These divisions—Culture, Branch, Tradition, Ware, and Type—are comprised of the groups in which sample artifacts were available for analysis. The chapter also examines the use of binary data and explains how such data are used in both phylogenetics and heatmaps. And it introduces the motifs that are the focus of the image tagging.

Chapter 4. Effigy artifacts:

Chapter 4 introduces the different types of artifacts used in the study and gives a brief history of their origin.

Chapter 5. Hypothesis:

Two sets of hypotheses are set forth: the first half concerns the transmission of information among individuals/groups; and the second half examines the idea that major changes in sociopolitical and religious ideologies can be tracked by changes in artifact decoration. The expectations for the three sets of hypotheses—vertical, horizontal, and oblique—are defined. The hypothesis for horizontal is divided into two separate hypotheses: one for unlimited interaction, the other for limited interaction.

Chapter 6. Methods:

In this chapter, I introduce the data and analysis and explain the various packages used in R/RStudio to do phylogenetic analyses to create the trees and the heatmaps. I also introduce several other software packages I used.

Chapter 7. Vision Recognition Analysis of Data:

Here, I explain the history of vision recognition analysis, the software used in this study to do the analysis, and the steps necessary to do the photo analysis.

Chapter 8. Data Analysis:

This chapter provides the results of the study. It goes through the analysis of the different levels: Culture, Branch, Tradition, Ware, and Type. Both the phylogenetic analysis and the related heatmap for each group are included. And it explains that phylogenetic signal tests were done for the Tradition data group because of its central location within the groups.

Chapter 9. Discussion and conclusion:

Chapter 9 is a recap of the hypotheses examined in this study, leading to the discussion about which hypothesis best fits the data collected. It also seeks to determine the amount of impact that this study may have on current debates. It concludes with possible avenues for future research.

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Chapter 2: Social Learning Models

The how and why of the movement of ideas in Southwestern Prehistory has been an overarching question in archaeology for decades, although diffusion and migration were regarded by American archaeologists as “anti-scientific non-explanations” (Lekson 2013). In an on again/off again relationship, diffusion and migration were personas non grata in American archaeology from the latter half of the 20th century until the early part of the 21st. That was when Michelle Hegmon stated that, “archaeologists have again turned considerable attention toward the movement of people and apparent spread of traits” (Hegmon 2003). Although arguing that, “diffusion is not an explanation” (Hegmon 2003), she did agree that information was transferred among groups.

For this study, diffusion (defined as “the spreading of something more widely” (Oxford Languages 2022) represents the transfer of knowledge from one source to another. The “apparent spread of traits” and the method(s) by which it was done are under consideration.

Cultural transmission is how behaviors are spread among humans, thus providing the footing for the emergence and preservation of traditions (Truskanov and Prat 2018). This transmission among humans can be as simple as a single model or as complex as a combination of models.

This chapter examines 3 models:

- Vertical transmission,
- Horizontal Transmission,
- Oblique Transmission

Within each, 2 paths are possible: cultural fidelity where the copying of an item is precise, with no variation from the original; and creation by trial and error (Truskanov and Prat 2018). This chapter covers the 3 different models of transmission, with a brief overview of each, and introduces the hypothesis associated with each model.

The Vertical Transmission or Guided Variation Model

In vertical transmission or guided variation, in general, parents/teachers distribute information by sharing learned traditions and encouraging imitation children/students to imitate them (Richerson and Boyd 2005; Shennan 2002). From early childhood and into the teen years, parents show their offspring the basic skills of a craft. As the child/student gains experience, they go through a transitional period where practice without intervention allows them to hone learned skills and to experiment (Jordan 2015).

Vertical transmission is also known as "Lamarckian inheritance" or the inheritance of acquired variations (Boyd and Richerson 2005; Eerkens et al. 2006). In it, the migration of information among different cultural spheres is minimal, and individual experience is used only when it’s known to be highly accurate. This approach results in a high degree of imitation and a low degree of innovation (Boyd and Richerson 2005). “Under guided variation, errors are introduced by an individual miscopying a character or design thus randomly creating a new symbol and setting up heritable continuity (artifacts that are stylistically similar)”

(Dunnell 1978; Eerkens et al. 2006; Lyman 2000). These new designs, being heritable, can be tracked phylogenetically. Information about them is retained locally.

The concept of the transmission of ideas and other cultural phenomena, i.e., “Culture,” among individuals as a consequence of social learning and as part of an evolutionary process has gained support in recent years. Theoretical models developed by Cavalli-Sforza and Feldman (1981) and Boyd and Richerson (1985) laid out the idea that culture changes in an evolutionary way, like its genetic counterpart in biology. But culture is different, for biological evolution only works vertically and in one direction, whereas cultural evolution works vertically, horizontally, or obliquely, and is bidirectional.

Cavalli-Sforza and Feldman (1981) stated that the vertical transmission of information among individuals, including parent/child or master/apprentice, while observable, might be difficult to distinguish from other types of transmission, such as horizontal. A cultural trait or information that is conservative in nature tend to be the slowest to change, thus lending themselves to vertical transmission (Cavalli-Sforza and Feldman 1981).

In homogeneous vertical transmission or a guided variation environment (one that is constant without external intervention), parents/teachers distribute information and encourage the imitation of learned traditions by children/students (Richerson and Boyd 2005; Shennan 2002). This activity results in the transformation of a cultural trait as a result of trial-and-error learning, and the passing on of this modified trait to others is regarded as a normal event (Boyd and Richerson 1985, 2005; Eerkens et al. 2006; Acerbi and Mesoudi, 2015).

Without external interference or intervention, the selection of these individual learning errors will rely primarily on cultural transmission and not individual learning (Boyd and Richerson 1985).

As individuals accept the modified cultural phenotype, they will, in turn, make modifications (i.e., mistakes) that differ from the original. The phenotype that they distribute to the next generation will be different from the one they received (Boyd and Richerson 1985). Those traits that are easiest to learn will be accepted, while those that are not will fall to the wayside. This results in a high degree of imitation and a low degree of innovation (Boyd and Richerson 2005).

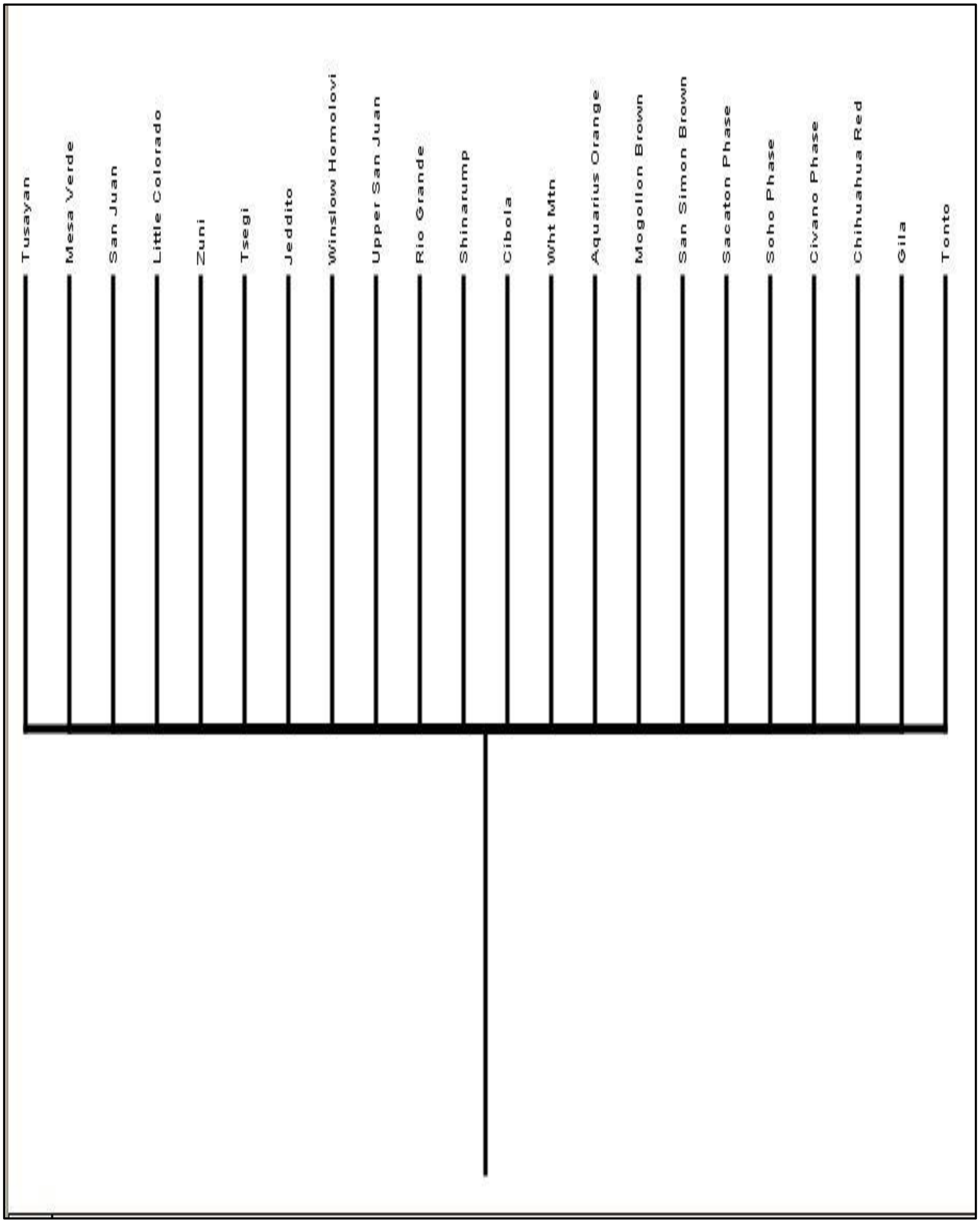

Figure 1 Polytomic tree

The random creation of a new symbol sets up heritable continuity (artifacts that are stylistically similar) (Dunnell 1978; J. Eerkens et al. 2006; Lyman 2000). These new designs, being heritable, can be tracked phylogenetically. In this homogeneous environment, the first hypothesis (vertical transmission) holds that ceramic types will exhibit design patterns in line with vertical transmission between parents and children or masters and apprentices. Branching will be exhibited within a Type (horizontal peer-to-peer) or among Types (oblique peer-to-peer). A tree will be generated from the data, with a result similar to Figure 1. This figure represents a polytomic tree (which means many temporal-based branches (Green 2013), where evolutionary relationships cannot be fully resolved.

This first hypothesis favors social learning over individual learning in relation to personal behavior (Boyd and Richerson 1985). Social learning in the vertical transmission model identifies traits in a role model (master) that are like those of the apprentice/student (Bandura, 1969).

The Horizontal Transmission Model

The above variation is not restricted to the vertical transmission model in a homogenous environment. Aoki et al. (2017) describes the horizontal transmission model as a "biased vertical transmission where the majority (frequency greater than ½) meme[1] [an idea-meme] is preferentially copied." This can take place in a heterogeneous environment where individuals from differing environments interact. And it can include cases where the interaction among individuals within a homogeneous environment, i.e., master/apprentice, expands to include interaction with individuals of differing environments (Boyd and Richerson 1985).

A horizontal transmission of information among peers comes about as this interaction among individuals from differing environments allows traits from sources other than an individual's mentor to be modeled (Bandura, 1969, Borgerhoff Mulder et al. 2006). Under Rogers's model of innovation diffusion (Rogers 1983), horizontal transmission theorizes that individuals who encounter a wide range of attributes related to their item of interest will examine and then adopt those attributes most suitable to their application (Eerkens et al. 2006). For example, two potters of equal social status within a village could share designs, or a potter could acquire ideas while trading with potters of equal social status in other villages (van der Leeuw and Papousek 1992).

Individual potters within the ceramic groups of the PHASNM who are working within the same Type could create designs that are copied by other potters who have been exposed to them by trade within the same Ware. For example, potters making Villa Ahumada Polychrome (a Type) find designs on Ramos Polychrome (also a Type) to their liking and copy them. Both Types are of the same Ware. The imitators could then take the designs and modify them to suit local customs and values, effectively commodifying design features from outside their own Type to fit their needs.

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[1] Defined by Richard Dawkins, who coined the phrase in his book, *"The Selfish Gene,"* in 1976, pg. 109.

Under this model, the general designs are believed to be found in limited numbers along all trade routes, while modified but identifiable replicas would be localized by adapting to area-specific ceramic traditions. If there is heritable continuity in these ceramic traditions, generational variation resulting from descent with modification (Prentiss et al. 2014) would be expected.

The first horizontal transmission hypothesis with unlimited interaction, scenario No. 1, allows for distribution among Traditions. Individuals are exposed to a variety of ideas from environments other than their own. These ideas are distributed among groups within a single Culture.

The second hypothesis, horizontal transmission scenario No. 2 allows interaction within the group only, restricting horizontal transmission to interaction within the group and allowing transmission among Types/Wares within the confines of a Tradition.

The Oblique Transmission Model

This third and final model (Figure 6; page 41) suggests that the introduction of ideas by adults, masters, or institutions of elite or higher social status, either internally or externally to the adopting cultural Type (Jensen 2016; Jordan 2014:24-26), causes traits to be adopted or left out in disproportionate ways. This lack of uniformity creates patterns in localized traditions that can be empirically identified.

In this model, cultural or sociopolitical influences would periodically dictate new ways of decorating effigy vessels that would modify previous symbols and patterns, thus leading to novel yet recognizable forms. These new designs, based on previous ones—although modified—could be shared among differing Types while retaining enough features of their original design to show evidence of heritability, at least of the original or least-altered traits.

The movement of these commodified designs would not be restricted to a specific area but would most likely spread primarily along trade routes. Thus, villages along the trade routes are likely to share some of the same designs, without modifications, for local use. The adoption of new symbolic images would support an inclusive regional “religious ideology,” as suggested by Crown and Bishop (1994). This ideology would make widespread transmission of ideas more consistent and thus congruent, without the need to further customize designs into different symbolic dialects (Schäffner 2004).

The extensive distribution would powerfully reinforce the concepts associated with the specific, recognized images (Ramachandran and Hirstein 1999). Using Shennan’s second model (2001), data will be analyzed to determine the amount of oblique transmission among the major traditions. Shennan suggests using a modified model to analyze oblique transmission because learning is no longer simply between parent and child but between a nonparent adult and a student. In this case, the nonparent adult must exhibit traits/skills that make them more likely to be chosen as a model for imitation.

If the ideas transmitted to the student are affected by directly biased transmission, the student has chosen what they believe to be the best method of doing a task. If the ideas are affected by indirectly biased transmission, then the student has chosen the nonparent adult because they are considered prestigious and, therefore, a role model. Regardless of the bias influencing students' decisions about their mentors, because transmission is oblique, students will accept the innovations introduced to varying degrees. This acceptance can be measured mathematically, and the results can be shown in graphs (see Shennan 2001 for a mathematical explanation).

This simple model is based on the premise of a one-nonparent/adult-to-one-offspring type of inheritance. By using the total number of attributes assigned to an object that are subject to selection, the popularity/success rate of a particular attribute can be determined by the number of times it appears.

Three different social learning models and the hypotheses related to each were discussed in this chapter:

*One common theme is that the production of ceramic goods was vertical in nature, with the child watching a parent and gradually attaining the skills necessary to make the item (Kamp 2001).

*Another is that potters from various places would observe and then copy designs (horizontal social learning) as suggested by Rogers (1983) and Washburn (2013).

*The third model is the introduction of ideas from a central agency dispersing them over a wide area in a specific form.

In the following chapter, Chapter 3, the concept of innovation vs imitation is explored, with a discussion of differences between objects and how these difference might indicate which form of transmission is which. Data acquisition and preparation is discussed, including the where and the how.

Chapter 3: Data

Innovation vs imitation

When studying a subject based on social learning methods, such as this one, the question of innovation vs imitation becomes relevant. Innovation is a maker's ability to develop new ideas and products through imagination and creativity, bringing new wares into being. (Team 2012). Imitation allows an existing idea to be spread among many different groups (Team 2012).

According to Arvanitis and Seliger (2014), innovators are generally more introverted and imitators more extroverted. Most imitators "are primarily market-and-profit-driven for survival purpose, pursuing 'make it look like, but cheaper' strategy," (Zhao 2019), whereas innovators aim at 'making it better.' For craftsmen merchants, imitation is great for business. By coming up with a cheaper/better version of the original idea, they can reach more people in a larger area (Shenkar 2010). Raustiala and Sprigman (2012) say innovation is a "incremental, collective, and competitive process" upon which the creation of new and better things depends.

For some innovations, including effigy vessels from the American Southwest, figuring out where a specific idea originated is difficult. The number of samples for each group is limited; the 360 total samples in this study a case in point. The vision software would need many more samples of each type of symbol from each of the Types to be able to distinguish minor variations among them. The dating of each artifact would have to be more precise, not the current 100-to-200-year time span. With more images of a particular symbol and a more precise method of determining when/where an object was made, the chances of separating innovation from imitation would increase.

Although determining an original design from later imitations is difficult, each artifact that exhibits a particular design adds information about the distribution of the idea behind it. By collecting data about the design, i.e., where it shows up, when, and what variations appear, patterns can be established regarding the social learning methods used to distribute the design.

Data

Where the data came from:

To use an analogy, Culture as categorized here can be equated with regions or areas of the country, like the West, Midwest, Southwest, Northeast, and Southeast. Branch, then, would be considered the states within each region. Traditions equate to the counties within the states, while Wares represent towns within the counties. At the very bottom are Types. These would be the neighborhoods where the items are manufactured.

Cultural areas:

Using the criteria for each of the categories as set forth by the New Mexico Office of Archaeological Studies Pottery Typology Project, the distinct cultural units, Culture, Branch, Tradition, Ware, and Type, are defined and examined. In this context, ceramic types are defined by their relation to one of the five geographical units, listed above, from broadest, i.e., Culture to the smallest, Type. Six major Cultures incorporate the widest range of motifs, but the least number of entities, Branch numbers 11, Tradition numbers 17, Ware numbers 30 and Type is the smallest unit in both size and number of motifs but the most numerous at 90 (https://ceramics.nmarchaeology.org/index/the-classification-system).

Symbols in image tagging:

Most of the symbols that are the focus of the image tagging are based on illustrations in *Patricia Crown's book "Ceramics & Ideology: Salado Polychrome Pottery."* Other symbols, such as parrots, banners, and macaws, were taken from the works of Haury (1976), Gladwin et al. (1938), VanPool et al. (2000); VanPool et al. (2006), Kidder (Kidder 1917; Kidder 1916; Kidder 1936) and others. These symbols are used for tagging the images used to train YOLOv5.

How data were collected:

Once the vision recognition program was chosen, in this case YOLOv5, the dataset must be created. Photos were obtained through an image search on Google for effigy vessels. From the image search, 554 images were selected. These images were then processed to enhance and modify features such as color, vertical and or horizontal flip, background color, and/or tint. These modifications resulted in a dataset containing 13,850 images. These images were then labeled with the chosen tagging symbols. YOLOv5 then detected objects and data was customized. After defining YOLOv5's model configuration and architecture, its detector was trained. The performance of the detector was evaluated—more than once. After satisfactory results were obtained, the program was used to evaluate the research dataset consisting of 360 photographic samples represented by 868 images. When symbols/motifs were found, they were then recorded as being present (1).

Use of binary data

When compiling tables for both the phylogenetic trees and heatmaps, a binary system was used to record the presence or absence of data. If found, a motif/symbol is represented numerically as present (1); otherwise, it is noted as absent (0).

Phylogenetics:

When constructing a phylogenetic tree, the Gusfield algorithm (Cmero 2015) allows the use of binary data. In SplitsTree, this data allows for the computation of recombination networks (Huson and Kloepper 2005). From these recombination networks, a splits network can be computed and plotted.

Heatmaps:

Phylogenetic trees are extremely useful. Depending on manipulation, i.e. bootstrapping, etc., the same set of data can produce numerous trees. However, binary heatmaps show a clearer picture of the data—either it is present (1) or not (0). This can be used as a basis for narrowing down the number of trees to be considered.

Comparison of phylogenetic tree and heatmaps

Because Culture has the least number of leaves (and the most artifacts), the resulting phylogenetic tree, Figure 2 (upper half), is clearer. As can be seen in the upper-most clade, the Ancestral Pueblo Southern Colorado Plateau, Anasazi or Ancestral Puebloans (APSCPA) and the Ancestral Pueblo Greater Mogollon (APGM) branch from the same node. The next entity to share traits is the Hohokam at the bottom of the diagram, with the Fremont branching off, and then the Patayan and Ancestral Pueblo Greater Upper Rio Grande Valley (APGURGV) branching from a common node.

In the heatmap Figure 2 (lower half), objects present are represented in blue, and those absent in brown. As can be seen APGM and APSCPA have many items in common. Next in commonality are the Hohokam, then the Fremont, APGURGV, and finally the Patayan culture.

As on the phylogenetic tree, the heatmap shows a close relationship between APGM and APSCPA. It also shows that the Hohokam share traits in common with the first two. The Fremont share traits in common with those three, as well as with the APGURGV. The heatmap shows that the Patayan relationship with the Fremont and the APGM is related to human figurines. Five of the six share avian forms, with the Patayan the only exception.

Further on in this chapter, the different data divisions will be explained. These divisions—Culture, Branch, Tradition, Ware, and Type—are where sample artifacts were available for analysis. The second half of the chapter deals with the motifs or symbols that are used for the analysis.

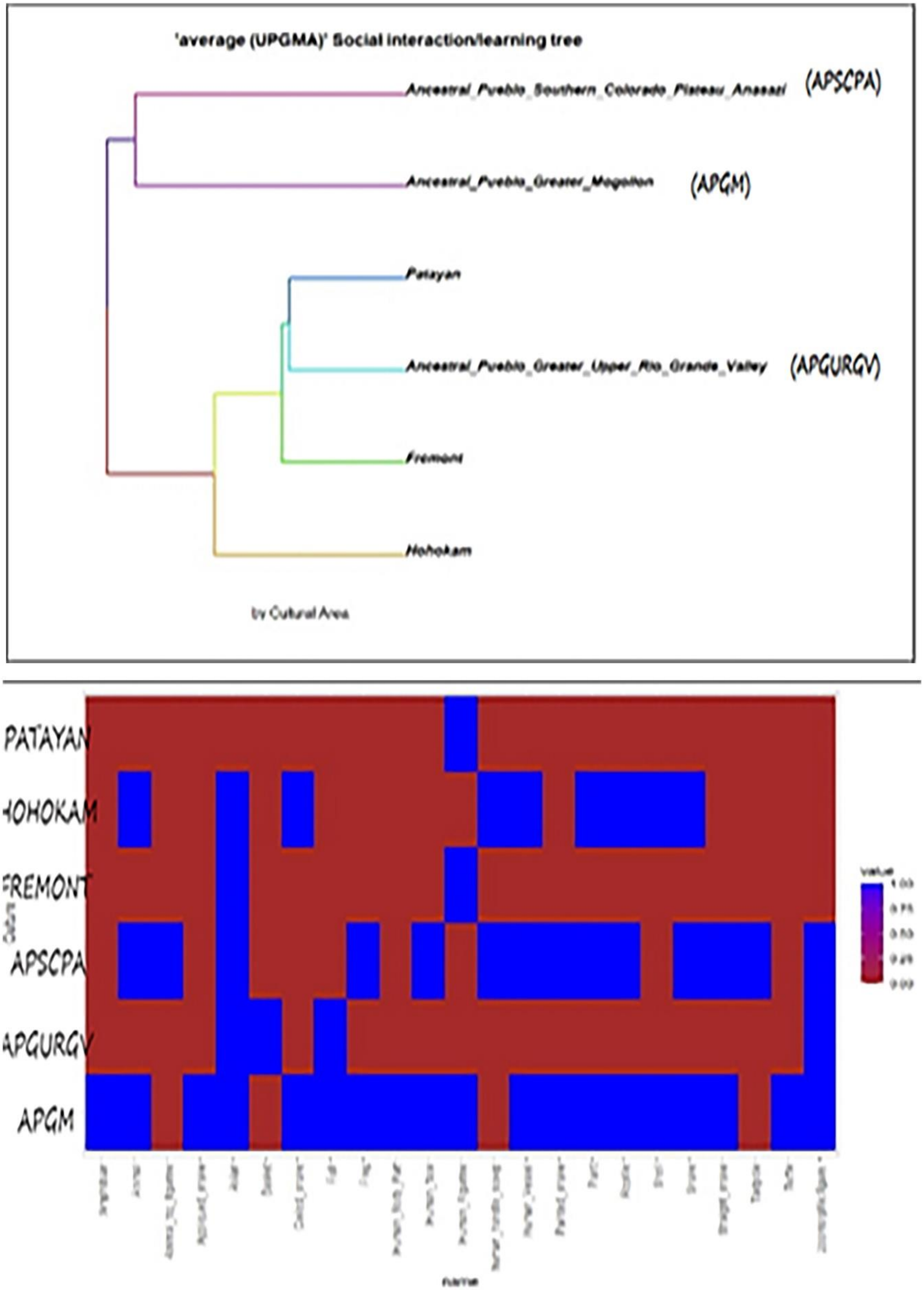

Figure 2 Comparison of Culture phylogenetic tree and heatmap.

Data Organization

The classifying of artifacts is an investigative technique that allows the sorting and grouping of comparable items, thus improving perceptions of associations between the items. It also creates a basis for the dissemination of information concerning the items among individuals. Each of the traits found on the samples used in this study was given a label, allowing like traits to be identified regardless of source of origin. Once evaluated, the relationship between different sources of origin of the trait could show whether the transfer of information concerning the trait was vertical (restricted to one source) or among several sources (horizontal or oblique).

To classify a ceramic item, archaeologists use initial reference points relating to spatial units defined by various scales that have both geographic and cultural connotations. The broadest unit is the Culture area. Culture areas, such as the American Southwest, are identified by distinct and long-lived collections of materials, and cultural developments based on ceramics and other quantifiable cultural items. Within each culture area, smaller areas exist in which combinations of traits are specifically shared among groups, and they are known as a Branch. A Branch is composed of Tradition(s) that have presumed historic connections. Tradition is further subdivided into Ware(s) and finally Type(s).

Culture

Within this study, Culture is the broadest spatial unit. It is looked at in a cultural sense, while its subdivisions are examined archaeologically in relation to the effigy artifacts they produced.

It commonly refers to broadly defined groupings to which distinct sequences of occupation and combinations of traits or materials are associated. Three of the cultural areas in this study were occupied by groups that researchers say were related to the Ancient Pueblo or Anasazi and were linked together based on wide-ranging similarities in cultural patterns and material characteristics.

The three included within a broadly defined Ancestral Pueblo group are: the Ancestral Pueblo, including the Greater Mogollon; Ancestral Pueblo, including the Greater Upper Rio Grande Valley; and the Ancestral Pueblo: Southern Colorado Plateau or Anasazi.

In addition to the cultures making up the Ancestral Pueblo, the Culture spatial unit includes areas occupied by the Hohokam, the Fremont, and the Patayan. The Salado and the Chihuahua/Casas Grandes, including the Gran Chichimeca, are an individual Branch under the cultural area of Ancestral Pueblo: Greater Mogollon.

Within a Culture, ceramics coexist that share a broad range of characteristics, but they often use a variety of finishing techniques, ranging from polishing to pigments for painted decorations. These differences help to place the artifact in the proper Branch within the Culture.

Branch

A Branch is characterized by broad and distinct combinations of materials that researchers have (M. J. Martinez 2022) identified as lying within the different Culture areas. Contemporaneous ceramics from areas assigned to different branches, while sharing broad suites of traits, can often be distinguished by differences in finishing techniques and the Type(s) of pigment used in painted decorations. Ceramics from different areas within a particular branch are further divided into ceramic Traditions.

Tradition

Traditions are described here as the smallest area in which pottery associated with different sequences can be consistently grouped. Ceramics that researchers have assigned to different regional Traditions in a defined area often exhibit similar characteristics, but they are differentiated by temper and paste resources, and sometimes by stylistic differences. Traditions represent the basic units through which ceramic Ware groups and Types are defined.

Ware

Within the classification system employed here, pottery assigned to different Traditions is further assigned to a specific Ware and Type. Ware(s) refer to basic technology- and function-based groupings common in pottery produced across much of the Southwest. They include a range of distinct technological practices in the production of pottery at a particular location that resulted in long periods of production and use of distinct forms. Examples of utilitarian Ware groups include gray and brown Ware(s) that were never painted and commonly, although not always, served as cooking jars. Examples of decorated Ware(s) that were usually painted are represented by a wide range of forms, including bowls and other serving vessels treated with white and red paint, glaze, and polychrome. Ceramic Type(s) are listed for each Ware defined within a particular Tradition.

Type

A Type is the basic classification defining the culture of origin. Archaeologists named them based on the geographic area in which they were first discovered and on their association with the Ware group that reflects their overall form and surface finish (Colton 1954). Ceramic types, therefore, are assigned a compound name that includes their geographic designation and their associated name. They include, for example, Cliff (Gila) Polychrome, Mesa Verde Corrugated, Reserve Plain Smudged, Sierra Blanca (Playas Variety) Incised, and El Paso Brown (Martinez 2022; Melissa J. Martinez 2022) (Martinez 2022).

Table 1 shows the organizational pattern of the motifs/symbols that were being sought in the computer vision recognition phase of the study. The majority of the motifs were obtained from the diagram provided by Crown and Bishop (1994) showing the ones most encountered in their work in the Southwest. Other motifs were taken from the works of Haury (1976), Gladwin et al. (1938), VanPool et al. (2000); VanPool et al. (2006); and others. The motifs were classified by overall appearance into the following groups:

Barbed	Macaw	Zoomorph
Checked	Rectangle	Triangle
Circle	Scroll	Square
Diamond	Animals	Spiral
Feather	Motif Misc.	Line
Ladder	Geometric figure	Facial parts

Table 1-General forms for motifs

Figure 3 Illustration in Patricia Crown's book, Ceramics & Ideology: Salado Polychrome Pottery

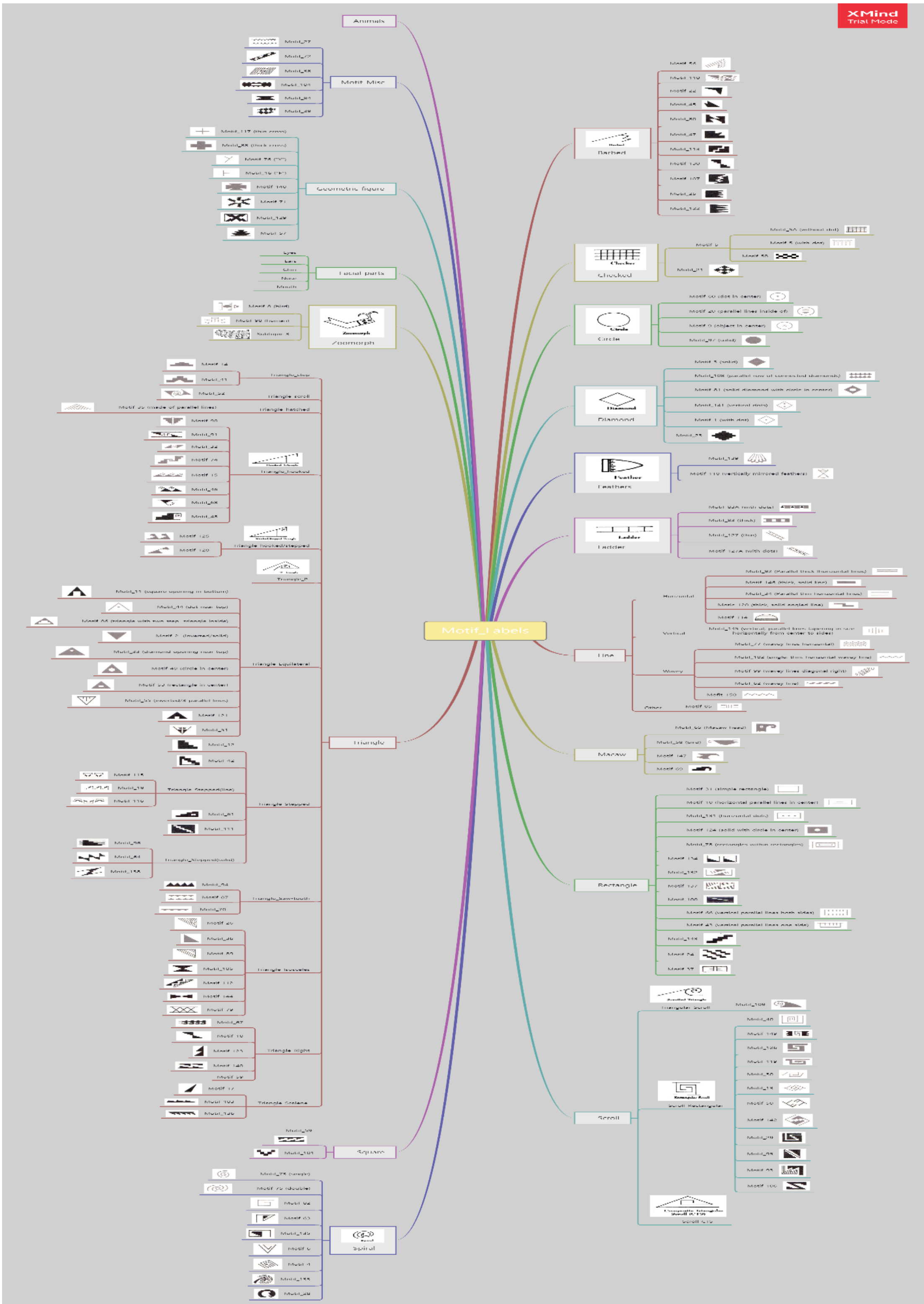

Figure 4 Motif classification chart

Each of the major motif/symbol groups is broken down into the actual motifs/symbols.

Within this chapter, the different groups as related to the artifacts under study were defined. Culture, Branch, Tradition, Ware, and Type are each explained. Culture is the overall dominant container into which the other four fit. Working down the list, data is most detailed. The motifs that are used in the study are also defined and illustrated. Chapter 4 discusses effigy vessels and their areas of origin.

Chapter 4: Effigy artifacts described

This chapter introduces the nine areas where the artifacts used in the study were found, giving a brief description of each. It also defines effigy artifacts, explains their history, and describes some of the decorative methods used. A general understanding of the relationships among the areas where the artifacts were found helps when trying to determine the amount of information transmission that occurred.

Effigy artifacts, including jars, pots, and figurines, are found wherever there are humans. The materials used in the construction of these artifacts vary in composition from grass and twigs with a clay head (Haury 1976), or bone (Di Peso 1974b), to representations of animals (Haury 1976) in dried or lightly fired mud, to the ornate Pilling figurines (Morss 1954) and the elaborately painted human effigy vessels (Di Peso 1974b).

House (2004) states that these effigy artifacts are found throughout the Western Hemisphere from the Arctic to the continental United States and Mexico and on down to South America. They are also found throughout Africa and the Far East. "Commonly, they [effigy vessels] are defined as containers that are sculpted in the likeness of a human or an animal," (Kaminski 2012).

Ceramics are not the only style of effigy artifact found in the PHASNM, but they are perhaps one of the most durable. Recovered effigy artifacts were also made of wood, shells, other plant materials (Gunnerson 1969: Fig. 39) and baked mud (Gunnerson 1969).

Although effigy artifacts come in many different shapes and forms as well as materials, ceramic effigy vessels generally come in one of four shapes:

Rim effigies—these are identified by the stylized heads and tails that project from the rim of the vessel. Birds and other creatures with the head of a cat and the tail of a serpent are found in this group.

Animal effigies—these range in form from domestic animals to creatures of the forest, including frogs, badgers, and wolves. Fish and seashells are also represented in forms that represent the creature or in a bottle shape. They can also come in the form of figurines.

Human-form effigies—these are found in three styles. One is the hooded effigy bottle; another is the head vase. The hooded effigy bottles have been found in relatively large numbers across the American Southwest, in Northern Mexico, and in the Southeastern United States, while the head vase is not quite as widespread (Kaminski 2012). The third is human effigies in the shape of figurines, including the Pilling figurines, flat, cookie-like objects found in Utah.

Plant effigies—these are found in several styles, including datura seed pods, gourds, cactus pears or seed pods.

Effigy definition

The following definition will be used:

"Effigies are …[artifacts] with modeled features that are anthropomorphic or zoomorphic in appearance. Vessel sherds that bear part of an anthropomorphic or zoomorphic feature are classified as effigies, as are body sherds that do not bear the features but that match with an effigy sherd from the same PL (point location number) (Blinman et al. 1984) or FS (field specimen) (Blinman et al. 1984). Effigies are often identified on the basis of pinches of clay that can be interpreted as ears, wings, or tails, as well as on the basis of shape and detailed modeling of heads and appendages," (Blinman et al. 1984).

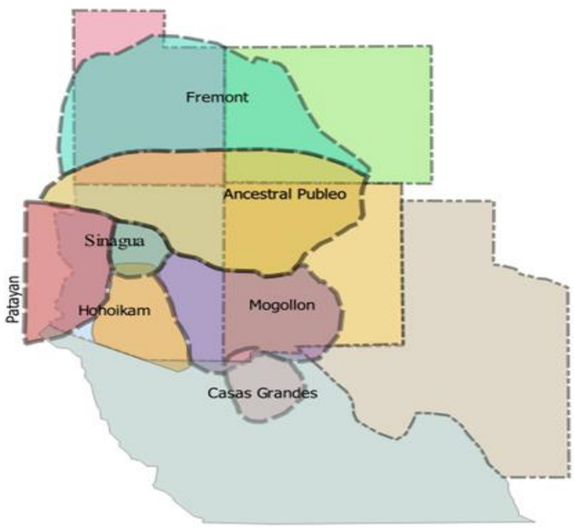

Figure 5 Map of general location of Cultures in study

Distinct cultural remains are found within the differing geographical areas of the PHASNM (Kantner 2004). One of the first (ca 1920-1930) to be named were the "Anasazi."[2] Then came the "Hohokam"[3] (ca 1930), who were named when their common traits were discovered around the Gila and Salt Rivers. They were followed by the "Mogollon," named after the Mogollon Mountains, their homeland (Cordell 1997; Kantner 2004). Morss in 1931 recognized the "Fremont" as a separate cultural pattern. Over the years, other material cultural patterns emerged: the "Patayan," the "Sinagua," and the "Salado." The majority of these cultures have produced effigy artifacts (Gruner 2019; Stark 1992). Figure 5 shows the general location of the mentioned Cultures.

Ancestral Puebloans

The Pre-Puebloan Southwest was occupied long before the first pit houses were built, but they may have been in use as long ago as 3200 BC (Kantner 2004). Research during the 1980s suggested that these settlements were used seasonally, occupied during the winter and abandoned during the summer. Plog (1997) argues that this trend continued until ca A.D. 600 to A.D. 800, when groups resided in the settlements year-round.

The early pottery made by the Ancient Puebloans[4] and the Mogollon was similar in both size and shape, and it was different from the vessels made by the Hohokam. Although similar in appearance, their construction techniques differed. The Anasazi used the coil and scrape method, while the Mogollon used the paddle and anvil technique (Plog 1997).

During the transition period from Basketmaker III (BMIII) to Pueblo 1, a number of pottery traits become apparent. Wheat (1954) lists, "Neck-banding, smudging, slipping and

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[2] Meaning varies by translation – 'old people', 'enemy ancestors' (see Walters and Rogers 2001)

[3] Pima word for 'all used up'

[4] Many modern native Americans take offense to the use of the name 'Anasazi' and there are numerous other names applied to the group so 'Ancestral Puebloans' is now in common use – see Kantner 2004.

polishing; quartered, offset-quartered, and sectioned design layout; use of rim solids, chevrons, checkerboards, fringing lines, and nested rectangle design elements; broadline painting, polishing over the decoration, and possibly black-on-red and red-on-orange wares," as some of them.

Pueblo I

In Southwestern Colorado and Northwestern New Mexico, the Pueblo I period lasted from ca A.D. 750 to A.D. 900. (Etzkorn and Powell 2011a) Ceramic ware during the Pueblo 1 Period consisted of grayware, neckbanded grayware, decorated whiteware, and redware.

Pueblo I grayware:

Grayware was the most common type because it was utility-oriented. During the Pueblo 1 Period, neckbanded grayware was introduced, so named from the distinctive bands of clay coils on the outside of the necks of the vessels that were used to build them. Decorations ranged from plain, unpolished surfaces formed from obliterated coils with the possibility of exterior coloring, such as fugitive red as seen in some Northern San Juan Gray Ware (Wilson 2012). Those from other areas, such as Cibola-Tusayan Gray Ware (Cibola Plain), are without decoration, and the exterior is a dull, gray color.

Pueblo I whiteware

Whiteware vessels were used primarily for holding food, and they were often finished with a white slip, then polished and decorated with simple, painted black designs. These included parallel lines with attached triangles, triangles with hooks, and tick marks. Neckbanding does not appear on effigy artifacts.

Another type common to the Pueblo I Period is the Piedra Black-on-white. Effigies are decorated with vertical or horizontal lines, triangle terraces, simple triangles, or abstract lines.

Pueblo I redware:

Polished and painted, redware appears for the first-time during Pueblo 1 Period. Named for its unusual orange- to red-hue when fired, redware is believed to have originated in Southeastern Utah. Because it has also been found in Southwestern Colorado, researchers think it was a prized item for trade. Effigy vessels, including types of Northern San Juan Red Ware, lack motif decoration, having only been fired to the characteristic orange/red color.

Pueblo II (ca. A.D. 900 to A.D. 1150)

During the Pueblo II Period, corrugated grayware replaced smooth grayware as the most common cooking and storage vessels. Like neckbanded grayware, the vessels' coils along the outside were left intact. Unlike neckbanded grayware, the coils covered the entire vessel, not just the neck. The characteristic "corrugated" texture was made with a finger or thumb. Experimental archaeology suggests that corrugated pottery is stronger, better able to transfer heat, and easier to grasp.

Pueblo II white and redware:

Whiteware continued to be made as it was during the Pueblo 1 period. Black designs were inscribed on a white background that had been slipped and polished. Designs were expanded to include dots and diagonal hachure. Redware continued to be made, and it showed up in other locations, suggesting it was used in trade.

Avian effigy vessels (such as Chaco-Cibola White Ware, Red Mesa Black-on-white (Peters 2018a)) sometimes display parallel lines representing feathers. Other vessels display bands of interlocking triangles or steps, with parallel lines on the rear section; still others display interlocking spirals with triangles.

Cibolan grayware appears in the record ca A.D. 800 to A.D. 920, while redware appears after A.D. 1025 (Blinman et al. 1988).

The Pueblo III Period: A.D. 1150 to A.D. 1300

Pueblo III period painted pottery is known for its beautiful designs and craftsmanship. Forms include those from earlier periods, with many vessels highly polished and slipped, so their surfaces were extremely smooth. Intricate painted designs include both thick and thin parallel lines framing broad bands filled with geometric shapes and areas of hachure (Etzkorn and Powell 2011c). Motifs expand to include horned/plumed serpent imagery, as seen in Mogollon (Mimbres and Jornada) motifs or decoration (Harmon et al. 2006b).

Figure 6—Chaco Avian effigy vessel

The Figure 6, the Chaco Avian effigy vessel (pg. 31), is typical of avian effigy vessels found in the Chaco region (New Mexico) during the early Pueblo III Period (ca A.D. 1050 to A.D. 1150). The vessel has a white or light buff base with "feathers" on both sides of the back and along the handle. Inverted triangles with parallel, diagonal lines are on the neck. The front of the vessel is similarly decorated, while the sides have a band of mirrored triangles where the wings would be. More feathers are located in the center of the band on the top. Figure 3 is from a photo taken by author at Chicago's Field Museum of Natural History (Tallier 2017).

Human figures were extremely popular as effigy vessels in the Chaco Canyon region, both of solid and hollow construction. Decorations can consist of a face that is flat and circular, with the lower portion of the eyes, nose, and mouth modeled with a slight upward tilt, resulting in a chin. Eyes and mouth are well formed, and both can be outlined in black. This is reminiscent of tattooing, with the use of dotted lines and scrolls (Pepper 1906, 1920).

Hohokam

Recent work in the Tucson Basin has established a pre-Hohokam occupation of the area that is described as the Early Agricultural Period (1500 B.C. – A.D. 150) (Chenault 2016). Stinson (2005) describes three types of figurines from that period. Two of them appear to be anthropomorphic: Type I consists of two large lobes of clay stuck together and then attached to a cylindrical piece; Type III consist of flat torsos with flattened heads, slit eyes, and noses made by pinching a large ridge. Similar examples of Type III figurines have been found in Northern Mexico (Chenault 2016). The third, Type II, exists as fragments only.

While rare in the Mogollon culture, figurines are abundant in the Hohokam culture between the years A.D. 0. to A.D. 1300 (Colton 1953). Gladwin and Haury (1976), during excavations at Snaketown, recovered over 500 human figurines, all modeled (not cast in molds), and many fired. The color of the clay used for the figurines was finer than for general pottery, ranging from dark (early phases) to buff (later phases).

Specimens were recovered from most of the seven distinct cultural development phases in the Gila Pueblo project (Pueblo 1939), but not the Sedentary and Classic Phases (Morss 1954). Gladwin (1942) revisited his work on Snaketown twice, first in 1942 when he revised the average duration of the original phases from 200 to 50 years, thus agreeing with the Basket Maker III Period (Gladwin 1942).

A second revisit of the data prompted Gladwin (1948) to state:

"Instead of a self-contained succession of seven phases, beginning with Vahki and rising through Estrella, Sweetwater, Snaketown, Gila Butte and Santa Cruz to Sacaton, now believe that at Snaketown we are dealing with the approximately contemporaneous cultures of two entirely different peoples."

These peoples were the Hohokam and the Mogollon; the Hohokam occupation began ca A.D. 750, after the Mogollon occupation ended (Haury 1976).

Figure 7 is a copy of the developmental chart Haury (Gladwin et al. 1938) developed for the Snaketown figurines. It appears to have been made before Gladwin's reappraisal of data in 1948, where the Gila Butte Red-on-buff became a transitional stage between Santa Cruz and Sacaton Red-on-buff and not a separate phase (Gladwin 1948).

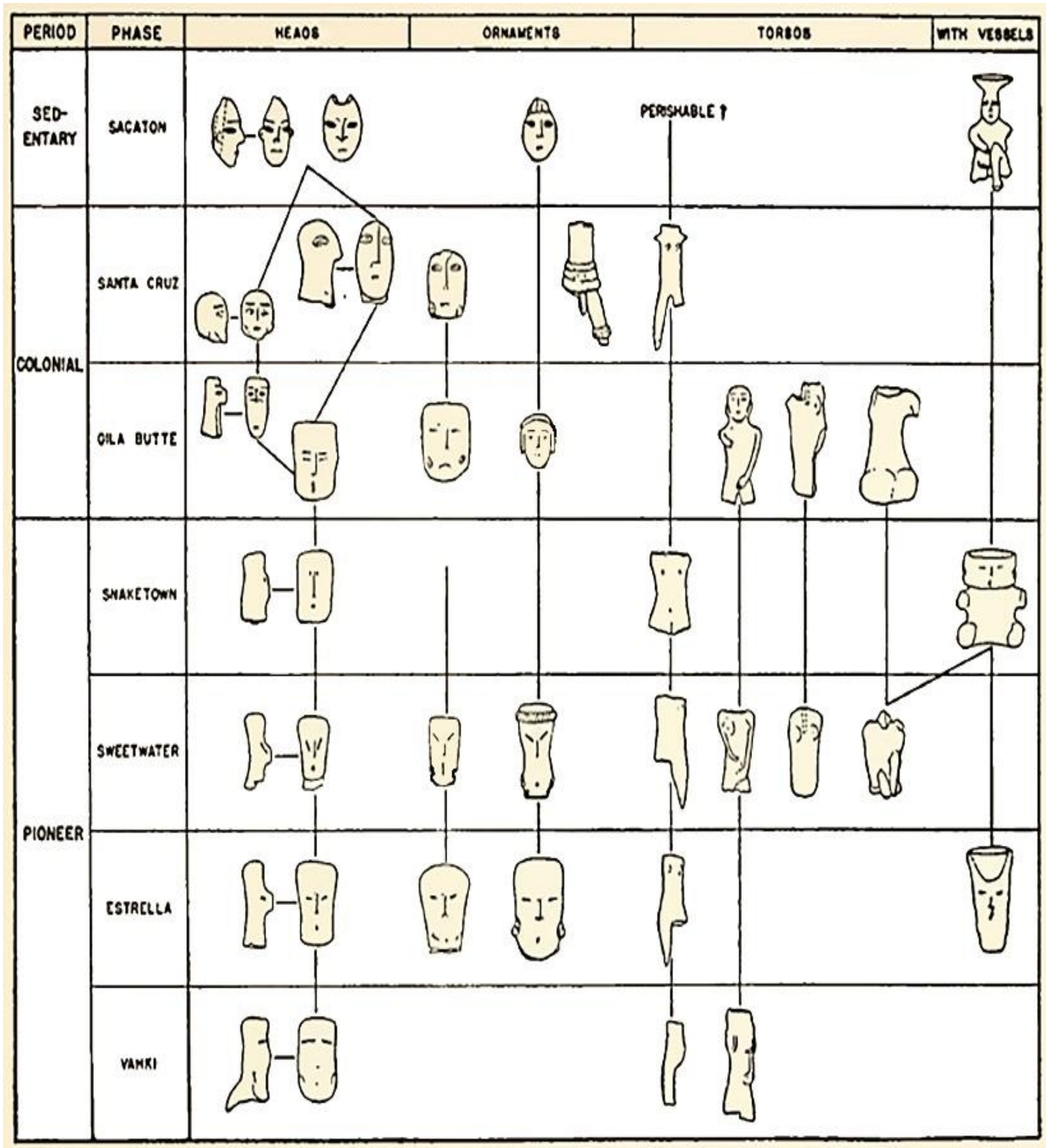


Figure 7—Developmental chart of Snaketown figurines (Gladwin et al. 1938)

Figurines from Snaketown during the Pioneer Period often have lightly fired clay rather than dried; females with breasts; strong eye and nose ridge details but little mouth or arm detail. They generally have lower limbs, and they may be painted (See Morss 1954 for a more detailed discription.) Pioneer figurines were typically made from two pieces of clay pressed together, one segment composing the head and torso, and the other, the legs. Details were added by pinching the clay, creating indentions, or by adding applique (Haury 1976). Figurines from the Pioneer Period are more abundant primarily because they are recovered from trash piles.

Progressing from the Pioneer Period to the Colonial Period (Santa Cruz Phase), the figurines take on a head shape like those made by the Fremont (shown in Pillings figurines as longer than they are wide), as are the shapes of the nose and chin. The eye in the shape of a “coffee-bean” is applied. The figurines still portray sexual character (i.e. breasts in females) in the thoracic region but not around the head.

Decorations begin to change during the Snaketown to Gila Butte Phases. Eyebrow slits are more consistently used and faces more closely to reflect human characteristics. Eyes become diamond-shaped, and pupils and mouths are represented by a slit. Eyes change once again during the Santa Cruz Phase to the coffee-bean shapes. Human characteristics, in the form of heads, appear during the Santa Cruz Phase on scoop or ladle handles (Morss 1954). Figurines are less abundant during the Colonial Period, for they are associated with cremations rather than thrown out with the garbage.

Animal effigies are also found at Snaketown. but Morss argues that they did not appear before the Santa Cruz Phase (Morss 1954). Haury, however, states that they did, but that the abundance and level of workmanship suggests they were used as toys. Haury (1976) also argues that a change in cultural habits raised the animal effigy from the status of a toy for children to something more important: they were made from the same clay as pottery, were more realistic, and often were painted to match the animal they represented (Haury 1976:267).

During the Sacaton Phase, figurines were designed with clay heads featuring a pinched ridge for a nose, and diamond-shaped eyes with punctuated pupils and a mouth slit. They could be used in conjunction with an organic body (grass or straw) in a cremation ceremony (Haury 1976:260).

Starting ca A.D. 1100, the Hohokam Classic Period lasted until ca A.D. 1500 (Bell and Lavender 1999). During this time, Haury notes that figurines were scarce, with few showing up during excavation. He reasoned that the ability and motive to construct figurines, “was on the path to extinction,” possibly a result of the outside influence of the Salado people (Haury 1976).

Mogollon A.D. 500 to A.D. 900;A.D. 1300 to A.D. 1400.

Although scarce, Mogollon anthropomorphic figurines, Figure 5, are believed to predate Snaketown figurines (Morss 1954). Figure 5 is from the second Museum-Gates expedition (1905). Among the earliest figurines within the PHASNM are those associated with the

Mogollon culture, and samples were found in the pit house village of Bluff Ruin in the Forestdale Valley of eastern Arizona.

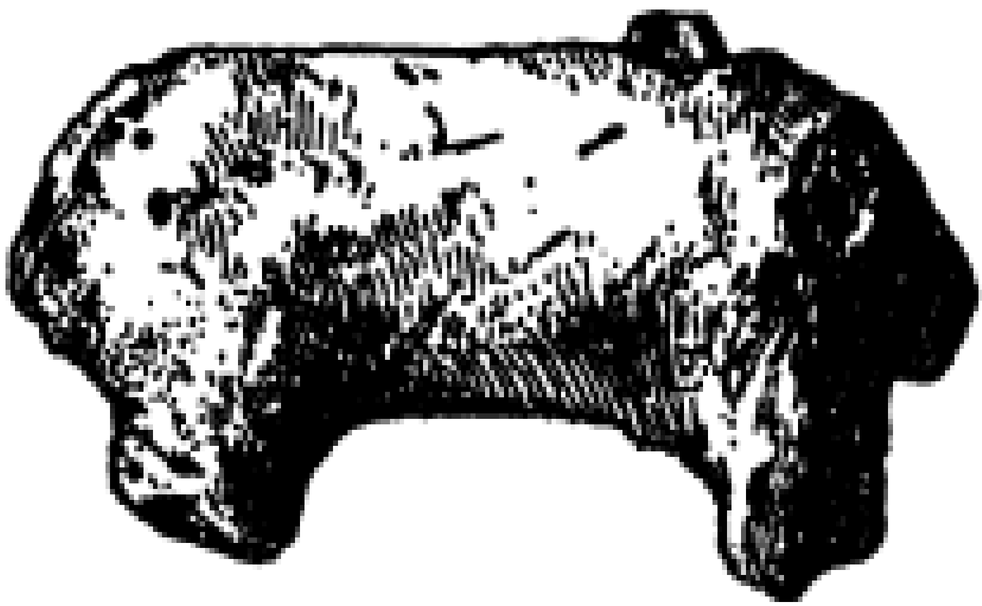
After Haury and Sayles, 1947 Bluff Ruin, Forestdale Valley, Arizona, Mogollon, Hilltop Phase ca. A.D. 200-400 (Morss 1954:100)

Figure 9-- Mogollon anthropomorphic figurines(Morss 1954:100)

Tularosa Cave, near Aragon, New Mexico. Georgetown Phase of the Mogollon, ca. A.D. 500-700.

(Morss 1954)

Figure 8—Mogollon human figurine(Morss 1954)



Pottery figurine from Tularosa Cave.

(Hough 1914)

Figure 10-- Mogollon animal figurine (Hough 1914)

Dated to between A.D. 287 and A.D. 312 (Morss 1954), these partial anthropomorphic figurines made of fired clay display a rounded head and a straight nose ridge with no mouth (Morss 1954:100). Eyes are applique, and an incised line between the eye and the outer edge of the head is possibly a continuation of the eye itself, suggesting a connection with Southern types. Basket Maker III and Pioneer Hohokam lack this feature (Morss 1954). Animal effigies are also found at Mogollon sites.

Six more figurines were discovered during the Forestdale phase at Bear Ruin. They were dated by tree-rings from A.D. 575 to A.D. 700 (Haury 1976). These figurines exhibited traits of Mogollon origin combined with Anasazi (Morss 1954). Haury, while excavating in the Classic Period at Snaketown, failed to recover any anthropomorphic figurines, but he did find a clay animal head in the lower San Francisco Valley. The two Mollogon figurines shown here were recovered in the Georgetown Phase stratum in the Tularosa Cave: Figure 10 is from Hough's 1914 book, *Culture of the Ancient Pueblos of the Upper Gila River Region, New Mexico and Arizona*. After ca A.D. 900, purely Mogollon style anthropomorphic figurines seem to disappear. Although anthropomorphic figurines are found in later Mogollon sites, they exhibit a mixture of Hohokam and Mogollon traits (Morss 1954).

Like the Hohokam, early Mogollon or Mogollon 1 ceramic artifacts came in polished plainware, and slipped and polished redware with the same style of decoration, but they were made by a coil and-scrape method. Complex designs become more prevalent in Mogollon ceramic artifacts as they move toward the Mogollon 5 phase, using more complex sectioning and quartered layouts with curvilinear elements, varying types of scrolls (both simple and interlocking), and depictions of life forms (Wheat 1954). Wheat (1954) argues that both the Mogollon and the Hohokam are descendants of the late Cochise culture: the Mogollon derived from the eastern branch, and the Hohokam from the western. Wheat also contends that the Cochise were the cultural equivalent of the Anasazi Basketmaker II.

Moving from early Mogollon 1 phase to the Mimbres phase, ceramic artifacts are plain brownware, then polished redware, then red-on-brown, then red-on-white, and finally black-on-white. Brownware evolves into a corrugated style and into black-on-white (Leblanc and Nelson 1976). Evidence of transition from pre-pueblo (Late Pithouse) is suggested by Shafer and Taylor (1986), who found a sealed midden containing transitional style pottery—black-on-white boldface sherds—beneath Classic Mimbres construction. After approximately A.D. 700, black-on-white pottery was integrated into the Mogollon culture.

Following the Mimbres phase (ca A.D. 1000 to A.D. 1200), the Animas phase, as described by Leblanc and Nelson (1976), contains ceramic ware associated with Casas Grandes that ranges from Playas Red Incised to Chihuahua polychrome, but primarily Ramos Polychrome. Gila Polychrome is found in Animas sites with dates ranging from A.D. 1200 to A.D. 1300 (Leblanc and Nelson 1976).

Fremont

North of the Anasazi or Ancestral Puebloans lies the Fremont culture. Still an enigma, the Fremont culture appears to be a melting pot of traits.

Inhabiting portions of Utah, Nevada, Idaho, and Wyoming between A.D. 500 and A.D. 1300 (Lambert et al. 2019), the Fremont culture is characterized by traits similar to those of the Basketmaker III period in the San Juan Anasazi area (Gunnerson 1960). In addition, the culture also exhibited traits from the Sevier culture in Western Utah and Northern Nevada that evolved from Desert culture. A third group, the Virgin Anasazi, also shared traits with the Fremont.

Effigy vessels have been found at several Fremont sites, including Snake Rock Village, Parowan Valley, and Five Finger Ridge (Richards 2014; Watkins 2016). From work done at Fremont sites, information has emerged concerning the Fremont culture and their relationship with birds. In addition to being a food source, feathers were used in rituals and communal activities, as well as for trade (Lambert et al. 2019:38).

Fremont effigy artifacts consist of both anthropomorphic figurines and avian-shaped vessels, with the anthropomorphic figurines more abundant. Avian effigy vessels are rare, with a total of six found so far: two from Parowan Valley sites; one from Five Finger Ridge in Clear Creek Canyon (Watkins 2016); and three from Marigold Cave in Yampa Canyon (History 2007). The three grayware bird effigy vessels/figurines recovered from Marigold Cave had three projections representing the wings and a tail and are constructed of unfired clay (History 2007; Watkins 2016), while the two from the Parowan Valley sites are incised to depict feathers on the wings and tail. The sample from Snake Rock Village resembles a duck in body shape, has coffee-bean eyes, and has a short beak or snout. On its front, parallel, diagonal lines are drawn from right to left downward (Watkins 2016).

The avian effigy found at Five Finger Ridge, Figure 7, while missing eyes, did have a coffee-bean applique applied to the surface (Janetski et al. 2011), resembling the other specimens found.

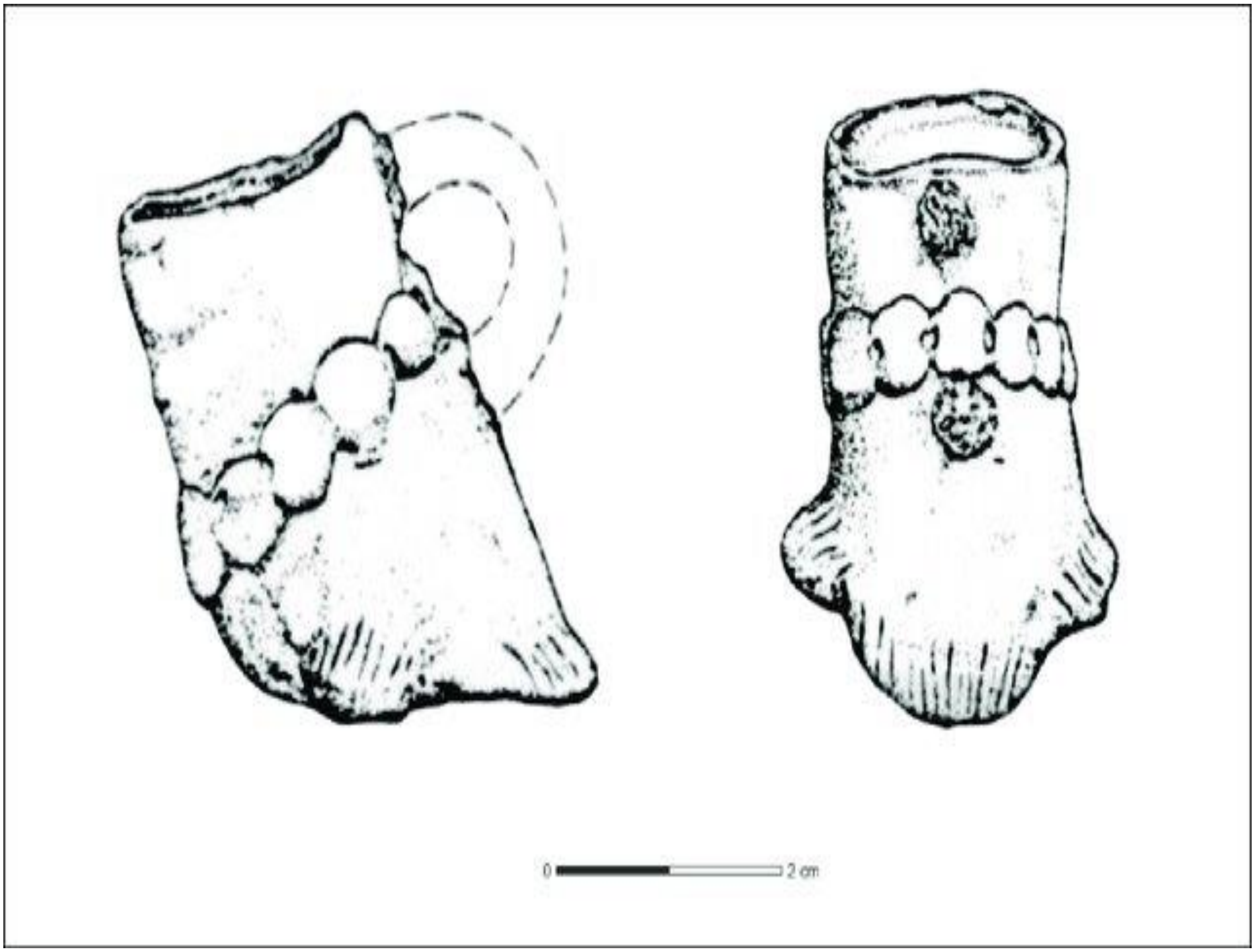


Figure 11--Bird effigy vessel with coffee-bean applique from Five Finger Ridge (Janetski 2011)

Fremont culture (Utah) produced elaborate anthropomorphic figurines that often resemble rock art figures (House 2010). The majority of figurines found at Fremont sites have been of unfired clay (Morss 1954) with great variations in size, shape, and decoration, but they represent the most elaborate figurines found north of Mexico (Gunnerson 1969). The Pillings figurines, discovered by Clarence Pillings of Price, Utah, in 1950 on his ranch in Range Creek Canyon, are a representative sample. They are more elaborate than their plain brethren from nearby cultures. Morss (1954: Fig. 20) assigned the Pillings figurines as well as those from the Basketmaker III period to the "northern tradition,"[5] (Heizer 1955) while the Pillings figurines painted in red and buff, he reassigned to the southern tradition (Gunnerson 1969). This is because the latter Pillings figurines feature a "disengaged chin," slit eyes, necklaces, earrings, hair, belts, and aprons.

Patayan

Little published information about the Patayan culture exists. McGuire (1982) states that work was done by Rogers at over 500 Patayan sites (Waters 1982), but he never reported on the excavations. Several archaeologists have done work on the Patayan culture (See McGuire 1982:216 for list).

The term "Patayan Root" was introduced by Colton (1953) to replace Gladwin's use of the term Yuman to refer to the large geographical area inhabited by the Patayan culture (Rogers 1945). Rogers disagreed with Colton's concept on the grounds that, to Colton, it was a cultural entity, but material evidence indicated it was a mixture of fragments from a collection of cultural groups (Rogers 1945).

In a local usage, the term Patayan (or Yuman) was acceptable, and Rogers proposed the original chronology. The first of three periods began around the start of the Santa Cruz Phase (A.D. 800 and ended ca A.D. 1050) before production began on Casa Grande Red-on-buff (McGuire 1982; Rogers 1945). Patayan (Yuman) II began at the end of Patayan I (ca A.D. 1050) and ended with the arrival of the Spanish (ca A.D. 1500). Patayan III ran from the arrival of the Spanish (ca A.D. 1500) until present times (Rogers 1945).

Harner (1958) suggested that, based upon their production of ceramics, the Patayan be broken into two groups: "Lowland Patayan" to refer to the makers of the Lower Colorado Buff Ware; and "Upland Patayan" for the manufacturers of Tizon Brown Ware. He further suggested that ceramic phase chronology be rewritten as: Bouse Phase 1 (ca A.D. 800 to A.D. 1000), the Bouse Phase 2 (A.D. 1000 to A.D. 1300), and the Moon Mountain Phase (ca A.D. 1300 to A.D. 1700). (See Harner 1958 for additional details regarding phases.)

Waters (1982) also weighs in. He places the Patayan I Period from ca A.D. 700 to A.D. 1000, in which he says that effigy head scoops are absent. Waters agrees with Rogers's other dates regarding the Patayan II and III Periods, saying that effigy head scoops are present during these periods but rare. He does not mention other kinds of effigy vessels.

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[5] The northern tradition as described by Morss is composed of Basketmaker II, III, and the Utah-western Colorado area; while the southern tradition encompasses the Mogollon, Hohokam, peripheral western Arizona, and northern Mexico.

Koerper and Hedges (1996) describe twelve anthropomorphic figurines of fired clay that were found at the Banning-Norris site in Costa Mesa, California, during the 1960s. They are quasi-cylindrical in shape, unlike the Southern Tradition Patayan figurines that are flat. Of the twelve specimens, eleven appear to be of a Lowland Patayan origin (Koerper and Hedges 1996). These figurines seem to reflect an accumulation of traits. Prescott figurines (A.D. 1000 to A.D. 1400) feature knobby or stumpy legs, a one-piece body with the upper end pressed flat, and minimal facial/head development or facial modeling. The stumpy leg is a trait found on several of the Patayan figurines; however, their eyes are appliquéd, and females lack the breasts found on Prescott figurines. Facially, Patayans have more in common with Hohokam anthropomorphic figurines. Overall, they appear to be a hybrid of Hohokam and Prescott traditions (Koerper and Hedges 1996).

Sinagua

Bounded on the north and northeast by the Anasazi, the east and southeast by the Mogollon, the south by the Hohokam and the west by the Patayan, the Sinagua made ceramic wares. But they appeared to prefer to obtain decorated pottery from the groups in the Kayenta and Winslow areas (Keller et al. 2011). Effigy artifacts are rare, with the few found constructed of dried clay with no painted decoration. The few human figurines found show a close resemblance to those of the Patayan culture to the west. Features include eyes consisting of simple slits, pinched noses, and punctuated mouths. No other features are found on the four specimens discovered.

Salado

The Salado were a phenomenon who produced Salado polychrome that was distributed throughout approximately 50,000 square miles in the ancient Southwest (Crown 1994). Clark (2001) describes hypotheses concerning the Salado enigma ranging from Gladwin’s (1935) assertion that it was a Puebloan migration, to Haury’s (1945b) hybrid culture, to Doyel’s (1976) indigenous development based on earlier Mogollon-Western Pueblo and Hohokam traditions. Di Peso (1976) considered the Salado the result of Mesoamerican intervention, while Crown (1994) argued they were a religious cult. To others, they remain an unanswered question.

Coming onto the scene relatively late in the game, Salado Polychrome shares attributes with Mimbres (A.D. 1000 – A.D. 1150). They include black-on-white pottery (Crown and Bishop 1994; Simon and Jacobs 2000). Leblanc and Nelson (1976) compare Mimbres Classic black-on-white to Salado Gila Polychrome, arguing that they share the attributes of vessel shape correlating with location of design band and concentric band lines.

While ceramic artifacts were produced throughout the Salado region, they were not confined to household utensils. Ceramic effigy artifacts were also in production. Forms varied from avian vessels to mammals and humans. Among the many avian species represented were owls, pigeons, turkeys, parrots, ducks, and coots (Crown and Bishop 1994). Body shape varies from oblong to globular with decorations varying from a continuous band to discontinuous, isolated designs. Of the designs found on avian artifacts, triangular motifs, in groups of two or four, make up "sacred plumes." These are found on the back. Although not the only group to make and use avian effigy vessels, the Salado used them more often (Crown and Bishop 1994). Crown cites Kenagy (1986:341) as stating that Salado bird effigies evolved from Tularosa Black-on-white, influenced by Sacaton Red-on-buff and Casa Grande Red-on-buff.

Mammal effigies come in assorted styles; vessels are shaped like the animals they represent, or the effigy is a decoration on the handle of another vessel. Eyes can be decorated, ears present a definite shape, and the absence or presence of limbs and other markings help distinguish the animal.

Three different forms proved to be the most popular at the Culture level. These are avian forms (N = 95), animal forms (N = 72) and human forms (N = 51). The form can be that of a jar with head features appliqued on and without any other features. Arms and legs can be applied by applique. Eyes can be elongated or appliqued coffee-beans. Other facial features such as nose, chin, and ears are generally present, with some ears showing holes for earrings. Human effigies represent both male and female forms. Decoration may consist of meandering rectilinear designs, vertical or diagonal lines, or other motifs. The decorations may represent tattooing, as suggested by Haury (1945a).

Chihuahua/ Casas Grandes

Effigy artifacts from the Chihuahua/Casas Grandes region appear in many different forms, ranging from avian to mammalian to human. Two features, polished black-ware and plumed serpent designs, appear to have come from Mexico (Gladwin 1957) after A.D. 1300. The rest of the design(s), he argued, could be traced to influences from Mogollon, Mimbres, or Salado cultures (Gladwin 1957).

Evidence of ceramic effigies dates from the Viejo Period, with polychrome effigies found through the Medio Period and across the Chihuahuan cultural area (Hendrickson 2000). Hendrickson (2003) describes in detail the motifs and layouts on Chihuahuan effigy vessels. He divided the individual motifs into six major divisions: triangles, geometric, avian, miscellaneous, Zoomorph, and scrolls. Within each major division are one or more subdivisions (Hendrickson 2000). Several of the motifs are also found on Mimbres/Mogollon effigy vessels.

Covering an area of approximately 95,500 square miles, the Chihuahuan cultural area is home to several cultural areas that produced a variety of effigy vessels. Among these styles are:

- Ramos – centered around Paquimé
- Babicora – to the south of Paquimé
- Villa Ahumada – to the east of Paquimé
- Carretas/Huerigos – northwest of Paquimé

One of the major sites found within the Chihuahua/Casas Grandes area is Paquimé. First observed by Europeans around the mid-1560s, it was described by Balthazar de Obregón, of the Ibarra expedition (Minnis and Whalen 2015). Obregón described Paquimé as a place of tall buildings with large, well paved patios, and whitewashed walls. He also described painted murals within the buildings (Hammond and Rey 1928). Paquimé slipped from archaeological interest until the mid- to late-1800s, when it was “rediscovered” by Bartlett (1854a, 1854b), Bandelier (1890), and others during the early years of the twentieth century. In the 1930s, interest once again picked up, with work being done by Brand (1935, 1943) and Sayles (1936). In 1958, the Joint Casas Grandes Expedition (JCGE) and the Instituto National de Antropología e Historia (INAH) began a full-scale archaeological assessment of the Casas Grandes site. The main emphasis of the JCGE was the Medio Period, perhaps its most vibrant.

The transitional periods for Casas Grandes originally given by Di Peso have been challenged, first by Dean and Ravesloot (1993) with information gained from tree-ring studies, then by Fish and Fish (1999) using Dean and Ravesloot’s data, and by Rakita (2009). Table 2, below, compares the original and revised dates:

Period	Beginning	Beginning	End	End
	Di Peso	Rakita	Di Peso	Rakita
Viejo	A.D. 700	A.D. 600	A.D. 1060	A.D. 1200
Medio	A.D. 1060	A.D. 1200	A.D. 1340	A.D. 1475
Tardio	A.D. 1340	A.D. 1475	A.D. 1660	A.D. 1660
Expañoles	A.D. 1660	A.D. 1660	A.D. 1821	A.D. 1821

Table 2-Casas Grandes dates

Gran Chichimeca

While many of the ideas put forward by Di Peso (See Di Peso 1974b: 8 volume set) have been challenged and some altered to reflect new information, i.e. dating of Casas Grandes, evidence is emerging that supports his ideas about the influence of Mesoamerica in the American Southwest. Horned serpents, common on Casas Grande pottery (VanPool et al. 2006), originally appeared in Teotihuacan (Math 2017) ca A.D. 300 and moved north from there (Nielsen and Helmke 2011).

Di Peso’s strong belief in the close relationship between Mesoamerica and the American Southwest led to him to remap Mexico and the Southwest into the Gran Chichimeca. During the Post-Classic Period (ca A.D. 900 to A.D. 1521) in Mesoamerica, traits from that area reach a peak in the Gran Chichimeca, with the step-fret pattern and the feathered serpent the most pronounced (McGuire 1993).

Initially believing that the pochteca were responsible for the distribution of ideas within the Gran Chichimeca, Di Peso modified his views and applied world systems theory (Di Peso 1983), finding his work more accepted than the original pochteca hypothesis. Di Peso explained in more detail the relationships among his assumptions, hypotheses, and supporting data (McGuire 1993). Basing his new ideas on four assumptions (Di Peso 1983), he argued that over time, three different types of economies existed in the Gran Chichimeca. Type I was hunter/gatherers (Di Peso 1983); Type II was farming (Di Peso 1983); and Type III was a base-level Mesoamerican market system (Di Peso 1983). Despite the debate over his ideas, the work of Di Peso is still considered a cornerstone of the archaeology of the PHASNM.

This chapter introduces the nine different areas that encompass where the artifacts used in the study were found, giving a brief description of each. It also defines effigy artifacts, describes some of the decorative methods used, and some of their history.

In Chapter 5, the two sets of hypotheses for the social transmission methods are set forth, the first half concerning the transmission of information between individuals/groups. The three sets of hypotheses, vertical, horizontal, and oblique are defined, with expectations. The hypothesis for horizontal is divided into two separate hypotheses: one for unlimited interaction, the other for limited interaction.

Chapter 5: Hypothesis

This chapter lists the two sets of hypotheses to be tested and the question(s) we are seeking to answer. The first question, "How was information concerning effigy form and/or shape and decoration transferred?" is the subject of the first set of hypotheses. The second question, "Can we, through changes in effigy artifact form and/or shape and decoration, track major changes in sociopolitical and religious ideologies?" is dealt with by the second set of hypotheses.

To test the first set of hypotheses, data will be taken from each of the groups and placed into a matrix as either being present (1) or absent (0). The matrix will then be analyzed in R/RStudio, and the results then examined, both in a phylogenetic tree and a heatmap. Although numerous trees may be produced, only one heatmap is produced because the item/artifact, etc., is either present or not.

Hypothesis H1: Vertical transmission

Hypothesis H1 looks at vertical transmission—the exchange of information between parents and children or teacher and student—and how it plays out among the various ceramic types found in the PHASNM. It tests whether information passed via vertical transmission would tend to stay within the originating group, with the students/apprentices' introducing errors when they participated in the manufacture of effigy vessels. These kinds of errors result from the copying of a character or design incorrectly and at random, thereby creating a new symbol variant and setting up the possibility that the variant will be passed on, proving heritable continuity of the modified form (i.e., artifacts that are stylistically similar) (Eerknes et al. 2006); (Eerkens and Lipo 2005); (Lyman 2000). If kept exclusively within the originating group, heritable continuity would be traceable but restricted. This lack of diffusion outside the originating group should be empirically identifiable and thus an elegant test of the vertical transmission model.

Hypothesis 1 H1:

Each ceramic type, restricted in distribution by method of transmission, will show design patterns in line with vertical transmission between parents and children or masters and apprentices. Within a Type (horizontal peer-to-peer) or among Types (oblique peer-to-peer) all taxa will appear on branches. The resulting tree, however, could be a polytomic tree (which means many temporal based branches (Green 2013), where evolutionary relationships cannot be fully resolved.

Expected Supporting Evidence for H1:

- Distribution of designs will be restricted to specific Types within Wares.

Hypothesis 1-H2: Horizontal transmission

Hypothesis 1-H2a: Horizontal transmission scenario No.1 Unlimited interaction

Hypothesis H2a, based on Rogers's model of innovation diffusion (Rogers 1983), establishes a basis for social learning in which individuals encounter a wide range of attributes related to the item of interest and then adopt those allowing for the quickest, most-economical methods of production and distribution (Eerkens et al. 2006). Horizontal transmission allows for the transmission of information among peers, either from within the individual's Type or through other Types found within Wares composing a Tradition. Designs would be shared when individual potters interact with each other, including at trade events, and they would take the designs and change them to fit local customs and values upon returning home. Unusual designs would be found in limited numbers, while changed but identifiable replicas would be localized within the adopting ceramic group.

Hypothesis 1-H2a:

Restricted in distribution, Types will show design patterns in line with horizontal transmission, where information among peers is transmitted horizontally, either from within the individual Type or from interactions with individuals from other Wares or Traditions. Branching may be shown within a single Ware group or among Ware groups within a single Tradition, or among Traditions within a single Culture.

Expected Supporting Evidence for H2

- Distribution of designs will extend from Types into Wares within a single Tradition, or among Traditions within Branches but not among Cultures.

Hypothesis 1-H2b: Horizontal transmission scenario No. 2, interaction within group only

H2b, also based on Rogers's model of innovation diffusion (Rogers 1983), states that individuals encountering a wide range of attributes of interest adopt those attributes that allow for the quickest, most-economical methods of production and distribution (Eerkens et al. 2006). Horizontal transmission, also known as conformist transmission, allows for the transmission of information among peers, either from within the individual's Type or from interaction with peers from other Types found within Wares.

Hypothesis 1 H2b

Restricted in distribution, Types will show design patterns in line with horizontal transmission, where information among peers is transmitted horizontally, either from within the individual Type or from interaction with peers from Types within the Ware. Peers are members of the same generational group, either as teacher/student or person/person). Branching may be shown both within a single Ware group or among Ware groups within a single Tradition, but not among Traditions or Cultures.

Expected Supporting Evidence for H3

- Distribution of designs will extend from Types into Wares within a single Tradition, but not among Traditions.

H3. Oblique transmission

Hypothesis H3, oblique transmission, examines the introduction of ideas by adults or by institutions with hierarchical systems, including elite or power-based, either within an existing Tradition or externally into a receiving Culture (Jordan 2015). Periodically, influential cultural or sociopolitical groups would introduce new designs. These new designs, based on previous ones and thus evincing descent with modification, would be passed among the various Traditions. They would not be restricted to specific areas but would be diffused across regions, primarily along trade routes. Potters in villages along the trade routes would share the same or similar designs, without notable modifications, for local use.

Hypothesis 1 H3:

Unrestricted in distribution, Traditions will exhibit design patterns in line with distribution by oblique transmission, where knowledge is spread by individuals with an assigned status, i.e., potter or tradesman. New designs/motifs will be shared by all cultures. Branching will be shown among Types within Wares and Traditions, and among Branches/Cultures.

Expected Supporting Evidence for H4

- Distribution of symmetry and design ideas will extend from individual Types through Branches into Cultures.

Null hypothesis

Null hypothesis 1 H4: extensively blended and thus unrecognizably patterned.

The null hypothesis, H4, examines the extensive blending and sharing of ideas that result from the unrestricted introduction of ideas by adults or institutions into a receiving Tradition (Jordan 2015). New designs are introduced via cultural or sociopolitical influences, and over time are diffused across all regions, primarily along trade routes. Potters in villages along the trade routes would share the same or similar designs throughout all Branches, without notable modifications, for local use.

Hypothesis 1 H4

Within unrestricted distribution, ceramic artifacts will show design patterns in common with unrestricted transmission, where information among groups is transmitted through interactions with other Traditions/Cultures. Branching will show extensive blending and sharing among Traditions/Cultures, thus producing patterns that cannot be readily recognized.

Expected Supporting Evidence for H4

- Distribution of symmetry and design ideas will be unrestricted, and analysis will reveal extensive sharing and blending of forms and motifs, making it difficult to decide the origin of the form or motif.

Hypothesis 2: Tracking major changes in sociopolitical and religious ideologies.

Despite significant geographic distances, Van Pool et. al. (2000, 2006) and Harmon et al. (2006b) argue that a historic relationship exists among the designs and decorations on ceramic vessels made by the Mogollon-Mimbres, the Northern and Southern Jornada, Casas Grandes, and Middle Rio Grande Traditions (Harmon, et al. 2006) of the American Southwest and Northern Mexico. The images found on samples from the different geographical areas exhibit designs that closely resemble each other. The researchers also argue that significant changes in designs reflect major social events. This suggested historic relationship is the inspiration for Hypothesis 2.

In describing a situation in which historic connections exist, Hypothesis 2 argues that ceramic designs stand as recipes for ideas that change as they reflect local responses to ongoing transformations in sociopolitical conditions. Hypothesis 2 examines the idea that connections among Cultures in the PHASNM are historic and that modifications in ceramic symmetry/design/decoration correspond to major social events by testing the likelihood of their relevance to major social fluctuations through the phylogenetic analysis of these modifications.

The coherent groups of common motifs/themes and the relationships of congruence among them within Types and Wares as defined by symmetry/design analysis will be subjected to phylogenetic analysis to establish any historic relationships among them.

Oblique transmission would occur during transitional phases, i.e., Pueblo 1 to 2 for the Anasazi, and ideas from external sources would progress along trade routes within an area, exposing local settlements to these new concepts. Local inhabitants would assess the new ideas ranging from architecture and agriculture to ceramics, and they would accept some and reject others. Washburn (1978) hypothesized that if potters in different locales were able to communicate with each other via trade, a "cross-fertilization of design ideas occur[red]" (Washburn 1978), and the designs produced would be similar in structure and composition. This transmission of ideas would allow the adoption of ceramic designs believed to be relevant to the local community's beliefs and values (Rogers 1983).

As different symbols and forms were introduced, local potters would evaluate (Washburn 1978; Zedeño (1998) the newly introduced ideas (information) considering the local community's customs, beliefs, and values, and select those of interest and discard the rest (Rogers 1983). Those selected would then be adapted for use in decorating local ceramics, including ceramic effigy artifacts. The development of these similarities over time would allow the demarcation of social progress and result in observable changes.

As shown by Zaslow and Dittert (1977), within the Hohokam area, this pattern of evaluation and incorporation resulted in continuity and evolution of design from ca. A.D. 200 until ca. A.D. 1450. Washburn et al. (2010) found that ceramic design in the Puebloan American Southwest changed in A.D. 900 and again in A.D. 1300, the result of changing values and beliefs within the local community. Because of the inheritability of the modifications and the fact that each separate community had its own set of beliefs and values, the movement, adoption, and subsequent modifications are heritable and should provide a strong phylogenetic signal (Collard et al. 2006; Harmon et al. 2006a, 2006b; Marwick 2012; O'Brien and Lyman 2003).

In addition to trade, the influx of new populations would also introduce new design systems. These designs, composed of forms and symbols, would reflect the culture of the migrating population (Adams 1996). This hypothesis is related to the transition of the Hohokam to Salado culture because of the influx of people into the Hohokam area from outside.

Hypothesis 2 H1

Major cultural and/or sociopolitical events will affect the design of ceramic effigy artifacts. These changes are reflected in the design of the decorations found on the ceramic artifacts and will coincide with ethnographic data concerning transitional phases.

Expected Supporting Evidence

- Changes in archaeological styles/designs will correspond to ethnographical data associated with transitional periods within Branches/Traditions.
- Ceramic effigy artifact designs will be temporally discernible and show continuity in overall designs, reflecting changes in community values and beliefs, i.e., changes resulting from the shifts from pithouses to single-story pueblos and then to multistory pueblos. Changes in branch structure regarding artifact/motif designs replicate those of sociopolitical groups.
- Branching among Branches and/or Traditions showing common ancestral nodes will be present, and the nodes will be identifiable as temporal points when the influx of new cultural or sociopolitical influences occur**.**

Null Hypothesis 2 H1 extensively blended and thus unrecognizably patterned.

Major cultural and/or sociopolitical events will have no noticeable influence on the ceramic effigy artifacts. Changes reflected in the design and symmetry of the decorations found on the ceramic artifacts will be the result of information sharing and oblique peer-to-peer transmission. These changes will not coincide with ethnographic data concerning transitional phases.

Expected Supporting Evidence

- Designs will be similar in appearance.
- Evidence of oblique transmission (peer-to-peer transmission), i.e., among potters or tradesmen, will be visible. Branching will occur among all Branches, Traditions, and Cultures.
- Distinct signals referring to a specific group will not be readily available, as blending and sharing of information will distort the signal.

In this chapter the questions and hypotheses have been set forth. In Chapter six, we examine the methods that will be used to examine the data that are discussed.

Chapter 6: Methods

The data obtained from the samples compiled for this study was examined by several different computer programs using different methods to determine if phylogenetic relationships are present. These programs, SplitsTree, R/RStudio, and MetaPIGA, used different mathematical models to determine the relationships. SplitsTree is a Splits Network Algorithm and R/RStudio—UPGMA and MetaPIGA—tests maximum likelihood.

Table 2 shows the hypothesis, test expectations, and analytical procedure used to test for the result.

Although phylogenetic trees are useful, the same set of data can be produced numerous trees. Binary heatmaps, for example, show a clearer picture of the data—either it is present (1) or not (0). This is useful as a basis for narrowing down the number of trees to be considered. Thus, it seems reasonable to use several different methods to examine the data.

To assess the degree of transmission among the twenty-one major ceramic Traditions, the Traditions must be broken down into their component parts, Wares. If a strong branching pattern appears within the resulting phylogenetic tree(s), there is a high probability that the information transfer is vertical in nature. Using what Shennan (2001) calls the “simple model,” we will examine data to determine the amount of vertical transmission within each individual Type.

HYPOTHESIS	TEST EXPECTATIONS	ANALYTICAL PROCEDURE(S)
Hypothesis 1 -- Social learning hypotheses		
Vertical transmission	Distribution of designs will be restricted to specific Types within Wares.	Phylogenetic tree Heatmap
Horizontal transmission scenario No.1 Unlimited interaction	Distribution of designs will extend from Types into Wares within a single Tradition, or among Traditions within Branches but not among Cultures	Phylogenetic tree Heatmap
Horizontal transmission scenario No. 2 interaction within group only	Distribution of designs will extend from Types into Wares within a single Tradition, but not among Traditions.	Phylogenetic tree Heatmap
Oblique transmission	Distribution of symmetry and design ideas will extend from individual Types through Branches into Cultures.	Phylogenetic tree Heatmap
Null hypothesis-- extensively blended and thus unrecognizably patterned.	Distribution of symmetry and design ideas will be unrestricted, and analysis will reveal extensive sharing and blending of forms and motifs, making it difficult to decide the origin of the form or motif.	Phylogenetic tree Heatmap
Hypothesis 2 -Tracking major changes in sociopolitical and religious ideologies		
Oblique transmission— Major cultural and/or sociopolitical events will affect the design of the ceramic effigy artifacts.	Changes in archaeological styles/designs will correspond to ethnographic data associated with transitional periods within Branches/Traditions.	Phylogenetic tree Heatmap
Null Hypothesis—extensively blended and thus unrecognizably patterned.	Designs will be similar in appearance. Evidence of oblique transmission (peer-to-peer transmission), i.e., among potters or tradesmen, will be visible. Branching will occur among all Branches, Traditions, and Cultures. Distinct signals referring to a specific group will not be readily available, as blending and sharing of information will distort the signal.	Phylogenetic tree Heatmap

Table 2 —Hypothesis expectations

Analytical Methods

In the previous chapter, the questions related to this study as well as the hypotheses to be tested were laid out. In this chapter, the methods to be used to analyze the data will be discussed. As in any study, various software packages will be used to analyze the data collected from the effigy artifact images. The images were analyzed using Visual Object Tagging Tool (VoTT) and YOLOv5, both of which are covered in Chapter 7.

The analysis of the data obtained by vision analysis was performed using the software packages SplitsTree5.0.0_alpha (D. H. Huson 1998; Huson and Bryant 2006), and R (R. C. Team 2021: version 4.1.1 (2021)) running in RStudio (R. Team 2021 Version 1.4.1717), and MetaPIGA 3.1 (Milinkovitch and Helaers 2011). The methods used for the phylogenetic portion of the study were the same for each of the categories—Culture, Branch, Tradition, Ware, and Type—and they were specific to the software packages.

SplitsTree5 5.0.0_alpha (Huson and Bryant 2006; D. Huson 1998)

The SplitsTree program uses the following methods to obtain a phylogenetic tree:

- The Hamming Distances method (Hamming 1950)
- The Neighbor Net method (Bryant and Moulton 2004)
- The Splits Network Algorithm method (Dress and Huson 2004)
- The UPGMA method (Sokal and Michener 1958)
- The Tree Embedder method (Huson et al 2012)

By using the Hamming Distances method, the distance matrix is created from the data. The method examines two strings of equal length and returns with information about the number of positions needed to differentiate one sequence from another or where corresponding characters in each sequence differ. The Neighbor Net method is used (default options) to obtain a splits graph that is composed of a collection of weighted splits. Each split corresponds to a collection of equal parallel edges. Removing the edges corresponding to a given split A|B partitions the network into two connected parts, one holding the taxa in A and the other containing the taxa in B (Bryant and Moulton 2004). Based on the Saitou and Nei Neighbor-Joining (NJ) algorithm, this method enables the creation of detailed networks. The Splits Network Algorithm method (Dress and Huson 2004) was used (default options) to obtain a Splits Network with nodes and edges. The UPGMA method (Sokal and Michener 1958) was used (default options) to obtain one tree. The Tree Embedder method (Huson et al 2012) was used (default options) to obtain a rooted tree drawing.

R and RStudio

R (a free software environment for statistical computing and graphics (R. C. Team 2021)) and RStudio (a free integrated development for R (R. Team 2021)) were used to explore phylogenetic data using a number of different packages. Among these are: analysis of phylogenetics and evolution (Paradis and Schliep 2019) that can read, write, plot, and manipulate phylogenetics data (Toparslan et al. 2020); ggtree, an R package for visualization of tree and annotation data (Yu et al. 2017); and ggpubr (Kassambara 2022). Using these packages and others, phylogenetic trees were produced, compared, and then plotted. The same data was used to create heatmaps showing the specifics of trait relationships among groups.

Other statistical packages used in the analysis were:

- Phangorn for Phylogenetic Reconstruction and Analysis: (Schliep et al. 2017; Schliep 2016)
- hclust: Hierarchical (Schliep et al. 2017; Schliep 2016) (Legendre 2012)
- Tidyvers: (Wickham et al. 2019)
- readr to Read Rectangular Text Data: (Wickham et al. 2022)
- phytools: (Revell 2012)
- ggdendro: (de Vries and Ripley 2020)
- Stats-package: (R. C. Team 2021)
- strap: (Bell and Lloyd 2014)
- stats: (heatmap()) (R. C. Team 2021)
- ggplot2: (Wickham 2016)
- Phylosignal: an R package developed by Keck et al. (2016)

The packages above were loaded into the R environment in RStudio. The first eight were used to analyze the data obtained from the vision analysis program for phylogenetic analysis. Ggtree and GGplot2 was used to draw the resulting phylogenetic trees and, in conjunction with phylosignal, to draw the outcome of the phylogenetic signal tests.

The heatmaps obtained using heatmap() in the stats package from the vision analysis program were also plotted using GGplot2. Final graphics were created using ggpubr.

MetaPIGA 3.1:

MetaPIGA-3.1 is designed to implement, under maximum likelihood, several stochastic heuristics to allow for the analysis and interpretation of large phylogeny. Designed for the biological sciences to handle nucleic-acid and protein datasets, it has been used with success in other areas such as archaeology, where morphological (presence/absence) data is common (Helaers and Milinkovitch 2010; Lemmon and Milinkovitch 2002).

Using the metapopulation Genetic Algorithm (metaGA), the heuristic for the analysis of data is defined as MetaPIGA. In this approach, trees are exposed to mutation events, evaluation, and selection (selection scheme set to improve; and then recombination set at 10%). P sets (populations) of 1 tree each (individual) are forced to collaborate in the exploration for optimal trees. At each phase or new generation, trees are mutated according to rules governing inter-population consensus. Under the selection scheme “improve,” as individual trees fail the test, they are discarded, and the current best individual replaces them. Within the recombination scheme (a large number of simultaneous topological mutations), individuals failing the test have a probability (10%) of recombining with a better individual to be included in a new tree (Milinkovitch and Helaers 2011).

In addition to metaGA, consensus pruning (CP) was used. If CP is used in a metaGA search, the differing populations must exchange topological information. Thus, generational runtime completion is determined by the slowest population (Lemmon and Milinkovitch

2002). The principle behind CP is that before an individual tree is mutated, a comparison of its topology must be made with that of the best trees in other populations. In addition, the program uses Stochastic CP *(as a default)* where topological mutations affecting a given branch are rejected with a probability proportional to the percentage of all trees across all populations that agree on that branch. CP provides the frequencies of internal branches shared among trees across populations, and it also indicates whether the populations converge toward a stable set of solutions, *i.e.*, towards a consensus with stable branch frequencies. Hence, CP provides a stopping rule not available to other heuristics (Lemmon and Milinkovitch 2002).

This chapter has examined the software programs and procedures used to analyze the data obtained from the vision recognition programs and to equate which procedures will be used to evaluate the data to determine which hypothesis is applicable.

In Chapter 7 we explore vision recognition analysis of data and how it is applied to the study of ceramic effigy vessels. We start with a general history of the subject, then look at the labeling process and the vision recognition program itself. The chapter concludes by addressing the study itself.

Chapter 7: Vision Recognition Analysis of Data

Archaeologists, working by hand, classify many of the found artifacts in archaeology. To be done accurately, this requires both skill and knowledge. Because levels of proficiency vary widely among individuals, some archaeologists are turning to computers and vision recognition as a way of standardizing pattern recognition. This chapter briefly explores computer vision recognition's background, the programs that make it work, and how it is used in an archaeological study. It takes a lot of time to acquire the skill to accurately identify an artifact or parts of an artifact. Computer vision recognition, which can be trained to do the job in hours rather than years, can work more efficiently and accurately. YOLOv5 has achieved a 99.3% average precision rate and has been able detect items in real time with a high accuracy rate (Liu et al. 2021).

Because of the high accuracy rate provided by computer vision recognition programs when used with properly tagged training images, the time required to analyze a large dataset is greatly reduced. To do a search by hand for each of the traits in this study would take an average of 10 minutes or so per image resulting in a search time of approximately 145 hours or over 18 eight-hour days.

The sample dataset used in this study contained a total of 361 artifacts from 90 different Types. The artifacts were represented by 871 images. A search for 230 different traits was performed on these images.

Out of the 871 images, Yolov5l found targets on 283 images. Although numerous images received multiple hits, those images that did not contain one of the targets (i.e., were plain pottery) would be counted as correct but were not included in the target count. Total analysis time was 53.140 seconds.

General history of vision recognition programs

In the early days (circa 1960s), Larry Roberts and his colleagues at the Massachusetts Institute of Technology (MIT) (Huang 1996) attempted to make computers mimic human vision. They first applied their efforts to blocks, but they were only able to extract 3-D geometrical data from 2-D views (Huang 1996). As their experience grew and advances were made in automating image analysis, they developed methods to observe and report data (Jirbandey 2018).

In 1978, David Marr of MIT used a bottom-up approach to scene understanding, creating a "primitive sketch" using 2-D images and low-level processing algorithms. The sketch can be viewed from two different angles (binocular stereo vision) (Dyer), thus creating a 2.5-D image. By processing the 2.5-D image with high level methods (structural analysis, reasoned knowledge), Marr created objects within the image in 3-D (Huang 1996). Although Marr's paradigm was important, it was also difficult to implement, and for practical purposes, a complete 3-D representation was unnecessary. "Purposive Vision" replaced Marr's paradigm, based on goal driven and qualitative algorithms (Huang 1996).

The largest current applications of computer vision are in the fields of Automatic Vehicle License Plate Recognition (ALPR) and facial recognition. ALPR (Hendry and Chen 2019) has numerous applications in the transportation and law enforcement fields, where, after a license plate is detected, it is placed within a bounding box[6] on the image being analyzed. Using character-based recognition, a 98.22 percent accuracy rate was achieved in plate detection and a 78 percent accuracy rate in plate recognition (Hendry and Chen 2019:55). On November 3, 2017, Apple introduced another application for computer vision with Face ID on its iPhone X (Vigliarolo 2020). This advanced computer vision application uses biometric technology to analyze the over 30,000 individual dots created on the owner's image to create a mathematical model (Support 2020); it's used the same way other vision programs use bounding boxes.

Image recognition in archaeology

With each passing day, the use of image recognition or computer vision is increasing in the field of archaeology. The majority of its applications to date have been for the 3-D processing of artifacts. Di Angelo et al. (2018) suggests a method of pottery fragment analysis that allows for a 3-D representation of a vessel made from the fragments. H'roura et al. (2019) applies a similar approach to bone recognition for zooarchaeology, and Bevan et al. (2014) applies computer vision to reconstruct 3-D images of the famous Chinese terracotta warriors.

Leitao and Stolfi (2002) developed a two-dimensional method for the reassembly of fragmented objects such as ceramic sherds to allow for the recombination of fragment lines using the highest probability that they originally were adjacent. Karasik et al. (2004) used the analysis of ceramic curvature to classify pottery. Although no improvement in classification was obtained, the analysis did retain information about increasingly complex profiles over time (Maaten et al. 2007). Eramian et al. (2017) applied image recognition to the analysis of bifacial lithic artifacts to create a search-and-retrieval system based on archaeologically significant characteristics. Computer vision techniques may also be useful for the indexing and retrieval of collections (Arifoglu et al. 2015).

Archaeologists have rarely employed shape-based analysis. Two papers describe how archaeologists used computer image recognition to track patterns. A study of Maya Glyphs done by Roman-Rangel et al. (2011) used the analysis of Maya syllabic phonetic signs (syllabograms) as shape-based descriptors, and in 2015, Arifoglu et al., used computer image recognition for both sequence and graph matching to identify Kufic scripts. These archaeologists found that these methods worked better than simple character recognition; however, its ability to identify and track changes in the design of motif patterns was limited.

How computer vision is done

Using Local Binary Patterns (LBP), a circular area is defined around each pixel that has a finite range of values. Makridis and Daras (2012)) applied image recognition to classify pottery sherds using local color- and texture-based features. In Makridis and Daras' method,

[6] The coordinates of the rectangular border surrounding the object being detected.

intensity values are either 1 or 0 for neighboring pixels, depending upon whether they are higher or lower than the original center pixel intensity. Calculation of the center pixel's LBP value is based on the number of changes among the ones and zeros around it. Their method also uses the Reddi Multithresholding Bag of Words method (BoW), where image descriptions, features, and frequency are clustered into a discrete fixed vocabulary. By using this, they were able to create a histogram of the words to represent images. Experimental results demonstrated that their method was efficient.

Setting up your database

The components needed to use vision recognition to study artifacts are:

- Vision recognition program
- Image tagging program
- Images for training the program
- Sample images for analysis.

For the vision recognition program to be able to learn and find specific features on the sample images, the program must be able to identify the specific features on training images. The more precisely the features are tagged, the better the results.

As with vision software, there are numerous image tagging programs to pick from. Also as with the vision software, three of the main criteria used were open source (free); speed and efficiency; and ease of use.

1. LabelImg, written in Python, does a respectable job; however, difficulties were encountered with the number of images it was able to tag.

2. Ybat is open source (free to use), fast and efficient, but not intuitive to use.

3. VGG Image Annotator is also open source (free to use), fast and efficient, but not intuitive to use.

4. Universal Data Tool (UDT) is open source (free to use), fast and efficient, but also not intuitive to use.

5. Microsoft's VoTT. It fulfilled all three of the criteria, allowing specific features on sample images to be labeled and the results to be saved with ease.

Image labeling

There are three ways to import images to create a collection of unlabeled images as a dataset for the labeling system:

- Bing Image Search,
- Azure Blob Storage,
- and from a local drive.

To use images stored on a local drive with VoTT, it is necessary to download the VoTT Installer. Because of problems with VoTT 2.2.0 (fatal crashes), VoTT 2.1.0 (for Windows) was used.

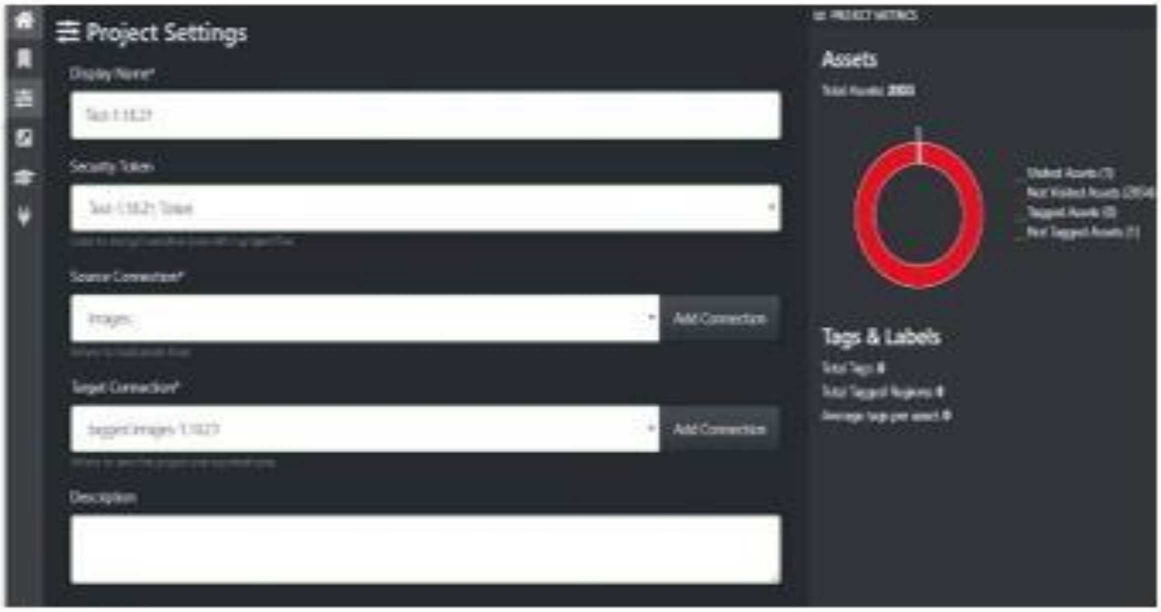


Figure 13 Project settings page in VoTT

Figure 12 Connections setup page

Figure 15 Export settings page VoTT

Figure 14 Tagged motifs on sample image

Setting up connections

When working with VoTT, the first step is to create the project in the project settings page. Figure 9 shows the settings page. Click on the slider icon on the left side of the page. Here, there are places for the display name of the project, a security token and source (\Training_Images) and a target image (\YOLOv5\Images) connections. Researchers insert the location of their data. On the project settings page, there's also a section for project metrics and for a list of tags to use.

To set up a source connection, click on "add connection" on the project settings screen on the right side of the source connection bar. This opens another connection settings page (Figure 10), where researchers can enter the source connection display name, a description, and a provider—Azure Blob storage, Bing image search, or their local file system—and then save the connection. A list of connections will be shown on the left side of the screen.

Once the source connections have been set up, researchers can follow the same procedure to set up the target connections. Clicking on the box with the arrow below the slider will take them to the export settings page (Figure 11). Found here are the file-type options used to export the data. These include Azure Custom Vision Service, Microsoft Cognitive Toolkit (CNTK), comma separated values (csv), PascalVOC, Tensorflow Records, and VoTT-json.

The export settings page allows researchers to decide which assets VoTT will export: all assets, only visited assets, or only tagged assets. The researchers can also decide whether to include images in the export and how the ratio of test to train images is set.

Labeling images in VoTT

After collecting and placing images relevant to the study in a folder, the images are imported into the labeling program. In VoTT, the image to be tagged is outlined by a rectangular box or a freehand polygon (Figure 12). The images to be labeled are on the left side of the screen, and the list of tags is on the right.

Converting from VoTT to YOLOv5

After individual motifs are tagged in each of the training sample photos using VoTT, both images and label information (Labelmap.txt) are uploaded to Roboflow (Roboflow.com 2020), where they are converted to and then exported in YOLO format. Although VoTT and Roboflow support several formats, YOLO uses a labels.txt file to link numeric classID to a class name (Solawetz et al. 2020). The text label file contains one row for each object labeled within the image, and it consists of the object class, its x_center, y_center, width, and height. The values range from 0 to 1 (Agarwal 2020).

After downloading and installing the chosen programs, a dataset of training images is created through a Google image search for effigy vessels or whatever is being studied, and then the images are downloaded from the internet. Locations where images may be found vary from small private collections to online university and museum collections. After collecting and assembling the dataset, the images are imported into the image-labeling program. The tags (labels) for target items within images are created using best practices (Jacob Solawetz 2020). Once completed, the saved tagging data is translated into YOLO format. Running the data through YOLOv5 (train.py) creates a file to be run in YOLOv5 (detect.py). The results are then examined for accuracy.

Choosing a vison recognition program.

With the advent of open-source computer vision software (OpenCV, SimpleCV, and Tensorflow) and computer image recognition software, researchers no longer need to write all their own algorithms. Each of the models shown in Appendix B will do an acceptable job of recognizing and detecting targets on images. The main criteria for selection were open source (free to use); speed and efficiency; and ease of use. After examining several of the choices (ResNet, R-CNN, MobileNet, and YOLO), the decision was made to use a member of the YOLO family because it met the three criteria.

You Only Look Once: the history and development of YOLO

YOLO versions 1, 2, and 3 did not meet the criteria outlined above. YOLOv5 was chosen because it fulfills those criteria, and it allows for the use of a Graphics Processing Unit (GPU). YOLOv5 is an evolving program, regularly making advances in both speed and accuracy.

Created for simplicity and speed, the YOLO vision model has developed rapidly over the past several years. From the original version, developed by Joseph Redmon (Redmon et al. 2016), it has evolved through several models, each with improvements, to the version used in this study, YOLOv5.

YOLO or YOLOv1

When first introduced by Redmon, YOLO was an innovative approach to object detection based on Darknet, a custom framework for CV (Jacob Solawetz 2020). Earlier, researchers had repurposed classifiers to perform object detection. YOLO, by treating object detection as a regression problem, analyzed full images through the use of a single neural network, predicting bounding boxes and class probabilities in a single evaluation (Redmon et al. 2016: 779). YOLO is simple in construction, giving it several advantages over earlier object detection programs. It is extremely fast in execution; it sees the entire image, allowing it to encode information about both classes and appearance; and it learns generalized representations of objects (Redmon et al. 2016:780). On the downside, YOLOv1 could only detect 49 objects with a relatively high localization error rate (Kamal 2019)

YOLOv2

Using the original YOLO as a basis, YOLOv2 contains several improvements over its predecessor. By adding BatchNormalization, performance was improved, resulting in a 2 percent increase in mean Average Precision (mAP) (Kamal 2019). YOLOv2 uses a high-resolution classifier that increases mAP by approximately 4 percent by adjusting resolution from 224x224 to 448x448 during initial training before detection training, allowing the network to adjust to the higher resolution input) (Kamal 2019). Another innovation was the inclusion of "convolutional with anchor boxes" or multi-object prediction within a single grid cell (Kamal 2019). YOLOv2 accomplished this by using k-means clustering to determine the value of k, plotting the average Intersection over Union (IoU), and using it to determine the distance between the bounding box and the centroid (Kamal 2019). Other changes included network architecture (Darknet-19); output shape; training (classification first, then detection); and multi-scale training (Kamal 2019).

YOLOv3

Based on YOLOv2, YOLOv3 is a bit bigger and faster, but it's more accurate. By predicting four coordinates for each bounding box (Kamal 2019), YOLOv3 creates a bounding box objectiveness score using logistic regression. By adding more connections to the backbone network layers and using three separate granularity levels, its performance in the detection of smaller objects was improved (Redmon and Farhadi 2018; Jacob Solawetz 2020).

YOLOv4

Fairly new to the YOLO family, YOLOv4 is designed to do real time detection using a single GPU for training (Jacob Solawetz 2020).

YOLOv5

Like the previous versions of YOLO, YOLOv5 is an object detection model. It is trained to look at an image, search for a subset of an object class (Jacob Solawetz 2020), and, once an object class has been located, enclose it within a bounding box.

YOLOv5 Models

Four models are available in the YOLOv5 object detector:

YOLOv5s (smallest and fastest) with an Average Precision (AP) value of 36.8 with a speed of 2.2ms using a single GPU.

YOLOv5m (medium) with an AP value of 44.5 with a speed of 2.9ms using a single GPU.

YOLOv5l (large) with an AP value of 48.1 and a speed of 3.8ms (a little bit slower but more precise) using a single GPU.

YOLOv5x (extra-large) with an AP value of 52.3 and a speed of 6.0002ms (a slim 4.2 percent) increase in precision at an increase of 57.9 percent in processing time also using a single GPU.

Employing the YOLOv5l (large) model available in YOLOv5, the computer vision software was adapted to detect and identify the motifs or patterns that decorate the exterior of Southwestern effigy vessels after the image labeling was done in VoTT.

Explaining YOLOv5 metrics

The best way to know how well a project is going is to examine the metrics produced when running the data. This is most easily done through visual graphs. YOLOv5 produces several graphs that indicate the final test results. Figure 13 shows the graphic output, and Table 3 explains the terms graphed.

The IoU, also known as the Jaccard Index, quantifies how similar the ground truth bounding box is to the predicted bounding box, with scores from 0 to 1. The closer to 1, the closer the two boxes are to each other (El Aidouni 2019).

The precision shows the probability of how well the predicted bounding boxes match the ground truth bounding boxes (El Aidouni 2019). Scores range from 0 to 1, with the higher number showing that more detected objects match the ground truth objects. In the sample image in the results section of this paper, the precision ranges from 0.60 to 0.82.

Recall, which also ranges from 0 to 1, is the probability that ground truth objects are correctly detected. It is used to determine whether the model is guessing enough (Dwyer and Solawetz 2020).

Mean average precision (mAP) shows the average precision over several classes in the analysis. When using MS COCO, the mAP over different IoU thresholds (0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9, 0.95) with a step of 0.05 is shown by mAP@[.5, .95], averaging not only the AP (average precision) over all classes, but also including the average on defined IoU thresholds (El Aidouni 2019). For a more in-depth look at YOLO metrics, see El Aidouni 2019.

As shown in the figure above, the left side describes the graphs reflecting the metrics for each of the criteria used in training YOLOv5. The right side briefly explains the labels

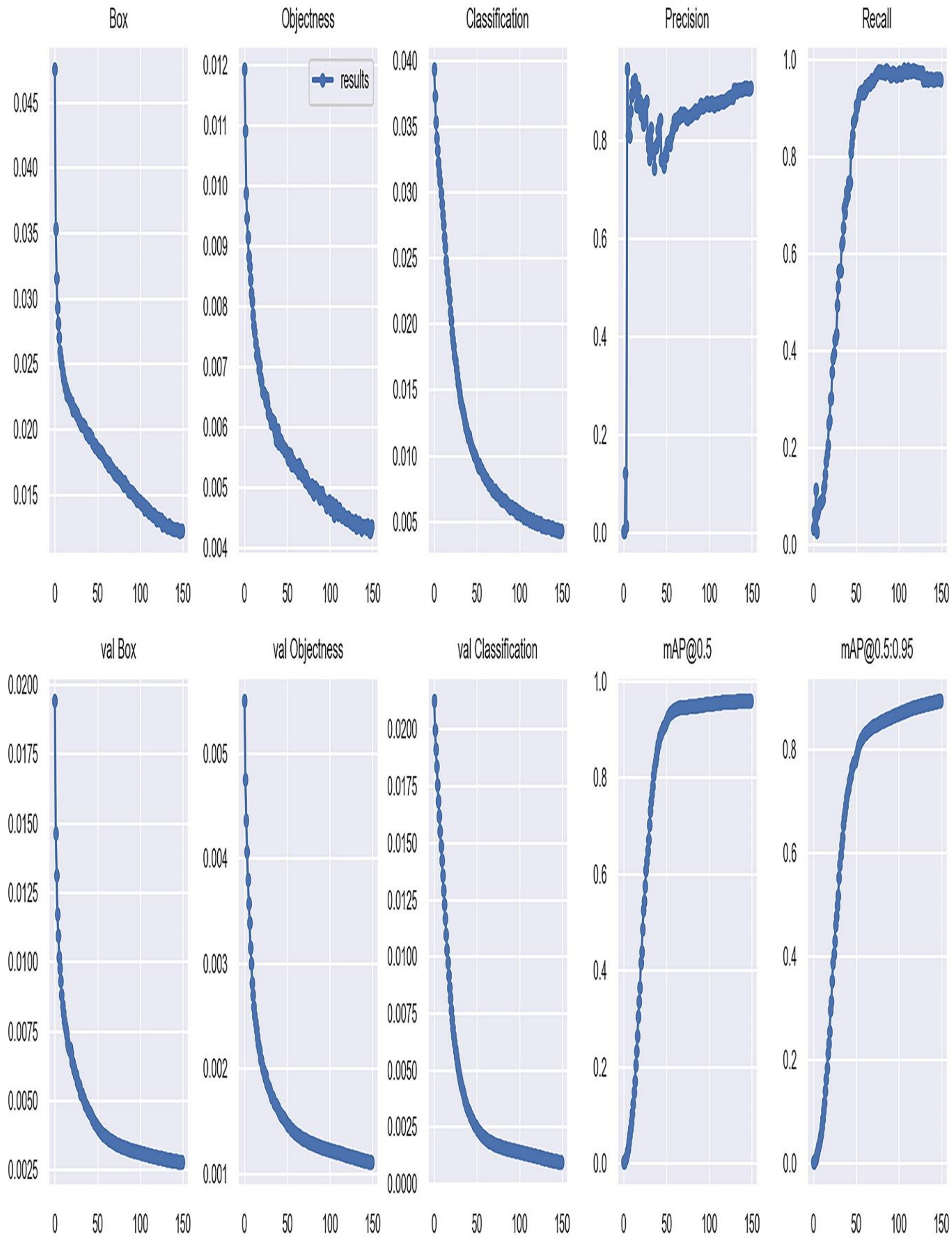


Figure 16 Graphic output data from YOLOv5

Glossary of terms	
Term	Explanation
GIoU	Generalized Intersection over Union is one metric used in comparing any two arbitrary shapes and creating an optimal bounding box based on average precision of the GIoU.
Objectiveness	The amount of certainty that a particular object is present in the bounding box.
val GIoU	is used to assess how well the model is generalizing the GioU.
val Objectiveness	is used to assess how well the model is generalizing objectiveness.
Classification	"A type of computer vision task that aims to determine only whether a certain class is present in an image (but not its location)"
Precision	A measure of how often a model guesses correctly when it does guess
val Classification	is used to assess how well the model is generalizing classifications.
mAP@0.5	Mean Average Precision
Recall	Measure of the ratio of true object detections to the total number of objects in the data set.
mAP@0.5:0.95	sets ten different IoU thresholds starting at 0.5 and increasing to 0.95 in steps of .05.

Table 3 Explanation of the terms in Figure 16.

for the graphs in the figure. These is some of the terminology connected with computer vision; for a more comprehensive list, see Dwyer and Solawetz (2020).

Specific attributes of ceramic effigy artifacts from cultures in the American Southwest were examined using YOLOv5l (large) because it most efficiently uses time and resources to develop accurate results. Being able to accurately distinguish among traits allows researchers to trace the temporal development of a particular trait within a specific culture and then to determine the extent of its spatial dissemination within a geographical area.

Dataset

The next step is to collect images for the training dataset. Using various keywords, i.e., effigy vessel, effigy artifact, Southwestern effigy vessels, etc. in a Google image search resulted in several thousand hits. From the image search, 554 images were selected. These images were then processed to enhance and modify features such as color, vertical and or horizontal flip, background color, and/or tint. These modifications resulted in a dataset containing 13,850 images.

By running Python in Miniconda3, Yolov5vl was set up for training. Using the 13,848 images in the dataset, the program was set to train for 150 epochs. After analyzing anchors, anchors/targets = 3.08 and the Best Possible Recall (BPR) = 0.9954, with images sized to 640x640 pixels, Yolov5l looked to identify 235 classes (labels) on the images in the training dataset. Yolov5l finished training in 96.947 hours. Weights to be used in the detection program were optimized and stored in the files last.pt—96.3MB, and best.pt—96.3 MB. Within the training session, the outcome was tested on an additional 79 images and validated on 159 more.

The output (weight files) from the training session were applied to the detect.py program (also run in Python using Miniconda3). The sample dataset analyzed consisted of 361 artifacts represented by 871 images. Out of the 871 images, Yolov5l found targets on 283 images. Although numerous images received multiple hits, those images that did not contain one of the targets (i.e., plain pottery) would also be counted as correct but not included in the target count. Total analysis time was 53.140 seconds. As seen in this chapter, computer image recognition shortens the time required for the analysis of data.

Within this chapter, the use of software to analyze photographic material was explored, and it was shown how it can be adapted to analyze archaeological artifacts. Details for tagging labels were given, and how to train and use YOLOv5 were discussed. The data provided in this step is the basis for the analysis done in the next chapter.

In chapter 8, data collected during the execution of the processes in Chapter 7 is analyzed using software programs SplitsTree, R/RStudio, and MetaPIGA with the results being displayed as phylogenetic trees and heatmaps. Phylogenetic signal is also investigated,

Chapter 8: Data Analysis

In this chapter, the relationship among traits/characteristics and Culture, Branch, Tradition, Ware, and Type are examined. Data collected from the analysis done by the vision recognition program provides the basis for the phylogenetic trees and for the heatmaps. Heatmaps show where items were and how they were distributed within groups: Culture, Branch, Tradition, Ware. and Type.

Because heatmaps use color-coded systems to present a graphical representation of data, they help visualize areas within the dataset that are the most important by emphasizing either the volume (or lack of volume). Using a binary heatmap (representing present with 1 and absent with 0) leaves little doubt as to whether the idea of a trait or item exists within the dataset. When used in conjunction with a phylogenetic tree, prior knowledge of the existence of and/or the amount of a trait helps to narrow down to the phylogenetic tree that best represents the data.

Later in this chapter, we examine the results of phylogenetic analysis of the data gathered from the image analysis using YOLOv5. After the data were placed in Microsoft Excel (Excel 2022), and broken down into subgroups from each of the groups—Culture, Branch, Tradition, Ware, and Type—the number of motifs found in each were tallied. Culture incorporates the widest range of motifs but the least number of entities (Fremont, Patayan, APGURGV, the Hohokam, the APGM, and APSCPA (Anasazi). The total number of motifs analyzed within a Culture are the compilation of all the samples found within all the Types related to the Culture. The number of motifs/characteristics for each of the other groups—Branch, Tradition, and Ware—are tallied in the same way. Table 3 shows the abbreviations used to conserve space in the following graphs and charts.

Culture	Abbreviation
Ancestral Pueblo: Greater Mogollon	APGM
Ancestral Pueblo: Greater Upper Rio Grande Valley	APGURGV
Ancestral Pueblo: Southern Colorado Plateau (Anasazi)	APSCPA
Fremont	Fremont
Hohokam	Hohokam
Patayan	Patayan

Table 4 – Abbreviations for Culture groups in heatmaps

Figure 17 shows the popularity of various motifs/forms by the number of times Yolov5l identified the object.

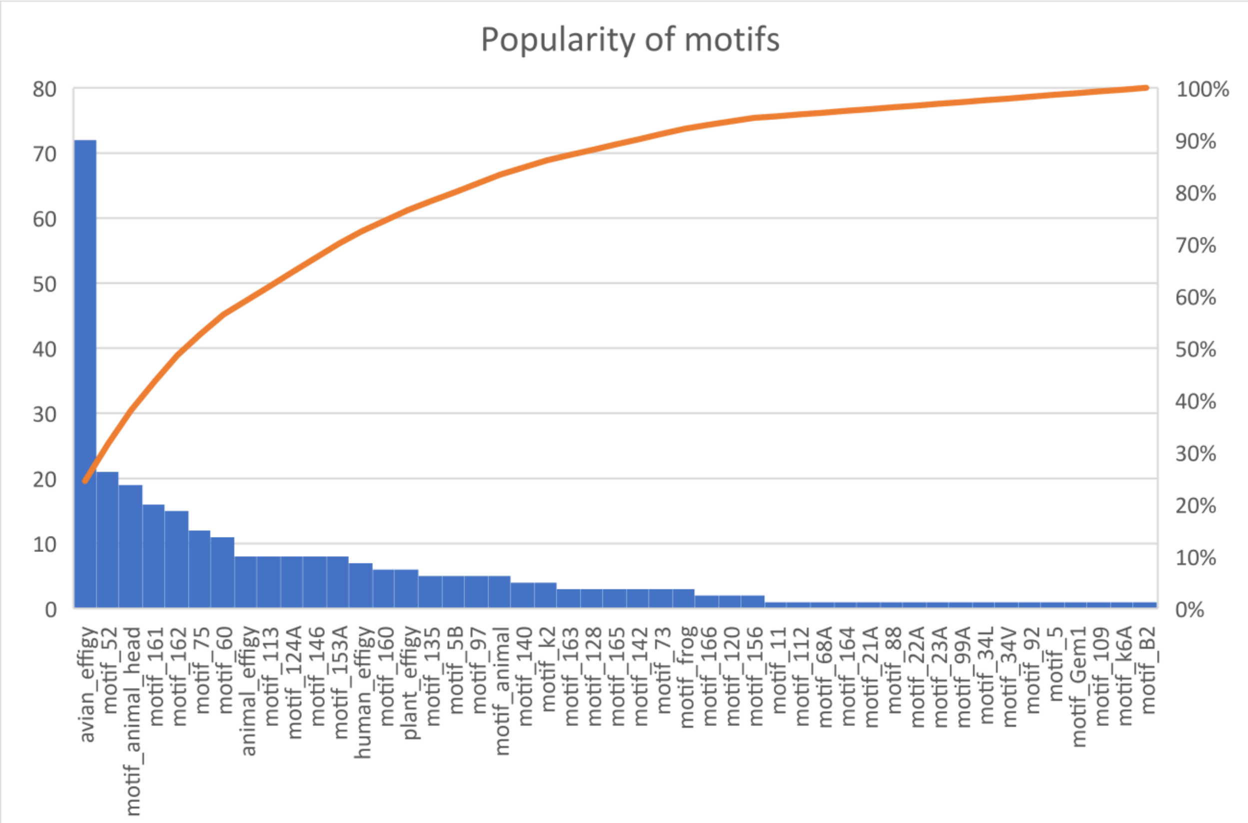


Figure 17—Popularity of motifs as found by YOLOv5l.

The data were placed in Microsoft Excel (Excel 2022), each of the groups—Culture, Branch, Tradition, Ware, and Type—was broken down into subgroups, and the number of motifs in each was tallied. The total number of motifs analyzed within a Culture is a compilation of all the samples found within all the Types related to that Culture.

Culture	Avian	Animal	Human_ Figurine	Human_ Vessel	Human_ Handle_ Scoop	Plant	Fish	Snake
APGM	29	21	1	46	0	1	1	0
APGURGV	3	0	0	0	0	0	1	0
APSCPA	3	44	0	3	1	2	0	1
Fremont	1	0	11	0	0	0	0	0
Hohokam	9	7	0	2	16	7	0	1
Patayan	0	0	6	0	0	0	0	0

Table 5 – Most popular forms among Cultures

Table 5 (Most popular forms among Cultures) represents the 8 most popular types of forms. From the samples gathered of Avian (N=95), Animal (N=72), and Human Vessel (N=51), the most popular was Avian. It showed up in 5 Culture(s), while Animal and Human Vessel/Human Figurine[7] appeared in 3.

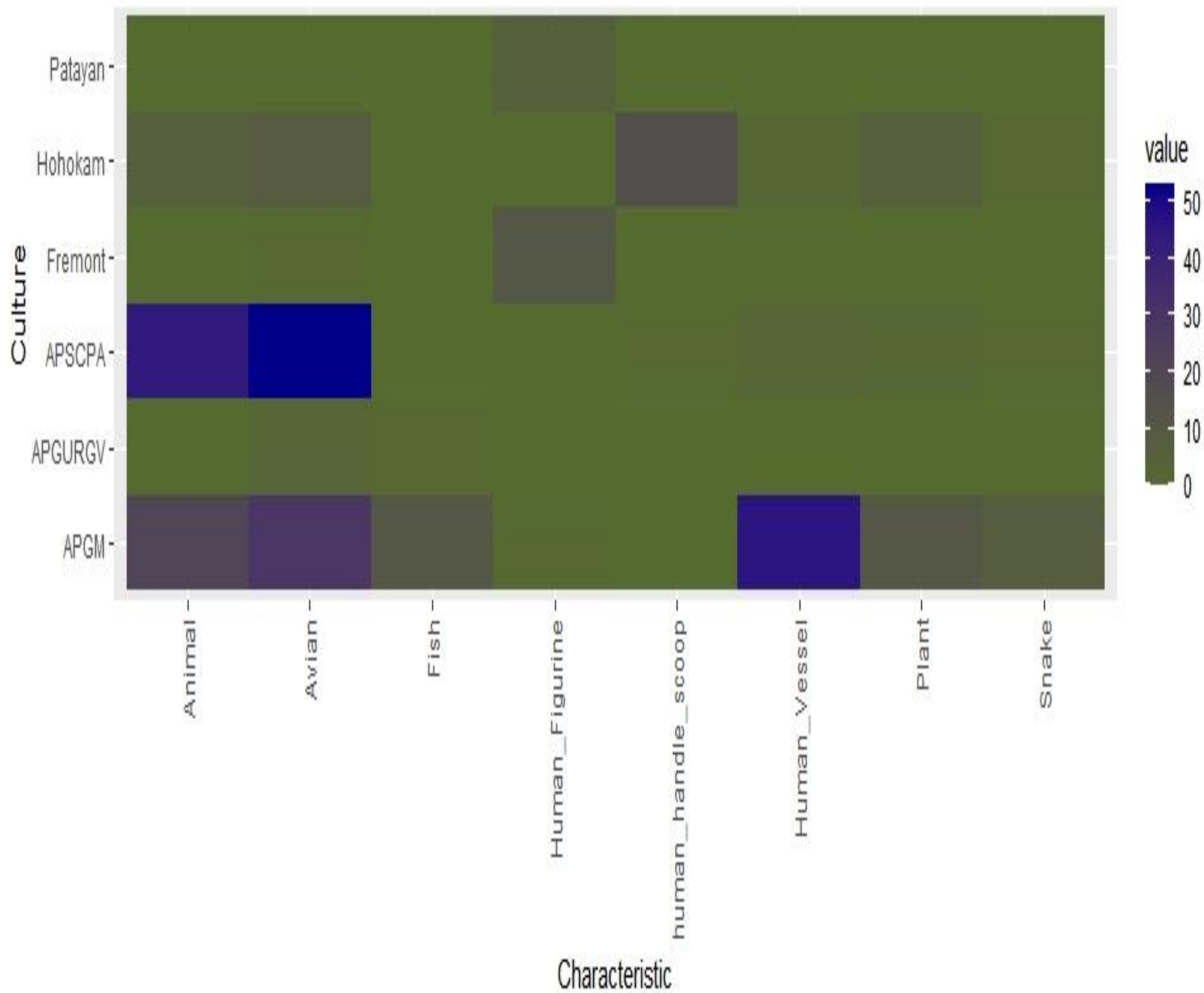


Figure 18-- Heatmap showing popular forms by Culture.

Figure 18 is a visual representation of Table 5, showing form popularity by color, with Avian forms being the most popular at 50+ (dark blue) in the APSCPA culture. Although there is some distribution of forms among Cultures, not all Cultures share the same forms. All the groups, Culture, Branch, Tradition, Ware, and Type were examined. Information concerning data is shown both as a phylogenetic tree (as generated in R/RStudio) and as a

[7] Human figurines and human vessels differ in appearance with the figurine being more like a gingerbread man, flat with defined arms/legs and possibly other body features . The vessel appears more of a pot or human-like, generally more decorated than the figurine that is more popular in the Fremont and Patayan cultures and while vessels appear more often in the Mogollon/Casas Grandes cultures.

heatmap (also generated in R/RStudio). Diagrams generated in SplitsTree and shown where needed to assist in clarification of results.

When compiling tables for both the phylogenetic trees and heatmaps, a binary system was used as the basis for data. If found, a motif or trait is represented numerically as present (1); otherwise, it is considered to be absent (0). When using binary data to construct a phylogenetic tree, the Gusfield algorithm (Cmero 2015) is what allows us to use binary data. Using binary data in a heatmap gives a very clear picture of where positive data is present on the graph.

Figure 19 continues the visual display of the relationships of traits by Culture, this time in a binary setting. If the forms/shapes represented in the heatmap are present, they show in blue. Although zoomorphic figures extend across the three cultures associated with the Anasazi/Mogollon, only Avian shows a continuous distribution in the Hohokam, Fremont, PGM, APGURGV, and the APSCPA cultures.

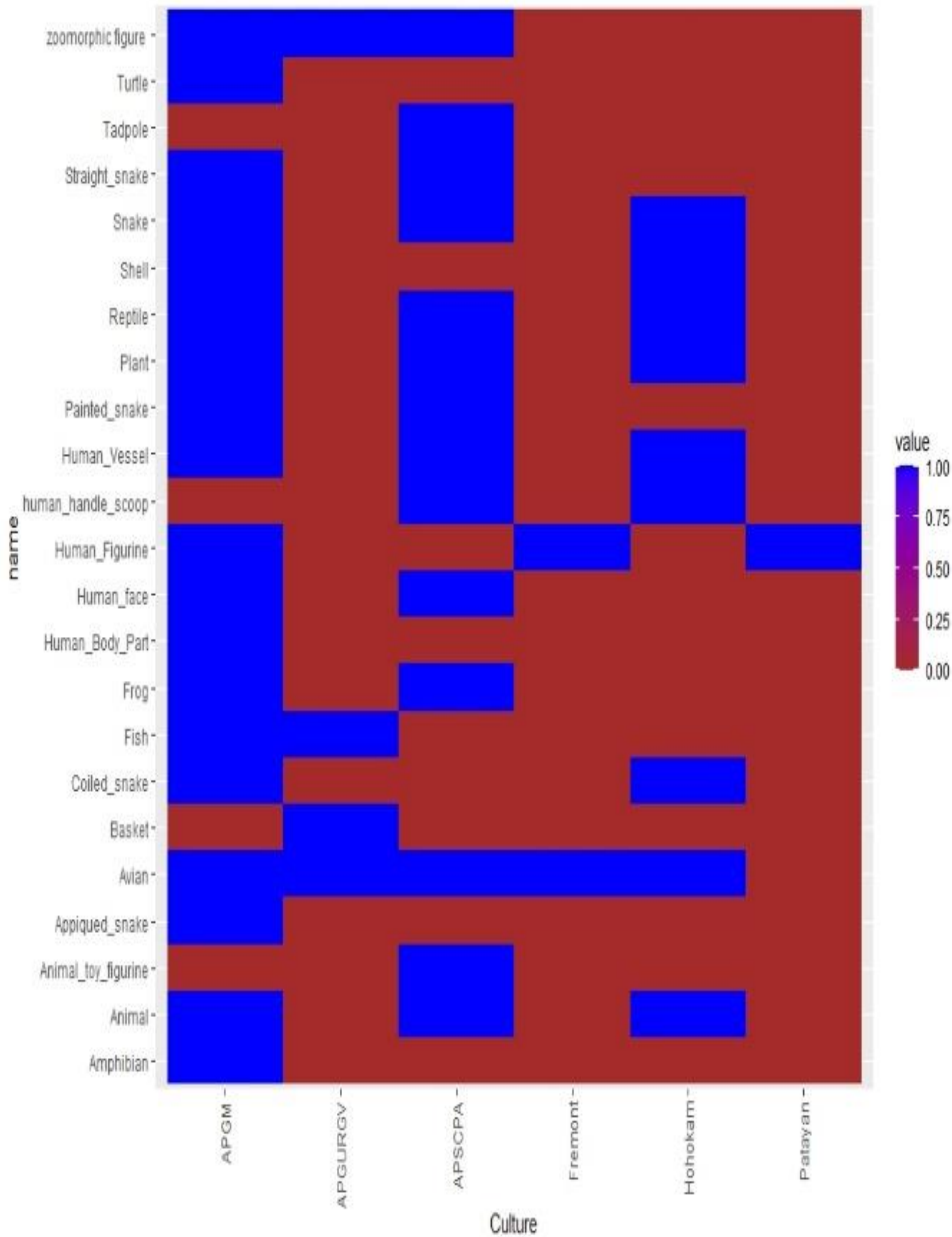


Figure 19-- Binary heatmap of traits by Culture

This sharing of Avian forms could represent horizontal sharing or could be the result of religious or supernatural beliefs (Lowenstein and Vitebsky 2011). Other objects shared by more than a single culture (i.e., plants, animals, snakes, etc.) are part of the natural environment where these cultures are located. The distribution of forms on the Culture level suggests a widespread horizontal sharing rather than an oblique distribution system.

Even though numerous traits/motifs/characteristics were confined to a particular Culture, others are common to the majority of Culture(s). Avian forms, for example, are found in five of the six cultures studied. They appear to be absent in the Patayan culture, however; the only examples of Patayan artifacts found were of human figurines.

Using R and RStudio

Phylogenetic analysis of the data was performed in R/RStudio using cluster analysis UPGMA (unweighted pair group method with arithmetic mean (Sokal and Michener 1958)) "because it is a straightforward method for constructing a phylogenetic tree from a distance matrix," (Weiß and Göker 2011). UPGMC was chosen for use in the R scripts because it is also available in SplitsTree5.0.0 alpha (Huson and Bryant 2006). Within the R package *hclust: Hierarchical Clustering*, several methods can be used (R. C. Team 2021): "ward.D," "ward.D2," "single," "complete," "average" (= UPGMA), "mcquitty" (= WPGMA), "median" (= WPGMC) or "centroid" (= UPGMC).

Description

Hierarchical cluster analysis is performed on a set of dissimilarities and includes methods for analyzing it. The hierarchical cluster analysis algorithm uses a set of dissimilarities for the clustered objects. Initially, each object is assigned to its own cluster, and then the algorithm proceeds iteratively, at each stage joining the two most similar clusters, continuing until it creates a single cluster. At each stage, distances between clusters are recomputed by the Lance-Williams dissimilarity update formula, according to the clustering method in use.

Within hclust are several different clustering methods:

- *Ward's* minimum variance method aims to find compact, spherical clusters.
- The *complete linkage* method finds similar clusters.
- The *single linkage* method (closely related to the minimal spanning tree) adopts a "friends of friends" clustering strategy.
- The methods "median" and "centroid" do *not lead* to a *monotone distance* measure, and the resulting dendrograms have *inversions* or *reversals* that are hard to interpret. But note the trichotomies in Legendre and Legendre (2012).

Two algorithms are regarded as capable of clustering wards. The one used in the first option, "ward.D" (equivalent to the only Ward option, "ward" in R versions 3.0.3) *does not* implement Ward's (1963) clustering criterion. But "ward.D2" implements that criterion (Murtagh and Legendre 2014). In "ward.D2," the dissimilarities are *squared* before cluster is updated. This should be (an unambiguous abbreviation of) one of "ward.D," "ward.D2," "single," "complete," "average" (=UPGMA), "mcquitty" (=WPGMA), "median" (=WPGMC) or "centroid" (=UPGMC). (hclust: Hierarchical Clustering).

Results using “average” or “UPGMC” for the hclust in RStudio and the ConvexHull SplitsTree network produced results for the different ceramic artifacts that were similar to the results described by Friesen et al. (2021) in their study of the Allium toksanbaicum.

Phylogenetic testing

Testing the phylogenetic signal found in Tradition.

Tradition is in the middle for the data series and contains derived information from the two data series that follow, Ware and Type. It was chosen to determine if a phylogenetic signal is present and what it represents. Because phylogenies hold signs of past evolutionary processes, the relationship creates a non-independent trait. The closer the species are related, the greater the lack of independence. This non-independence is measured by a phylogenetic signal (Münkemüller et al. 2012).

Phylosignal, an R package developed by Keck, et al. (2016), uses different methods to compute and test phylogenetic signal, one of which is Moran's I index, considered the standard measure of autocorrelation (Keck et al. 2016).

As stated by Keck et al. (2016)), phylogenetic signal is defined as “the tendency for closely related species to display similar trait values as a consequence of their phylogenetic proximity.” Using the R package “phylosignal,” Tradition data was examined to determine the phylogenetic proximity of motif/trait values. Using the strict definition of phylogenetic signal as stated by Blomberg et al. (2003), it is the “tendency for related species to resemble each other more than they resemble species drawn at random from the tree.”

Any relationship between a continuous trait value and the tree on which the Tradition is a leaf will show up as a statistical dependence and, therefore, as a phylogenetic signal. Figure 17 represents a Moran's I index of autocorrelation for the Tradition data plotted onto a phylogenetic tree. The left side is random sampling of taxa showing the number of Traditions positive at 7 (indicating inheritance or sharing between groups and is part of a cluster) and negative at 10 (dissimilar traits between groups or non-sharing). The right side is from Tradition data; tree information is gathered from analysis in SplitsTree. The interaction shown for the five positive branches could be the result of shared traits or forms, i.e., avian forms, figurine forms, or a method of decoration, such as pinched eyes or mouths. The other 12 Traditions show a small negative (from less than -1 to a little over -2), indicating less sharing. Three Traditions reflect no visible deviation from zero.

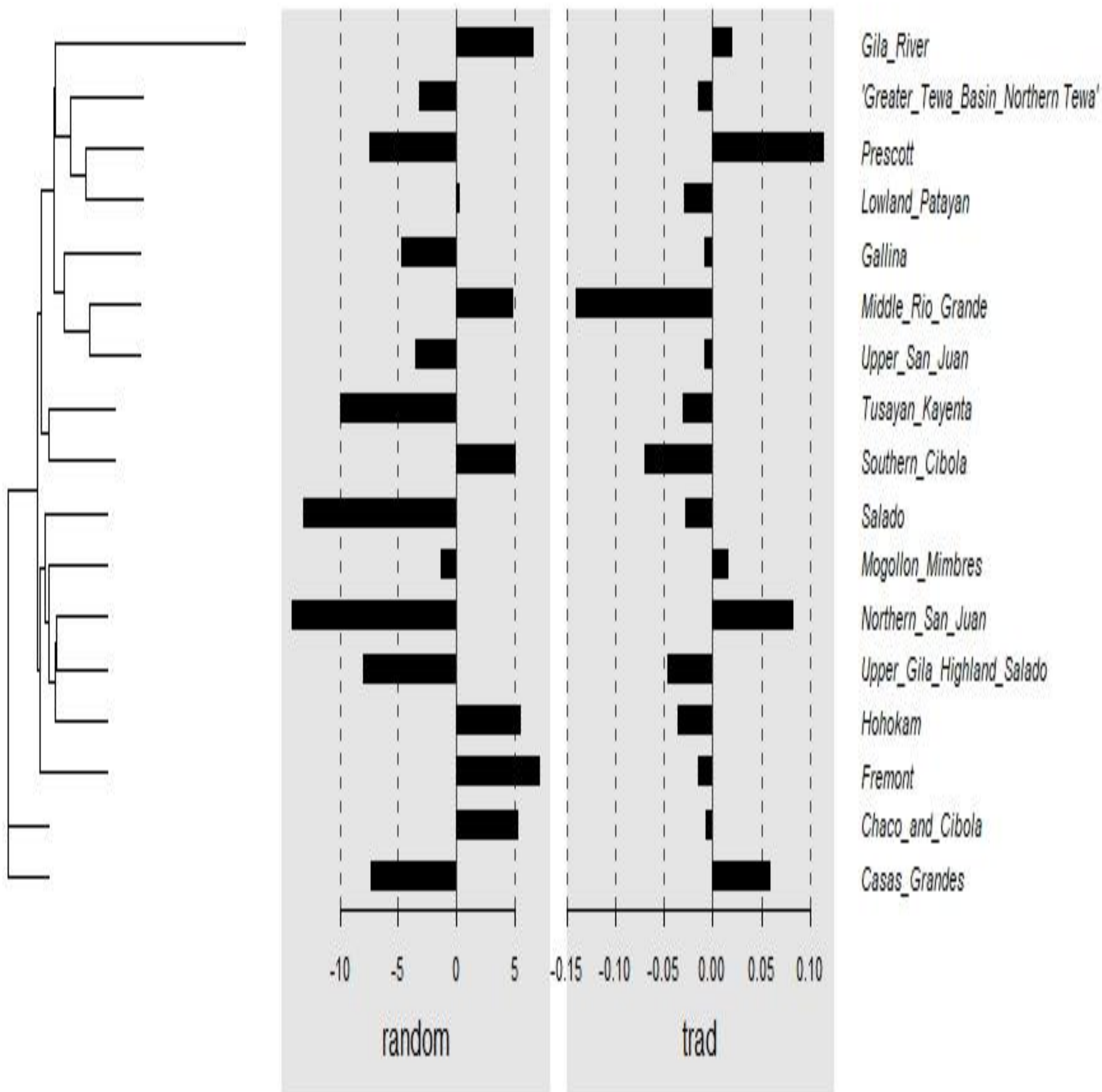


Figure 20 Moran's I index of autocorrelation for the Tradition data plotted onto a phylogenetic tree.

Table 6 shows the actual values used in the computations.

Tradition	Random	trad
Casas Grandes	-7.337166	0.059911922
Chaco and Cibola	5.356558	-0.007044220
Fremont	7.184396	-0.015118607
Hohokam	5.524817	-0.035256303
Upper Gila Highland Salado	7.933771	-0.046413557
Northern San Juan	-14.063299	0.083398250
Mogollon Mimbres	-1.291993	0.016714667
Salado	-13.067971	-0.028237444
Southern Cibola	5.049809	-0.070172739
Tusayan Kayenta	-9.906536	-0.030857545
Upper San Juan	-3.499915	-0.008733288
Middle Rio Grande	4.890350	-0.139826546
Gallina	-4.752206	-0.008864245
Lowland Patayan	0.287526	-0.029755980
Prescott	-7.410139	0.115351986
Greater Tewa Basin Northern Tewa'	-3.195548	-0.014657289
Gila River	6.646407	0.020524401

Table 6 Values used in computation of Moran's I index.

Table 6 shows the actual values used in the computations. In Figures 18 and 19, the solid black line represents the Moran's I index of autocorrelation (Moran 1948, 1950).[8] Phylogenetic correlograms for 2 traits: (A) *trad (or Tradition)*, and (B) *random*. The solid bold black line represents the Moran's I index of autocorrelation, and the dashed black lines represent the lower and upper bounds of the confidence envelop (here 95%). The horizontal black line indicates the expected value of Moran's I under the null hypothesis of no phylogenetic autocorrelation. The colored bars show whether the autocorrelation is significant (based on the confidence interval): red for significant positive autocorrelation, black for nonsignificant autocorrelation, and blue for significant negative autocorrelation.

When the autocorrelation is positive, most commonly the trait is inherited from a common ancestor, while a negative autocorrelation indicates a greater difference in the trait regarding close connections than is found in a random pair of taxa (Diniz-Filho 2012, et. al.). The phyloCorrelogram for Trad, Figure 18 shows Moran's I index of autocorrelation to range from

[8] Local Moran's index ranges from positive 1 to negative 1. A positive value indicates similar values, either high or low, while a negative value indicates dissimilar neighboring values .

-0.15 to +0.05. Using confidence envelope of 95, the dashed black lines represent the lower and upper bounds of the phylogenetic signal. This indicates that interactions among Tradition(s) were limited.

In contrast, Figure 19 shows the phylogenetic correlogram for the randomly generated data, shown in Table 6 under the column ‘Random.’ As with Figure 18, using the confidence envelope of 95%, the dashed black lines represent the lower and upper bounds of the phylogenetic signal, the main difference between the two figures (besides the numbers used to generate the graph) is the inclusion of the two red segments that show a significant positive autocorrelation (Keck et al. 2016).

Using the data found in Table 7, a one sample T-test was run to determine the viability of our hypothesis concerning information and social learning techniques.

Hypothesis 1 H2 Horizontal transmission scenario No.1 Unlimited interaction Restricted in distribution, Types will show design patterns in line with horizontal transmission, where information among peers is transmitted horizontally either from within the individual Type or from interactions with individuals from other Wares or Traditions. Branching may be shown both within a single Ware group or among Ware groups within a single Tradition, or between Traditions within a single Culture.

Versus the null hypothesis

Null hypothesis 1 H5: extensively blended and thus unrecognizably patterned.

The null hypothesis, H5, examines extensive blending and sharing of ideas that result from the unrestricted introduction of ideas by adults or institutions into a receiving Tradition (Jordan 2015:24-26). New designs are introduced via cultural or sociopolitical influences, and over time are diffused across all regions, primarily along trade routes. Potters in villages along the trade routes would share the same or similar designs throughout all Branches, without notable modifications, for local use.

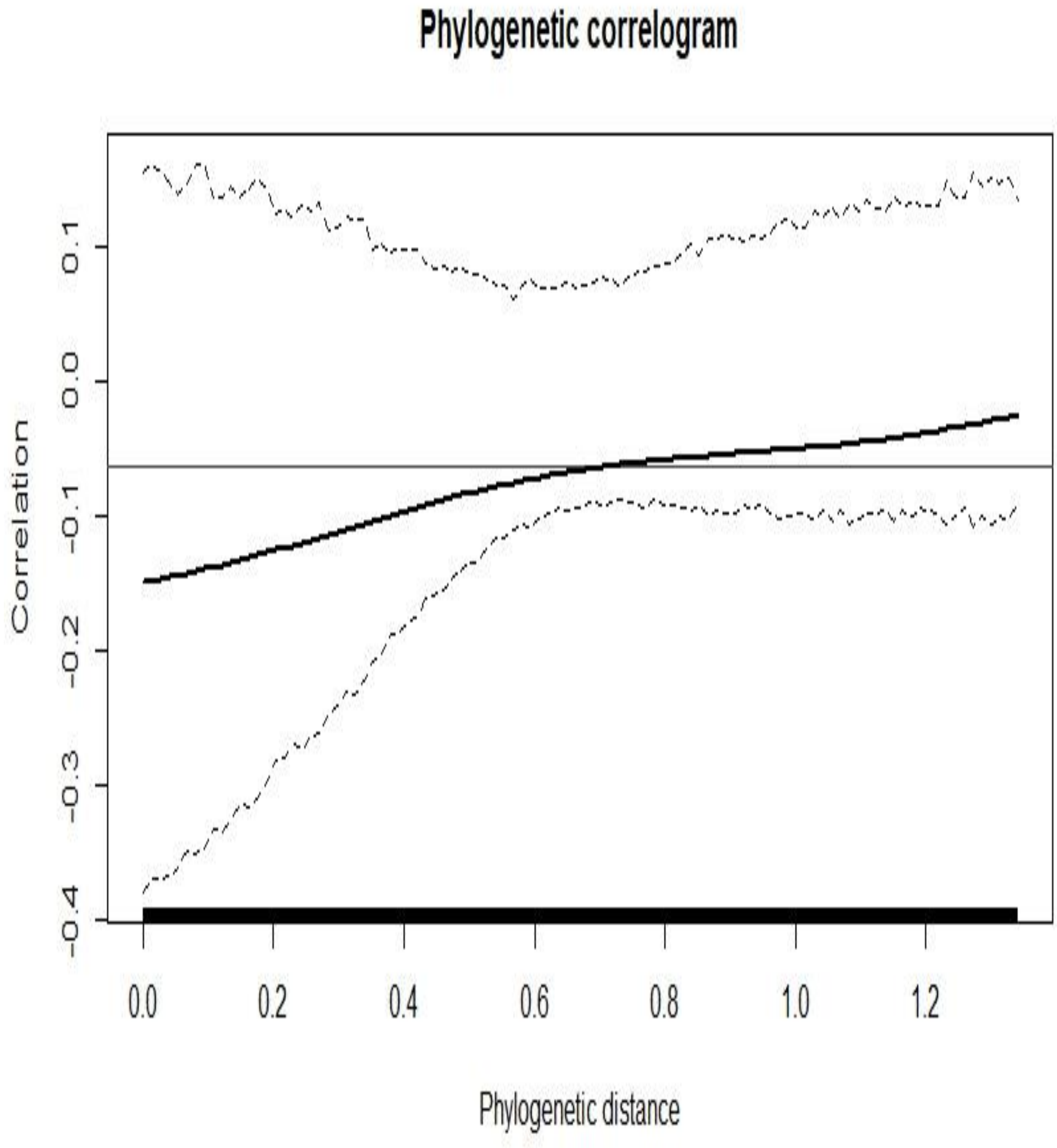


Figure 21 Phylogenetic distance correlogram from Tradition data.

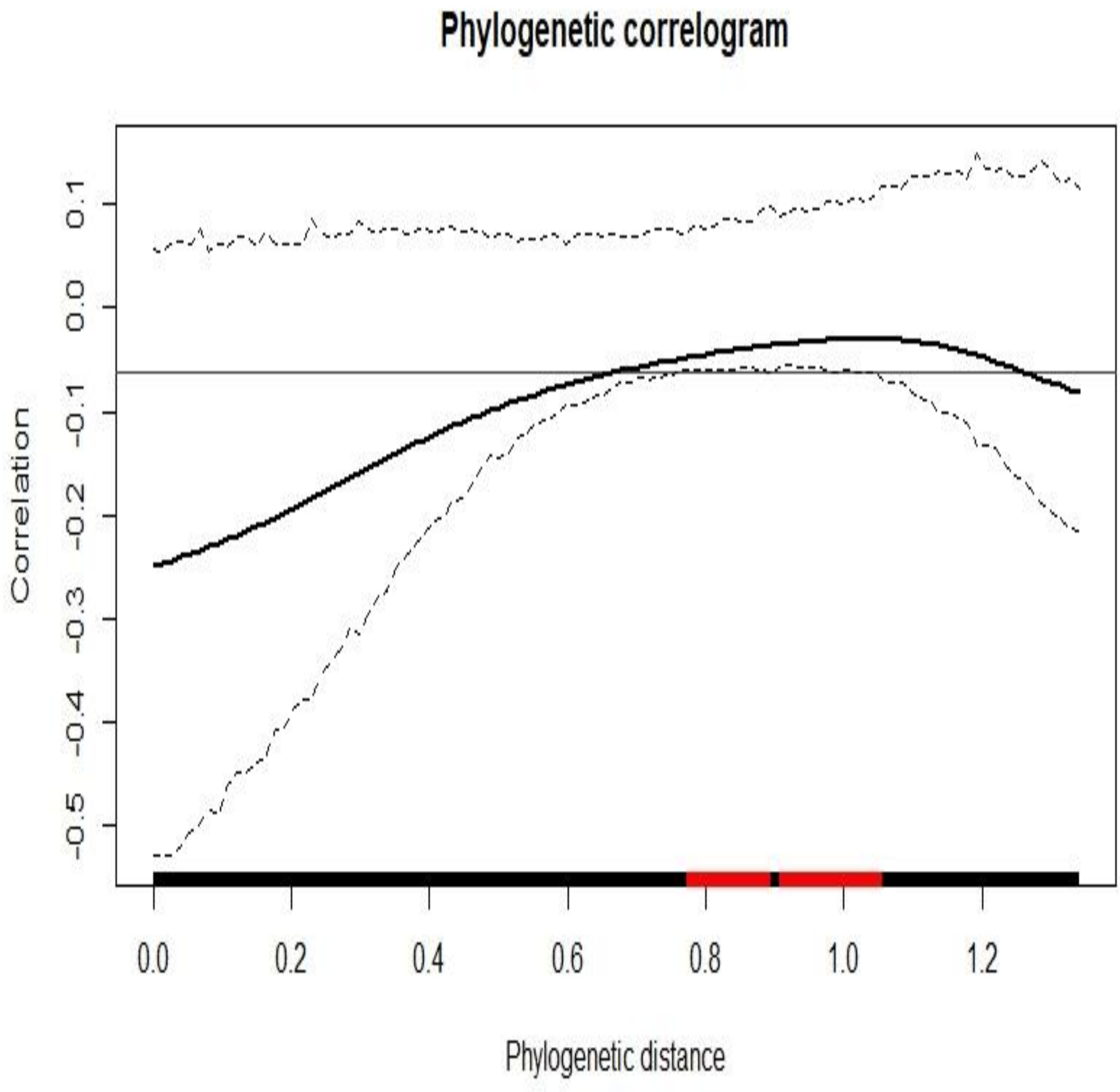


Figure 22 Phylogenetic random distance correlogram.

Table 7 shows the distribution of motifs/traits found in each Tradition. By using this data, summary statistics are produced. Table 8 shows that the minimum number of motifs/traits found is 1, 1st Qu., is 4, so 25% of the data is below this. The Median value is 8, indicating that half of the values are above this number and half are below. The Mean is the midpoint of the data, 3rd Qu., is the number that is 75% higher than the Min., and Max is the maximum value in Table 7.

	Trad	number
1	Lowland Patayan	1
2	Prescott	1
3	Greater Tewa Basin (Northern Tewa)	3
4	Upper San Juan	3
5	Gallina	4
6	Middle Rio Grande	5
7	Fremont	6
8	Gila River	6
9	Salado	8
10	Mogollon-Mimbres	19
11	Tusayan (Kayenta)	25
12	Northern San Juan	28
13	Upper Gila (Highland Salado)	31
14	Southern Cibola	36
15	Hohokam	39
16	Chaco and Cibola	107
17	Casas Grandes	137

Table 7 Distribution of motif/traits among Traditions.

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
1	4	8	27	31	137

Table 8 Summary of data in Table 7.

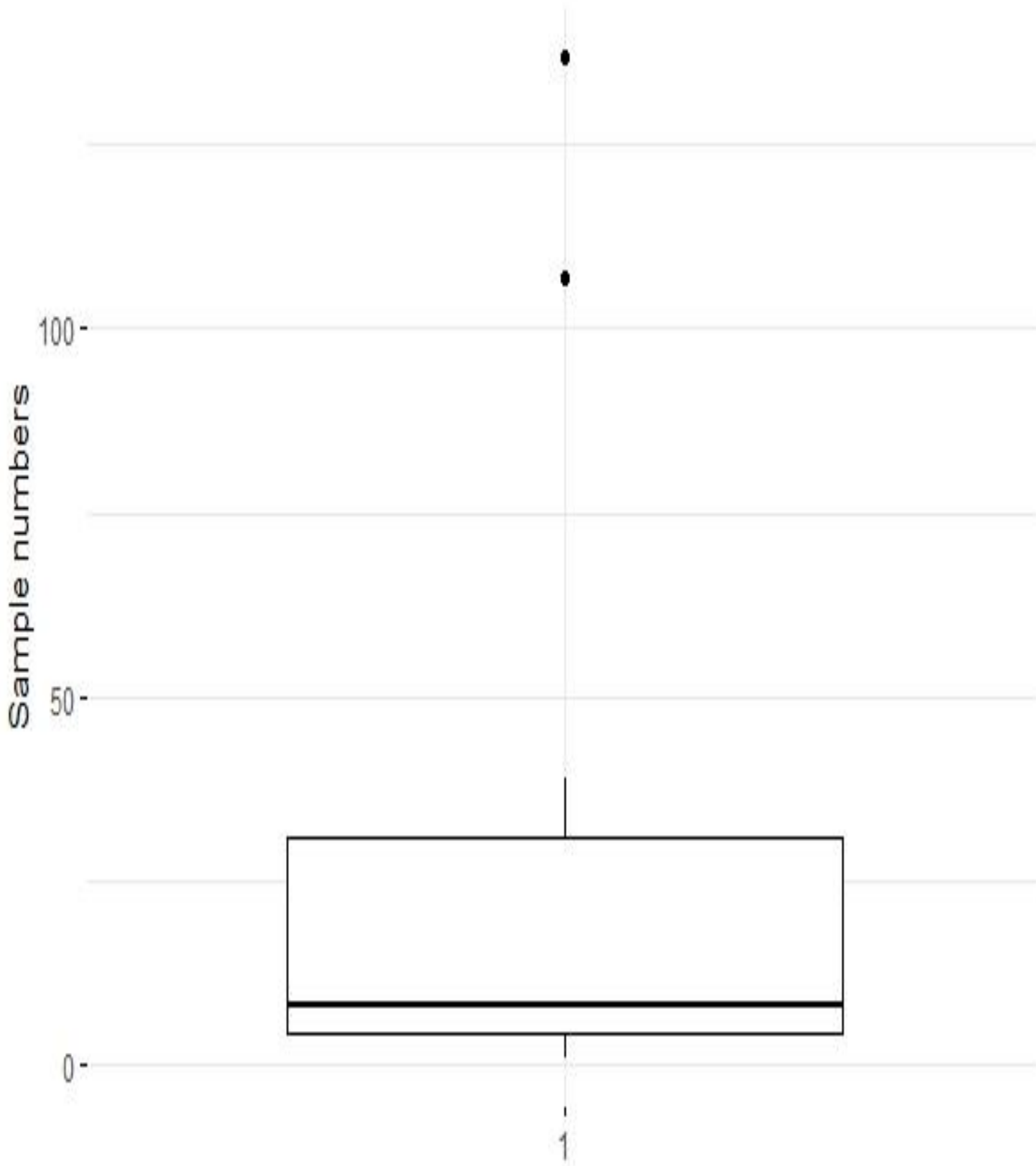


Figure 23 Boxplot of data found in Table 7.

Next it is necessary to check one sample T-test assumptions. Because n = 17, it is necessary to check the data for normal distribution. Using the Shapiro-Wilk normality test and then plotting the results will show if the data is normally distributed. If the data is normally distributed, then the Null hypothesis will be true; otherwise, the Alternative hypothesis is true.

Results from the Shapiro-Wilk normality test show that the p-value (W = 0.67891, p-value = 6.736e-05) is considerably smaller than the significance value of 0.05 and that it varies greatly from the normal distribution, with the confidence interval equal to 7.266151 46.733849, at a 0.95 confidence level, using the theoretical mean/median (mu) of eight. Figure 21 illustrates the distribution of data from Table 7.

Running a one sample t-test, results show t = 2.0411, df = 16, p-value = 0.0581, where t is equal to the t-test statistic value, df equals degrees of freedom, and the p-value is the significance level of the t-test. Because the p-value is close to significance of 0.05, as long as the true mean is not equal to 8, the alternative hypothesis is true. The confidence interval at 95% is 7.266151 to 46.733849, and the sample estimate for the mean is 27.

Using Wilcoxon signed rank test with continuity correction to check out the results of the Shapiro-Wilk normality test gave values of V = 100, p-value = 0.05159, with the alternative hypothesis: true location is greater than 8.

From these tests the null hypothesis appears to be false and the alternative hypothesis, Horizontal transmission scenario No.1 Unlimited interaction, is true.

Filtering the data by Culture, Branch, Tradition, Ware, and Type allowed the capture of the required information. Each subset of data was placed into a separate sheet and then saved as a csv file. Each csv file was loaded into R-Studio (R. Team 2021), using R (R. C. Team 2021). The csv file was placed into a dataset using the function "read.csv" (Wickham et al. 2022) and then processed using the command "hc <- hclust(dist(Tradition[9]), "average") #UPMGA."

[9] File name varies with the type of data being used, i.e., Culture, Branch, Tradition, etc.

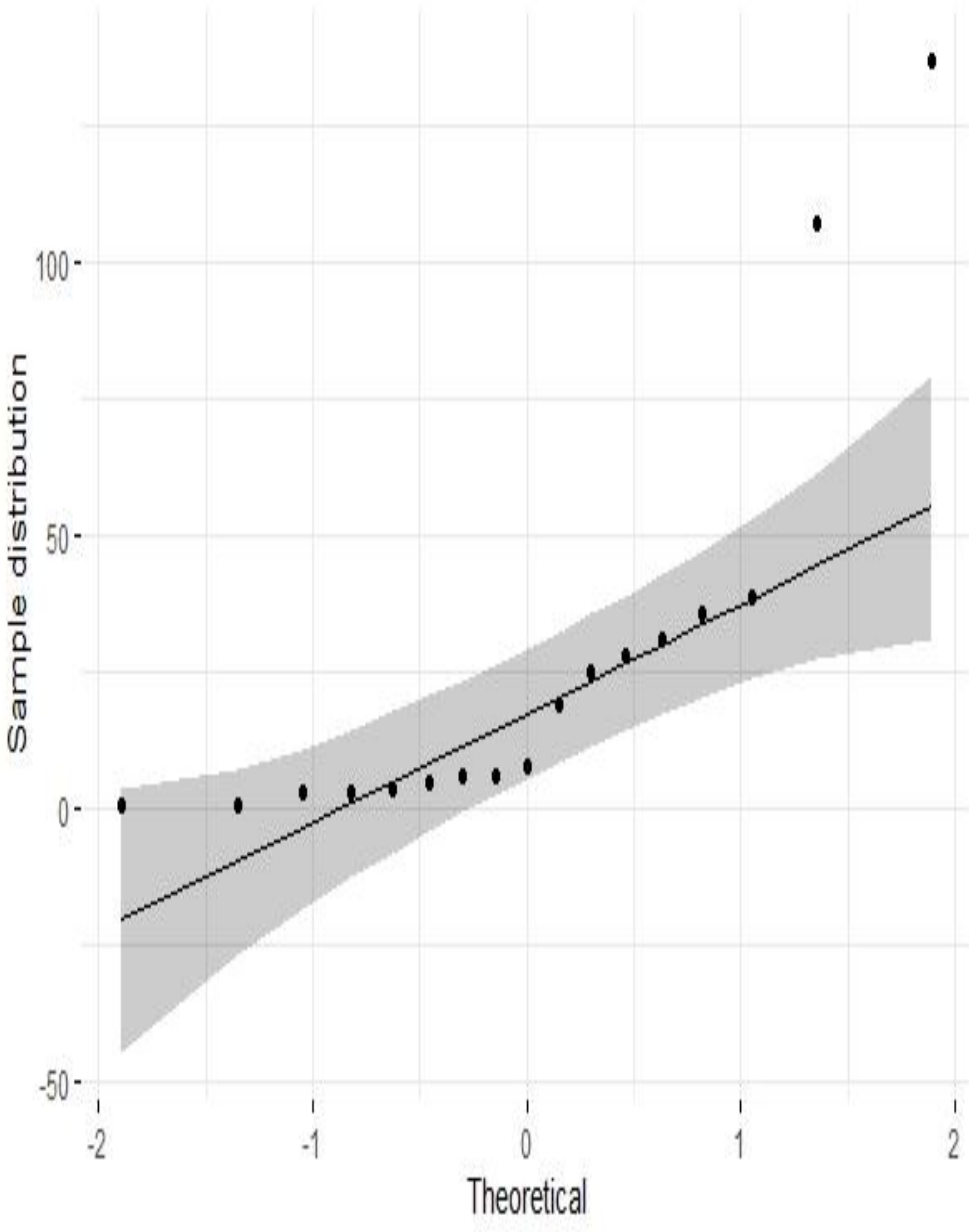


Figure 24 Illustrates the distribution of data from Table 7.

Culture

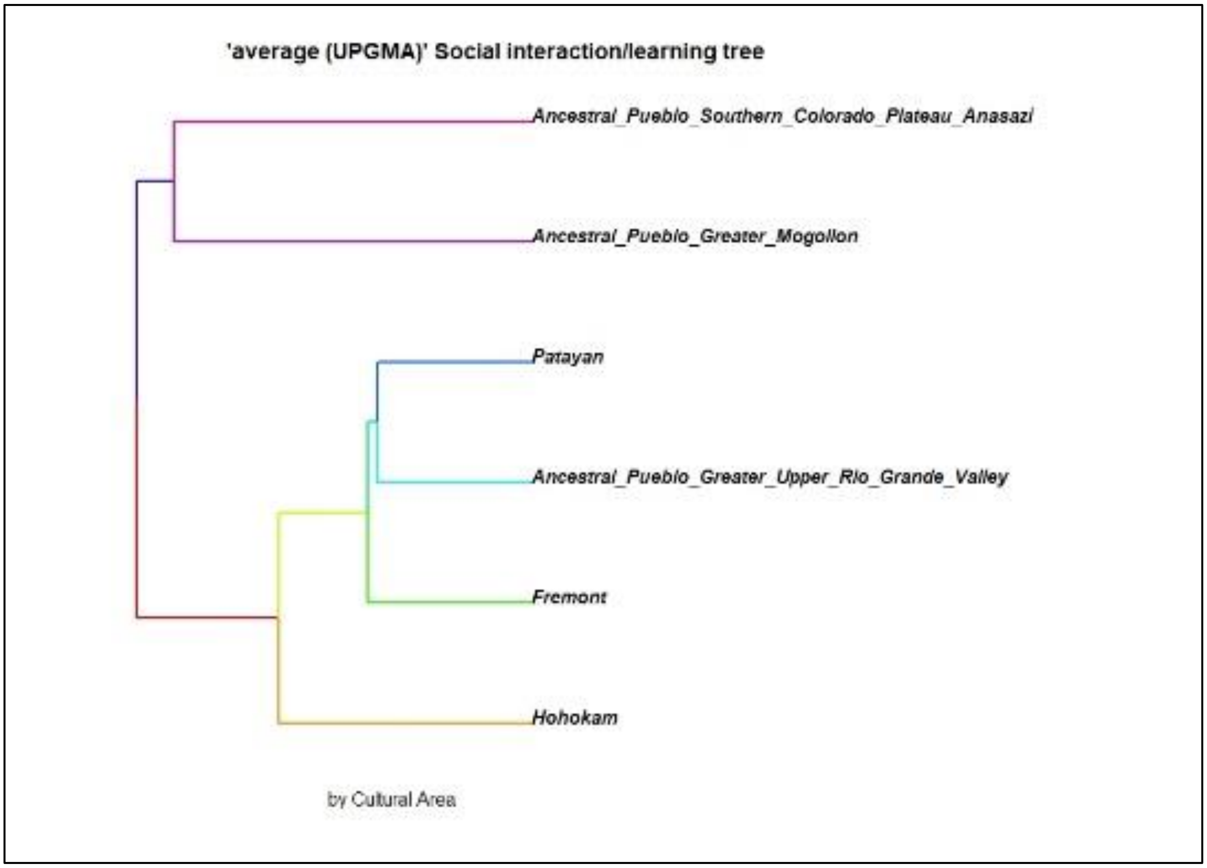


Figure 25-- Phylogenetic tree representing Cultures

Figure 22, a phylogenetic tree produced in R/RStudio, places the Fremont, and Ancestral Pueblo Greater Upper Rio Grande Valley in the same clade, along with the Patayan Culture. The Hohokam Culture is in a separate clade, while R places the Ancestral Pueblo Greater Mogollon and Ancestral Pueblo Southern Colorado Plateau Anasazi together in a single clade.

The software programs R and RStudio using packages ggplot2 (Wilke 2019), tidyverse, and dplyr (Wickham et al. 2019) were used to consolidate data into visual graphics. A heatmap diagram shows the distribution of forms across the cultures. If the item/object is present, it is represented by a “1,” and if absent, a “0.” The legend on the right side of the diagram shows the color range. In Figure 23, the colors used are green and blue, with blue representing the largest amount found, in this case 53 related to APSCPA. In the heatmaps, the value is either 1 for present or 0 for absent.

The heatmap (Figure 23) shows that traits are shared more between the APGM and the APSCPA, with the Hohokam sharing some traits. The shape/form of Avian is a common theme for all but the Patayan culture. The Patayan culture shares the trait of form in the shape of a human figurine with APGURGV, and the Fremont culture.

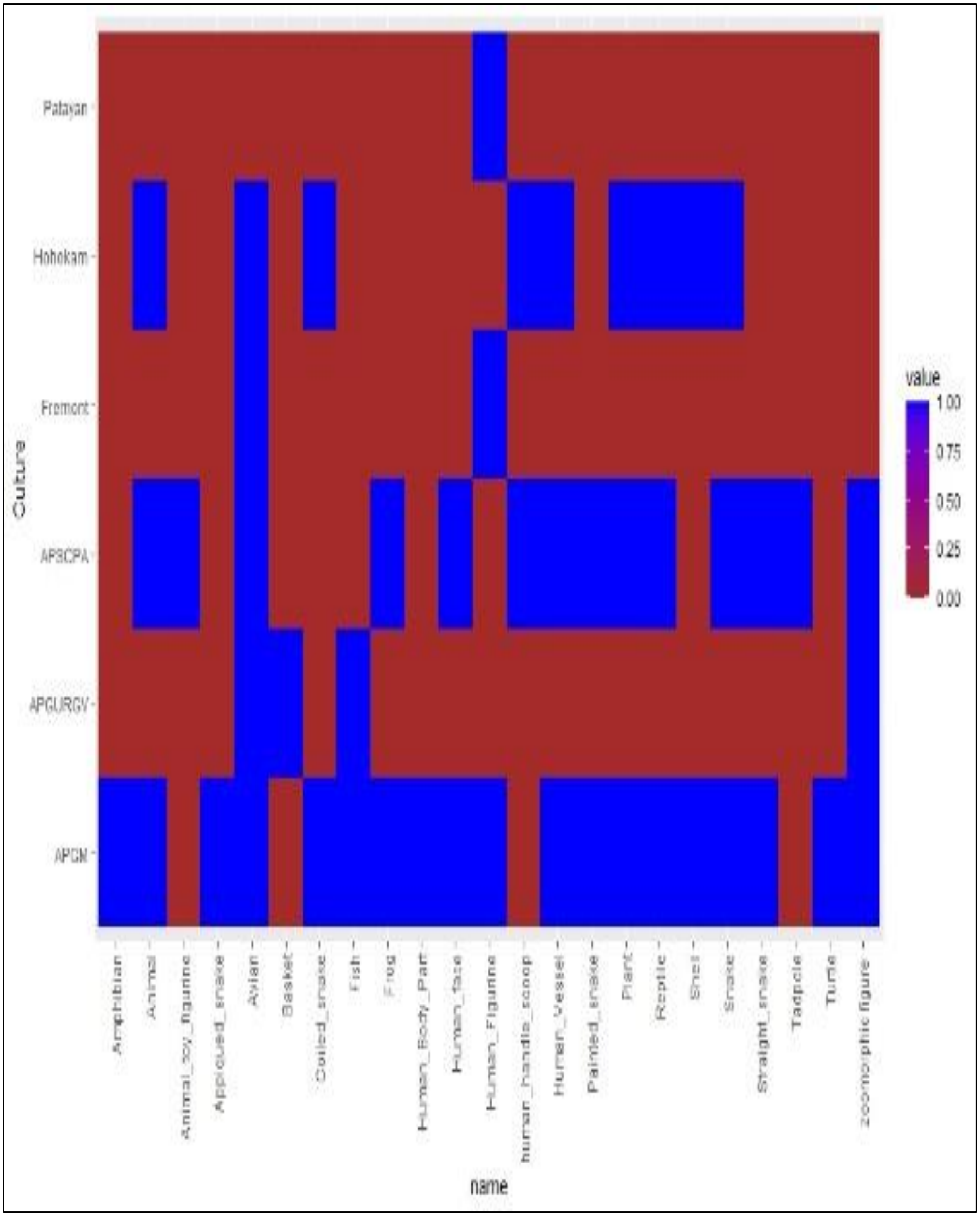


Figure 26--Heatmap showing distribution of traits for Cultures

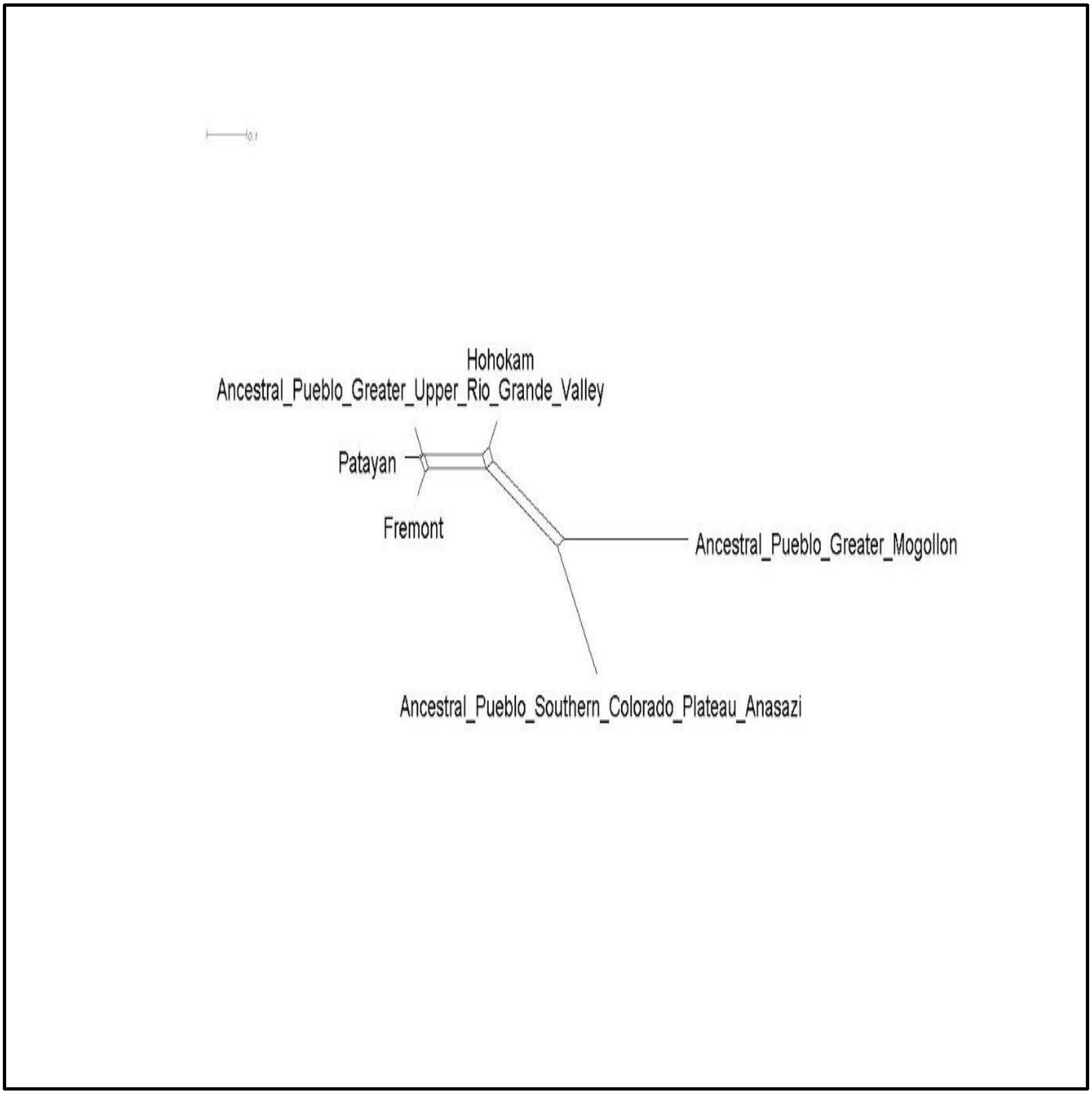


Figure 27-- SplitsTree diagram of Culture sharing.

Represented in the diagram above (Figure 24) are the relationships among Cultures as displayed in an automatically generated SplitsTree neighbor-net from a pairwise distance matrix. The Cultures, Patayan, Fremont, and APGURGV, (on the left) show a closer interaction with each other than they do with the rest. The Hohokam do show interaction with both groups on the extreme ends. The APGM and APSCPA share an interaction between themselves and with the others. This sharing of ideas is limited and appears to be restricted to generalized artifact forms and decorations.

Branch

Deeper analysis of the data collection brings us to the level of Branch. Table 9 was created using a distance matrix created in PAUP (Swofford 1998) and then in a Nexus file for importation into SplitsTree.

Pairwise distances between taxa

Below diagonal: Total character differences
Above diagonal: Mean character differences

	1	2	3	4	5	6	7	8	9	10	11
1 Central_Anasazi	-	0.52174	0.59130	0.56522	0.48261	0.46522	0.54348	0.61304	0.59565	0.59130	0.50000
2 Chihuahua	120	-	0.69565	0.66087	0.58696	0.56957	0.64783	0.71739	0.70870	0.70435	0.68261
3 Eastern_Mountain_Anasazi	136	160	-	0.11304	0.23043	0.26522	0.13478	0.04783	0.08261	0.04348	0.14348
4 Fremont	130	152	26	-	0.23043	0.26522	0.15217	0.10000	0.09130	0.11304	0.20435
5 Greater_Salado	111	135	53	53	-	0.26087	0.22609	0.22609	0.21739	0.22174	0.23478
6 Hohokam	107	131	61	61	60	-	0.22609	0.26957	0.25217	0.24783	0.24348
7 Mogollon_Highlands	125	149	31	35	52	52	-	0.13043	0.12174	0.13478	0.16522
8 Northern_Rio_Grande	141	165	11	23	52	62	30	-	0.05217	0.04783	0.14783
9 Southern_Patayan	137	163	19	21	50	58	28	12	-	0.08261	0.16522
10 Southern_Rio_Grande	136	162	10	26	51	57	31	11	19	-	0.13478
11 Western_Anasazi	115	157	33	47	54	56	38	34	38	31	-

Table 9 Pair-wise distance matrix from PAUP.

In Figure 25, the diagram from R/RStudio places the Central Anasazi branch (APSCPA Culture) and the Chihuahua Branch (APGM Culture) together but in separate clades, consistent with the diagrams in the Culture section. Interaction (sharing and/or blending of ideas) occurs between the two. Climbing the ladder of the second clade, the branch length of the Hohokam Culture is longer than any of the others because it is more closely related to the Greater Salado than the Northern Rio Grande, Southern Rio Grande, or the Eastern Mountain Anasazi, which have the shortest branch lengths. The rest, Western Anasazi, Mogollon Highlands, Fremont, and Southern Patayan, lie between these two groups within the clade.

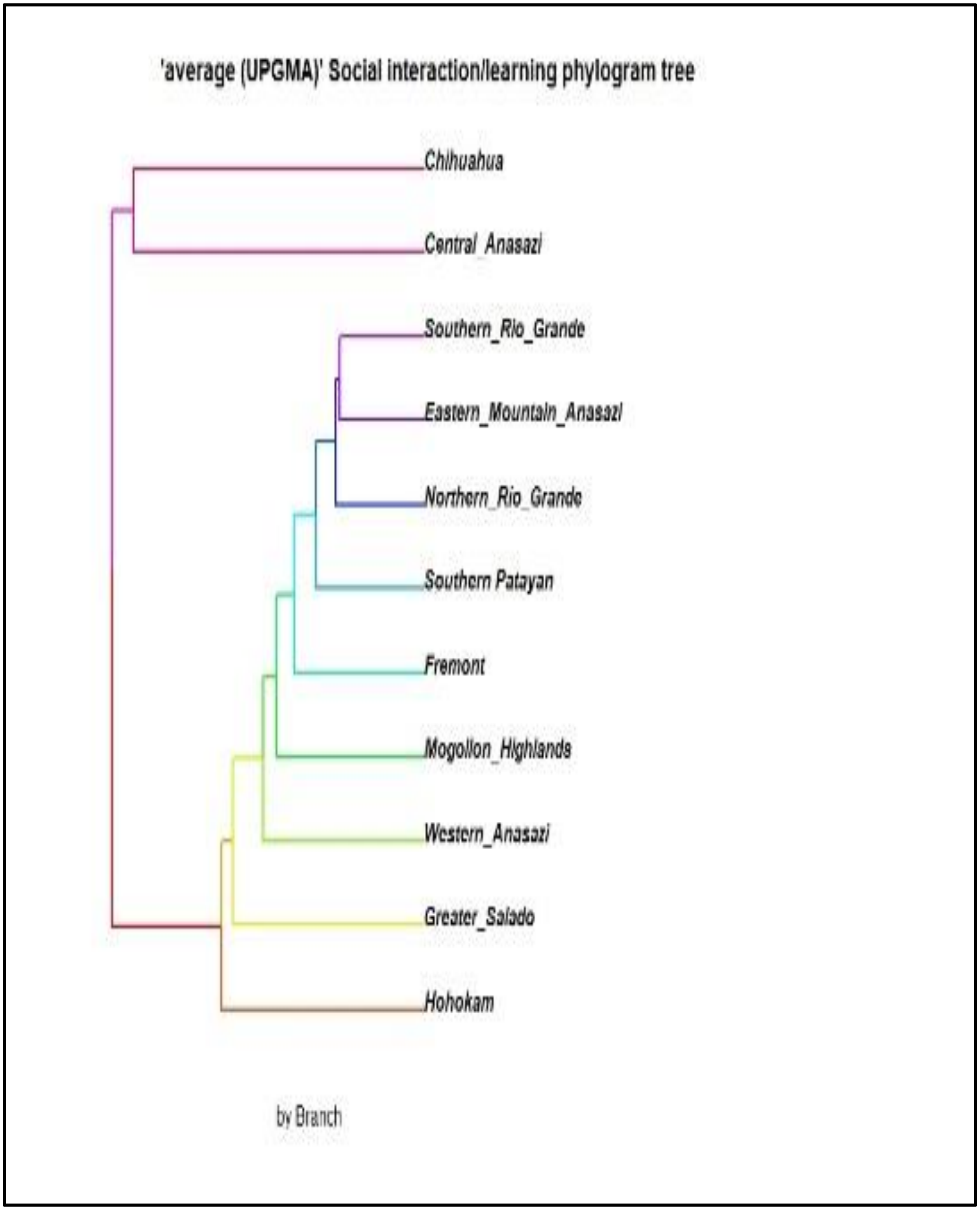


Figure 28 Phylogenetic tree by Branch.

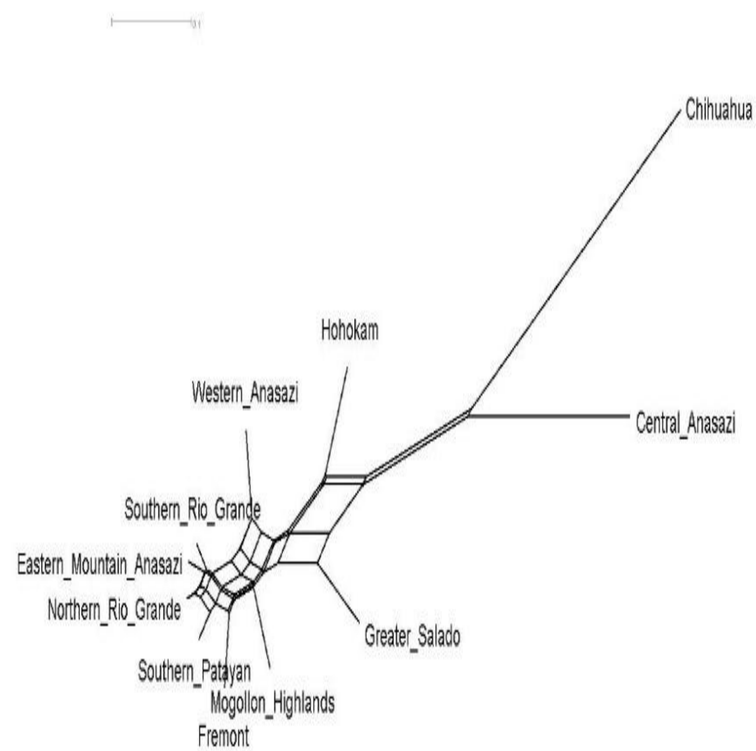


Figure 29-- SplitsTree diagram representing Branch interaction.

The SplitsTree neighbor-net diagram (generated from the pairwise distance matrix shown in Table 9) shows a close relationship (more apparent sharing and blending of ideas) among the Eastern Mountain Anasazi, Fremont, Mogollon Highlands, Northern Rio Grande, Southern Patayan, Southern Rio Grande, and Western Anasazi. The Greater Salado and Hohokam branches are closer to the center of the diagram, showing that while interaction did take place, it was on a more limited scale. The SplitsTree diagram places the last two Cultures (the Chihuahua and Central Anasazi) at the far end of the diagram, indicating a much-reduced degree of interaction.

Figure 26 suggests a significant amount of interaction among the Eastern Mountain Anasazi, Fremont, Mogollon Highlands, Northern Rio Grande, Southern Patayan, Southern Rio Grande, and Western Anasazi, with the amount of interaction becoming more limited with the Greater Salado and Hohokam, and much more limited between the Chihuahua and Central Anasazi. Once again, interaction appears to be more on a socioeconomic (trading) level rather than on an overall organization (religious or political) level.

As illustrated in Figure 27, many traits (shown in green) are shared between Chihuahua and the Central Anasazi, some of which are also shared by the Hohokam and Greater Salado. Although there several actual motifs are shared, many of the other shared traits relate to artifact form and physical appearance.

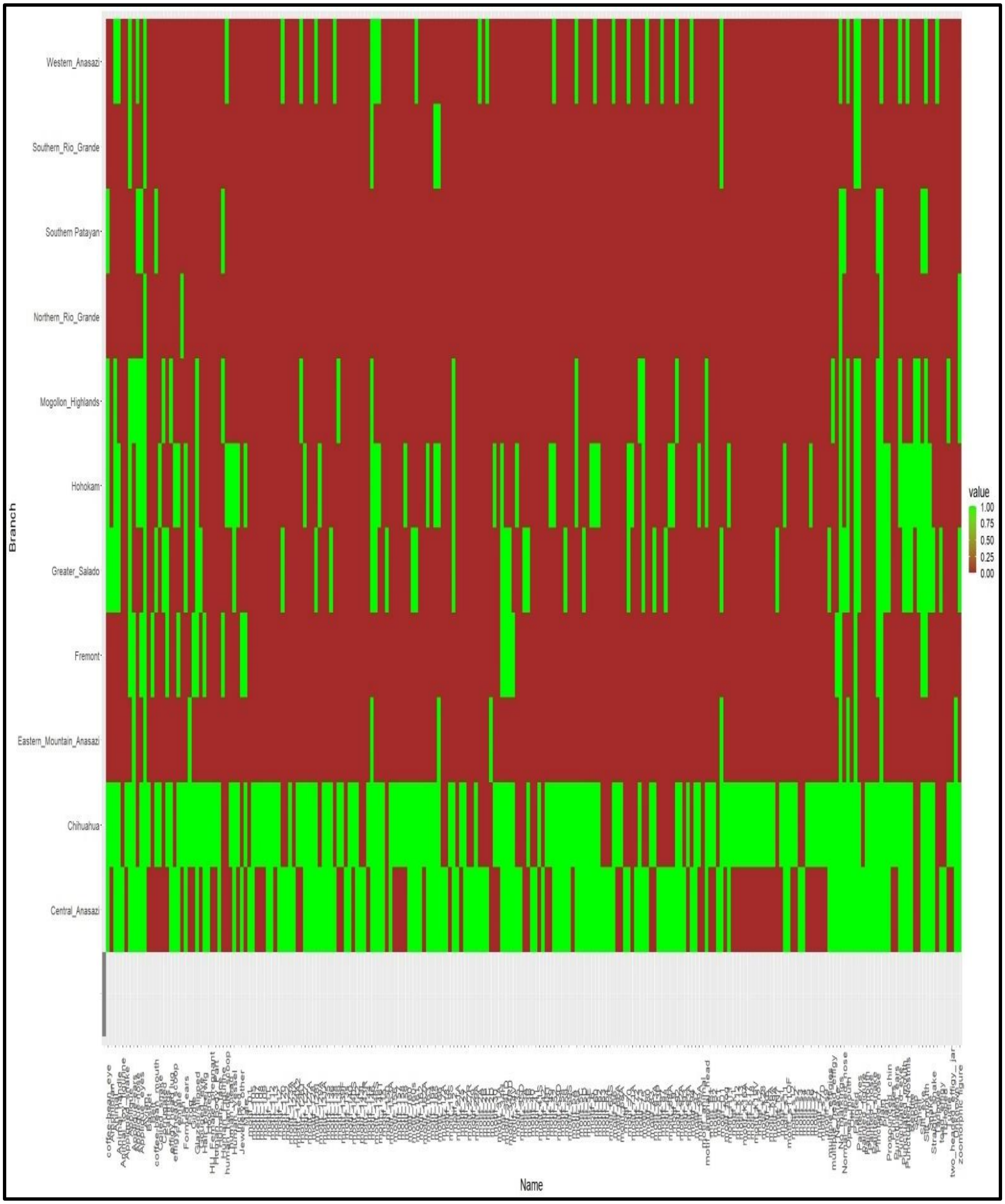


Figure 30-- Heatmap representing Branch traits.

Tradition

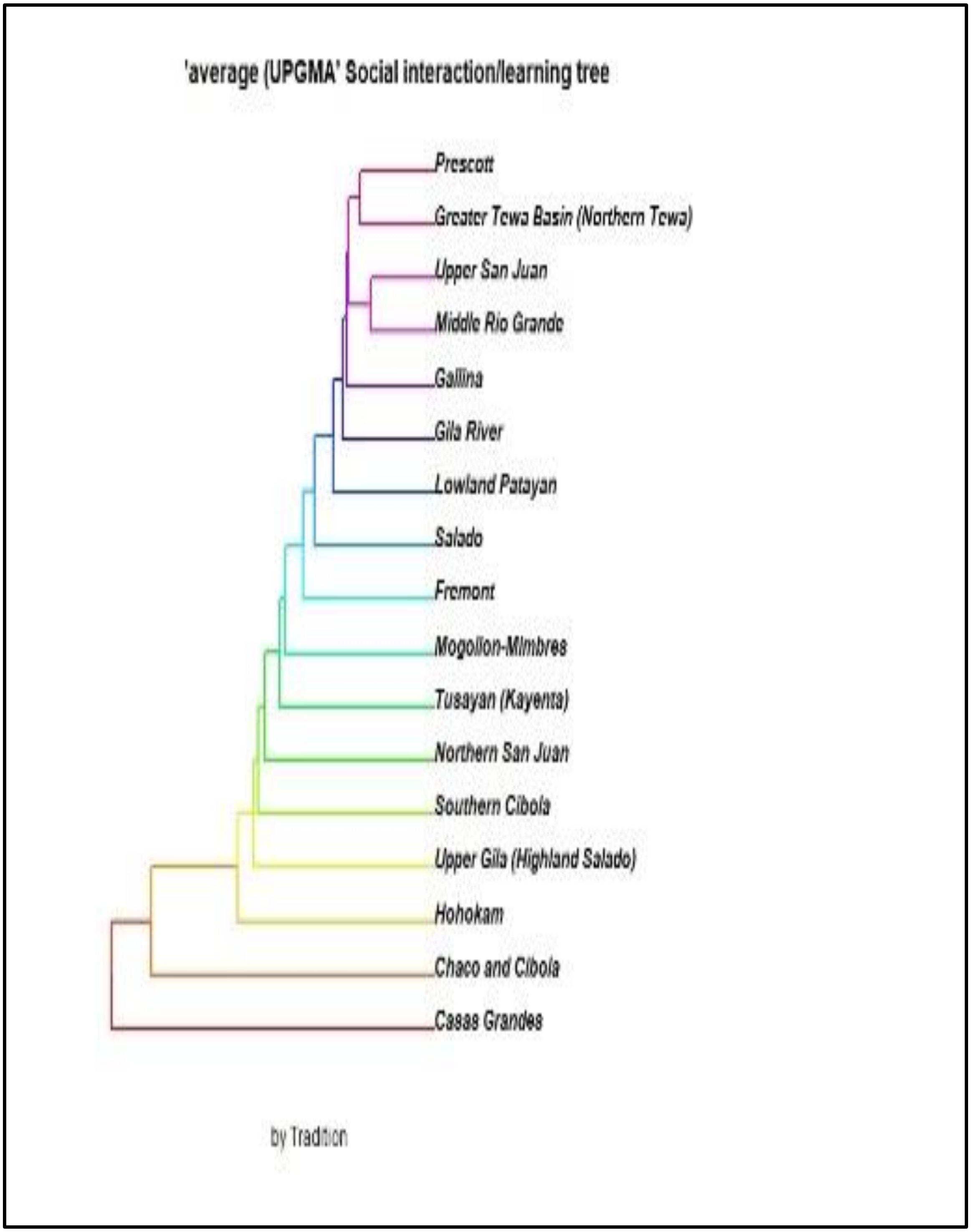


Figure 31 Phylogenetic tree represnting social learning found in Tradition.

Breaking the data down further increases the number of entities involved. Seventeen traditions are represented in this study. Figure 28 is the cladogram generated by R/RStudio. It places the Prescott and the Greater Tewa Basin (Northern Tewa) in one clade, adjacent to the Upper San Juan and the Middle Rio Grande. Next are the Gallina and Gila River, along with the Lowland Patayan. Branching off the clade just described are the Salado, then the Fremont, the Mogollon-Mimbres, the Tusayan Kayenta, the Northern San Juan, the Southern Cibola, and the Upper Gila (Highland Salado). The Hohokam, Chaco and Cibola, and Casas Grandes are in separate clades.

Branch length can be used to show the amount of divergence from the source within a given tree. The longer the branch, the more divergence. Because branch length is indictive of the divergence (EMBL-EBI 2022) that has occurred, Casas Grandes has less in common with the Prescott than does the Upper San Juan or the Middle Rio Grande. Both images suggest interaction among the Cultures but not as much with Chaco and Cibola, or Casas Grandes. The clade consisting of the Gallina, Gila River, Middle Rio Grande, Upper San Juan, and the Greater Tewa Basin Northern Tewa, Prescott and Lowland Patayan is grouped together at the bottom of the diagram. There are indications of a significant amount of blending and sharing of information.

Both the Salado and Fremont Traditions as well as the Traditions of Upper Gila Highland Salado, Northern San Juan, Southern Cibola, Mogollon Mimbres, Upper Gila Highland Salado, Hohokam, and Tusayan Kayenta are involved in the sharing of ideas. On the right side of the diagram, it appears that the Casas Grandes and Chaco and Cibola Traditions interact and thus share ideas, much like both the Middle Rio Grande and Upper San Juan Traditions, and the Greater Tewa Basin Northern Tewa and Prescott Traditions. Each group has more interaction with each other, but still engages in informational transmission with the other 11 Traditions. The appearance of the Neighbor-Net diagram Figure 29 suggests that distribution of ideas was unrestricted, passing freely among each of the Traditions, most probably through trade.

As seen in the heatmap Figure 30, representing the 230 characteristics present in 17 Tradition(s), blue indicates the presence of the characteristic while brown represents the absence. Most of the characteristics shown, although not exactly the same ones, appear in both the Casas Grandes and the Chaco and Cibola Tradition(s), indicating a definite interaction between the groups. The dispersal of characteristics among the remaining 7 Culture(s) indicates interactions among them, most likely through trading or other intermittent associations.

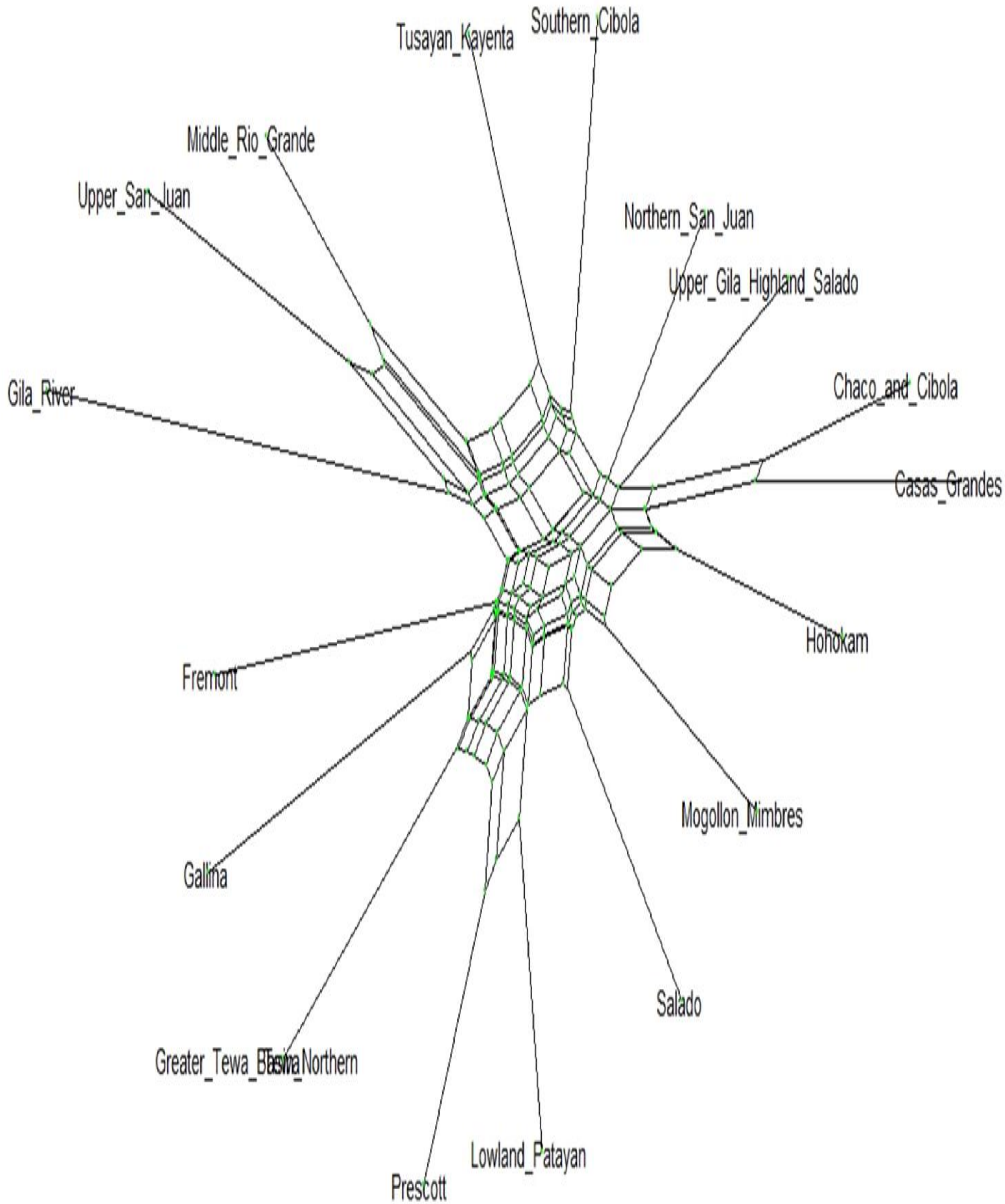


Figure 32 Splits network representing sharing in Tradition.

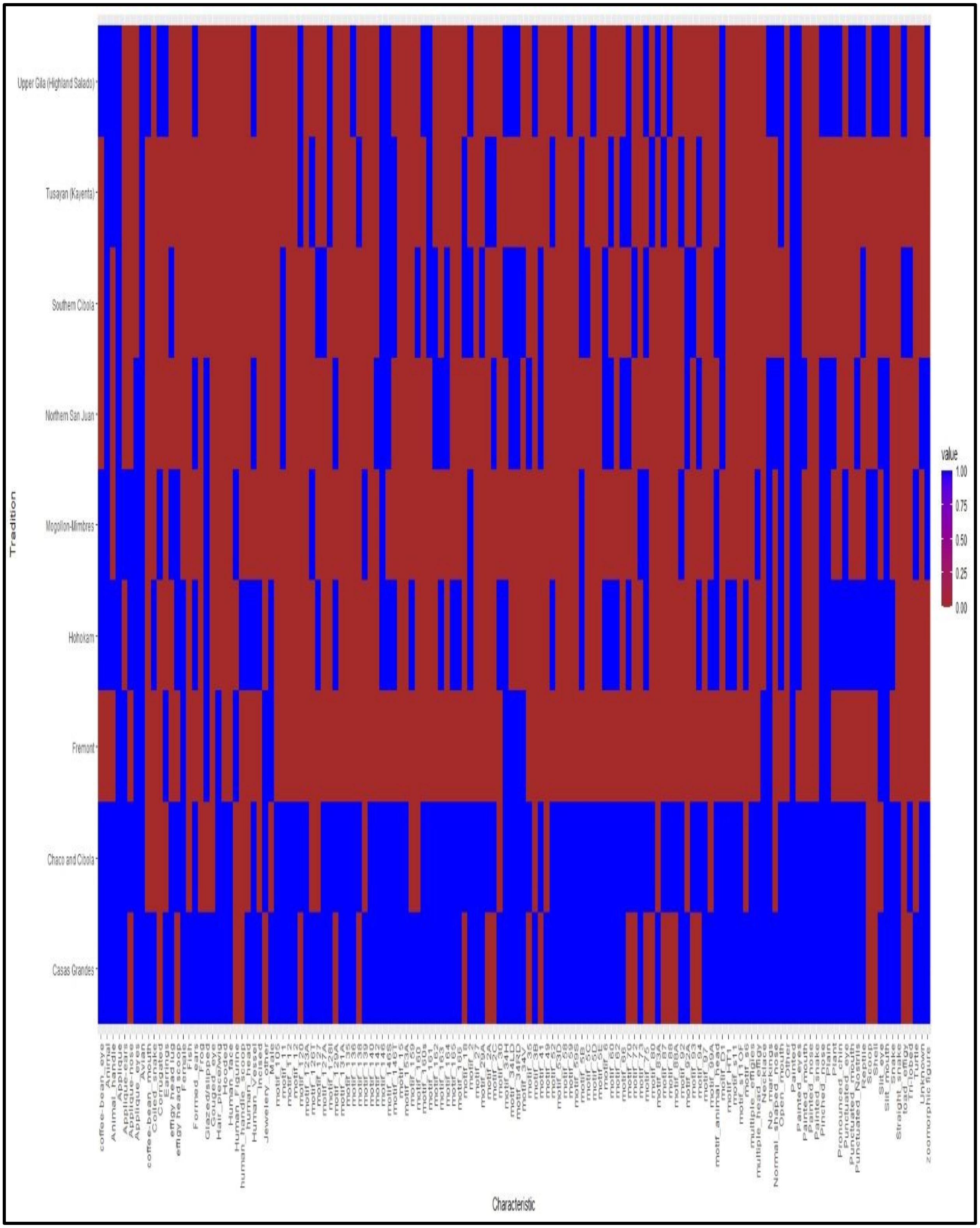


Figure 33 Heatmap of shared traits in Tradition.

Ware

Moving from Tradition to the more specific (in this case, Ware), the number of groups examined increases from 17 to 30. Table 10 lists the abbreviations used in the heatmaps that follow.

Ware	Abbreviation
Chaco Cibola White Ware	CCWW
Casas Grandes Decorated or Polychrome Ware	CGDPW
Gila Salado Utility Ware	GSUW
Casas Grandes Utility Ware	CGUW
Northern San Juan White Ware	NSJWW
Pimeria Brown Ware	PBW
Mimbres Decorated White Ware	MDWW
Tusayan White Ware	TWW
Cibola Tusayan Gray Ware	CTGW
Hohokam	HOHO
Hohokam Buff Ware	HBW
Roosevelt Red Salado Polychrome Ware	RRSPW
Little Colorado White Ware	LCWW
Tsegi Orange Ware	TOW
Mogollon Red Ware	MRW
White Mountain Red Ware	WWRW
Gallina White Ware	GWW
Middle Southern Rio Grande Glaze Ware	MSRGGW
Mogollon San Simon Brown Ware	MSSBW
Lower Colorado Buff Ware	LCBW
Fremont	FREMONT
Upper San Juan White Ware	USJWW
Mogollon Brown Ware	MBW
Winslow Orange	WO
Northern Rio Grande Gray Ware	NRGGW
Prescott	PRESCOTT
Northern San Juan Gray Ware	NSJGW
Northern Rio Grande Historic Plain Ware	NRGHPW
Salado	SALADO
Northern San Juan Red Ware	NSJRW

Table 10-- Name abbreviations for Ware

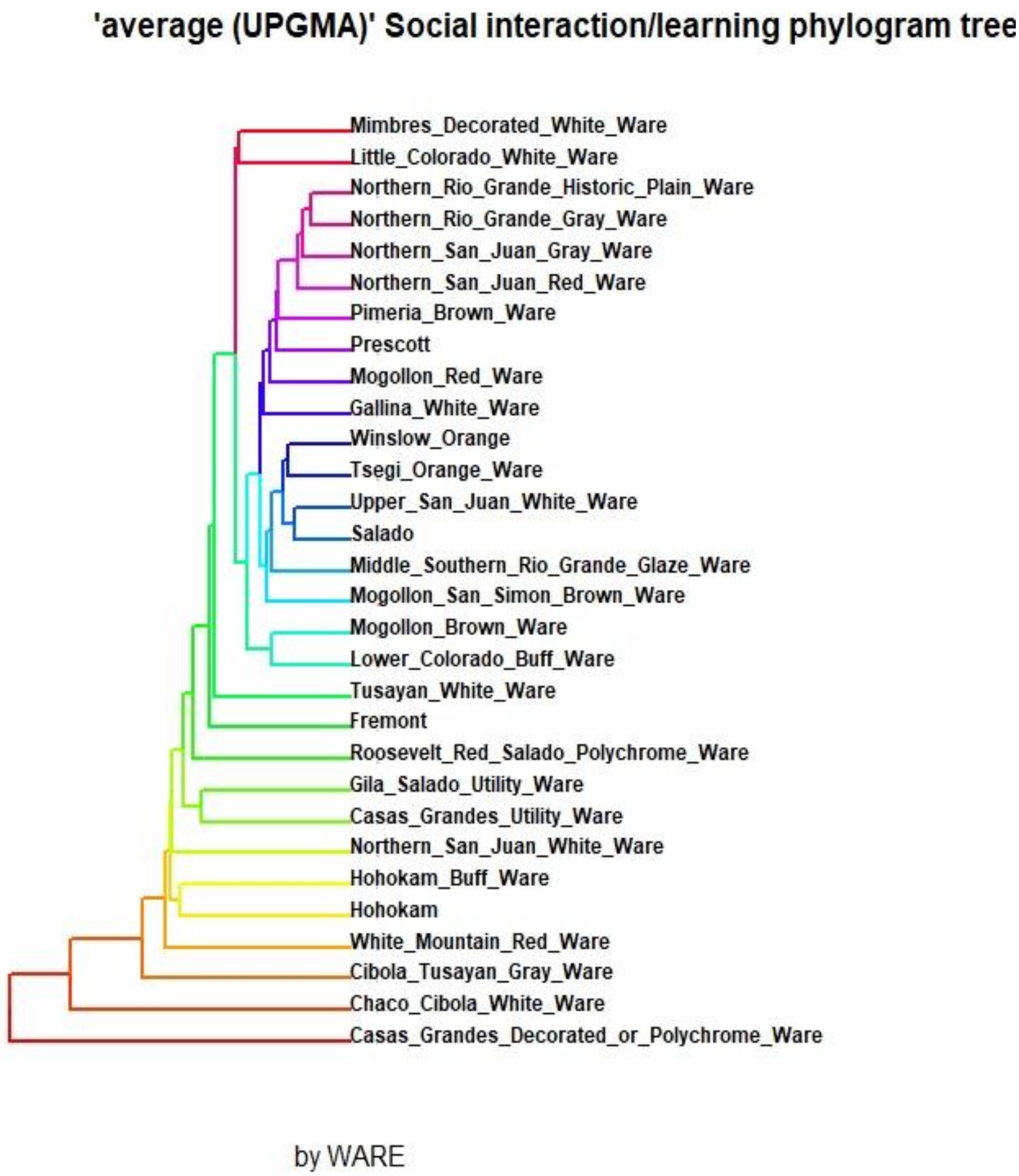


Figure 34 UPGMA Phylogenetic tree showing Ware distribution.

Figure 31 shows the phylogenetic tree as generated in R/RStudio using the “average” or UPGMA algorithm, while Figure 33 shows the same data in heatmap form. In Figure 31, the first clade on the bottom is that of Casas Grandes Decorated or Polychrome Ware (CGDPW). Examining Figure 32, CGDPW is second from the bottom and exhibits the most traits. Branching from Casas Grandes Decorated or Polychrome Ware is Chaco Cibola White Ware (CCWW). Referring to the heatmap, Figure 33 shows CCWW Chaco (Cibola White Ware) on the bottom of the diagram. These two Wares share numerous traits. As each of the Wares branch off into a separate clade, Figure 32 shows a decrease in interaction among the Wares.

The second half of the clade consists of Salado together with Upper San Juan White Ware, and then Tsegi Orange Ware and Winslow Orange.

The entire clade is closed out with Mogollon San Simon Brown Ware. All these Wares are located in an area that includes northern New Mexico, southern Utah, southern Colorado, and eastern Arizona. Tsegi Orange Ware was widely traded across Arizona, Utah, and New Mexico (Peters 2018b).

The last clade represents 10 Wares divided into 4 subclades. The first contains Northern San Juan Red Ware, then Northern San Juan Gray Ware, then Northern Rio Grande Gray Ware, together with Northern Rio Grande Historic Plain Ware. The next branch is Mogollon Red Ware, and the next subclade contains Gallina White Ware together with Pimeria Brown Ware. The last subclade shows Lower Colorado Buff Ware together with Mogollon Brown Ware and Prescott on a separate branch. This group covers an area that includes southern Utah, southern Colorado, most of New Mexico, and much of Arizona. Figure 35 shows the Colorado River Basin, home to many of the Wares in the study.

Figure 35 Colorado River Basin

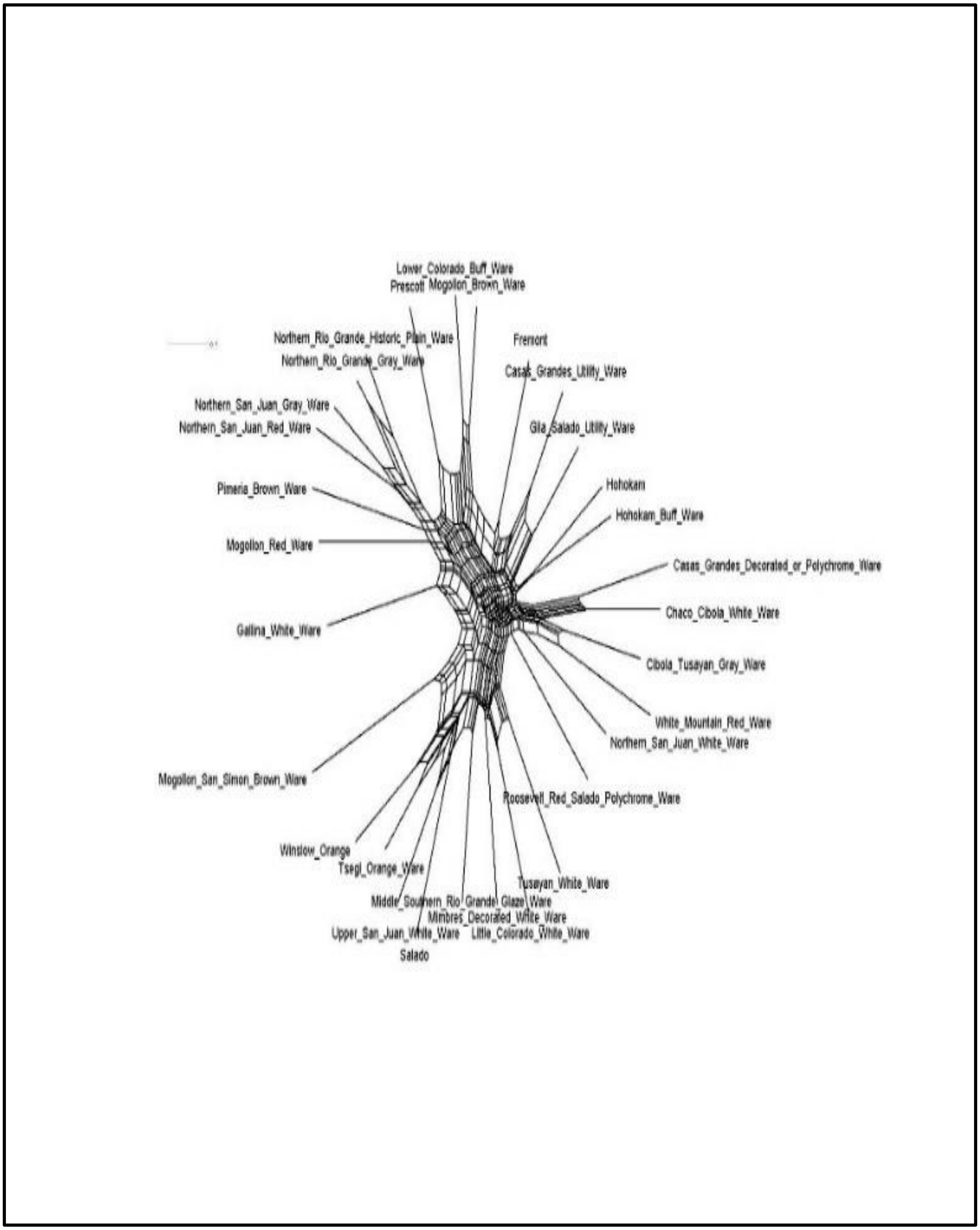


Figure 36 Neighbor-Net diagram of Ware sharing and blending.

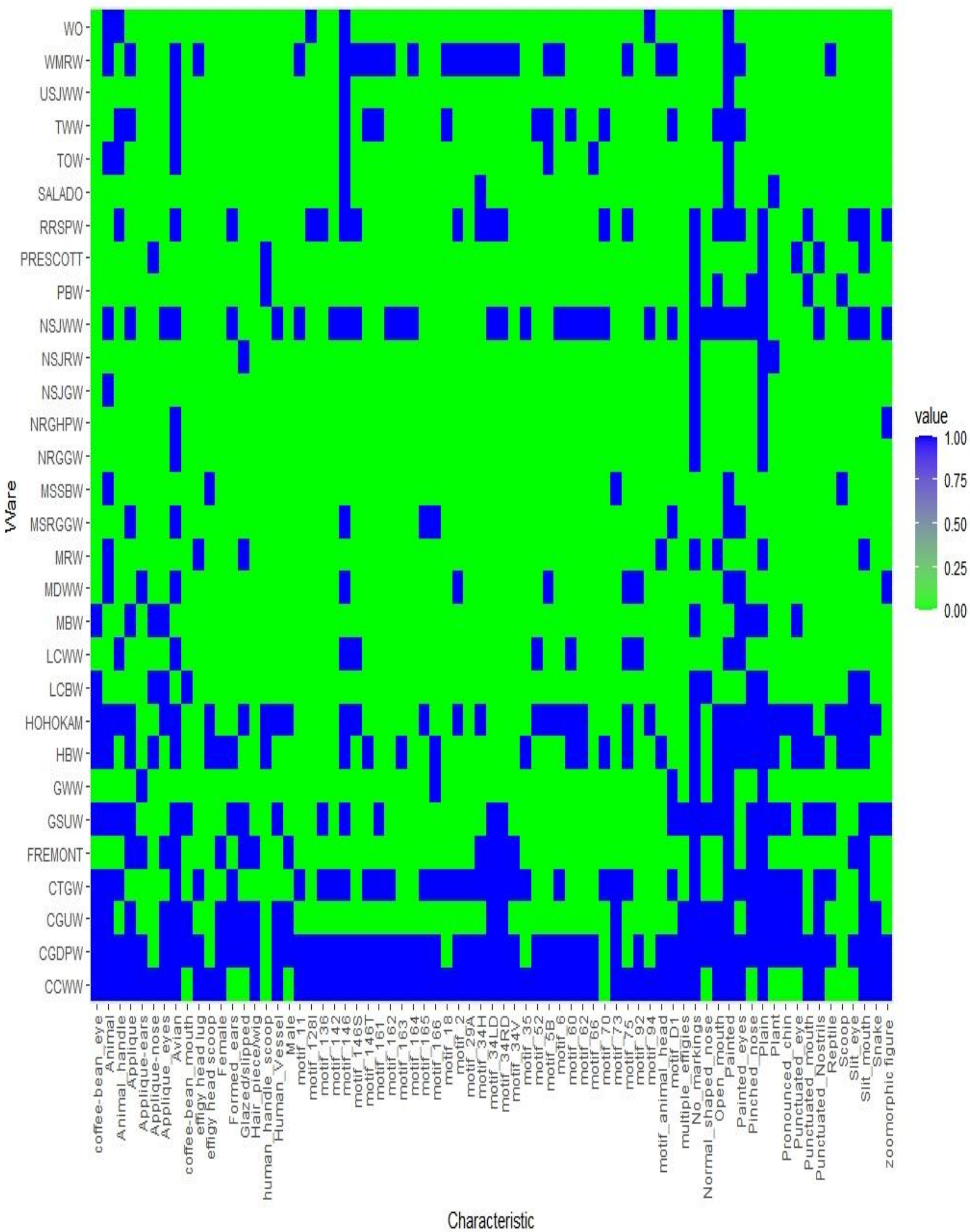


Figure 37 Heatmap showing distribution of traits in Ware groups.

Figure 32 represents a Neighbor-Net diagram of the sharing and blending of the Wares examined. In the lower left corner, Salado and Upper San Juan White Ware are shown together, and Tsegi Orange Ware is with Winslow Orange. The same is true for various other groups. Also noticeable is the amount of blending and sharing among each of the Wares. Even Chaco Cibola White Ware and Casas Grandes Decorated or Polychrome Ware shown on separate branches of the tree diagrams are shown as separate but sharing information.

Thirty Ware(s) represented in the study. As seen in the heatmap in Figure 33, CCWW (Chaco Cibola White Ware), CCDPW (Casas Grandes Decorated or Polychrome Ware), and the CGUW (Casas Grandes Utility Ware) show many shared characteristics or traits. CTGW (Cibola Tusayan Gray Ware) also exhibits similar characteristics as the first 3.

The data for "motifs," shows a wide dispersal across the 30 Ware(s), but no continuous connection, again suggesting transmission by trade or observation. Many of the shared traits are shown to be either forms/shapes or physical characteristics, such as facial features, i.e., eyes, noses, and/or mouths.

Among the most represented of the motifs is Motif 146, a thick line that is found on many human vessels and on other artifacts.

Traits/characteristics seem distributed in such a manner that physical appearance, i.e., mouth, eye, nose structure (open, slit, punctuated, coffee-bean, and appliqued), is shared among the Chihuahua, Central Anasazi, Greater Salado, and Hohokam Branch(s). Motifs are more dispersed across the different Ware(s). A

lthough few, if any, items show up in just one or two Ware(s), which would be the case if the transmission were vertical, many traits/characteristics show up in a limited number of Ware(s). This suggests that the information concerning design was transmitted among various Ware(s) (Bandura 1969; Borgerhoff Mulder et al. 2006)) and then adapted for local use (Rogers 1983).

Type

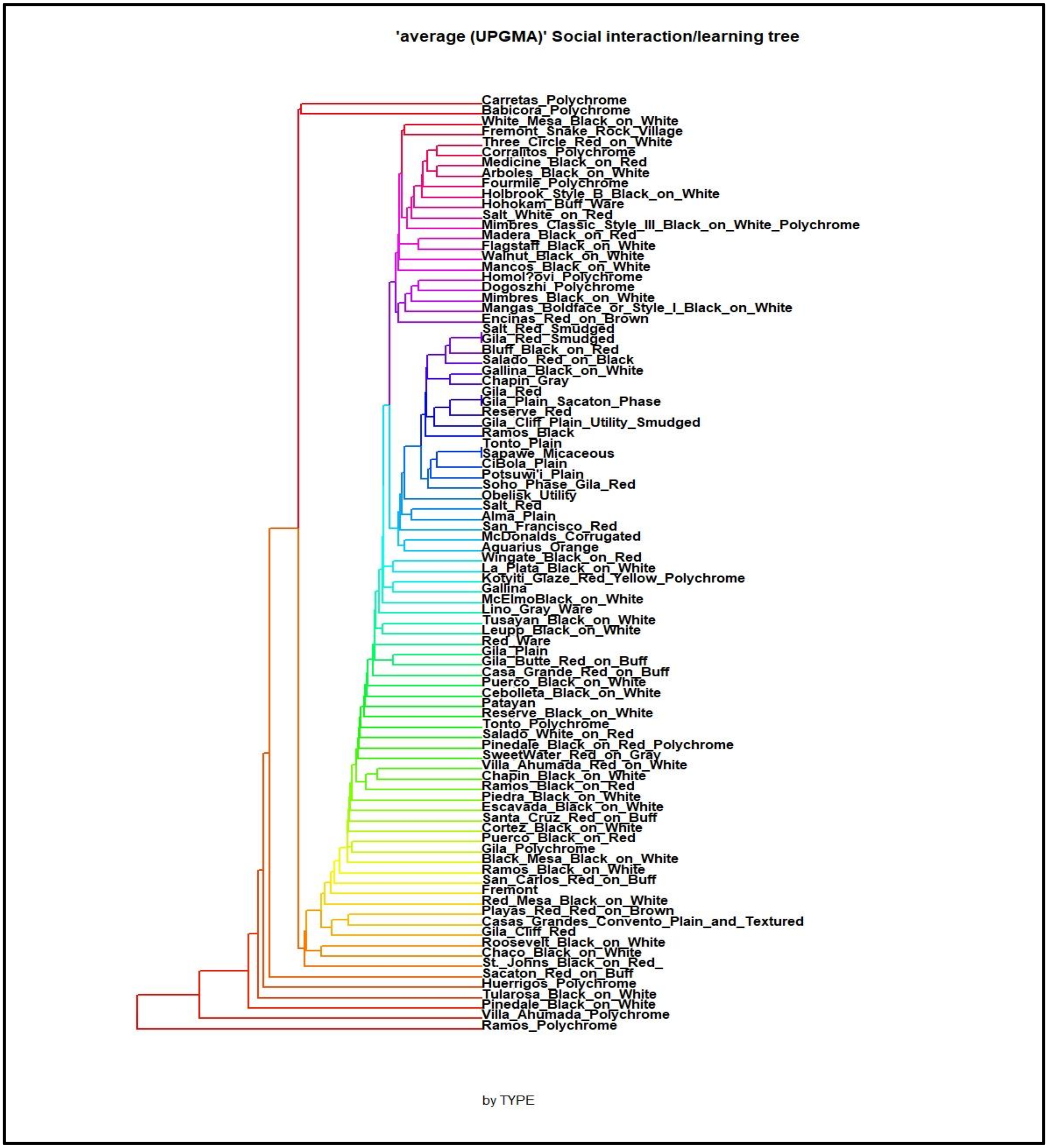


Figure 38 Phylogenetic tree showing the relationships between the 90 different Types.

With Types, we are getting closer to the actual origins of the artifacts. This is a good time to review the analogy of relationships regarding the different cultural data categories, where Culture relates to regions or areas of the country, like West, Midwest, Southwest, Northeast, and Southeast. Branch, then, would be considered the states within each region. Traditions equate to the counties within the states, while Wares represent towns within the counties. At the very bottom are Types. These would be the neighborhoods where the items are manufactured. This data sample holds the 90 Types examined in this study.

Figure 34, generated in R/RStudio, places Types from the Casas Grandes Tradition on a single branch such as Ramos Polychrome, or on a branch off a main branch such as Villa Ahumada Polychrome which branches off of Ramos Polychrome, or on a branch that links with another branch such Huerrigos Polychrome with Carretas and Babicora Polychrome.

Corralitos Polychrome is not included with the other Types in the Casas Grandes Tradition but in a clade with Three Circle Red-on-white from the Mogollon-Mimbres Tradition.

Figure 35 shows the distribution of traits within the Types examined. The nearly solid blue line near the top of the heatmap is Ramos Polychrome. The next Type displaying a large number of traits is Villa Ahumada Polychrome, which shares many of the traits found in Ramos Polychrome. Figure 36 represents a closeup of the 4 Types with the most traits. In addition to the 2 Types named above, Tularosa Black-on-white and Pinedale Black-on-white, both from the Chaco and Cibola Tradition,, also share many of the same traits. This would indicate an interaction among the 4 Types, thus supporting the hypothesis of unlimited interaction, allowing for distribution among Traditions.

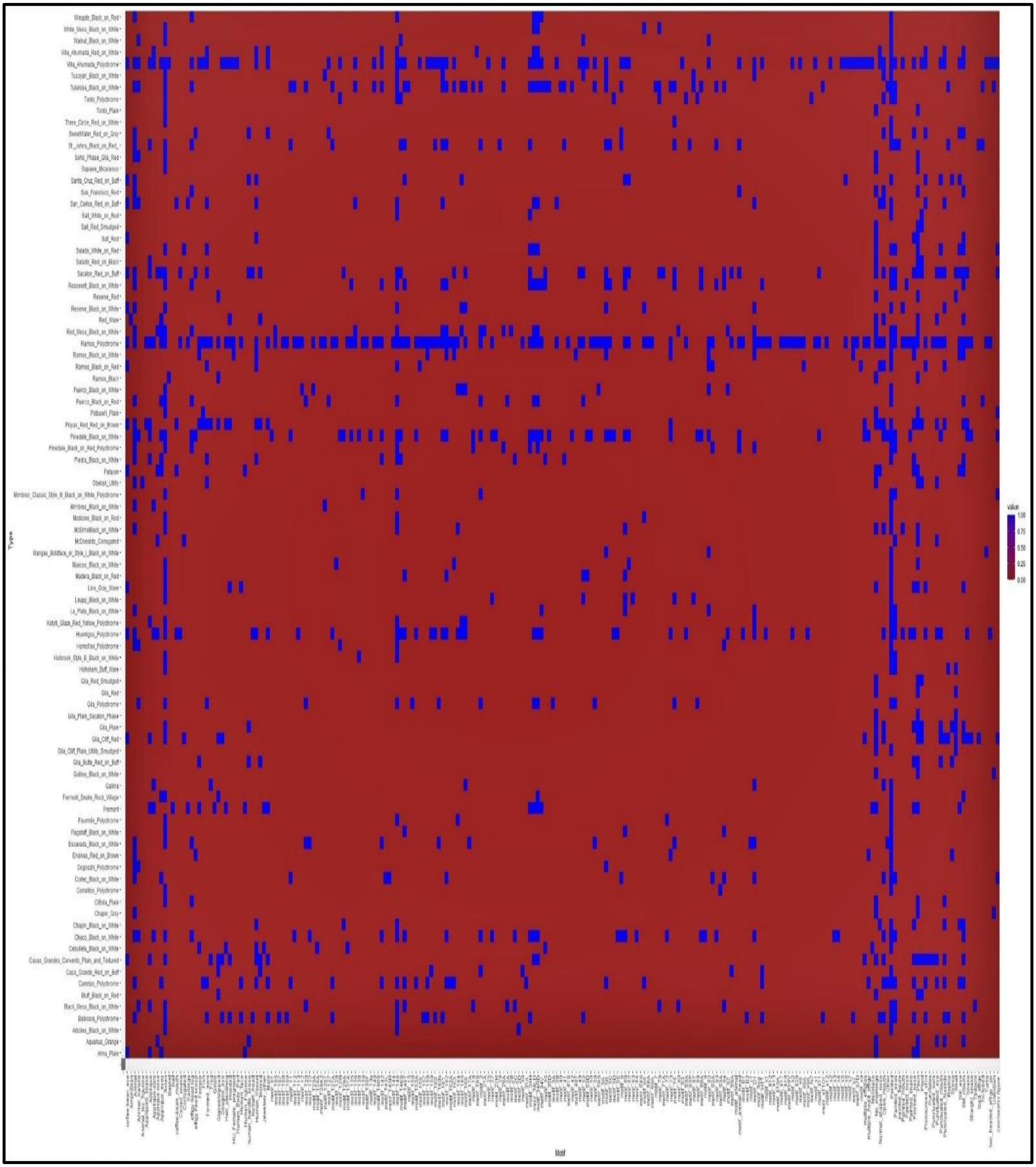


Figure 39 Heatmap showing distribution of traits within Types.

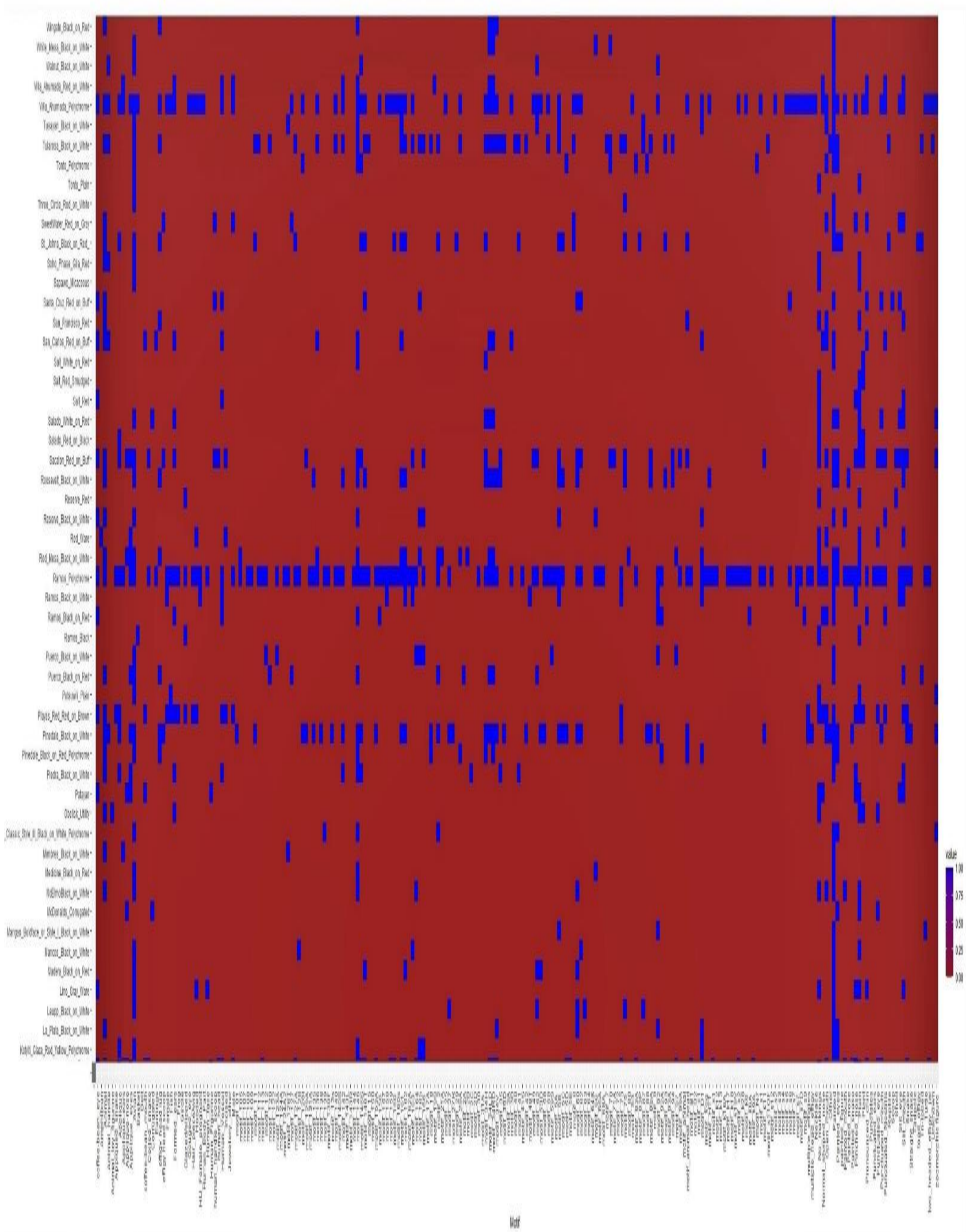


Figure 40 Heatmap showing the 4 dominant Types regarding traits.

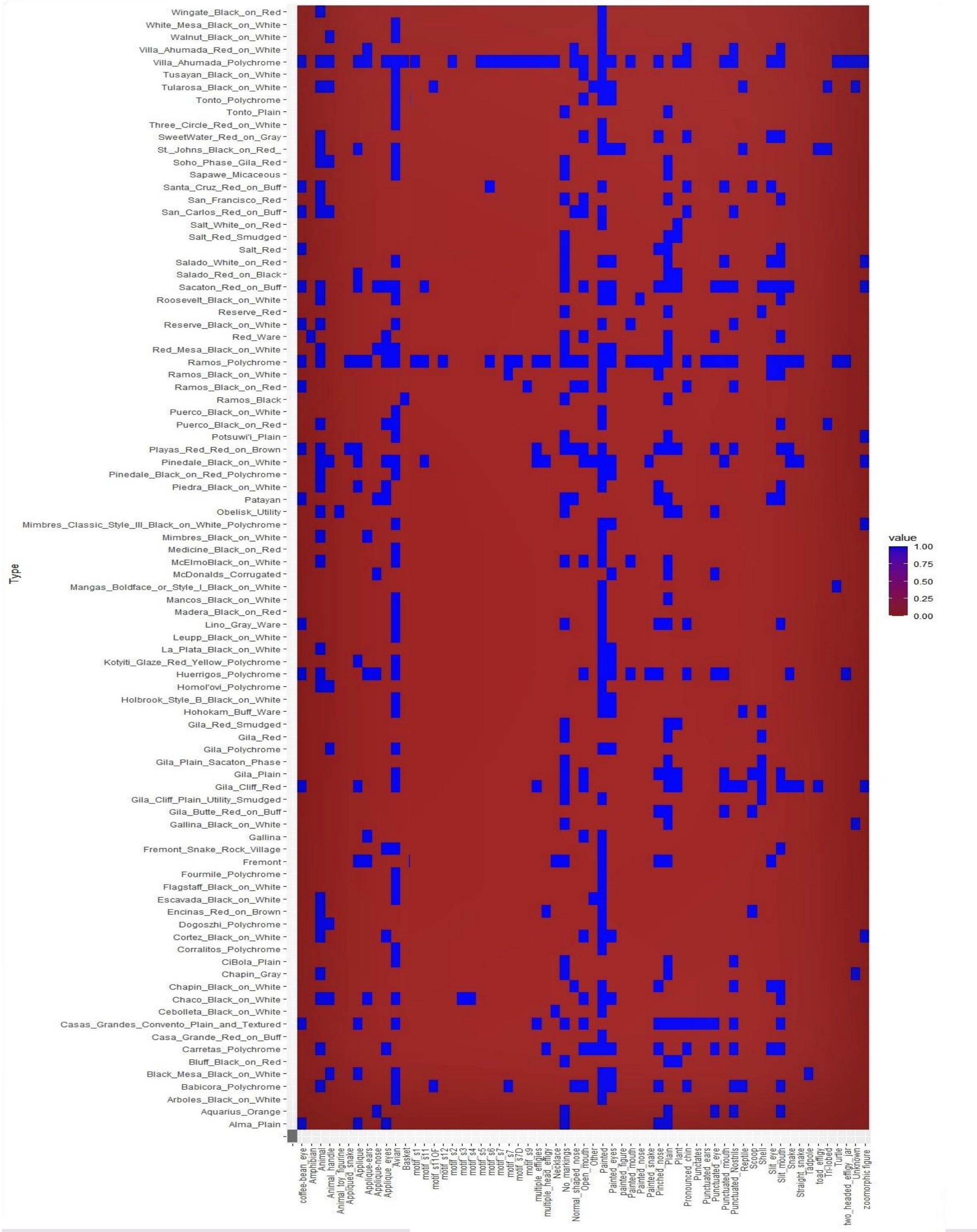


Figure 41 Heatmap showing most commonly shared traits.

As can be seen in Figure 37, at the Type level, the most shared traits on the artifacts are form/shape and physical features. Items such as form/shape could be a result of information transfer among groups or independent invention based on direct observation by the individual creating the object. Because many of the forms/shapes are those of animals, the origination of the shape could be by direct observation. The same can be postulated for physical features; however, the application of the physical features suggests information transfer, i.e., coffee-bean eyes and mouths.

The SplitsTree Neighbor-Net diagrams below, Figures 38 and 39, give a better indication of the interaction among the types. Each figure shows a different section of the Neighbor-Net diagram with the Types that show interaction through blending and sharing.

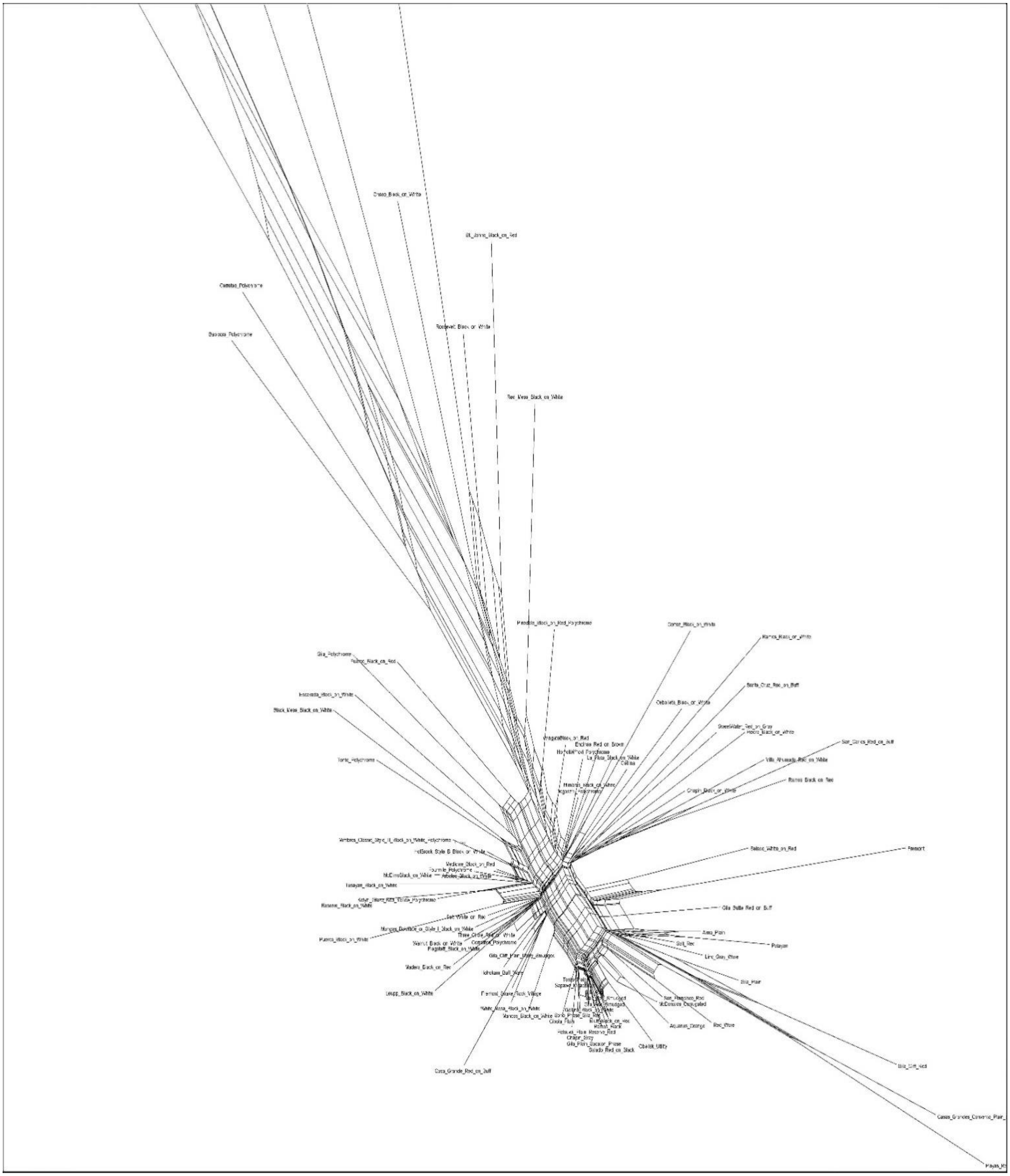


Figure 42 Neighbor-Net diagram of sharing and blending at the Type level.

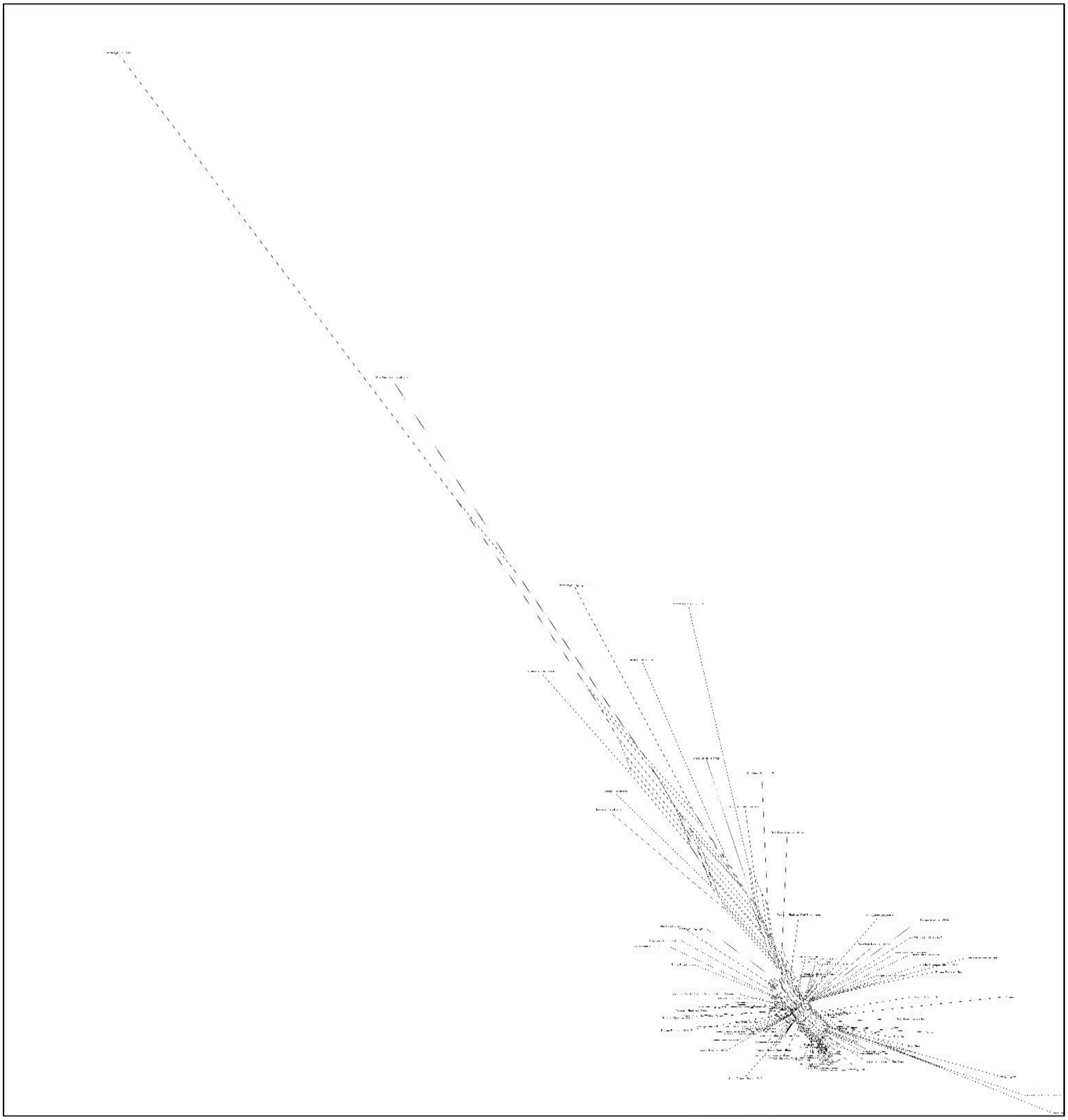


Figure 43 Main body of Neighbor-Net diagram of sharing and blending at the Type level.

Figure 39 shows a closeup of the main section of Figure 38. There is a definite sharing of traits among the different types; however, some Types appear to have restricted their interaction with the main body. One of these is Salt White on Red, another is White Mesa Black on White. Most types appear to have interacted with each other.

The two farthest out, Ramos Polychrome and Villa Ahumada Polychrome, show interaction between each other and with Huerrigos Polychrome, Carretas Polychrome, and Babicora Polychrome. This is to be expected, for all are situated within the Casas Grandes Tradition and have connections with many of the other Types. Figure 38 shows this interaction. The Types are shown in the upper left-hand side of the illustration.

Looking at Figure 39 (an enlargement of the connections shown in Figure 38), reveals several Types in common. In both figures, the Fremont, Gila Cliff Red, Casas Grandes Convento Plain and Textured, and Playas Red-Red on Brown are highlighted, thus indicating that a pathway exists for information to travel among the groups.

In the lower right-hand corner of Figure 38, several Types are highlighted. Among them are Potsuwi'i Plain, Gila Red Smudged, Chapin Gray, Cibola Plain, and Salado Red on Black.

These connections make the transference of information possible throughout the Type system, from the Ramos Polychrome Type to Tusayan Black-on-white (from the Chihuahua Branch to the Western Anasazi Branch). This would indicate a scenario where individuals from different groups would intermingle, observing and sharing ideas. Such intermingling could be the result of trading artifacts in village markets as suggested by van der Leeuw and Papousek (1992). This supports the hypothesis of horizontal transisson with unlimited interaction.

The result of the analysis of the interaction on all levels, Culture, Branch, Tradition, Ware, and Type, show that although some groups did appear to only use vertical transmission (Hypothesis 1, H1), the majority of the interactions regarding the sharing of information was done in an unrestricted way (Hypothesis 1, H2) with information being shared among all groups, not just within a single Tradition (Hypothesis 1, H3).

Although oblique transmission (Hypothesis 1, H4) cannot be completely ruled out, there has been no indication that the transfer of information was dominated by individuals in command or associated with elite groups. Also, data failed to show evidence for the oblique transmission model. Motifs/characteristics were not found to be widespread and consistent across the samples. Although data for the Chihuahua Branch did show consistency throughout its Traditions, the other Branches did not. Nor was there evidence in the data to support the idea of an inclusive regional "religious ideology," as suggested by Crown and Bishop (1994:7). Because recognizable patterns are displayed on all levels, the Null Hypothesis (Hypothesis 1, H5) has been proven false and is, therefore, discarded.

Even though this is a small sample upon which to theorize, some conclusions may still be indicated. Although vertical tranmission was used to teach ceramics in many cases, this vertical transmission was supplemented with external ideas. These ideas were distributed freely and not as the result of socio-religious or political pressures. Individuals, while trading, observed and accepted those ideas of interest, returning to their places of origin to spread them. Table 12 shows the hypothesis and drawn conclusion.

Improvements for future research will include better versions of computer vision programs as well as better tagging techniques for assisting the computer to better visualize the objects being sought. Larger databases of images, already tagged, will assist in image detection.

The second hypothesis was to examine if, through the use of computer image recognition and cladistic analysis, changes in cultural behavior could be determined by the changes in iconographic images. Examination of motifs and other characteristics failed to provide a definite timeline for these changes. Ceramic dating is not accurate enough, generally between 100 to 200 years or so, to provide exact dating, and the database of images with sufficient detailed tagging to allow for evolutionary tracking is also insufficient. Refinements in both areas would allow for the testing of this hypothesis.

HYPOTHESIS	SUPPORTING EVIDENCE	OUTCOME/RESULTS
Hypothesis 1 Social learning hypotheses		
Vertical transmission	Distribution of designs will be restricted to specific Types within Wares.	Found only in a few Types.
Horizontal transmission scenario No.1 Unlimited interaction	Distribution of designs will extend from Types into Wares within a single Tradition, or among Traditions within Branches but not among Cultures	Found to be true in the majority of the cases examined.
Horizontal transmission scenario No. 2 interaction within group only	Distribution of designs will extend from Types into Wares within a single Tradition, but not among Traditions.	Evidence suggests unlimited interaction, not restricted to single group.
Oblique transmission	Distribution of symmetry and design ideas will extend from individual Types through Branches into Cultures.	No evidence for the oblique transmission.
Null hypothesis extensively blended and thus unrecognizably patterned.	Distribution of symmetry and design ideas will be unrestricted, and analysis will reveal extensive sharing and blending of forms and motifs, making it difficult to decide the origin of the form or motif.	Proven false because of recognizable patterns found on all levels.
Hypothesis 2 Tracking major changes in sociopolitical and religious ideologies		Insufficient data to form conclusion
Null hypothesis extensively blended and thus unrecognizably patterned.	Distinct signals referring to a specific group will not be readily available, as blending and sharing of information will distort the signal	Null hypothesis stands.

Table 11 Conclusions drawn from analysis of transmission data.

Chapter 9 addresses the basic questions sought to be answered in this study, discusses the work done, and offers some conclusions.

Chapter 9: Discussion and conclusion

The aim of this dissertation is to discuss the possible practices of cultural information transmission and to examine several different hypotheses related to that transfer. Four hypotheses are discussed in two sets.

The first set relating to the transfer of information among the different peoples of the Southwestern United States and Northern Mexico was different. Sufficient studies have been done regarding the collection and classification of ceramic material from these areas.

The set of hypotheses related to the first question, "How was information transferred concerning effigy form and/or shape and decoration transferred?" are based on the three current types of transmission: vertical, horizontal, and oblique. Vertical transmission is where a parent (or instructor) transfers information to a child (student) from strictly within a group.

The second mode of transmission is horizontal. This study divides horizontal transmission is divided into two separate modes: the first, horizontal transmission scenario No. 1 with unlimited interaction allows for distribution among Traditions; and second, horizontal transmission scenario No. 2, allows interaction within group only, restricting horizontal transmission to interaction within the group and allowing transmission among Types/Wares confined by a Tradition.

The third mode of transmission, oblique, suggests that the introduction of ideas by adults, masters, or institutions of elite or higher social status, either internally or externally to the adopting cultural Type (Jensen 2016; Jordan 2014:24-26), causes traits to be adopted or left out in disproportionate ways, creating patterns in localized traditions that can be empirically identified. In this model, cultural or sociopolitical influences would periodically dictate new ways of decorating effigy vessels that would modify previous symbols and patterns, thus leading to novel yet recognizable forms.

Although there was little to work with for the second set of hypotheses, it asks the question "Can we, through changes in effigy artifact form and/or shape and decoration, track major changes in sociopolitical and religious ideologies?" Several problems arise when looking at this question:

- Dating of ceramic artifacts is not an exact science. The most prevalent method, the use of pottery styles, has been used for decades (Zorich 2021). Only recently (last 40 years or so), has radiocarbon dating been used. This lack of precise dating restricts the use of ceramic artifacts in attaching ceramic changes to socio-political and cultural changes.
- A second problem that arises is that there are multiple names for many of the different ceramic types found in the American Southwest and northern Mexico (Colton 1953), as archaeologists named them based on the geographic area in which they were first discovered and on their association with the Ware group that reflects their overall form and surface finish (Colton 1954).

The photographs of artifacts collected for this study came from collections found at numerous universities and colleges, and from private collections. A database of images found on the web was compiled (13,850 images after manipulation) and then used to train the computer vision program YOLOv5. After the training session (the program was set to train for 150 epochs and ran for 96.947 hours) the sample database consisted of 361 artifacts represented by 871 images. Out of the 871 images, Yolov5l found targets on 283 images. Numerous images received multiple hits. Total analysis time was 53.140 seconds.

Placing the information collected from the vision analysis into a spreadsheet, the data was separated by Culture, Branch, Tradition, Ware, and Type, and prepared for analysis in R/RStudio. In R/RStudio, both phylogenetic trees and heatmaps were prepared for examination (see Appendix A for sample r-script). Checking data for phylogenetic signals at the Tradition level using Moran's I index, (one of the methods found in Phylosignal an R package developed by Keck et al. (2016), where +1 is a perfect signal and -1 is no signal), results ranged from a positive 0.1153 for the Prescott tradition to a negative 0.0088 for the Galina tradition. These figures indicate while there was sharing between Traditions, it was minor.

Examination of both the phylogenetic trees and the heatmaps, especially at the Type level, suggests that the dispersal of information concerning shape/form and decoration of effigy ceramics was more random than ordered. Figure 36 shows that out of 90 Types, eight have the greatest interaction or sharing:

- Villa Ahumada Polychrome
- Ramos Polychrome
- Playas Red Red-on-brown
- Babicora Polychrome
- Corralitos Polychrome
- Huerrigos Polychrome
- Chaco Black-on-white
- Pinedale Black-on-white

The first six are in the Casas Grandes Tradition and the last two are in the Chaco and Cibola Tradition, suggesting that geographical relationships play a part in the type of information transmission that occurs.

For many years culture historians believed that cultural transmission was a useful tool to track the flow of ideas through time and match artifacts with the norms of a culture (normative theory) (Lyman and O?Brien 2004). Although denigrated by Binford (1965) and placed on the fringe of archaeological theory since the 1960s, beginning in the early 2000s, a minor resurrection appears to have occurred. In 2003, the following definition of the normative concept of culture was given by Sharer and Ashmore (2003), “the normative concept of culture holds that within a given society, behavior patterns are the result of adherence to a set of rules, or *norms*, for behavior….the remains of past cultures recovered by the archaeologist may be assumed to represent past behavioral norms….Pottery can be viewed as a reflection of norms” (Sharer and Ashmore 2003).

Viewed in this light, the method of transmission of information is also a “reflection of norms.” The distribution of traits found on effigy artifacts reflects the mode of transmission among individual groups or populations. At the Tradition level, the data shows (Figure 33) strong evidence that the Chaco and Cibola Tradition, and the Casas Grandes Tradition shared many common ideas. This evidence suggests that Lekson’s hypothesis (Lekson 1999; Lekson and Van Dyke 2015) regarding the migration of the inhabitants of Chaco Canyon southward to Paquimé might be correct. On the other hand, Crown and Bishop’s hypothesis (Crown and Bishop 1994) concerning an inclusive regional “religious ideology” defined by specific symbolic images does not appear to be the case as none of the motifs examined was found to be continuously distributed throughout any of the datasets, Type, Ware, Tradition, Branch, or Culture.

Debates regarding how Southwestern regional areas functioned has ranged from arguing about managerial hierarchies and political complexity (Feinman et al. 2000) to a corporate-network continuum with councils of authorities who used their power to control many of the aspects of communal life (Feinman et al. 2000). This control would be the driving force for the hypothesis of a "religious ideology," as stated by Crown and Bishop (1994) and Gilman et al. (2014), that was controlled by the powerful elite, providing an easy method of communication. This study shows that there is no universally shared set of motifs/icons within the Southwest. Much of the shared traits that have been found are those of form/shape, something that could come from either independent invention (direct observation) or through information transfer. Other shared traits are physical, i.e., applique attachments to figures or figurines, including eyes, noses, necklaces, etc.

As with other studies that looked at motifs within cultural groups, (Zaslow 1977), Zaslow (1990), (Zaslow 1980), Zaslow and Dittert (1977), Washburn et al. (2010), and others, analysis shows the transfer of information can be traced among groups. Although Zaslow and the others examined individual groups, this study was conducted on a macro scale involving 90 different groups. It showed that the evolutionary history of information transfer concerning a trait can be traced. Further studies, with more detailed tagging and a larger sample database, will substantiate this work.

The End

Appendix A: Computer programs

The following computer programs and their methods were used in this study:

SplitsTree5 5.0.0_alpha (Huson and Bryant 2006; D. Huson 1998).

- The Hamming Distances method (Hamming 1950)

was used (default options) to obtain the distance matrix. The Hamming Distances method examines two strings of equal length and returns with information about the number of positions needed to differentiate one sequence from another or where corresponding characters in each sequence differ.

The Neighbor Net method (Bryant and Moulton 2004) was used (default options) to obtain splits, cyclic. Based on the Saitou and Nei Neighbor-Joining (NJ) algorithm, this method enables the creation of detailed networks.

- The Splits Network Algorithm method (Dress and Huson 2004)

was used (default options) to obtain a Splits Network with nodes and edges.

- The UPGMA method (Sokal and Michener 1958)

was used (default options) to obtain one tree.

- The Tree Embedder method (Huson et al 2012)

was used (default options) to obtain a rooted tree drawing.

Sample SplitsTree program:

```
#nexus
[! Seeking a Common Origin
Branch without dates
PhD Dissertation
Lee R Tallier Jr 2022
Processed by SplitsTree4]

BEGIN Taxa;
DIMENSIONS ntax=11;
TAXLABELS
[1] 'Central_Anasazi'
[2] 'Chihuahua'
[3] 'Eastern_Mountain_Anasazi'
[4] 'Fremont'
[5] 'Greater_Salado'
[6] 'Hohokam'
[7] 'Mogollon_Highlands'
[8] 'Northern_Rio_Grande'
[9] 'Southern_Patayan'
```

[10] 'Southern_Rio_Grande'
[11] 'Western_Anasazi'
;
END; [Taxa]

BEGIN Characters;
DIMENSIONS nchar=230;
FORMAT
datatype='standard' missing=? gap=- symbols="01" labels=left transpose=no interleave=no;
MATRIX
'Central_Anasazi'
111000110111111110111111101001011110111110110011010000010110011001011110111110111
1101011111111111110111111100111100101101111111111101111010111111000000111101010 0
1010111111111011001111100110000010000000011100110001111010100001000000
'Chihuahua'
10101111111111111111110111101111111111100111011111101011111111010111101100001111
11110100001001111111100011110100010111111100000011110001111111111011110011111111
1111011111000111111001011011111111111111100011011111100101011011111111
'Eastern_Mountain_Anasazi'
00000000000010000001000000000000111000100000000000000100000000100000000000000000
00001000000000000000100000000000000000000000000000000000000000010000000000000000000
0000000000000000000000000000000000000000000000000000000000000001000000
'Fremont'
01111110010110000000000110000111111011001000000000000000000000000000000000000000
00000000000000000000000000000000000000000000000000000000000000000000000000000000
0000001111000000000000000000000000000000000000000000000000000000000000
'Greater_Salado'
00000101110101111011000011110001111011100100011011010010100000000001000010000000 0
00010000000000000000100001001000100000000101100001001100000000010001000010000000 00
0000001110000000000000100000000000000000000000100000100000000000111000000
'Hohokam'
00000001011101011011001110100111111111100100101010010011000000111000000010000001 0
00010100000000101000110001000100011000010001100000000000001011001000000000100001000
0000001000010010100000000000000000100000001010000000000000000010000010000
'Mogollon_Highlands'
00000001001110000001100111001000111101110100001000011000000000001000011000000000000
00010000000000000000100000100000000101001000010000000000000000000000000000010000000
0000000000000000000000000000000000000000000000000000000000000000000001

'Northern_Rio_Grande'
00000000000000000000000000000001100001000000010100000000000000000000000000000000
00000000000000000000000000000000000000000000000000000000000000000000000000000000
0000000000000000000000000000000000000000000000000000000000000000000000

'Southern_Patayan'
00000001010100100000001111000001100000001000000000000000000000000000000000000000
00000000000000000000000000000000000000000000000000000000000000000000000000000000
0000000000000000000000000000000000000000000000000000000000000000000000

'Southern_Rio_Grande'
00000000000000000001000000000000011001000000000000000000000000000000000000000000
00000000000000000001000000000000000000000000000000000000001100000000000000000000
0000000000000000000000000000000000000000000000000000000000000001000000

'Western_Anasazi'
00000000001000010011001010000001111001100000100000000100000000000000000100000000
00000010010001000001110010010000000100100010001000011000100000000000000000000000
0000000000100000000000000001000000000000000000000000000001000000100001

;

END; [Characters]

BEGIN Distances;

DIMENSIONS ntax=11;

FORMAT labels=left diagonal triangle=both;

MATRIX

[1] 'Central_Anasazi' 0.0 0.5217391 0.59130436 0.5652174 0.4826087 0.46521738 0.54347825 0.6130435 0.59565216 0.59130436 0.5

[2] 'Chihuahua' 0.5217391 0.0 0.6956522 0.66086954 0.5869565 0.56956524 0.6478261 0.7173913 0.70869565 0.70434785 0.6826087

[3] 'Eastern_Mountain_Anasazi' 0.59130436 0.6956522 0.0 0.11304348 0.23043478 0.2652174 0.13478261 0.047826085 0.08260869 0.04347826 0.14347826

[4] 'Fremont' 0.5652174 0.66086954 0.11304348 0.0 0.23043478 0.2652174 0.1521739 0.1 0.09130435 0.11304348 0.20434782

[5] 'Greater_Salado' 0.4826087 0.5869565 0.23043478 0.23043478 0.0 0.26086956 0.22608696 0.22608696 0.2173913 0.22173913 0.2347826

[6] 'Hohokam' 0.46521738 0.56956524 0.2652174 0.2652174 0.26086956 0.0 0.22608696 0.26956522 0.2521739 0.24782608 0.24347825

[7] 'Mogollon_Highlands' 0.54347825 0.6478261 0.13478261 0.1521739 0.22608696 0.22608696 0.0 0.13043478 0.12173913 0.13478261 0.16521738

[8] 'Northern_Rio_Grande' 0.6130435 0.7173913 0.047826085 0.1 0.22608696 0.26956522 0.13043478 0.0 0.052173913 0.047826085 0.14782609

```
[9] 'Southern_Patayan'              0.59565216 0.70869565 0.08260869 0.09130435 0.2173913
0.2521739 0.12173913 0.052173913 0.0 0.08260869 0.16521738
[10] 'Southern_Rio_Grande'          0.59130436 0.70434785 0.04347826 0.11304348 0.22173913
0.24782608 0.13478261 0.047826085 0.08260869 0.0 0.13478261
[11] 'Western_Anasazi'              0.5 0.6826087 0.14347826 0.20434782 0.2347826 0.24347825
0.16521738 0.14782609 0.16521738 0.13478261 0.0
;
END; [Distances]

BEGIN Sets;
  TAXSET 'Outgroup' = 'Central_Anasazi';
END; [Sets]

BEGIN Trees;
[TREES]
    [1] tree 'UPGMA'=[&R]
(Eastern_Mountain_Anasazi:0.02173913,Southern_Rio_Grande:0.02173913,(Northern_Rio_Gra
nde:0.023913043,(Southern_Patayan:0.036231883,(Fremont:0.052173913,(Mogollon_Highlands
:0.067391306,(Western_Anasazi:0.08007246,(Greater_Salado:0.113354035,(Hohokam:0.12690
218,(Central_Anasazi:0.26086956,Chihuahua:0.26086956):0.6067633):0.013548137):0.0332815
72):0.012681159):0.015217391):0.01594203):0.01231884):0.002173913);
END; [Trees]

BEGIN Splits;
DIMENSIONS ntax=11 nsplits=19;
FORMAT labels=no weights=yes confidences=no intervals=no;
PROPERTIES fit=58.09 compatible;
CYCLE 1 2 3 10 8 9 4 7 11 5 6;
MATRIX
[1, size=1]     0.02173913      1 2 4 5 6 7 8 9 10 11,
[2, size=1]     0.02173913      1 2 3 4 5 6 7 8 9 11,
[3, size=1]     0.023913043     1 2 3 4 5 6 7 9 10 11,
[4, size=1]     0.036231883     1 2 3 4 5 6 7 8 10 11,
[5, size=1]     0.052173913     1 2 3 5 6 7 8 9 10 11,
[6, size=1]     0.067391306     1 2 3 4 5 6 8 9 10 11,
[7, size=1]     0.08007246      1 2 3 4 5 6 7 8 9 10,
[8, size=1]     0.113354035     1 2 3 4 6 7 8 9 10 11,
[9, size=1]     0.12690218      1 2 3 4 5 7 8 9 10 11,
```

```
[10, size=1]    0.26086956     1,
[11, size=1]    0.26086956     1 3 4 5 6 7 8 9 10 11,
[12, size=2]    0.6067633      1 2,
[13, size=3]    0.013548137    1 2 6,
[14, size=4]    0.033281572    1 2 5 6,
[15, size=5]    0.012681159    1 2 5 6 11,
[16, size=5]    0.015217391    1 2 5 6 7 11,
[17, size=4]    0.01594203     1 2 4 5 6 7 11,
[18, size=3]    0.01231884     1 2 4 5 6 7 9 11,
[19, size=2]    0.002173913    1 2 4 5 6 7 8 9 11,
;
END; [Splits]

BEGIN Network;
DIMENSIONS ntax=11 nvertices=21 nedges=20;
DRAW to_scale;
LAYOUT rectilinear;
TRANSLATE
2 'Eastern_Mountain_Anasazi',
3 'Southern_Rio_Grande',
4 'Northern_Rio_Grande',
5 'Southern_Patayan',
6 'Fremont',
7 'Mogollon_Highlands',
8 'Western_Anasazi',
9 'Greater_Salado',
10 'Hohokam',
11 'Central_Anasazi',
12 'Chihuahua',
;
VERTICES
1 -9.0 6.5 s=n,
2 0.0 3.0 s=n,
3 0.0 4.0 s=n,
4 0.0 5.0 s=n,
5 0.0 6.0 s=n,
6 0.0 7.0 s=n,
```

```
7 0.0 8.0 s=n,
8 0.0 9.0 s=n,
9 0.0 10.0 s=n,
10 0.0 11.0 s=n,
11 0.0 1.0 s=n,
12 0.0 2.0 s=n,
13 -8.0 7.0 s=n,
14 -7.0 6.5 s=n,
15 -6.0 6.0 s=n,
16 -5.0 5.5 s=n,
17 -4.0 5.0 s=n,
18 -3.0 4.5 s=n,
19 -2.0 4.0 s=n,
20 -1.0 3.5 s=n,
21 -10.0 6.0 s=n,
;
VLABELS
2 'Eastern_Mountain_Anasazi' l=7 f='Dialog-PLAIN-24',
3 'Southern_Rio_Grande' l=7,
4 'Northern_Rio_Grande' l=7,
5 'Southern_Patayan' l=7,
6 'Fremont' l=7,
7 'Mogollon_Highlands' l=7,
8 'Western_Anasazi' l=7,
9 'Greater_Salado' l=7,
10 'Hohokam' l=7,
11 'Central_Anasazi' l=7,
12 'Chihuahua' l=7,
;
EDGES
1 12 1 s=11,
2 13 10 s=9,
3 1 13 s=12,
4 14 9 s=8,
5 13 14 s=13,
6 15 8 s=7,
7 14 15 s=14,
```

```
8 16 7 s=6,
9 15 16 s=15,
10 17 6 s=5,
11 16 17 s=16,
12 18 5 s=4,
13 17 18 s=17,
14 19 4 s=3,
15 18 19 s=18,
16 20 2 s=1,
17 20 3 s=2,
18 19 20 s=19,
19 11 21 s=10 w=0.5,
20 1 21 s=10 w=0.5,
;
INTERNAL
1 -9.0 2.0,
2 -8.0 11.0,
3 -9.0 7.0,
4 -7.0 10.0,
5 -8.0 6.5,
6 -6.0 9.0,
7 -7.0 6.0,
8 -5.0 8.0,
9 -6.0 5.5,
10 -4.0 7.0,
11 -5.0 5.0,
12 -3.0 6.0,
13 -4.0 4.5,
14 -2.0 5.0,
15 -3.0 4.0,
16 -1.0 3.0,
17 -1.0 4.0,
18 -2.0 3.5,
19 -10.0 1.0,
20 -10.0 6.5,
;
END; [Network]
```

```
BEGIN st_Assumptions;
uptodate;
chartransform=Uncorrected_P;
disttransform=UPGMA;
treestransform=TreeSelector;
splitstransform=Phylogram Cladogram = true Angle = 60.0 Slanted = false;
SplitsPostProcess filter=dimension value=4;
 exclude  no missing;
autolayoutnodelabels;
END; [st_Assumptions]
```

R and RStudio methods:

Using RStudio, an Integrated Development Environment (IDE) for the R programming language, an additional analysis of the data for this project was done in R, a language and environment for statistical computing and graphics.

The following statistical packages were used in the analysis:

- Ape:

Functions include reading, writing, plotting, and manipulating phylogenetic trees, analyses of comparative data in a phylogenetic framework, and ancestral character analyses. Phylogeny estimation can be done with the NJ, BIONJ, ME, MVR, SDM, and triangle methods, and with several methods that handle incomplete distance matrices, including NJ*, BIONJ*, MVR*, and the corresponding triangle method (Paradis and Schliep 2019).

- Phangorn for Phylogenetic Reconstruction and Analysis:

Phangorn allows for the estimation of phylogenetic trees and networks using Maximum Likelihood, Maximum Parsimony, distance methods, and Hadamard conjugation. It also offers methods of tree comparison, model selection, and visualization of phylogenetic networks (Schliep et al. 2017; Schliep 2016).

- hclust: Hierarchical Clustering:

This function performs a hierarchical cluster analysis using a set of dissimilarities for the \(n\) objects being clustered. At each stage, distances between clusters are recomputed by the Lance-Williams dissimilarity update formula, according to the particular clustering method being used. (R. C. Team 2021). The agglomeration method should be (an unambiguous abbreviation of) one of "ward.D," "ward.D2,", "single," "complete," "average" (= UPGMA), "mcquitty" (= WPGMA), "median" (= WPGMC), or "centroid" (= UPGMC). The default is "average." UPGMA and WPGMA clustering are wrapper functions around hclust. “Note, however, that methods ‘median’ and ‘centroid’ are not leading to a monotone distance measure, or equivalently the resulting dendrograms can have so-called inversions or reversals which are hard to interpret” (Legendre 2012).

- Tidyverse:

Tidyverse is a language for solving data science challenges with R code by suppling functions for data import, tidying, manipulation, and visualization (Wickham et al. 2019).

- readr to Read Rectangular Text Data:

provides a fast and user-friendly way to read rectangular data, such as “csv,” “tsv,” and “fwf.” It takes data stored in a file or a database, and reads it into a data frame in R. Data import is supported by the core readr package (Wickham et al. 2022).

- phytools (Revell 2012):

Contains functions for phylogenetic analysis, including methods for visualizing, manipulating, reading, writing, and even inferring phylogenetic trees.

- ggdendro (de Vries and Ripley 2020)

package makes it easy to extract dendrogram and tree diagrams into a list of data frames.

- strap: (Bell and Lloyd 2014)

Stratigraphic Tree Analysis for Paleontology Functions is used for the stratigraphic analysis of phylogenetic trees.

- ggplot2: Create Elegant Data Visualizations Using the Grammar of Graphics

“A system for 'declaratively' creating graphics, based on "The Grammar of Graphics". You provide the data, tell 'ggplot2' how to map variables to aesthetics, what graphical primitives to use, and it takes care of the details.” (Wickham 2016)

- ggpubr: 'ggplot2' Based Publication Ready Plots

“The 'ggplot2' package is excellent and flexible for elegant data visualization in R. However the default generated plots requires some formatting before we can send them for publication. Furthermore, to customize a 'ggplot', the syntax is opaque and this raises the level of difficulty for researchers with no advanced R programming skills. 'ggpubr' provides some easy-to-use functions for creating and customizing 'ggplot2'- based publication ready plots.”(Kassambara 2022)

Sample R/RStudio program(s)

Sample program to calculate heatmap for Culture:

```
library(ggplot2)
library(tidyverse)
library(reshape2)
library(igraph)
library(corrplot)
library(dplyr)
library(ggrepel)
library(gplots)
Culture <- read.csv("G://raw_data/8.9.22-Culture-hmx.csv")
print(Culture)
Culture_tb <- as_tibble(Culture)
name = Culture$name
value = Culture$value
par(oma = c(2, 1, 2, 2) + 0.1)
p <- ggplot(data = Culture_tb, aes(x = Culture, y = name, value = value)) +
  geom_point(aes(color = value, size = 1.)) +
  theme_bw()
p
# heatmap
ggp <- ggplot(Culture_tb, aes(name, Culture)) +                    # Create heatmap with ggplot2
  geom_tile(aes(fill = value)) +
  theme(axis.text.x = element_text(angle = 90, vjust = 0.5, hjust = 1)) +
  theme(axis.text.y = element_text(angle = 360, vjust = 0.5, hjust = 1))
ggp + scale_fill_gradient(low = "brown", high = "blue")
```

Sample program to calculate one sample T-test

```
# One_Sample_T_test
# Adapted for use from r-script by Priank Goyal, 03/02/2020
# by Lee R Tallier Jr, 11/01/2022 for use in dissertation.

library(ggplot2)
library(ggpubr)
```

```
data.frame <- Tradition11


my_data<- data.frame
head(my_data, 17)
summary(my_data$number)

ggqqplot(my_data$number, ylab = "Sample distribution",
         ggtheme = theme_minimal())
res <- t.test(my_data$number, mu = 8)
res
res$p.value
res$estimate

shapiro.test(my_data$number)
summary(my_data$number)
ggboxplot(my_data$number,
          ylab = "Sample numbers", xlab = FALSE,
          ggtheme = theme_minimal())
res$conf.int

res <- wilcox.test(my_data$number, mu = 8, alternative = "less")
res
res$p.value

#Phylogenetic signal
# Adapted from phylosignal: an R package to measure, test, and explore the phylogenetic signal
# François Keck,corresponding author 1 , 2 Frédéric Rimet, 1 , 2 Agnès Bouchez, 1 , 2 and Alain Franc 3
#  Ecol Evol v.6(9); 2016 May PMC4799788
# by Lee R Tallier Jr
# for use in PhD dissertation --
# SEEKING A COMMON THEME: A STUDY OF CERAMIC EFFIGY ARTIFACTS IN THE PRE-HISPANIC AMERICAN SOUTHWEST AND NORTHERN MEXICO USING COMPUTER IMAGE PATTERN RECOGNITION AND PHYLOGENETIC ANALYSIS
# 2022
# install.packages(c('tibble', 'dplyr', 'readr'))
```

```
library(phylosignal)
library(adephylo)
library(ape)
library(phylobase)
library(tibble)
library(dplyr)
df = read.table('Trad17',sep = '\t', header = TRUE)
Trad17['trad'] <- NA
tre <- read.tree(text = Trad17$tre)
phyloclust(tre,state,focal,nsim=100)
dat <- list()
dat$trad <- dat$trad
dat$random <- rnorm(17, sd = 10)
dat$trad <- rTraitCont(tre)
dat <- as.data.frame(dat)
print(dat)
p4d <- phylo4d(tre, dat)
barplot.phylo4d(p4d, tree.type = "phylo", tree.ladderize = TRUE)
phyloSignal(p4d = p4d, method = "all")
phylosim <- phyloSim(tree = tre, method = "all", nsim = 100, reps = 99)
plot(phylosim, stacked.methods = FALSE, quantiles = c(0.05, 0.95))
plot.phylosim(phylosim, what = "pval", stacked.methods = TRUE)
trad.crlg <- phyloCorrelogram(p4d, trait = "trad")
random.crlg <- phyloCorrelogram(p4d, trait = "random")
trad.crlg <- phyloCorrelogram(p4d, trait = "trad")

plot(trad.crlg)
plot(random.crlg)

trad.lipa <- lipaMoran(p4d)
trad.lipa.p4d <- lipaMoran(p4d, as.p4d = TRUE)

barplot.phylo4d(p4d, bar.col = (trad.lipa$p.value < 0.05) + 1, center = FALSE , scale = FALSE)
barplot.phylo4d(trad.lipa.p4d, bar.col = (trad.lipa$p.value < 0.05) + 1, center = FALSE, scale = 
FALSE)
```

Ware Phylogenetic tree

```
## 01/21/2022
## Modified/written by Lee R Tallier Jr.
## for PhD dissertation.


#generic rscript for phylogenetic trees
rm(list = ls())
getwd()
#Install phylogenetic packages
install.packages('ctv')
library('ctv')
install.views('Phylogenetics')
update.views('Phylogenetics')
install.packages('geoscale')
install.packages('fancytree')
install.packages("tidyverse")
install.packages("readr")
install.packages("ggdendro")
#required items
require(ape)
require(phytools)
library(phytools)
require(datasets)
require(graphics)
library(ape)
library(phangorn)
library(seqinr)
library(strap) #loading the library
library(readr)

#Start analysis
#Read csv file

Ware <- read_csv("G:/raw_data/Ware.csv")
View(Ware)
```

```
df_Ware1 <- Ware
head(df_Ware1$Group)
#row.names(Ware) = Ware[,1]
hc <- hclust(dist(Ware), "mcquitty") #UPMGA "ward", "single", "complete", "average", "mcquitty", "median" or "centroid".
data <- as.phylo(hc)
tree <- hc
is.binary(data)

df_Ware1

waretree <- list(edge = matrix(c(2, 1), 1, 2), tip.label = "a", Nnode = 1L)
waretree <- data
class(waretree) <- "phylo"
str(waretree)
fig.align = "left"
plot.phylo(waretree, edge.color = rainbow(length(data$edge)/2), tip.color = "brown", edge.width = 2, font = .00002, label.offset = 0.5, type = "phylogram", cex = .0001, x.lim = 25)
tiplabels(Ware$Group, cex = 1., font = 2, bty = "n", bg = "white", adj = c(0., 0.), frame = "none")
title("'mcquitty (WPGMA)' Social interaction/learning tree",   adj = 0.25,  # Title to the left
      line = 1.75, sub = "by WARE ",cex = .55)
!is.matrix(Ware)
d = cophenetic(waretree)
d

summary(waretree)
sum(waretree$edge.length)
writeNexus(waretree, file="G:/raw_data/waretree.tree")
```

MetaPIGA 3.1

methods:

MetaPIGA-3.1 is designed to implement, under maximum likelihood, several stochastic heuristics to allow for the analysis and interpretation of large phylogeny. Designed for the biological sciences to handle nucleic-acid and protein datasets, it has been used with success in other areas such as archaeology, where morphological (presence/absence) data is common (Helaers and Milinkovitch 2010; Lemmon and Milinkovitch 2002).

The metapopulation Genetic Algorithm (metaGA)

To define the heuristic for the analysis of data, the metapopulation Genetic Algorithm was selected. Within this approach, trees are exposed to mutation events, evaluation, and selection (selection scheme set to improve; and then recombination set at 10%). P sets (populations) of 1 tree each (individual) are forced to collaborate in the exploration for optimal trees. At each phase or new generation, trees are mutated according to rules governing inter-population consensus. Under the selection scheme "improve," as individual trees fail the test, they are discarded, and the current best individual replaces them. Within the recombination scheme (a large number of simultaneous topological mutations), individuals failing the test have a probability (10%) of recombining with a better individual to be included in a new tree (Milinkovitch and Helaers 2011).

Consensus Pruning

In addition to metaGA, consensus pruning (CP) was also used. If CP is used in a metaGA search, the differing populations must exchange topological information. Thus, generational runtime completion is determined by the slowest population (Lemmon and Milinkovitch 2002). The principle behind CP is that before am individual tree is mutated, a comparison of its topology must be made with that of the best trees in other populations before a mutation can occur.

"'Stochastic CP' *(default)*:"

topological mutations affecting a given branch are rejected with a probability proportional to the percentage of trees across all populations that agree on that branch. CP provides the frequencies of internal branches shared among trees across populations, and it also indicates whether the populations converge towards a stable set of solutions, *i.e.*, towards a consensus with stable branch frequencies. Hence, CP provides a ***stopping rule*** not available to other heuristics" (Lemmon and Milinkovitch 2002).

Appendix B: – Computer vision programs

Information in this section come from an unpublished work on computer vision (Tallier 2019)

Vision software

With the advent of open-source computer vision software

(OpenCV, SimpleCV, and Tensorflow) and specifically computer image recognition software (see Table 1) the need for researchers to write their own algorithms has decreased. Image labeling programs have also become more widely available. Each of the models shown in Table 1 will do an acceptable job at recognizing and detecting targets on images. The main criteria for selection were:

1. Open source (free to use)
2. Speed and efficiency
3. Ease of use

After examining several of the choices (ResNet, R-CNN, MobileNet, and YOLO), the decision was made to use one of the YOLO family. YOLO versions 1, 2, and 3 were tried and discarded for the project. YOLOv5, was chosen because if fulfilled the 3 criteria and also it allows for the use of a GPU.

Computer Vision Model	Model Type
YOLO v3 Keras	Keras Object Detection :: Keras TXT
YOLO v3 PyTorch	PyTorch Object Detection :: Darknet TXT
YOLOv4 PyTorch	PyTorch Object Detection :: Darknet TXT
YOLOv4 Darknet	Object Detection :: Darknet TXT
YOLOv4-tiny	Darknet Object Detection :: Darknet TXT
YOLOv5	PyTorch Object Detection :: YOLOv5 TXT
ResNet-32	Fast.ai v2 Classification
Resnet34	Fast.ai v2 Classification
Faster R-CNN	Tensorflow 1.5 Object Detection :: TFRecord
EfficientDet-D0-D7	Tensorflow 2 Object Detection :: TFRecord
EfficientNet	Keras Classification
EfficientDet	PyTorch Object Detection :: COCO JSON
Detectron2	PyTorch Object Detection :: COCO JSON

Image labeling software

As with vision software there are numerous choices to pick from. Also, as with the vision software, 3 of the main criteria were:

Open source (free to use)

Speed and efficiency

Ease of use

LabelImg, written in python, does a good job, however, I encountered difficulties with the number of images I was able to tag.

Another program tried and dismissed was Ybat. While it met the first 2 criteria, I did not find it intuitive to use. However, with spending time exploring the program will probably make it fit the third criteria. It does seem to run well in the browser Opera.

Table 13 -- Image labeling programs

Image labeling software	Description
LabelIMG	a graphical image annotation tool and label object bounding boxes in images
Ybat - YOLO BBox Annotation Tool	Fast and efficient BBox annotation for YOLO, and VOC/COCO formats
VGG Image Annotator	VGG Image Annotator is an image and video annotation tool built by researchers at Oxford University.
Universal Data Tool	**An open-source tool and library for creating and labeling datasets of images, audio, text, documents and video in an open data format**
VoTT	An electron app or building Object Detection Models from Images and Videos.

Both image tagging programs, VGG Image Annotator and the Universal Data Tool (UDT) appear to be good programs. While both the UDT and the VGG Image Annotator meet the first 2 criteria, they suffer from the same problem as the first 2 programs. There is a bit of a learning curve (lack of ease of ease of use) to be able to master the programs.

The last vision program is Microsoft's VoTT (visual object tagging tool). In my case it fulfilled all of the 3 criteria, allowing me to label my sample images and save the results with ease.

Explaining metrics

The intersection over union (IoU) also known as the Jaccard Index, quantifies how similar the ground truth bounding box is to the predicted bounding box, with scores from 0 to 1. The closer to 1, the closer the 2 boxes are to each other(El Aidouni 2019).

Precision is the probability of how well the predicted bounding boxes match the ground truth bounding boxes (El Aidouni 2019). Scores range from0 to 1, with the higher the number the more the detected objects match the ground truth objects. In the sample image found in the results section, the precision ranges from .60 to .82.

Recall, which also ranges from 0 to 1, is the probability that ground truth objects are correctly detected.

Mean average precision shows the average precision over the number of classes in the analysis. When using MS COCO, the mAP over different IoU thresholds (0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9, 0.95) with a step of 0.05, and is shown by mAP@[.5, .95], averaging not only average AP over all classes, but also including the average on defined IoU thresholds (El Aidouni 2019). For a more in-depth look explaining yolo metrics see El Aidouni 2019.

Testing YOLOv5

YOLOv5l

Metrics

Training time: 100 epochs completed in 5.379 hours.

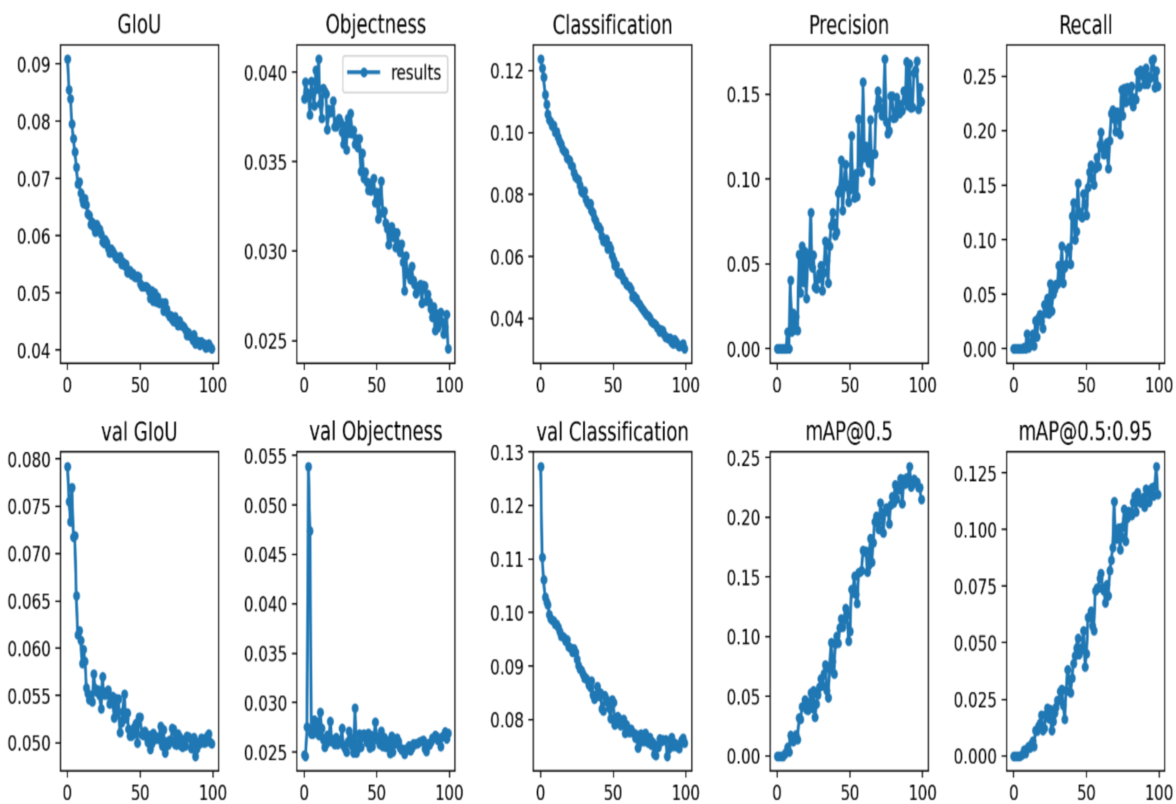
Weights: Optimizer stripped from runs\weights\best.pt, 97.8MB

Detect time: Done. (39.826s)

Images with motifs detected:197

Total number of images: 847

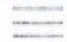
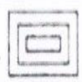
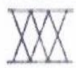
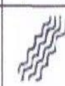
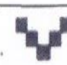
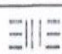
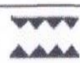
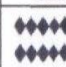
Percent of hits: 23.37

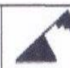
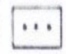
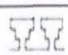
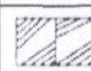
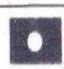


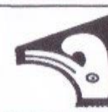
Appendix C: -- Motifs/symbols

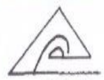
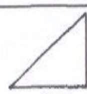
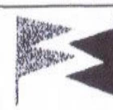
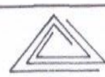
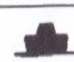
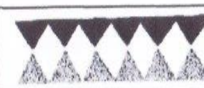
motif_no	motif_picture	description	used		motif_no	motif_picture	description	used
motif_1					motif_18			
motif_2	2D	2A w/ Lines	2B	2C	motif_19		motif 19S	
motif_3		3a solid square	3B		motif_20			
motif_4					motif_21			
motif_5					motif_22			
motif_6					motif_23			
motif_7					motif_24			
motif_8					motif_25			
motif_9					motif_26			
motif_10					motif_27		motif_27B w/ Dots	
motif_11					motif_28			
motif_12					motif_29		motif_29A thin lines	
motif_13					motif_30			
motif_14					motif_31		31A w/ Dot 31A w/	31B
motif_15					motif_32			
motif_16					motif_33			
motif_17					motif_34		34A – lines I 34A [illegible]	34LD \\ 34RD //

motif_no			used		motif_no			used
motif_35		motif_35A			motif_53			
motif_36		motif_36A w/lines/Ticks			motif_54			
motif_37					motif_55			
motif_38					motif_56			
motif_39					motif_57			
motif_40					motif_58			
motif_41					motif_59		motif_59S Single	
motif_42					motif_60			
motif_43					motif_61			
motif_44					motif_62			
motif_45					motif_63			
motif_46					motif_64		motif_64S	
motif_47					motif_65			
motif_48		motif_48T Triangle			motif_66		motif_66A	
motif_49		[illegible]			motif_67			
motif_50					motif_68		motif_68R	
motif_51					motif_69			
motif_52		[illegible]			motif_70			
motif_53		motif_53B w/Dot			motif_71		motif_71A	

motif_72					motif_91			
motif_73					motif_92		424 Vertical	
motif_74					motif_93			
motif_75					motif_94			
motif_76					motif_95			
motif_77					motif_96			
motif_78					motif_97			
motif_79					motif_98			
motif_80					motif_99			
motif_81					motif_100			
motif_82					motif_101			
motif_83					motif_102			
motif_84					motif_103			
motif_85					motif_104			
motif_86					motif_105			
motif_87					motif_106			
motif_88		motif_88/11 MED Cross			motif_107			
motif_89					motif_108			
motif_90					motif_109			

motif_110					motif_128		motif_128I Inverted	
motif_111					motif_129		motif_129A	
motif_112					motif_130			
motif_113					motif_131		motif_131A 2Dots	
motif_114					motif_132			
motif_115					motif_133			
motif_116					motif_134			
motif_117					motif_135			
motif_118					motif_136			
motif_119					motif_137			
motif_120					motif_138			
motif_121					motif_139		motif_139F	
motif_122					motif_140		motif_140a	
motif_123					motif_141			
motif_124		A	A2		motif_142			
motif_125					motif_143			
motif_126		motif_126I			motif_144			
motif_127		127A			motif_145			

motif_146	 146D		motif 146T		motif_k11			
motif_147					motif_k12			
motif_148					motif_k13			
motif_149					motif_k14			
motif_150					motif_k15			
motif_k1					motif_k16		motif K16A w/ outer lines	
motif_k2					motif_k17			
motif_k3					motif_k18			
motif_k4					motif_k19		K19V 	
motif_k5					motif_k20			
motif_k6					motif_k21			
motif_k7					motif_k22			
motif_k8					motif_k23			
motif_k9					motif_k24			
motif_k10					motif_k25			

motif_k26					motif_k-1916-2			
motif_k27					motif_s1		4 -point bmrb	
motif_151	 "P" Triangle				motif_s2		opposed bmrb	
motif_152	 Triangle				motif_s3		pennmnts bmlmnced colors	
motif_153	 Zoomorph				motif_s4			
motif_154	 Triangular Scroll				motif_s5			
motif_155	 Spiral				motif_s6		interlocking scroll	
motif_156	 Scrolled Triangle				motif_s7		interlocking lines	
motif_k-1916-1					motif_s8		interlocking scroll	
motif_k-1916-2					motif_s9		interlocking lines (NON)	
motif_k-1916-3		K3B			motif_s10			
motif_k-1916-4					motif_s11			
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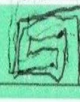
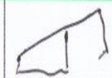
motif_k-1916-6					motif_s13			

			Used					Used
motif_157					MOTIF_M1	 motif_M1		
motif_158						 motif-HT1		
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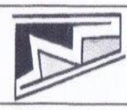
motif_162								
motif_163					O	ORANGE		
motif_164					JR #✓			
motif_165					1	Green #6		
motif_166					2	Blue #5		
motif_5a		 5E CRISS-CROSS			3	Gold #4		
motif_5b		5C w/DOTS	motif5D DIAMONDS w/DOTS		4	GREY #3		
motif_83a		motif_83P Just Dots			5	Lt Gray #2		
motif_127a					6	Yellow		

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