In F.T. Marchese (Editor) Understanding Images: Finding Meaning in Digital Imagery. Springer-Verlag, New York, 1995, pp. 29-53.

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Cognitive Origins of Graphic Productions

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4.1 Introduction

Long before there was written language, there were pictures. Maps, whether drawn in sand or on paper, whether inscribed in stone or carved from wood, appeared in ancient cultures all over the world. Ancient cave paintings and petroglyphs depicted animals and ancient pottery tokens and notches in bones represented accounts. These surviving pictorial relics are probably but a small fraction of the wide use depictions must have had. Although petroglyphs and stelae and cave paintings and pottery shards survive, no interpreters of their inscriptions do, so we can only speculate about their meanings. The remarkable compendium of Colonel Garrick Mallery, *Picture Writing of the American Indians* (1893/1972) [1], gives us a contemporaneous glimpse into the many functions of pictorial language. In 1876, while stationed in the upper Midwest in the military, a pictographic calendar of the Dakota nation came into his possession. He published it with interpretation, attracting the interest of the Secretary of the Interior, who requested Mallery's services. The Secretary of War obliged by ordering Mallery to continue his field work in ethnology. Mallery went on to gather a valuable collection of hundreds of examples of picture writing, including calendars, histories, legends, sayings, stories, and letters. He was able to verify the interpretations of many of them by consulting the people creating and using the picture writing just as this form of expressing thought was being replaced. Two examples appear in Figure 4.1. The first is a birch bark notice informing people that the writer had gone across the lake to hunt deer. The second is also on birch bark, and depicts a

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battle between the Ojibwa and the Sioux in which the Ojibwa lost one man.

How can these depictions be characterized? Of course, generalizations are problematic. Many of the more sophisticated communicative depictions consist of discrete elements in a linear array. The elements appear to represent persons or objects or events, and the linear array seems to correspond to a sequence. The sequence is typically temporal, either the sequence of events, as in the second example (where time goes from right to left), or a sequence of thoughts/words, or both, as in the first example. Simpler depictions, like many petroglyphs, often consist only of icon-like elements, with no relations between them.

A:

B:

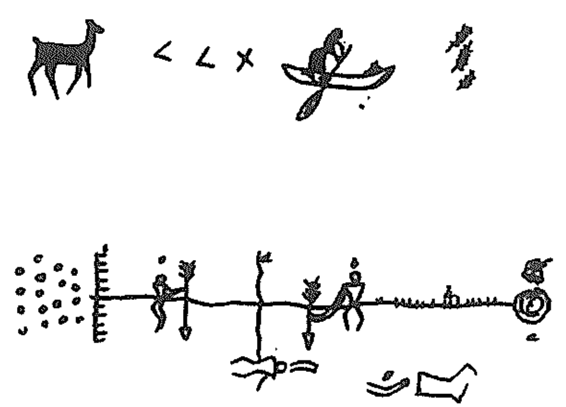

FIGURE 4.1. Pictographic messages on birch bark (Ref. 1). A) "I am going across the lake to hunt deer" (p. 331); B) Battle between Ojibwa and Sioux (p. 559).

Many of the surviving depictions seem to have been used in communication and record-keeping. Other depictions seem to have had aesthetic and sacred functions. Depictions have served all the functions of written language, and then some. Depictions are compelling. Compared to purely symbolic script, they are easy to produce and easy to understand. Indeed, in his first encounter with pictures at an early age, a child was able to correctly label simple line drawings of objects he was familiar with from real life [2]. Pictures are increasingly used on highways, in airports, in books, in the mass media, and in computers. Depictions are not just used, their current popularity and ease of production has insured that they are also abused(for examples, see Tufte [3], Wainer [4]). Of course, interpreting depictions is not always immediate, and often depends on shared conventions. Even if we recognize an icon as an airplane, it is not immediately obvious that it stands for an airport, though it is undoubtedly more readily interpreted than a comparable word in an unknown alphabet.

The graphic inventions for both concrete and abstract concepts produced by different cultures show remarkable similarities, and show similarities to the graphic inventions produced by children. The changes in graphic inventions over time within cultures often parallel the changes over time within children. One theme of this paper, then, is that ontogeny recapitulates phylogeny in the production of graphic inventions. Some of the uses of space to convey meaning in depictions have parallels in language and gesture as well. These similarities and parallels suggest that the depictions of many concepts and relations are natural or cognitively appealing, that there are cognitive principles underlying the similarities. That is the second theme of this paper. All along, I will discuss a number of graphic inventions produced by children, and compare them to historical examples for similar concepts. I will attempt to draw some cognitive principles for graphics from these examples.

4.1.1 Elemental and Relational Concepts

It is common in discussions of language to distinguish objects or elements from attributes or relations or predicates, the subjects of discourse from the qualities or activities attributed to them. This distinction has parallels in the grammatical distinction between subject and predicate. It also has parallels in the distinction made in cognition between schemas or data and operations performed on them. This is a functional distinction, and while it holds for many cases, it breaks down for others. Two assertions about elements and relations seem self-evident. First, it is easier to depict concrete elements than to depict abstract elements or to depict relations, concrete or abstract. Depicting items of food is easier than depicting a restaurant, which, in turn, is easier than depicting a law firm. Depicting a customer is easier than depicting making a purchase and depicting a car is easier than depicting renting a car or selling one. The second assertion is related. There seems to be a bias to interpret iconic depictions as things, outcomes, or states, rather than as ongoing activities, changes, or processes. A depiction of a plow is more likely to be taken to represent the object plough than the act of plowing, and a depiction of a leg is more likely to be taken as the object leg than the act of walking, though in early Sumerian, as can be seen from Figure 4.2, a plow-like logograph stood for "to plow" and a leg-like logograph stood for "to go" [5].

4.1.2 How Depictions are used to Convey Meaning

There seem to be two basic ways that depictions convey meaning. The first is through pictographs or symbols, that is, drawn entities that are meant to stand for concepts directly or for elements of language that refer to concepts. The other way that depictions carry meaning is by the spatial arrangement of the pictographs or symbols. For the most part, pictographs or symbols have been used to represent elements, and pictorial space to convey relations between elements, but there are notable exceptions, including the arithmetic operations to be discussed shortly.

Now a word about terminology. Instead of the rather cumbersome term "graphic invention," I will often use the term "representation." Here, "representation" will refer to something drawn on paper or displayed on a computer screen, or inscribed in clay, something out there that everyone can see, rather than the typical sense of representation in cognitive psychology as a private mental structure that is presumed to intervene between knowledge out there and mental processing.

4.2 Pictographs and Symbols

4.2.1 General Principles

4.2.1.1 Icons and "Figures of Depiction"

To represent elemental concepts, people have long used icons. This is straightforward when the icon is a depiction of the thing to be represented, such as a fish or a bird or a horse. Often a depiction of the entire object is used to represent the object, but in other cases, perhaps for simplicity, a part of the object, usually a significant part,

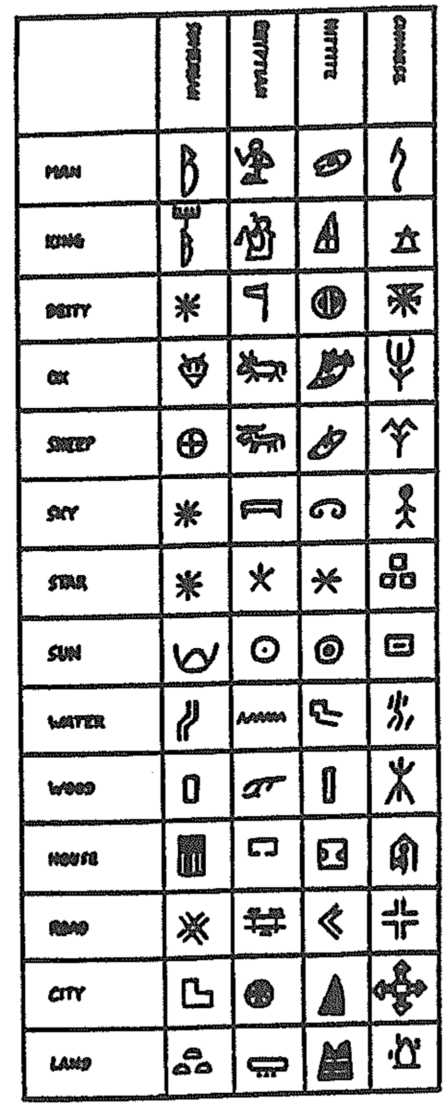

FIGURE 4.2. Pictoral signs in the Sumerian, Egyptian, Hittite, and Chinese writings (Ref. 6 ,p. 98). Reprinted with permission.

is used to represent the object. In Figure 4.2, the Hittite sign for a man was the head of a man, and the Sumerian sign for an ox was the head of an ox. The Crow Indians used horse foot prints to signify and quantify horses [1]. These are examples of synecdoche, using a part to represent a whole. Synecdoche is common not only in pictorial signs, but also in figures of speech, using the same principle. Ranchers count "head" of cattle, and teenagers drive their "wheels" to school. Related to synecdoche is metonomy, where an associated object is used to represent an object. To convey famine, the Dakotas portrayed empty racks for drying buffalo meat [1]. In Figure 4.2, all of the signs for water use the movement of water to portray water. Crowns are used to represent kings, both in pictures and in speech. "The church" and "the White House" may refer to buildings, but they may also refer to the institutions the buildings symbolize.

4.2.1.2 Rebus Principle

Indeed, most authorities agree that most writing systems began as pictures, presumably representing meaning directly [6]. Representing meaning directly quickly becomes problematic. For example, it is difficult to represent abstract concepts and proper names. All true writing systems solved those problems by inventing ways to represent sound. One widespread means of representing sound is based on the rebus principle where a pictograph of an object with a similar name is used to represent something that cannot be easily depicted [5, 7, 8]. An example would be writing "before" using a picture of a bee and the numeral 4. The contemporary use of hearts to mean "love" in bumper stickers is an application of the rebus principle. There is recent and still controversial evidence that Sumerian cuneiform, the world's earliest writing system, grew out of the shapes of clay tokens used in accounting, rather than from depictions [9]. Nevertheless, the evolution of cuneiform from representing meaning directly to representing sound presumably followed the same rebus principle.

4.2.1.3 Schematization

Even when an icon is used in a straightforward manner to represent the thing the icon depicts, icons are schematic and undergo further schematization over time. That is, icons are simplified representations of classes rather than representations of classes. The reasons for this are many. With constant repetition, ease of execution be-

comes as important as ease of recognition. Schematic icons take less artistic talent and less time to produce. Artistic detail is not essential for effective communication. Further schematization is usually a joint product of efficiency and the representing medium. Cuneiform was inscribed using a stylus in wet clay, whereas hieroglyphs were drawn on papyrus (or inscribed in stone). Although many cuneiform patterns and glyphs started iconic, they became schematized, and in different ways (Figure 4.3). For cuneiforms, dramatic changes came when larger clay tablets were introduced. In order to hold the tablets comfortably, the signs were rotated ninty degrees, leading to a loss of iconicity. Signs that were drawn or painted underwent other changes. Because modern icons, such as those used on highways or in airports, are reproduced mechanically rather than by hand, the pressures toward schematization are less.

4.2.1.4 Conventionalization

Many concepts are difficult to represent pictorially, even applying "figures of depiction." Depictions can be based on acoustic associations as well as visual associations, as in the applications of the rebus principle. Depictions may also be totally arbitrary. In all of these cases, and in the cases where pictographs become so schematic that their depictive origins are obscured, when the symbols become accepted by a group of users, they become conventionalized. Conventionalization is a normal process occurring in all forms of communication.

4.2.2 Children's Early Writing

Ferreiro and Teberosky [10, 11, 12] working in Latin America and Tolchinsky-Landsman and Levin [13, 14, 15] working in Israel asked preschool, preliterate children to write words or sentences. This is not a pure task in inventing representations because these children were growing up in environments with books and other printed matter, so they had exposure to writing, and even perhaps to the notion that writing represents sound. Most of the early inventions of children were uninterpretable, but did reveal a number of characteristics of writing.

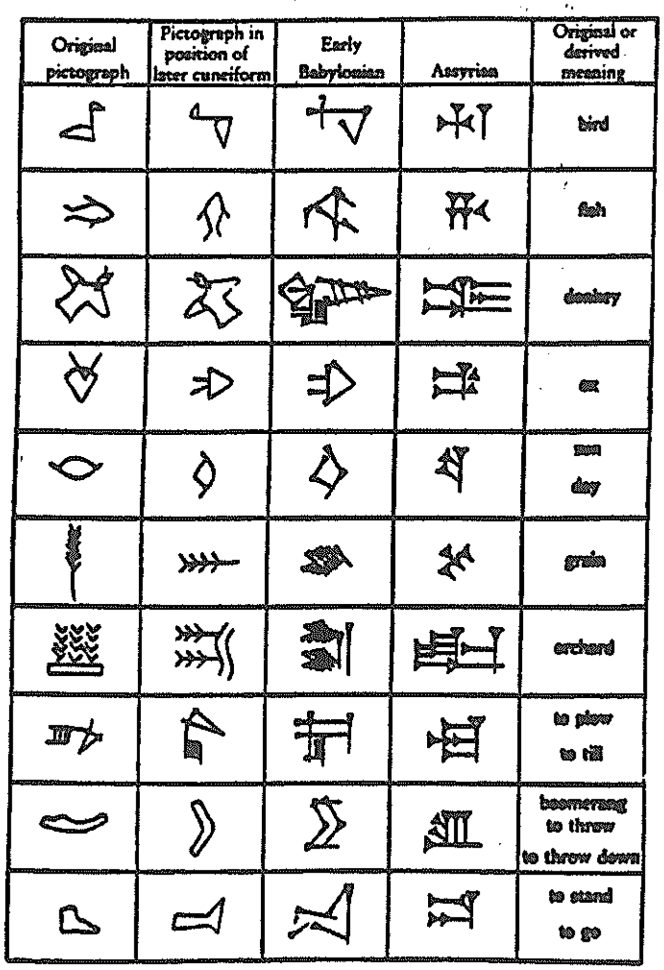

FIGURE 4.3. Rotation and loss of iconicity of some Sumerian signs. (Ref. 5, p. 74). Reprinted with permission.

4.2.2.1 Spatial Arrangement

For one thing, the overall organization of children's early writing was linear, as is true of all writing systems in the world. Some writing systems have a columnar organization, some have a row organization, and some, like Japanese, have both, but all systems have a linear organization, perhaps reflecting linearity of speech. In these experiments, sentences were short and simple, and separate words were enunciated as such. Children tended to produce one mark, sometimes a complex mark, for each word. That is, they discerned words as units and used empty space to separate them. Although we take the concept of a word for granted, that concept seems to have arrived together with the advent of written language (small, personal communication). And although we assume that written languages separate words spatially, that hasn't always been the case. Classical Greek was written continuously, with no breaks for words, sentences or paragraphs.

4.2.2.2 Symbols

Children produced marks for objects (nouns) earlier than they produced marks for activities (verbs). Since many of the marks children produced for words were not iconic, this suggests that the priority of signs for objects over actions is more than just the greater accessibility of icons for objects than for activities. Let's look more closely at the characteristics of the marks children produced for objects. Many of them resembled the objects in one way or another. For example, if given a choice of colored markers, children often chose a marker of the same color as the object, say, red for apple and tomato. Often, children's marks matched the objects in shape, say, round for ball and long for rope. Color and shape are strong influences on young children's categorization (cf. [16]), and shape is a strong influence on young children's use and generalization of their early words [17]. Size of the object, too, was reflected in children's marks for words; elephant got a larger mark than ant. Yet, although many of the children's marks resembled the objects in physical characteristics, others reflected properties of the sounds of names of the objects. For example, objects with longer names got longer marks, and repeated sounds got the same symbols.

4.2.2.3 In Sum

The attempts of preliterate children to write reveal many of the characteristics of writing systems developed all over the world. They display a linear organization, they separate words, and they produce marks for concrete objects prior to marks for activities. In producing marks for words, children used the same correspondences that written languages have used, correspondences of appearances of the objects and the written signs, that is, representing meaning directly, and correspondences of the sounds of the names of the objects and the written signs, that is, representing meaning by representing the sound system of language.

4.2.3 Children's Early Arithmetic

Unlike fully developed writing, arithmetic symbols do not reflect the sounds of the names of the numerals or operators. Mathematical writing is a visual system, not a phonetic system. In truth, many modern day writing systems have visual, non-phonetic elements as well. The visual elements of writing include spacing between words, punctuation, numerals, and certain signs important enough to be included on keyboards, %, $, and &. Although mathematical writing does not reflect sound, current mathematical writing does not reflect appearance either, though, like writing, historically, some aspects of it did.

4.2.3.1 Representing Numbers

Hughes [18] asked preschool and early school-aged children to represent various arithmetic concepts on paper. In one task, he put one to six bricks on a table, and gave a child a piece of paper, asking the child, "Can you put something on paper to show how many bricks are on the table?" (p. 55). There were four types of responses. *Idiosyncratic* responses were squiggles, bearing no relationship to the number of bricks. *Iconic* responses were pictures of things other than bricks, where the number of things corresponded to the number of bricks. Often the iconic responses were lines, like tallies, but sometimes they were unrelated objects, like houses. These two categories of responses were dominant in the preschool years, but dropped to very low levels in the first grade. *Pictographic* responses were pictures of bricks, where the number in the picture corresponded to the number on the table. This type of response increased in frequency from preschool to first to second grade, and dropped in third grade. Finally, *symbolic* responses used the conventional numerals. This type of response was infrequent in preschoolers, but increased steadily thereafter, so that by third grade, it was the dominant response.

4.2.3.2 Representing Zero

Hughes' next step was to brush aside the bricks, and to ask the child to "show that there are no bricks on the table" (p. 63). The children who were using the numeric symbols put down zero with little difficulty. Children who did not know the numeric symbols, however, were often confused, and did not know what to put. Some left a blank, and some drew a line. In short, amongst children who did not know zero, there was considerable confusion and little agreement.

4.2.3.3 Representing Addition and Subtraction

Hughes and his collaborator Jones [18] used techniques similar to those that extracted number representations from children to extract representations of addition and subtraction. In one task, they put two bricks on the table, and then added two more, and asked, "Can you show that we first had two bricks and then added two more?" (p. 72). In another task, they removed one brick from a pile, and asked, "Can you show that I took one brick away?" (p. 73). These questions stumped the children. Many simply recorded the total number of bricks, or the numbers of the two sets of bricks to be added. None of the children, not even those who used arithmetic daily in the classroom, used the standard plus and minus signs

Some of the children drew hands to show the action of adding or subtracting, or feet to show bricks walking away. Other children used arrows. On the whole, the depictions were not satisfactory representations of these abstract concepts.

4.2.4 Historical Examples of Arithmetic

4.2.4.1 Counting Systems

The children's inventions were then compared to the history of written number systems in other cultures in support of the idea that ontogeny recapitulates phylogeny. Except where noted, the historical discussion comes from Hughes [18]. Prior to recording numbers, whether by writing or notching, it is likely that people used parts of their bodies, especially fingers, to count and to represent sums. Systems for keeping track of quantities using fingers and other body parts appear in many cultures. Words for numbers are often related to words for fingers, take our own "digit," for example.

4.2.4.2 Representing Numbers: Pictographs

The first known system for representing numbers was (by Hughes' definition) pictographic [9]. In ancient Sumeria, a single ovoid (jar-like) token stood for a single jar of oil and five ovoid tokens stood for five jars of oil. Other items were counted by tokens with other shapes. Later, the tokens were replaced by incisions in clay, but the principle of counting different types of things with different types of symbols remained. Schmandt-Besserat [9] argued that this way of keeping records of property and property transactions drove the development of written language.

The principle of counting different kinds of things with different kinds of symbols is reflected in language in classifiers. Although classifiers are not common in English, there are some common examples. We don't request "five papers" (unless we mean scholarly papers or newspapers); instead, we request "five sheets of paper." Similarly, we refer to "six slices of bread" and "three sticks of gum." Classifiers are mandatory in many languages, where use of specific classifiers typically depends on object shape, much like "sheet," "slice," "stick," and "roll" in English. Modern-day analogs of Sumerian pictographic counting are to be found in Isotypes, a system for pictorial graphing invented by Otto Neurath [19], in which bar graphs are constructed from icons representing the quantified elements, such as using sheaves of wheat, barrels of apples, and pairs of shoes to indicate yearly output for different countries (note that sheaves, barrels, and pairs serve as classifiers in the previous sentence).

4.2.4.3 Representing Numbers: Tallies and Symbols

After pictographs came tallies, which appeared with great frequency in ancient systems. In Sumeria and probably elsewhere, tallies preceded written language. Like pictographs, tallies preserve a one-to-one correspondence between the number of objects and the number of written marks. Tallies are more abstract than pictographs because they do not reflect the kind of thing being counted. Since what is

important for counting is the number and not the object, a neutral mark that is easy to make suffices, exactly what was produced spontaneously by many cultures and by preschool children. Tallies, however, become cumbersome for large numbers, and are difficult to use in operations on numbers. This creates pressure to develop symbols for the numbers. Number symbols evolved in ancient Egyptian. The Semitic languages used letters to represent numbers, a system borrowed by the Greeks. This system was compact compared to tallies, but did not have a place holder, so that the relations between multiples of ten were obscured.

Readers may notice that in Hughes' young subjects, tallies were replaced by pictographs, whereas in Sumerian history, tallies replaced pictographs. As was noted, tallies are more abstract than pictographs as they can be used for counting anything, whereas pictographs can be used for counting only one kind of thing. Hughes' situation did not encourage the development of abstraction as he only had the children representing numbers of bricks. If he had requested that the children represent the quantity of a number of different kinds of things, tallies might have replaced pictographs, as they did historically.

4.2.4.4 Representing Zero

Symbols for zero evolved far after symbols for numerals, and many widely used systems did not have a zero. Some ancient number systems, such as the Babylonian and the Maya, did develop ways to denote zero, both as the empty set and as a place holder. The Babylonian system did not survive in western mathematics. The present day zero (like the present day number symbols) arrived to the west from India via Arab mathematicians. It was adopted to represent the empty set in the seventh century, and as a place holder about two hundred years later.

4.2.4.5 Representing Addition and Subtraction

Historically, special symbols for arithmetic operations were a late development. The Egyptians used pairs of walking legs, from left to right to signify addition, and from right to left to signify subtraction. An Alexandrian mathematician used an upward pointing arrow to denote subtraction. Both these symbols imply motion, and both were used by children in Hughes' studies for similar purposes. None of these symbols was widely used, and none survived. The plus and minus signs in use today appeared in Germany in the fifteenth century, and the equal sign about a century later.

4.2.5 Historical and Developmental Parallels in Arithmetic Representations

The parallels between children's inventions and historical inventions of numbers are striking. Prior to recording, body parts, especially fingers, were and remain used for counting and keeping track of sums. Early permanent records, Sumerian tokens, counted different kinds of things with different tokens, a practice that endured after writing began. For ancient Sumerians and Hughes' young children, the number of sheep or bricks was indicated by a one-to-one correspondence between items in the world and pictures or tokens of the items. Later, tallies replaced pictographs or tokens. In tallies, the same marks are used to represent quantities irrespective of the type of quantity. Still later, number symbols replaced tallies. Number symbols are more efficient, both in conserving space and in arithmetic manipulations. The children most likely did not invent number symbols, rather, they seemed to be applying what they were learning in school. Historically, number symbols were slow to be developed, and symbols for arithmetic operations appeared even later. Complex as elemental concepts can be, relational concepts can be even more complex, and consequently more difficult to depict.

4.3 Pictorial Space and Pictorial Devices

4.3.1 Children's Graphic Productions

The arithmetic operations have generally been represented by symbols. Another way to represent relational concepts is to use spatial relations in pictorial space. Maps are a simple and straightforward example, where distances and spatial relations among cities are represented in miniature by distances and spatial relations on paper. Another prevalent modern example are graphs. In contrast to maps, graphs are a relatively recent invention. Graphs began to appear in significant numbers in Europe only in the late eighteenth century [3]. I turn now to discuss cross-cultural research on children's graphic productions for a variety of concepts.

4.3.1.1 Task

Kugelmass, Winter, and I [20] were interested in how children use space to represent increases in abstract concepts, temporal, quantitative, and preference. The task we developed was simple. We sat next to a child and gave the child a square piece of paper and some stickers. We told the child that we were going to put down a sticker for, say, breakfast time, and the child should put down one sticker for lunch time and another sticker for dinner. That was one of the temporal concepts, and there were one or two others depending on the experiment. Examples of a quantitative dimension were the number of books in a child's backpack, the number of books at home, and the number of books in the library. For preference, we asked the child for their favorite food, a food they dislike very much and a food they sort of like. For all these attributes, the task was the same. The experimenter put down the first sticker in the middle of the square page, and the child put down the next two stickers.

4.3.1.2 Information Preserved

We were primarily interested in three aspects of the data. The first was *information preserved* in the children's mappings on paper. Would they see the relation as *nominal*, as three unrelated items, and put the stickers down in a disorganized fashion, or would they see the relation as *ordinal*, and put the stickers on a line? In the second and third studies, we asked children about inequally spaced items, giving them the opportunity to preserve *interval* information in their mappings. In nominal representations, things belonging to the same category are placed together, and there are no relations between categories. In ordinal representations, the order of the items is meaningful and interpretable, and in interval representations, the intervals between items are meaningful and interpretable, the greater the spatial distance between items, the greater the conceptual distance. As expected, there were age effects in the information preserved in mappings. Some of the kindergartners and first graders preserved only nominal relations, though most of them preserved ordinal information. Only a few of the fifth graders preserved interval information, though with considerable coaching, some of the third graders came to represent interval. There were some effects of content as well. Interval information was represented at an earlier age for the most concrete concept, time, next for the quantity, and latest for the most