Abstract patterns and representation: the re-cognition of geometric ornament

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2. Core knowledge of geometry and number

2.1. Introduction:

In Chapter 1, I concluded that the recognition and making of geometric decorative patterns requires specific cognitive competences needed to process repetitive regular arrangements and the capacity to recognize shapes. In this chapter, both types of competences will be discussed from the perspective of cognitive science. I will determine the extent to which the competence to understand repetitive regular arrangements relates to what in cognitive psychology is referred to as core knowledge of number and core knowledge of geometry. The reason for focusing on core knowledge primarily is because a number of researchers working from the theory on core knowledge have carried out very specific and detailed experimental research on the competences of number and geometry, competences that in this thesis are assumed to be necessary requirements to recognize and make geometric patterns. This means that there is a large body of empirically supported knowledge about these cognitive competences. According to core knowledge theory, certain types of knowledge are innate, constituting as it were the cognitive foundations for the acquisition of knowledge through learning. The assumption is that core knowledge is present at birth as a set of dispositions that will develop as the infant grows up.[1] Psychologist Elizabeth Spelke claims to have found evidence in experiments with young children that support the innateness of the recognition of specific aspects of number and geometry.[2] Neuroscientist Stanislas Dehaene has provided psychological evidence for this position. With regard to the recognition of shapes, Dehaene identified brain regions that are involved in recognizing shapes and their constituents.[3] This neuroscientific evidence largely seems to support an older theory by psychologist Irving Biederman stating that the recognition of complex shapes is based on the recognition of a limited number of

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[1] See for an overview Spelke & Kinzler 2007. The core knowledge theory departs from the assumption that core knowledge is non-species specific and thus shared with other animals. However, in this thesis the recognition and making of geometric patterns in humans is central and therefore I will not extensively discuss core knowledge in animals.

[2] Spelke, Lee & Izard 2010, pp. 1–22.

[3] Dehaene 2009, pp. 133–142.

basic shapes, which Biederman called geons.[4] These contain crucial information about the nature of the object such as its corners and the cross-sections of contour lines.

This chapter discusses the extent to which core knowledge theories of number and geometry, as well as the recognition-by-components theory developed by Biederman, are sufficient to define the cognitive competences that enable humans to recognize and make geometric patterns. Therefore both theories will also be discussed from the perspective of more recent developments in cognitive science such as those in neuroscience whereby areas in the brain that are involved in the processing of certain stimuli or in the execution of certain cognitive tasks (such as for instance seeing a picture or counting a number of objects) can be mapped more precisely and thereby also provide new insights about how knowledge in the brain is organized. If the presence of the competences to recognize repetitive regular arrangements as identified in the last chapter can be explained by core knowledge the consequence would be that like core knowledge recognizing and making geometric patterns is partly innate too. This suggests that geometrical patterns occur in many cultural traditions around the world because the competences to understand such patterns are basically present at birth in every human being. Ultimately makers of geometric ornaments use this innate capacity to develop their skills in relation to their specific cultural environment, and it is this combination of nature and culture that will then determine how geometric patterns become manifest. The context will also determine how viewers react to geometric patterns and in what manner they are endowed with meaning. But it must be determined first whether the core knowledge of number and geometry theory indeed defines the cognitive competence to comprehend repetitive regular arrangements adequately and correctly. Therefore this chapter will begin with a more general discussion on the nature of core knowledge.

2.2. What is Core Knowledge?

The core knowledge thesis holds that all cognitive cultural skills, such as the ability to make or solve formal geometry or reading maps, draw from a set of innate

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[4] Biederman 1987, pp. 123–128.

psychological and neuronal mechanisms. These mechanisms are shared with nonhuman animals, and are therefore not human specific like language and music. Core knowledge systems are assumed to be the building blocks of unique human cognitive skills. In order to understand the specifics of human cognition researchers study both the core knowledge systems as well as the mechanisms by which these systems facilitate new concepts and cognitive processes. Psychologist Elizabeth Spelke argues core knowledge systems such as those for number, geometry, objects and agents have four features. They are believed to be *domain-specific*, which means that each system deals with specific entities such as numbers, agents, objects, and places in the spatial environment. Core knowledge systems are also believed to be *task-specific* in the sense that each system uses its own representations to deal with specific 'questions' about the world. Face recognition for instance deals with the identification of congenial agents, the categorization of objects with actions caused by objects, spatial orientation with determining where one is located, while number concerns the quantities of objects and events. Core knowledge systems are also relatively *encapsulated*; they only receive a limited portion of information from the sensory system and only transfer a limited portion of information to the output system of the organism. Finally, they are relatively autonomous and therefore not susceptible to the subject's explicitly held beliefs or goals.[5]

2.3. Core knowledge of number related to quantifying

One of the best-studied core knowledge systems is that of number. Hauser and Spelke argue that humans are the only species capable of fully understanding natural number. Verbal counting for instance starts around the age of two. At this stage children do not yet understand the meaning of counting words nor do they understand how the counting mechanism works. By the age of two-and-a-half years they are able to use counting words within the counting routine correctly, but they understand only the concept of 'one'. Each word that refers to more than 'one', such as 'two' and 'three' is

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[5] Spelke 2000, p. 1233. For more research on core knowledge in animals see Vallortigara 2012. On core geometry in animals see Spelke & Lee 2012.

simply understood as ‘more than one’. The understanding of the concepts of ‘two’ and ‘three’ slowly develops consecutively.[6] At the age of five human children have an understanding of infinite counting. They understand that each concept in the counting routine is an addition of the former by ‘one’.[7] Hauser and Spelke observe that this is quite remarkable when compared to animals. There have been successful experiments with chimpanzees who were eventually capable of learning some of the human Arabic number symbols and were able to understand the concept of ‘one’, but the step to also understand the concepts of ‘two’ and ‘three’ took them just as much effort as understanding ‘one’. Apparently chimpanzees do not seem to possess a learning set for number and are not able to interpret every newly acquired Arabic number as the symbol for a new cardinal value; a kind of inference drawing they are not capable of. After having learned three or four counting words, human children know to figure out without training how counting works, while for the chimpanzee in the experiment, it took about 20 years to reach no further than the symbol for nine.[8] The most important conclusion that Hauser and Spelke draw from this comparison is that human children are able to draw inductions. From a specific cognitive operation they have been able to master a common principle applicable to any similar kind of operation; namely that the list of integers is constructed through a principle of succession, which generates an infinite list of numbers. In other words, based on a few acquired concepts for number, children are able to figure out, understand, and apply simple algorithms without training. According to Hauser and Spelke, children construct concepts of natural numbers based on two core knowledge systems of number: one system for approximate cardinal values and large sets of objects and events; the other for exact representations of small sets of objects and events.[9]

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[6] Hauser & Spelke 2004, p. 854.

[7] About the development of the counting routine in children see Carey 2009, pp. 220–254; Wynn 1990, pp. 155–193.

[8] Kawai & Matsuzawa 2000, pp. 39–40.

[9] Hauser & Spelke 2004, pp. 854–855.

2.3.1. Object Tracking System: exact, small numbers 1, 2, 3, 4.

Hauser and Spelke further discuss that the features of the system of small exact numerosities are traceable in infants, children and adults. Response time of adults in calculation tests increases significantly when persons are confronted with numbers above four; while when performing tasks with numbers from one to three, it remains stable and fast. Experiments with children show similar results that indicate that they too respond faster when tasks are limited to small numbers. Hauser and Spelke argue on the basis of these experiments that the core knowledge system for number appears to have the following characteristics.[10] The system is limited to a size of three or four numbers maximum; it operates when elements occupy specific spatial positions but fails when elements are imposed or embedded in one another.[11] The system works when elements are separated by empty space but fails when they are connected by a grid of lines; it works when elements are stationary, when elements are constantly moving but nevertheless remain visible, and when elements are constantly moving with short moments of occlusion; it fails however when elements appear irregularly or when elements disperse or fuse.[12]

2.3.2. Approximate Number System: relative magnitudes.

Hauser and Spelke further argue human adults perform well in making approximate estimations about the size of large quantities non-randomly: the larger the quantity, the better the estimation. Humans also perform well in making estimations about the proportion between sets of quantities and they are able to determine which set is the largest or smallest. The bigger the difference, in proportion between two quantities, the more accurate the estimation. Both human children as well as animals are able to distinguish between quantities based on an abstract process independent of sensory modality; in other words different visual, auditory or other kinds of objects and events can possess the same quantitative aspects, and human adults recognize this. The same

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[10] Hauser & Spelke 2004, pp. 858–860.
[11] Trick & Pylyshyn 1994, pp. 80–102.
[12] Scholl & Pylyshyn 1999, pp. 259–290.

applies to the mode of the stimulus, which can either be spatial or temporal. The system for approximate cardinal values therefore has at least two important features: it allows humans to accurately distinguish between large sets depending on the ratio between these sets and this works whatever the sensory modality of their perception.[13]

Humans appear to combine the two core knowledge systems of number to understand concepts of number and counting routines; this can account for the general difference between humans and non-human primates. Induction, such as how children come to understand the counting routine, could underlie all concepts of natural number. According to one hypothesis children are able to make inductive inferences because they learn to map the word *one* to an object and when they learn the word *two* and *three* they learn to map them on the representation of two objects. When they learn the counting routine wherein each new number is the sum of the previous added by one, they also learn to apply that to the representations of objects they map; three objects plus one object makes four objects etc.. If true then it should also appear that natural number in adults depends on three systems; two core knowledge systems of number, and natural language.[14]

At this moment it is not yet well understood under what kind of evolutionary pressures core knowledge systems would have developed as distinct from human systems such as that of natural language. It seems obvious though that animals benefit from being able to precisely quantify small numbers, for instance, when they form small coalitions, when mothers have to 'count' their children and when individual animals engage with interpersonal exchange. They equally benefit from the approximate number system when searching for food or when there is aggression between groups.[15] As for the unique human system one possible explanation is that the systems for number and language are driven by a more generative mechanism, which allows humans to create an infinite array of meaningful expressions. Hauser and Spelke argue that the question then remains whether this mechanism was first available for number or for language. This is still not clear.[16]

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[13] Hauser & Spelke 2004, pp. 855.

[14] Hauser & Spelke 2004, p. 861.

[15] Lyon 2003, pp. 495–499.

[16] Hauser & Spelke 2004, p. 861–862.

2.4. Core knowledge of geometry related to dimension

Just as natural number is rooted in universally shared core knowledge systems, cognitive scientists assume formal geometry is rooted in a universal conception of space. There are two reasons why they assume this. First of all, only certain properties of spatial figures are theoretically relevant in geometry. For example, there are axioms regarding angles but not regarding orientation. With this knowledge in mind it can be stated that geometric representations are more specific than spatial representations. One of the arguments holds that in order to be geometrical, spatial representations need to confirm invariances based on properties that are theoretically not relevant for formal geometry For instance, in Euclidean geometry there are definitions regarding angle but not regarding properties concerned with orientation such as horizontality and verticality. Besides, a number of concepts from Euclidean geometry, such as a line's infinite thinness, and its infinite extension in space, cannot be verified by means of experience. A research group led by psychologist Véronique Izard therefore considers the possibility that all humans have access to the spatial content of Euclidean geometry for two possible reasons. It could be that humans acquire this knowledge based on their perception and experience of space, which appears to be general enough to be universal, but it is also possible that Euclidean geometry expresses certain core concepts that underlie human perception of space. At the same time, geometric concepts might be accessible only to those who have received enough instruction, or who devoted enough energy to the mental construction of those concepts.[17]

Like the system for number, core knowledge of geometry probably consists of two sub-systems. The first sub-system enables the subject to navigate its spatial surroundings. It is geometric in the sense that the system is concerned with quantitative information about the shape of the environment but at the same time ignores information about colour, texture or the shape of landmark objects. The system for

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[17] Izard et al. 2011, pp. 319–320. The first option brings up the question to what extent those core concepts of space perception relate to human experience of space. For instance, core principles of spatial perception could have been shaped during the course of evolution in reciprocity to actual spatial experiences. In other words, the psychological and neuronal mechanisms behind perception of space and experience of space might be more intertwined than one might consider at first glance. On Euclid's concept of the line's infinite thinness see Byrne 1847, pp. xviii–xxi.

instance fails in determining angle, and two-dimensional representations. The second sub-system is doing just that; it codes small objects that can be handled and small-scale two-dimensional representations.[18] This system is discussed first because it probably relates to the recognition of geometric patterns in the sense it concerns the recognition of the properties of geometric shapes.

2.4.1. Core knowledge of geometry & shape recognition

In Euclidean geometry angle and length proportions are defining features of figures while position and orientation are not.[19] The status of sense and size are variable.[20] There is research on infants and young children indicating angle and length have a privileged status in shape perception. The perception of direction nevertheless requires a next step, which comes down to the ability to mentally align objects. This would mean the intuitive basis of geometry would be a non-oriented Euclidean geometry; in other words, geometry based on the ability to distinguish shape.[21]

Véronique Izard, Pierre Pica, Stanislas Dehaene, Danielle Hinchey and Elizabeth Spelke designed three different experiments to test this on children and adults from the United States and the Mundurukú tribe from the South American Amazon. The first experiment was about the ability to recognize the deviant shape in three sets which each contained five equal shapes and a different one. Each set targeted at the property of angle, length or sense. In all age categories participants were better in detecting the deviants with regard to angle and length than the deviant for direction. Even the youngest children were able to use angle and length to find the deviant but only adults could rely on 'rotation' to find the deviant with regard to direction. Trials with interferences, such as irrelevant variations of size and angle, resulted in an increased reliance on these variations when determining the deviant shape and caused the

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[18] Izard et al. 2011, p. 320.

[19] See for instance Dijksterhuis 1929, pp. 117–119, 137–142.

[20] Sense is defined as; 'the geometric property that distinguishes two figures that are mirror images of each other.' See Izard et al. 2011, p. 331. Sense requires the ability to perform mental rotation of shapes.

[21] Izard et al. 2011, p. 324. By 'intuitive' they mean; 'knowledge accessible to explicitly report, (...) without being able to explain why (...).' Izard et al. 2011, p. 331. Non-oriented also means that in the case of transformations of shape these transformations do not affect the theorems of the theory. Such transformations are translation, rotation, symmetry and size invariance. Izard et al. 2011, p. 323.

participants to pick out the largest or smallest shape as the deviant. Irrelevant rotation however, apparently did not increase such reliance and therefore did not disturb the performance. According to the researchers these results were surprising because it appears to be the case that pre-schoolers are certainly able to perform mental rotation tasks once they receive explicit instruction, or when they perform in the context of playing Tetris games. The researchers assume that in this case the involvement of motor skills might enhance their performance with regard to sense relations. In other words, the competence of mental rotation is probably supported by the actual physical movement of the body and therefore by the ability to walk around an object and perceive it from different angles. The researchers argue that despite using mental rotation in some contexts, the fact that children did not seem to be able to use it in the above experiment could indicate that orientation differences are not important in shape classification. The children were nevertheless trying very hard to solve the orientation trials but instead of using mental rotation and checking for sense deviance they were merely picking the deviant randomly. The researchers argue that this could indicate that adults possess a more integrated concept of shape; a concept rooted in a variation of cognitive mechanisms. The concepts about shapes children use appear to be linked solely to shape perception systems, which according to the researchers, indicates that before motor resources are integrated with the concept of shape, sense (mirroring) is not an important aspect of the definition of shape. The results of the experiment thus indicate that with regard to the classification of shape, when confronted with pictures, sensitivity for angle and size is universal while sensitivity for sense is not.[22]

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[22] Izard et al. 2011, pp. 324–326. Universal is defined as; 'Present in all normally developing human beings, irrespective of their environment, level of education, etc.' Izard et al. 2011, p. 330. A second experiment in which children had to pick out the straight angle from a set of six angles and the parallel lines from a set of six non-connected lines, revealed that amongst children, the knowledge of the concepts of 'straight angle' and 'perpendicular line' facilitated the detection of these figures, while the knowledge of the term 'parallel lines' did not have an effect on the detection of parallel lines. These results suggest that different normative categories developed along different trajectories with a category for parallels presumably in place from the beginning, while the category of 'straight angle' is constructed when the child has the relevant lexicon available. Mundurukú children scored above chance in picking out the straight angle which indicates that 'straight angle' might be a universal category of angle even though instruction in the relevant lexicon does seem to play a role in the acquisition of this category amongst U.S. children. Further research is needed on the role of experience in categorizing straight angles. The researchers argue this could be done in a comparative study with a group of Mundurukú participants living in timbered villages containing a lot of straight angles and another group living in a more rural environment, which both perform the same geometric tasks. It could further be

Dehaene's team carried out extensive experiments with the Mundurukú in order to further investigate what basic principles of geometry this tribe understands. A similar method as outlined above was used in which participants were asked to pick the 'odd' shape out of sets of six shapes containing five equal shapes and one different shape. The researchers had carefully minimized cues that could unwittingly point to the deviant shape to make sure that the participant had to use the geometrical concept tested for to be able to pick out the deviant. Those concepts contained the elements of Euclidean geometry such as points, lines, parallels and straight angles. In the case of testing the concept of a trapezoid, the deviant shape would be non-trapezoidal. It would nevertheless be quadrilateral and its size and orientation would fit within the range of size and orientation of the other trapezoids. Thus they made sure that size and orientation could not function as clues in finding the deviant. The results showed that participants older than six scored above chance. They performed very well on the concepts of connectedness, and on the Euclidean concepts of line, points, parallels and straight angles, as well as on the concepts of geometrical figures like squares, circles and triangles. Symmetries and metric properties were harder for them to detect but they still performed above chance. However, they did not when they were shown slides with triangles in a mirror symmetry relation. Nor were they able to when they were shown slides in which the deviant shape was a randomly ordered mirror image of the other shapes. These cases require the ability to make a mental transformation and a comparison from one shape to another and this appeared to be hard to accomplish.[23] Besides, the fact the experiment was carried out with pictures meant that the recognition of the depicted mirror symmetries depended on the cognitive ability to

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possible that the acquisition of the geometric vocabulary aids children in forming a category for straight angle without such implying sensitivity for the geometrical properties of the figure; they could perceive straight angle as special precisely because they have a name. The extensive non-perceivable concepts of Euclidean geometry could be universal as well. According to the researchers this could be the result of 'core knowledge' or of interaction with the environment. Concepts of geometry are partly developed around the age of five or six years old. Even though Euclidean geometry appears to be universal it nevertheless seems to appear as result of mental construction. The researchers showed that contrary to adults, the categorization of parallel lines with young children does not seem to depend on a rich conceptual theory of geometry but probably from perceptual features of parallel lines such as the fact that the distance between the lines is constant and the fact that the two parallel line segments appear to be identical as well as the fact that parallelism represents a singular point of angle value; in this situation the subject does not have to compute angle. Izard et al. 2011, pp. 326–328.

[23] Dehaene, Izard, Pica & Spelke 2006, p. 381.

translate rotation in three-dimensional space, which humans are able to accomplish, for example, when picking up an object and rotating it while holding it in their hands, to rotation of shape as represented on the two-dimensional surface. Apparently this is difficult and requires more cognitive effort.

The researchers showed it turned out that the performance of Mundurukú adults was identical to that of Mundurukú children and American children. American adults however, performed better in tests where mental rotation was required. In terms of the gradual differences in participants' ability to understand the concepts, i.e. which concepts are easier and which are harder to understand, a comparable distribution of capacities emerges. Even though educated American adults scored better in tasks where mental rotation was required, these tasks still required more effort than the tasks requiring the concepts of angle and length solely. Based on their experiments, the researchers therefore conclude that Mundurukú and American children, as well as uneducated adults of isolated cultures, share the same geometric competences.[24]

These results suggest the universal presence of a basic understanding of certain geometrical concepts. The logical question is at what moment in the child's development this knowledge emerges. For children and adults, angle and length appear to be the more stable and more easily available features of shape recognition. Sense however requires more of the subject's attention and it requires the ability to make mental rotations of shapes, a capacity which probably also relates to the motor system. Children seem to have a lot of difficulty distinguishing shapes which are each other's mirror images. At a certain point adults are able to master this but even for them mental rotation is a more difficult operation than the recognition of geometric features such as angle and length. Research on the different brain regions involved indicates possible causes. Sense relations of objects appear to be processed by different neurons than those dedicated to the geometric features of objects such as angle and length.[25] Therefore, Izard and Spelke presume that humans overcome the difficulty of detecting sense relations when they learn to read alphanumeric characters. They argue that the

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[24] Dehaene, Izard, Pica & Spelke 2006, p. 383.

[25] Turnbull 1997, pp. 567–569. These findings are based on tests with two patients, one with a visual-spatial disorder who was still able to identify objects but could not grasp their upward orientation, the other with a disorder in visual object recognition who could grasp the upward orientation but could not identify the objects.

ability to distinguish mirror images is crucial in order to be able to recognize the difference between q and b. Learning to read thus seems to foster the integration of geometrical concepts necessary to distinguish the different alphanumeric characters. Izard and Spelke refer to research indicating that the difficulty to read mirror images indeed appears to disappear at precisely the age when children learn to read; this age varies by culture.[26]

Even though mirror symmetry also occurs in the natural environment, for instance, in the form of flowers and butterflies, the capacity to make a distinction between the two mirror images is apparently only of interest when both images signify something different. That is clearly not the case with the two halves of a flower petal or the two wings of a butterfly but obviously it is with language characters and signs in general. Even though the recognition of mirror symmetry requires cognitive effort apparently its advantages prevail. After all, mirror symmetry allows two different significances to be attributed to two different signs, which are only different to a minimal extent. Instead of inventing a large amount of characters mirror symmetry enables humans to use a signs' mirror image in order to signify different content. This probably generates a cognitive benefit despite the fact that it still takes more effort for the subject to recognize mirror symmetry than angle and size. In general, the case of mirror symmetry shows that the making and recognizing of signs probably contributed to the further conceptualization of perceptual properties of the world.

To obtain a more detailed picture of the age at which different geometric concepts are understood, Izard and Spelke executed the same experiment on shape recognition as Dehaene, Izard, Pica and Spelke but tested it first with participants in the age group of three to five years. Next they ran the experiment with participants from five to 51 years of age. It appeared to be the case that pre-school children were able to analyze the properties of visual objects and to pick out the deviant shape from sets of geometrical figures. They also appeared to share the performance profile with infants and adults. Children performed better on angle and length when compared to sense (mirroring), which was hard for them to grasp. Again, it appeared that even though adults were able to grasp sense, this also remained more difficult for them than angle

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[26] Izard & Spelke 2009, pp. 213–216; Serpell 1971, 314–315.

and length.[27] Compared to the second group it appeared to be that despite differences in age and education, the most difficult problems were similar for both adults as well as three year olds. In tasks where shape recognition was involved, angle and length kept prevailing above sense. With regard to development it seems that geometrical skills develop steadily during the course of childhood. Izard and Spelke claim that the essential geometrical knowledge is acquired even before formal training in geometry commences in high school. Therefore they argue that this development probably depends largely on everyday experience although cultural factors must also have an influence.[28] Alongside results from tests about distinguishing geometrical figures, results from tests, which were directed at distinguishing the specific properties of angle, length and sense, also confirmed that sensitivity for angle and length is present at a very early age while for sense it develops during adolescence. It also revealed that sensitivity for length is fully matured at the age of eight while sensitivity for angle keeps developing until the age of ten.[29]

2.4.1.1. Shape recognition

The core knowledge system of geometry obviously relates to the recognition of geometric shapes at least with regard to the properties of angle and length. If sensitivity to angle and length are already present at an early age while sensitivity for sense requires more development, then this insight derived from core knowledge experiments must have consequences for the conception about how shape recognition works. It could for instance mean that angle is one of the most fundamental and defining features that allows humans to recognize shapes.

This is what was also argued for in earlier theories on shape recognition. One of the more pioneering theories has been formulated by psychologist Irving Biederman who argued that the recognition of shapes, and thus of objects, is largely based on

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[27] Izard & Spelke 2009, pp. 217–226.
[28] Izard & Spelke 2009, pp. 227–230.
[29] Izard & Spelke 2009, p. 242.

recognizing their invariant components.[30] Biederman's study exactly addressed the program by Spelke since Biederman postulated that edges, in other words, those junctions where lines constituting shapes meet, are the essential elements by means of which humans are able to recognize a shape and distinguish one shape from another. To a certain extent it can be stated that Spelke found empirical evidence for what Biederman already postulated. Because edges appear to be such an essential feature of shapes it may therefore not come as a surprise that a concept of angle is probably innate.

Biederman's theory appeared to be significant for later empirical studies on shape recognition but it is also relevant with regard to geometric decorative patterns. Biederman meticulously showed how shape perception is a step-by-step process and he showed how the essential concepts such as angle, length and parallelism function within that process.

Biederman postulates a hypothesis similar to one in linguistics, which claims that humans only need a limited arsenal of phonemes in order to represent all the words in all languages spoken around the world, e.g. humans would need a limited amount of geometric components by which all visual bodies and objects can be recognized, imagined and represented. According to Biederman, this limited number of components would then be distinguishable on the basis of 'combinations of contrasting characteristics of the edges in a two-dimensional image (e.g. straight vs. curved, symmetrical vs. a-symmetrical) (...)'.[31]

Biederman argues that humans recognize objects rapidly, even though they might be orientated towards the object differently all the time, their view on objects might be distorted by visual noise, the object might be partly occluded or the object is new to them. That leads Biederman to formulate three assumptions: if objects are recognized rapidly this excludes extensive judgment of all the details but indicates that the access to the mental representation of objects seems to depend on those visual properties that are equally decoded rapidly. The second assumption is in line with the former. It holds that the information, which forms the basis of object recognition, in

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[30] Biederman's theory in turn relied on the pioneering work of neuroscientist David Marr. See for instance Marr & Nishihara 1978, pp. 269–294.

[31] Biederman 1987, p. 116.

order to be rapidly processed, consists of those properties of objects that, regardless of the object's orientation in space, regardless of visual distortions, are invariant. Finally, the system should not fail when only partial information is available, for example, when an object is occluded by another object. In other words: a tiger should still be recognized quickly as a tiger, even when a tree occludes its body and only its head and tail are visible. Biederman argues that perception proceeds according to a number of stages of processing. At an early stage the edges of objects are deduced. The part of the brain responsible for this deduction would be responsive to differences in luminance, texture or colour of the perceived surface. What seems to occur at this point in the process is the abstraction of contour out of the raw visual stimuli received by the senses. Biederman continues his argument by stating that the result of this extraction stage is what he refers to as 'a line drawing description of the object.' It would be the abstraction of 'line', which allows humans to contemplate form and indeed to recognize objects. According to Biederman properties like colour and texture are therefore not unimportant, but secondary to form, when it regards the identification of the object.[32]

Next, the non-accidental properties of edges are further investigated, such as collinearity or symmetry while concave parts are parsed into non-accidental properties as well, which together make up the necessary constraints on the basis of which the

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[32] Biederman 1987, pp. 117–118. Biederman refers to experiments from which it is clear that the time to distinguish a target shape from distractor shapes increases when shapes must be examined from a number of features. It is relatively easy to distinguish a blue square from green squares but more difficult to distinguish a blue square from green circles and green squares. In other words, as long as the attention remains focused on a particular feature of a visual shape, humans are fast and relatively accurate regardless of the number of distractors. As soon as more features are involved (for instance a conjunction of both shape and colour) the attention needs to be distributed and response time increases. See Treisman & Gelade 1980, pp. 101–113. Other research shows that shapes on line drawings are recognized easier and faster than shapes on full colour images. They apparently allow the visual system to focus on the distinctive features of shapes immediately. See Hochberg 1978, pp. 135–136. Experiments conducted by Dorothy K. Washburn indicate that both artists and non-artists are able to recognize geometric patterns consisting of two colours by focusing on those areas, which were homogenous in colour and from which the pattern appears. One-coloured patterns, (black and white) were recognized by focusing on the contour edges along the negative edges of the background area. Both colour and form aspects are thus the primary indicators in the recognition of form. However, contour line is so fundamental that even when other visual features such as colour and texture are absent, forms can still be recognized. From Washburn's experiments it would be evident that both artists as well as non-artists use the same strategies for the recognition of shapes, at least with regard to abstract geometrical patterns, which formed the testing material in these experiments. Washburn therefore concludes that by making such patterns artists likely respond to those aspects of visual perception that could be regarded as universal. From the perspective of the making of images as a way of communication such as strategy seems beneficial. See Washburn 2000, p. 201.

components can be identified. In the following stage, these components are compared to object representations stored in memory, which will eventually lead to the identification of the object. It may be that an object can be identified on the basis of a limited comparison of the components as long as the similarity between the components of the observed image and the mental representation are proportional to a certain extent. This theory thus assumes that when humans perceive an object the primary sense data such as received by the retina are represented as a segmented image in which the segmentation takes place at points of critical concavity where significant differences in curvature can be located. These segments can be compared to a limited set of geometrical ions (geons). These can be imagined as blocks, cylinders or spheres for instance (Fig. 27). They often, but not always, have a straight axis and are symmetrical although not in the case of wedges. They can be distinguished on the basis of perceptual features that are relatively independent of the object's position and other possible visual distortions. The idea behind the recognition of objects by components thus departs from the assumption that despite the enormous complexity that shapes of objects may have, their constituents are basic and limited in number. Again, the comparison with linguistics is immediately apparent. Just like a limited amount of phonemes allow the production of endless amount of words, the limited amount of geons allows the production of an endless variety of shapes. They would be the literal building blocks of shapes.[33]

This principle will be familiar to any first-year art student because it appears as similar to the basic principles by which complex shapes are drawn; to draw a church tower is to draw a rectangular block topped by an elongated pyramid, hence, it is arguable that Biederman's theory is in fact a theory of representation as well, or perhaps a theory of representation by definition, because the argument Biederman makes about the cognitive and perceptual processing of shapes is grounded in the concrete and culturally informed knowledge about what geometric shapes are and how they can be constructed. He assumes that at the psychological level the recognition of shapes unfolds in a similar way as when humans would have to create a complex shape in the

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[33] Biederman 1987, pp. 117–118.

drawing class, namely by identifying the invariant properties of its more simpler constitutive forms.

According to Biederman the central inference at work in the visual system dictates that the properties of edges in the three-dimensional world are likely to be the same as the properties of edges in a two-dimensional image. Biederman explains when an image contains a straight line; the visual system will infer that this edge will produce a straight line in the three-dimensional environment as well; when the image is symmetrical, the visual system will infer that the object in the three-dimensional world projecting the image will be symmetrical as well.[34]

The visual system would draw inferences from the two-dimensional image to the three-dimensional world on the basis of five non-accidental relationships: (1) when a line is straight or when points are arranged on a straight line one infers that this will be the same in the three-dimensional world; (2) the same applies to lines which are curved or points arranged on a curved line; (3) if a shape on a two-dimensional image is symmetrical, in the sense that both halves lateral to the central axis are each other's mirror image, humans infer that this will be the same in the three-dimensional environment; (4) the same applies to lines, which are parallel to each other; (5) the visual system would further draw inferences from points at which two or more lines intersect and at which edges are formed. Biederman explains this with the example of a simple brick, which consists of three outer vertices in the shape of an arrow and three parallel lines (Fig. 28). If one would have to draw this, one could draw an arrow, which points to the left. The straight line of the arrow then forms the central axis of the shape. At its outer right, one draws a short arrow orientated upper-right and a short arrow orientated lower right and finally connects the left arrow to the right arrow by drawing two straight lines. As a result the brick would have an inner-y vertex as well. Each component can be identified on the basis of a few opposite properties: straight or curved, symmetrical or asymmetrical, parallel or non-parallel, whereby in the latter case vertices emerge which can either be arrow-like or fork-like.[35]

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[34] Biederman 1987, p. 119.

[35] Biederman 1987, pp. 120–123. The five basic properties are thus: 1. Collinearity 2. Curvilinearity. 3. Symmetry, 4. Parallelism, 5. Vertex. Biederman shows that in the case of a cylinder there are two curved edges connected by two parallel lines. At the points where with the brick there were two arrow-shaped

The points at which lines intersect and where Y or arrow vertices appear are the indicators of three-dimensionality. It may be the case that in some regions of the image processed by the visual system, shapes appear in which such vertices are absent. Biederman explains that they could be dealt with in two ways; either the visual system regards them as variations of the geons but with an axis length of zero or they are not treated as such variations but should be regarded as planar geons.[36]

Biederman showed that the visual system recognizes components mainly by devoting attention to those regions where there is concavity. The same applies to the recognition of complete objects. Biederman designed an experiment with three versions of drawings of five everyday objects. In the first version the participant recognizes the complete contours of the object while in the second version only the crucial vertices are visible; in the third version only the straight and slightly bent lines of the objects are visible. It appeared that in the latter case objects were not easy to recognize while in the case of contour lines limited only to those of the vertices they were. This may be accounted for by the phenomenon that straight and slightly curved lines between concavities are easily filled in by the visual system while the actual concavities contain crucial information about the properties of the object and therefore deserve the system's attention. Even when the intermediate segments are increasingly removed an object remains relatively well-recognizable on the basis of the vertices; conversely,

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vertices, two y-vertices appear. Parallelism is also an indicator of whether there is concavity because when lines are not parallel they either expand or contract. When lines at one side of the shape meet in a vertex, logically a pyramid shape or a cone is formed. Curved lines tend to expand towards the middle of a shape and tend to contract towards the edges such as in the case of a shape of a lemon. Furthermore, geons can either have a straight or a curved axes and either straight or curved edges; a brick has a straight axis and straight edges while the cylinder has a straight axis and curved edges; a cylinder can expand and form a cone; a cylinder can expand and contract and form a lemon-like shape. What happens, according to Biederman, is that the visual system would abstract from the objects received by the retina their constitutive components (geons). These volumetric geons are subsequently to be distinguished on the basis of the two-dimensional properties of their cross-section and longitudinal axis; for instance a brick has straight edges, symmetrical along its longitudinal axis and has a symmetrical cross-section, it is constant in size (it does not expand or contract) and its axis is straight. On the basis of all these invariant properties Biederman proposes thirty-six possible geons.

[36] Biederman 1987, p. 125. Biederman assumes the latter is the case and adds to the thirty-six volumetric geons seven possible planar geons. In total there would now be 43 geons and Biederman explicitly mentions this number is close to the number of phonemes necessary to produce English words. There would be five possible symmetrical planar geons: squares, circles, rectangles, triangles and ellipses. In addition there are two a-symmetrical planar geons: trapezoids and drop shapes.

when the vertices are removed the object becomes increasingly difficult to recognize when the intermediate segments are also increasingly removed (Fig. 29).[37]

When recognizing shapes humans rely on knowledge gained in earlier encounters with objects and humans would only have to scan as it were, for certain information about invariant properties, to determine whether one deals with a similar kind of shape. What becomes apparent from Biederman's theory is that re-cognition, in the sense someone has the knowledge about the object present, is closely related to re-presentation; the object is present once the subject recognizes its shape. Following Biederman's argument humans would in principle be able to recognize and represent an infinite amount of shapes because they can all be built up by means of a limited amount of constitutive shapes (geons) which are each recognizable by their specific invariant properties.

It must not come as a surprise that his argument is supported and clarified by means of images and it is images that inform the reader what the assumed geons look like and how they would constitute complex shapes. Perhaps pictures and words, in the form of metaphors and analogies, are the only means by which scientists are able to describe the mental processes underlying the visual perception and cognition of objects and bodies. This should also make one at least cautious not to confuse the neural processes underlying mental representation nor the mental representations themselves, whatever their nature is, with representation in the sense of the use of concrete signs and pictures within a cultural and scientific context. At the same time the cultural use of images *does* have an influence on the concepts used in scientific theories about perception and cognition, as well as on theories about the relation between mental representation and pictures. The underlying problem might be that it is only possible to arrive at a conception of how the perception of complex visual patterns works by means of using a geometrical metaphor. The question is also therefore how representations in the sense of pictures or graphic signs relate to mental representation: a complicated but inevitable question, which will be addressed more extensively in Chapter 3.

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[37] Biederman 1987, pp. 135–136.

2.4.1.2. Neuroscientific knowledge about the recognition of shapes of objects

Regardless of the possible objections against Biederman's theory there is significant neuroscientific proof that the recognition of the shapes of objects and bodies indeed proceeds according to a process of increasing complexity whereby in the first stages, neural networks process the basic components such as lines and only in the late stages networks of neural networks process the shape in its full complexity.[38] This is certainly no proof for the existence of geons but it does show that specific parts in the visual cortex are dedicated to specific and invariant properties of shapes. Therefore there is reason to assume that the recognition of geometrical elements such as line and angle, as well as the related concepts of length and direction, seem to have a neural substrate and are universally present, not only in humans, but in other animals as well. In fact, much neuroscientific research on visual perception started with research on animals. For instance, research on macaque monkeys has revealed that their brains contain highly specialized neurons that are dedicated to very specific objects such as particular faces, objects, or even specific concepts; a neuron for example fires when the subject sees an image of a certain person but it will not fire when exposed to other visual stimuli. This evoked the question whether the brain is truly made up of millions of highly specialized neurons each dedicated to a specific visual body or object.[39] Stanislas Dehaene argues that highly specialized neurons indeed exist but they should be considered as the result of computations from a much larger network of neurons. On the basis of recent research Dehaene explains the process as it develops from the moment millions of photoreceptors on the retina are exposed to waves of light until the moment a dedicated neuron responds to an image of a specific person or object. This neuron should be conceived as the top of a pyramid underneath which several processes take place involving many groups of neurons. This is a complex process in which Dehaene distinguishes at least three important developments. He argues that neurons at the primary level of the visual cortex, referred to as V1, respond to simple stimuli such as

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[38] Rolls 2000, pp. 205–218

[39] Quiroga et al. 2005, pp. 1102–1107.

lines and the contours of objects. The more complex stimuli like curves, edges, parts of forms or even entire shapes trigger neurons at the higher levels. Neurons in the V2 area of the visual cortex already respond to combinations of lines and curves; in short, at each level of the visual cortex neurons fire at increasingly complex stimuli. At the same time neurons at the higher levels also respond to stimuli from an increasingly broader portion of the receptive field of the retina allowing the recognition of complete scenes. Finally, neurons at the higher levels respond to an increasing amount of invariance, at the lower levels, for example, they only respond to changes in position or changes in size. In other words: all these networks of neurons operate together and could be conceived as pyramids which allow ‘dedicated’ neurons at the top to fire at specific objects and bodies. Dehaene refers to research by Keiji Tanaka who discovered that the monkey brain contains neurons dedicated to specific fragments of shapes. By showing complex images which were gradually brought down to their most elementary shapes while simultaneously measuring neuronal responses, Tanaka and his team managed to map regions of neurons which fired at similar shapes. According to Dehaene neurons, which fired at an image of a cat, still fired at an image of two superimposed discs, indicating that this specific neuron is dedicated to that specific property of the initial complex image, namely the strongly abstracted shape of the body and the head of the cat reduced to the superimposed discs. By gradually reducing the complexity of the stimulus those neurons can be traced, which still respond to that simple stimulus. The conclusion, therefore, is that those neurons are dedicated to those specific properties of the image still exposed in the simple stimulus. Tanaka’s research group also discovered that these neurons are grouped physiologically in cortical columns. They discovered groups of neurons which fired at combinations of lines forming Y and T-junctions, stars, profiles resembling faces and other objects, etc. Dehaene argues in this way a catalogue of elementary shape variations come to the surface. [40]

Tanaka’s research group discovered the above with a smart experiment, which departed from the gradual reduction from the complex to the simple. It does give an idea of how the visual system works conversely from the simple to the complex making a rough ‘sketch’ first by mapping the basic contours and invariant properties of the

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[40] Dehaene 2009, pp. 129–136; Tanaka 2003, pp. 90–99.

basic forms of the image and gradually compute the increasingly more complex properties of the image allowing simultaneously more variation and distortion. Dehaene discusses Tanaka's discoveries from the perspective of the neurological foundation of linguistic characters. Dehaene develops an argument that the origin of linguistic characters must be founded in this basic shape catalogue and he develops a plausible hypothesis for this argument. These basic form components were selected during the course of evolution because they appeared to contain crucial information to code the visual environment. Dehaene for instance mentions that when two objects occlude each other, their contours will produce a T-junction. These kinds of occlusions are so common in the visual environment that it is not surprising that neurons developed that are specifically dedicated to T-junctions in order to determine which object is in front of the other. The same applies to objects that have a hole in them. This will have the shape of a closed form such as an O. Again, because such shapes are frequently occurring, neurons will fire particularly at closed O-like shapes. There are many of these types of invariant properties, which contain such basic and common but therefore crucial information about the visual environment that neurons developed that are dedicated in particular to the detection of these properties; in the form of shape segments these are as it were anchored in the visual cortex. According to Dehaene much of the letters humans use in written language are so similar to these shape segments that he proposes a shared origin in what he refers to as 'a stock of geometrical shapes'. Dehaene argues:

> 'We did not invent most of our letter shapes: they lay dormant in our brains for millions of years, and were merely rediscovered when our species invented writing and the alphabet.'[41]

Dehaene wonders whether this recognition of 'proto' shapes is genetically coded or whether it emerges during the course of child development as the result of a learning process. Research on babies made clear that they are for instance able to recognize faces and are sensitive to object occlusion. This capacity indeed suggests that the recognition of shapes is partly innate. However, the maximum number of human genes

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[41] Dehaene 2009, p. 139.

is not sufficient to code for the recognition of shapes of what seems an almost unlimited number of possible objects and bodies in the visual environment. Besides, research in the last decades has increasingly revealed that the human brain is highly plastic. Thus, it is very likely that in the course of evolution some shape segments have been encoded because they are so common and so crucial for the recognition of shapes in general. Simultaneously, the visual brain probably largely develops in interaction with the environment and as a result of these interactions neurons will become sensitive to certain visual patterns; the visual brain's development is a result of the sophisticated interplay between what is innate and what is learned. Even though the basic structures are innate it is nevertheless crucial for the survival of the organism that the visual brain at the same time is highly adaptive and is able to become sensitive to new visual constellations.[42]

Dehaene's argument comes down to the following: a minimal amount of innate knowledge about shape is necessary as the foundation with which the visual brain in interaction with the environment is able to make sense of a complex world. According to Dehaene, the overall architecture of the visual brain is universal as well as the neuronal learning mechanism, which allows neurons to respond to new visual patterns and make new connections in order to encode such patterns.[43]

In summary: certain invariant properties of shapes are essential features to recognize the nature of a shape. Therefore it is obvious to assume that the human brain will probably select from the visual stimuli it receives transmitted from the objects from our everyday surroundings those invariant properties first. Dehaene and Tanaka's research programs show that the brain contains neurons and groups of neurons indeed, dedicated to the processing of specific junctions of lines (or vertices as Biederman calls them) such as T-shapes or Y-shapes, from which certain angles emerge. On the basis of the insights of Spelke, Biederman and Dehaene's each of their own research programs it is now possible at least to state that there are psychological and neuronal mechanisms active, that could be regarded as universal dispositions, which allow humans the recognition of some of the defining invariant properties of shapes, namely the

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[42] Dehaene 2009, pp. 14 142. See also Damasio 1994, pp. 108–109.

[43] Dehaene 2009, pp. 14 147.

recognition of line, as well as the competence to recognize its direction, the concept of parallelism, and the intersection of lines with other lines, which in turn allows the recognition of angles, in other words those aspects that are the formal conditions for the recognition of shapes.

2.4.2. Core knowledge of geometry: spatial navigation

The formal conditions that have to be met to recognize shapes is only one part of the whole of formal conditions required to recognize and make geometric decorative patterns. In Chapter 1, I discussed decorative patterns applied on flat surfaces such as walls and floors. Under those conditions decorative patterns are never really perceived as flat, symmetrical and ordered as their original design intended them to be. To the perceiving subject decorative patterns on floors and walls appear to stretch out in front of them. As such these patterns are altered as a result of the deformations caused by the laws of optics and perception that dictate that the further away shapes of objects are, the smaller they appear and that the shapes of objects deform when viewed upon from a different angle. This means that at least to some extent the core knowledge system concerning the navigation in the spatial environment may play a role not so much in the recognition of geometric patterns but in the making of those patterns. The perceiving subject of a mosaic floor may infer from the formal deformations that the two-dimensional pattern extends into three-dimensional space. The maker of such a floor, however, needs to rely on a competence that allows the maker to be able to mark certain points of the design. To be able to do so means that the maker needs to orientate and navigate through space.

From an evolutionary perspective, it seems logical to assume that geometrical core knowledge might initially have provided humans with the basic concepts in order to make sense of a variable and imperfect three-dimensional environment through which they have to navigate, for instance, when they were hunting or gathering. In order to test for spatial navigation capacities, Dehaene, Izard, Pica & Spelke designed an experiment revolving around the use of a simple two-dimensional map to navigate towards a marked target landmark in a three-dimensional environment. It was placed within a defined area, which in total contained three landmarks. After looking at the map, the participant turned away, had to reorient and find the landmark in the actual surface layout. Performance on finding the correct landmark appeared to be above chance in general, even in tests where the shape of the target landmark no longer differed from the shapes of other landmarks. In this particular case, participants had to rely purely on the geometrical relationships of distance, angle and sense of the different landmarks in correspondence to those on the map.[44] Again, the performances of the Mundurukú were comparable to those of American children. The researchers reported that only trained American adults performed significantly better. Despite a difference in absolute results, the performance profiles of adult American and Mundurukú however show a similar pattern, just as was the case with the angle and length experiments.[45]

Prior to the experiment with map reading, a rich tradition in reorientation tasks in controlled three-dimensional environments, both with humans and animals, had already been established. Spelke, Lee & Izard summarize some of the main conclusions that can be drawn from that tradition. Rats appeared to be able to use the length and the relative dimensions of the walls of a room in finding the target food after being disoriented.[46] There is evidence from research with different species of animals that this capability to use the geometric features of the environment develops independently from experience. Chicks and fish hatched and raised in a circular environment were nevertheless able to orientate in a rectangular environment the first time they encountered it.[47] Cues such as the brightness and texture of surfaces apparently did not seem to help animals to reorient. The system for navigation also failed in recognizing shapes applied to flat surfaces and shapes of objects placed in the environment. It appeared that rats solely orientate by the shape of the experimental room and not by the shapes of figures applied to the walls.[48] Spelke, Lee & Izard refer to other research, which showed that four-year-old children also did not reorient using landmark objects,

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[44] Dehaene, Izard, Pica & Spelke 2006, pp. 381–384.

[45] Dehaene, Izard, Pica & Spelke 2006, p. 384.

[46] Cheng 1986, pp. 149–178.

[47] See for instance Brown, Spetch & Hurd 2007, pp. 569–573 & Chiandetti & Vallortigara 2008, pp. 139–146.

[48] Cheng & Gallistel 1984, pp. 409–424.

rows of columns, or arrays of black and white stripes painted on the floor.[49] Even when walls of rectangular rooms are painted in bright colours children apparently look for the target object in all corners of the room regardless of the relation between the corners and the colour of the adjacent walls. On the other hand, children were able to reorient in a room with a wall containing large and diffused circles on one side, and a wall with small, dense circles on the other. Spelke, Lee & Izard propose that the system for navigating through three-dimensional environments fails to capture features of objects and surface markings because these require a lot of attention to detail while a clear focus of the system on the geometric properties of the three-dimensional layout, may provide humans with distinct representations that are economic in terms of the quantity of information needed to orient, and stable in terms of not having to deal with moving objects in the spatial layout.[50] This could mean that core knowledge which allows humans to navigate through space might also be a precondition for humans to be able to define a space such as is the case when marking a piece of land or marking the dimensions of a floor. But the visual features that are successively applied to a floor, such as geometric decorative patterns, are not used, at least not naturally, to orient and navigate *through* space even though the deformations of those visual features allow the perceiving subject to infer that the floor stretches out *in* space.[51]

2.4.3. Integration of the systems

A number of core knowledge systems have now been identified and in addition, I have also discussed Biederman's theory and the neuroscientific research with regard to shape recognition. It can be determined, therefore, that certain aspects of the core knowledge system dedicated to the recognition of small objects and shapes, such as the competence to comprehend angle, length and direction, are involved in the recognition of geometric motifs. The object tracking system that allows humans to connect three or four numbers accurately to objects that occupy specific and proportionally-related

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[49] Lee & Spelke 2008, pp. 743–749.

[50] Spelke, Lee & Izard 2010, pp. 5–7.

[51] In cultural contexts visual patterns *are* deliberately applied to be used as navigational devices. The geometrical patterns and roundels on medieval church floors were for instance used as ceremonial pathways. See Foster 1991, pp. 4–6, 131–149.

spatial positions does not allow humans to comprehend the pattern in its totality but it does allow them to understand the principle of regular repetition of one or more stationary elements. However, that system would fail in regard to other defining aspects of geometric decorative patterns such as mirror symmetry, comprehending hierarchies of motifs that are imposed on or embedded in one another, and the arrangements of motifs connected by a grid of lines. The system of spatial navigation might only play a role in the background and probably specifically with regard to the aspect of defining a surface layout when making a decorative pattern for instance in an architectural context.[52]

Regardless of the sensory modality of the set or pattern, the system for approximate numbers allows humans to estimate the size of large quantities and about the proportion between sets of quantities enabling them to determine which is the largest. The combination of the two core knowledge systems of number is probably possible because humans learn to map counting words on objects. The principle of the counting routine, the inference that any new number is the sum of the previous plus one, is extended to the numbers of the objects to which the counting words apply; three objects plus one object makes four objects etc..

With regard to geometric patterns, the integration of the number systems is needed to enable humans to see a decorative pattern as a regular repetitive arrangement

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[52] The findings from core knowledge research that suppose a two-way system for the perception of space and shape are also supported by neurophysiological evidence. Animal studies have shown that different kinds of spatial information are processed in different parts of the brain in comparable ways as in humans, for instance, in rhesus monkeys in which one system concerns the visual identification of objects while the other system concerns the visual localization of objects. See Mishkin, Ungerleider & Macko 1983, p. 414. The neuroscientists Margaret Livingstone and David Hubel refer to these systems as the 'where' and the 'what' system. The 'where' system concerns the interpretation of the overall spatial organization of a surface layout but also the positions of the moveable objects contained in it, which are determined by edges and discontinuities in the visual field that indicate the presence of these objects. The 'what' system concerns the analysis of the visual scene in much greater detail and processes the colour, shape and surface properties of objects. Livingstone and Hubel propose that the 'where' system is evolutionarily older enabling the organism with the primary need to navigate its environment in order to find food and avoid natural enemies. The 'what' system evolved later and in particular in primates. See Livingstone & Hubel 1988, p. 748. The neuroscientists Melvyn Goodale and A. David Milner have proposed two separate pathways as well but depart from an approach in which the action of the subject relative to the object is more central. In their model, the 'where' pathway also concerns the identification of objects based on visual properties such as shape and colour. The 'how' system constantly provides the subject with the necessary spatial information regarding the relation between the subject and the object, which is important in action such as when the subject is grabbing an object. See Goodale & Milner 1992, p. 23.

of one or more motifs and to distinguish within the pattern different groups of motifs, not only on the basis of formal properties but also on the basis of quantity. All in all, this indicates that the recognition of geometric decorative patterns requires the integration of the different core knowledge system with knowledge that is acquired and culturally depended.

Language seems to be the uniquely human achievement that fosters the integration of the two number systems. With regard to visual artefacts the question would not only concern the problem on what fosters the successful integration of innate and acquired knowledge but also to what extent visual artefacts are the products of such integration or whether they as cultural devices, like language, in themselves precondition this integration.

Izard and Spelke argue that in order for humans to fully comprehend Euclidean geometry both systems of geometry have to operate together and this should be construed over the course of development. They argue that this could either emerge spontaneously such that all humans at some point possess the basics of Euclidean geometry which enable them to use angle, length and sense in a wide variety of uses, or it could emerge as a result of the use of cultural artefacts, for instance, in reciprocity with maps or spatial language.[53] Research indicates that children from a very early age are able to identify objects within two-dimensional representations and are able to identify small-scale representations such as toy dolls and cars.[54]

The system for navigation, however, is different. Spelke, Lee & Izard argue that before the age of two-and-a-half, children are able to learn to detect relative positions of objects in a photographed room or a small model of the room itself but they cannot yet transfer this information to the actual scale of the layout itself. Apparently children are able to understand pictures and models of objects much earlier than pictures and models of spatial layouts. Spelke, Lee & Izard argue that this might be due to the fact that navigating through the three-dimensional layout by means of small-scale models or

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[53] Izard & Spelke 2009, p. 246.

[54] Spelke, Lee & Izard therefore refer to research by Mandler & McDonough, 1996 and Rakison, 2003. See Spelke, Lee & Izard 2010, p. 13. Pictures as well as small-scale objects representing humans and animals are universally found. Pre-historical pictorial representations of animals and human body parts have been found all over the world, which suggests that most cultures have surrounded themselves with such images for long periods in history already. See Onians 2006, pp. 397–428; Mendoza Straffon 2014, pp. 42–69.

maps of that layout, confronts children with an additional problem. They argue that the representation of the spatial layout in some aspects fundamentally differs from the actual layout of which they are a representation. Maps are significantly smaller than the represented layout and a map, is itself, a moveable object while the represented layout is stable. This means that each time the map is consulted, the subject has to attune the position of the map in relation to the layout it represents. Because a map is a small, portable, two-dimensional surface representing a three-dimensional layout, and scale-models are small moveable and manipulable objects, Spelke, Lee & Izard argue that they fall within the domain of core knowledge for form perception while the actual spatial layout they represent falls in the core knowledge domain for navigation. They argue the fact that there are two systems of core knowledge could explain why the making of pictures, maps and models of spatial layouts, is a much more recent cultural achievement than the making of pictures and models of objects. Hence, in children's development the latter would also mature at an earlier age.[55]

The assumption is that through children's experience with maps, objects and small-scale models, they begin to see surroundings not only as navigable space but also as visual manifestations with forms that have distinct geometrical properties such as angle. Alternatively, as a result of experience with physical and mental rotation, children also probably learn to see small-scale objects and two-dimensional representations as visual layouts that can be perceived from multiple perspectives. The argument therefore holds that over the course of development children learn to apply both core systems and their specific ways of analysis to similar types of visual arrangements allowing them to discover new spatial relationships between distances, angles and directions. This would enable them to construct more abstract concepts of geometry than those provided by the initial core knowledge systems.[56] However, it is still obscure what enables children to perceive the navigable surroundings such as a large-scale shape, which has the properties of visual objects such as angles, and what makes them perceive small-scale objects and two-dimensional representations such as the arrangement of paths and locations, which can be imagined as navigable in the mind.[57]

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[55] Spelke, Lee & Izard 2010, pp. 13–14.

[56] Spelke, Lee & Izard 2010, pp. 16–17.

[57] Spelke, Lee & Izard 2010, p. 17.

2.4.3.1. Perspectival drawings

Dillon and Spelke suggest that children might combine information from both geometric systems when they view perspectival drawings and photographs. This suggestion is based on earlier research, which revealed that children do not use patterns of shapes on walls in navigation tasks in symmetrical rooms. But when shapes are used as symbols on a two-dimensional map and refer to landmarks in a three-dimensional environment, they can apparently activate the core system for navigation.[58] Dillon, Huang and Spelke show that children are apparently able to interpret maps from the perspective of either one of the core knowledge systems depending on context. They confronted children with a navigation task in a fragmented triangular surface layout, which consisted only of three sides and no angles, and with a surface layout consisting of only three angles. With regard to the first layout children were able to use their sensitivity for distance and direction to find the landmark. In this case, the map presented, elicited their core knowledge for navigation whilst, with regard to the context of the surface layout consisting only angles, they used the core system for shape recognition.[59]

Perspectival drawings are characterized by representing both the surface layout, as well as the objects contained in it. It combines these features integrated in a single scene. At a very early age children are capable of recognizing objects in line drawings by their contours only. Compared to more abstract representations and cartoons, children would be better at extracting relevant information about objects and actions from perspective line drawings and photographs. In general, it appears to be that the more 'realistic' the picture of an object the better young children appear to be in relating the depicted object to the 'real' world object.[60] In cultures without an abundance of picture

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[58] Dillon & Spelke 2015, p. 895.

[59] Dillon et al. 2013, pp. 3–4. The question would be whether this is comparable to the hypothesis that language facilitates the integration of both core knowledge systems of number. But at the same time this raises other fundamental questions. It assumes that core knowledge systems can be integrated at a higher cognitive level but it remains unclear how humans during the course of evolution have reached that capacity to integrate core knowledge systems and what the nature of that capacity is. Should one for instance conceive this as a capacity to draw inferences across core knowledge systems? And if so, how and at what point does it develop?

[60] Ganea, Pickard & DeLoache 2008, pp. 46–66. It should be noted though that within this research images were used, which not only showed geometric properties but colour properties as well.

books or other pictorial sources children would develop the skill to refer from a pictured object to the real world object eventually, but much later.[61] Dillon and Spelke wonder whether perspectival drawing facilitates the integration of both core knowledge systems as compared to overhead maps.[62]

Dillon and Spelke designed and executed experiments to find out whether four year olds would be able to use line drawings and photographs of a novel room and a novel object in order to spot locations in the room or on the object. For the depictions on photographs, the researchers used a standard empty room with clear scenic properties such as being large, concave and navigable. The object was created with pieces of Lego with whose constructions and pictures children are familiar and whose constructions can grasp similar geometric relationships to those of a room. The object created was, however, small, solid and could be handled. Children were first confronted with a line drawing or a photograph of the room and the object, and were then asked to place an object in a determined location in the room or on the object in accordance with a dot marking the location in the picture. Contrary to the hypothesis that line drawings and photographs facilitate the ability to rely both on surface as well as landmark shape information, it appeared that children achieved much better results at corner target locations in the scene context, and at landmark target locations in the object context. This is in line with the previous findings from experiments with maps where children relied selectively on surface information when finding targets at the midpoint of extended surfaces, and on landmark shape information when finding landmarks in the environment. Furthermore, within the object context more errors were made with regard to direction. They also made more landmark errors in the scene context although this difference was marginal. However, Dillon and Spelke found no evidence that in line drawings or photographs, information from both geometric systems was integrated.[63]

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[61] Walker, Walker & Ganea 2013, pp. 1315–1324. It is still a research topic whether the ability to refer from pictures to real world objects is fostered by early exposure to two-dimensional pictures and/ or cultural experience with others using pictures and symbols to communicate about objects in the world. It appeared also that the performance of the older Tanzanian children in this study was better when the pictures were more realistic. The researchers argue that it would also need further cross-cultural research in order to determine the extent to whether this is a universal phenomenon.

[62] Dillon & Spelke 2015, pp. 895–896.

[63] Dillon & Spelke 2015, pp. 896–899.

Although the previous shape recognition experiments showed that children are able to analyze the geometrical properties of forms using the properties of angle and length, they did not draw from this system when confronted with the representation of three-dimensional objects in a line drawing of a scene. Dillon and Spelke suppose that the performances in analyzing form and scenes do not correspond because each draws on different geometric information. But the researchers also take into account that the shape recognition tasks in their experiment did not capture significant variation in the sensitivity for geometric shapes in children when such shapes are depicted in a perspectival line drawing as opposed to when they see shapes of objects in real life or depicted in photographs.[64]

Dillon and Spelke conclude that it seems children are flexible in using either distance and direction information or object shape information when interpreting perspectival line drawings. They are, however, limited in the ability to combine both sets of information. This finding fits in with the results of experiments on the use of overhead maps. Dillon and Spelke formulate three main findings: they argue that while interpreting pictures of scenes four-year-olds rely on the same information that they use for navigating actual three-dimensional surroundings; they rely on object shape and small-scale visual form information, when interpreting pictures of objects; they do not seem to integrate both systems, neither when confronted with perspectival drawing or photographs.[65]

According to Dillon and Spelke it is striking to note that contrary to what one might have suspected, children did not analyze the small-scale two-dimensional line drawing of a three-dimensional scene using their system for analyzing object shape and two-dimensional surface markings, but used their system for navigating three-dimensional surface layouts. At the same time they were successfully using the two-dimensional forms in analyzing the three-dimensional layout. Dillon and Spelke would have also suspected that children would draw more easily from both their shape and navigation system because perspectival line drawings depict objects and surroundings from points of view with which children are familiar from everyday experience while

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[64] Dillon & Spelke 2015, p. 902.

[65] Dillon & Spelke 2015, p. 903.

overhead maps do not. However, children appeared to be just as limited in integrating the two systems. Apparently the properties inherent to the drawings themselves did not guide their geometric intuition but those to which the drawings referred, which were either the scene or the object. Although the perspectival drawing of the Lego object also captured the spatial structure, which included the object, children did not use the system for navigation. Dillon and Spelke explain that neuroscientific research indicates that parts of the brain devoted to global scene recognition are activated when confronted with Lego scenes but apparently the system of object recognition is activated once it is indicated that such scenes contain a Lego object. Dillon and Spelke argue that it might be this context in particular, which affects the kind of core knowledge system that is activated. They propose further research with the same Lego structure but presented as both a large scene and a small-object.[66]

Hitherto, no concrete evidence has been found that perspectival drawings facilitate the integration of both core knowledge systems. However, Dillon and Spelke conclude by arguing that children from four years old may also show signs of integration of geometric core knowledge when interpreting pictures from the moment they begin to integrate these systems in other more abstract tasks. Their ability to switch to one of the systems in tasks involving overhead maps and perspectival line drawings, depending on the context of these media, might contribute to an understanding of the relationship between the geometric content of both core knowledge systems and thereby contribute to the process of learning to integrate them. This ability to have an integrated comprehension of geometric content then becomes fully matured in adolescence.[67]

2.5. Conclusion

At the end of Chapter 1, it was concluded that the cognitive competences needed to recognize and make geometric decorative patterns at least require the competence to recognize shapes, the competence to individuate one feature from another, and the

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[66] Dillon & Spelke 2015, p. 904.
[67] Dillon & Spelke 2015, p. 905.

competence to recognize a regular arrangement of elements along one or more straight axes, i.e. the competence to recognize and make geometric decorative patterns requires competences of number and geometry.

In this chapter, I have tried to show that core knowledge researchers assume two systems related to core knowledge of number that condition numerical cognition. The Approximate Number System allows humans to recognize different ratios of large sets to decide which is larger, smaller or which is more or less. The system would therefore enable a subject to judge whether one pattern is larger or smaller than another. However, such a comparison does not concern the recognition of patterns as such. With regard to the latter the Approximate Number System does not seem to play a specific role. The Object Tracking System, however, probably conditions the competence to individuate one visual feature from another, which is one of the conditions to recognize visual patterns, but the system also has its limitations. The system enables humans to accurately individuate objects that are either stationary or moving, up to a maximum of three or four and only under the condition that these objects are separated by empty space and not connected by a grid of lines. In Chapter 1, it has been made clear that many patterns in decorative contexts *are* constructed of grids of lines. Moreover, decorative patterns generally consist of more than four repeated elements. Humans are probably capable of understanding individual elements as being part of a larger whole because that larger whole has distinctive properties when compared to those of the individual elements.[68] I stated that a pattern is a regular arrangement of elements along one or more single axes. This means that repetition, regularity and direction are defining properties of patterns. The competence to recognize a regular arrangement of distinct elements that form a pattern is therefore probably conditioned by the integration of the geometric competences allowing the subject to recognize and understand length, direction and distance.

The competences that foster the recognition and making of the geometric properties of shapes and objects are in the core knowledge paradigm also conditioned by two systems. The system for the recognition of small objects and two-dimensional representations is conditional for the recognition of the invariant and defining

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[68] Pylyshyn 2009, pp. 38–39.

properties of shapes such as angle and length. The results from cross-cultural research with children and adult participants indicate that shape recognition on the basis of the properties of angle and length appears to develop universally and independent of and prior to formal education in geometry. However, to accomplish mental rotation to understand a feature like mirror-symmetry appeared to require more cognitive effort even for human participants who were experienced in formal geometry. With regard to decorative patterns, the examples presented in Chapter 1 show that mirror symmetry is a recurrent feature in decorative patterns. This could mean that despite the obvious simplicity of many decorative patterns, features requiring more cognitive effort from the viewing subject might enhance the pattern's attractiveness.

It can be concluded, therefore, that line is the main building block of shapes and as such its recognition must be at the basis of the recognition of the invariant formal properties of shapes. To understand the property of angle the subject needs to recognize and individuate a number of lines and needs to be able to understand the possibility that lines can intersect and form angles. In recent research from visual neuroscience, networks of neurons have been identified that code for line and even code for line under specific conditions such as diagonal lines orientated left or right. In other words, the core knowledge system conditioning the recognition of shape has a neural substrate in the form of networks of neurons dedicated to the processing of the invariant properties of shapes.

The geometric core knowledge system for spatial navigation appeared to play a minor role in the recognition of geometric decorative patterns. Perhaps it plays a role in the making of patterns, together with the underlying core knowledge systems for number and the ability to count, for instance, in the case of marking and dimensioning the layout of a flat surface ornament such as a mosaic floor.

In general, it can be concluded that some aspects of pattern recognition (individuating visual elements, recognizing angle and length) appeared to develop independent of formal training while other aspects (mirror-symmetry) require either training or experience with handling objects to accomplish mental rotation which is the precondition for the understanding of mirror-symmetry. Both the recognition of patterns and the manufacturing processes involved in making patterns are conditioned by the integration of numerical and geometric core knowledge systems. This integration is probably fostered by both language and the use of cultural artefacts.

Core knowledge theory thus provides an empirically founded functional description at the psychological level of the cognitive competences needed to recognize and make patterns. It must be concluded that in their ability to describe the underlying cognitive competences of pattern recognition core knowledge researchers also describe the basis of the recognition of the formal properties of decorative patterns. However, core knowledge does not enable an understanding of what makes the recognition of decorative patterns different from the recognition of patterns in general. They have not described the specific conditions and constraints under which a pattern is recognized as decorative in particular. Still, it is in this context that patterns can also be recognized as references to, or as representations of. Therefore, the next step in this thesis is to determine the conditions and constraints under which geometric decorative patterns are able to refer to, or make present something else, as well as to determine the kind of properties that are involved in establishing this potential to refer to, or make present something else.