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WHY HUMANS CAN COUNT LARGE QUANTITIES ACCURATELY

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1. Introduction

In Western culture, we effortlessly use numerical concepts and symbols in our everyday lives – especially the positive integers. These convey a notion of preciseness and objectivity, and we readily assume that almost everything can be expressed as a numerical value. For instance, intelligence is 'measured' using IQ-scores, and popular magazines frequently provide tests to quantify your happiness or sex-appeal in a scale from, say, 1 to 20. Enumeration is so much part of our daily life, that we tend to take the sophisticated symbolic skills and numerical competence that underlie this capacity for granted. Here I would like to address some questions about the cognitive basis for our ability to count and quantify almost anything. In other words, what cognitive skills are necessary for counting? First, I will give some examples of counting in other animal species. Next, I will discuss how counting develops in human infants and children. Subsequently, I will ask what makes human counting unique, and how this ability could have evolved. Finally, I will discuss its implications for the philosophy of mathematics. I will draw on cognitive archaeological research to provide an answer to the questions when did human counting arise, and how can it be explained as a biological adaptation.

2. How do we count?

When we count, there are several cognitive mechanisms at work. I would like to distinguish between explicit counting on the one hand, and the much broader field of numerical competence on the other, which includes unconscious counting-mechanisms like subitization and rough estimation.

2.1 Explicit counting

With 'counting', we usually mean explicit counting. To count, you first choose the objects you want to count. You thereby assume that anything is countable, and that the use of positive integers to quantify objects can be generalized. This is called the abstraction principle of counting, the principle that any discrete element is countable. Counting implies the use of symbols. If you want to count a collection of, say, six household-objects, you put a series of symbols, spoken words, in a one-to-one correspondence with the objects to be counted. These number-words are always in a fixed order. The last number that is put in correspondence with the last item to be counted represents the total quantity of items. This application of the principles of cardinality and ordinality is quite a sophisticated cognitive achievement. Cognitive psychological research indicates that it is only present in humans from the age of three and a half to four years. This capacity has no equivalent in other animals.

2.2 Numerical competence

The range of numerical skills humans exhibit is larger than explicit counting. We rely on other cognitive mechanisms to assess quantity, without the use of conscious counting. Subitization and estimation are two such mechanisms. Subitization is used to count very limited collections of objects – four or five at the most – at a glance; estimation is used to assess any quantity of larger collections of objects and to compare them. You may already have noticed that counting very small collections of objects, typically fewer than five, does not require explicit enumeration. If you spot three cars on a road, you do not need to use symbols such as number-words to enumerate them, but you can reliably state 'there are three cars on the road'. (Evidently, in order to state this observation explicitly, or to communicate it to others, one has to use number-words.) This cognitive mechanism is called subitization. For over a century, psychologists have known that the amount we can reliably count at a glance is very limited. In an experiment which was devised as early as 1886, adult subjects were shown displays of randomly arranged objects or dots, which they had to quantify as quickly as possible. The time required to enumerate the dots and the rate of errors remain relatively constant for one, two or three dots, but rise dramatically when the number exceeds four. This experiment has since been repeated over twenty times with the same result: typically, humans can subitize collections of up to three objects. Beyond that, they rely on estimation and the results become less accurate (Dehaene 1999). To determine whether this capacity is a learned cultural trait or an innate cognitive domain, it has been repeatedly tested in infants between five and twelve months of age. Arguably, because these children could not have learnt subitization from their parents via language and cultural transmission, any evidence that subitization is present in infants offers a valuable insight into this cognitive capacity.

Humans are also capable to quantify any large set of objects without explicit counting using estimation, e.g. when we state that a group consists of about twenty people, or when we see a flight of about ten geese. Though this process is always approximate and necessarily inaccurate, it is generally considered a way of counting, since it enables us to quantify collections of objects, and to make relative numerical comparisons.

3. Do animals count?

Do other animal species have cognitive mechanisms similar to human counting? Several experiments show that they have numerical competence, but that they do not use symbols to count explicitly and accurately. I will review evidence of subitization and estimation in two particular case-studies, which are both related to the assessment of group-size.

3.1 Subitization

Subitization has been documented in a wide variety of vertebrate species. I will explore one case study more deeply, to show why animals would be able to count small collections of objects or groups. Assessment of number is useful for animals who live in social groups and who engage in intergroup-conflicts. Larger groups tend to defeat smaller groups. This has been observed in many social species, including humans, ants, social carnivores and primates. In general, animals should enter an intergroup contest only when the probable benefits outweigh the possible costs. If social animals do possess numerical skills, they would be more willing to engage in fights if their party outnumbers their opponent's. This prediction was tested in an experiment with female lions in the Serengeti National Park of Tanzania (McComb et al. 1994). Female lions from the same pride collectively protect their territory from other females. Territory-ownership is marked both by scent and roaring. Lions know the roar of every other female and male in their pride – so unfamiliar roaring always implies intrusion into the territory by unfamiliar individuals. When female lions fight, the chance of fatal injury or even death is extremely high. Game-theoretical modelling predicts that they will avoid fights when the chances of winning are low, because the costs of losing are high.

Female lions from several prides were confronted with a hidden tape playing one or three unfamiliar roaring intruders. They were more likely to approach a group of three intruders when their own pride consisted of three or more individuals, than when it numbered fewer than three. A single individual or a pair of lions was more likely to confront a single roar than a chorus-roar. If in such a case, a single individual did approach the tape recorder, she generally walked more cautiously towards it then did members of larger groups; she often recruited help from distant group-members by roaring. This experiment shows that lions are aware that overlapping roars represent more individuals than a single roar. It also shows that lions are aware of the numerical properties of their own pride, and that they compare it with the size of the intruding group. Significantly, they are only likely to approach the intruders when their own number matches or exceeds the number of roars heard on the tape.

Other experiments, using the same playback-technique, have shown that lions use their numerical skills in a context-sensitive way. Female lions from the Ngorongoro-crater (Tanzania) were more ready to approach the tape recorder than did those from the Serengeti. However, the population density of lions in the Ngorongoro-crater is four times higher than that of the Serengeti. The relative value of a territory for a resident pride is therefore higher, which is why the lions are more willing to defend it (Heinson 1997). In a similar playback-experiment with male lions (Grinnell et al.1995), resident members of a pride approached the tape even when they were outnumbered. This tendency only decreased when they were outnumbered three to one. Male lions are more ready to attack intruders than females, because they have so much more to lose. Unlike lionesses, who live in prides for most of their lives, lions' pride membership usually lasts only for about three years during which they can reproduce. Afterwards they are chased by other coalitions of intruding males. Once chased, it becomes very difficult to find residence in a new pride, so they are usually doomed to live a solitary life, without reproductive prospects.

3.2. Estimation

Estimation has been observed in a wide variety of clades, including many species of birds and fish. An interesting example is provided by an experiment with the European minnow, a species of shoaling fish (Barber & Wright 2001). Animals living in groups benefit from anti-predator responses, such as dilution effects and earlier predator detection. They also suffer costs, such as competition for the same resources. Not all groups are equally attractive to potential or actual members. Larger groups may be preferable because living in those groups is generally safer. Controlled experiments (e.g. Krause & Godin 1995) in which predators were allowed to capture prey in larger or smaller shoals have revealed that, despite their preference for larger shoals, predators were more successful capturing fish from smaller shoals. This is why we would expect shoaling fish to choose a large shoal over a smaller one. Familiar individuals may be more attractive than unfamiliar ones, because the cohesion in the group may be higher or competition for the same resources may be lower. The European minnow was tested for its preference for either familiar individuals or large groups. In a typical experiment, 30 test fish were presented with two shoals consisting of unfamiliar individuals, in the following numerical size combinations: 10 versus 10, 9 versus 11, 7 versus 13, 4 versus 16. Test fish did not show a consistent preference for either of the stimulus-shoals when each contained 10 fish. However, as the size differential between the two stimulus shoals was increased, test fish showed an increasingly significant preference for the larger group. In a second run of the experiment, the test fish were allowed to choose between smaller shoals with familiar individuals, or larger shoals with unfamiliar individuals. When the difference between shoal-sizes was small, they consistently preferred the ones with the familiar individuals. However, when the difference between the shoal sizes increased to 4 familiar individuals versus 16 unfamiliar ones, they consistently chose the largest group. Obviously, these animals are capable of making flexible decisions based on numerical cues.

3.3. Explicit counting

Numerous experiments have been carried out to see if non-human animals are capable of explicit counting. In one study that ran over several years the female chimpanzee Ai was taught to assign Arabic numerals from 1 to 9 on a keyboard to a number of dots on a screen, either in a row or randomly positioned (Biro & Matsuzawa 2001). She was slow, but remarkably faster and more accurate when the dots numbered fewer than four, indicating that she used a form of subitization similar to humans. In spite of extensive training during years, Ai's performance never reached the level of that of humans. It was good (about 80 %), but not accurate – it especially became inaccurate as the number of dots increased beyond four. The moderate results of the test show that Ai never explicitly counts, but instead relies on a form of estimation. She would never use symbols in the wild to represent numerical entities – she does so because human experimenters trained her extensively. Evidence for explicit counting in non-human animals is thus weak at best; rather, it tells us more about the efforts and techniques of the experimenters than about the mental abilities of chimpanzees.

4. How do human infants learn to count?

The last two decades have witnessed a paradigm-shift in the ideas on the development of counting-skills in infants and children, both as the result of improved experimental procedures and of a more thorough understanding of the way the human brain develops during early infancy.

Experiments indicate that numerical competence such as subitization and estimation arise much earlier in development than explicit counting.

4.1 Numerical competence

There are only three possible explanations for how humans acquire numerical competence. The first is cultural diffusion: children would learn counting-procedures from their parents or other adults and gradually learn to apply these principles. If this were the case, we would expect counting to arise relatively late in development, after children have acquired enough linguistic skills to learn cultural traits. The second is individual discovery. This idea was put forward by the psychologist Jean Piaget (1952), who stated that children gradually acquire numerical competence as they interact with the world. By dividing items or putting them together and observing the results, they would gradually understand that quantities can be represented abstractly; in this way they would acquire the ability to perform arithmetic (adding, subtraction, dividing...). If this were true, we would expect numerical abilities to arise when children's motor skills are sufficiently developed to interact with the world – typically, this is after nine months of age, since this is the age in which infants can voluntarily grasp and release objects (Wynn 1998: 113). Third, numerical competence could arise as the result of an innate cognitive domain. If this were the case, we would expect it to arise early in development – before nine months of age. To test whether infants are capable of subitization is more difficult than testing older children because obviously they cannot tell the experimenter how many items they see. To bypass this problem, experimenters use the violation of expectation procedure. This procedure relies on the assumption that the infant's attention is drawn to things they do not expect, rather than to things they are used to. Magicians use the same principle to attract the attention of their adult audience (Hauser & Carey 1998). The addition and subtraction experiment devised by developmental psychologist Karen Wynn (1992) tested the ability of five-month-old infants to reason about number in an abstract fashion. In a typical run of the experiment, infants are presented with a puppet on a theatre. Next, a screen is put in front of the puppet. As the subjects are looking on, the experimenter places another puppet behind the screen. However, in some cases, one of the puppets is secretly removed. The infants should expect to see two puppets, one plus one, when the screen is dropped. Indeed, infants who are confronted with an unexpected result – one plus one equals one – stare significantly longer at the theatre than those who see the expected result – one plus one equals two.

The sense of number in children proves to be quite abstract. In another experiment, six-month-olds were tested on their ability to detect numerical correspondences in stimuli presented to them in different modalities (Starkey et al. 1983, 1990). They were shown a display with two slides representing household-items. The shape, texture, colour and size of these items varied with every slide. One of the slides had two objects, whereas the other had three objects. The infants heard a number of drumbeats, either two or three. The looking-time to each of the slides presented simultaneously was measured. Infants preferred, i.e. looked longer at the slide with the number of objects corresponding to the number of drumbeats. This shows that infants can detect numerical correspondences across modalities, making it extremely unlikely that subitization arises as a by-product of general perceptual skills. The data obtained from these and similar tests are robust. Not only have the experimenters taken care to avoid any influence on the results (e.g. the looking-time of the infants is measured by two independent observers, who do not witness the experiment itself), but they have been repeated in different laboratories, using different stimuli. The experiments indicate that counting is a specialized cognitive domain (Butterworth 1999). Since it arises early in infancy, it cannot be learned from individual experience, nor from cultural transmission, which makes it an innate cognitive domain.

4.2 Explicit counting

Unlike subitization, explicit counting arises relatively late in human development, usually between three and three-and-a-half years of age. Children probably rely heavily on their linguistic skills to learn it, since there is great individual variation, as it is closely linked to the age in which children manage to speak their maternal language fluently.

This is nicely exemplified in the experiment 'give Big Bird x toys'. Children of two and three years of age typically fail the following test: when asked to give a certain quantity of toy animals to Big Bird, e.g. five, they grab any amount of toy animals, say three. When asked 'are you sure these are five toys, can you count them for me?' one of the subjects typically replied, '1...2...5...that's five animals!' At the age of about three and a half, most subjects manage to solve the same test they had failed on more than six months before (Wynn 1998: 123). This experiment shows that young children under three-and-a-half years of age do not understand the application of symbolic units (in this case, number words) to enumerate discrete entities. Though they have some sense of number, the use of symbols to represent them is something they learn at a later age.

5. The biological basis for counting

5.1 Numerical competence as an adaptive trait

We have seen that human infants share numerical competence (subitization and estimation) with many other animal species. It is present in all vertebrate species examined for it (Hauser 2001). Why do human and other animal brains possess numerical competence? Evolutionary biology provides the best concepts and analytical methods to explain biological phenomena. Ever since Darwin, biologists have explained biological properties as the result of natural selection. According to the adaptationist approach, intricate and complex features are the result of an ongoing process of the selective retention of random mutations due to relatively greater reproductive success. As a result, anatomical and cognitive features become more complex and better adapted to their environment. We can therefore assume that any complex trait was or is adaptive, i.e. it has in some way promoted the probability of survival and reproduction in the ancestors of the organism possessing that particular trait (see, e.g., Orzack & Sober 2001).

Are there any underlying characteristics of numerical competence that make it a valuable adaptive trait? The answer to this question is related to the more general question, why do animals have brains. Every organism, including bacteria, plants and animals, interacts with its environment – it responds to its environment. This is because every life-form is basically a body, a bounded object carrying a genetic code which is transmitted to offspring when the organism reproduces itself. Through these boundaries all interaction with the world takes place, like foodintake, sexual reproduction, and other exchanges of matter and energy. Some of these interactions are beneficial to the organism, some are neutral, others are detrimental. These stimuli can evoke a response from the organism. Such responses can be either adaptive or non-adaptive, e.g. a small animal that cannot stand heat well could shrivel in response to it (a non-adaptive response), or it could move away from the heat-source (an adaptive response). Organisms that respond adaptively to their environment can reproduce more successfully than those that respond non-adaptively. Thus, natural selection favours traits that enable an organism to respond adaptively to external stimuli (Humphrey 1993). Relatively immobile or sessile organisms such as plants develop several ways to interact with their environment in an adaptive manner, such as thorns, or flowers with attractive scent and colour to attract insects. Very small organisms such as bacteria and unicellular eukaryotes have very quick successive generations and develop several skills to deal with a hostile environment, like antibodies or chemical resistance to predating organisms. Animals on the other hand are mobile and have a slow generation-time. Interaction with their environment is therefore more complex than that of sessile or microscopic organisms. To respond adaptively, an animal must have a device that enables it to interact with its environment. The brain is the organ that makes sense of the environment, and that can make adaptive decisions to the cues it receives through the senses. Since the information received through the senses is simply too complex to do anything with, the brain, in order to make sense of the world, must possess mechanisms to break this incredible complexity of the environment down into simpler data. This is where innate cognitive domains, such as naïve physics, naïve biology, or the sense for number can and do play a critical role. They break the information down into simpler data, which the brain of the animal can use to base its decisions upon. To be able to perceive the world in terms of numerical entities is a way to make complex data simpler, it offers an abstraction of the environment. This is probably why numerical competence is present in all vertebrate species examined for it.

5.2 An adaptationist explanation for explicit counting?

I have reviewed some of the evidence for the claim that a biological explanation is plausible for numerical competence. I will now address the question whether an adaptive explanation could also be proposed for explicit counting. Explicit counting is reliably documented as a human universal. Some of the surface characteristics may vary, but deeper characteristics are invariant across cultures. In particular, all counting procedures in every culture known involve the establishment of a one-to-one correspondence between the objects to be enumerated and a set of items in a stably ordered list (Starkey et al. 1990; Ascher 1998). This list may contain number-words, but this is not necessarily the case. Some languages have very few number words, e.g., several Australian Aborigine-groups have only words for 'one', 'two', 'many'. In these cultures however, other means are used to symbolize quantities, like pebbles or notches on a tally. Other cultures have no specific number-words at all but use other words to count. For example, many Papua cultures use parts of the body to enumerate things. They are used in a fixed order: starting with the left hand little finger, they count little finger, ring finger, middle finger, index finger, thumb, wrist, lower arm, upper arm, shoulder, neck, and so on to the right hand little finger. They work in the same way as our number-words, for example, in a counting context right eye will always mean sixteen (Rauff 2003). The Malinke from Senegal say 'a whole person' when they mean twenty (ten fingers and ten toes); 'a bed' in an enumeration context means forty, because a bed contains a man and a woman. Some authors have erroneously thought that these people do not fully grasp the abstraction principle of counting, because they do not use specialized number-words. However, all explicit counting relies on the universal human capacity for representing concepts using symbols, hence the similarities between counting systems of widely differing cultures.

Could an adaptationist approach equally apply to explicit counting or even to symbolic representation of information in general? All counting systems rely on the use of symbols that can store, represent, and transmit information about quantified entities. *Homo sapiens* is the only species capable of storing and transmitting information through means other than the own body (Donald 1991, d'Errico 1995, d'Errico 1998). This capacity to use symbols as a means of external storage of information, marks a critical step in human mental evolution. We have to examine when it arose in human evolution, and what selective pressures could have brought it forth. Because the first occurrence of any cognitive trait can tell us something about its adaptive significance, it is useful to look in the archaeological record when humans first used material culture in a symbolic manner. The oldest unequivocal evidence for symbolic artefacts comes from the Kenyan site Enkapune Ya Muto, with ostrich eggshell beads dated at about 50 000-45 000 BP (Ambrose 1998). Before this time, all technology had a purely utilitarian function, for instance, stone tools to break open bones or scrape meat from them. Beads however do not serve any such function: they are used to adorn the human body. The use of symbolic artefacts marks a transition in behaviour and technology in Africa at about 45 000 BP and in Europe at about 40 000 BP, usually called the Middle to Late Stone Age transition in African archaeology, and the Middle to Upper Palaeolithic transition in European archaeology. According to several archaeologists (e.g. Mithen 1996, Mellars 1996, Klein & Edgar 2002), a biological explanation accounts for this relatively abrupt change in behaviour, probably a reorganization of cognitive abilities.

The oldest evidence of external symbolic storage are Late Stone Age and Upper-Palaeolithic *Artificial Memory Systems*. These are means of recording, storing, transmitting and handling information outside the actual body. Objects containing numerical information acting as *Artificial Memory Systems* are widespread across human cultures, for example, abacuses, rosaries, tallies, and quipus. Formal analysis of prehistoric notched artefacts in bone or other organic materials can reveal something of the way Palaeolithic peoples used material culture to externalize thought-processes like counting. Of course, we can never really retrieve what exactly was counted. The code for the symbols is lost to us forever, as we simply do not have enough information about these societies to find out what they mean (d'Errico 1995). The fact that they have ordered sets of notches or incisions indicates that these artefacts were used to represent numerical information. Microscopic analysis shows that they were used in a wide variety of ways. We can for instance see whether the maker attempted to make the elements morphologically different. The accumulation of the elements can be inferred by analyzing the tools with which the engravings were made. If several tools were used and abandoned subsequently, we can infer that the accumulation of the engravings was gradual, similar to a tally-stick (d'Errico 1998). If the tools were used simultaneously, we can infer that the artefact was conceived as a whole, representing different items with different symbols, like a calendar (Marshack 1972, 1991).

5.3 Palaeolithic counting-systems

I will give some examples to illustrate that the several ways of counting and storing numerical information externally that we see in current societies were already present from 50 000 - 45 000 BP on. My aim is to show that Late Stone Age/Upper Palaeolithic cultures had the same procedures for explicit counting as we see today.

The La Marche Antler (fig. 1) provides a good example of an *Artificial Memory System*. This piece of antler was recovered in the cave of La Marche, France (d'Errico 1995, 1998). It dates most probably from the Upper Magdalenian (between 17 000 and 11 000 BP). Microscopic analysis reveals that the marks were made with several tools, using different techniques, such as pression, rotation, indirect percussion. Often, the antler was turned 180˚ in order to produce different kinds of notches. The patterns on figure 1 indicate the sets of marks carved by the same tool. The capital letters divide the marks into groups or sets. The arrows indicate when the antler was turned within groups of marks produced by the same point. All the marks within a set were made at the same time, with the same tool, using the same technique. Sometimes the same tool was made to produce two different sets, e.g. C on face 2 and J and L on face 1. On first sight, the number of different points superficially implies accumulation over time; however since some tools were used to produce several sets, it is highly unlikely that this was a tally. Rather, the La Marche antler was most likely made in a single session (d'Errico 1995). All the marks visible could have been produced with seven or eight points, and as stone tools have two points, only four tools were required to make all the marks. Apparently, the engraver aimed to produce the largest number of morphological differences between the sets, using a minimal number of tools. Though it is impossible to guess what this object was used for, it is clear that several sets of items were being counted. It is intriguing that the sum of all the marks of face 2 equals 212, which is precisely seven observational lunar months (Marshack 1991).

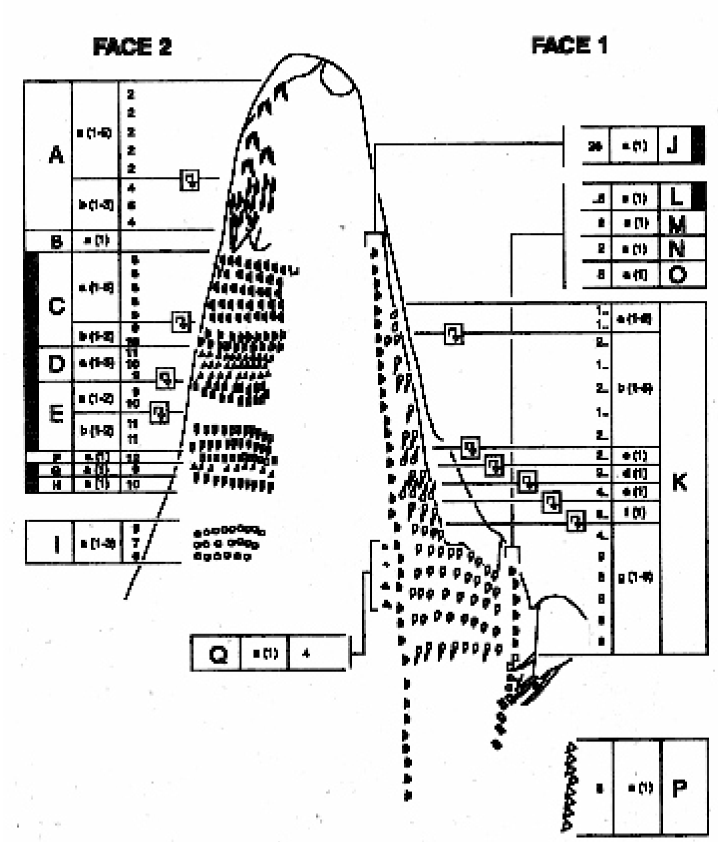

FIGURE 1. The La Marche antler. Reprinted with permission from the author, from d'Errico 1995: 183 (Figure 19).

How could the use of *Artificial Memory Systems* be adaptive? We can only assess their adaptive benefits when we look at them in the context of other behaviours. The appearance of the first symbolic artefacts coincides with a behavioural revolution. Several archaeologists (e.g. Stringer & Gamble 1993, Kuhn & Stiner 1998, Klein 1999) have pointed out that Middle Stone Age and Middle Palaeolithic peoples hunted and gathered less efficiently than Late Stone Age and Upper Palaeolithic peoples. Related to the rise of *Artificial Memory Systems* could be the recognition of cyclical patterns in the environment. Recognizing cyclicity is important for mobile hunting-gathering groups, because it enables them to optimize hunting and gathering by timing their visits to certain sites according to cyclical patterns in plant growth and animal migration. Thus, the use of symbolic artefacts to store, retrieve and transmit such patterns is adaptive, because it enhances reproductive success.

An interesting case-study illustrating Late Stone Age people's ability to exploit cyclicity is the capture of Cape fur seals in south-western African coastal sites, compared to those of Middle Stone Age sites (Klein et al. 1999). Fur seals breed on off-shore islands, the majority of births occurring between late November and early December. About nine months later, adult seals force their young from the rocks into the sea. Large numbers of these young seals wash ashore, exhausted or dead. It would be extremely convenient for mobile hunter-gatherers to time their visits to these sites during this period. Skeletal material from seals in sites with human occupation dating to the LSA is indeed mostly from young seals of about nine months old. This implies that LSA people timed their visits to the coast to fall within the August-October peak in juvenile seal availability. In contrast, Middle Stone Age sites do not show such a fixed pattern. The seals recovered from these sites are commonly older, ranging from sub-adults to adults. This latter pattern is very similar to that found in dens of fossil hyenas, scavengers that routinely roamed the coast. Figure 2 shows how bones from the LSA site fall mostly in the 9 month-old interval. By comparison, the MSA sites have a much greater variability, comparable to the fossil hyena-dens.

The use of material culture to store and transmit information marks a fundamental change in human cognitive evolution. Without this, much of our thoughts and ideas would simply not be possible. The external storage of information enables us to store information in a reliable fashion, so that its content can exceed the capacity of the individual brain to memorize and transmit this information. Science would be utterly impossible without *Artificial Memory Systems*, since it relies on the accurate and accumulative storage and transmission of information, as in books or journals. The use of *Artificial Memory Systems* in counting and other forms of mathematical practice can thus be situated in an adaptive human ability to store and transmit information outside the brain.

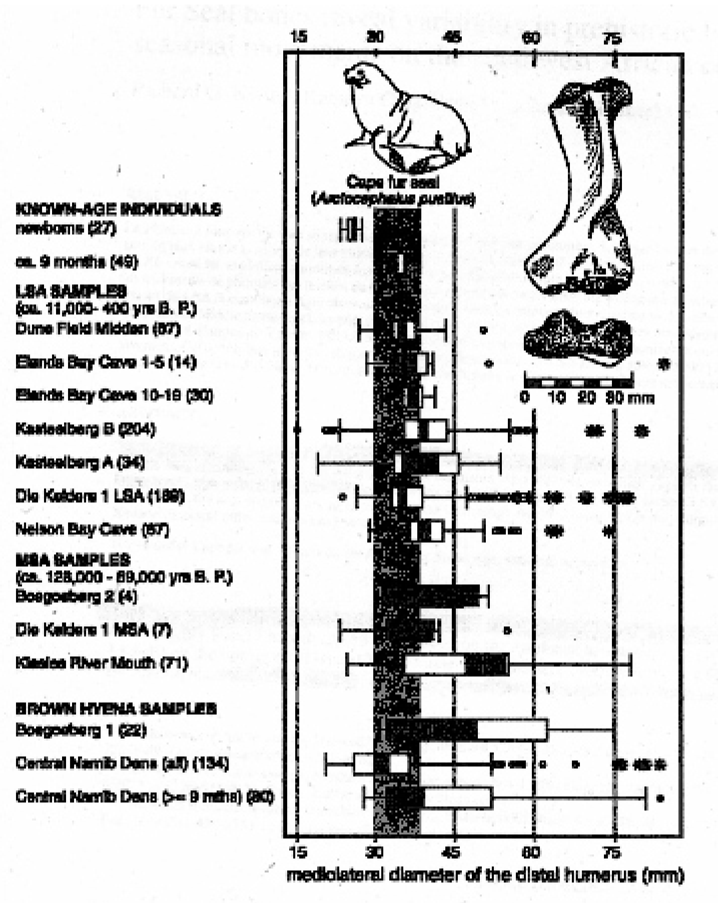

Figure 2. Mean age of fossil remains of Cape fur seals from south-western African coastal sites of human occupation and fossil hyena-dens. Reprinted with permission from Richard G. Klein, from Klein et al. 1999: 188 (Figure 2).

A second case-study illuminating the use of cyclicity in Late Stone Age contexts as opposed to Middle Stone Age contexts is the exploitation of riverine fish. Traditional fishermen in Africa plan their movements to coincide with certain phases in the reproductive cycle of fish in order to catch them in greater number and with the greatest ease. Numerous archaeological sites with fish remains indicate that Late Stone Age people relied heavily on fish for their diet. They show patterns of intense, seasonal and specialized fish exploitation. At Ishango, Congo, located along the Upper Semliki River, archaeologists have found extremely dense concentrations of fish remains, together with hundreds of barbed points used to spear fish. Ishango is dated at about 25 000 BP. More than thirty percent of the remains belong to the genus *Barbus*, a large minnow-like fish. The size range of the fish remains represents a primarily mature population, probably on a spawning migration. This implies that the prehistoric fishermen at Ishango timed their capture to the rainy season, when large quantities of *Barbus* congregate in river mouths on their seasonal spawning migration. The repeated rainy-season occupations at the Ishango sites indicate the predictability of these spawning runs (Stewart 1994). Interestingly, an artefact indicating symbolic storage of information has been recovered at Ishango. This so-called Ishango bone (fig. 3) is a 10 cm long piece of bone, inlaid with a sharp piece of quartz at one end. Figure 3 shows a schematic representation of its incisions. As stated earlier, we have no way of knowing whether this was a calendar to help time migratory events of fish, or a record to count the amount of fish captured. We see an understanding of number, for example, two sides display 60 strokes in different patterns, one of which is divided in prime numbers (Pletser & Huylebrouck 1999).

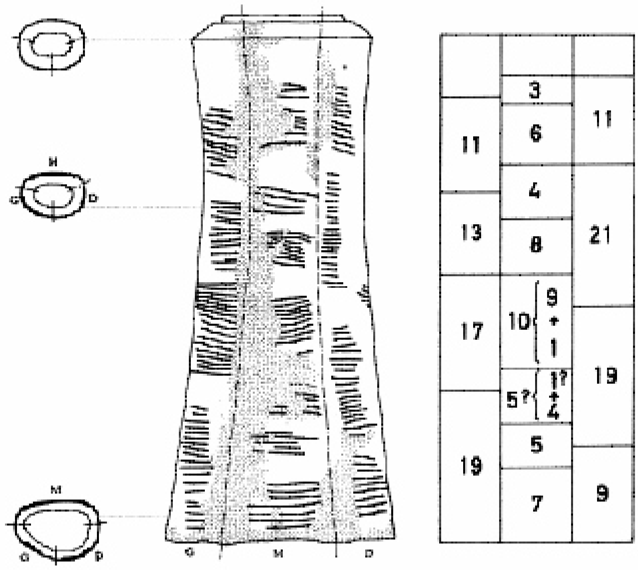

FIGURE 3. The Ishango bone. Reprinted with permission from the Koninklijk Belgisch Instituut voor Natuurwetenschappen.

6. Relevance for the philosophy of mathematics

This review of counting in animals and humans has implications for the philosophy of mathematics. Mathematical realism or Platonism holds that mathematical entities have an existence independent of the human mind. One of the best arguments for this claim is the indispensability argument, as formulated by Quine and Putnam: since all empirical sciences rely on mathematics, we ought to believe in the reality of the mathematical entities needed to describe scientific phenomena, in order to believe in the reality of scientific statements. On the other hand, a special case of constructivism, which states that mathematical entities are constructions, is mathematical intuitionism, which holds that mathematical entities have no existence outside the human mind. An evolutionary approach makes the indispensability argument dispensable. Since basic mathematical constructions in the animal and human mind are the product of evolution by natural selection, they must somehow have promoted the survival and reproductive success of the ancestors of those organisms. This is only likely if there is some correspondence between those innate cognitive domains, like numerical competence, and the physical world. Thus, mathematics can be considered a reliable tool to describe scientific phenomena – even if it has no existence outside the animal or human brain. For the same reason, man-made *Artificial Memory Systems* that contain mathematical ideas can be considered to contain information about the world. Since the manufacture of these objects requires skill, energy and time, they must have benefits (such as the ability to remember cyclical patterns) to outweigh their costs.

7. Conclusion

Many animals possess innate cognitive mechanisms to reason about number. They use these skills to respond adaptively to their environment. Human infants also possess innate numerical skills, which arise in development before they could possibly be attributed to individual learning or cultural imprinting. Explicit counting relies on the use of culturally embedded symbolic forms of representation in which items to be counted are put in a one-to-one correspondence with the symbolic entities which represent them. Even though these systems differ widely between cultures, they have deep and unchanging characteristics, which make them a human universal. As I have argued, the use of *Artificial Memory Systems*, external means to store and transmit information, is a unique human faculty that arose in Africa at about 50 000 - 45 000 BP. It marks a critical step in human cognitive evolution, initially enabling us to exploit the environment more efficiently – and, ultimately, making science and mathematics as we know it possible.

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