On Cognitive Artifacts[1]

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> All this hints at the role of material culture as the backbone of an evolution of knowledge. … what if the game-changing role of material culture as a means of cognition also extends to the symbolic means of our thinking … ? (Renn 2020, 50–1)

Abstract

Wearing the hat of a cognitive anthropologist rather than an historian, I will try to amplify the ideas of Renn's cited above. I argue that a particular subclass of material objects, namely "cognitive artifacts," involves a close coupling of mind and artifact that acts like a brain prosthesis. Simple cognitive artifacts are external objects that act as aids to internal computation, and not all cultures have extended inventories of these. Cognitive artifacts in this sense (e.g., calculating or measuring devices) have clearly played a central role in the history of science. But the notion can be widened to take in less material externalizations of cognition, like writing and language itself. A critical question here is how and why this close coupling of internal computation and external device actually works, a rather neglected question to which I'll suggest some answers.

1. Introduction

I hope and believe that the ideas here are quite relevant to the history of science, although they are drawn from other domains of academic thinking, especially anthropology, philosophy, language science, and the cognitive sciences in general. The central idea in a nutshell is that the power of human thinking is owed very largely to its *externalization*, which allows us (often quite literally) to manipulate ideas represented in objects, devices, or external codes. This is of course not a new idea—Jerome Bruner already outlined it succinctly in (Bruner 1966), and it can be traced much further back still. But it has since been much further developed independently in a number of disciplines, and the ideas can now be stitched together and fruitfully recycled. My own contribution here is to try and sketch *exactly why externalizing ideas so empowers them.*

[1] This preprint is adapted from a forthcoming book (Bennardo, Chrisomalis, and De Munck, forthcoming), but closely reflects the paper I gave at Trieste in honor of Jürgen Renn on July 2022.
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The story I will outline has relevance for the history of science in the following ways. First, the hybrid nature of externalized thinking—part cognition, part external device or representation—explains why the manipulation of instruments and representations plays such an important role in the development of scientific and technological thought. It embeds the history of science and technology within a general theory of cultural evolution (although that is not developed here). By so doing, it equally explains how easily scientific progress can go into reverse: the loss of either idea or instrument destroys the hybrid advantage. In addition, by focusing closely on how exactly these externalizations of thought and process work, we may be better able to see why some such hybrids were winners and others withered on the vine.

I start from the position that culture is such an improbable biological outcome that it needs an evolutionary perspective to explain its emergence.[3] We could begin by asking: What is the function of culture? Given the many overheads (including the cognitive effort, the costs of behaving altruistically and giving away good tricks), what are the payoffs? The central function, I would suggest, is for sharing things that are useful (i.e., tricks for doing things), and the payoffs are that individuals get more out than they put in. What they get out, I suggest, is a whole new form of cognition, which has a curious ontological status and is not wholly in the head.

A way of thinking about the shared tricks that constitute culture is to think of culture as composed of multitudes of *tools*, some concrete and some abstract. The concrete tools are mostly devices that amplify the body: hammers, knives, levers, pulleys—even horses, jet planes, and jack hammers are essentially bodily prostheses. The kind of exoskeleton that deep sea divers use is a kind of prototype to bear in mind. In contrast to these bodily prostheses, the more abstract tools are devices that amplify the mind: they are what I will call *cognitive artifacts.* They may be concrete things like a slide-rule, an abacus, or a computer, and their job is not to amplify the body, but to extend our mental powers. The rest of this paper outlines these mind-expanding tools, and tries to show how our cultural worlds are pervaded and sustained by them, and indeed how they constitute the backbone of culture.

[3] In Levinson (2022), I suggest that the source of the human propensity to share lies in an early evolved use of alloparenting, requiring some kind of matching of empathy and communication.

2. Culture as Cognitive Technology[4]

2.1 The Idea of a Cognitive Artifact

Nearly half a century ago, Jack Goody (1977) introduced the idea of a "technology of the intellect." His key example was the invention of writing. When writing is first introduced in a society, he noted, it is used for very simple mundane uses, of which making lists is the most prominent. Such lists have two rather different uses: they can be forward-looking to-do lists (like shopping lists or recipes), or they can be backwards-looking lists (as in records of tribute received). The first has a directive or computational character, while the second performs a mnemonic function. In both cases, he noted, in externalizing thought, and freezing the evanescent linguistic signal, they make new modes of cognition available: you can inspect the signal, reorder it, count the elements, and edit it. It enables meta-cognition. He held that these cognitive effects were revolutionary, and that writing therefore "changes the type of data an individual is dealing with, and it changes the repertoire of programs he has available for treating this data. Whether or not it changes the hardware … is another matter, but on the analogy of language the possibility is there" (1977, 109–10).

That speculation turns out to be correct: literacy radically rewires the brain, colonizing the fusiform gyrus at the expense of our face-recognition and strengthening the white-matter connections between the hemispheres and elsewhere (Dehaene 2009; Carreiras et al. 2009). It is a revolutionary piece of cultural technology. Goody also pointed to the extraordinary sociocultural effects of literacy, which allows communications over space and time, with consequences for the very distinct histories of the literate civilizations of Eurasia and the non-literate civilizations of sub-Saharan Africa. Literacy after all allows the cumulative use of data and records which lie behind the growth of science and technology, the bureaucracies of vast empires, the rise of mass communications, and indeed, many aspects of the modern condition.

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[4] An extended version of this argument can be found in (Levinson 2020). In turn, this draws on the work of Edwin Hutchins (1995), Jean Lave (1988), Lucy Suchman (2007), Andy Clark (Clark & Chalmers 1998), ethnoarchaeologists (e.g., Malafouris 2013; Overmann and Malafouris 2018), human-machine interaction (Norman 1993), and ultimately Vygotsky ([1936] 1986)—movements that have gone under the rubrics of Activity Theory, Distributed Cognition, Extended Mind, Situated Cognition, Material Engagement, and so forth.

Goody concentrated solely on literacy, but I believe the idea of technologies of the intellect has in fact far wider applicability (see Levinson 2020). A "cognitive artifact" is, in my favored sense to be developed, an external aid to internal computation (see also Norman 1991). There's no shortage of obvious examples, from the abacus to the slide rule, from the theodolite to the compass, from the map to the diagram, or from the electronic calculator to the computer. But there are much simpler examples, and they are all around us.[5]

Consider this simple example: a Tzeltal man, who is typically a subsistence farmer, carries with him a meter-long wooden staff. As well as a walking stick, a weapon of self-defense against dogs on a trail, and sometimes a rod of office, it is basically a dibber: when planting corn he pokes it three times into a little heap of soil and plants three corn kernels. Then he uses the full length of the stick to measure the place for the next little heap, and so along the row; then he goes up one stick's length and plants the parallel row. If he plants twenty heaps per row, and there are twenty rows, he knows he can expect 1200 (400 x 3) corn cobs (unless the variety yields two cobs per plant, in which case he can double it). So, he can calculate the likely harvest and decide whether to plant more. If he hires someone to do it, he will pay by the number of rows. If he is thinking of selling the field, or buying it, he knows how much of the family's needs he will lose or gain. That simple stick gives him a system of precise estimation.

Every system of weights and measures is a simple piece of cognitive technology, and most of them had their origin in just such calculations: an acre, for example, was the area that medieval peasants could plow in one day with a team of oxen. The enormous value of a simple measure of length was brought home to me by watching Rossel Islanders make houses and canoes from bush materials. Rossel Islanders, traditionally at least, use no measures. For example, looking for a ridge pole they trot off into the jungle and find the longest straight timber of the requisite diameter they can find. They carry these heavy timbers (sometimes weighing more than 300 kg) back down the mountain, haul them up on top of the house structure, and chop them off to fit the emerging shape. If they had a tape measure, they could save themselves a lot of sweat and a lot of wasted materials.

[5] Although they are sometimes so simple that they are not always easy to recognize. Consider the transparent window on a bottle of engine oil that allows you to see how much is left, or the depth gauge on a river crossing, or the LED that lets you know your device is plugged in, or any symbol like a road sign warning of rockfalls.

The measure would be a way to carry with them a precise estimation of what is needed. Rossel Island has no market economy and no pressing use for weights and measures, unlike traditional Mayan communities like those that speak Tzeltal.

A cognitive artifact then is an aid to solving a mental problem by means of an external instrument, which returns some value which can be re-internalized. Figure 1 represents this export of a mental problem out of the head *via* a query to an external device, which then returns a value which can be re-imported into mental computations. In the parlance of the philosopher Andy Clark (2011)[6], this is a "coupled system," a circuit that depends both on an inner and outer component. It is because the outer instrument is externalized that it can be shared, and indeed is subject to the processes of cultural evolution, which typically hones the instrument into an ever more efficient form. Those processes of cultural evolution are absolutely central to the efficacy of these ever-improving devices, and thus to the development of technology and scientific advance.

Thinking of culture as composed largely of such coupled systems (and I will enlarge the scope below) gives us a satisfying way of cashing out Durkheim's (1895) ontological insight that "social facts" are "things" that cannot be reduced to psychology.

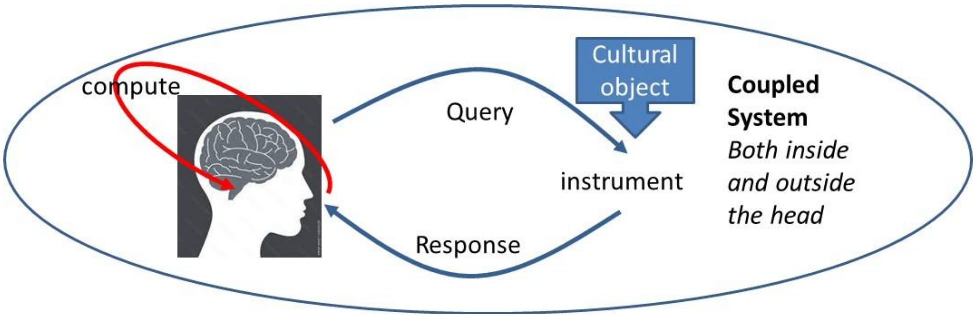

Fig. 1: Cognitive Artifacts as Coupled Systems Bridging Mind and Matter.

Let us turn to obvious examples of cognitive artifacts to get further clarity. There is no dearth of examples in the history of technology. Aids to spatial navigation—where the problem is to solve location and direction—have been much studied and include Micronesian star maps, medieval portolan charts, Roman strip maps, compass roses, astrolabes, sextants, and the modern GPS and radar systems. Traditional Polynesian navigation relied on master navigators memorizing star rising and setting points, and

[6] I should however distance myself from the metaphysical claims of Clark and others (Clark & Chalmers 1998; Clark 2011) that mind can then literally spill into the environment, and is no longer confined to the head; such ontological claims are not germane to the present argument.

internalizing rules of thumb about wave interference, orographic cloud, and the predominant settings of winds and currents (Gladwin 1970; Feinberg 1988; Lewis 1972). The Western tradition externalized these processes—measuring speed by a chip log, star azimuths with the astrolabe, direction by compass, and so on—using these measurements to plot locations on a chart (Hutchins 1995), so answering "Where am I?"

Another much studied domain is the measurement of time, both diurnal and calendrical. Simple systems include noting the location of celestial bodies and noting the fruiting or migration times of natural species. Thus, Rossel Islanders arrange to meet on the morrow by pointing to where the sun will be, while Tenejapan Mayans may arrange to meet before dawn by pointing to where the moon will be, which requires more careful observation—here, gestures act as externalized aids to computation (see also Floyd 2016). On Rossel Island, the seasons are estimated by changes in prevailing wind directions and the coastal running of fish, like sardines and mullet, triggering events in the agricultural calendar. So, the noting of external events can answer the problem of when to plant taro seeds.

From such humble beginnings, artifacts and machines for temporal reckoning slowly developed: for diurnal reckoning, water clocks, sundials, and clockwork clocks which counted divisions of the day for purposes as diverse as shared irrigation (Iran), allocating time for plaintiff and defense in a court of law (Rome), the opening of markets (Greece and Rome), or times of worship (Aveni 1989). For calendrical reckoning, complex celestial measurements were undertaken using instruments as massive as Stonehenge or the Caracol at Chichen Itzá. Huge investments in astronomical observation were made to bring the lunar and solar cycles into alignment with the solar year.

A final obvious example is geometry and mathematics. Innate number concepts are restricted to subitizing (recognizing between one and five objects at a glance) and estimating masses: it is counting that seems to bridge across the systems, giving us precise quantities (Dehaene 1996). Peoples who lack number words like the Pirahã are famously unable to match precise quantities (Gordon 2004; Frank et al. 2008). First steps involve matching external counters with the things to be enumerated, and the body provides a convenient set of digits for this purpose (Bender and Beller 2012). Other early methods of reckoning involve tallies—the 20,000-year-old Ishango bone may even have acted as an early slide rule (Ifrah 1998; Marshak 1972). Rossel Islanders keep track of thousands of shell "coins" by collecting the strings on which they were strung in tens, counting the strings and then multiplying in their decimal number system. Devices like the abacus, which go back to Sumerian times, speed up mental computations for seasoned number users (Wang 2020), while today most of us use calculator apps. The actual form of the externalization of number concepts crucially matters, as history shows: the Roman non-positional system hindered calculations, while the Arabic system favored them. More exactly, as Chrisomalis (2020) explains, although Roman number representations could easily be supplemented with calculations on the abacus, there was no easy way to show the workings of the calculations in the numerical notation—hence double-entry bookkeeping was instrumental in ushering in the Arabic notation. Geometry is another area where externalization makes available mental calculations that are otherwise not achievable—the Babylonians already had approximations to *pi*, ways of calculating the areas of various figures, and even calculus (Ossendrijver 2016).

A computational cognitive artifact has the following properties:

1. There is a recurrent cognitive problem, finding the value of f(x) = ?
   e.g., *How big is the gap? (measuring for a door)*
2. The artifact is externalized in a publicly accessible medium
   e.g., tape measure
3. The instantiated artifact is shared in type, and honed by cultural evolution
   e.g., standardized units on a compact retractable metal coil
4. There is a procedure for operating on the instantiation
   e.g., holding the tape against the gap
5. The process is economical: the cognitive advantage outweighs the costs of externalization
6. The output of the process must be re-internalizable (e.g., memorable)
   - if f(x) = y, y must be easily assimilated
     e.g., the number of centimeters

Fig. 2: Characterization of a Computational Cognitive Artifact.

I believe these examples are sufficient to illustrate the idea of a cognitive artifact. Let us now firm up the concept. Figure 2 provides a characterization, using the simple example of a measurement system (like a modern tape measure) to estimate how big a door I need to fill the door frame. As spelled out there, there is a mental problem to be solved, represented here as a function with an unknown value, and the use of an external device—the cognitive artifact—yields the value in a format easily returned to the mind.

The simple example makes clear that we are not talking about artificial intelligence here—the artifact itself can be as simple as the Tenejapan measuring stick.

This is, however, only one species of cognitive artifacts, namely one that aids active computation. Jack Goody (1977) drew attention in the case of literacy to its two functions: a list could be an inventory of what I need to do, or it could be a record of what I have already done. In the latter case, the writing serves the purpose of recall—perhaps by an actor other than the writer. All of our historical, bureaucratic, and scientific records are of this type, and they enable that amazing accumulation of knowledge that characterizes advanced literate societies. This is another type of cognitive artifact, which rather than enabling computation, enables the retrieval of an earlier solution.

Curiously, it seems that the very origin of Sumerian writing (and thus ours) lies in mnemonic clues to the contents carved in the top of clay envelopes which contained tokens (representing, e.g., a debt of five sheep; Schmandt-Besserat 1996)—after a while, the tokens became superfluous, and the mnemonics took over. Once again, though, we can generalize away from literacy and look at other ways in which simpler retrieval systems work. Consider a knotted handkerchief, for instance, to remind me to contact Jill in the morning. It works because by encountering the knotted handkerchief in my pocket in the morning, I am reminded of the intention to call Jill, which caused me to knot it. Or consider the use of notches in a bone used to keep a tally of the days passed in this location, or the successful kills in the hunt—such tallies seem to go back to the Upper Paleolithic (Bahn 2016, 324ff.).

Simple mnemonics may be private, as with the handkerchief, or they may be public, like road signs reminding one not to speed. On Rossel Island, people erect taboo signs to signal and remind people that a coconut plantation is no longer free for foraging, while many kinds of boundary markers in other societies serve a similar purpose (*tim* trees in the case of Tenejapa, planted at the boundaries of fields). Non-literate retrieval systems can be vastly more complex than this. Consider the ancient Peruvian *quipu*—knotted cords that served (amongst other things) to keep track of tribute paid in the Inca empire, using a positional system that kept track of vast numbers (Urton 2003)—a system still used a century ago by herders keeping tabs on their flocks.

Let us call this a mnemonic cognitive artifact and give the following characterization, as in Figure 3.

A mnemonic cognitive artifact has the following properties:

1. A cognitive artifact for recall has the function of encoding the thought *A* at time *t*, in such a way that it can be retrieved at a later time t_{+n}
   e.g., How much did I pay for the ticket?
2. There must be some external marker of *A*, call it *ά*, such that encountering *ά* brings *A* to mind
   e.g., a printed receipt
3. To be recoverable by random others, there must be a shared convention that *ά* stands for *A*
   e.g., the receipt has a standard form
4. The procedure for encoding *ά* is effective and simple enough to be economical
5. The encoded thought *A* must be recoverable, useful, and easily assimilated at time t_{+n}

Fig. 3: Characterization of a Mnemonic Cognitive Artifact.

2.2 How Cognitive Artifacts Work—Thought Transduction

It is not entirely self-evident why cognitive artifacts have the efficacy they have. Why does translating a mental problem into an external medium seem to automatically aid computation? One principal reason seems to be that the problem now has a double representation—one in an internal mental medium and the other in an external medium. Each kind of representation may offer different kinds of cognitive affordances. It has been noted, for example, that children faced with Piagetian problems gesture the correct answer before they learn to expound it verbally (Goldin-Meadow 2015), and if one gives route directions, one will find that one's gestures precede the verbal instructions as one literally "feels out" the solution.

Another feature is that the transfer from inside to outside involves some kind of *transduction*, something other than a direct 1:1 mapping (in engineering, a transducer is a device that converts energy from one form into another—e.g., sound waves into electrical current and back into sound waves). An abacus used by a speaker of a decimal system re-represents number in terms of units of fives and ones. Linear speech is converted into two-dimensional orthography stripped of many expressive features. A guess at the size of a timber is converted into a precise set of conventional units. Transduction typically involves the following transformations:

a) Transduction often involves a mapping into a higher or lower dimensional space—1D to 2D (musical notation, writing, written addition of a string of orthographic numbers), 1D to 3D (sundials, astrolabes), 3D to 2D (maps, blue prints, geometry of solids), 3D to 1D (oral recitations of, e.g., Aboriginal song lines, or a reduction of an itinerary to a list)
b) The transduction mostly involves a mapping into a more concrete medium—e.g., an abstract number into the tactile medium of the abacus, or an abstract direction into gesture—where it can literally be manipulated
c) At the same time, the external representation simplifies and strips away incidental distracting properties: consider a map, which only represents a few chosen features of the landscape, or a musical score that abstracts away from variable phrasing and performance
d) The transduction may involve a mapping from a weaker sense into a more dominant one, e.g., internal representations of sound into vision (writing, musical notation), abstract reasoning into visual spatial representations (graphs, Venn diagrams, numbers), or abstract order or number into tactile manipulations (prayer beads, abacus)
e) It may involve the transduction of a fleeting or changing signal into a static one where time is frozen, as in writing or musical notation, or a seismograph
f) The external device may physically constrain the solution space, so reducing errors, as with an abacus, or a pilot's checklist with tabs to be flipped one by one
g) Crucially, by externalizing a computation, parts of it can be put in an external memory buffer, so overcoming the highly limited buffer capacities of our working memory, as explained further below. The importance of this is evident when doing long division, or remembering a string of digits, or going through a checklist in preparation for a journey

These transductions of thought into different types of representation seem to capture Goody's (1977) insight that the early uses of literacy involve the exploitation of metacognitive rumination, which is less available for flashes of thought in the mind or the ephemeral signals of speech. In addition, they offer some account of what Goody, following Bruner (1966), called the *amplifying* function of externalization. From the point of view of the user, the cognitive artifact may substitute an entirely different and easier task for the target one, as when logarithms are added to multiply large numbers, a procedure partially automated in a slide-rule (Norman 1991).

Another prominent property of cognitive artifacts is that they involve both externalization and re-internalization, often repeated recursively, as when writing and re-drafting, or doing complex calculations. Such repeated re-ingestion will inevitably remake the internal representation into a format closer to the external representation. The oral performance of a literate person is not like the oral performance of an illiterate praisesinger (as noted in Goody 1987), nor is the mental arithmetic of a mathematician like the mental arithmetic of a peasant. Skilled and practiced users of these repetitive transductions may end up not actually needing the externalization, as with skilled abacus users who can use a mental representation of the 3D thing without resorting to the external aid (Frank and Barner 2012; Barner et al. 2016). In the same way, while I may need notes to keep my lecture on track, skilled orators have since Cicero (Yates 1966) used internal systems of mnemonics based on imagined externalization (for example, by traversing an image of a familiar room). What the example of literacy shows is that this recursive re-ingestion induces the mutual adaptation of brain to external device and external device to brain, in what Deheane and Cohen (2007) have called a "cultural recycling of cortical maps." It is this mutual adaptation that characterizes a "coupled system" between mind and device.

It is possible to invent private, secret cognitive artifacts, as when one uses external clues to remember software passwords—this is prominent especially in mnemonic cognitive artifacts. But a huge part of the efficacy of cognitive artifacts is that they are mostly shared, public representations. As a consequence, they have been honed, often by eons of cultural evolution (as with our alphabet or number systems) to maximize the metacognitive affordances of the external representation (e.g., making addition or multiplication easy) and to minimize the effort of transduction when externalizing and re-internalizing the representations. Sometimes there will be an arbitrary quality to the external representation—e.g., it could be in inches or centimeters—drawing attention to the fact that part of what makes it valuable is the very fact that it is a shared, standardized system even when the format is suboptimal (like the QWERTY keyboard).

Summary: How Cognitive Artifacts Work

- Double representations in different formats give extra "handles" for computations or retrieval
- Transductions into a different dimensional media afford different operations, allowing metacognitive rumination, inspection, and the "freezing" of temporal succession
- Stronger senses can be used to reinforce weaker ones, as with the visual representation of abstract properties
- Externalization offers mid-computation "memory buffers," thus overcoming the severe limitations of working memory
- Externalized representations can be honed by cultural evolution to maximize the metacognitive handles and minimize the efforts of transduction
- External representations tend to simplify, selecting a few dominant features of the underlying thought
- Recursive externalization and re-ingestion bring inner and outer formats closer in alignment, easing the difficulties of transduction

Fig. 4: The Efficacy of Cognitive Artifacts.

2.3 Language as a Cognitive Artifact

So far, the proponents of cultural models may retort, "Sure, those are interesting examples, but they hardly add up to that massive knowledge base that we call a culture." Yes, but we have not finished yet. Any theory of culture has to come to grips with language. One of the most striking things about the human species is that it is the only one on the planet which has a communication system that varies so fundamentally across social groups at every level of structure—from the sounds to the syntax, from the syntax to the semantics (Evans and Levinson 2009). Language is the foundation for cultural diversity, one of the prime modes of its transmission across generations.

Language of course is also a cognitive artifact, if an enormously complex one. It transduces a thought into sound waves. It solves the problem of making overt an intended meaning. It has an external form or representation which is shared—we learned our languages in an open forum. A language offers some of the same computational advantages we have already noted of dual representations—when I express a thought, I streamline, simplify, and clarify it to myself. Thus, I can re-internalize my now clarified thought. Writing a paper like this, the thought goes in and out a few times before stabilizing on the page. Now, just like the tape measure or the calculator, I have inherited the technology which has been honed by cultural evolution to serve a community of speakers. What I have inherited, amongst other glorious things, is a vast repository of ready-made concepts packed into words.

Most of these words encode notions that would take a lot of round-about description to convey by other means (e.g., ogee, logarithm, architrave, sonata, algorithm, *pi*, shaman, etc.). At the outset of cognitive science, George Miller (1956) pointed out that these perform a crucial computational function. We can only hold, he suggested, 7 ± 2 items at once in working memory (we now know the mode is much less than this, more like four; Cowan 2001). So, the only way we can compute complex things is by packing complex concepts into memorable chunks, as we do in maths when we let *x* stand for the output of another operation. Think about words as pointers to complex concepts in virtually unlimited long-term memory—but unless they themselves form a chunk (as in a sentence), you can only hold four or five such random pointers in short-term memory at a time. A culture, then, provides you with a huge stock of words and expressions, a bonanza of "zipped" thoughts, little nuggets of intensive meaning. These allow us to get complex multi-stranded thoughts through the bottleneck of working memory. And although linguists tend to think of the lexicon as an unstructured repository, it comes with immanent structure, as in the taxonomies, partonomies, "semplates" (Levinson and Burenhult 2009), and semantic fields which are familiar objects of anthropological enquiry.

In addition, every language provides us with its own recursive structure for building complex propositions. Studies have shown that those who have been deprived of full-blown language in early childhood have difficulty conceptualizing complex embedded propositions (Pyers and Senghas 2009). Besides the major constructions of the central syntax of a language, languages have additional mini-grammars like those found in their numeral systems or their kinship systems, which again can recursively construct specialized thoughts of arbitrary complexity.

The transduction of thought into speech is an amazing process involving upwards of a second and a half of intensive mental processing and the deployment of over a hundred muscles, and in conversation it often has to work in parallel to the processing of the incoming turn at talk (e.g., Levinson 2016). We ease the process by learning to regiment our thoughts into a form that fits the categories of the particular language (Slobin 1996).

It is because of this that our mental categories come to match language-specific grammatical and lexical categories, yielding many features of "linguistic relativity" (see Levinson 2012). The socially-shaped patterns of usage come to dominate the way we think: In one culture we think in terms of left vs. right, in another in terms of north vs. south. In one culture we think of relatives in terms of a Crow system, in another according to an Omaha system of reckoning. In one culture we think in terms of blue vs. green, while in another we think in terms of grue, and so on.

In sum, languages have all the hallmarks of cognitive artifacts. They transduce thoughts into a socially shared medium in order to solve myriad problems; they are tools for persuading, cajoling, encouraging, ordering, comforting, and exchanging information with our social others. We re-imbibe thoughts clothed in language, benefiting from the transduction into a streamlined and culturally shaped medium.

2.4 Generalizing the Idea: Other Kinds of Cognitive Artifact

I have outlined two main types of cognitive artifacts, the computational and the mnemonic. These two types are central exemplars, but there are almost certainly other kinds of cognitive artifacts. At the risk of over-widening the category, consider the following. Cultures use various means of inducing mood changes, that is, altering the emotional stance of participants. These may include mood-changing substances like alcohol or kava, or emotion-inducing cultural performances like music and dance. One might object that these changes are mechanical, natural causations, but it is noticeable that they do not necessarily work across cultures: kava and Chinese opera leave me cold, while alcohol often turns my Pacific friends into zombies rather than socialites. Ritual flagellation may induce trance in a Hindu devotee, but I doubt it would work on me. Nor will magic mushrooms automatically make a shaman out of you. Within a culture, these mood changing artifacts work in the requisite direction because there are already expectations of the state that should be reached. Presuming that emotional states are part of our cognition (and not in a separate compartment of the mind), then devices for changing those states might also be candidate cognitive artifacts (see Figure 5 for a rough characterization).

There is a goal state, an emotional tone *T*, to be obtained.
There is an artifact or performance that is publicly recognized to induce this tone *T*.
The artifact or performance is honed by cultural evolution to induce this tone *T*.
There is a specific procedure for using this artifact or performance.
There is a good probability that undertaking the procedure will induce *T* as desired.

Fig. 5: Characterization of an Emotion-Inducing Cognitive Artifact or Performance.

Music and dance might be the most powerful and most common devices of this sort, but more extreme events like human sacrifice or sacred mortal combat (as in the Mayan ball game) might be others, inducing mixtures of fear and wonder. These kinds of human activities are hard to explain in terms other than their intended emotion-inducing functions.

Representational art may also have this function—after all, it is historically deeply associated with ritual, religion, and multi-modal performances. Consider too the architecture intended to make those who enter feel small and insignificant or wonder at the crystallization of massive labor and expense—the emotions one feels on the thresholds of castles, cathedrals, palaces, or parliaments. Clearly, huge amounts of effort and resources are expended in mind-bending external devices, performances, and installations.

A more straightforward extension of the notion of cognitive artifact is through perception. The history of science is populated by devices that extend the range or acuity of human perception. If telescopes and microscopes allow us to see things somewhat beyond our normal vision, radar, infrared sensors, and X-rays make visible the invisible. The current direction of wearable technology is likely to make cyborgs of us all (Clark 2003). Perceptual prostheses, however, may not be technologically complex at all—as Bateson (1972, 359) famously pointed out, the blind man's stick makes an extended cognitive system. Barking guard dogs or the Capitoline geese also served as extra eyes and ears.

A completely different line of reasoning may lead in the direction of seeing social teams as computational devices. The argument here has been well rehearsed by Edwin Hutchins (1995) who showed how, for example, a team of sailors on the bridge of a ship may navigate the behemoth via a division of labor in which each sailor reports readings from different devices (sonar, radar, line of sight) to a central navigator plotting the course. The "distributed cognition" movement may itself have lost steam, but the insights are perfectly valid: we solve a lot of problems by outsourcing them to a team. In the simplest case, I can ask you when we went to Rome together, using your recall device to solve my failed one.

In more complex cases, a team of scientists or developers can jointly solve long-standing problems. Whole bureaucracies can operate merely to answer the questions posed by the state. In complex societies there are elaborate divisions of epistemic expertise and labor, and we employ accountants, lawyers, surveyors, web designers, and translators. The modern trend of course is to try and shrink these teams by substituting them with artificial intelligence, merely the latest step in a long line of experiments with cognitive artifacts. The insights of the "distributed cognition" movement nicely tie cognitive anthropology into the study of social interaction and social organization (see Enfield and Kochelman 2017).

2.5 The Payoffs of Viewing "Scientific Cultures" as Built out of Cognitive Artifacts

Notoriously, science at any one time and place is not a homogenous and harmonious whole, but a buzzing confusion of rival ideas, techniques, and instruments. The framework of cognitive artifacts can easily encompass variation (not everyone needs to use the same tools, or use the same mental tricks with identical tools), and therefore has no need to idealize away from variation, imperfect performance, and real-time processing. Above all, cognitive artifacts escape the head: they are partially in the environment and subject to all the normal processes of cultural evolution, with rival designs competing for use, often in an ever-upwards spiral of sophistication. Cognitive artifacts are tools in active use, not abstract data structures, and together with a theory of cultural evolution can encompass rapid technological and mental change. That external part of the hybrid at least can be empirically studied with comparative ease. At the same time, because we are dealing with a hybrid of internal and external representation, once the internal side is not transmitted, the key to the external device may be lost, as with the ancient Peruvian *quipu*. While the sophistication of the Antikythera mechanism betrays a history of development, the lack of parallels shows how fragile these composite idea-machines are.

From the fact that human cognition is so interdependent with these externalizations, it follows that our cognition itself has a curious ontology (Clark and Chalmers 1998; Overmann 2017). Is it my recollection or my digital diary's that I have an appointment on April 1, 2023? Is it my belief or my calculator's that the square root of 3 is 1.73205080757? Is it my estimation or that of the bubble in my spirit level that this door jamb is level? Is it my estimation or the map's that there is a distance of 430 km between Trieste and Rome? Clearly, human minds form coupled systems with their cognitive tools—we have partially outsourced our cognition, and in doing so hugely *amplified* it, as Goody (1977, 109ff.) was fond of pointing out.

A cognitive artifact's perspective also has the merit of tying scientific development—partially, obviously a story of mental triumphs, directly to external culture—to artifacts, to their use, to social interaction, to social transmission, and, by way of the cognitive division of labor, to the organization of society. In this way, it does not leave history of science marooned from all the other historical and cultural trends studied in other sciences. In addition, it offers some kind of account of how culture and technology enhances cognition, and thus an account of how culture endowed humans with an evolutionary advantage. It suggests that culture is not some outcome of oversized brains, but rather of the way in which cognition interacted with the social environment in a feedback relation over hundreds of thousands of years resulting in the gradual development of this expensive organ.

To conclude, I have offered here a "take" on the special nature of human cognition that may perhaps be congenial to historians of science. It is cobbled together from the previous efforts of many scholars in cultural anthropology (in the situated and distributed cognition traditions especially), archaeology, philosophy, psychology, linguistics, and other sciences. I view the mongrel nature of the ideas as a positive virtue, because they show how to connect the history of science more directly to a wide spectrum of the surrounding sciences, from psychology to anthropology. How we evolved this deep coupling of our cognition with our shared culturally-shaped environment is a topic of first importance for a range of disciplines.[7]

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[7] Niche construction theory offers a pan-species approach to feedback relations between constructed environment and organism (Odling-Smee et al. 2013, Laubichler & Renn 2015); the full human exploitation is going to require special explanation (one factor sketched in Levinson 2022).

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