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RESEARCH ARTICLE

Exaptation in the Co-evolution of Technology and Mind: New Perspectives from Some Old Literature

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Abstract

The term exaptation, describing the phenomenon that an existing trait or tool proves to be of new adaptive value in a new context, is flourishing in recent literature from cultural evolution and cognitive archaeology. Yet there also exists an older literature from the nineteenth and twentieth centuries which studied more or less systematically the phenomenon of "change of function" in culture and tool use. Michel Foucault and Ludwig Noiré, who devoted themselves to the history of social institutions and material tools, respectively, occupy an important place among them. This article offers a brief overview of this literature and attempts to show that it provided ideas that remain relevant to current approaches to cognitive archaeology, in particular regarding attempts to understand the impact of technological evolution on the human mind.

Keywords Exaptation · Cultural evolution · Cognitive archaeology · Material culture · Technology · Agency · Material engagement

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1 Contemporary Approaches to the Study of the Cultural Evolution of Cognition

Current approaches in cultural evolution and especially in cognitive archaeology, such as the theory of Material Engagement or the Tübingen EECC model (Box 1), aim at understanding the cognitive evolution of humanity against the background of material culture and technology. They share the view that cognitive evolution cannot be reduced to the history of the brain and its spectacular growth ("encephalization"), but comprises an irreducible socio-historical dimension rooted in material culture. Material culture is held to play a twofold role in the evolution of the mind, (a) by having affected the selection pressures of biological evolution in the past ("co-evolution of nature and culture," cf. Ambrose, 2010; Boyd & Richerson, 1985; Laland et al., 2010), and (b) by scaffolding cognitive functions of the organism by means of cultural artifacts ("extended mind," "external cognitive scaffolding," "situated cognition," cf. Clark, 2006; Clark & Chalmers, 1998). The EECC model focusses on identifying different levels of cultural and cognitive capacities, characterized by an increasing degree of complexity, based on the analysis of prehistoric technology in so-called cognigrams, and seeks to understand cultural evolution primarily in terms of the underlying mechanisms of cultural transmission and, in particular, of cumulative cultural evolution (Haidle et al., 2015; Tennie et al., 2009). Material Engagement complements this approach by treating artifacts not merely as indicators of cognitive capacities existing independently from them, but trying to understand their active role in cultural and cognitive evolution (Ihde & Malafouris, 2019; Malafouris, 2013; Mosley, 2021). This implies the twofold challenge of, first, understanding the inherent dynamics of material culture and, second, understanding its influence on human cognition. In both respects, the notion of "exaptation," which has appeared with increasing frequency in the literature in recent years, seems promising. If 15 years ago it had to be content with brief guest appearances, for example, in de Beaune (2004, 2008) and Haidle (2012), it has recently played the main role as "a plausible biocultural mechanism at the basis of cultural evolution" in d'Errico and Colagè (2018).

Box 1 Basic terms

Cultural Evolution: Culture, studied through the lens of biology, comprises "all behaviors and knowledge that are acquired and passed on within and between generations through social learning" (Schuppli & van Schaik, 2019, referring to Boyd & Richerson, 1985). As such, culture opens a further channel of intergenerational transmission besides genetic inheritance and ecological inheritance or niche construction ("triple inheritance," Odling-Smee, 2007). Cultural Evolution studies the inherent evolutionary laws of culture, the mechanisms of cultural transmission and the irreducible dynamics they generate. Interactions between natural and cultural evolution are called "co-evolution"

Cognitive Archaeology: Cognitive Archaeology is a subdiscipline of Archaeology that aims at reconstructing, on the basis of the remains and relics of their material culture, the cognitive space and cultural capacities of prehistoric groups (Haidle, 2015, 863, de Beaune, 2011, Renfrew et al., 1993). This includes, in a narrower sense, the cognitive skills directly involved in the production and use of tools, as well as, in a broader sense, products of intellectual activity such as cosmology, religion, and ideologies

Exaptation: This term describes the phenomenon that a biological or cultural trait that already exists (for any reason) exhibits a new adaptive value in a changed environment (Gould & Vrba, 1982). It is also referred to as "recycling" or "repurposing" (Dehaene, 2004; Overmann, 2017)

Material Culture: Material culture studies focus on the material aspects of culture and challenge the idea that artifacts are inert and passive objects which owe their form and meaning exclusively to human intervention. "In seeing the material properties of things as central to the meanings an object might have, much work within material culture studies is critical of the idea that objects merely symbolize or represent aspects of a pre-existing culture or identity. A key area of contestation in the literature on material culture is the question of agency and the ways in which objects can produce particular effects or allow and permit certain behaviors or cultural practices." (Woodward, 2013) Materiality and agency imply the possibility of exaptations: since functionally defined artifacts "necessarily have structural properties along with their functions, they may also be able to fulfill quite different functions from those originally intended" (McLaughlin, 2014, 175)

Material Engagement: The theory of Material Engagement (Ihde & Malafouris, 2019; Malafouris, 2013) builds a bridge between material culture and cognition with a view to providing an account of how material culture may have contributed to the emergence of cognition. The possible roles played by material culture range from its being a mere catalyst for biological and cultural evolution to its constituting an active component of cognition in the sense of extended cognition

Tübingen Model of the evolution and expansion of cultural capacities (EECC): The goal of the EECC model (Haidle & Conard, 2011; Haidle et al., 2015) is to study the development of cultural capacities. Cultural capacities are understood as the potential ranges of concrete cultural performances as these can be directly observed in the behavior of (human and non-human) animals or indirectly inferred from the preserved archaeological record of material culture. Cultural performances can be made comparable through analysis in cognigrams, which allows them to be described in terms of the so-called problem–solution-distance (PSD; cf. Haidle, 2012, Haidle & Stolarczyk, 2020). The EECC distinguishes (provisionally) eight levels of cultural capacity: socially facilitated information, social learning, tradition, basic, modular, composite, complementary, and notional. In order to understand the evolution of cultural capacities, the EECC model distinguishes three dimensions of development: evolutionary-biological, historical-social, and ontogenetic-individual. The three dimensions interact in various ways. The ontogenetic-individual development takes places in a cultural niche, what is crucial for understanding human culture (Haidle & Schlaudt, 2020)

For this reason, it may be interesting to halt for a moment in order to survey the existing literature and to draw some basic insights from it about the possible scope and relevance of the mechanism of exaptation in cultural and cognitive evolution. This is particularly interesting in the specific case of exaptation, because there exists a considerable older literature predating the coining of the term exaptation in 1982, and which is either completely unknown or whose relevance to this topic is overlooked. Bringing this literature to our attention may be helpful for understanding the full significance of the role which exaptation might have in cultural evolution. We will see that some authors, in particular Ludwig Noiré, were hopeful that a notion of exaptation would also allow us to understand the evolution of technology and in the last instance also the impact of technology on cognition, its forms and contents.

In this article, I will briefly introduce the term exaptation (Sect. 2), and then take a short look at the older literature which describes or even theorizes about mechanisms in cultural history which today we would call exaptation (Sect. 3). As a first consequence of this study of the literature, I will propose a generalized concept of tools that includes not only material tools but also social, symbolic, and bodily aspects, thus making visible the whole scope of exaptations (Sect. 4). In the concluding section (Sect. 5), I will briefly try to show that Noiré's thesis of an influence of tool use on cognition, in particular the idea that a perception of "neutral" physical objects arises only from tool use, needs not be regarded as a mere speculative fancy of a nineteenth century writer, but can indeed be substantiated within the framework of current hypotheses of cognitive archaeology. In doing so, I will mainly rely on François Sigaut's notion of *décentration*, which describes the cognitive consequences of the process of learning how to use a tool that has its own agency (5.1). I will suggest that exaptation itself, involving a potential conflict between different uses and affordances of an object, could be a potential engine of *décentration* (5.2).

2 The Term "Exaptation"

The term exaptation was introduced in 1982 by the biologists and paleontologists Stephen Jay Gould and Elisabeth S. Vrba as an additional mechanism of Darwinian evolution alongside adaptation (Gould & Vrba, 1982, see also Pievani & Serrelli, 2011, Pievani & Sanguettoli, 2020). Classical adaptation means that a trait (a physical or behavioral characteristic) that has arisen by chance (through genetic mutation) gives rise to a selective advantage. This can be distinguished from the case where, under changing environmental conditions, a pre-existing trait proves to be of new adaptive value.

> We suggest that such characters, evolved for other usages (or for no function at all), and later 'coopted' for their current role, are called exaptations. [...] They are fit for their current role, hence *aptus*, but they were not designed for it, and are therefore not *ad aptus*, or pushed towards fitness. They owe their fitness to features present for other reasons, and are therefore *fit (aptus)* by *reason of (ex)* their form, or *ex aptus*. (Gould & Vrba, 1982, 6).

Gould and Vrba cite several candidates for cases of exaptation in biological evolution, from Archaeopteryx feathers to mammalian lactation to the use of repetitive DNA. But there are also many examples which are directly relevant to cognitive evolution. Leroi-Gourhan mentions (20 years before the introduction of the term "exaptation") two examples which are of outstanding importance for human evolution, namely the development of the hand from an organ of locomotion to a kind of tool organ and, as a result, the development of the lips and the mouth, which, relieved by the hand, transforms from an organ of object manipulation to an organ of speech (Leroi-Gourhan, 1964, 40). In each case, one is dealing with cases of repurposing. With direct reference to a cognitive phenomenon, Dehaene has formulated the hypothesis that written culture re-purposes a neural module for pattern recognition. Dehaene speaks of "neuronal recycling" (Dehaene, 2004). A similar theory can be found earlier in the work of the linguist Derek Bickerton, who suggested that cognitive abilities such as off-line thinking rely on a neural workspace which was originally selected for language (Bickerton, 1995, 96 and 105).

As indicated by Gould and Vrba, exaptation comprises two cases, namely the recycling of existing adaptive traits as well as of non-adaptive traits. The latter are, so to speak, evolutionarily neutral elements that arose as mere by-products. Gould and Lewontin illustrated this already in 1979 with a cultural example: spandrels (Gould, 1997; Gould & Lewontin, 1979). Spandrels are architectural elements that result from a constraint of a particular design. If a dome is to rest on four columns connected by arches, triangular free spaces result above each column, delimited laterally by the two converging arches and upward by the edge of the dome, which themselves have no structural or artistic function. Once present, however, these elements can be used for artistic design, that is, they can be "exapted," as they provide space for painting additional frescoes. The example of spandrels already shows that the theory of exaptation needs not be limited to biological evolution, but that one can expect such cases in cultural evolution and in the history of technology as well. In fact, one should even expect exaptations to be ubiquitous in culture because, as we know thanks to Material Culture Studies (Box 1), material artifacts are always richer and encompass more potentialities than those activated in their current use (McLaughlin, 2014). Their "agency" is thus as much "a reserve for potential exaptations that can be exploited when environmental conditions change" as is the case for organisms (Pievani & Sanguettoli, 2020, 7). In fact, the mechanism of exaptation is already extensively used in the explanation of technologies, both for prehistoric techniques (d'Errico et al., 2018; de Beaune, 2000) and for modern technology such as lasers or 3D printing (Dew et al., 2004, Beltagui et al., 2020; cf. also the many applications in La Porta et al., 2021). The focus of these studies has been on the theory of "invention."[1] If one does not want to leave inventions unexplained simply as a *creatio ex nihilo* — and this is what pseudo-explanations such as chance or genius amount to — one has to specify a mechanism that allows one to identify

[1] In the archaeological literature, it has become more or less customary to distinguish between "invention" as the creative act of developing new technologies and "innovation" as their transition into a population's shared cultural stock, cf. Hovers 2012.

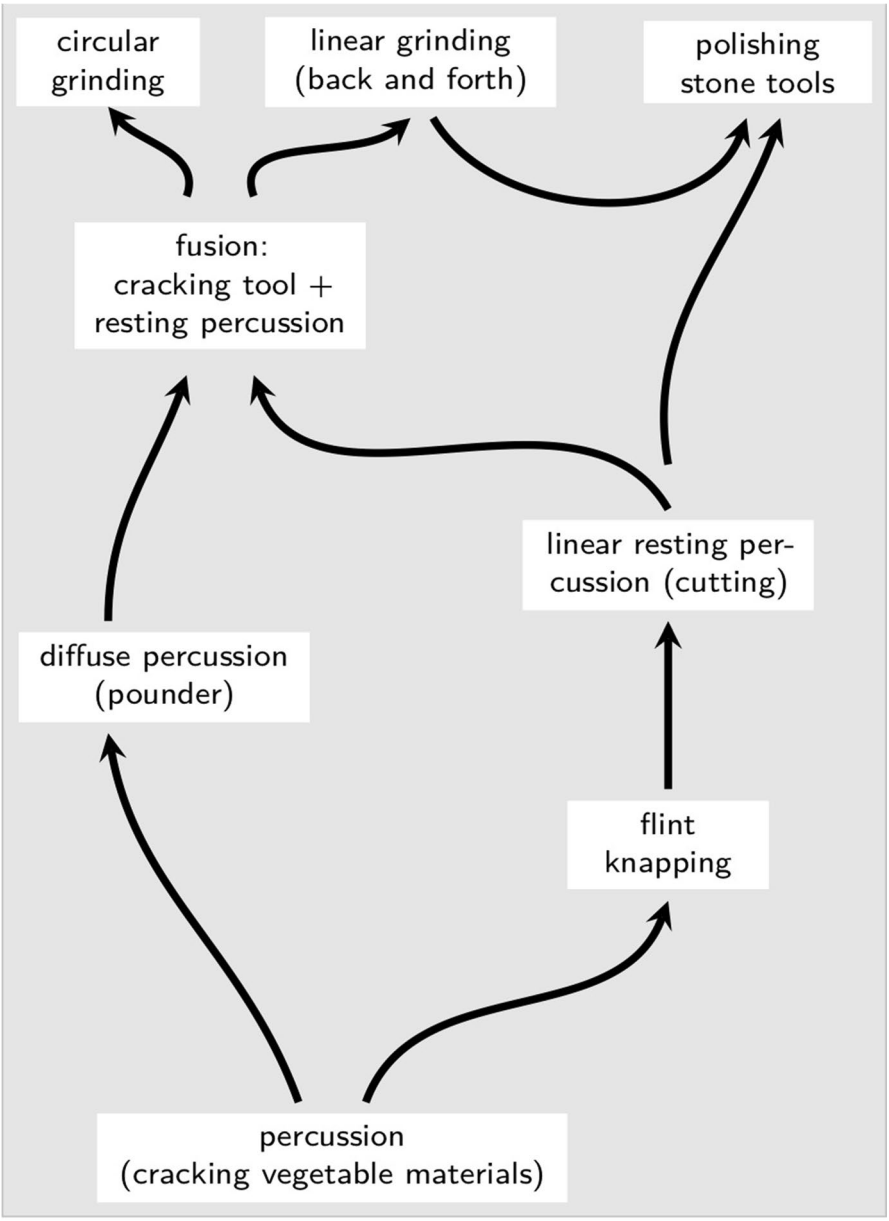

Fig. 1 The evolution of percussion and the associated tools through exaptation and recombination, following de Beaune, 2004, simplified and slightly modified

the structural preconditions of invention and, second, to explain how something new emerges from them (de Beaune, 2004). Leroi-Gourhan has used the term "enabling environment" ("milieu favorable") to represent the totality of such structural preconditions (Leroi-Gourhan, 1965, 19): "progress is less a matter of personal genius

than of a collective enabling environment." De Beaune (2000, 2004) has been able to demonstrate with many examples how exaptations and recombinations of existing elements can be used to understand invention within such a milieu (Fig. 1). If we add to the structural conditions the aspect of their perception, we arrive at the current term "affordance landscape," which we will rely on later (cf. Pezzulo & Cisek, 2016; Rietveld & Kiverstein, 2014).

The concept of exaptation has also attracted criticism, especially from Daniel Dennett. A basic problem is whether it can clearly be distinguished from adaptation. Dennett contended (1995, 280) that "every adaption is one sort of exaptation or the other—this is trivial, since no function is eternal." Larson et al. (2013, 497) explain: "Most traits are under multiple selective pressures and the relative importance of those pressures can shift dynamically […, making it] difficult to say at what point a trait became exapted, or to relate functions and effects to the multiple selective pressures. Moreover, in some sense, every trait is likely to have been modified from pre-existing versions that, at some time point, were not used in the way that they are now. As a result, all adaptations can also be said to be exaptations, thus rendering the term redundant." Larson et al. find it more convenient to restrict the use of the term exaptation to the field of technology, where intentionality is involved, what makes it easier to distinguish between the original function a trait was selected for and the current function a trait is maintained for. Gould himself (1997, 10752) clearly acknowledged the difficulties of extracting unambiguous cases of exaptation from "the imperfect archives of evolutionary sequences." Recently, Pievani and Sanguettoli (2020, 16) further defended the notion of exaptation for natural selection. Based on the discussion of recent evidence, they come to the conclusion "that exaptation has had its empirical revenge 25 years later [i.e. after Dennett's attack]." We need not get deeper into this discussion, however, because (1) my aim is to concentrate on cultural evolution, for which field even the critics admit a rather unproblematic use of the term, and (2) even though it might be difficult unambiguously to identify pure cases of exaptation and of adaptation in the empirical record, this is a purely practical problem, whereas on a conceptual level, both mechanisms can perfectly be distinguished and thus also should be kept apart.

3 Exaptation ante litteram

The term exaptation, as we have seen, was explicitly introduced by Gould and Vrba as a neologism. But the concept denoted by it, viz. the idea of a change of function of natural or artificial entities, occurs much earlier in the literature. In a few places, which I present below grouped into two categories, this idea occupies a pivotal systematic position and became the starting point of something like a "theory" of exaptation in cultural evolution, i.e., a systematic study of its potential importance and scope. Many of the relevant texts are today either almost forgotten or their potential relevance for our thinking about exaptation has been overlooked. In any case, it can be stated that we are dealing in this literature with more or less unconnected "islands" of thinking about functional change as a mechanism of cultural evolution,

so that it by no means adds up to a linear tradition. But precisely because of their sometimes high aspirations, these texts can still be important sources of inspiration. Our aim in this section is thus not to write a history of thinking about function change in cultural evolution, but to identify forgotten insights and neglected perspectives.

3.1 Wundt, Engels, Foucault, and the Exaptation of Institutions

A first author to be mentioned here is Wilhelm Wundt (1832–1920), the founder of experimental psychology. Throughout his (extensive) work, one frequently encounters the developmental principle of the "heterogony of ends" (*Heterogenität der Zwecke*) according to which unintended secondary consequences can become the actual intention of an action (Wundt, 1980, 194; see Janich, 2006, Eisler, 1902, 1908). The heterogony of ends clearly is a case of what we now call exaptation. Wundt declares this principle to be the fundamental law of mental and cultural development: it "governs the whole mental evolution" (Wundt, 1889, 328) and "constitutes a regularity which can be found in the most various ways in the study of comparative psychology or ethnology [*Völkerpsychologie*]" (Wundt 1904–1920, vol. X, 325–6). In stark contrast to the omnipresence of this principle in Wundt's work, however, stands, unfortunately, the superficial use he makes of it in concrete terms. In his ten-volume *Völkerpsychologie*, i.e., a kind of ethnology or comparative psychology, the most fruitful use he makes of it is probably in its application to social institutions in volumes 7 and 10, where Wundt (like Emile Durkheim after him, cf. Durkheim, 1895) warns in particular against the fallacy of inferring from the present utility of an institution the causes of its existence (and thus "to confound beginning and end," Wundt 1904–1920, vol. X, 154). The present purposes of institutions are the result of their development, which in general, however, do not explain their existence, since according to the principle of heterogony, institutions can, after all, change their purpose.

If one is looking for a social history that reconstructs developments in detail in terms of exaptation, one has to leave Wundt. Some interesting examples of functional change of institutions are discussed by Friedrich Engels in *The Origin of the Family, Private Property and the State* from 1884, where he comments on the research of the American anthropologist Lewis H. Morgan. Engels' first example is money, which illustrates well what we call today the "agency" of material culture (see Box 1): money was created by humans but soon emancipated itself from human control and unfolded its own dynamics:

> The Athenians were soon to learn, however, how quickly […] the product brings to bear its rule over the producer [… W]hen men invented money they little suspected that they were creating a new social power, the one universal power to which the whole of society must bow. It was this new power, suddenly sprung into existence without the knowledge or will of its own creators, which, in all the brutality of its youth, exposed the Athenians to its rule. (Engels, [1884] 1990, 216–7)

A fully fledged example of function change in Engels' book is monogamous marriage. Originally set up as an instrument of subjugation, monogamous marriage eventually became the cradle of the ideal of romantic love:

> [Monogamous marriage] was not in any way the fruit of individual sex love, with which it had absolutely nothing to do […]. On the contrary, it appears as the subjection of the one sex by the other [… But] monogamy was the only form of the family under which modern sex love could develop. (Engels, [1884] 1990, 173, and 177)

Many such examples can certainly be found in the literature. If, however, one is looking for an approach that *systematically* explores the idea of functional change in the history of social institutions, Michel Foucault is, as far as I know, the only reference to turn to. It is well known that the French historian used archaeology as a metaphor for his historiographic method, notably in *Les mots et les choses* from 1966 and *L'Archéologie du savoir* from 1969 (in Foucault, 2015). That Foucault was a committed exaptationalist, however, is hardly known, although that is precisely what he was, and herein lies his real relevance to cognitive archaeology. The history of the prison provides a paradigmatic example. In *Surveiller et punir* from 1975, Foucault shows that the prison did not originally have the function of punishment, not to mention re-education. Rather, it served to render enemies inoffensive and to detain culprits, "holding the person and his body as security" (Foucault, 1995, 118). The prison became the institution we are familiar with today only through an exaptation: in a new situation, society improvises and remedies itself with the existing institutions, which it uses for new purposes. "The prison form antedates its systematic use in the penal system" (Foucault, 1995, 231). — Seen through this lens, institutions are thus just as much the result of an "evolutionary bricolage" (Pievani & Sanguettoli, 2020, 21) as organisms and technical artifacts.

Foucault applied this principle of function change not only to the prison but to the asylum, the hospital, and the psychiatric clinic. But he also explained the basic idea of his approach in a more abstract manner in several of his shorter writings, where he described his evolutionary method, which he baptized "genealogy," and which he opposed to what he called, polemically, the "metaphysical" approach. The latter understands the functions of institutions as fixed entities which remain constant through history and also explain the institutions' existence. In order to make visible the fallacy committed by this approach, Foucault drew on the analogy of the origin of the eye — an example that Lucretius had already used to make a point against teleological explanations: the fact that we see with our eyes does not entail that we have them for seeing![2] In the same sense, Foucault teaches that "we should avoid thinking of emergence as the final term of a historical development; the eye was

[2] Lucretius Carus, 1714, 378–8: "But now avoid their gross Mistake, who teach, / The Limbs were made for Work; a Use for each: / The Eyes design'd to see, the Tongue to talk / The Legs made strong, and knit to Foot, to walk; / The Arms fram'd long, and firm, the servile Hands / To work, as Health requires, of Life commands; / And so of all the rest, whate'er they feign, / Whate'er they teach, is Nonsense all, and vain. / For proper Uses were design'd for none; / But all the Members fram'd, each made his own.".

not always intended for contemplation, and punishment has had other purposes than setting an example" (Foucault in Rabinow, 1984, 83). What seems valuable to us today and determined by evident utility may owe its existence, as Foucault points out, to a mere accident (Rabinow, 1984, 81). For the geneaologist Foucault, there is "no essential meaning" (ibid. 86), and "Nothing is fundamental" (ibid., 247). Hence, there is place for the change of function as a dynamic principle in a history without fixed meanings. The approach of Historical Epistemology drew the consequences of this for the special case of the historiography of science. Rheinberger (1997) used the example of protein synthesis to show how a research project that began as cancer research could take completely new paths and pursue completely new goals by systematically exploring the inherent potentialities of the experimental set-up. Freudenthal and McLaughlin (2009, 6–8) generalized this for the historiography of science: scientific development is driven by means, not by goals.

A first lesson from Foucault is therefore that historical developments are not to be reconstructed teleologically but must be understood without fixed meanings and functions. A Darwinian truism, sure, but the literature cited shows that for the evolution of technology, we are only now beginning to discuss a plausible analogous evolutionary mechanism in the form of exaptation, and furthermore, for the history of institutions, this lesson has really yet to be learned. Another perhaps more surprising consequence is that we can never be completely sure about the purposes existing institutions do serve. Indeed, some classic controversies from the cultural and social sciences illustrate this point. The theory of human capital had to realize at a certain point that it is not at all clear what the function of the school in contemporary society is: do schools teach cognitive skills, or do they socialize children to function well in the modern working environment? (Bowles & Gintis, 1976; Gintis, 1971). Another classic example which we already mentioned above is, of course, money. The current discussions about public debt and, e.g., the controversial proposals of Modern Monetary Theory show that we still do not really understand the inner laws of money, although it was us who created this institution. That its history shows instances of exaptation has in any case been made plausible by David Graeber: "Credit systems preceded the invention of coinage […] Barter, in turn, appears to be largely a kind of accidental byproduct of the use of or paper money" (Graeber, 2011, 38–40). Here we see a historiography of money purged of fixed meanings, and in which exaptation can become effective (see Pahl, 2021 for a current exaptivist approach to the history of money).

Finally, it should be said about Foucault that he also assumed a causal influence of institutions on human psychology. It is, after all, characteristic of his approach to consider subjectivity and the self as dependent variables determined by institutions, especially disciplinary practices (cf. Heyes, 2010). Of course, it is generally very useful to remind scientists of the plasticity of subjectivity even on a short historical time scale (e.g., against the assumption of Evolutionary Psychology that our basic psychological makeup was evolutionarily fixed in the Pleistocene and has persisted basically unchanged since then; on Evolutionary Psychology cf. McKinnon, 2005). Foucault's approach, however, did not pursue the idea of a co-evolution of institution and forms of cognition. The existing connection is rather that Foucault rejects the idea of unchangeable forms of cognition just as he rejected the idea of fixed

functions of institutions. We will find a stronger link between exaptation and the impact of technology on cognition in a second tradition which I will present next.

3.2 Exaptation of Tools and the Evolution of Cognition: Hartig and Noiré

A second line of tradition, closer to cognitive archaeology because of its focus on technology and cognition, appears in the late nineteenth century (its deeper intellectual roots are not easy to determine, but will not be the subject of the present paper). In 1872, the German engineer Ernst Hartig (1836–1900, for biographical details, see Buchheim & Sonnemann, 1989), with the explicit aim of identifying developmental laws of prehistoric culture, speaks of a "law of function change":

> As soon as man had first seized a tool (the "primitive tool", found in nature) for a certain purpose, for a certain mechanical transformation of his physical environment, he gradually adopted through tentative experimentation other modes of use of which this primitive tool was capable, and through the recognition of this success and the gradual adaptation of the tool to each of these modes of use he gradually put himself in permanent possession of a larger number of tools of his own manufacture. (Hartig, 1888, my transl.)

As a (purely speculative) example, Hartig mentions the development of crushing from pounding, and again of grinding from crushing, which, although modified in many details on the basis of empirical evidence, has, as we have seen at the beginning, been confirmed today by de Beaune (2000, 2004) as displaying an underlying mechanism of exaptation. Worth mentioning are also the further considerations which Hartig relates to this law, and which refer to the question of cognition. Besides a legal consideration — can mere exaptations be the subject of copyright protection? — there is a logical–linguistic problem of cognitive development: Hartig notes that "technology precedes language formation" and that in the technological vocabulary names of activities (verbs) are usually derived from names of tools (nouns): "to hammer" from "hammer," etc. In the case of change of use, however, several activities are associated with one tool, and the relationship of the newly added activity and its name is not captured by the traditional logical relations of "abstraction" or "determination" (i.e., ascending and descending in the hierarchy of terms by omitting or adding determinations). The theory of exaptation thus moves beyond the horizon of "logic" in the understanding of the nineteenth century (i.e., the theory of concept formation and deductive and inductive inference).

Hartig's talk from 1872 was not published until 1888, but the relatively little known philosopher Ludwig Noiré (1829–1889) — who worked as a high school teacher and is perhaps best known for his intervention in the contemporary debates about the origin of language — already knew it when he wrote his extensive book *Das Werkzeug* (The Tool), published in 1880. This book, which can probably be considered the first systematic study of the change of function in the evolution of technology, offers a veritable jungle of inspiring ideas. The overarching goal of the book is to understand the evolution of mind, which Noiré — in line with Leroi-Gourhan's later rejection of the "cerebralist" approach (Leroi-Gourhan, 1964, 19,

33, and 42) — does not want to reduce to a mere "effect of the natural growth of the brain substance to macrocephaly" (Noiré, 1880, 25). Instead a theory of mind must also take into account humanity's "life activity." Today we would speak of cultural evolution as an irreducible component of the evolutionary process.

An elementary component of life activity is the use of tools, the evolutionary dynamics of which needs to be understood. Again in line with Leroi-Gourhan (and Sophie A. de Beaune who follows him in this approach), Noiré does not recognize explanations of inventions from chance or genius — a "creation out of nothing" (231) — but seeks to identify the enabling factors of invention. This is where the "change of use or even change of function" (231) comes into play as a central mechanism. What Noiré describes is, more precisely, a change of function which is followed by subsequent adaptions, optimizing the instrument for the new use. In sum, technology evolves "gradually," "when the original, simpler tool has been adapted through *new* usage to the *new* purpose, i.e. when it has taken as a result of a *change of usage* a new, hitherto non-existent form" (Noiré 1880, 256).

Noiré distinguishes three levels where the principle of "change of use" is effective: the biological organism, tools, and language. Each of these levels has its own dynamics, in which the mechanism of function change is involved. For the tools, Noiré draws a line from the wedge or chisel as a digging tool through a series of changes of functions and subsequent adaptations to the knife (280–4). Like Hartig before him, and like de Beaune does today (Fig. 1), Noiré thus tried to trace family trees or genealogies of technologies the structural law of which consists in the change of function. At the level of the body, it is, for example, the hand that is transformed from an organ of locomotion to one of grasping and finally to a kind of universal tool (99ff — we already quoted this example from Leroi-Gourhan). In language, Noiré cites the emergence of number words (243). He borrows this example from the philologist Lazarus Geiger (1829–1870), who himself also speaks of a "transformation of function":

> far more frequently [than the case of the 'death' of words and grammatical forms], transformation of function occurs, where the old form is used for a new idea, and where the old organ adapts itself to a new purpose of life, which was originally foreign to it. Hence it is that the functions of linguistic forms can never be logically predetermined, as little as those of animal organs. (Geiger, 1868, I, 361, my transl.)

The emergence of number words by exaptation is more thoroughly presented a little later by the philosopher and ethnologist Lucien Lévy-Bruhl, clearly stating the difficulties that evolutionary thinking poses for our habits of thought: an evolutionary emergence of number words from rudimentary counting practices implies that, "however paradoxical the statement may appear, it is nevertheless true that for long ages primitive man counted before he had any numbers" (Lévy-Bruhl, 1925, 202) — just as the prison existed before the penalty of imprisonment, credit before coinage, and marriage before the ideal of romantic love. Today the concept of exaptation is intensively discussed precisely in the study of the emergence of numbers (d'Errico et al., 2018; Overmann, 2017); Schlaudt, 2020). A general attempt to reconstruct the evolution of language — i.e., the linguistic inventory of vocabulary and of

grammatical forms — mainly through the mechanism of exaptation is put forward by the linguist Mufwene (2013, 2019).

To this three-level operation of function change, Noiré's theory adds the important aspect of a reciprocal influence between the different levels. One example is the influence of technology on behavior. The development of the hand is a prerequisite for tool use and production. In turn, the use of the tool has an effect on the body. Noiré cites the twisting movement of the hand and the use of the outstretched arm as a lever as forms of behavior that could only have evolved in tool use (Noiré, 1880, 280, 296, 349). These two examples help us understand the scope of Noiré's theory: it is a theory of the influence of technology on *learned* human behavior, but not yet a theory of coevolution, i.e., of selection pressures altered by technology (such as Ambrose, 2010; Laland et al., 2010).

The second example addresses the interaction between tool use and cognition. Noiré was not interested in the cognitive prerequisites for tool use, but pursued the idea that tool use influences our thinking, which is quite exciting from the point of view of contemporary cognitive archaeology, especially Material Engagement theory: "The tool, however, is a special, highly important kind of medium, which enters between subject and object, oscillates between both, participates in both, and thus has become […] the fertile ferment of thought formation" (140–1). For Noiré, the influence of tool use on thought seems to operate mostly through the medium of language: Language is constitutive of thought (words are the "organs of thought," 240), and technology in turn is constitutive of language ("The word and the work! they cannot be separated," 151), simply because Noiré locates the origin of language in collective action and, particularly, in the division of labor (145, 151; the "technology hypothesis" in the contemporary discussions ties the evolution of language even closer to tool use, see Morgan et al., 2015 and Cataldo et al., 2018). But Noiré also mentions a more direct impact of tool use on thought: the tool separates the acting subject and the activity from the object worked on (20, 61), and it embodies causality (34, 197f). According to Noiré, we thus develop in the use of tools our subjectivity and our self-consciousness, but also the idea of external objects and causal relations connecting them. He also hints at a parallelism between hand and reason, but without further developing the idea. The hand is a "universal organ," just as reason is, and can be considered as a sort of "external brain" (91–3).

The ideas of Noiré and, through him, of Hartig have hardly been noticed. In a footnote to his essay "Form and Technology" from 1930, Ernst Cassirer appeals approvingly to Noiré's idea "that the work-tool […] represents a basic means in the process of 'objectivation' out of which the worlds of 'language' and 'reason' emerge" (Cassirer, 2012, 51). The working group around Lev Vygotsky in the so-called cultural-historical school of developmental psychology in the Soviet Union seems likewise to have taken note of Hartig's and Noiré's thought. The early Aleksei Leontiev, at that time a collaborator of Vygotsky, mentions "Hartig's law" in his writings.[3] This is interesting because this school has a close proximity to

[3] Cf. Keiler 2008, who refers to the German translation, Leont'ev 2006; an English translation of Leontiev's early writings seems not to be available.

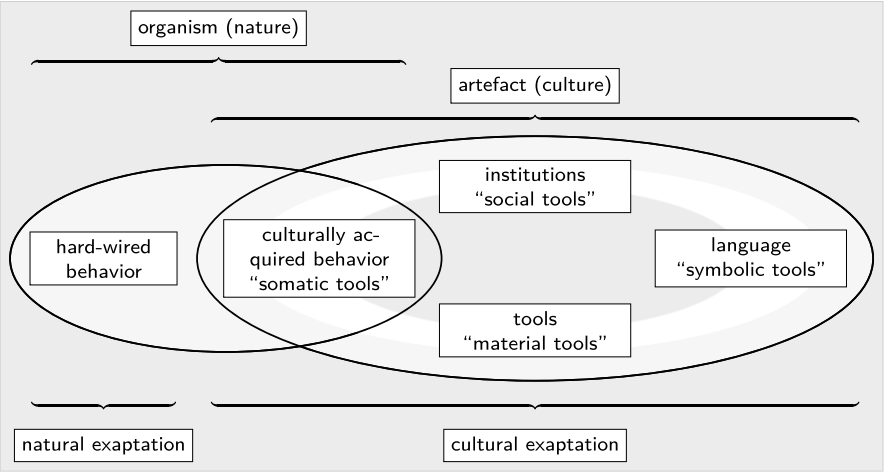

Fig. 2 A generalized notion of tools, covering all candidates for cultural exaptation

contemporary developmental psychology (Michael Tomasello characterizes his own approach as "neo-Vygotskian," cf. Tomasello, 2019, ch. 11) and cognitive archaeology (Reindl et al., 2018; Theiner & Drain, 2017). As is the case today in the Tübingen Model for the evolution of cultural capacities (Box 1), Lev Vygotsky and Aleksandr Luria emphasized as early as around 1930 that human development does not reduce to phylo- and ontogenesis but includes a third, irreducible, sociohistorical dimension. This third axis has its own dynamics that determine the socio-cultural niche in which ontogenesis takes place (Luria & Vygotsky, 1992). Tools embody this sociohistorical dimension in a paradigmatic way. With reference to Noiré's theory of language, D'Alonzo (2017, 64) formulates a conjecture that certainly applies to his theory of technology: "Probably Noiré's theory was appreciated by Marxists because the theory of language origins set out by Engels in his [The Part played by Labour in the Transition from Ape to Man, from 1876] started to be largely known [in the 1920s]" (D'Alonzo, 2017, 64). Here, however, the traces of a reception of Hartig's and of Noiré's work on the principle of function change vanish, and here we also leave our review of the historical literature.

4 The Scope of Exaptation: a Generalized Notion of Tools

A first lesson that can be drawn from this short review of the historical literature concerns the consequences for the scope and structure of the domain in which cultural exaptations — alongside natural exaptations in the evolution of the organism — can occur. We have seen that exaptation is not limited to tools in the classical sense (freely movable material objects, manipulated or modified by humans, cf. Mann & Sargeant, 2009, 1171, and Haidle, 2015, 849) but applies to three other elements too: learned behavior, institutions, and language and writing. Accordingly, one can provisionally distinguish between four types of tools: material tools, physical or

Table 1 Overview over various studies of exaptation, historical and contemporary, quoted in the text

Exaptation				
Natural	Cultural			
	Tools	Behavior	Institutions	Language
Body parts (Gould & Vrba, 1982; Leroi-Gourhan, 1964) Neuronal networks (Bickerton, 1995; Dehaene, 2004)	Prehistoric tools (Noiré, 1880, Hartig, 1888, de Beaune, 2000, 2004) Modern technology (Dew et al., 2004, Beltagui et al., 2020, La Porta et al., 2021)	Transfer of linear movement from cutting to grinding (de Beaune, 2000, 2004)	Prison (Foucault, 1995) Marriage (Engels, 1990) Money (Graeber, 2011; Pahl, 2021)	Numbers (d'Errico et al., 2018; Geiger, 1868; Lévy-Bruhl, 1925; Schlaudt, 2020) Language in general (Mufwene, 2013, 2019)

somatic tools, social tools, and symbolic tools (Fig. 2 and Table 1). "Material tools" correspond to the traditional notion of tools as freely movable material objects, "somatic tools" refer to the use of one's own body in learned behavior, "social tools" are institutions, and "symbolic tools" comprise spoken language and writing but also painting and the production of art works. The four categories are not mutually exclusive but are merely intended to highlight a characteristic aspect: language is also an institution, but not all institutions are symbolic; body parts and behavior can be symbolic, but not all symbols are physical; symbols are material, but not all material tools are symbolic, etc.

Exaptations of traits of organisms and of material tools are the standard cases discussed in the literature. But we saw that social tools or institutions show exaptations too, and we have also seen examples of symbolic (linguistic) exaptations. Table 1 provides an overview of the cases referred to so far. Of course, such a table may not be able to capture all cases of exaptation, because it is conceivable that a change of use may cross the categorical boundary, e.g., a material tool may become a symbol.

5 Exaptation and the Impact of Tool Use on the Mind: Reconsidering Noiré with Sigaut

Historically speaking, the reception of Hartig and Noiré came to a dead end. However, regarding Noiré's claim to study the influence of tool use on the mind, he converges with today's cognitive archaeology. We can think, for example, of the hypothesis of a "coevolution between the manufacturing and use of tools and advanced forms of causal thinking," recently explored by Gärdenfors and Lombard (Gärdenfors & Lombard, 2020, 1). In this final section, we may thus try to evaluate Noiré's theses in the light of current theories. Noiré's basic idea was that through — and only through — the use of tools, the notion of a "thing," i.e., an autonomous entity capable of acting as a cause in a causal series, can arise:

> the tool enters the sphere of abstraction through which alone things, detached from the context of the environment and the phenomena merging one into the other everywhere, can be thought, i.e., can come into being for human thought. (Noiré, 1880, 37)

This raises the question of what can be done with such a hypothesis today. Should we consider it a speculative curiosity from the nineteenth century, which, if at all, is merely of historical interest — or is it possible to extract something from it that can be exploited in today's cognitive archaeology? In the remaining pages, I will argue for the latter by connecting Noiré's hypothesis to ideas from contemporary cognitive archaeology.

5.1 Sigaut's Notion of Décentration

If one looks for an equivalent (though historically unconnected) approach in today's literature, one is most likely to find it in the work *Comment Homo devint faber* by

the French agricultural engineer and historian François Sigaut (1940–2012), published in 2012 on the initiative of Sophie A. de Beaune and bearing the telling subtitle "How the tool created man." In this late work of Sigaut's, which, if I am not mistaken, is far from having found its way into the international canon, the author advances two sophisticated main theses (cf. also Hussain & Soressi, 2021, 4). The first is that tool use does not anthropomorphically mimic our naked actions (the spoon, for example, replacing the concave open hand in drawing water), but instead, the other way around, "in technical actions performed without a tool, it is the body that works according to the model of an absent tool" (Sigaut, 2012, 8, my transl.). Behind the counterintuitive formulation lurks nothing other than a theory of material engagement, according to which the successful use of a tool consists in using it in accordance with its own "behavior" or "will," i.e., its agency (96, 132). The tool, as an active agent, does not represent a mere "extension of the hand" (96) — and conversely, the naked hand, once accustomed to tool use, can only imitate the absent tool, which is precisely the point of Sigaut's first thesis.

The second thesis is no less surprising than the first, and it is here also that the proximity to Noiré and the relevance for cognitive archaeology becomes manifest: while Gibson's notion of affordance — as a description of the fact that things "demand or invite appropriate behavior" (Gibson, 1979, 102) — seems to lend itself to describing the materiality and agency of the tool, Sigaut insists that this approach would miss the whole point of the tool. "Tools aren't affordances, or, if you want, they are invented, artificial affordances, and this changes everything," he states (Sigaut, 2012, 120). Natural affordances, for Sigaut, have their place only in the "closed" environment of non-human animals as described by Jakob von Uexküll. The environment of an animal, Uexküll taught, "consists only of those questions which the animal can answer," i.e., of those elements to which the animal can react in an appropriate way due to its evolutionary built-in behavioral responses (von Uexküll, 1921, 71–2). The environment of an organism is the "sum of the stimuli affecting an animal," and it is the "world-as-sensed" (von Uexküll, 1926, 126). This world is closed and static insofar as every stimulus sensed by an organism has a biologically fixed and automatically triggered answer, and, as Uexküll stresses, is inherently meaningful, i.e., the meaning the surrounding objects have for the organism — as food, as a threat, as shelter, and so on — is immediately perceived as such (von Uexküll, 1940). The material tool shatters this closed and meaningful cosmos: "The invention of the tool cuts a hole into this closed universe" (Sigaut, 2012, 121). The tool lacks natural affordance (and thus a preprogrammed answer from the organism) because, first, it is not given by nature; second, because its use is not instinctive but can only be accessed through a process of learning; and third, because it is not useful outside of a suitable context, especially without a suitable object to be worked on (ibid., 118–131). Not only does the environment here become cultural as opposed to the biologically defined environment of non-human animals, a first "neutral element" (ibid. 119) also emerges in the cosmos of the human animal with the appearance of the tool, due to the absence of a suitable, pre-programmed behavioral response.

Sigaut calls the mechanism which brings this neutral element to the consciousness of the acting organism "décentration." By this, he understands a "division

of attention" or a split of the focus of attention: the attention is no longer solely directed to the immediate goal, which is defined by the needs of the agent, but also to the tool, which interposes itself as a means and a mediator between the agent and the target object. Sigaut points here to a "paradox" of human tool use:

> [the use of tools] implies a completely new mental exercise for the agent. In its ordinary actions, the animal can apply all its attention to the goal that it pursues, since the only means that it mobilizes are its own organs and the corresponding automatisms. In tool-based actions, this is no longer possible, because the tool forces me to act in a new way, foreign to the repertoire of my innate automatisms. The tool is only a means, but it imposes itself on me with as much force as if it were a goal; it becomes a secondary goal, in a way. (Sigaut, 2012, 132, my transl.)

The idea thus seems to be that the use of the tool consists in a trade-off between the will of the agent and the "will" of the tool or its agency, requiring a learning phase in which the user has to harmonize her or his will with that of the tool, the latter becoming itself a kind of actant and is indeed perceived as such.

This hypothesis of Sigaut happens to be perfectly in line with the theories of Uexküll and the ecological theory of perception in general. Sigaut takes as his starting point the premise of Uexküll's and Gibson's ecological theory of perception that things in the organism's environment are inherently meaningful. Organisms do not see "objects" on which they superimpose meaning; rather, they directly perceive meaningful things, with respect to which the idea of a physical thing is a secondary, derived abstraction. These physical things can certainly be referred to as "neutral elements" (and indeed the term "neutral object" appears in the older English translation (von Uexküll, 1982, 27–8) of the theory of meaning (von Uexküll, 1940), albeit as a unifying translation of various terms such as "objects," "relationless objects," and "simple relationless objects," von Uexküll, 2010, 140–1). Given these premises, the task then consists in explaining how this abstraction, leading to the idea of neutral, physical objects, comes about.

Ingold (1992, 41–2), sharing the perspective of the ecological approach to perception, interprets the neutral elements as "raw material" resulting from a "disengagement." The idea seems to be that a tool transmutes into a neutral object, so to speak, as soon as it has lost its practical significance and is merely contemplated. It remains unclear, however, what this disengagement, which seems to be modeled after the cliché of the contemplative scientist (Shapin, 1991), consists of and what it results from. In comparison, Sigaut's approach has the advantage of locating *décentration*, and thus the potential cognitive significance of the tool, precisely in its active use, i.e., in the users' material engagement with the tool, and not, like Ingold, in the opposite, i.e., its passive contemplation. Moreover, Sigaut's notion of "cultural affordances" in no way contradicts the ecological theory of perception. Uexküll explicitly admitted that we perceive the meaning of all those objects "that we have *learned* to use" with the same certainty as their shape or color (von Uexküll, 2010, 94, my emphasis), and even though, to my knowledge, James Gibson himself never commented on this question, the notion of "learned affordances" seems to be widely

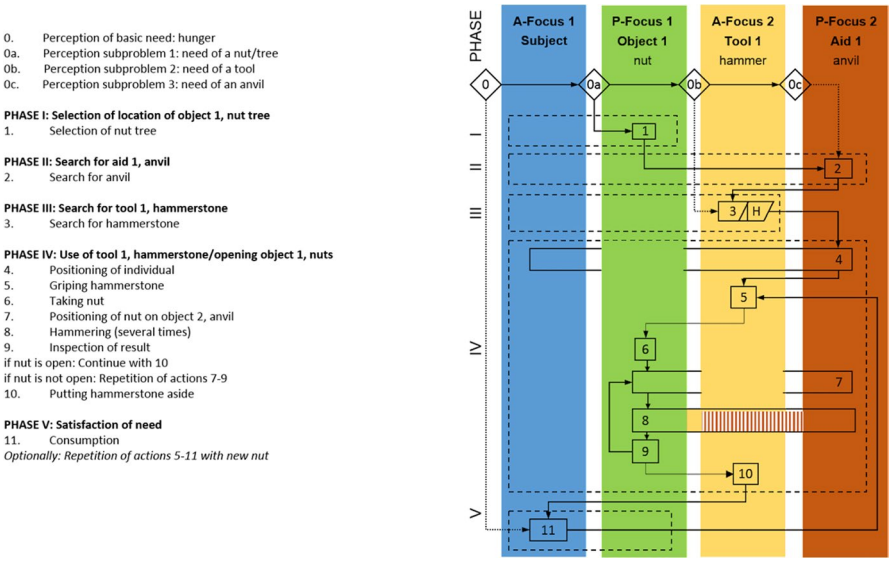

Fig. 3 Cognigram of the cracking of *Panda oleosa* nuts by chimpanzees, from Lombard et al., 2019, courtesy of Miriam N. Haidle. In addition to the linear sequence of steps (the *chaîne opératoire*), the cognigram also visualizes the subject's changing foci of attention during the action

accepted in the literature that follows him (cf. Norman, 2002, 135, and Baggs & Chemero, 2021).

The notion of *décentration* can furthermore be operationalized through the method of cognigrams, developed by Miriam Haidle in current cognitive archaeology (Haidle, 2012; Haidle & Stolarczyk, 2020) and which permits us to measure the complexity of tool use in terms of (1) the "problem-solving distance," i.e., the number of intermediate steps leading to the solution of a problem, and (2) the number of active foci of attention (Fig. 3). Hitting a nut with a stone not only involves an additional intermediate step (looking for a suitable stone to use as a hammer) but also adds a new active focus of attention: one for the stone hammer, which has to be directed in a controlled way, and a second one for the nut, which has to be actively fixed (with the other hand or the feet). Spelled out in these terms, Sigaut's hypothesis would then be that the cognitive complexity (measured by the number of active foci) does not solely reflect the neurological capacities of the tool user but is, so to speak, imposed on the user through her or his engagement with the material. The neural basis would still be a necessary condition, but is here inscribed in a cultural dynamic.

5.2 Exaptation as the Mechanism Behind décentration

At this point, I would like to take these reflections one final step further. If we assume that the learning of tool use — as the discovery of an affordance of an object that was previously meaningless in practical respects — can trigger a process of

décentration, might then not exaptation — which, as Mastrogiorgio and Mastrogiorgio (2020, 86) explain, "can be conceived as the discovery and emergence of new affordances of an artifact and, broadly speaking, of new uses" — also be an effective engine of this process? Noiré kept his two main theses clearly separate: (a) technology develops through exaptation, and (b) technology influences cognition (by generating neutral, causally effective objects in perception). When we interconnect both theses, we can raise the question of whether exaptation itself can transform meaningful tools into neutral physical objects. Interestingly, already in 1940, Uexküll hinted at a potential link between exaptation and the notion of neutral objects. According to him, meaningful objects are characterized by a hierarchy of properties: "For the window, transparency is the 'leading' property, whereas curvature represents a supporting property. For the vase, on the contrary, curvature is the leading property and transparency the supporting property" (von Uexküll, 2010, 141). When objects change their function, Uexküll explains, the hierarchy is overturned and a formerly accidental property takes the place at the top (ibid.). Can exaptation perhaps also lead to the notion of a neutral object where all properties have equal rights?

Let us recall that *décentration* and the split of attention that it entails can occur in learning because, according to Sigaut's analysis, learning to use a tool involves a potential *conflict*, namely a conflict between the will of the user and that of the tool. My hypothesis that exaptation may be an another plausible mechanism behind *décentration* is based on the observation that exaptation too involves a potential conflict, but now a potential conflict between *different uses* of the same tool. Both conflicts have their roots in the materiality or agency of the tool.

If we want to develop this idea, we have to identify the conditions under which the potential conflict involved in exaptation can or does occur (the theory of competing affordances from Cisek, 2007 refers to competing affordances within the affordance landscape, but not within the same object). That the different affordances of one and the same object — its "latent affordances," as we may call them — do not necessarily clash and can co-exist without conflicting with each other, is immediately evident when we remember that affordances (or Uexküll's "meanings") are essentially *relational* properties, existing as relations between (1) an object (the tool, e.g., a hammer stone), (2) an organism using this tool, and (3) an environment (e.g., objects to be worked on, such as a nut to be cracked with the hammer stone). Clearly, it will now depend on the organism and the context which of the object's multiple latent affordance is actualized. When applied to a screw, a screwdriver is used orthodoxly; when applied to a paint can, it becomes a lever to remove the lid, and, once the can is open, it becomes a whisk to stir the paint (example from Ingold, 1992, 47). Uexküll resolves the conflict between latent meanings of the same objects by referring to the tool user's "mood" (Fig. 4).

Accordingly, it depends on the contextual parameters which of the latent affordances of an artifact become actualized and which remain latent. As a mere sequence of context-determined affordances, exaptation fails to produce a *décentration*. In many concrete situations, only one affordance dominates, and the tool never becomes a neutral element. But we can easily imagine circumstances under which exaptations can lead to conflicts between functions. The easiest case is when two different but incompatible uses of an object concur in the same situation. Only when

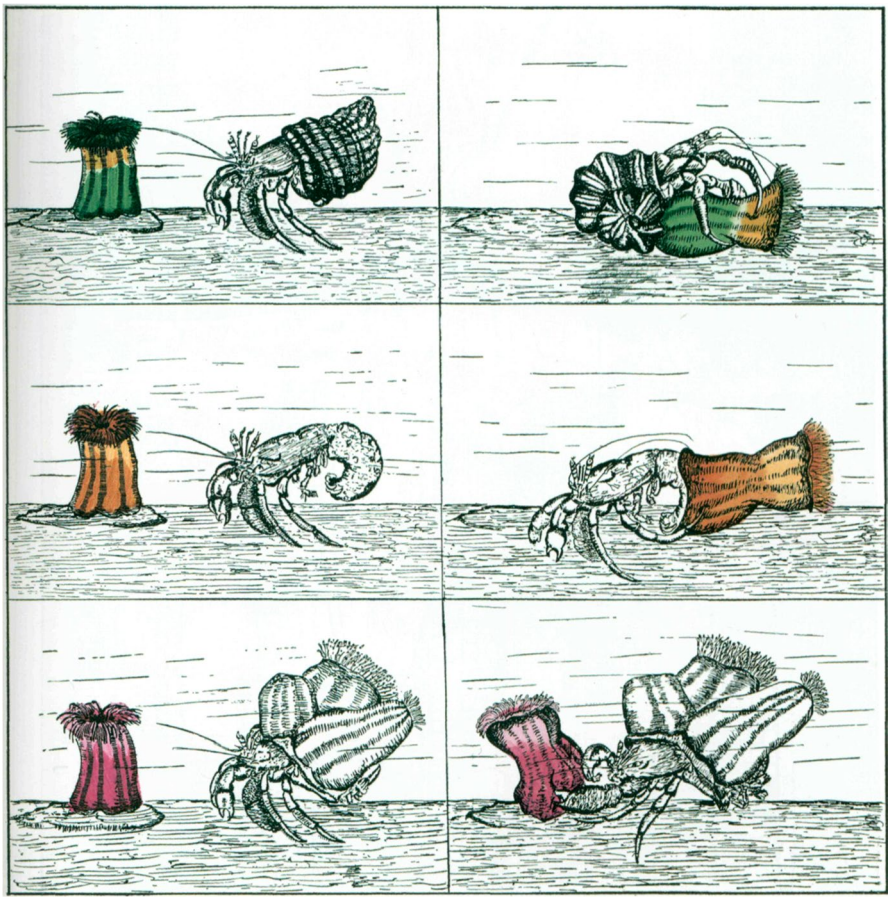

Fig. 4 (From von Uexküll, 1934): A hermit crab can use — or "exapt" — sea anemones in different ways: "We see in each case the same sea anemone and the same crab before us. But, in the first case, the anemones that the crab had carried on its sea-snail shell have been taken from it. In the second case, the snail shell has also been taken from it, and, in the third case, a crab carrying a snail shell and a sea anemone was allowed to go hungry for some time. This was enough to put the crab in three different moods. The anemone changed its meaning for the crab according to each of the three different moods." (von Uexküll, 2010, 93)

a breeze blows across the desk does the teacup unfold its affordance as a paperweight. But as soon as you want to drink the tea, you have to lift the cup — and leave the papers to the wind again. One cannot have both teacup and paperweight at the same time. In more complex cases, the conflict may also be socially mediated, since exaptation requires that a tool can be used "wrongly," namely against the prevailing norm. Viewed in this way, it would be at a meta-level triggered by functional or social conflict that tools become neutral elements that act on our cognition, as described by Sigaut, e.g., by forcing new foci of attention.

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