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The Concrete Universal and Cognitive Science

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Abstract Cognitive science depends on abstractions made from the complex reality of human behaviour. Cognitive scientists typically wish the abstractions in their theories to be universals, but seldom attend to the ontology of universals. Two sorts of universal, resulting from Galilean abstraction and materialist abstraction respectively, are available in the philosophical literature: the *abstract universal*—the one-over-many universal—is the universal conventionally employed by cognitive scientists; in contrast, a *concrete universal* is a material entity that can appear within the set of entities it describes, of which it represents the essential, paradigmatic case. The potential role of concrete universals in cognitive science is discussed.

Keywords Abstraction · Abstract universal · Cognitive modelling · Complexity · Concrete universal · Simplicity

The goal in this paper is to review the concept of the concrete universal and to suggest some of its implications for cognitive science. The concrete universal has a venerable philosophical history, beginning with Plato but finding more expression in Hegel, and being taken up by modern materialists in the Vygotskeyan tradition, but it is largely neglected in western cognitive science. It will be introduced in relation to three interconnected issues facing cognitive scientists:

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1. The limits of abstract universals. The universals that cognitive scientists standardly employ are abstract universals, which provide only half of the picture.
2. The challenge of complexity. A fuller understanding of cognition must involve the complexity of the real-world context and of the history of the cognizing individual.
3. Mechanisms and explanations. Cognitive scientists need to reconcile the different modelling paradigms currently used to address the same data.

These three issues are elaborated, followed by a review of the concept of the concrete universal and a discussion of what it may mean for cognitive scientists.

1 The Limits of Abstract Universals

A critical goal of cognitive scientists is to identify universals. In a recent debate on language universals, Smolensky and Dupoux (2009) expand on the conventional view of universals by defining a universal principle as “a property true of all human minds”. They distinguish such “cog-universals” from “des-universals”, which they define as superficial descriptive properties true of the expressions of all languages. We will see, below, that what are being envisaged in these two cases—like the universals typically entertained in cognitive science—are *abstract universals*.

Classically, universals are entities that unify two or more (generally many) different entities: for instance, *verb* unifies “sneeze”, “breathe”, “inhabit”, “invoke”, …; *phoneme* unifies /p/, /t/, /æ/, /θ/, …. These examples are abstract universals, created by the researcher defining something that is common between a number of different entities or situations. In equivalent processes, formal linguists define a word as a verb if it can be substituted for other syntactically contextualized verbs, and define a speech sound as a phoneme if its presence changes the identity of a word. Thus the abstract universal category of verb, or of phoneme, operates as a kind of (relatively empty) species-name unifying a range of different entities, with the sense and meaning of the term being determined by this process.

Such a process of abstraction—generating abstract universals—appears as the natural and necessary way of creating categories and providing theoretical traction on a domain, particularly so in the cognitive domain which is typically perceived dualistically as separate from the physical. The categories produced can be used to capture *ordered relations* within the domain. Formal syntax is a prime example and testifies to the productivity of this approach, specifying a theoretical vocabulary for linguistic structures and giving rise to a wealth of insightful generalizations; equally, in the computational modelling of cognitive processes, as in the interactive-activation (e.g. McClelland and Rumelhart 1981; McClelland and Elman 1986) and connectionist paradigms (e.g. Seidenberg and McClelland 1989), there is an ordered mapping between qualitatively different levels of representation. In these ordered relations between theoretically specified abstract entities, different perspectives can be taken such that (a) one entity may subsume another (e.g. syntactically, a determiner phrase subsumes a determiner and a noun; in the Interactive-Activation model of word recognition, the word node representing CART subsumes the position-specific letters C, A, R, and T); (b) one entity may resemble another (e.g. syntactically, the possibility of conjoining two constituents is a test of their similarity; in McClelland and Elman's TRACE model of speech perception, similar words compete at the lexical level); (c) processes may occur within the extent of an entity (e.g. Vendler 1968, shows that there are preferred orderings of adjectives within an English noun phrase; in TRACE, interlexical competition is played out across the physical extent of two competing input words).[1] Note that the ordered relations between abstract universals in a functional model can be specified numerically, using a mathematical algorithm to produce quantitative behaviours, but the ontological status of the entities remains the same and such mathematical models are still subject to the general limitations imposed by abstract universals. To take an example from a non-cognitive domain, the Periodic Table, the abstract universal "noble gases" unifies He, Ne, Ar, Kr, Xe, and Rn by virtue of their being inert and gaseous. This category allows us to describe ordered relations between the noble gases and the categories of the halogens, the other non-metals, the metalloids, and the metals; these relations were valuable in getting initial theoretical traction on the physical chemistry represented in the Periodic Table, and remain valuable pedagogically.

We will go on to contrast abstract and concrete universals, but for now we will observe two critical features of an abstract universal. First, it can be defined in set terms as *non-self-participating* (Ellerman 1988): it does not itself occur in the set it defines. Thus, for instance, "verb" itself is not a "doing word"; people can speak English, French, and Pirahã, but no-one speaks "language"; "largeness" is not itself large.

Second, an abstract universal is invariably defeated by new data; it always encounters some aspect of the real world that it was not intended to cover, thereby defining the limit of the theory/model in which it features. In our non-cognitive example, the abstract universal "noble gas" is defeated by new data such as the gradation in the elements' boiling points or the potential extension of the group to the elements Uuo or Uuq. Such defeat is the typical case with computationally implemented cognitive models: the author makes initial decisions on the entities (i.e. abstract universals) the model will contain, often based on assumptions concerning simplicity and tractability, and the model is then explored with little or no qualitative extension to its architecture. The model functions within the declared domain, simulating the corresponding human behaviours, and can remain current within the research literature, but is not significantly elaborated.[2] An example is McClelland and Elman's (1986) successful TRACE model of speech perception: it contains the abstract universals of features, phonemes and words, and is still being productively explored after 25 years, but it has not been extended to include other aspects of linguistic structure such as lexical stress, syntactic structure, syllabicity, and so on. Relatively simple models and models applied to gain initial traction on a particular

[1] This small typology of perspective-taking in abstraction is based on one presented by Ollman (2003). Ollman (2003) does not discuss the abstract-concrete distinction.

[2] As an exception to this observation, Perry et al. (2007) present what they term "nested incremental modeling" as a way of extending an implemented computational model, based on the principle of incorporating the most effective components of existing models addressing the domain in question.

domain are typically not intended by researchers to be realistic in many ways but rather to demonstrate the viability of particular properties of the processing architecture (McClelland 2009); thus TRACE demonstrates the rich emergent effects that an interactive-activation architecture permits. Nevertheless, the literature shows that criticisms of models rely on the more marginal data, and that modellers sometimes respond by improving input and output representations (e.g. Plaut and McClelland 1993), or by increasing the scope of some aspect of the domain to a more realistic size (e.g. del Prado Martín 2003); most researchers see the goal of computational modelling as contributing to a virtuous spiral of implemented modelling, prediction, human experimentation, and model adaptation. Note that the scaling-up of models in terms of the number of entities, or types of entity, they contain typically brings other issues related to their complexity in its wake.

There is current controversy about language universals (e.g. Evans and Levinson 2009, and associated commentaries; Frost 2012). Evans and Levinson argue that even seemingly core categories such as noun or recursion seem not to be truly universal (see Kinkade 1983, and Everett 2005, respectively); there are examples from the Ethnologue's 6912 languages of the world (http://www.ethnologue.com/) in which every non-trivial universal can be argued not to apply. A re-evaluation of universals is therefore timely. It is beyond the scope of this article to address many examples of universals, and Murray (1988, p. 127) notes that decisions about the status of particular cases of universals are often not straightforward. The contention in this paper is that most universals employed by cognitive scientists turn out to be abstract universals and that if a concrete universal has been deployed it will typically not have been explicitly presented as such. Naturally, neither of these points precludes the literature containing productive discussion of determinate abstractions. For instance, Chomsky's proposed Language Acquisition Device was presented as a dedicated physical organ of the mind/brain, both exemplifying generative syntactic principles, and instantiating them (see, e.g. Chomsky 2000, pp. 19–20). A model may in principle contain any number of determinate abstractions, but it is a further step to correctly order these entities and to identify one of them as a concrete universal for that domain.

We provisionally conclude that abstract universals are theory-derived entities that give us valuable multiple perspectives on the ordered relations within a domain, but which fail to provide access to the complete contents of the domain, and understanding thereof.

2 The Challenge of Complexity

Van Orden and Stephen (2012) pose the question "Is cognitive science usefully cast as complexity science", asking whether we require "a sea change in how we go about cognitive science" (p. 5). The case for a complexity science approach to studying human cognition has been under construction for at least a decade and a half (cf. Gilden et al. 1995); the case against this paradigm shift rests on longstanding assumptions concerning simplicity and explanation. For reviews of the role of simplicity in cognitive science theorizing, see Weisberg (2007) and Chater and Vitányi (2003). The respective cases for and against the complexity approach, are rehearsed by Van Orden and Stephen, and by the associated papers and replies.

In brief, the complexity-theory paradigm is based on nonlinear dynamical systems theory, encouraged by the advances that this approach has enabled in the physical sciences and in economics. Within this paradigm, the coordination dynamics approach has generated specific research applied to human movement (Kelso et al. 1981, 1984; see Kelso 2003, pp. 51–52, for a short review), a rich technical and conceptual vocabulary, and wide-ranging philosophical claims (e.g. Kelso and Engstrøm 2006). Stephen and Van Orden (2012, p. 95) cite Kelso (2003) as "an actual explicit multistep outline for how to do empirical work in complexity science" (p. 95).

The contours of the complexity theory approach are efficiently sketched by Wagenmakers et al. (2012), who (in presenting the case against) condense the approach to the slogan that 1/f noise is a signature of systems that are nonlinearly coupled, dynamical, self-organized critical, synergistic, scale-free, exquisitely context-sensitive, interaction-dominant, multifractal, and inter-dependent (p. 88). We can add to this list the idea of *metastability*—a sensitive type of stability in which the system is poised near to its critical points, such that a small perturbation can cause a system-wide qualitative change. Kelso (2003) reports that phenomena such as binding, information creation and hysteresis can be found in the behaviour of the non-linear interaction of oscillators.

Most of the effort of cognitive scientists exploring the complexity science approach has been concerned with the establishment of the signature 1/f scaling in a variety of perceptual, cognitive, and linguistic domains (see Kello et al. 2010). Other efforts have involved identifying *bifurcations* in behaviour—tipping points at which relatively small changes can dramatically alter the local or global disposition of the system. The provisional conclusion of such research is that the cognitive domain under study is a complex system made up of a (possibly open-ended) variety of entities in the real-world context, in the body, and in the brain of the individual, and that these entities interact multiplicatively to produce the sort of metastable dynamic interactions that have been investigated mathematically.

Wagenmakers et al. level the criticism that this sort of research does not provide actual explanations of what is going on in particular circumstances; for this "a formal complex-systems model that succeeds where a standard model fails" is required (p. 91). Although there have been interpretations of the potentially adaptive nature of 1/f scaling in some cases (see Kello et al. 2010, for examples), for Wagenmakers et al. the absence of specific formal models suggests that the complexity science approach risks appearing as just "colorful verbiage", "speculation, wrapped in jargon, inside wishful thinking" (p. 92).

A long philosophical tradition (cf. Hegel's "The truth is in the whole") allows us to argue for *completeness*, in stark contrast to the simplicity typically assumed to be a goal of modelling (see Weisberg 2007, for a brief discussion of completeness in the context of idealization). Without rehearsing more of the complexity debate, we can conclude that the complexity of the environment, of the physical brain, and of the history of the cognizing individual constitute a powerful challenge to conventional cognitive science, a challenge that is currently only being taken up in a small proportion of cognitive science research.

3 Mechanisms and Explanations

McClelland (2009) summarizes contemporary modelling frameworks in cognitive science: connectionist/PDP models (Rumelhart and McClelland 1986), rational and Bayesian approaches (Knill and Richards 1996), dynamical systems approaches (see above), symbolic and logic-based approaches (Anderson and Lebiere 1998; Fodor and Pylyshyn 1988; Pinker and Ullman 2002), cognitive architectures and hybrid systems (Sun 2002). Although McClelland points to the possibilities for the productive interaction—or at least peaceful co-existence—of these different approaches, recent decades have seen examples of the opposite, particularly in the high-profile symbolic *versus* connectionist debate. What are the implications of researchers using these qualitatively different frameworks to contest the same data? This question is a major issue facing cognitive scientists.

On the one hand, we might think that this situation corresponds to Multiple Models Idealization (Weisberg 2007), in which two or more models are used to simulate the data in complementary ways; the researcher is interested in accurate simulation rather than a realistic explanation based on a single model (for Levins 1966, it is "the intersection of independent lies", p. 423). Or we might assume perspectival realism, in which each model addresses different aspects of the real world (Giere 1999; Rueger 2005). On the other hand, we might think that contests between competing models with respect to benchmark data might resolve conflicts (although this assumption probably underestimates the flexibility of complex models to assimilate new data, as well as simplifying the realities of the culture of scientific research).

The issue of realism with respect to cognitive processing is also raised by the turn towards seeing cognition as optimal and rational (see, e.g. Griffiths and Tenenbaum 2006). The authors of current critiques of universals in language research and in reading research have concluded in favour of "extraordinary plasticity" (Evans and Levinson, p. 429) and "optimization" and "flexibility" (Frost 2012). However, acknowledging that a particular aspect of cognitive processing is optimal is far from specifying the material details of that processing. Baayen et al. (2011) express just this sentiment in discussing their modelling of lexical processing based on the Rescorla-Wagner equations (Wagner and Rescorla 1972) for discriminative learning, saying "The advantage is precision and model simplicity, the disadvantage is 'explanatory disappointment'" (p. 70). We reach the same conclusion when the equivalence of different algorithms is demonstrated; for instance, McClelland (2012) has reported that the interactive-activation architecture of models such as TRACE generates outcomes equivalent to Gibbs Sampling (Casella and George 1992). Our understanding of a cognitive process advances by knowing that particular mappings between different types of representation are tractable, and by observing the emergence of unexpected behaviours from particular implementations (McClelland et al. 2010). However, as we have seen, it is frequently the case that when two or more cognitive models compete it is effectively only within the level of representation and algorithm of Marr's Tri-Level Hypothesis (Marr 1982); at the computational level the goals are the same or very similar—they are models of the same processing domain—and the implementation level is very often simply ignored. This stalemate is typically accepted as a case of multiple realizability or is simply not resolved theoretically in the most productive way (although again see Perry et al. 2007). The suggestion in the current paper is that the type of materialist abstraction discussed below will illuminate constraints between the three levels. For instance, when implementation is in nervous tissue, then parallel processing becomes more plausible than serial processing, as noted in the connectionist literature; when language processing is in a female brain, then there appear to be algorithmic consequences (Hsiao and Shillcock 2005; Ullman et al. 2002). If the implementation changes to involve nervous tissue in multiple brains, or to include material artefacts then there are implications for how the processing domain is conceived at the computational level. In the Tri-Level Hypothesis the essence of a process—the "what", the information-processing point of view (Marr 1982, pp. 27–28)—is seen as residing at the computational level; in the current approach, involving a concrete universal, the essence critically involves the implementational level and its role across the other two levels.

In summary, multiple paradigms are in use to model the same or overlapping data, often converging on apparently optimal solutions, and challenging cognitive scientists to resolve the relationships between the approaches. This problem is closely connected with the other two problems considered above, the limits of abstract universals and the challenge of complexity. All three problems require us to understand the relationship between simplicity, complexity and the essence of some particular cognitive processing. We now turn to the concept of the concrete universal as a way of addressing this challenge.

4 The Concrete Universal

In contrast to abstract universals, Hegel identifies a role for a *concrete universal* (Stern 2007). In fact, the issue goes further back, to Vico and his "imaginative universal" (Verene 1981), and to Plato. Ellerman (1988) briefly reviews the literature on Plato and concludes that it is ambivalent concerning concrete universals, with the full extent of the issue only becoming clearer with the twentieth century consideration of set-theoretic paradoxes. However, it was Hegel's discussion of concrete universals (itself influenced by Goethe's *Urphänomen*, cf. Blunden 2012, p. 102) that informed the modern materialist tradition, leading to the more recognizably cognitive research of Vygotsky, with his closely associated concept of the *germ cell* that expresses in microcosm the processing in a domain, and his *unit of analysis* beneath which the processing in a domain cannot be captured (Leont'ev 1981; Vygotsky 1978). The Vygotskian tradition found its foremost[3] philosophical representative in Evald Ilyenkov, himself heavily influenced by Hegel; Ilyenkov (1982) presents an extended philosophical discussion of the concrete universal with respect to Marx's theory of value (and cites Marx 1859—again part of the Hegelian tradition—explicitly discussing the issue, p. 146; see also Murray 1988, Chapter 10, using "general abstractions" versus "determinate

[3] Ilyenkov's readership is in inverse proportions among western and Soviet/Russian cognitive scientists.

abstractions" to refer to abstract and concrete universals, respectively). See Bakhurst 1991, and Larvor 1992, for a discussion of Ilyenkov on the concrete universal. Ellerman (1988) argues that concrete universals are the relevant universals for category theory (MacLane and Birkhoff 1967; MacLane 1971), so that the concrete universal represents the perfect paradigm example of a property, its essence.[4] Rojek (2008) reviews concrete universals in arguing for a trope theory consisting of tropes and concrete universals. After this brief review of the very small literature explicitly dealing with concrete universals,[5] we now consider more closely the claims made of this type of universal.

Stern (2007, pp. 130–131) summarises how Hegel envisages the concrete universal to be truly concrete, quoted below in full (italics in original):

1. It is not merely a property, in the sense of being a way an individual may be: rather, it is *what* the individual *is*, in so far as that individual is an instance of that kind of thing; it is therefore a substance universal (e.g. 'man' or 'rose') and not a property universal (e.g. 'red' or 'tall').
2. It supports generic propositions, such as statements of natural law ('human beings are rational agents') and normative statements ('because this person is irrational, he is a poor example of a human being'); these are therefore to be distinguished from universally quantified statements ('all human beings have earlobes', 'all swans are white'), which tell us about the shared characteristics of a group of individuals, rather than the characteristics of the kind to which the individuals belong (men qua men are rational).
3. It can be exemplified in individuals which have different properties, so that there need be nothing *further* in common between these individuals than the fact they exemplify the same concrete universal (the way in which one individual is a man may be different from the way in which another individual is a man).

Another way of differentiating concrete universals from abstract universals is that the former are *self-participating*: a concrete universal occurs as itself in the set of entities that it defines (Ellerman 1988). Thus, to return to our non-cognitive example above, Ilyenkov (1982) suggests the hydrogen atom as a concrete universal for the domain of the Periodic Table: it exemplifies what is going on in that domain in the simplest terms. It contains the essential arrangement of nucleus and electron shell necessary to understand the rest of the elements. Critically, the hydrogen atom itself occurs within the set of elements.

[4] Characterizing the concrete universal as self-participating raises the twentieth-century issue of the paradoxes of self-containment, which are particularly relevant to cognition, given the widespread reliance on recurrent connectivity. As Ellerman (1988, p. 412) notes, set theory can only be a general theory of abstract universals. He argues that category theory is the formal escape from the inconsistencies of set theory; category theory captures the idea of the participation relation as the "uniquely-factors-through" relation, and a universal uniquely factors through itself by the identity morphism (see, also, Ellerman 1995, 2007).

[5] I exclude the contemporary critical realism literature and the older British idealist literature as outside the scope of this article.

The concrete universal in any domain is identified by a process of abstraction that takes away (in the mind of the modeller) more and more of the real-world domain until only the critical entity remains. This process of abstraction, resulting in *finding* the candidate concrete universal, is in contrast to the (Galilean) idealization that occurs in *generating* an abstract universal.

Finding a concrete universal identifies something material that is a far abstraction within the domain, but note that the concrete universal is something that still has content; in contrast, the abstract universal is a theory-dependent, relatively contentless entity. In our non-cognitive example of a concrete universal, the content is in part relational (the relation between the nucleus and the electron shell, for instance). Note that the process of identifying the concrete universal is not one of trying to find the smallest entity, on the erroneous assumption that the domain grounds out at some atomic level.

Because it is a material entity, the concrete universal in the model/theory can always engage with new data in closer approximations to the domain being modelled, in a way that an abstract universal cannot. In our non-cognitive example, the abstract universal "noble gas" cannot engage with the detailed data concerning the physical chemistry of the relevant elements. The concrete universal of the hydrogen atom, a materially existing entity, cannot be superseded in quite the same way; we can, of course, still in some sense falsify a particular candidate concrete universal by identifying a different candidate that generates a more parsimonious story, perhaps involving a slightly different domain.

The concrete universal is a universal, but it has all the richness of the particular. Whereas an abstract universal can be defined as something abstract (typically seen as a property) that inheres in many other different things, a concrete universal is an entity in which many other different things inhere. As Rojek (2008, p. 375) notes, there may be something to be unpacked in the term "inherence", and he also describes the concrete universal "as an entity in which many different things are"; Ellerman (1988) uses the term "participates in". The term "concrete" expresses the fact that a concrete universal knits together many other entities. In contrast, the abstract universal knits together few other entities.

Finally, unlike an abstract universal, which receives its definition when it is created, the concrete universal carries on having more content generated for itself (a) as more is found out about the entity that constitutes the concrete universal and how it interacts with the rest of the domain, and/or (b) as its role in the real world develops (typically in the case of cultural/social processes).

5 Implications for Cognitive Modelling

We began by outlining three problems for cognitive scientists, all intimately connected with the roles of simplicity, complexity, and abstraction in theorizing. Those three problems could have been expressed in other terms, and could have been aimed more specifically at Cognitive Science's constituent disciplines, and the problems would still have revolved around the issue of abstraction.

Laboratory research is spontaneously materialist, measuring aspects of real behaviours, but when cognitive scientists translate these behavioural observations into cognitive models/theories it is typically in terms of models/theories composed solely of abstract universals. As we have seen, such theorizing can be productive and pedagogically useful, revealing the ordered relations between the abstract entities in the domain, but the cognitive scientist sees less than half of the picture by entertaining just the "simple" end of the dimension of complexity, with no principled way of connecting it to the "complex" end. The concept of the concrete universal potentially allows us to address these current issues in cognitive science. Specifically it gives us the following.

(a) *A comprehensive position on universals* It can give us the fuller philosophical picture, in which the two different types of universal complement each other in cognitive modelling and theorizing. Cognitive scientists do not typically have a clear view of the status of models; the application of sophisticated mathematics and the involvement of biologically and anatomically oriented levels of description have partly obscured the ontological questions, helped along by the fetishism of simplicity. If we see the process of Galilean idealization as being one of creating an abstract universal from a consideration of that which is common between a number of real world examples, rather than—as is conventional—one of creating a simpler, more tractable, fictitious version of the real world, then we are pointed towards considering the complementary alternative of materialist abstraction and a concrete universal. However, as well as having a role in the philosophical foundations of cognitive science, the concept of the concrete universal must prove itself in implemented computational modelling; we consider a number of issues related to specific implementations below.

(b) *The concrete universal as paradigm example* In contrast to conventional hierarchical functional models, the concept of the concrete universal encourages us to see the whole model as a *set* of entities (the entities being levels of processing or encapsulated processors in cognitive architectures), with the entity identified as the concrete universal being the simplest, paradigm example within that set, or domain.

For example, in the domain of reading, we might see the anatomical vertical division in the human fovea (Shillcock et al. 2000, 2010) as a substance universal in a model of the visual pathways and processes in reading; this simple, most peripheral divided anatomy is a paradigm example of the structural principle that we see in the other entities contained in the reading processor. These other entities, such as eye-movement control, attentional processing, lexical processing, the mental lexicon, and so on, can each embody a hemifield/hemispheric dimension. In implementing computational models of reading, there is an option of whether or not to include an attentional component, for instance; and if one is included, there is an option of whether or not to give it a realistic hemispheric dimension (cf. Kinsbourne 1970). In this specific example of modelling reading, moving beyond abstract universals to identify the concrete universal within the domain motivates modellers (a) to include in the modelling domain any entity relevant to reading that has a hemifield/hemispheric dimension, and (b) to instantiate the hemifield/hemispheric dimension in any entity in the model. Note that the attentional processor being developed in this case has content other than the vertically divided structure that we are taking as the concrete universal; the two entities, the attentional processor and the divided fovea, may be in no other way similar to each other (see Stern's point 3, above), the concrete universal being simply the furthest abstraction—the paradigm case—within the domain. These two moves (including an attentional processor and respecting its hemispheric structure) will have implications for the internal architecture of such a model: the processing in each hemifield/hemisphere becomes relatively encapsulated and the structures established necessitate particular patterns of connectivity, and further detail can be precipitated out by the concrete universal, corresponding to anatomical and/or functional structure, even though it is still co-existing with abstract universals in the model.

In summary, the concrete universal motivates our decisions about what entities to include in the domain and how to develop them. Figure 1a is a schema of a model containing the concrete universal (A) along with other elements (A_1, A_2, A_3, A_4) which all share in the concrete universal to some or other extent.

(c) *Instantiating the functional connectivity of a concrete universal in a model* In (b) above, the modelling imperative was to develop a model that is isomorphic with the known anatomy of the reading system, both its anatomical structures and their patterns of connectivity. Reading and vision researchers have the advantage of greater transparency between anatomy and function (at least in the more peripheral processing) than exists in other domains of cognitive processing such as speech perception. Some researchers tentatively suggest the alignment of functional models with large-scale brain anatomy (e.g. Price 2000, Fig. 12; Reichle et al. 2003, Figs. 13, 14). The status of the universals in a particular model is critical. If the model contains exclusively abstract universals, then aligning model connectivity and large-scale brain regions will not be able to go beyond expressing the ordered relations between abstract universals in the domain.

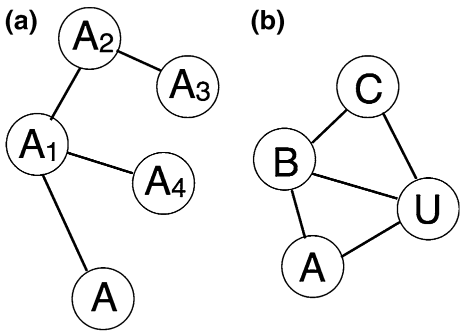

Fig. 1 Schematic representation of the two extremes of the range of roles a concrete universal may play in an implemented cognitive model. **a** The concrete universal, *A*, is the simplest paradigm example of a substance universal that appears as an aspect of each of the different entities A_1, A_2, A_3, and A_4. **b** The concrete universal has direct connections to every other entity in the model. See text for further details

What modelling options exist when there is much less transparency between brain anatomy and function, as in speech perception? In this case, conventional, hierarchical functional models such as TRACE have seemed a natural stopping point (in terms of qualitative development of the model's architecture). Such models typically consist of hierarchies of abstract universals connected together as levels or stages that are defined by distance from the sensorium and/or by part-whole relationships (cf. TRACE's feature, phoneme and word levels). However, proposals that high-level information should have an early role in processing (see, e.g. Ahissar and Hochstein 2004; Fahle and Poggio 2002; Gibson 1969; Luria 1966; Sechenov 1863) and more recent proposals concerning predictive coding (Clark (in press); Friston 2005; Lee and Mumford 2003; Rao and Ballard 1999) query just how much we can cash out the association of large-scale structure and function that began with the nineteenth-century "connectionist" aphasiologists (Caplan 1987), and they also query the outside-in direction of processing typically assumed in cognitive models. A concrete universal's pervasive role in the domain may still be expressed, however, in a functional model in which the processing stages are of abstract universals, as in the features, phonemes and words in TRACE. The concrete universal can be specifically represented in the model and direct connectivity can be extended between this concrete universal and every other entity in the domain. Figure 1b shows such a schema in which the concrete universal, U, is directly connected to other entities in the model, A, B, and C.

As a specific example of the model type shown in Fig. 1b, a candidate for concrete universal in the domain of speech perception might be the speech sound perceived as schwa (/ə/, the first sound in "about", the last in "panda") together with the relation it has to word meaning.[6] The schwa-sound is the simplest, paradigm example of a phoneme, and is coded as such within TRACE's phoneme level. We can also see it as the simplest paradigm example of a lexical entry ("a"). In our laboratory we have explored an implemented version of TRACE in which a single node in the model represents the schwa-sound and directly participates in the input, phoneme, and lexical levels. The overall operation of the model survives this change, and a new pattern of strengths and weaknesses of the model emerges, requiring detailed further investigation (see *self-identifying reference deleted, forthcoming*).

[6] Some of the background justification for this example is taken from existing formal theorizing: schwa is seen as a bare [-cons] root, or as a root node with an empty (vocalic) place node, "the maximally unmarked vowel … marked for being a vowel ([-cons]) but for nothing else … (Van Oostendorp 1999). Van Oostendorp continues "If a language has schwa in its vowel inventory, this segment usually has a special role to play in the phonology of the language", and goes on to define its special nature as consisting of the constrained contexts in which it occurs, with respect to syllabic structure and to stress, and its relation to reduction and deletion. He suggests that "as many phonological properties as possible should be made to follow from the interaction of [the minimal nature of schwa] and general principles of phonology … no linguistic rule or constraint should specifically refer to schwa" and "schwa literally is a *substructure* of all the other vowels" (italics in original). In English, schwa plays a special role in virtually every subdomain of language processing. N.B. This example, together with the above example of a concrete universal in a cognitive model of reading, is intended simply to give the flavour of the issues involved rather than to substantiate the particular cases.

When two entities in a model (e.g. the lexical and phoneme layers in our TRACE example) both participate in the concrete universal, this activity represents a principled material interface between these entities. Hub-and-spoke architectures have been proposed in the literature, in which hidden units integrate the representations from separate sources but are themselves amodal (e.g. McClelland et al. 2009); the concrete universal provides us with a substance universal instead of the bare amodal individual implied in hub-and-spoke architectures.[7]

The best pattern of connectivity in any model of any domain is an empirical issue specific to that case, but as we have suggested here a functional model divided into levels can be relaxed in a principled, productive way by implementing the concrete universal's pervasive role in the domain. Figure 1 shows the two extremes (considered in (b) and (c) here) in a range of ways in which a concrete universal may mediate processing in a computationally implemented architecture.

(d) *A principled way of defining a domain of cognitive processing* Churchland et al. (1994) criticize conventional modular research practice and call for a "heterarchical, interactive … theory" (p. 59). In conventional cognitive science there is a powerful inertia against making models more elaborate than their initial specification; even when researchers determine to make qualitative additions to an implemented cognitive model, there is the problem of how to make a principled—rather than an eclectic—addition. The hegemony of abstract universals has produced functional models that are hierarchical and modular. The concrete universal offers us a principled route in the opposite direction, towards larger, heterarchical, more realistically complex domains. The domain is constituted by all the entities exemplified by or mediated by the concrete universal, as we have seen in (b) and (c) above. A concrete universal can itself unify as few as two entities, but it is the larger, more complex domains that are naturally of more interest.

In (b) and (c) we saw the concrete universal as a paradigm example and as a pervasive influence, respectively. These are not mutually exclusive properties. Rather, they are the two mutually defining aspects of the concrete universal; both will always be present, and one cannot be understood without the other. In summary, the concrete universal, representing the essence of the processing being studied, is a principled way of defining the modelling domain.

(e) *Recognition of individual differences* Philosophical categories such as the universal, the particular, and the individual can have a fuller, more integrated role in theorizing based on the concrete universal. Historically, cognitive scientists have tried to control differences between individuals by carefully selecting and matching the participants in experiments and by comparing group means; some differences have been corralled into broad cognitive styles (e.g. Riding and Rayner 1998), uncontrolled differences have been afforded relatively low status in reporting and theorizing, or have been treated as noise. This approach is also found in the study of cognitive impairment, both acquired or developmental, although it has been harder to sustain in this case due to the difficulties in matching participants. Overall, the

[7] See Stern (2007) for more on the concrete universal as a solution to the philosophical problems associated with "bare individuals" and trope theory in specifying individuals.

goal has been to devise models that are general across all adult individuals. With advances in theory and experimentation, more details of individual differences in cognitive processing have become apparent, making such generalization more difficult. Critically, the recent development and application of mixed effects modelling (Baayen et al. 2008) is providing cognitive scientists with the tools to locate individual differences in cognitive processing within a broader model. The concrete universal provides the conceptual foundations for this development. It allows our cognitive modelling to become oriented to case studies of real individuals that are explored in more and more depth as presenting as more or less typical instances. We investigate real individuals and report them as such, and we can see that this or that participant is a more typical example of a literate English-speaking adult, for instance, as opposed to positing an idealized reader. In our specific example of a vertically divided fovea as a concrete universal in a model of eye-movements in reading, we can consider different individuals normatively as exemplifying more or less strictly vertically divided processing across the domain.

(f) *Increasing the level of detail of a concrete universal in a model* Because a concrete universal is a real, substantive entity it can be invested with more and more detail in an implemented cognitive model, representing a principled way of introducing increasingly detailed material into what may in large part otherwise be a conventional functional model. As an example, increasingly detailed acoustic information might be introduced into TRACE via the schwa sound so as to interface with the existing abstract universals and potentially precipitate out new structure in the model.

(g) *Active use of both types of universal* The two types of universal complement each other theoretically, but in an implemented cognitive model the real potential is in active, flexible movement dialectically between the abstract and the concrete, rather than endorsing one at the expense of the other. The most abstract characterization of “chair” as a noun is just as critical to cognition as the most concrete characterization of this particular chair in this real-world context in the further context of all the chairs I have known. This movement between the abstract and the concrete is fundamental to cognition, and it may not be too speculative to associate this movement with the most significant polarity of the processing architecture of the human brain—that between the left and right hemispheres (see McGilchrist 2009, for one view of this relationship, in the context of a comprehensive review of hemispheric differences).

(h) *A coherent perspective on the roles of essence*, *simplicity*, *complexity*, *completeness*, *explanation*, *abstractness*, *concreteness*, *analysis and synthesis* Working out the full role of the concrete universal involves moving away from the simple/abstract end of the dimension of complexity and towards the complex/complete/concrete end by adding detail onto the concrete universal in necessary ways, reversing the initial process of abstraction but gaining additional insight into how the different entities materially articulate with each other. This *ascent to the concrete* can always provide a positive answer to the question “will it still work when this other relevant factor is taken into consideration?” because the concrete universal is a real, substantive entity engaging in necessary interactions with the rest of the world. Being able to move either way along this dimension, in a double-movement of analysis and synthesis, constitutes an explanation of how the domain works. The more we can knit together the different aspects of the real world, mediated by a single concrete universal, the more parsimonious our theorizing becomes. In these ways the concrete universal is the essence of the domain.

In recent decades, one of the responses to the challenge of complexity has been to propose a move away from static, substance-based metaphysics, toward dynamic process metaphysics, inspired by complex systems theory and advances in physics (see, e.g. Bickhard 2009, 2011; Campbell 2009; Hooker 2009; van Gelder 1998). Campbell (p. 463) equates materialism with physicalism and sees them both as committed to basic particulars and subject to arguments against such an ontology and for a process-based interactive ontology. What are the implications for a materialism featuring concrete universals that involve substance/matter as well as movement and relations, like the case of hydrogen in the Periodic Table or the more cognitively oriented examples discussed above?

First, there are strong resonances between the strand of materialism featuring concrete universals, represented by Ilyenkov, and the emphasis placed on levels, emergence, activity, and interactivity in process-based metaphysics. However, this materialism, endorsed in the current paper, is partly distinguished as follows: (a) the universe is assumed to be inexhaustibly deep; (b) genuine antimonies, such as wave-particle duality, are accepted and, indeed, such contradictions are seen as the motor of emergence; (c) matter and motion always coexist. The concrete universal is intimately connected with the issues of levels and emergence as it is seen as embodying the essence of processing at a particular level (cf. Vygotsky's unit of analysis); reduction to a lower level does not result in a more parsimonious picture. The concrete universal defines the domain and speaks in interesting ways to issues of autonomy and interaction (cf. Hooker's remark, p. 529, "In a phase space only the global dynamical states and their time evolution is specified, not the organised processes that produce the dynamics, hence it cannot capture directed organisation. There is at present no obvious resolution to the general theoretical problem of how to incorporate organisational principles into dynamical models in a principled way.

6 Conclusion

We have reviewed an aspect of the issue of abstraction that has been neglected in conventional, Western cognitive science, and we have suggested how a different type of universal, the concrete universal—arising from a materialist as opposed to a Galilean abstraction—may be of fundamental importance to cognitive scientists in the implementation of working computational cognitive models.

We began with three issues. The concrete universal represents an approach to these issues. First, regarding the limits of abstract universals, the concrete universal completes the picture of abstraction from the complexity of the real world. Second, the concrete universal represents a route from simplicity to complexity and completeness. Finally, a clear, comprehensive picture emerges of the ontology underlying the different mechanisms and modelling paradigms current in cognitive science.

Identifying the concrete universal in a research domain therefore becomes a primary goal of modelling, followed by the elaboration of that entity's role with respect to existing abstract universals. As the discussion has shown, this procedure is a detailed and challenging way of thinking about the essence of a particular type of cognitive processing. This process is "carving nature at its joints" *par excellence*, and in any particular domain at any particular juncture, that most sophisticated engine of active inquiry, the brain, can be relied upon to have identified the most effective universal.

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