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RECURSION, ITERATION, AND METAREPRESENTATION

Some researchers pinpoint recursion as our species' key computational ability, making humans cognitively unique (e.g., Hauser, Chomsky, and Fitch 2002; Corballis 2003). It may give us many abilities hypothesized to be uniquely human: language, theory of mind, complex problem solving, mathematics, and mental time travel (episodic memory/future planning) (Hauser, Chomsky, and Fitch 2002; Corballis 2003; Parker 2006; Stone and Gerrans 2006).

Within psychology and linguistics, *recursion* is understood as a property of certain types of representations. Whether internal to the mind or external, representations that can contain other representations of the same type are recursive. Language, mental states, mathematical formulas, and spatial representations all have this property. One can have a thought about someone else's belief about another person's thoughts, or one can have a picture of a picture of a picture: Both are *recursive representations*. *Recursive processing* requires that recursive representations be unpacked in a systematic way, from the highest to lowest level, in order to produce some output.

Recursion is distinct from the related concept, *iteration*, but the two are often confused. Both involve repetition. In programming, iteration is the repetition of a process within a computation, with a top-level control structure that "sees" all the steps involved (Anderson 2007). In recursion, however, the number of steps is unknown to the highest level of the function; all that is known to that level is whether an end condition has been satisfied or whether the problem needs further breaking down (Anderson 2007; Suh 2007). In language, we can construct infinitely long sentences by iterating elements, for example, "I have lived in the U.S. and England and Australia and …" Each iterative phrase is independent, not requiring reference to the other phrases, only to the top-level clause containing the phrases (Parker 2006). We can also construct infinitely long sentences by using recursively embedded elements, for example, "The blogger said that Bush thought that Cheney thought that Libby believed that the reporter did not know that Plame was a spy." These elements are not independent, requiring full unpacking of each embedded level to understand the full meaning of the sentence. Each level of embedding *refers to* another level: One cannot know the semantic value of "Cheney thought that … " without knowing the semantic value of the clauses it includes.

Recursion should also be distinguished from the related concept *metarepresentation*. Some use the terms interchangeably, using *metarepresentation* to mean a representation of a representation (e.g., Corballis 2003). It means being able to represent the relationship between the representation and what it refers to: to understand that a picture of Niagara Falls *stands for* that visual scene, or that someone's belief that Santa Claus exists *represents* that potential state of the world, or that *rocks*, the noun, *refers to* a set of stone objects. Metarepresentation requires recursive embedding of representational relationships, but it is not identical to recursive embedding (Stone and Gerrans 2006). Metarepresentation may also be uniquely human (Suddendorf 1999).

Marc Hauser, Noam Chomsky, and W. T. Fitch (2002) have offered the hypothesis that recursion is the defining feature of language, making it uniquely human. Other features of language, however, do not follow directly from recursion and also seem to be uniquely human, such as words, fine phonemic discriminations, and motor control of mouth, larynx, and so on. (enumerated in Pinker and Jackendoff 2005; Parker 2006, Chapter 5).

Whether recursion is the single defining feature of language or not, it might be uniquely human. Testing for recursive capacity directly is difficult. Instead, researchers rely on demonstrations of animals' ability to do tasks dependent on explicit recursion. Some claim that animals do implicit recursion in certain tasks, for example, ants doing dead reckoning, but this is difficult to substantiate. Although recursion is an efficient solution to many problems, unless one can test for the explicit content of the recursive steps in a computation, it is always possible that animal brains solve problems using some other, nonrecursive computational technique. Thus, comparative research uses tasks believed to depend on explicit recursion: mathematics, theory of mind, problem solving involving interdependent steps, mental time travel, or certain kinds of syntax (Corballis 2003; Parker 2006). So far, no study has demonstrated that our closest relatives, great apes, can do any of these tasks with the range and flexibility of humans (Corballis 2003; Hauser 2005; Suddendorf 2006). For now at least, recursion can join a set of *possibly* unique human cognitive capacities: other aspects of language, flexible control of attention and inhibition, expanded working memory capacity, and metarepresentation (Suddendorf 1999; Kawai and Matsuzawa 2000; Hauser 2005; Pinker and Jackendoff 2005; Stone and Gerrans 2006). Recursion may not be *the* key to unique human cognition, but it is no less worthy of study for being one of many keys.

– Valerie Stone

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REFERENCE AND EXTENSION

Extension and *reference* are technical terms in the philosophy of language, formal semantics, and pragmatics. We outline their roles in three types of theoretical effort – compositional semantic theories (which make use of both terms), various *theories of reference*, which purport to tell us what it is for a word to have a certain referent, and views that understand reference as something people do with words. The first two are semantic accounts; the last conceives of reference as a matter of language use, so of pragmatics.

Reference and Extension in Compositional Semantics

We begin with the use of reference and extension in compositional semantic theories. In this domain a *referent* is generally a thing that a proper noun "refers to" or "names," and an extension a set of objects to which a predicate applies (the term *denotation* is sometimes used interchangeably with both reference and extension). However, compositional semanticists often generalize one or the other notion so that almost any kind of expression, including a sentence, can be said to have a referent or an extension.

With few exceptions, compositional semantic accounts are versions of **TRUTH CONDITIONAL SEMANTICS** – attempts to specify the meanings of sentences in terms of their truth conditions. Since natural languages allow for infinitely many sentences, the truth conditions of sentences must be specified recursively in terms of the semantic values of their parts, and referents and extensions are semantic values that enable us to do just this. For example, we can specify the truth condition of the sentence "John smokes" in terms of the referents and extensions of its parts as follows: "John smokes" is true if and only if the referent of "John" (namely, John himself) is a member of the extension of "smokes" (the set of things that smoke).

The primary historical source for compositional semantics along these lines is Gottlob Frege's ([1892] 1997) account of *Bedeutung* – often translated as "reference" (also as "denotation"). In it, a referent is assigned to every meaningful expression. Frege assumed that each complex expression is the result of combining a functional expression (such as a predicate) with one or more arguments (such as names) (see PREDICATE AND ARGUMENT). Further, he assumed that the referent of a functional expression F is always a function f, and that the referent of any expression X that F accepts as an argument is the sort of object that is among the arguments of f. Specifically, if F is a functional expression and X an expression that F accepts as an argument, the referent of F is the function that maps the referent of X onto the referent of $F(X)$. Thus, the referent of a complex expression is always the result of applying the referent of one of its constituents, as a function, to the referents of its other constituents, taken as arguments. The referent of a sentence as a whole is identified with its truth value. Thus, the referent of "Chomsky" is Chomsky, the referent of "is clever" the function that maps each object x onto *truth* if x is clever and onto *falsehood* otherwise, and the referent (truth value) of "Chomsky is clever" is truth if and only if Chomsky is clever.

It may seem surprising that the referent of a sentence is its truth value, but it should be kept in mind that *reference* is used as a technical concept within compositional semantics. Given the use to which the concept is put, this is not an unnatural assumption: Frege was interested in a compositional semantics that would tell us how the truth values of sentences are determined by the referents of their parts, and all natural languages have fragments in which, when a sentence has *other sentences* as parts, the truth value of the whole depends only on the truth values of the constituent sentences. Fragments of languages in which this is the case, and in which the referent of a complex expression in general depends only on the referents of its parts, are called *extensional*. Thus, in an extensional fragment, expressions having the same referent can be substituted in any sentence without altering its truth value (contexts in which such substitutions preserve truth value are also called extensional). Frege was primarily interested in constructing a semantics for the language of mathematics, which is extensional, and so choosing truth values as referents of sentences was natural. However, natural languages as wholes are not extensional. In contexts involving **PROPOSITIONAL ATTITUDES, MODALITY**, and counterfactuals, the substitution of clauses having the same truth value may alter the truth value of the whole sentence. To account for such contexts, Frege held that each sentence or other expression has, in addition to a referent, another kind of semantic value, which he called the expression's *sense* (*Sinn*). The sense of a sentence is what he called a *thought*, or, in contemporary terms, a **PROPOSITION**. In order to maintain a version of the principle of **COMPOSITIONALITY**, he held that the truth values of nonextensional sentences are determined in part by the senses of their constituents (see SENSE AND REFERENCE).

For various reasons, Frege's approach is now considered antiquated. Most recent work in formal semantics for natural languages is inspired by Alfred Tarski's work on the definability of *TRUTH* for formal languages. Richard Montague (1974) was the first to apply Tarski's work productively to (fragments of) natural languages. Here, *extension* is the preferred term. The extension of a predicate is, again, the set of things to which it applies. Although terminology varies, in this framework, too, one can speak of the extension of almost any expression, including a sentence, so that one identifies a sentence's extension with its truth value. Applying Tarski's approach, the aim is to recursively characterize not only the truth conditions of sentences but also the entailment (logical consequence) for a language using the notion of extension: A sentence S_1 is said to entail a sentence S_2 in language L if and only if there is no assignment of extensions to the semantically simple expressions of L (no "model of L") under which S_1 is true and S_2 false. On this approach, the logical constants differ from other