

## THE REPRESENTATION OF CONCEPTS IN OWL

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### Abstract

This paper discusses the theoretical basis of the formalism used as a foundation for OWL, a system for representing and processing conceptual knowledge. This formalism attempts to capture the expressive power of natural language by adopting the underlying representational conventions and "conceptual models" of English. The formalism is built around specialization, which is perceived to be the key organizing principle of English at a deep conceptual level. The use of specialization in combination with another low-level structural device, reference, leads to a simple but powerful structure, the concept, which is ideal both for the representation of a broad spectrum of conceptual knowledge and for computation on existing machines equipped with large, high-speed, random-access memories.

### Introduction

OWL is a system for representing and processing conceptual knowledge, intended for applications requiring interaction with humans in natural language, at a human-like level of competence. Development of OWL has been proceeding for the past two years within the Automatic Programming Group of Project MAC under the direction of William A. Martin. It is his successor to an earlier system called MAPL.

This paper discusses the theoretical basis of the OWL formalism for conceptual knowledge, which serves as a foundation for the OWL system. The purpose of this formalism is to allow conceptual (i.e., non-imagistic) knowledge to be expressed in terms of concepts and connections between concepts; in this respect, it does not differ from such existing formalisms as Quillian's semantic memory or Schank's Conceptual Dependency networks. It is quite different, however, in respect to details of structure, notation, and computer implementation. Among the advantages we expect to obtain from the OWL formalism are:

(1) despite its simplicity and uniformity, we expect it to be suitable for representing a broad spectrum of conceptual knowledge at all levels of abstraction and detail, in a "natural" way;

(2) it provides an organizational framework that should allow processing tasks required for comprehension of natural language to be carried out effectively and efficiently on a serial computer;

(3) its organizational framework is such that its performance should not deteriorate significantly as the size of its knowledge base and the scope of its applicability increase, given an adequate amount of high-speed, random-access memory;

(4) the notation for it will be easy for English speakers to learn and use; and

(5) its structures and notation are especially effective for dealing with very large knowledge bases.

There are several distinct aspects of the OWL formalism which we might examine. This paper focuses primarily on the structural aspect, but also looks briefly at the notational, English, and operational (i.e. implementation) aspects. For further description of the formalism, see Martin and Hawkinson.

To have any reasonable chance of realizing our goals for OWL in the near future, we have felt it wise to structure knowledge in OWL in accordance with the principles of organization of the human cognitive system, insofar as we understand them, even though the continual advance of our understanding mandates continual evolution of the OWL formalism. Since much of the significant evidence we have of this organization derives from our understanding of the structure of natural language, we have tried to use those linguistic insights to develop a formalism that would capture the expressive power of natural language without sacrificing computational efficiency. We felt we could succeed in this only by adhering as closely as possible to the representational conventions and conceptual models of one particular natural language, English, even for the representation of "deep-level" structures, i.e., structures at the level of Schank's Conceptual Dependency networks or Minsky's frames. An obvious advantage of a formalism based on the structure of English is that translation back and forth between it and English might be done with relative ease; this is important not only for the OWL system as ultimately developed, but for the development process itself.

We do not yet know enough about the structure of English to have a definitive blueprint for our OWL formalism. We have had, in fact, to decide among competing alternative solutions to a host of representational problems by applying principles of economical system design — being careful, however, not to compromise our primary guideline of choosing representations that are readily mappable into English and vice versa. The structural organization we have arrived at as a result of our design efforts seems so simple and natural, and the evidence for its pervasive use throughout natural language seems so intuitively convincing, that we feel it must hold profound implications for psychological models of human cognition. For example, it might be used as the basis for a strongly predictive model of word phrase association.

Though the OWL formalism has been implemented in LI5P, OWL does not in fact adopt or build upon

LISP's model of how data should be structured, namely, in terms of tree-like list structures and property lists of atomic symbols. Rather, the OML formalism provides an alternative scheme for the low-level ("sub-frame") structuring of knowledge (hence data) that is, I believe, as fundamental in character as that provided by LISP. This formalism might prove a suitable foundation not only for the OML system, but also for other high-level systems like Moore and Newell's Merlin or any of the recently proposed "frame" systems.

### The Theoretical Basis for the OML Formalism

In developing the OML formalism for conceptual knowledge, the first big issue that confronted us was how to classify and "index" the enormous number of concepts OML would need for human-like competence in natural language. We started with three fundamental principles:

(1) that essentially all conceptual knowledge should be represented in terms of a uniform, simple "building block", which we call a concept;

(2) that the set of all concepts should be arranged into a single conceptual taxonomy (concept tree) in such a way that individual concepts would "inherit" from superior concepts most of their properties, especially "Beta-properties" that indicate what to do with concepts in various interpretive contexts;

(3) that the vast bulk of the conceptual taxonomy should be determined "derivatively", so that a few tens of thousands of individual classification decisions might suffice to determine a conceptual taxonomy containing millions of concepts.

Almost a corollary of the second principle is that the concept tree should have a low, relatively uniform "fan-out" (where almost all concepts have fewer than, say, ten immediate subconcepts), since it is unreasonable to expect a concept to inherit most of its properties from concepts significantly more general than it. A low, relatively uniform fan-out also offers important structural and computational advantages.

We adopted these fundamental principles primarily because we judged that a formalism based upon them would simplify the task of building a large OML knowledge base just enough to make that task feasible. However, we would not be surprised to find that these principles were also fundamental to the organization of human conceptual memory, which, after all, must acquire and maintain an even larger knowledge base.

Underlying the OML formalism for conceptual knowledge, and hence the structure of a concept, are two basic structural devices: specialization and reference. Properly utilized, these devices permit the formalism to satisfy our three fundamental principles, and they also give it great expressive power and characteristics that make it efficient to work with. (To eliminate a possible source of confusion, note that when we speak of the structure of a concept, we understand it to be located at some one fixed place within a particular copy of a particular knowledge base, though it may be *referred* to in any number of places.)

### Specialization

Specialization is a means for identifying a concept uniquely by a pair of entities: the concept's genus, a superior concept in the concept tree, and its specializer, most often also a concept.\* Every concept in OML must, in fact, be identified by specialization, and thus a concept is often itself referred to as a specialization (of its genus). The significance, if any, of a concept's specializer cannot be determined according to a few simple, set rules; indeed, it may be arbitrary, though it typically depends on some generalization of the concept at or near the level of the genus.

The fact that every concept must have exactly one genus does not mean that a concept cannot be "a kind of" more than one thing. Actually, as we shall later see, a concept can have any number of distinct characterizations. This means that a genus could be viewed as simply a characterization singled out to provide identification for and primary classification of a concept. The choice of a genus is nevertheless very important, since in practice, most low-level interpretive decisions as to what to do with a given concept must, for reasons of serial processing efficiency, depend on its genus alone. Fortunately, as we will demonstrate below for English, a natural language expresses many concepts in terms of an appropriate genus and specializer, and most of the rest can be determined through the use of simple, productive, language-specific rules. Only a relatively small number of hard choices remain for the conceptual taxonomist, but it is important that he make them wisely (though on philosophical grounds, it seems unlikely that there is one true conceptual taxonomy).

Specialization is directly evident in natural language; in fact, I believe it to be the most important technique of signification (concept identification) within natural language. Let us look at some English phrases that identify concepts by means of specialization. In our examples below, we will underscore the part of each phrase that identifies the genus. The rest of each phrase, minus simple connectives like "of", "as", "than", and sometimes "to", "for", and "in", identifies the specializer (only because we have deliberately excluded extraneous modifiers, such as leading articles, that apply to the phrase as a whole). Of course, a genus or a specializer can itself be a specialization.

hit the ball, hitting the ball

get a book, get a job, get to go,  
get lost, get wet, get up

look up the name, put off my decision

\*It has been observed that the term specializer can be misunderstood by persons who are just becoming familiar with OML terminology. It should be understood to mean "that component of a concept which makes it special" or "that component of a concept which makes it a particular specialization of the genus", not as "that which produces the specializations of a concept".

go by bus, want him to know  
 flower garden, garden flower (Jespersen)  
 computer sales, August sales,  
           sales increase  
sales of computers, sales for August,  
           increase in sales, sales in dollars,  
           big in size  
glass of milk, can of beans, all of us  
 robins' nests, John's father,  
           John's being late  
 left hand, capital letter,  
           passenger tire  
black tie (but not blue tie)  
Friday, seller, wanting, wanted  
 sky blue, dead wrong, easy to read  
big for a cat, bigger than an elephant,  
           less than 3  
in the house, in June in trouble,  
           in toto, in stock, in good faith  
in back of the bus,  
           in the back of the bus  
let go of the block, let the block go

Let us now generalize from some of these sample phrases in terms of parts of speech, ignoring for now the possibility of exceptional cases.

verb direct object  
verb infinitive, verb adjective,  
           verb particle (preposition)  
verb secondary clause  
 noun nominal, nominal "of nominal,  
           genitive nominal  
adjective infinitive, noun adjective  
 "as" adjective "as" nominal  
preposition nominal, stem suffix

What criteria have we used here to recognize an English phrase as a specialization? First, the phrase must be meaningful as a concept, the test for which is that the phrase as a whole must denote something that could be further described. Secondly, the phrase must have a sub-phrase which one can say the whole phrase is "a kind of", though perhaps only in some very abstract sense (e.g., "In trouble" is a kind of "In" only in some abstract sense of the word "in"); the maximal such sub-phrase (e.g., "on top" rather than "on" in the phrase "on top of the table") identifies the genus of the phrase. Thirdly, the phrase must contain another sub-phrase which, when properly interpreted in context, combines with the genus to identify, independent of the context, the concept represented by the phrase as a whole; this other

sub-phrase, if it exists, is the specializer. A couple of examples should help to clarify this last criterion. The phrase "the red book", though it satisfies the first two criteria, does not satisfy the third, since neither "the" nor "red" nor "the red" combines with genus "book" to unambiguously identify, independent of context, the book being referred to. The phrase "my father" on the other hand, would be a specialization since it has a genus, identified by "father", and a specializer, the referent of "my" (presumably determinable from context), which together identify the concept (though not necessarily its referent) uniquely without need of context. A useful diagnostic for English phrases that are specializations is that, in most cases, both the genus and specializer will carry stress, with the stress on the specializer *at least* as strong as that on the genus (when no word in the phrase is being stressed for the sake of emphasis).

In actuality, a large proportion of English grammatical constructions may be treated as particular forms of specialization, that is, different syntactic patterns that all do basically the same thing, namely, identify a concept by specifying its genus and specializer. Analyzing English constructions as specializations, where possible, often obviates their analysis in terms of traditional grammatical categories, such as parts of speech. Where it is possible to analyze an English phrase as a specialization that "matches" a "sufficiently specific" concept in the knowledge base, there is no real need to also match it to some more abstract grammar rule.

Indeed, if we view the genus, specializer, and syntactic properties of each generic concept in an OML knowledge base as a grammar rule, we can envision a conceptual grammar which, for a large knowledge base, could easily include hundreds of thousands of such rules. In a conceptual grammar, idioms would be rules, not exceptions to rules. A conceptual grammar acknowledges and emphasizes the essentially idiomatic character, at every level, of natural language as used, whereas traditional grammars have tended more to emphasize the essential regularities that can be abstracted from instances of its use. From our point of view, in fact, the principal goal of a traditional grammarian is to approximate a large conceptual grammar by a grammar of relatively few rules expressed in some particular formalism, a task of immense difficulty. Traditional grammars, even if they could be realized, would not be as satisfactory for OML as a more straightforward conceptual grammar. Because most of what is needed for a conceptual grammar is already required to be in the knowledge base for purposes of conceptual modeling, it would almost certainly be less work to create a conceptual grammar for a large knowledge base than to program the mapping between OML conceptual structures and structures produced by a parser for some traditional grammar.

Thus far, we have analysed as particular forms of specialization only those English words and phrases wherein both genus and specializer are manifest. However, for the sake of uniformity, we would like to treat monomorphemic words as specializations and also many specific phrases and constructions that fail to express either the genus or the specializer or both. Thus, we typically treat the concept corresponding to a

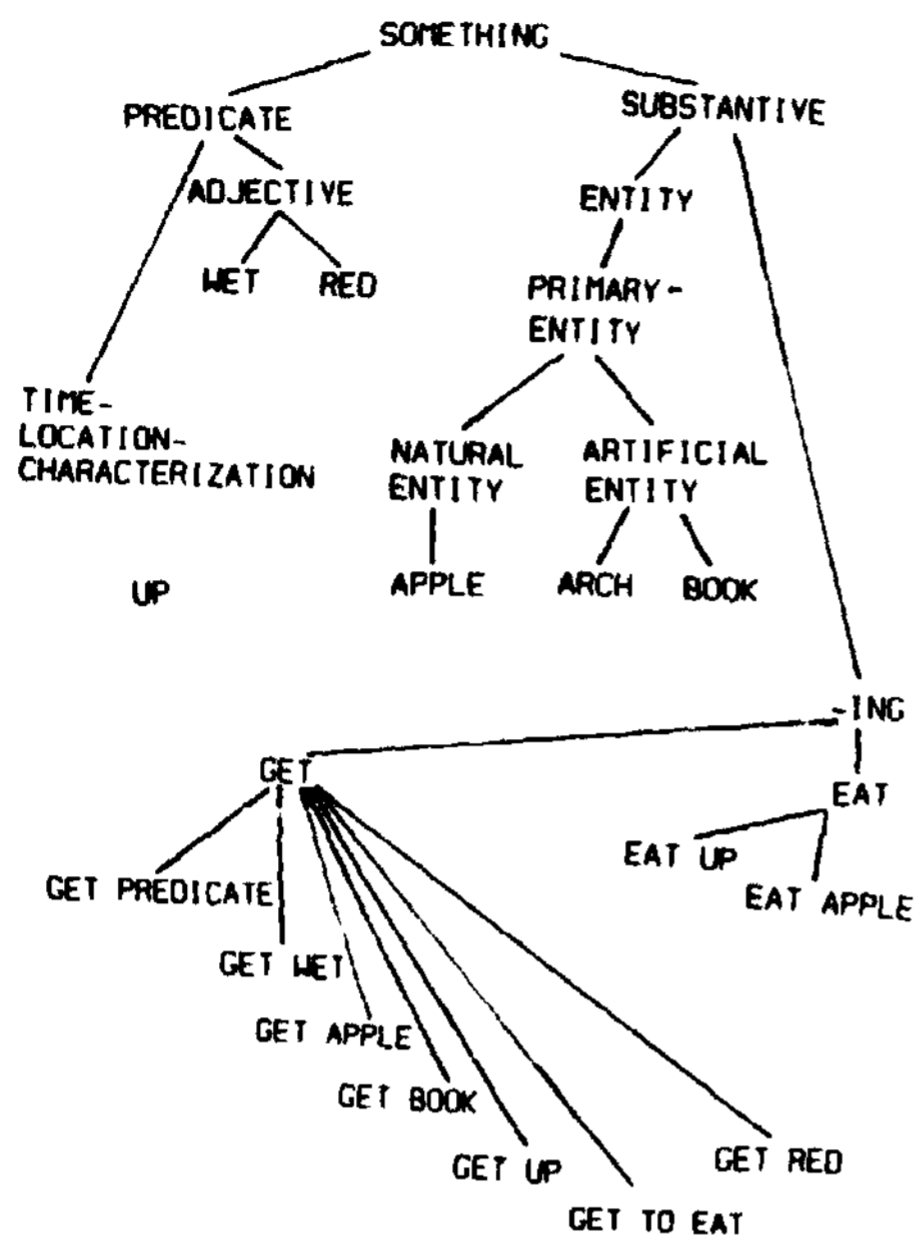


FIGURE 1. A Tiny Concept Tree

monomorphic word as some appropriate genus specialized by the written symbol for that word, e.g., the concept spider as the concept insect specialized by "spider." Non-word morphemes, such as "-ing" are treated similarly. We call such concepts symbol meanings. (Concepts specialized by concepts, on the other hand, are said to be classified; in this case, the classifier may be referred to as a classifier.) An idiomatic concept like "hot dog" is dealt with in a way that is somewhat analogous to the treatment of symbol meanings; in particular, "hot dog" is treated as the concept sandwich specialized by the concept consisting of concept dog specialized by concept hot. (Note that there is another meaning of "hot dog" that would require the concept skier in place of the concept sandwich.) More generally, we have observed a diachronic tendency for concepts to become identified in English by their specializers, e.g. "capital letter" by "capital" and "New York City" by "New York", where both forms are in common use, and "general officer" by "general", where the first form (the one revealing the genus) is now archaic. As Martin points out, this tendency to identify a concept by its specializer is just a special case of the widespread, more general phenomenon in English of a concept being identified (named) by some other, usually "closely related" concept.

We could continue to exhibit here successively more elaborate forms of specialization, but that would take us beyond the scope of this paper and into Martin's paper, which presents a far more comprehensive theory of English. As it is, our treatment above of "spider" and "hot dog" cannot be argued here to be anything more than conventional; a deeper justification could not possibly be given without that more comprehensive theory.

We have defined and discussed specialization as a means for *identifying* concepts, but specialization may be equally viewed as a means for *classifying* concepts. Both the genus and specializer of a concept contribute to that concept's classification. The contribution of the genus is readily apparent - the gross structure of the concept tree can, in fact, be defined as the set of all mappings from concepts to their genres (or, alternatively, from concepts to their specializations). This gross structure is then further refined by making use of the specializers, a process known as derivative subclassification. The rule for derivative subclassification of concepts by their specializers may be stated, somewhat imprecisely, as follows: subclassify the specializations of a concept as their specializers are classified.

An illustration will serve to clarify the meaning of derivative subclassification. Figure 1 shows the gross structure of a tiny concept tree (or a tiny extract from a large -- the analysis applies in both cases). Figure 2 shows that same structure refined by derivative subclassification, i.e., the fine structure of the tree. Notice that new generic concepts have been introduced into the tree such that, for every pair of classified specializations that share a common genus, say  $g$  specialized by  $s_1$  and  $s_2$  there will exist a corresponding specialization of  $g$  by the most specific common superior of  $s_1$  and  $s_2$  except when that superior is the superior genus "something". Thus, for instance, concepts "get adjective" and "get substantive" are introduced,

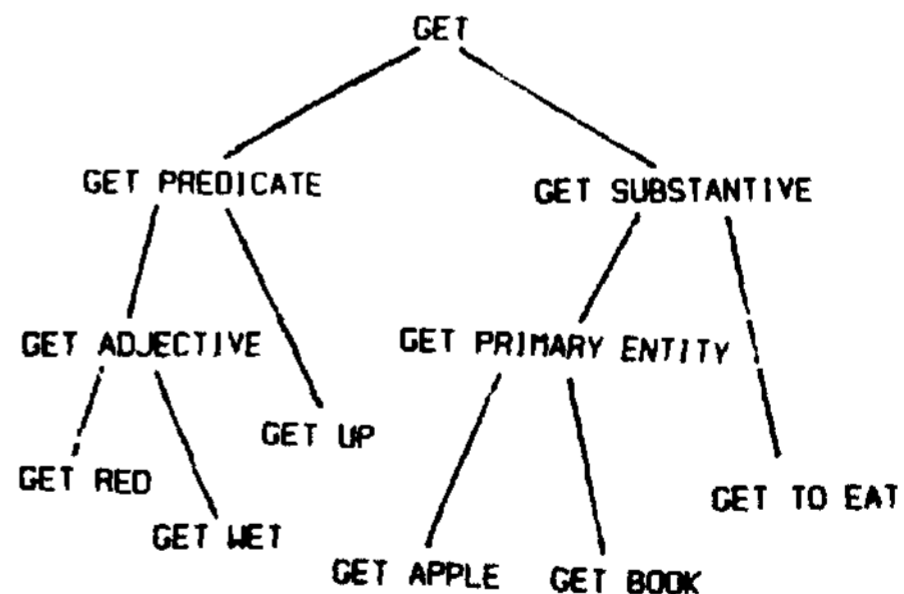


FIGURE 2. The Tiny Concept Tree of Figure 1 Refined by Derivative Subclassification

but "get entity" and "get natural-entity" are left out (although one or both could later be introduced either directly or in consequence of other newly formed specializations of "get").

To facilitate further discussion of the fine structure of a derivatively subclassified concept tree, we need to define a few additional terms. To begin with, we will define the term generalizer to be the immediate superior of a concept in a derivatively subclassified concept tree. Thus, the generalizer of "get book" in the concept tree of Figure 2 would be "get primary-entity". Note that, unlike the genus, the generalizer of a concept may change as new concepts are introduced into the concept tree. The generalization path of a concept is the sequence of concepts encountered in moving from it to the SUBBUB genus by successively taking the generalizer at each step. Again with reference to Figure 2, the generalization path of "get wet" would consist of "get adjective", "get predicate", "get", "-ing", "substantive", and finally "something". The generalization path of a concept is the primary path along which properties are inherited; we would therefore expect "get wet", for instance, to inherit certain of the properties of "get adjective", "get predicate", etc. (Some properties are not inherited by inferior concepts because they are contradicted at lower levels or because they are specifically known not to apply beyond a certain depth). We will use the term conceptual node to refer to a concept and all its subconcepts. Thus, in the concept tree of Figure 2, there is a conceptual node for "get", which consists of "get" and the subtree beneath it, together with whatever might be attached thereto. Finally, generic subconcepts in a conceptual model are said to be senses of the concept at the top of the node. Hence, "get adjective" and "get substance" could be described as senses of "get".

What is the significance of using a derivatively subclassified concept tree? First of all, if we were to have a conceptual taxonomy with tens of Billions of concepts (which we would surely need to approach a human level of competence in natural language), we might expect derivative subclassification to account for at least 99% of the classification decisions required to build that taxonomy. Secondly, if, when building our taxonomy, we contrive to put a limit (say ten) on the number of *symbol meaning* specializations a concept may have, then that same limit can be shown to hold for the number of immediate *classified* specializations any concept could possibly have. Thus, we can easily arrange to get a concept tree whose fan-out at any given node is strictly limited. Thirdly, if we put into our concept tree a representative sample of the specializations of a particular concept (as they occur in ordinary use of the language), derivative subclassification will provide us with a useful and intuitively reasonable set of senses of that concept to attach inheritable properties to. Thus, if our sample of the specializations of "have" includes, say, "have a tail", "have four legs", and "have a top", where "tail", "legs", and "top", are already classified as "parts", then derivative subclassification will give us the sense "have as part", which, as the head of an important conceptual submodel of "have", will carry many inheritable properties. (The question of how we might *automatically* derive properties for "have as part" from its inferior concepts is

interesting, but beyond the scope of this paper.) Note that just because a concept like "have a tail" is a subconcept of "have as part", there is no need to explicitly spell out "have as part" when expressing "have a tail" in a formal notation, any more than there is a need to do so when expressing it in English. In fact, we might go so far as to say that a rule of derivative subclassification is necessary in a very large, finely subdivided taxonomy to allow economical identification (naming) of concepts within it. Finally and in sum, derivative subclassification furnishes the Beans for satisfying the three fundamental principles proposed near the beginning of this paper.

## Reference

Reference, the second of the two basic structural devices of OWL, is the Beans by which one concept or symbol may refer to another. By the term reference, we are trying to suggest the general function of a connection that is symbolic (non-physical), unidirectional, precisely definable, and differentiated only as to function (not, say, by a label on the connection); these important properties of reference are not conveyed well by such terms as "pointer", "association", or "associative link". The most important computational property of references is that the references under a concept or symbol (to other concepts or symbols) may be accessed trivially from it. In fact, a concept may be thought of as being composed entirely of references, arranged in an orderly way. (A symbol has a spelling in addition to references).

We distinguish three categories of reference: the generalizer and specializer of a concept, indexing, and description. Except for generalizer and specializer references, which are recognized by where they appear in a concept's structure, the category of a reference may be determined solely by inspection of the referent (the concept referred to). Of course, in an actual computer implementation, we might use a more elaborate structure for a concept than is strictly necessary, so that we can categorize a reference or retrieve all references of a particular category more rapidly than by inspection of the referent. It is well to be aware, though, that such elaborations of structure are not theoretically activated or required.

indexing in OWL is a category of reference used to connect (1) any concept to its immediate specializations, (2) any concept to all concepts specialized by it, or (3) any symbol to its symbol meanings. Thus, with indexing, it is easy (computationally) to go from the symbol "spider" to the concept spider, and from there to specializations like red spider and black widow spider, and also to concepts classified (specialized) by spider, such as spider web, spider monkey, and spidery. An index reference can be recognized as such by the fact that the concept or symbol it is under will appear as either the generalizer or the specializer of the referent. Thus, a reference to spider web under spider would be identified as an index reference by the fact that spider is the specializer of spider web. Note that index references under a concept c are sometimes called "back pointers"

because they "point back at" concepts whose generalizer or specializer "points at" c.

There is one unresolved problem with index references of type (2) above. Whereas index references of types (1) and (3) are halted in number by derivative subclassification and by the low level of morphemic ambiguity in English, respectively, there will exist in the knowledge base many concepts having hundreds of index references of type (2), e.g., the concept house. This goes against a principle we would like to be able to adhere to, namely, that the number of references under any one concept should never significantly exceed, say, twenty. The likely solution to this problem is a second form of derivative subclassification to subclassify all the concepts specialized by a given concept. However, we have not yet adopted such a solution, in part because it turns out to be unsatisfactory to use the obvious counterpart of the rule for derivative subclassification of the concept tree.

Description is a broad category of reference that, by definition, includes every reference not used for indexing or for the generalizer or specializer of a concept. The term description is nonetheless quite appropriate, since individual descriptive references (or descriptors) can almost always be said to describe the concept they're under (the subject of the description). We will distinguish here, on functional grounds, two principal types of descriptive reference, namely characterizations and modifiers, each with numerous subtypes. But we will side-step, for now, the difficult problem of providing effective criteria (tests) for such distinctions, relying instead on illustrative examples and on the normal English meanings of the terms we have chosen for the types and subtypes.

A characterization is an alternative, partial description of a concept (the subject of the characterization). For example, a particular dog might be characterized as follows: a nuisance (abstract characterization), Mary's pet and Fido's father (relational characterizations), a good swimmer (skill characterization), a chaser of cars (habitual role), and the dog who ran across our yard yesterday (event participant).

Relational characterizations deserve special note. In OWL, a relationship A a is represented by a two-way characterization: a as a value characterization under R specialized by a, and R specialized by b as a relational characterization under a. Thus, for instance, "Ellen is the mother of Sam" would be represented by the value characterization "Ellen" under "Sam's mother" in conjunction with the relational characterization "Sam's mother" under "Ellen". Semantic case relationships such as "New York was the location of the demonstration" and arithmetic relationships such as "5 is greater than 3" would be handled in an analogous way. This composite technique for representing relationships, which has been borrowed directly from English, offers at least two important advantages over the traditional logical formulation widely used as the basic connective link in semantic networks. First, specialization of the relation by one of its arguments produces a conceptual model for the relation; such a conceptual model serves as an effective framework for organizing knowledge of specialized uses of the relation. For example,

the conceptual model of "father" might be expected to include the senses "father of a person", "father of a country", "father of a science", and "father of a bride", each appropriately described. Second, whenever there are relationships that are identical except for their value arguments, the set of distinct value arguments will be automatically grouped as value characterizations under the shared relational characterization. Thus, if Mary has both a dog and a cat, they would both appear as value characterizations under "Mary's pets". We might also point out here that OWL does not represent reversible relationships canonically, e.g., "the elephant is bigger than the mouse" would be represented differently from "the mouse is smaller than the elephant"; humans also seem not to canonicalize such relationships.

A modifier is any descriptor not deemed to be a characterization of its subject. Typical modifiers are: "black" (property), "actual" (feature), "the" (determiner), "all" (quantifier), and "in the box" (location). Note that sometimes the dividing line between modifier subtypes is not sharp (e.g., between properties and features).

A descriptor that is often applied to a particular concept tends to become a specializer of that concept. For example, "fat man" is specialized by a modifier ("fat") and "father figure" by a characterization ("father"). A concept specialized by a descriptor is usually more specialized in meaning than if that descriptor was acting *only* as a descriptor; thus, not every black bird is a blackbird, nor is every round house a roundhouse.

An important transformation in OWL, again a reflection of a similar transformation in English, is the conceptualization of a description to produce a predication. (We use the term predication here in the classical sense of a predicate applied to, i.e., specialized by, some subject). A description (descriptor under some subject) is transformed into a predication as follows: first, the predicate is formed as a specialization of "being" (the copula) by the descriptor; then, that predicate is specialized by the descriptor's subject to give the predication. The reason for conceptualizing (making a concept out of) a description is so that the description can itself be described, specialized, or otherwise used as a concept. In linguistic terminology, both the process of conceptualization and the resulting predication would be referred to as nominalization. An example of a predication in English is the phrase "John's being happy", which we have already used above as an example of specialization.

#### The Structure of the Knowledge Base

All knowledge in an OWL-based system is held in a single, large, unified knowledge base of concepts and symbols, except for a rather small though important amount embedded in LISP and machine language programs and their associated data structures. This knowledge base is not structurally partitioned by subject matter, by permanence (long-term vs. "intermediate-term"), by type of concept (semantic vs. episodic, individual vs. generic), or by level of abstraction (surface language vs. primitive action, for example), although obviously such distinctions must often be

inferred by inspection of individual concepts. There is even no separate lexicon -- knowledge about English words and grammar is distributed throughout the knowledge base and is essential to its organization.

All of the following terms are virtual synonyms of knowledge base: world model, semantic network, Knowledge Net (a Merlin term), conceptual data base, conceptual memory, conceptual grammar, conceptual taxonomy, and concept tree. The terms conceptual taxonomy and concept tree do not encompass symbols, but then symbols play only a minor role in the knowledge base. Symbols correspond to English words and morphemes and contribute no more to the knowledge base than do the spellings of words to the content of a book. Essentially the entire body of knowledge is represented in terms of concepts.

When OWL structures are modeled in terms of L15P data structures, a concept is typically represented by a list of its constituent references, where the first two list elements are the generalizer and specializer, respectively. A symbol is represented by the atomic symbol whose "pname" shares its spelling, and the references under the symbol appear on a list carried as the value of a property of the atomic symbol.

#### Relation to Other Work

Various uses of specialization, especially for compounds, have long been recognized by grammarians. Bloomfield, for example, discusses how the meanings of various kinds of compounds depend on the meanings of their constituent parts, thereby illustrating many of the properties of specialization. (He also compares his classes of compounds to similar classes used by Sanskrit scholars over two thousand years ago). Jespersen saw the "specializing power" of a modifying phrase (one of the lower "rank"), noting that "the object serves to make the meaning of a verb more special". However, no one appears to have understood the universality of specialization as a means for identifying and classifying concepts expressible in natural language, even though binomial systems of nomenclature have been used to identify and classify biological species ever since Linnaeus introduced the first such system in 1753.

Conceptual taxonomies ("hierarchies of knowledge") are of classical origin. Raphael was perhaps the first person to consider using a conceptual taxonomy as part of a computer system interacting with a user in English. He rejected it, however, on pragmatic grounds, citing the complexity of the required structure and the difficulty of producing a "useful" taxonomy. During that same period, Quillian made a serious attempt to design a model suitable for a large semantic memory, but his organizing principles were too weak and his structure was connected in too ad hoc a fashion to be effective in dealing with knowledge on a large scale. There has only recently been a revival of interest in using large conceptual hierarchies, triggered primarily by disenchantment with the poor efficiency and non-intuitive functioning of systems using logic-based rules of inference. (Inheritance of properties, which is primarily what hierarchies are good for, is probably the simplest and most "natural" rule

of inference). However, the hierarchical structures proposed by Moore and Newell, Winograd, and Fahman permit concepts to belong to any number of classes, none of which is particularly favored, whereas in OWL each concept is considered to belong to only one class (its genus), though it may have any number of characterizations (each itself a distinct concept). The OWL use of hierarchy is superior if a genus can be readily chosen for each concept and if inheritance of properties along the generalization path of a concept is often sufficient for making low-level decision as to what to do with that concept.

To the best of my knowledge, the closest relative of the OWL formalism for conceptual knowledge is found in the Merlin system of Moore and Newell. As a prelude to making comparisons between these two formalisms, let us tabulate corresponding terms:

<u>OWL</u>	<u>Merlin</u>
knowledge base	Knowledge Net
conceptual taxonomy	hierarchy of knowledge
concept	p-structure
genus	schemata
description	component
characterization	alternate view

Note first that in Merlin there is no equivalent of specialization as an essential aspect of every concept in the knowledge base. Thus Merlin has no universal means of concept identification (aside from full specification of the schema and all components) and no fine structuring of the concept tree through derivative subclassification. (Actually, genus-specializer identification of concepts can be found among samples of Merlin structures, e.g., [EYES BLUE] and [TASK LOGIC], although other p-structures of a similar form, e.g., [AUTHOR NEWELL-SIMON-SHAW] and [+ 3], do not follow the same [genus specializer] paradigm, at least according to OWL's English-based criteria for what constitutes a specialization). Second, each alternate view of a p-structure can adequately represent it as a principal view, whereas a characterization of an OWL concept is an entirely separate concept that need be only a partial description and which could be the characterization of any number of other concepts. Mapping among alternative characterizations is not a fundamental operation in OWL as it is in Merlin. Thirdly, OWL represents essentially all knowledge as concepts in a single, unified knowledge base, whereas Merlin uses a separate formalism for expressing procedures (actions), which are, however, attached to and considered part of the Knowledge Net. Neither OWL nor Merlin makes a basic structural distinction between individuals and generics.

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