# EXTENDING THE EXPRESSIVE POWER OF SEMANTIC NETWORKS

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Abstract "Factual knowledge" used by natural language processing systems can be cos.vcn itr.t ly represented in the form of semantic networks. Compared to a "linear" representation such as that of the Predicate Calculus however, semantic networks presort rrecial problems with respect to the use of logical connectives, quantifiers, descriptions, and certain other constructions. Systematic solutions to these problems will be proposed, in the form of extensions to a more or less con vent iorial net work rotation. Predicate Calculus translations of network propositions will frcguently be gi vc n for comparison, to illustrate the close kinship of the two forms of representation.

## I. Intoduceion

Semantic networks (or nets) mean different things to different people. They are verjour.lv thought of as diagrams on paper, as abstract s^\t- of n-tuples of some sort, as data structures in. computers, or even as inioination structures :n brains. My concern here will be with semantic nets; as graphical enalogus of data sti uctuK ^. r,epreientirg "UrIr" in a computer system lor understanding natural language. They aid both :n the foraulaticn and exposition of the da*a structures they resemble. Examples of such graphical aids are found in the work of Ouillian (1968,1969), Palme (1971), Schank (1972,197?), Simmons 6 Bruce (1971), Anderson £ Bower (1973), Hendrix et al. (1973), Rumelhart et al. (1972), Mylopculos et al. (1973), and many other writers. Semantic nets are also used to advantage in the mechanization of other forms of understanding, particularly scene understanding, e.g., by fcxiisttn (1970), Gtwean (1971), and rirscheinε Fischler (1971).

The infernal and disparate ways ir which semantic nets have been used preclude their precise definiticn in a nonrestirtivr way. Howtvr, they have generally shared the icllowing characteristics:

Particular as well as genera 1 concepts are represented as labeled or unlabeled rodes of a graph.
Propositions consist of subgra phs with links. to a predicative concept and to a suitable number of conceptual arguments for the predicate. Explicit proposition nodes aie sometimes introduced as points of attachment for these links, and as units or: which prepositional operators (e.g., "knows that") can operate.

<3) Duplication of nodes denoting the same concept is avoided. Thus several arcs associated with several distinct propositions may rhare the sate concept node. Such nodes are usually regarded as corresponding to a unigue computer sto-rage location, i.e., the entry point for accessing knowledge about that concept. Similarly proposition nodes are regarded as unigue.

In comparison with Predicate Calculus encodings of factual kncwlfdge, semantic nets seem ore natural and understandable. This is due to the cne-to-one correspondence between ncdes and the concepts they denote, to the clustering about a particular node of propositions atout a particular thing, and to the visual immediacy of "interrelationships" among concepts, i.e., their connections via sequences of propositional links These properties of semantic nets aid in the design of comparison algorithms, such cs that of Ouillian (1968,1969) for finding intersecticn nodes for two related concepts, or that of Winston (1970) for comparing two complex scene descriptions. Certain kinds of deductive inference also appeer to be facilitated by the network representation (Sandewall, 1970).

(laving acknowledged some advantages of semantic nets over the Predicate Calculus representation, I should like to emphasize that I regard the two fcrms of representation as closely akin[1]. I will often supply predicate Calculus equivalents of network propositions in order to illustrate their near-isomorphism. Furthermore, semantic networks proposed so far have been expressively weaker than Predicate Calculus, particularly in their handling of quantification and of higher-order stateaents. In the following sections 2 will develop a network representation which permits the use of n-ary predicates (n = 1, 2, 3. ..), logical ccnnictivcs, uniestrictid quantification (including quantification over predicates), lambda abstraction, and norextensional operators such as belief and counterfactual implication. The representation easily accomodates propositions of the type encoded by Ouillian (1968,1969), wirrton (1970), Schank (1972), and Fumelhart et al. (1972) in thtir networks. Comparison with network representations used by these and other authors are made as far as space permits. Sec. II introduces the fasic propositional notation, and Secs. III-V progressively extend the power of the notatien.

## II. Atomic Prorositions

The basic node type in the notation to be developed is the concept node. Concept ncdes may denote individuals such as John, Canada, a particular chair, or a particular real number; they may denote sets such as a set of of children, a set of numbers, or a set of properties; or they may denote predicative concepts such as (the universal concept) chair, red, honest, virtue, larger than, in front of, between, or aives. Nodes may be labeled with names for the concepts they denote, e.g., Jchn, chair, chairl, chair2; ordinary attributive- terms such as "chair" are reserved for the co responding universal concepts, while numerically suffixed words such as "chairl" are used tor particular instances of the concepts.

The smallest unit of information in a semantic ret is the atomic proposition. An atomic proposition consists cf a proposition npde, a PRED link to a predicative node, and links to a suitarle number of concept nodes serving as arguments of th* predicate. The argument links are marked ia some systematic way, e.g.. A, B, C, etc., to distinguisn the first, second, third, etc., arguments. Examples are shown in Fig. 1(a)* (c), alcrg with their Predicate Calculus representations. All nodes in Fig. 1(a)-(c) are regarded as type nodes in Quillian's (1966) sense and correspond to unique storage location s. Note that the links in a proposition are directed from the fioposition node to the components of the proposition. The only significance of this convention is that it ensures nonambiguity of the

[1] Formal logical representations are often wrongly aligned for supposedly committing the designer to the application of syntactically oriented uniform inference procedures. This criticirn confuses the languege of logic with its calculus. Nothing whatever prevents the application os heuristic or plausible inference routines to Predicate Calculus assertions. Indeed, FLAtiKER-likc systems combine heuristic inference procedures with a restricted fora cf Predicate Calculus in the data base.

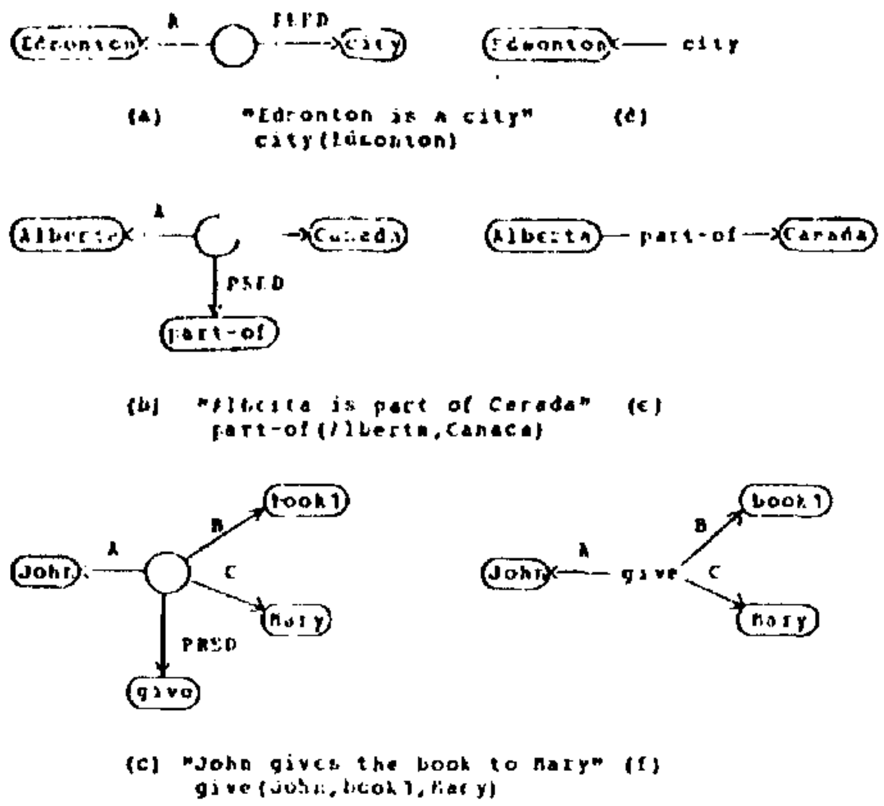


**Fig. 1. Atomic propositions, in full and abbreviated.**

network syntax. In a computer implementatien the links could be reversed or two-way, depending on computational needs.

The propositional diagrams may be simplified ar. fellows. Any explicit proposition node along with its link to the predicative node way be replaced by a predicate token. viz., the (noncircled) nane of the predicate. Since predicate tokens implicitly establish proposition nodes, separate tokens oust be used in separate propositions, even if the predicates involved ere the same. Another permissible simplification of the diagrams is the omissicn of link markers when the predicate is monadic (i.e., denotes a property) or dyadic (i.e., denotes a binary relation); in the dyadic case the first and second arguments are then distinguished by omitting the arrowhead on the link to the first argument. The simplified diagrams for the propositions in Fig. 1(a)-(c) are shown in Fig. 1(d)-(f). I will usually opt for the simplified notation in the sequel, except in diagramming certain higher-order constructions.

The proposed propositional notation is closely related to various extant notations. Fig 1 (e) is essentially in the style of Winston (1970), although Winston does not introduce proposition nodes as distinct from concept nodes. I regard Fig. 1(d) as the proper monadic analogue of the dyadic notation. Diagrams 1 (a)- (c) closely resemble the prepositional graphs of Rumelhart et al. (1972). Figs. 2 and 3 indicate how the present conventions relate to those of Quillian (1969) and Schank (1972) respectively. A fuller comparison with a discussion of "cases" can be found in Schubert (197«).

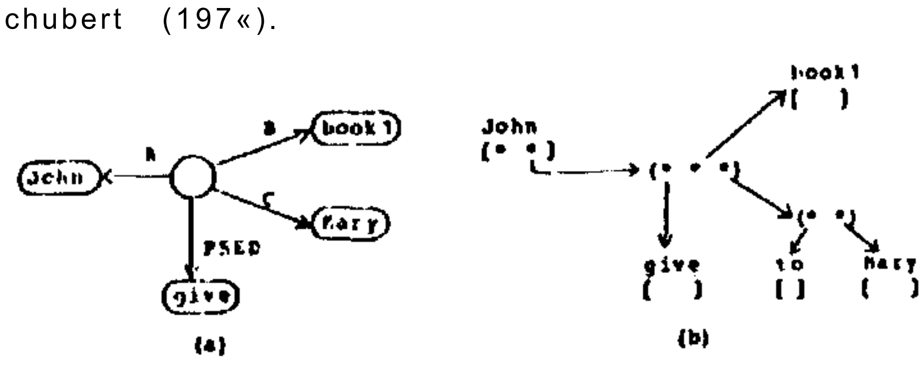


**Fig. 2. Compariscn with TLC notation "John gives the book to Mary"**

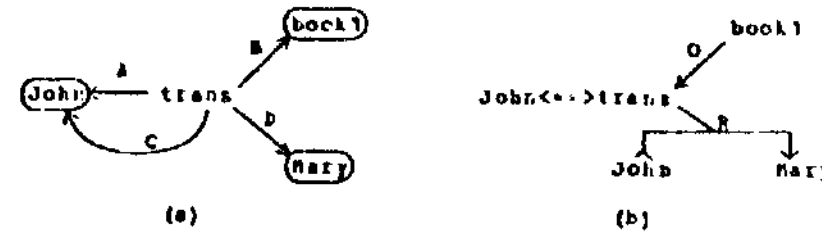


Fig. 3. Comparison with Schank's notation "John transfers the book froa John to Mary"

III. Logical Connectioes.

ID most varieties of semantic nets very little use is made of logical connectives. There is little need for conjunction, since usually all propositions in the net are assumed to be asserted, and of ccurse this is eguivelent to assertion cf their conjunction. That several researchers have chosen to do without disjunction as well is perhaps traceable to the fact that assertion cf "pvg" is in a sense only half as infcreative as assertion of any of the binary conjuncts which imply it (pεg, -pεg, *or* pε-g) , yet is just as bulky.

Nevertheless disjunction and other connectives are commonplace in ordinary discourse and in any case they are needed for truth-functional completeness. NOW everyone who uses semantic nets employs some sort of negation device and cf course negation together with conjunction *is* truth-functionally corplrte. The probler with most of the negation devices, however, is that they are applicable to atomic sentences only (e.g., putting "not" in front of a predicate, or crossing off a subject-predicate link); and negation of atoms together with conjunction is *not* truth-functionally complete. It is quite clear what the alternatives are. If we want to restrict negation to atoms, we need to introouce an additional logical connective (e.g., disjunction or implication). If we want to stay with negation and conjunction, we heve to extend the negation convention so that it is applicable to cor, June's, In either case we need to create graphical entities which correspond to composite sentences Composed of arbitrarily many atomic sentences. The obvious solution lies in the introduction of explicit nodes for logical compounds of prepositions (or open sentences), with graphical links to the components. Fig. 4 illustrates the formation of disjunctions by the use of graphical links to tokens of the disjunction operator. The net states "Mary is not at home; she is either at school, or en the playground, or at the zoo; if she is not at schcol, her mother will be angry". I

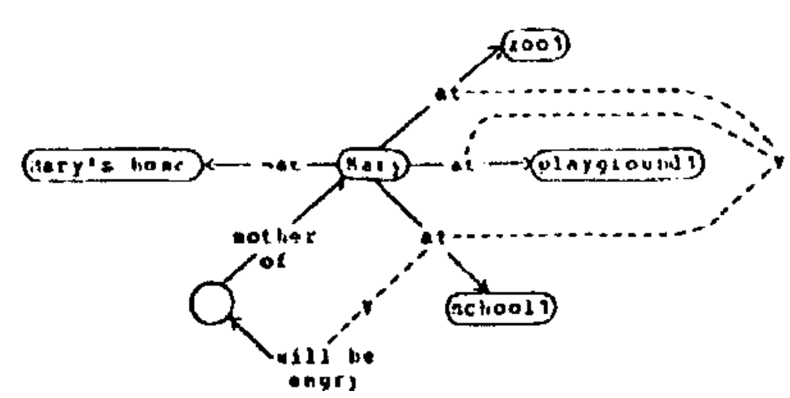


fig. *u.* "rtary is rot at hone; she is either at school, ox on the playground, or at th? zco; if she is rot et school, her nether will be angry."

will assume that the operator "V" takes cue or sore operands. Its general fort is shewn in Fig. 5.

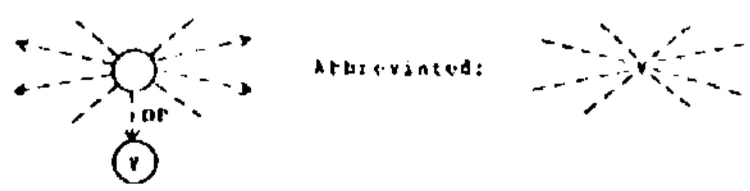



Fig. 5. Generalized disjunction.

Broken lines are used for the operator-operand links to make the logical compounds visually distinguishable. Note that no distinguishing markers are needed on the links, since disjunction is a symmetrical operation. The arrowheads can be dropped when there is no ambiguity, i.e., when the operands are not themselves logical compounds.

The use of "will be" in Fig. 4 as a modifier of "angry" is an evasive manoeuvre, serving to avoid discussion of time. Of course none of the predicates appearing illustratively in this paper are proposed as primitives in an understanding system. The "¬at" in Fig. 4 is an abbreviation for "¬ ---> at", which shows "¬" as a monadic operator on the place-holder "at" for the proposition "at(Mary, Mary's home)".

If desired, other logical connectives can be introduced in exactly the same way. For example, it would have been more natural to render "If Mary is not at school her mother will be angry" by means of implication instead of disjunction, even though this requires the use of an extra negation operator*. A generalized implication operator is shown in Fig. 6. This allows for a conjunct of

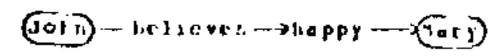

Fig. 6. Generalized material implication.

arbitrarily mary antecedents and a conjunct of arbitrarily many consequents. No labels are needed in the abbreviated rotation if consequent and antecedent links are shown emerging fort and aft of the implication symbol respectively. Equivalence is defined analogously (symbol <=>), allowing arbitrary sets of conjuncts to be eguivalenc«d.

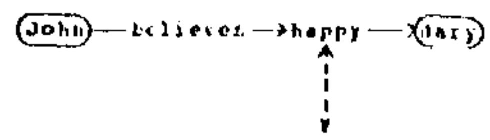
For a semantic net containing logical compounds, we must revise the usual convent ion of regarding all propositions in the net as asserted. The convention I will adopt is that the complete **semantic net <u>asserts exactly those propositions which are not constituents of compound propositions</u> (i.e., operands of connectives or** modal operators). Graphically this meanns that exactly those propositions are asserted which are not pcinted to. Tus in Fig. 4, for example, "Mary is not at hone" end "mary is at school or her mother will be angry" art asserted whereas "mary is at the zoo" and "Nary is at school" aic not. This raises the questicn of how to assert a proposition which is also a constituent of a compound proposition. First, for logical compounds this need never occur. Tor example, *if* a constituent p of a disjunction pVgVr is knewn to be assertable, then that entire disjunction can be replaced by the proposition p and the alternativer. qVr deleted. The reason is that pMpVqVr) <=> p- Simildr simplifications result if a constituent of 5n_y logical compound is asserted. For propositional attitudes, causes, intentions end the like, however, we may indeed want to assert a constituent independently of the compound. In this case we can use d is junction with a single operand,

V --> p ,

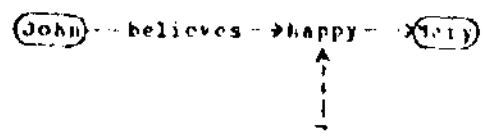
as a way of saying "p Isolds". Since the "compound" proposition established by the token V is not pointed to, it is automatically asserted. Alternatively we could use conjunction of a single proposition (with an explicit *"ε")* or even double negaticn to the sane effect. Examples are shown in Fig. 7. The "beliefs" diagrammed in this figure



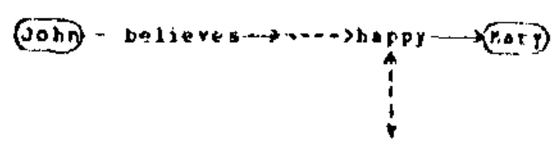

(a) "John believes that Mary is happy"




(b) "John believes that Mary is happy and she is"




(c) "John believes that Mary is happy but she isn't"




(d) "John believes that Mary isn't happy but she is"

Fig. 7. Asserting propositions by means of monadic disjunction

are examples cf "propositional attitudes"; they are governed by modal operators about which 1 will have a little more to say in Sec. V.

? will conclude this section with some remarks on existing notations. Quillian (1968) used a "hopping arrow" to conjoin or disjoin sets of propositions. However, any such arrow was associated with a particular <u>suhject</u>, and as one of the disjunctions in Fig. 4 illustrates, disjoiicd proposition* ne-?d not have any subject (or object) in common. Winston (1 3 7 0) re s-trictt d himself tc implicit conjunction plus negation of atoms, although he obtained some of the effect of disjuncticn by means of a "may-be" operator. Rumelhart et al. (1972) state that they allow arbitrary compound propositions in the internal representetion, but in their graphical notation they allow enly chaining together of propositions making up an "episode". Schank (197 2,1973) makes little attempt to deal graphically with logically connected propositions, as he is usually not concerned with displaying more than 2 or 3 related propositiors. He uses negation of atomic propositions and places connectives in the spaces between prepositional subgraphs ("conceptualizations") to indicate their logical relations. Andersen 5 Bower (1973) could easily have introduced unrestricted binary connectives since they use explicit proposition nodes, but it is net clear to me whether or not they did. They discurs disjunction only in connection with checking the semantic net for the presence of either of two propositions, rather than inserting explicit disjunctions. As for implication, it appears that they regard their particular manner of using subset relations as giving the full power of implication. All of their examples, hewever, involve atcmic antecedents, and it is not cbvious how a sentence like "The customs official detained all bearded men who were wearing beads" would be

* I am taking a rather literal interpretation of the sentence, ignoring the implicit causal proposit ion.

represented, in which "man", "bearded", and "wearing Leads" are implicative antecedentr. Note that the given sentence must be distinguished from both "A nu0mber of bearded men wearing beads were detained by the custcms official" and "All of those detained by the customs official were bearded men wearing beads".

## IV. Quantifiers

It is important to have logical quantifiers within semantic net notation for several reasons: many statements of ordinary discourse involve quantifiers ("He called every day but the phone was always busy") ; the representation of qeneraj. knowledge in declarative form requires quantifiers ("All children like sweets"); the definition of complex concepts requires quantifiers ("At all times when an individual is walking some fcot of that individual *xs* touching the ground..."); and definite descriptions of sets require quantifiers ("the people of Canada") .

Yet the treatment of quantifiers in semantic-nets has generally been rether cursory. Often quantifiers ar regarded as monadic modifiers of concept nodes, indicative of "how many there are" of that item (i.e., set cardinality). Universal quantifiers are then attached in the same way, even though the logica! operator A ("for all") is not at all indicative of cardinality. The only systematic attempts to include quantifiers in semantic rots of which I am aware are those of Palme (1971) and andercn ε Bower (1973) . Feline's symbolism is based on Ssrdewall's (1970) aralysis of proocrty-^tructures. In. that approach quantifiers are attached singly or in pairs to predicates, e.g., to syrbolize a tranrfcrmation from a binary relation R on individuals to a binary relation on sets ARA <=> lambda XY[ (Ax) (Ay) member (x,X) *C* member (y,Y) => P (x,y) ]. However, this doesn' t allow for 3 or more quantifiers in a proposition ("Any politician can fool some of the people all of the time") ■ Anderson ε Bower's treatment is not entirely satisfactory either. First, there is a difficulty about quantified implicative propositions with complex antecedents, which steins from the deficient implicative nctation. One way of characterizing the difficulty is that there is no apparent method for distinguishing definite and indefinite set descriptions, such as "the set of all degs that chase cats" versus "a set of dogs that chase cats", and hence no way of distinguishing statements involving such descriptions antecedently. Second, the rule that quantifiers in the subject position of the propositional tree have the largest scope leads to difficulties. In particular, it is awkward to raise a propositional object to the level of maximum scope, as Andersor. ε Bower are well aware. For example, they are forced to render "There is a cat that all dogs chase" as "There is a cat distinguished by the tact that all dogs chase it", where "distinguished by" is a pseudo-predicate introduced to allow objects to be raised to subject position. Additional problems are encountered in quantification over time, since in Anderson ε Bower's notation the "time context" includes an entire proposition in its scope. For example, there is no direct way to handle the distinction between "There is always someone there" and "There is scmeone who is always there". Finally Anderson ε Dower neglect to suppiy quantifier precedence rules when the scope of a quantifier extends over logical combinations of propositions, as it certainly may.

The notation I will propose is analogous to quantifier-free normal form in Predicate Calculus. Propositions are expressed in prenex form (i.e., quantifiers have maximum scope), existentially quantified variables are Skolemized, and universal quantification is implicit . This first cf all requires a distinction between existentially and univercally quantified nodes, A simple method is the use of sclid lines for txistfntially quantified concept nodes (as in all previous figures) , and broken lines for universally quantified nodes. Graphical Skolemization then consists of linking each existenti ally quantified node to all universally quantified nodes on which it depends (i.e., whose universal quantifiers precede the existential quantifier in prerex form). I shall use dotted lines for these dependency links for easy distinguishability from propositior.al and logical links, "or example, "All dogs chase some cat" is represented as shown in Fig, ε (a) . In Predicate Calculus notation this is

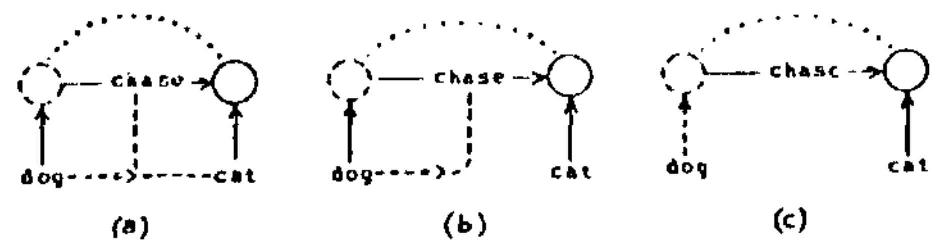



**Fig. 8. "All dogs chase some cat"**

(Ex) (dog (x) => (Ey)[cat(y) Echase(x,y) ]) ,
or dog(x) => [cat (f(x) ) echase (x f (x) ) ],
Skolemized. Now if we can assume (Ey)cat(y), i.e., there is at least one cat (or alternatively, that there is at least one dog), then this becomes
cat (f(x)) ε [dog(x) => cha se (x, f (x) ) ]
which corresponds to the slightly simpler diagram shown in Fig. 8(b). Here the "cat" proposition is no longer regarded as a consequent of the "dog" proposition. This type of simplification is often appropriate for encoding natural language statements, since we do not usually communicate in terms of propositions which are trivially true by virtue of the nonexistence of their referents[3]. . further simplification is indicated in Fig, 8(c), which is based or. the implicit notation for implication explained in Schubert (1974). The diagram for the proposition "There is a cat which all dogs chase" differs from Fig. 8 only in the absence of the dependency link between the "cat" and "dog" nodes. As another example consider the proposition "There is always someone there". This might be diagrammed as in Fig. 9(a), after adding the assumption that there is at least one moment of time. Note that a time argument has been added

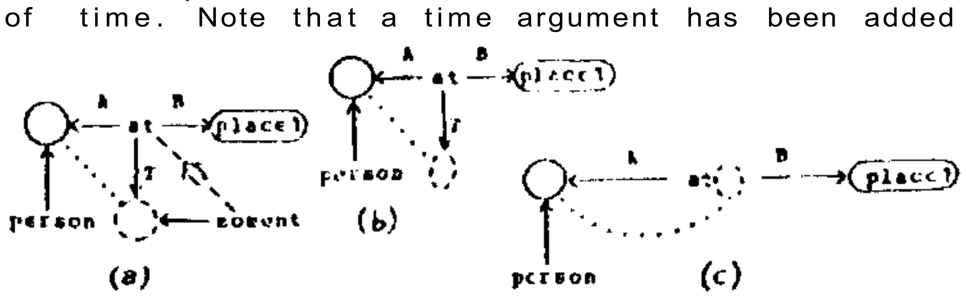



**Fig. 9. "There is always someone there"**

to the predicate "at". The representation reems a little ur.natural because of the reed to restrict the universally quantified node to "moments" and the implicative dependence of the main relationship en that restriction. This suggests that it would be more natural to use a many-sorted logic, with each argument of each predicate restricted to a particular subdomain of the domain of discourse, and with time forming a distinct sort. Then guantificaticn over a time argument would automatically be restricted to moments of time. This is the course *1* will take, at least nominally. Sortal distinctions could be made explicit by using distinct nods shapes lor distinct forts, or by using a distinct kind of argument marker on argument pointers to entities of each distinct sort, e.g., always using OBJi (i = 1,2,...) to point to arguments of the sort "physical object". In fact the latter techrique is used by Rumelhart et al. (1972) . Father than

[2] Which *is* not to say that we do not communicate about nonexistent entities.

commiting myself to a particuar method here, I shall leave sortal distinctions implicit, except in the case of tiee. Time calls for special treatment because of its central importance in structuring events. I will use pairs of parentheses instead of circles for moments of time and mark pointers to morcnts of tine "T". A name for a moment of time can be placed between the parentheses. Broken parentheses i ndicate universally quantified time variables. With these conventions Fig. 9(a) can be redrawn as shewn in Fig. 9(b). "There is sorreone who is always there" would merely lack the dependency link of Fig. 9. The representation of time dependence can be simplified further with the aid of two additional conventions. The first is to place the time at which a proposition hclds directly alongside the predicate token of that proposition, as in Fig. 9(c). The second is to use time intervals as time arguments (an some suitable sense of interval - e.g., see Bruce, 1972). If T is a tine interval, then a proposition of the form P(x,y,...,T) is taken as an abbreviation of (At)[member(t,T) => P(x, y ,,. . ,t) J. In the graphical notation I will use square trackets instead of parentheses for nodes denoting time intervals, and mark pointers (if any) to such nodes "71" instead of "T". Two equivalent ways of representing "The sun rose" are shown in Fig. 10. In both versions quantificaticr.

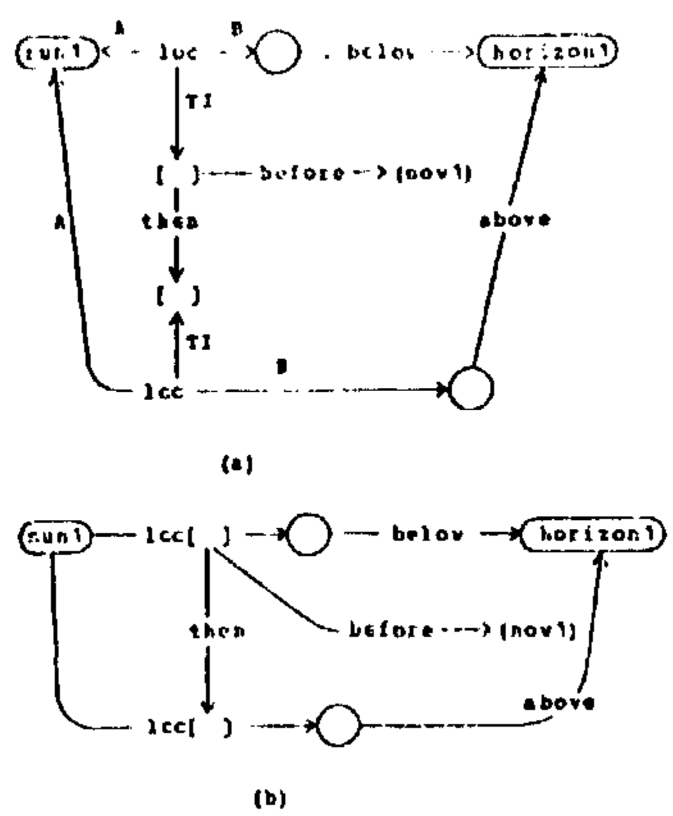



**Fig. 10. "The sun rose".**

over moments of time has been entirely suppressed by means of the interval notation. "Then" is taken as a relation between adjacent time intervals, and "before" as a relation between moments or intervals of time. For complete sets of time relations see Findler ε Chen (1971), Bruce (1972), or Schank et al. (1973) .

mary hiqher-order constructions are easily expressed with the notation already introduced. For example, "John has all of his father's faults, and ctreleesness is one of thea" is represented as shown in Fig. 11. Note that both the abbreviated and unabbreviated notaticn for propositions have been used here. Three of the proposition nodes ere explicit, while "father-of" and the two occurrences of "fault" establish three implicit proposition nodes. The higher-order predicate is of course "fault", and the universally quantified node should te read "for all predicates". Here the implicit restriction of quantification to appropriate sorts has been extended to apply to types as well, i.e., since "fault" is a predicate on predicates, its argument in any proposition is implicitly restricted to the type "predicate".

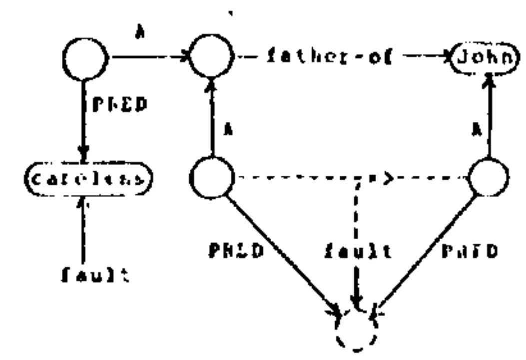



Fig. 11. "John has all of his father's faults, and carelessness is one of them"

Here I shculd renark that past claims about the equivalence of certain varieties of remantic net notation to second (or higher) order logic have not been tacked by adequate quantificationa1 apparatus. Statements about predicates alone do not demonstrate a seccr.d-order capability, as they can be made in a many-sorted first-order logic.

Finally I should point out that the logical quantifiers are unsuited for expressing many natural language quantifiers. I believe that natural language quantifiers not readily expressible in terms of the logical quantifiers, such as "several", "many", "most of", "a few more than", etc., can te handled systematically by the use of (fuzzy) properties of set cardinality and relations between set cardinalities, plus standard set relations such as set inclusion. For examples see Schubert (1974) and Cercone ε Schubert (1974).

## V. Further Fxtensions

In this section I will briefly illustrate the representation of definite and indefinite descriptions, lambda expressions, and modal constructions. A fuller exposition is given elsawhere (Schubert, 1974) .

Russellian descriptions of individuals and sets are illustrated in Figs. 12 and 13 respectively (e.g., Quine, 1960). The descriptions

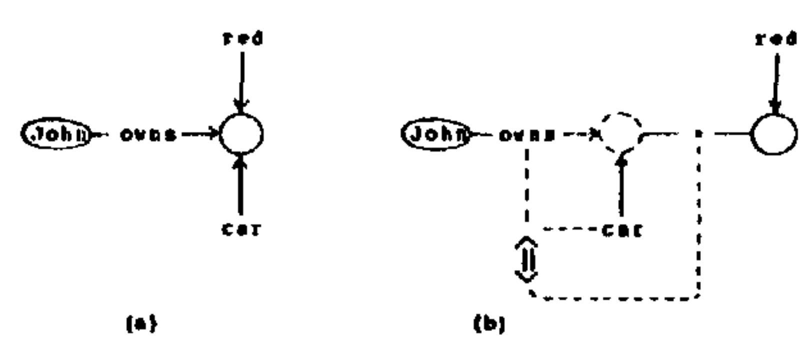



**Fig. 12. Indefinite and definite descriptions**
**(a) "Jchn owns a red car"**
**(Ex)[cwns(John,x) & car(x) & red(x)]**
**(b) "John's car is red"**
**(Ex)(Ay)[owns(Jchn,y)&car(y) <=> x=y] & red(x)**

are underlined in the figure legends, and Predicate Calculus translations are given for comparison. A rongeneral but frequently useful aethod cf abbreviating such descriptions is proposed in Schubert (1974).

In diagramming Russellian descriptions, I am not doing so as an uncritical advocate of Russell's theory. Certainly it is incorrect to regard referential descriptions as nothing but disguised assertions (see Strawson, 1950). The role I envisage for Russellian descriptions in a semantic net-based language understanding system is best seen by example. Suppose that the language understanding system is told "John's car is red". The systea would first look for an existing node to use as referent of "John's car". We need not be concerned with the details of this search here, noting only that if it succeeds, no new

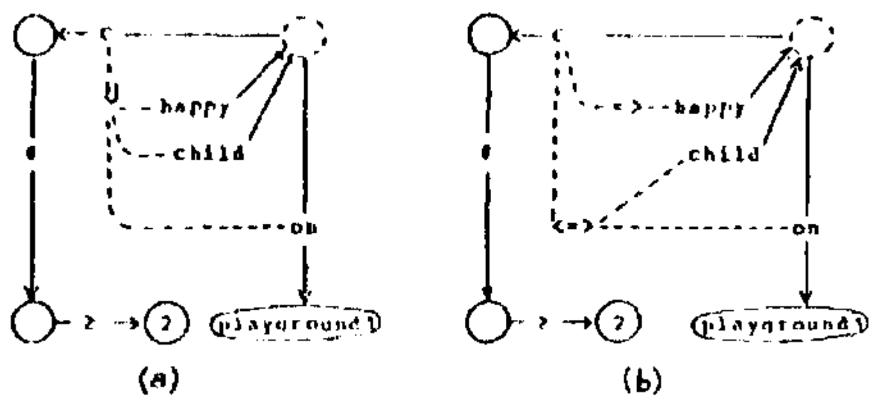



Fig. 13. Indefinite and definite descriptions of sets.
(a) "There are happy children on the playground" (ES) (#S≥2 & (Ax)[member(x,S) => happy(x) & child(x) & on(x,playground1)])
(b) "The children on the playground are happy" (ES) (#S≥2 & (Ax)[member(x,S) <=> child(x) & on(x,playground1)] & [member(x,S) => happy(x)])

description is placed in memory. Only "led" is predicated about the node found (provided this predication is consistent with prior knowledge). If the search fails, however, the system creates a new existentially quantified node with the attached proposition that this is the one and only car John has, possibly in a sense of "has" determined by context. This Pussellian existence assertion is placed in memory, provided it is consistent with prior knowledge. If all goef: well, the net of Fig. 12(b) is the final result. But suppose that the existence assertion contradicts prior information to the effect that John has no car. Then the attempt to insert a new rode in memory is aborted, and thus no referent fcr the predication *"is* red" is made available. Seeking a resolution of the difficulty encountered, the system might well respond "Cut I thought John doesn't have a car". Thus 1 see "presupposition failure" as an operational phenouenon, rather than as a logical phencnenon calling for complex model-theoretic Bianoeuvei ing (e.g., risk, 1969).

Ihe problem raided by lambda abstraction and medal operators such as "nccassar i1y", "knows", •'want i", and "causes" is that statements involving thoo cannot in *qenttel* be converted to prerex form. *Ihus* the scope conventions introduced for quantifiers are inadequate. ThP convertions can be generalized by allowing (dotted) scope dependency links between proposition nodes and quantified nodes, to indicate that the quantifiers lie within the scopes of the ope rotors which form those propositions. The new links supplement the dotted links already introduced to indicate the relative scopes of quantifiers. Two examples are given in fig* 14. The lambda pointer in Fig. 14(a) from the

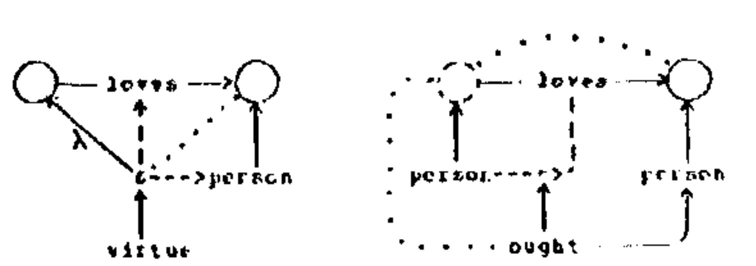



Fig. 14. Lambda abstraction and modal operators.
(a) "Loving someone is a virtue" virtue(lambda x[(Ey)person(y)&loves(x,y)])
(b) "Everyone ought to love someone" ought[(Ax)(Ey)person(y)&[person(x) => loves(x,y)]]

conjunctive proposition node to the first argumen* of "loves" abstracts the predicate "loving someone" fro» the open sentence "x loves someone". The operands of the modal operator "ought" in Fig. 14(b) are regarded as implicitly conjoined. Deletion of some of the scope dependency lir.ks m, the two diagrams yields other (less plausible) readings of the sentences.

## VI. ££li£i.a£il!.SLJ&£5i£rKE

I have put forward seme views on the proper construction and interpretation of semantic networks, and suggested systematic methods tor expressing operations such as logical combination and quantification in these networks. The proposed repre mentation is a fairly direct extension of several quite successful, superficially disparate representations, such as SchaDk's conceptualizations, Winston's descriptive nets, and Sandewall*s property-structures. Consequently the computational procures that create end utili2e their data structures can readily be adapted to structures bas»d on the present representation. This indicates that the increased expressive power the suggested representation proviaes should be of real value ir. the design of underttandir.q systems.

A variety cf problems in the representation of knowledge could raise additional guestiens of notational adequacy. Examples are the handlinq of vagueness, events, the lexical meanings of complex concepts, and overal1 knowledge orgar.izaticn. we are currently studying sone of these problems in the ccntext of a practical attempt to design a language understanding system.

This work was intended to establish a notational basis for research on a "state-based" conceptual representation by Nick Cercore and myself. A great deal of credit goes to Nick for contributing to the ideas herein. I am indebted to G. Prideaux, C. G. Morgan and F, *J.* Pelletier for pointing me to some relevant literature, and to the latter two fcr several very helpful discussions. I am also grateful for J. R. Sampson's and K. V. Wilson's comments- on *he original manuscript, which hopefully have led to a ▪ore readable version. The research was supported by the National Research Council of Canada under Operating Grant no. ABBie.

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