Two approaches to the study of diagnostic thinking are compared, one mainly propositional, namely that of Patel and Groen (1986), the other mainly semantic, that of Lemieux and Bordage (1986). Patel and Groen analyzed the linear dimension of cardiologists' discourses while solving a case of acute bacterial endocarditis, that is, the before and after propositional rules. A secondary analysis of two of their pathophysiological protocols is done using structural semantic techniques from Lemieux and Bordage where the vertical dimension of the discourses is analyzed, that is, the levels of meaning or semantic axes. Contrary to Patel and Groen's position, making an accurate diagnosis is not explained in terms of pure forward reasoning through networks of causal rules, but by means of networks of semantic qualities abstracted from the symptoms and signs. The semantic qualities operate in the clinician's mind in terms of binary oppositions (e.g., sudden-gradual, unilateral-bilateral) whereby each pair of properties constitutes a semantic axis (e.g., sudden-gradual). The successful diagnosticians are those who use the most diversified and pertinent set of semantic axes and, therefore, have a deeper representation of the problem.

One of the major tasks of medical education is to identify the characteristics of "good" and "not-so-good" diagnosticians. Although research in this area has been very active and productive (for summaries, see Elstein & Bordage, 1988; Feltovich & Patel, 1984), medical education has only just recently investigated the structure of clinical reasoning (e.g., Lemieux & Bordage, 1986; Patel & Groen, 1986). The work of Patel and colleagues is aimed at unraveling the relational rules contained in diagnostic reasoning by using propositional analysis and production systems (Groen & Coughlin, 1986; Patel & Frederikson, 1984; Patel, Groen, & Frederikson, 1986; Patel, Groen, & Scott, 1988). Lemieux and Bordage (1986) also investigated the relational rules of diagnostic thinking by using a different approach, namely, structural semantics. The goal of this article is to reanalyze some of Patel and Groen's (1986) data using a structural semantic...
approach. The article first contains a description of the theory, methods, and results from Patel and Groen's (1986) and Lemieux and Bordage's (1986) studies. Patel and Groen's methodology is then critiqued according to a structural semantic perspective followed by a structural interpretation of two of their pathophysiology protocols. The purpose of this secondary analysis is to highlight semantic processes that were left unexplored by Patel and Groen and, up to now, not very well known to researchers interested in medical diagnostic thinking or cognition in general.

1. PROPOSITIONAL ANALYSIS OF DIAGNOSTIC THINKING

Patel and Groen (1986) used propositional analysis methods to analyze the protocols of seven cardiologists as they solved a case of acute bacterial endocarditis. They used a text description of the case with all the desired data present. Each subject read the case (2.5 min) and was then asked to "write down as much of the text as he/she remembered" (p. 97); this constitutes the recall protocol. Following this, the subject was asked to describe, in writing, the underlying pathophysiology of the case, the pathophysiology protocol, "without reference to either the text or the previous recall response" (p. 97). Finally, each subject was asked to provide a diagnosis. Patel and Groen noted, however, that all the subjects listed their diagnosis during the pathophysiology response (p. 97).

Propositional analysis, as used in Patel and Groen (1986), embodies the notion of causal networks contained in each discourse. A causal network "can be viewed as a network of if-then rules or productions" (p. 95), as one would find in studies of expert systems. Propositional methods are used to analyze how successions of words are grouped into segments or "propositions," some of which are leading and others subordinate. The links between propositions were viewed as "antecedent–subsequent" relationships. The type of narrative structure analyzed corresponds to the linear, temporal, before and after distribution of the elements in the discourses. By combining propositional analysis and expert system methods, Patel and Groen's goal was to elucidate how the causal production rules distribute themselves linearly within propositional "chunks" (i.e., the text-based knowledge as expressed in the pathophysiology protocol), as well as the precise moment the specific diagnosis of acute endocarditis appears. Each subject's relational organization was described through the use of a coding system from traditional grammar (e.g., attributes, objects). They considered the relational organizations as semantic structures even though their analysis was "more concerned with problem solving than comprehension" (pp. 93–94). They also wanted to verify a possible correspondence between the relational structure of the case text and the structure of the pathophysiology protocol.

Their general conclusion is that the four cardiologists who correctly diagnosed the case used a "bottom-up and pure-forward" reasoning; that
is, they began their response with the text-based knowledge and went through a network of causal rules in a forward direction toward the diagnosis: “All of these rules are in a forward direction toward the diagnosis. There is no instance of backtracking” (p. 105). Conversely, the three subjects who did not correctly diagnose the case used a “top-down, backward” reasoning or “a mixture of forward and backward reasoning, beginning with a high level hypothesis and proceeding in a top-down fashion to the propositions embedded in stimulus text” (p. 91). The choice of relevant and irrelevant propositions was also used to differentiate the two groups of subjects; the accurate diagnosticians selected more relevant propositions (p. 105).

2. STRUCTURAL SEMANTIC ANALYSIS OF DIAGNOSTIC THINKING

Lemieux and Bordage (1986) analyzed the semantic structure of 2nd-year medical students and neurologists as they solved a neurological paper case of numbness while thinking aloud. The final diagnosis was a cervical arthrosis causing both a myelopathy (i.e., a spinal cord injury) and bilateral radiculopathies (i.e., a nerve root injury). The protocols were transcribed and coded using conceptual and methodological tools derived from structural semantics. Nine students and five neurologists solved the case. The students all attended problem-based, small-group sessions in neurology at the Université Laval in Québec City and were classified by their tutor as either very strong (n = 5) or very weak (n = 4) in their ability to solve clinical problems. The goal of the study was to analyze and compare the cognitive strategies of the subjects in order to describe their semantic competence as expressed in their clinical discourses.

Lemieux and Bordage presented the clinical information in successive segments. The case contained 36 segments, each containing a number of related symptoms or signs such as: There is an atrophy of the intrinsic muscles of the right hand with weakness of the abduction of the fingers. This segment contains three sets of clinical cues: “atrophy of the intrinsic muscles,” “right hand,” and “weakness of the abduction of the fingers.” The stimuli were also organized according to a fixed order of presentation going from the chief complaint to the history, the physical findings, and ending with the ancillary investigation. The information provided was sufficient to make a precise diagnosis.

The object of structural semantics is to study the systems of meaning contained in discourses such as those of physicians diagnosing a case. Structural semantics, as issued from modern linguistics (Greimas, 1983) and semiotics (Eco, 1984), views language along two dimensions: linear and vertical (Ducrot & Todorov, 1979, pp. 108–111). The linear dimension corresponds to the syntactic, before and after, order of terms. (Although Patel & Groen did not explicitly define their type of linear organization of the
propositional segments as the "syntactic aspect" of the discourses, one would do so from a structural semantic perspective; Ducrot & Todorov, 1979.) The vertical dimension of language corresponds to the underlying semantic structures that allow a subject to organize the meaning contained in factual information into multiple levels of signification called "semantic axes." The semantic axes represent logical levels of abstractions. The abstraction procedure is considered as a schematization mechanism of meaning. The levels of abstraction correspond to the deep structures of language, as opposed to the superficial structures assigned by most linguists to the linear dimension of discourses (for a review, see Ducrot & Todorov, 1979, pp. 235–247). In order to derive an abstract concept from empirical medical information, the clinician associates the information with a qualitative semantic property (e.g., sudden), which is organized in his or her mind in opposition to its counterpart (e.g., gradual). The two polar terms constitute a specific semantic axis (i.e., sudden–gradual). The two main cognitive functions of semantic axes are to classify meaning in terms of binary oppositions and to organize the diagnoses according to each polar term (e.g., to evoke disorders that occur suddenly as opposed to those that are gradual). Thus, the binary oppositions can be used to discriminate between pertinent and nonpertinent diagnoses (e.g., if a case implies a sudden onset, the disorders associated with a gradual progression will be considered less pertinent or nonpertinent).

The process of abstraction is present throughout the resolution of a clinical case and the configuration of the various semantic properties evoked by a clinician constitutes the relational rules applied to his or her deep semantic networks. It is thus possible to recognize the vertical pathway used by a clinician going from one semantic axis to another by noting the abstract terms expressed while solving a case. Methodologically then, the depth of the representation of a problem can be measured. To say that one's thinking is "deep" is not just a figure of speech; it means that the clinician views a case according to multiple semantic axes (see Figure 1).

The process of associating symptoms or signs with abstract properties corresponds, in structural semantics, to the "form" of the contents. Any content, such as symptoms and signs, is divided into two structural semantic levels: the elementary level of its substance, the "substance" of the contents, and the deep level associated with the abstract properties evoked, the "form" of the contents. For example, the expression, "atrophy of the intrinsic muscles," constitutes a clinical sign whose elementary meaning (substance) corresponds to a "reduced volume of the muscles of the hand." At a deeper formal level (form of the contents), the same expression can be viewed along a specific semantic axis, for example, "motor-sensitive." A second expression, whose elementary meaning is different from the first, for example, "weakness of the abduction of the fingers," can also be associated from
...There is a motor and sensitive problem on the right and on the left
however more so on the right. I think that the causes of a local compression
can be eliminated even though it is asymmetrical. I can't see how a local
cause like a brachial plexus involvement, a Pancoast tumor, can be present
on both sides. I'm looking for a problem that could affect both sides like a
syringomyelia or for a more general neurological problem such as a poly-
neuritis that could begin asymmetrically. Now I'm thinking of a myelopathy at
C7-8-T1, maybe caused by a cervical arthrosis that would be bilateral yet more
pronounced on the right than the left. (Excerpt from subject T's response to
segment 21.)

QP34: (a) motor and (b) sensitive
QP46: (a) right and (b) left
QP30: (b) more so
QP50: (b) asymmetrical

Figure 1. Example of a vertical (deep) semantic structure with its semantic axes (QP) and
diagnoses (H).

a formal perspective to the same abstract property, namely, a “motor”
deficiency. These two different clinical signs both share the same formal
meaning, that is, the analogous relationship of motor. On the other hand,
these signs are formally distinct, from the perspective of this axis, from all
the other clinical signs that could be associated with the inverse “sensitive”
quality (e.g., “reduced sensation in the 4th and 5th fingers”). Furthermore,
the two expressions associated with a motor deficit (“atrophy of the in-
trinsic muscles” and “weakness of the abduction of the fingers”) can evoke
yet new formal properties, namely “peripheral” lesions (and not “central”)
and “focal” lesions (and not “diffuse”). The expressions are multidimen-
sional and can convey various formal properties. When considered in
association with the “right hand,” the three expressions can further evoke a
“unilateral” (and not “bilateral”) property, and so on.

Thus, the theory of the form of the contents in structural semantics is
essentially a theory of abstract relationships. The deep meaning of a symptom
or a sign is never totally understood alone but in relation to its semantic position within a set of symptoms and signs. The previous example illustrates, on the one hand, how a group of symptoms or signs (e.g., atrophy and weakness) sharing a common abstract property (e.g., motor) are structurally similar. Thus, the sequential presentation of symptoms and signs is converted into sets of semantic properties corresponding to the depth of the semantic field used by the clinician to diagnose a case. On the other hand, the mechanism by which a formal quality is thought in opposition with its polar term corresponds to the mental process of semantic differentiation. This allows the clinician to compare symptoms or signs and to contrast diagnoses according to precise angles. An opposite qualitative term is not necessarily expressed each time a formal quality is evoked. The use of both polar terms depends on the nature of the problem and the discriminating value of the opposition in each case.

The coding system used to analyze the clinicians' discourses followed well-established methods in semiotics (Ducrot & Todorov, 1979; Eco, 1979, 1984; Staiano, 1986) and modern linguistics (Greimas, 1983); a detailed description of the coding system can be found in Lemieux and Bordage (1986). In semiotics, the specific nature of the discourses or any other type of contents analyzed is always taken into consideration and is viewed as a distinct cognitive genre (e.g., Carlson's analysis of theater, 1990; Metz's analysis of cinema, 1971; Nespoulous, Perron, & Lecours' analysis of gestures, 1986; Propp's analysis of fairy tales). (Nonverbal contents such as visual, kinesthetic, or tactile perceptions are studied through a special branch of semiotics called semiology; Saint-Martin, 1990.) The coding system, as applied to medical diagnosis, refers to three components of the physician's discourses: the constituent units, that is, the clinical symptoms (e.g., numbness = S3), signs (e.g., atrophy of the intrinsic muscles = G16), and ancillary findings (e.g., radiograph showing decreased intervertebral spaces at C6-C7-T1 = G51), the morphological units and the mental operations that make up diagnostic competence. The morphological units refer to a specifically medical, or in the present case, neurological grammar. The notion of "morphology" refers to the narrative components of the contents. Thus, instead of considering some elements as simple "attributes or objects," as would be the case in a traditional grammar (like the one used by Patel and Groen, 1986), the elements are considered as specific components of a medical grammar (e.g., "age" as a delimiting factor rather than a simple attribute; "spine" as an organ rather than an object). The simple use of a symptom or a sign in a clinical discourse is first recognized as the inclusion of a constituent (syntactic) unit (coded S or G) to which can be added a number of possible morphological functions (e.g., predisposing factor: S2 + D).

The coding system also contains the various mental operations associated with five categories of competence analyzed in the discourses, namely:
1. **Definitional competence**: Substance and form of the contents (e.g., "The numbness is bilateral": S3 + QP42b) and effect of the contents (e.g., "The numbness affects the upper limb": S3 + F + S4).

2. **Classificatory competence**: Pathophysiological taxonomy (e.g., "It's a degenerative disorder": CP7).

3. **Hierarchical competence**: Importance of an element (e.g., "That is not what I would consider first": >).

4. **Associative competence**: Linearity; analogy, difference, equivalence, and compatibility relationships (e.g., re analogy, "A peripheral problem just like in a radicular lesion": QP38a = Y + V4).

5. **Generative competence**: Inclusion or exclusion of a diagnosis (e.g., "It looks like an Alzheimer's" $H2); causal relationships and logical deductions.

One of the definitional elements in the coding system is central to the structural analysis of the discourses, namely, recognizing the form of the contents coded as "QP." The QP combination constitutes a specific entity that simultaneously embodies the recognition of the elementary meaning (Q) and formal semantic property (P) of a sign or symptom. Each pair of QPs constitutes a bipolar semantic axis (e.g., QP42: unilateral–bilateral or QP36: local–general). All the QPs expressed by the subjects were numbered and each pole of the axis identified by a and b (e.g., asymmetrical: QP50a-asymmetrical: QP50b). It thus becomes possible to analyze the nature and the number of semantic axes explored by each clinician as well as the number of times each element of an axis is mentioned (i.e., a and b). The network of QPs for each subject corresponds to his or her deep semantic structure.

The definitional competence also contains strategies to evoke the "effect" of a symptom or a sign on the body as opposed to its substance or form. It will be argued later that Patel and Groen's analysis is closer to this functional dimension of the definitional competence, that is, what symptoms and signs do (coded F; e.g., "The infection produces a fever": CP3 + F) than those of Lemieux and Bordage, which also include the semantic meaning of the contents, that is, what symptoms and signs are (coded QP; e.g., "He had a low-grade, intermittent fever": S + QP32a + QP37b).

Lemieux and Bordage (1986) concluded that the subjects who adequately solved the case are those who evoked the greatest number of distinct semantic axes and who organized the symptoms and signs into a pertinent system of relationships of abstract semantic properties. The successful diagnosticians, either students or specialists, are those who evoked the most diversified set of abstract relationships (semantic axes) and, therefore, who have a broader, deeper, and more pertinent semantic representation of the problem. (These results were confirmed with the analysis of three additional neurological cases solved by the same subjects; Bordage & Lemieux, 1991.) Structural similarities between the novices (2nd-year medical students) and the experts
(neurologists) who successfully solved the cases were thus identified. Furthermore, it was possible to differentiate different modalities of mental processing within the group of novices. Beyond Feltovich's (1981) characterization of the knowledge base of novice physicians as both “sparse and imprecise,” the use of structural semantics revealed five types of discourse organization, the latter four of which are found among novices:

1. **Full economy**: reduced syntax and semantic richness (e.g., the neurologists).
2. **Empty economy**: syntactic and semantic poorness (e.g., weak students).
3. **Empty dispersion**: syntactic display with no sound semantic basis (e.g., weak yet verbose students).
4. **Full dispersion**: redundant syntax and semantic richness (e.g., strong students and some specialists).
5. **Intermediate**: using alternatively full and empty dispersion forms within a case.

Thus, the novices who missed the case did so for different reasons: Some did not think enough (i.e., the inertia of the empty economy where the symptoms and signs are not well defined and few diagnoses are considered), whereas others thought wrongly using a verbose, nonstructured encyclopedic vocabulary (i.e., empty dispersion). The empty dispersion form is characterized by subjects who generate multiple diagnoses as the symptoms and signs come and go, thus resulting in lists of unrelated and unexplored diagnoses with no global representation of the case. The discourses are empty because they contain very few semantic axes. On the other hand, the full form (many semantic axes) is a characteristic of the students and neurologists who solved the case; their syntax may be concise (full economy) or repetitious (full dispersion), but their semantic axes are all varied and precise. In the full dispersion form the diagnoses are extensive whereas in full economy, they are limited; in both cases the diagnoses are adequate. Repetitions that are not semantically erroneous cannot be viewed as strictly imprecise, but simply as an indication of sparseness.

The successful diagnosticians have a common formal competence, that is, they adequately transform the elementary meaning of the medical contents into deep semantic networks. Their knowledge is not only an extensive collection of discrete information, but is organized (schematized) according to a diverse set of semantic axes that constitute multiple perspectives from which to tackle a clinical problem and to generate pertinent diagnoses. This highlights the important role that the deep abstract relationships play in understanding a medical problem and in generating and eliminating diagnostic interpretations. To think in terms of opposing properties is a widely described process in anthropology (Lévi-Strauss, 1958, 1962) and in many disciplines concerned with problems of meaning (e.g., sociology, Baudrillard,
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1978; architecture, Bourdieu, 1970; communication, Eco, 1972); its uniqueness in clinical medicine is to use the properties to evoke diagnoses. Although certain properties are clearly and uniquely binary (e.g., motor-sensitive), others may have continuous values (e.g., low, medium, high). However, the intermediate values (e.g., medium) can only be interpreted in relation to the two polar terms that define the semantic axis (e.g., low-high).

3. DIFFERENCES IN METHODOLOGIES

Patel and Groen’s (1986) methods to analyze the recall and pathophysiological protocols will be further presented and critiqued according to a structural semantic perspective.

Recall Protocol
Patel and Groen numbered each segment of each sentence in the case description using Winograd’s (1972) system of major and adjunct clauses, for example, “urinalysis showed numerous red cells,” (p. 98) a major declarative clause (i.e., Segment 1), and “but there were no red cell casts.” (p. 98) a bound adjunct (i.e., Segment 2). The words contained in each segment were numbered using a decimal system (e.g., urinalysis: 1.0; showed: 1.1). The connections between propositions are called “linking propositions” (p. 98) and are used to define rules. The case contains 10 linking propositions, 8 of which are causal relationships (“cause refers to some statement regarding the functioning of the underlying pathophysiology,” p. 98), one an equivalence relationship, and another a temporal relationship (p. 98). Thus, the analysis of the recall protocols yields information on the number of propositions recalled by each subject and any changes in the linear order of the proposition in the clinicians’ discourses in relation to the description text.

The grammatical functions of each word were coded from a linguistic point of view and not from a specifically medical one (e.g., “red” and “acute” are attributes; “prostration” is an action). This domain-free coding system was used by Patel and Groen to increase the generalizability of a model “designed to apply in any coherent domain of knowledge” (p. 94).

The recall protocol appears to be a memorization test of the clinical information in order to evaluate the subject’s ability to reproduce textually the exact syntax of the case. The fact that Patel and Groen found little evidence of a constructive process in the entire set of recall protocols could also be related to the nature of the task required from the subjects, that is, “to write down as much of the text as he/she remembered” (p. 97).

Pathophysiology Protocol
The propositions and the words in the pathophysiology protocols were coded by Patel and Groen using the same numerical system as in the recall
protocols. The narrative functions of the words were also coded similarly using traditional linguistic methods.

The pathophysiology responses were analyzed using three techniques: (1) recall-inference analysis; (2) mapping the linear order of the propositions in the recall and pathophysiological protocols compared to the case description using the same numerical device; and finally, (3) frame notation to describe the if-then production rules related to the diagnosis. Each technique will be discussed.

Patel and Groen defined a recall as "either a direct match or a proposition that results in replacing a word with one of its synonyms" (p. 100). An inference is "a transformation that preserves at least part of the meaning of the original proposition" (p. 100). Consider, for example, the following first sentence from their case description and Subject 5's initial pathophysiology response (Subject 5 successfully solved the case):

**THIS 27 YEAR OLD UNEMPLOYED MALE WAS ADMITTED TO THE EMERGENCY ROOM WITH THE COMPLAINT OF SHAKING CHILLS AND FEVER OF FOUR DAYS' DURATION.** (Patel & Groen, 1986, Table 1, p. 97)

**THE IMPORTANT POINTS ARE THE ACUTE ONSET OF CHILLS AND FEVER IN A YOUNG MALE WITH PUNCTURE WOUNDS IN THE LEFT ANTECUBITAL FOSSA INDICATING HIGH PROBABILITY OF DRUG ABUSE AND THEREFORE SUSCEPTIBLE TO ENDOCARDITIS.** (Patel & Groen, 1986, Table 3, p. 99)

This initial response illustrates a number of phenomena whose coding would be different from that of Patel and Groen had a structural semantic approach been applied. The initial portion of the response (i.e., up to and including the word "male") contains two important transformations compared to the case description and rightly considered by Patel and Groen as inferences: "27 year old" is transformed into "young" and "four days' duration" into "acute." However, although Patel and Groen recognized the "superordinate" nature of these two concepts, they simply coded them as attributes. From a semantic perspective, these two responses would be considered as two formal qualities, namely, QP81a: young and QP41a: acute, using Lemieux and Bordage's (1986) notation. This example illustrates the low discrimination value of certain linguistic functions used by Patel and Groen, such as the notion of attributes. They also coded the word "important" as an attribute, whereas in structural semantics it would be considered a hierarchical function because the subject uses the term to indicate the priority of the acute concept in the case. The low discrimination power of the traditional linguistic coding system is further exemplified by coding "differential" as an attribute in the last sentence of Subject 5's response: "THE HISTORY OF BEING SCRATCHED BY A CAT RAISES THE DIFFERENTIAL DIAGNOSIS OF CAT SCRATCH FEVER..." (Patel & Groen, 1986, Table 3, p. 99); this would be considered an opposition or difference operation in structural semantics.
Patel and Groen considered the terms "young," "acute," "important," and "differential" morphologically analogous, that is, having the same linguistic function of attribute. Thus, the coding of certain narrative functions does not translate the functions operating in the physician's mind. In deciding to apply a very general, domain-free method of coding, Patel and Groen's system of distinctions is not sufficient to capture the morphology of clinical discourses. The simple addition of inferences without considering the structural semantic value of these transformations can lead to incomplete interpretations. This will be discussed later when sections of the pathophysiology protocols of Subjects 5 and 6 are reanalyzed using structural semantic procedures.

Subject 5 later states in his pathophysiology protocol: "WITH PUNCTURE WOUNDS IN THE LEFT ANTECUBITAL FOSSA" (Patel & Groen, 1986, Table 3, p. 99). This sign is the 14th proposition in the case description. The cardiologist mentioned it as the 8th proposition in his recall protocol and in the first segment of his pathophysiology protocol. This illustrates how Patel and Groen compared the propositional order among the three texts (1986, Figure 1, p. 101). They concluded that "there appears to be little correspondence (at the level of linking propositions) between the relational structure of the [description] text and the recall protocol and that of the pathophysiology protocol" (p. 101). This wide distributional variability appears a priori quite predictable, if one considers the highly oriented nature of the task required by the subjects, that is, in the recall protocol, "to write down as much of the text as he/she remembered" (p. 97) and in the pathophysiology protocol, "without reference to either the [description] text or the previous recall response" (p. 97). This latter instruction ignores the semantic references in the case description and is mentally impossible, because each pathophysiology response is a conversion, at an organizational abstraction level, of the empirical case description. Patel and Groen likely used this instruction to refer to the word-for-word syntax of the case presentation.

Patel and Groen used a frame notation to describe the directionality of causal networks related to forward and backward reasoning. The causal networks are viewed as a system of if-then production rules expressed in terms of antecedents and consequents. Contrary to their belief, their method ceases to be domain-free from the moment they evaluate the process of generating medical diagnoses.

The frame notation uses two coding systems. The first reflects the numerical order of the subjects' responses in the pathophysiology protocol (as in Patel and Groen, 1986, Appendices III & IV, pp. 113–114). The second indicates the type and direction of the if-then relationships as coded by arrows. There are various types of relationships: proximity, location, support, condition, time, cause, identity, and category. The propositional chunks are viewed as nodes between links; certain nodes are "and-nodes," that is, they wait to fire until all their other antecedents fire. It is, thus, a
schema of causal processes used to analyze how the if-then rules determine
the moment the text-based knowledge appears and the moment the diagnosis
is generated.

4. DIFFERENCES IN INTERPRETATIONS

Patel and Groen (1986) concluded from Subject 5’s frame notation struc-
ture that he, like all those who correctly diagnosed the case, used a bottom-
up, pure-forward reasoning; that is, the text-based knowledge followed by
the diagnosis (pp. 105-107). On the other hand, Subject 6 (who did not
solve the case) used a top-down, backward reasoning; that is, “begins with
a general hypothesis regarding bacteremia and works backward to the text-
based knowledge” (p. 106). The other subjects who did not solve the case
used a mixture of backward and forward reasoning. Patel and Groen’s con-
clusion concerning the forward–backward determinism in medical diagnosis
(i.e., successful diagnosis equals forward reasoning), would not hold had a
structural analysis been performed. Thus, a secondary analysis of two of
their pathophysiological protocols is presented to elucidate better the
semantic processes of medical diagnosis.

By reanalyzing Subject 5’s initial response, one can see that it already
contains the complete correct diagnosis: acute and endocarditis. In the third
and fourth segments of his pathophysiology protocol he mentions other fac-
tual information (i.e., backtracking to the text-based knowledge) and
repeats once again the diagnosis of acute endocarditis:

THE SHORTNESS OF BREATH (SOB) ON EXERTION AND THE EARLY DIASTOLIC
MURMUR PLUS WIDE PULSE PRESSURE SUPPORT AORTIC INSUFFICIENCY AND
THUS AORTIC VALVE ENDOCARDITIS. THE NORMAL SPLEEN SIZE INDICATES A
MORE ACUTE PROCESS. (Patel & Groen, 1986, Table 3, p. 99)

There is evidence of a mixture of forward and backward reasoning in Sub-
ject 5’s response. The term acute is coded in the frame notation (Figure 2, p.
102) only in the fourth proposition as if it had only been mentioned once,
whereas it appears in the very first segment of the response (Table 3, p. 99).
Furthermore, the progression of the text-based knowledge of this subject is
not a pure bottom-up form of reasoning. From a semantic perspective, the
concept of “acute” is not simply an elementary fact but an abstraction,
which, as it will be shown later, brings together a number of clinical facts
(e.g., normal spleen size and shaking chills) and not just one (i.e., 4 days’
duration as indicated by Patel & Groen). The concept of “bottom reason-
ing” as perceived by Patel and Groen is thus in marked conflict with struc-
tural theory.

The production rules used by all seven cardiologists in the pathophysiology
protocols are then identified using a summary diagram (Figure 3, p. 103).
The diagram was generated a posteriori by another cardiologist and contains the 15 rules that yield the accurate diagnosis (Table 4, p. 104). The diagram produced by this eighth cardiologist represents the canonical knowledge used by the four clinicians who adequately solved the problem and gives the rules necessary to explain the diagnosis given by these clinicians. The rules are presented as a series of if-then links which end with the following final consequent: "acute bacterial endocarditis with aortic insufficiency from drug use" (p. 104). The diagram representing the canonical or common knowledge base of expert cardiologists contains a number of antecedents that produce consequents. Some consequents are transformed into antecedents for new production rules.

The main contribution of Patel and Groen's (1986) article is the disclosure of the production rules. However, this contribution to causal logic in medicine cannot be considered as a result of the analysis of the temporal order of the propositions in relation to the diagnoses. Their propositional method has not produced in of itself the rules that distinguish the various linear discourse organizations of those who solved the case correctly. This is true for the study of both the moment the text-based knowledge appears (i.e., bottom-up or top-down types of reasoning) and the moment the diagnosis appears (i.e., forward or backward reasoning). Even if the forward–backward variable had been observed, there is no need to make it a deterministic characteristic of the successful resolution of a clinical case. Gale and Marsden (1983), using a different terminology, showed that this variable is not significant and that many pathways can lead to a diagnosis. Lemieux and Bordage (1986) also showed that, for the subjects who solved the numbness case, some (e.g., neurologist Z) used a hypothetico-deductive approach (i.e., backward reasoning), whereas others used the opposite approach and, most often, a mixture of both. Any attempt to find invariant pathways, either syntactic or semantic, is doomed to failure because the pathways are immensely diversified from person to person.

Finally, Patel and Groen concluded from their study that the production rules "appear to derive from the physician's underlying knowledge base rather than any information in the text itself" (p. 91). This conclusion is inadequate because it is based on an inappropriate theoretical assumption. Their interpretation implies an exclusively syntactic determinism because the description text is thought to be linguistically useful only when the subjects reproduce it in its original syntax. This interpretation does not recognize the semantic referential role of the description text. The description text does not have a discrete and discontinuous value as suggested by Patel and Groen, but rather a dynamic referential function by which the reader correlates and opposes the information with his knowledge in memory. The contents of the case are not strictly "combined" (p. 96) with the cardiologists' canonical knowledge but represent for the clinician a
referential model or structural pattern of semantic analogies and distinctions. Patel and Groen's general conclusion also ignored a semantic assumption that each pathology has a specific structure, and thus, a specific referential model. (The notion of a specific model is not equivalent to that of a "prototype" (Bordage & Zacks, 1984), which refers to an exemplary pathology in relation to a typology.)

It would be more accurate to hypothesize that the major difference between the successful diagnostician (Subject 5) and the nonsuccessful one (Subject 6) lies in their ability to recognize pertinent relationships between abstract properties. This comparison is the object of the following structural semantic analysis of sections of Subject 5 and 6's pathophysiology protocols. Because the case description in Patel and Groen's study was given all at once, as opposed to gradually for Lemieux and Bordage (1986), the ability to confront a number of alternative diagnoses is reduced. For example, it is not possible to know whether the subjects evoked the possibility of an acute pyelonephritis from the very first sentence of the case description. This disorder also bears an acute form, and also occurs in young patients with a number of similar symptoms (e.g., fever and chills). The task requested from the subjects, that is, "to provide a diagnosis" (p. 97), further constrains the process of generating multiple differential diagnoses where a mixture of forward and backward reasoning would likely occur.

Patel and Groen noted two inferences in Subject 5's first proposition: acute and young. The empirical unit "27-YEaR-OLD" (p. 99) is transformed into young, and "FOUR DAYS' DURATION" (p. 99) into acute. Acute is also related in the first segment to certain qualities of the chills and fever: "...THE ACUTE ONSET OF CHILLS AND FEVER..." (p. 99). The case description also contains the following stimuli: "FEVER OF 40°C AND SHAKING CHILLS," which were correctly mentioned in the recall protocol. It can be deduced from the entire proposition containing the term acute, that this formal property is at least the result of a network of semantic qualities associated with acute, namely elevated temperature (QP32b: elevated) and shaking of marked chills (QP30b: marked). The acute quality can also be deduced implicitly from certain other formal properties related to "FOUR DAYS' DURATION" (p. 99), such as short duration (QP58b), sudden onset (QP33a) or rapid (QP63a) or recent development, all of which are semantic qualities compatible with the empirical findings. It cannot be proven that Subject 5's initial response that these additional relationships existed; however, it can be assumed that at least one of these relationships was evoked when his 4th proposition is analyzed: "THE NORMAL SPLEEN SIZE INDICATES A MORE ACUTE PROCESS" (p. 99). This sentence implies that the cardiologist recognized that the disorder was either too recent, too short, too rapid, or too sudden for the spleen to increase in size. The term "ACUTE" aggregates a set of formal characteristics related to fever, chills, duration, and absence of splenomegaly. Contrary to Patel
and Groen’s interpretation, the “ACUTE” inference is not a simple transformation of “FOUR DAYS’ DURATION” into a superordinate concept, but a more global property involving a complex network of formal qualities. The definition of an inference, as proposed by Patel and Groen, is also too limiting from a semantic perspective because it ignores the complex process by which the elementary meaning of an empirical cue can be formally associated with multiple semantic properties.

The deliberate exclusion of the comprehension function in the analysis of the rules of solving clinical problems can lead to incomplete interpretations, even erroneous ones related to the syntactic organization itself, and by extension, the causal networks. The sequence in the pathophysiology response of Subject 5 is a result of semantic operations that lead to the diagnosis. These semantic operations are not exclusively causal but constitute an abstract transformation of the empirical findings contained in the case. To ignore the generative and referential value of the case description in the organization of the pathophysiology response constitutes a fundamental omission stemming from Patel and Groen’s textual and numerical interest in the number of words contained in a proposition.

Subject 6 did not make the appropriate diagnosis. Here are the first two segments of this pathophysiology response:

GENERAL BACTEREMIA AND SEPTICEMIA ARE SECONDARY TO B. RESULTING IN CNS RESPONSE TO SEPTICEMIA (CHILLS, FEVER) AND WITH SEEDING OF ORGANISMS ON THE AORTIC VALVE RESULTING IN SUBACUTE AORTIC INSUFFICIENCY DUE TO LEAFLET DESTRUCTION AND HENCE A COLLAPSING PULSE. BUT WITHOUT SUFFICIENT SEVERITY OR DURATION TO CAUSE CLINICAL HEART FAILURE OR CARDIOMEGALY. (Patel & Groen, 1986, Appendix IV, p. 114)

Two formal properties characterizing the fever and the chills are not recognized by this cardiologist, namely elevated (QP32b) and marked (QP30b). There is evidence however in the second segment that he probably recognized one formal property, namely, the short (QP58b) duration (i.e., “WITHOUT SUFFICIENT DURATION”); but as noted by Patel and Groen, he wrongly associated short duration with not serious (QP55b) and thus incorrectly concludes that it is subacute. This cardiologist makes an erroneous semantic association that stems from an incomplete configuration of the important formal qualities in the comprehension of the problem as a whole. Production Rule 4 is incomplete (i.e., “[If] fever, [then] bacterial infection”; Patel & Groen, 1986, Table IV, p. 104) because it fails to incorporate the notion of 40°C and its association with highly elevated fever. Thus, there are if-then relationships that are of a structural semantic nature (e.g., if elevated and marked and short duration, then acute) that refer to the formalization of the contents and not exclusively to causal relationships.
The unsuccessful diagnostician failed to evoke properties belonging to two important semantic axes, namely elevated (QP32b) and marked (QP30b). The difference between his performance and that of the successful clinician lies in their unequal semantic competence, that is, their formal qualification of the symptoms and signs. The case description itself contains a number of formal properties [e.g., transient (QP37b); regular (QP90a); wide (QP106b)]. Subject 5 uses more formal properties in his pathophysiology protocol than Subject 6 (a total of 11 as opposed to 7, a 1.6-fold difference; 2 of the 7 are inaccurate). The ability to abstract the semantic properties from the case is greater for the cardiologist who made the diagnosis. (Lemieux & Bordage, 1986, with their open-ended, think-aloud procedure, found an average of 32 to 38 different semantic axes for the subjects who accurately diagnosed the numbness case.)

These results also coincide with the greater number of inferences made by the ones who correctly diagnosed the case as opposed to those who did not. Inferences are most often semantic qualities. This is illustrated in Subject 5’s inference of ‘‘ON EXERTION’’ (p. 99) (QP64a) from ‘‘when he tried to climb the two flights of stairs in his apartment’’ (p. 97). The notion of ‘‘ON EXERTION’’ is a good example of a semantic property whose role is to aggregate the empirical stimuli from a specific text and to abstract from the stimuli a formal concept (on exertion). This example also illustrates how a semantic formal property constitutes a ‘‘framework’’ (Lévi-Strauss, 1962), that is, an element of schematization which allows the semantic regrouping of various types of contents into one principle. The quality on exertion, could be applied to a number of neighboring empirical events such as while mowing the lawn, while lifting a heavy object, or while playing tennis. Those events have distinct elementary meanings (i.e., substance of the contents) but they are all comparable from a formal perspective. They all belong to the semantic class (Lévi-Strauss, 1962) related to the concept of on exertion. Thus, if under different circumstances than the one presented in the case, a clinician encounters the symptom ‘‘shortness of breath when mowing the lawn,’’ for example, he will recognize that the symptom is formally analogous to the one previously encountered in his practice (i.e., when climbing stairs) even though there is a difference in the empirical contents (i.e., the syntax). Each formal property constitutes a method of semantic classification of empirical contents. Thus, the concept of ‘‘young’’ can incorporate a number of possible ages (e.g., 5-, 17-, or 20-year-old); the concept of ‘‘elevated’’ in relation to fever can cover a range of values (e.g., 38°C, 39°C, 39.5°C, 40°C). The formal properties allow the clinician to recognize, beyond the wide variety of symptoms and signs possible, the structural similarities between different clinical contexts. The formal properties transform encyclopedic knowledge into a dynamic system of similarities and differences. This structural system of classification is essentially
malleable and adaptable as opposed to any preestablished and static pathophysiological taxonomies. The semantic properties constitute multiple networks of associations among various pathophysiological systems.

**DISCUSSION**

The comparison of the propositional and structural dimensions of diagnostic thinking brings out the fact that to understand fully the dynamic processes by which diagnoses are generated, one needs to go beyond a linear forward-backward analysis of the discourses. The analysis must include a vertical dimension that contains the networks of appropriate abstract properties related to the differential diagnosis. The use of propositional analysis sheds some light on the directionality of the relational rules associated with the linear dimension of the discourses. Patel and Groen (1986) showed how the accurate diagnosticians selected relevant propositions and causal rules to make a diagnosis. The distinction between relevant and irrelevant propositions or rules illustrates the clinician's ability to include in his diagnostic thinking the propositional chunks that are materially necessary to solve the problem. For Patel and Groen, the notion of relevancy is related to the necessary inclusion of a syntactic clinical finding in the diagnostic thinking, whereas for Lemieux and Bordage (1986), the neighboring notion of pertinence is related to whether or not a finding, or a set of findings, is compatible with the deep semantic aspects of the problem, that is, the semantic properties. The clinician who recognizes the underlying structure of a clinical problem makes, from a propositional perspective, an appropriate selection of relevant clinical findings and, from a structural semantic perspective, an abstraction of those findings into pertinent networks of formal qualities. These two structural components interact to activate causal logic and the generation of appropriate diagnoses. Overall, it is the deep underlying structures that determine clinical competence. The selection of the appropriate diagnosis is based on a system of semantic nuances, the formal qualities, that compose a vertical pathway through which various levels of meaning are progressively evoked. What Patel and Groen described as pure forward reasoning is more a reflection of their method of investigation than the actual reasoning of the clinician. For example, the structural notions of *acute* and *young* were operating in the clinician's mind from the very onset of the case and were driving his thinking.

The main conceptual contribution of structural semantics to diagnostic thinking is the concept of "semantic axes" as a vertical, dimensional, and oppositional "mental space" (Ducrot & Todorov, 1979, p. 108), which allows a clinician to organize his or her knowledge by means of a semantic classification system, the formal qualities. Any research on medical diagnosis must include a structural semantic component because deep structures
are essential to the understanding of "good" diagnostic thinking. The notion of semantic networks within propositional analysis and expert systems must be revised and enriched both theoretically and methodologically.

By discarding comprehension from their study of problem solving, Patel and Groen overlooked some fundamental semantic aspects of the structure of diagnostic thinking. Their coding system does not recognize the specific genre of medical diagnosis, and thus their narrative functions are not sufficiently precise to describe a medical grammar. To produce a purely "domain-free" analysis appears to be an impossible task when the object of analysis includes the specific function of generating medical diagnoses. Their coding system also does not fully acknowledge the dynamic function of the inferences made by the clinicians. The semantic analysis of the inferences made by the clinicians is essential in order to understand the cognitive mechanisms by which the clinical cues are transformed into formal properties, and subsequently used to classify similar and opposing diagnoses. Researchers in cognition have stressed domain-independent analyses. Bordage and Lemieux (1991), on the other hand, and following semiotic traditions, analyzed at length and with a highly discriminating methodology a specific domain of cognition. It is the only means of obtaining a detailed description of a structure. The generalizations or domain-free rules should derive from results of specific analyses and not the reverse. Thus, the general rules of human cognition will be more precise and exhaustive, and also, the distinctions between genres or domains will be clearer. In trying to generate general models a priori, the field of cognition is shortchanging itself.

Patel and Groen's experimental tasks are too limiting if one is trying to understand problem solving [e.g., "to describe (again in writing) the underlying pathophysiology of the case without reference to either the text or the previous recall response" and "to provide a diagnosis," p. 97]. Subjects must be able to express more freely their thinking in order to disclose their mental structures. Otherwise, incomplete interpretations of the diagnostic process may occur. A think-aloud procedure with successive presentation of clinical information may be more informative. The use of the description text goes beyond its simple restitution (syntax) and must include an analysis of its referential function in the clinician's mind. There is a relationship between the clinician's knowledge and the information in the text. Furthermore, to focus only on what pathophysiological systems do overlooks what symptoms and signs are and how the two interact in generating and excluding diagnoses.

Finally, and in relating theories of diagnostic thinking to the practice of medical education, we believe, like Patel and Groen, that medical educators should be critical of the great importance given to the hypothetico-deductive model of clinical reasoning (Barrows & Tamblyn, 1980; Elstein, Shulman, & Sprafka, 1978). The selection of appropriate diagnoses is based on more
complex structural phenomena such as the ones described in this article. Medical students run the risk of ignoring their structural strategies if their education emphasizes solely the enumeration of symptoms and signs contained in various diseases (i.e., their syntax) or causal rules. The semantic competence of medical students could be enhanced by making their formal properties more explicit, such as, Did the symptoms appear *slowly* or *rapidly*, *recently*, or *some time ago*? Are they *constant* or *intermittent*, *unilateral* or *bilateral*, *focal* or *diffuse*, *superficial* or *deep*, *peripheral* or *central*? By making the semantic associations more visible and conscious, for example, in medical textbooks (Bordage & Lemieux, 1990), the students could learn to solve a problem by first defining it before blindly generating lists of diagnostic impressions. Well-controlled definitional strategies, that is, the adequate recognition of the substance, form, and effect of the symptoms and signs, are the best means of arriving at a diagnosis.

The semantic competence of students or experts in other fields of cognition could also be enhanced by making their definitional strategies more explicit. The study of semantic properties has wide applicability because semantic axes are used to access deep meaning associated not only with discourses but with other types of perceptions. Applications are not limited to cultural or symbolic domains of meaning such as art or communication, but also to a variety of other domains of human activity as illustrated here.

REFERENCES


