MASSACHUSETTS INSTITUTE OF TECHNOLOGY

ARTIFICIAL INTELLIGENCE LABORATORY

A.I.Memo No 798 November 1985

The Use of Censors for Nonmonotonic Reasoning and Analogy in Medical Decision-Making

Hormoz Mansour

Abstract

A patient rarely has a single, isolated disease. The situation is usually much more complex since the different parts of the human organism and metabolism interact with each other and follow several feedback patterns. These interactions and feedback patterns become more important with the addition of the external environment. When a disease is present, the first steps of the medical diagnosis should be to research and to determine whether another disease interacts with ("Censors") or changes the significant symptoms, syndromes, or results of the laboratory tests of the first disease. Understanding of this interaction and the appropriate reasoning is based on a type of non-monotonic logic. We will try, within this paper, to see the effect of two diseases on each other. One important part of the effect of two diseases on each other is the entrancing effect of what we call "Censors." In addition, causal reasoning, reasoning by analogy, and learning from precedents are important and necessary for a human-like expert in medicine. Some aspects of their application to thyroid diseases, with an implemented system, are considered in this paper.

A modified version of this paper will soon appear in "Computers in Biology and Medicine," an international journal of the National Biomedical Research Foundation.

This research was conducted at the Artificial Intelligence Laboratory of the Massachusetts Institute of Technology. Hormoz Mansour is supported by a grant from several scientific and cultural organisations in France.

Table of Contents

1. Introduction

Over the last ten years, there has been a real emergence of Artificial Intelligence in medicine. Many ingenious systems have been implemented; among these are Casnet/Glaucoma (1974), Mycin (1976), PIP (1976), Digitalis Therapy Advisor (1976), and Internist-1 (1977); [33]. There have been some attempts to go beyond these systems. In particular, Caduceus [33] and ABEL [27] consider specific medical situations where several diseases may be present. In this paper we will consider situations where several diseases are present which have an inhibiting effect on possible symptoms of each other. This inhibiting or blocking effect, which we call a "Censor," will be analyzed and developed in this paper. In addition, we will discuss the cause and effect relationship and a type of learning and reasoning by analogy.

These ideas, particularly the one related to Censors, were inspired by our observations and studies in medical environments. The different conversations and observations that we had with the experts of New England Medical Center generated an idea related to the mechanism of Censors. The neuroendocrinology specialists use this approach quite commonly. The understanding of this interaction and of the appropriate reasoning is based on a type of non-monotonic logic. Our observations of the medical environment have led us to consider this type of reasoning as one that is related to a commonly found reasoning in medicine.

Non-monotonic reasoning is a logic where the introduction of new axioms can invalidate or change old conclusions. For example:

```
if      high-thyroid-hormone-secretion
then    T3 increased
unless  renal failure
```

We want to emphasize that we have chosen the limited domain of thyroid diseases where we have actually observed these mechanisms occurring in everyday medical practice. Our secondary task is to check and verify the applicability of these ideas in other domains of medicine.

All these considerations are incorporated into the development of a medical diagnostic system for neuroendocrinological diseases. The implemented system contains 22

Censors : eleven of these Censors prevent specific diagnoses, while the remaining half block the action of the first eleven. Besides these Censors, the system also contains some 300 findings which are related to almost all cases of hyper and hypothyroidism. Furthermore, the 300 findings are divided into different descriptions and each of these descriptions is related to the clinical state of a given patient.

This new approach could eventually provide a better model for clinical decision-making.

2. A Brief Review of Neuroendocrinology

Within this section we will study several glands along with their interaction with and control of other glands. The central nervous system (CNS) controls the secretion of most glands, both internal (endocrine) and external (exocrine). The part of neuroendocrinology, which we will study here, is the hypothalamus and pituitary axis with TRH (Thyrotropin-releasing hormone) and TSH (Thyroid-stimulating hormone) secretions.

A GLOBAL FEEDBACK PATTERN

This paper focuses on the thyroid gland secretions T3 (tri-iodothyronine) and T4 (thyroxine), which are activated by TSH, thyroid stimulating hormone and TRH, thyrotropin-releasing hormone. In turn, the thyroid secretions are influenced by other secretions such as growth hormone, estrogen and glucocorticoids (Figure 1). Also, on a higher level, somatostatin interacts with growth hormone, which interacts indirectly with the thyroid secretions.

In neuroendocrinology, the pituitary-thyroid axis is an excellent example of a negative-feedback self-regulatory system. This regulation is achieved by interaction among at least three groups of hormones; TRH stimulates the synthesis and the release of TSH by the pituitary thyrotrope; TSH, in turn, activates the release of the thyroid hormones T4 and T3. The circulating thyroid hormones exert feedback effects on the pituitary to regulate TSH secretion. Interaction between the negative-feedback effects of T4 at the pituitary level and the stimulatory effects of TRH appears to be the primary control of TSH secretion. Although this simple model describes most of the regulatory factors in the pituitary-thyroid function, other mechanisms influence the rate of TSH secretion. These include peripheral degradation of TSH, thyroid hormones, and TRH, as well as the physical state of thyroid hormones in the blood. An inhibitory hypothalamic hormone (somatostatin) that affects TSH secretion also exists.

A FEW WORDS ABOUT TSH AND TRH

Human pituitary thyrotropin (TSH) is a glycoprotein that has a molecular weight of 28000 and is secreted by specific basophilic cells of the anterior pituitary (thyrotrope cells). TSH is made up of two chemical subunits, a and b. The "a" subunit is devoid of biologic activity. Determinants of the immunologic and biologic actions of TSH are located in the "b" subunit. Circulating TSH is identical to pituitary TSH; small amounts of the "b" subunit are also normally secreted into the blood. Sequential blood sampling has shown that basic TSH levels fluctuate considerably throughout the day and night. Episodic or pulsatile TSH release has been demonstrated, and the highest levels of

TSH release are usually observed during the morning hours. Thyrotropin-releasing hormone (TRH) was the first of the hypothalamic hormones to be chemically identified, synthesized, and administered to humans. Its identification was a landmark in neuroendocrinology.

PITUITARY-THYROID FEEDBACK

Administration of increasing doses of T4 to hypothyroid individuals produces a graded suppression of plasma TSH levels. When data relating TSH to T4 concentration are plotted to show TSH as a function of plasma T4, a curvilinear relationship is evident (Figure 1). Extensive studies of this phenomenon have shown that plasma TSH is a function of the negative log of the plasma T4. In terms of servosystems analysis, the thyroid hormone concentration in the blood can be viewed as the "controlled variable." The normal "setpoint" of pituitary-thyroid function is the resting concentration of plasma thyroid hormone maintained by a specific concentration of TSH. The secretion of TSH is inversely regulated by the concentration of thyroid hormones so that deviations from the control setpoint lead to a corresponding changes in the rate of TSH secretion.

HYPOTHALAMIC-PITUITARY-THYROID DISEASE

Modifications in TSH secretion observed in clinical diseases of the pituitary and thyroid generally confirm predictions based on classic formulations of pituitary-thyroid negative-feedback regulation. There are basically two categories of diseases, hypothyroidism and hyperthyroidism.

HYPOTHYROIDISM - This is the effect of long-standing thyroid insufficiency on the pituitary, or failure of pituitary TSH secretion.

HYPERTHYROIDISM - Hyperthyroidism is due to overactivity of the thyroid gland and TSH secretion is inhibited, as is the response to TRH [20]. We are concerned, in the following pages, by these two aspects of hypothalamic-pituitary-thyroid disease.

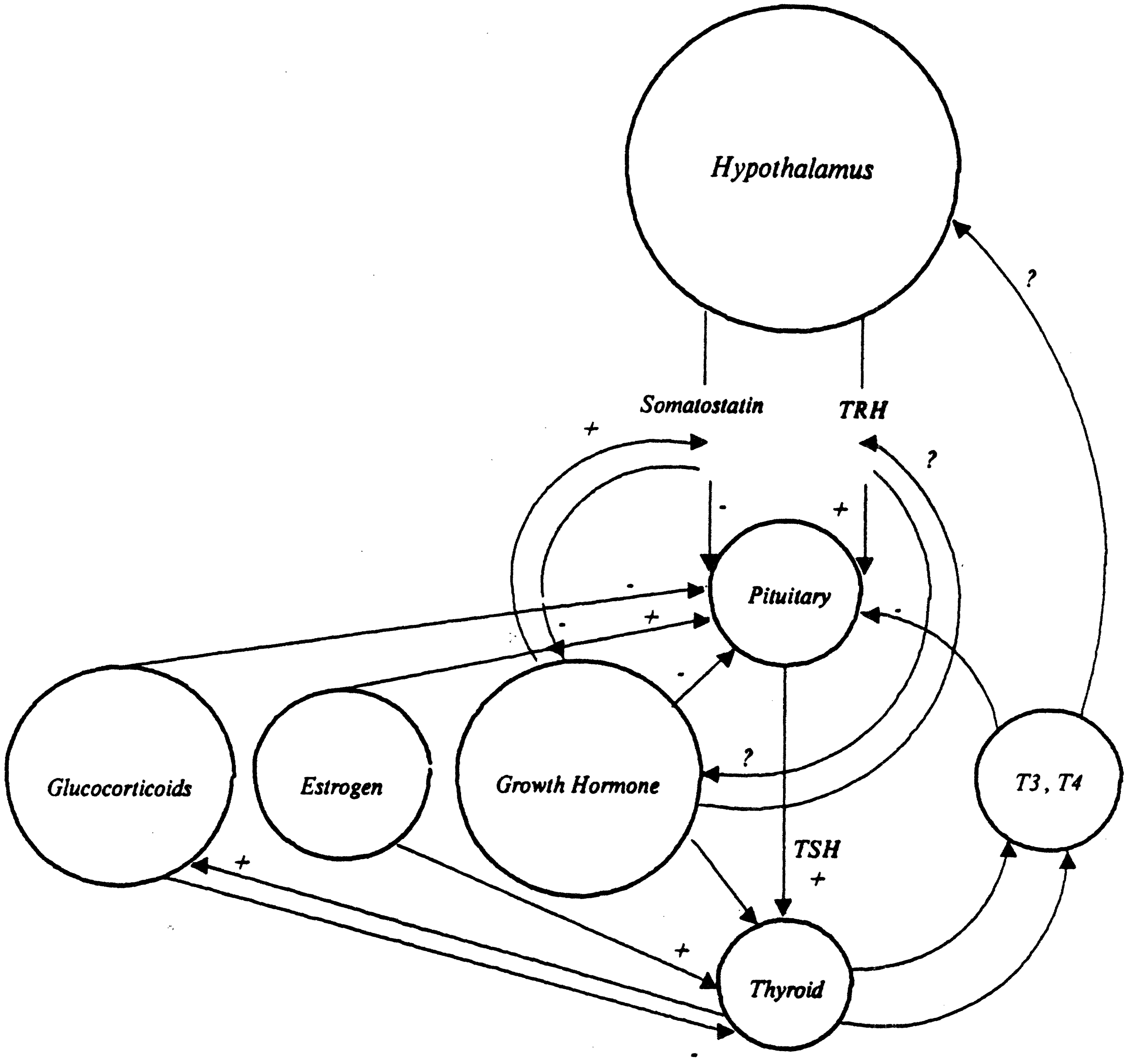

FIGURE 1

A model for regulation of Hypothalamus, pituitary and Thyroid Hormones

3. The Concept of "Censor"

A patient rarely has just a single, isolated disease. The different parts of the human organism and metabolism interact with each other and follow several feedback patterns for their regulation. These interactions become more important with the addition of the external environment and with the psychological influences involving emotions and mentations. Those interactions on a bio-cybernetic or psycho-somatic level could have an inhibiting or an amplifying effect on each other. In this paper we discuss the inhibiting or blocking effect.

All these inhibitors are expressed in terms of "Censors," which prevent some normal reactions from occurring. When several diseases are present, the first step of the diagnosis should be to determine whether one of the diseases could inhibit or change the significant symptoms, syndromes, or the results of the laboratory tests of the other disease.

The word "Censor," primarily used by Freud, is an important element of Minsky's "Society of Minds" [24]. Although we have adopted the same word as Minsky, our intended meanings are quite different. Minsky's censors are the agents which interact with other agents in his theory of mind, and prevent them from being active. Our censors are from the medical domain, and are the factors such as infection, surgery or overeating, which interact with different elements of humans diseases and prevent them from being in their real states. More specifically, the Censors are the medical agents which cause the value of some laboratory test to be obscured and prevent the physician from making the right diagnosis.

For example, a patient with hyperthyroidism should have an increase in the thyroid secretion T3. In spite of the presence of the clinical findings related to hyperthyroidism, the laboratory's test may not show any increase of T3. A more detailed study of the causalities shows that the patient had an infection (cf. Appendix) which prevented T3 from increasing. This second element, infection, is called a Censor because it prevents T3 from being elevated.

As we will see (cf. Interaction with Censors), the understanding of this type of interaction and reasoning is based on non-monotonic logic. With this type of logic the conclusion can be invalidated, or censored, by the new axioms. The invalidation of the conclusion could be reinvalidated again by the arrival of new axioms that invalidate the previous censor, and through a type of non-monotonic reasoning, again allows the conclusion as follows :

```
if      high-thyroid-hormone-secretion
and     renal failure
then    T3 not increased
unless  kidney transplant
```

When a disease is hypothesized, the basic step of the diagnosis should be to determine the internal, external or psychological elements ("Censors") which inhibit or change (because of their interactions) the significant symptoms, syndromes, or the results of laboratory tests. If we do not identify these Censors, there is a danger that we would neglect some basic factors which could result in misdiagnosis.

It seems that the medical specialist, in order to make a proper diagnosis for a disease, thoroughly investigates his medical knowledge to find possible causes for the disease and their corresponding effects. In other words, he tries to recognize the real problem and to find a proper solution to that problem. To find the real problem, the medical specialist has to find the different factors which could obscure the findings and symptoms; these factors are called Censors.

4. Precedent and Analogy in Medicine

4.1. Ideas About the Use of Reasoning by Analogy in Medical Decision-Making

There are many types of reasoning by analogy; probably the most powerful is the one involving causal structure, which consists of a precedent situation and a new situation with a causal structure that matches the precedent.

In going through this type of reasoning, we are tempted to ask: How do physicians reason? How and in which way does previous knowledge and experience help them in the different stages of diagnosis? We will try to see how it is possible to use a model of reasoning by analogy in medical decision-making. We will also study the effect of a second disease, which could be a Censor. The combined effect of reasoning by analogy in the case of one disease and the eventual blocking point caused by a second disease is the most interesting part of the diagnosis. It suggests how a physician refers to his previous knowledge and tries, by using a precedent analogy, to make a diagnosis. In fact, there is a combined effect of reasoning by analogy and the blocking points which are the "Censors" that create a new situation.

Another approach to analogy to consider in its application to medicine is a type of contextual analogy. Context is another aspect of constraint relations in the analogy between two domains; for each symptom, multiple constraint relations could exist, with each of them shown as a context. By context we mean the association of some relations and causes which create symptoms for a given disease. It appears that this type of analogy has special applications in medicine. The medical findings and symptoms could be the same in different contexts. It is the association of the context with the related finding that makes sense when diagnosing certain types of diseases. A contextual approach basically considers the result, which is immediately observable by a physician, of those relations that create that special context.

Two systems have been implemented with the most significant symptoms and findings of hyperthyroidism and its Censors. The first is based on analogy with causal relation as a constraint relation. The second system is based a type of contextual approach in reasoning with all of the related symptoms.

4.2. Using Causal Relations in Analogy Based on Precedent and Censors

Medical diagnosis, considered here as a problem-solving process, is based on a description already acquired as a precedent by the system and the description of a new patient. If there is a correlation (matching) between (1) the findings and the causal relation of one description, and (2) the findings and the causal relation of the case of a new patient, there is a solution to the problem, a diagnosis for the the disease, and a principle for the system to learn.

The descriptions, as well as the different patient cases to be diagnosed, are described in an English-like input. An elementary sample shows the causal relation as well as the type of English-like input:

Description-1. This is a description about a patient. The patient has hyperthyroidism because the patient's T3 is increased.

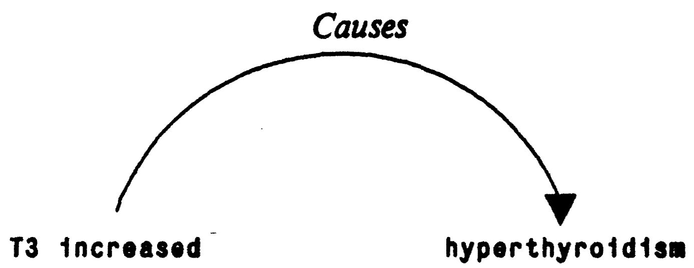

FIGURE 2

Another sample in an English-like input shows the chain of causality between thyroid's secretion, T3 and hyperthyroidism.

Description-2. There is a patient who has hyperthyroidism. The patient has hyperthyroidism because the patient's T3 is increased. The patient's T3 is increased because the patient's thyroid has high-thyroid-hormone-secretion.

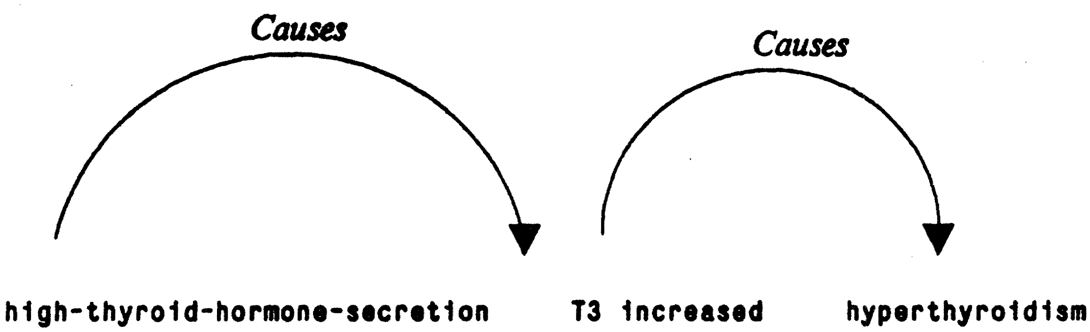

FIGURE 3

Each diagnosis is deduced in the form of an if/then/else rule, with the symptoms as the if/part. The successive generation of these rules creates the flexible knowledge base for the system.

The following description and related exercise show a proper analogical situation between a precedent description and the case of a patient which leads to a diagnosis and generates a rule:

```
Description-3. There is an alcoholic patient*.
The patient has hyperthyroidism. The patient has hyperthyroidism
because the patient's T3 is increased. The patient's T3 is increased
because the patient's thyroid has high-thyroid-hormone-secretion and
causes the patient to have sleep-disturbances, diplopia,
hyperpigmentation, hyperphagia, profound-delirium, erythema and
palpitations.
```

Now we have the case of a patient with a number of symptoms characteristic of hyperthyroidism as follows:

```
Case-1. Jacques who is a  patient has sleep-disturbances, diplopia,
hyperpigmentation, hyperphagia, profound-delirium, erythema and
palpitations. Jacques has high-thyroid-hormone-secretion.
```

The case of this patient (case-1) corresponds to the factual precedent (description-3) already expressed above. There is a proper match between the symptoms in the precedent and the case and thus the system is able to make the diagnosis that Jacques actually has hyperthyroidism. Note however that this conclusion is valid only if the patient's T3 is increased, a fact not mentioned in the case description. The result of this is expressed using the following rule with all of the symptoms as the if/part and the diagnosis as the then/part with the clause "unless" that corresponds to T3 increased.

* The fact of "alcoholism" does not intervene in the process of reasoning by analogy. The relevant facts are the findings which do interfere with the chain of causality and consequently with the analogy. The findings are sleep-disturbances, diplopia, etc.

From a theoretical point of view, the introduction of the operator "unless" relies on nonmonotonic logic, which will be developed in the following sections.

```
if

  [THYROID HAS    HIGH-THYROID-HORMONE-SECRETION]  is TRUE
  [THYROID CAUSES [PATIENT HAS SLEEP-DISTURBANCES]]  is TRUE
  [THYROID CAUSES [PATIENT HAS DIPLOPIA]]  is TRUE
  [THYROID CAUSES [PATIENT HAS HYPERPIGMENTATION]]  is TRUE
  [THYROID CAUSES [PATIENT HAS HYPERPHAGIA]]  is TRUE
  [THYROID CAUSES [PATIENT HAS PROFOUND-DELIRIUM]]  is TRUE
  [THYROID CAUSES [PATIENT HAS ERYTHEMA]]  is TRUE
  [THYROID CAUSES [PATIENT HAS PALPITATIONS]]  is TRUE

then

  [PATIENT HAS HYPERTHYROIDISM]  is TRUE

unless

  [T3 INCREASES]  is FALSE

based on the exercise,  CASE-1

and the precedent, DESCRIPTION-3
```

4.2.1. Necessity for a Derivative-Rule

Finding the diagnosis by using reasoning based on a factual precedent is a powerful way of reasoning. Things are learned and remembered. A new situation (the new patient) is always referred in one way or another to one situation already learned or known by the physician and a diagnosis finally occurs.

All of the different situations together are the different references used by the physician for the patient. The rules that are created as a principle are, as we have already mentioned above, the different cases known by the physician.

A certain number of symptoms encourage the physician to request laboratory tests to see whether T3 or T4 are increased abnormally to reach the diagnosis of hyperthyroidism. When all of the learning takes place, the system knows in the form of the appropriate precedents and rules all of the symptoms gathered together from different cases, which cover all of the symptoms of hyperthyroidism.

Now, let us consider a common situation where a patient's symptoms do not correspond to just one precedent but are divided among the different precedents. In such a situation factual precedent alone is not sufficient to arrive at a diagnosis.

The following is a very simple example where the case of a patient shows the interaction between two simple precedents.

This is one of the precedents:

```
Description-4. X is a description about a patient. The
patient has hyperthyroidism because the patient's T3 is increased.
The patient's T3 is increased because the patient's thyroid has
high-thyroid-hormone-secretion and causes the patient to have diplopia,
burning-eyes, hyperhydrosis and lymphocytosis.
```

This is a second precedent:

```
Description-5. X is a description about a patient. The
patient has hyperthyroidism because the patient's T3 is increased.
The patient's T3 is increased because the patient's thyroid has
high-thyroid-hormone-secretion and causes the patient to have
warm-skin, dryness-of-eyes, profound-delirium and
difficulties-in-concentration.
```

And now, with the case of a patient as follows:

```
Case-2. E is an exercise about Francoise. Francoise who
is a patient has burning-eyes, profound-delirium, warm-skin,
dryness-of-eyes, lymphocytosis and diplopia. Francoise has
high-thyroid-hormone-secretion.
```

As we can see within this simple example some of Francoise's symptoms would have matched some symptoms from the first precedent and some other symptoms from the second precedent. A factual precedent does not allow us to make a conclusive diagnosis for Francoise. Therefore, we have adopted, in this case, the strategy of a diagnosis based on all precedents; in other words, the strategy of a derivative-rule.

In the implemented system, extraction of a rule based on one precedent is inspired from other related work which exist in artificial intelligence laboratory of MIT [37]. But as we saw above, a factual precedent does not allow us to make a conclusive diagnosis in most cases. The reality of the world does not often follow the strategy of reasoning in analogy based on a factual situation. The different situations often merge with each other for creating a new situation which has a need for all of the precedent situations. In the medical domain this is often the case.These considerations led us to consider in our implemented system, the strategy of a derivative rule.

The basic difference between a rule and a derivative-rule here is on the matching level. Whereas a rule is determined and created whenever a proper matching between the case of the patient and one precedent occurs, the derivative-rule is determined and created after the matching of the symptoms of the patient is made with all of the symptoms of the if/parts of all of the rules already created.

As an example, in the last case, derivative-rule created for Francoise looks like this:

```
if
  FRANCOISE HAS

  BURNING-EYES is TRUE
  PROFOUND-DELIRIUM is TRUE
  WARM-SKIN is TRUE
  DRYNESS-OF-EYES is TRUE
  LYMPHOCYTOSIS is TRUE
  DIPLOPIA is TRUE

then

  FRANCOISE HAS HYPERTHYROIDISM is TRUE

unless

  [T3 INCREASE] is FALSE

based on the, case-2

and the precedents, ALL PRECEDENTS
```

4.2.2. Causality Among Several Precedents

Causality among several precedents is an important feature of this type of reasoning by analogy. When a situation is described, it is possible that from a large amount of information and symptoms concerning a precedent, we would want to have a particular fragment of the causal structure contained in the description of a patient. A part of the precedent is may be useful because we will later make the synthesis of these precedents. In other words, *Situations synthesized from precedents...constitute constraint-describing summaries that may be worth remembering as plausibility principles*[37].

In our case and for the diagnosis of hyperthyroidism, because of the complexity of the situation, the chain of causality, and the different levels of learning, we need to synthesize different precedents to reach a final conclusion. The following example shows the acquisition from two different precedents and one final conclusion based on both.

One description with one causality:

```
Description-6. X is a description about a patient. The patient has
hyperthyroidism because the patient's T3 is increased.
```

This could have been one part of a detailed description. Now another description with another causality, as part of another detailed description:

```
Description-7. X is a description about a patient. The patient's T3 is
increased because the patient has high-thyroid-hormone-secretion.
```

As observed here, we can learn from the first description about the causality between hyperthyroidism and T3, and from the second causality between T3 and thyroid's secretion.

When we have a patient description that does not match any of the cause/effect relations of the precedents, but that has a cascade of cause/effect relations between the different precedents, the system is able to go through this cascade and match the cause of the first description to the effect of the last description, and to then find the effect or the diagnosis for the patient whose description contains just a cause. In other words, the synthesis of the two previous cases could solve a class of problems which have that synthesis of cause/effect relation. One example of this synthesis is the case of a patient who has thyroid's secretion-high as follows:

```
Case-3. E is an exercise about Anne. Anne is a patient. Anne has
high-thyroid-hormone-secretion.
```

Is it possible to conclude that Anne has hyperthyroidism?

The system proceeded to recognize, based on a second description, the causality between thyroid's-secretion and T3. Then it recognized the causality between the T3 and hyperthyroidism, which is also the solution to the problem or the diagnosis for Anne. Finally, if we had these isolated descriptions and problems to solve, the system would learn the following rule as a principle:

```
if

  [PATIENT HAS HIGH-THYROID-HORMONE-SECRETION] is TRUE

then

  [PATIENT-1 HAS HYPERTHYROIDISM-1] is TRUE

based on description-6 and description-7
```

The tree diagram of the creation of a rule "diagnosis" based on two precedents.

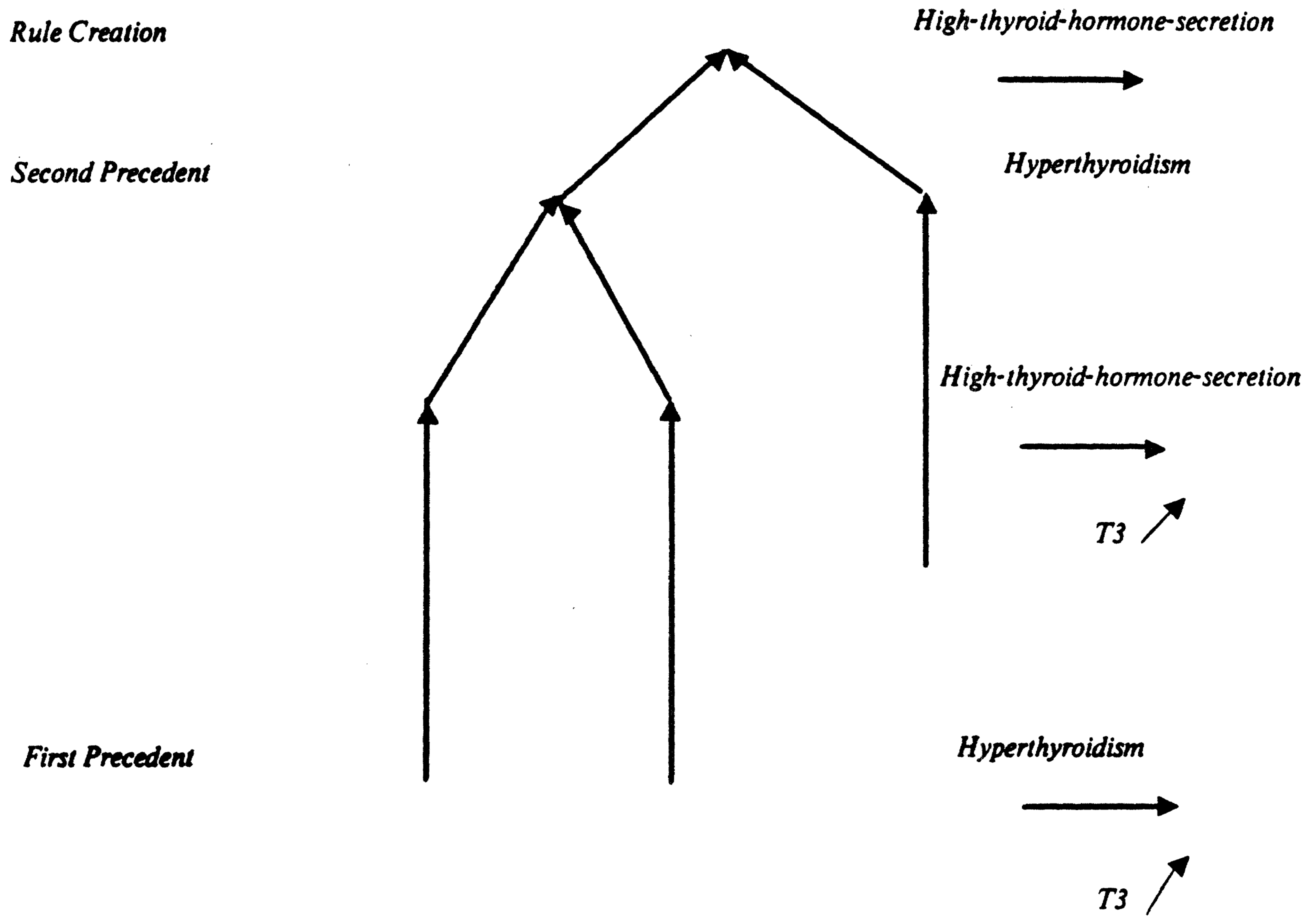

FIGURE 4

5. Interaction with Censors

5.1. Use of Non-monotonic Logic

At this level, as we have already mentioned, there is an interaction with other diseases. The system, so far, is able to determine whether one of the diseases, indicated below, is able to inhibit, censor, or change the result of laboratory tests. In other words, it is able, by the interaction with other diseases, to change the increased or decreased value of the thyroid secretions T3 and T4. This interaction is based on non-monotonic logic. Non-monotonic reasoning is a type of logic, where the introduction of new axioms can invalidate, censor, or change old conclusions. As illustrated in the following example:

```
If      premise
then    conclusion
unless  censor
```

Here is an example from hyperthyroidism where the new axiom, renal failure, can censor or invalid the previous conclusion, which was T3 increased:

```
If      high-thyroid-hormone-secretion
then    T3 increased
unless  renal failure
```

This type of reasoning and the invalidation of the conclusion could be revalidated again by the arrival of new axioms that invalidate the previous censor and through a type of non-monotonic reasoning, again allows the conclusion as follows:

```
If        high-thyroid-hormone-secretion
and       renal failure
then      T3 not increased
unless    kidney transplant
```

This type of reasoning using non-monotonic logic with the 'unless' clause (which defines the Censor) is not based on a standard logic approach. Let's examine what usually happens in monotonic logic. For example, modus ponens says : "If with an axiom we have a --> b and there is another axiom with the form a, then b logically follows." If b is a theorem to be proved, then we have the answer. Continuing with modus ponens, we may have an ever increasing list of axioms necessary to show that a desired theorem is true.

Now, what happens in non-monotonic logic? The answer is that within this type of reasoning, we can revise previous assumptions in light of new observations and subsequently reach new conclusions. That means, if we have an axiom like a and another like a --> b, it is possible that we can not infer b.

This is shown with another clause which is "unless c." Now, if we are given a and a --> b, we cannot conclude b until we have checked c. An important fact to mention is that the arrival of a new axiom like "unless c" when c is true, does not create a negation of a --> b, but it could limit, block, or revise the assumption. Again, if it happens that c is not true anymore, the previous conclusion becomes valid again.

For example, an axiom such as "noon --> sun shines" could be revised with "unless eclipse". The last axiom does not say that at noon the sun does not shine, it just says that as long as there is an eclipse (revision of belief) the sun does not shine and as soon as the eclipse disappears (new revision of belief), the sun shines again.

In the case of thyroid disease we state the following axiom : high-thyroid-hormone-secretion --> T3 increased, "unless renal failure." The unless clause can not be interpreted in terms of classical negation. It just says that if there is renal failure then the implication "high-thyroid-hormone-secretion --> T3 increased" does not apply. When the unless clause is not true any more, such as with kidney transplant, we come back to the initial situation.

There can be multiple instances of the unless-clause for each modus ponens.

This is observed in many situations, e.g. common sense reasoning and medical diagnosis. The reality of everyday life, with multiple situations and revisions, is the real source of non-monotonicity. Classical (monotonic) logic can not describe such situations.

In summary, the non-monotonic logic permits us to reconsider, in light of new observations, the entire conclusion that was reached and to revise our beliefs. Some of the related forms of non-monotonic works are described by M. Davis; [4], J. McCarthy; [21], D. McDermott, J. Doyle; [22], R. Reiter; [29], R. Weyhrauch; [35] and T. Winograd; [36].

5.2. Concept of Censors in Medicine

A disease, such as hyperthyroidism or a urinary tract infection, may often present as a single entity in an otherwise healthy young individual. However, as the individual ages, the number of underlying diseases present tends to increase. These different diseases may or may not influence each other with respect to clinical manifestations, laboratory findings, rate of progression, or therapeutic interventions.

As an example of such interactions, let us examine the common situation in which patients abuse both alcohol and cigarettes, resulting in the multiple complications of both, e.g. cirrhosis, upper gastrointestinal bleeding, anemia, chronic obstructive pulmonary disease, bronchogenic carcinoma, and coronary artery disease.

As an example of their clinical interaction, one might find a patient with COPD (Chronic Obstructive Pulmonary Disease) with chronic hypoxia and secondary erythrocytosis who undergoes a marked clinical worsening with an upper GI bleed because of loss of the oxygen carrying capacity of his red blood cells. In this case the bleed would be a "Censor" which might obscure the usual clinical finding of facial plethora due to the erythremia. The bleeding is also a "Censor" in that it will prevent the usual laboratory finding of an elevated hemotocrit. Conversely, the bleeding aggravates the clinical condition because of its contribution to tissue hypoxia.

Finally, the underlying severe COPD presents as a severe risk factor for surgery, should surgical intervention be required for the GI bleeding. this is another kind of "Censor" in which the presence of a second disease may alter the outcome of a therapeutic intervention. The recent appreciation of this latter type of "Censor" has spawned a new subspecialty interest, especially in the area of medical problems influencing surgical outcome. (ref- Molitch ME (ed). Management of medical problems in surgical patients. F. A. Davis, Philadelphia, 1982)

In the present paper we focus on Censors in the context of one disease causing an alteration of the typical laboratory findings of a second disease, as in the example of renal failure influencing T3 levels in a patient with hyperthyroidism. However, it should be recognized that this concept of Censors is more widely applicable to clinical findings and outcomes, as noted above.

5.3. Classification of Censors

In the cases of hyper and hypothyroidism, which are the most characteristic of the neuroendocrinological diseases, we have classified the whole range of diseases that have the effect of blocking or censoring hyper or hypothyroidism into two categories.

The two categories are:

1- Conditions which cause a decrease in T3 an T4 levels in blood

Surgery

Stress

Interaction with Glucocorticoids

Renal Diseases

Hepatic Diseases (chronic)

Infections

Malnutrition

Androgen use

2- Conditions which cause an increase in T3 and T4 levels in blood

Pregnancy

Oral Contraceptive

Overeating

The reasoning is the following: the basic part of the diagnosis of hyper and hypothyroidism, after all of the significant symptoms have been observed, is the test for the increased or decreased state of T3 and T4, the thyroid's secretions. As we know, when T3 and T4 levels are increased, the medical expert diagnoses for hyperthyroidism and when levels of T3 and T4 are decreased, for hypothyroidism.

Each of the diseases or situations stated in the two precedent categories has a determinant effect on the secretions and is the source of inhibition and confusion. Therefore, we called them Censors, because they prevent T3 and T4 from being in their proper state, either increased or decreased, for hyper and hypothyroidism. As an example, a patient with hyperthyroidism who shows all of the clinical aspects of hyperthyroidism plus infection does not show an increase of T3 on the laboratory test.

5.4. System with Censors

The rules for a diagnosis that the system creates are supplied with an "unless" condition that is a type of augmenting diagnosis. For example:

```
if
 thyroid hormone secretion is high
 ......
then
 patient has hyperthyroidism
unless
 T3 is not increased
```

The previous rule is blocked by one of the Censors that has a rule-like form as follows:

```
if
 patient has an infection
then
 T3 is not increased
```

This previous rule becomes a Censor with a blocking possibility over the first rule; it is therefore impossible to conclude hyperthyroidism. The blocking factor itself could be blocked and the diagnosis again follows the appropriate pattern. The following rule or Censor blocks the first one:

```
if
 patient takes antibiotics
then
 patient will not have infection
```

When infection (the first censor) is present, the principal clue to the diagnosis of hyperthyroidism, T3 increased, is no longer true. When the patient takes anti-biotics, the infection disappears and T3, again increased, allows us again to diagnose for hyperthyroidism.

To better understand this approach and the way that the Censors interact with each other, we will examine the following case of a patient where stress is the first Censor and end-of-stress is the second. The first Censor, which concerns stress, has the following description:

```
Censor-1. C1 is a Censor about a patient. The patient's T3 is not
increased because the patient is depressed. The patient is depressed
because the patient is stressed. Make C1 a Censor using the patient's
T3 is not increased.
```

The consequence of Censor-1 is the following rule, which has an unless condition (see section 5.1). That means, T3 is not increasing unless patient is not depressed.

```
if
 [PATIENT IS STRESSED] is TRUE
then
 [T3 INCREASES] is FALSE
unless
 [PATIENT IS DEPRESSED] is FALSE
```

In the case of a patient who is stressed :

```
Case-4. Jacques who is a patient has sleep-disturbances, diplopia,
hyperpigmentation, hyperphagia, profound-delirium, erythema and
palpitations. Jacques has high-thyroid-hormone-secretion and he is
stressed.
```

With the Censor present, we are not able to proceed to any diagnosis. As we saw previously, the system observes many symptoms that are due to hyperthyroidism. In addition, the system is aware that if hyperthyroidism is the correct disease diagnosis, the patient's T3 level should increase. However, the principal cause is blocked and we are not able to find T3 increased. The final message consists of the determinant message that T3 is not increased and a diagnosis is not available.

The second Censor has the following description:

```
Censor-2. C2 is a Censor about a patient. The patient is not depressed
because the patient is at the end-of-stress. Make C2 a Censor using
the patient is not depressed.
```

We easily conclude the following rule from axiom Censor-2.

```
if
 [PATIENT IS AT THE END-OF-STRESS]
then
 [PATIENT IS DEPRESSED] is FALSE
```

We now consider the case of a patient who is at the end-of-stress:

```
Case-5. Jacques who is a patient has sleep-disturbances, diplopia,
hyperpigmentation, hyperphagia, profound-delirium, erythema and
palpitations.  Jacques who was stressed has
high-thyroid-hormone-secretion and is now at the end-of-stress.
```

With the second Censor present, the reasoning is the following: First of all, because of the second Censor and because the patient is at the end-of-stress, the patient is not depressed any more. Because of the first Censor, not being depressed any more allows T3 to increase again.

Now we are again presented with all of the symptoms mentioned previously. Also, the increased levels of the thyroid secretions finally makes the system diagnose for hyperthyroidism again and the following rule is created, which looks like the first one except that it is based on the Case-5, Description-3, and Censor-2 as follows:

```
if

  [THYROID HAS    HIGH-THYROID-HORMONE-SECRETION]  is TRUE
  [THYROID CAUSES [PATIENT HAS SLEEP-DISTURBANCES]]  is TRUE
  [THYROID CAUSES [PATIENT HAS DIPLOPIA]]  is TRUE
  [THYROID CAUSES [PATIENT HAS HYPERPIGMENTATION]]  is TRUE
  [THYROID CAUSES [PATIENT HAS HYPERPHAGIA]]  is TRUE
  [THYROID CAUSES [PATIENT HAS PROFOUND-DELIRIUM]]  is TRUE
  [THYROID CAUSES [PATIENT HAS ERYTHEMA]]  is TRUE
  [THYROID CAUSES [PATIENT HAS PALPITATIONS]]  is TRUE

then

  [PATIENT HAS HYPERTHYROIDISM]  is TRUE

unless

  [T3 INCREASE] is FALSE

based on the exercise, CASE-5

and the precedents, DESCRIPTION-3 and CENSOR-2
```

As stated before, the medical specialist should thoroughly investigate his medical knowledge to find the real causes and the corresponding effects. In other words, we have to find the different elements that could obscure the findings and the results of the laboratory test.

Summarizing, the use of Censors, as shown above, could give a new perspective to clinical observation and clinical decision-making: a systematic study of the problem or secondary disease (related to the first disease), which has an important effect on the causality and leads to a false diagnosis.

6. Relation of Augmented Rule with the Near-Miss Idea

We saw, when two diseases are present, that we should consider the different points of interaction that could create a misunderstanding of diagnosis for either disease. The existence of several diseases could be the cause of an incorrect diagnosis. It appears that a Censor and an unless condition of a rule, such as "undernourished" or "infection", must be considered as the different points or axes through which a type of Near-Miss [38] reasoning occurs. We can observe the genesis of a near-miss idea when comparing a description containing one of the elements that blocks the reasoning (a Censor) and the rule with an unless possibility (the consequences) with one description without a blocking factor. In the universe of near-miss, the reasoning is based on incomplete information. Something should occur to make learning possible, to solve a problem and to create a concept.

In this paper we have discussed the different elements that obscure the complete information necessary for diagnosis, the problem to be solved and the learning that is possible. For example, when there is renal failure, we cannot diagnose hyperthyroidism. When a kidney transplant is performed, the proper reasoning takes place and the problem is solved. The different Censors that we have mentioned are the different axes needed for near-miss reasoning concerning the diagnosis of thyroid disease.

On a global level, the medical reality is the domain of interaction of the common conditions; renal failure obscures the diagnosis of another common condition, hyperthyroidism. All of these common condition interactions could have multiple effects on each specialty in the medical environment. When we do a systematic search of the elements that prevent the correct diagnosis and the problem solving for a specific domain such as thyroid disease, we have, in fact, established the different axes where the reasoning could have failed.

In this type of non-monotonic reasoning, the arrival of a new axiom could prevent the application of the basic premise, or a previous axiom permitting the diagnosis. We have generalized this non-monotonic reasoning with the censor mechanism and have shown how the near-miss idea is applied in medicine. The near-miss idea could be a powerful approach which permits, in a specific area, a non-monotonic way of reasoning in classifying the set of Censors that prevent the correct diagnosis. We approached the diagnosis of thyroid disease with a systematic research of Censors, a non-monotonic way of reasoning and, ultimately, an application of the near-miss idea in medicine.

7. Using Contextual Analogy and Censors

A context is considered as another aspect of constraint relations in the analogy between two situations. As we have already mentioned, in each situation a multiple constraint relation could exist: each one regarding the subject could be shown as a context. Therefore, by context we mean the association of some relations and causes that create a situation for a given domain.

Within this approach we create the association of the context with the related finding. A contextual approach considers the result immediately observable by a physician. A great number of physicians are often tempted to relate the symptom and the context to another one. In other words, another form of causality appears in their manner of reasoning, which is the association of context. This approach sometimes leads the physicians to the precise diagnosis, whereas multiple causes for each finding can be confusing and can give some indication but not enough information.

An excellent clinical domain for using the contextual analogy is in the case of neuroendocrinological diseases. The clinical context in which we could have the maximum amount of information is most specifically the thyroid diseases. Within hypo and hyperthyroidism, we have selected some nineteen contexts which determine the different categories of the diseases, as follows:

1- Skin
2- Connective Tissue
3- Eyes
4- Cardiovascular System
5- Otolaryngeal System
6- Gastro Intestinal Tract
7- Metabolic Changes
8- Vitamin Metabolism
9- Renal Function
10- Skeletal System
11- Neuromuscular System
12- Emotions and Mentations
13- Female Reproductive System
14- Male Reproductive System
15- Blood
16- Adrenal Cortex
17- Catecholamines and the Sympathoadrenal System
18- Thyroid Storm or Crisis
19- Pediatric Aspect

The specialist who examines a patient considers interactions between these different contexts; he does not consider symptoms in isolation from each other. In hyperthyroidism, for example, a physician may observe as the first context a complication in the eye; it could be connective tissue disorder or something else.

Many diseases can result in these types of complications. The physician, with the different contexts in mind, is naturally tempted to pursue his investigation before asking for any laboratory tests so that he will have a clearer idea about the reason behind the symptom and see how it is related to hyperthyroidism. As a second context, the observation of warm-skin or erythema, which are directly related to endocrinic problems, could lead him step by step to a better diagnosis.

The physician then goes through another context, which is asking the result of tests used to measure and assess the levels of T3 and T4, the thyroid's secretions. Increased or decreased T3 and T4 gives a better understanding of the situation.

The results of the laboratory tests concerning T3 and T4 have a determinant effect on the diagnosis of hyperthyroidism. Nevertheless, in the presence of Censors which interact with thyroid function, the result of the thyroid test may undergo substantial changes. We have enumerated, as shown in Chapter 4, the Classification of Censors which prevent thyroid diseases from being correctly identified. If the results of laboratory tests for T3 and T4 are not both positive and increased, we then study the interaction of the patient with the Censors.

For example, in hyperthyroidism, one of the most common contexts to consider is the eye. The physicians observes that within the eye there is a finding that is called exophthalmos. The result is the common finding for the disease to be diagnosed, hyperthyroidism, concerning the context of the eye.

As discussed before, the context in this example is considered to be another aspect of constraint relation in the analogy between two situations. In this case, the disease to diagnosis is one situation and hyperthyroidism is another. The diagnosis is done by creation of the association of the context with the related findings.

Skin is another context. The symptom erythema creates another analogy between the disease to be diagnosed and hyperthyroidism, with skin as a context. The association of the two contexts and the analogy of the findings with the related symptoms pushes the physicians to ask for the important test regarding the increased value of T3 and T4. With T3 and T4 increased, the physicians could diagnose for hyperthyroidism. If these two factors are not increased, the physicians verifies if there are any Censors, which prevent these secretions from being increased.

If the Censors are found, the physicians then asks for the ultimate test, which is the TRH/TSH test. This is an important, but very long, slow test that is usually performed to either confirm or reject the previous diagnosis. In fact, the patient could have a renal disease preventing T3 and T4 from being increased and could also have either exophthalmos or erythema without having hyperthyroidism. If the result of the test for TRH/TSH is positive, the physicians observes that exophthalmos and erythema were related to hyperthyroidism but that a second disease, infection, would have prevented T3 and T4 from increasing.

8. Conclusion

Concepts such as blocking points or Censors, which are important and interesting features in the effect of multiple diseases on each other, as well as cause/effect relations and reasoning by analogy within an implemented system, were all considered in the diagnosis of thyroid diseases.

Our approach toward medical decision-making was basically a type of non-monotonic reasoning where the censoring mechanism played the primary role. The idea was based on clinical observations of how certain diagnoses related to these diseases were made in a medical environment. Therefore, we consider this work to be based on our observation of medical practice. Later, we systemized a set of the so-called Censors for all thyroid diseases. Another future step would be to generalize this crucial part of the medical diagnosis, the mechanism of Censors or blocking points, to other medical domains and to establish a systematic number of Censors for each diagnosis.

An extension of this work, in the future, would be a more in-depth approach to non-monotonic reasoning and its relation to censoring and the near-miss idea. For a precise domain of medicine, defining the different axioms where censoring would be an important component could invalidate reaching a conclusion and problem solving. Another important component would be the element of qualitative process [8], such as, in the case of neuroendocrinology, the cessation of process of conversion of T4 to T3. The different conversions, specifically hormonal and their variations based on qualitative processes, could be another important component in the study of the nonmonotonical approach and the near-miss idea.

Finally, we should approach the implementation of a generalized network of near-miss where each Censor is one particular case of near-miss that prevents and blocks the system from making a diagnosis. Another element of the system would be the systematic study of the variance in conversion as a qualitative process, which creates another axis of reasoning for near-miss. This would enable the system with multiple axes of near-miss to have more powerful reasoning and would permit a more in-depth explanation for the diagnosis. In this case, the Censoring and qualitative processing would be two major axes of non-monotonic reasoning.

9. Appendix

In previous sections we discussed the two main categories of censors. Here we discuss each one individually and their effects on different composites of the thyroid's secretions.

SURGERY

After any type of surgery, a normal patient has a decrease of T3, T4 and TSH:

-T3	decreased	instead of normal
-T4	normal or decreased	instead of normal
-TSH	normal or decreased	instead of normal

There could be confusion with hypothyroidism. After recovery, there is a new variation of T3, T4 and TSH:

-T3	normal
-T4	normal
-TSH	normal

In this case, surgery which prevents T3, T4 and TSH from having their effective value is Censor1. The time necessary to fully recover from surgery and to have normal levels of T3, T4 and TSH again is Censor2 which inhibits Censor1.

STRESS

In any other type of stress (not mentioned in the category of stress), for a normal patient and a patient with hyperthyroidism, there is a decrease of T3:

-Normal patient T3 decreased instead of being constant

-Hyperthyroid patient T3 decreased or normal instead of increased

Stress that prevents T3 from being constant (normal patient) or from increasing (hyperthyroid patient) is decreased (leading to confusion with hypothyroidism). In this case, stress is Censor3. The cessation of stress is Censor4 which inhibits Censor3 and makes T3 constant or increased.

INTERACTION WITH GLUCOCORTICOIDS

Medication with glucocorticoids and ACTH causes a decrease of T3 in a normal patient and in a patient with hyperthyroidism:

-T3 decreased for normal patient instead of being constant

-T3 decreased for hyperthyroid patient instead of increased

Here, there is also a possibility of confusion with hypothyroidism. Glucocorticoids is Censor5, which prevents T3 from being constant (normal patient) or from increasing (hyperthyroid patient). Not being under Glucocorticoids medication is Censor6, which inhibits Censor5, and makes T3 constant (normal patient) or increase (hyperthyroid patient).

RENAL DISEASES

In the case of a normal patient with a renal disease, there could be a decrease of plasma T4 and a decrease of T3:

-Free T4 normal or increased instead of being normal

-Total T4 normal or decreased instead of being normal

-Total T3 decreased instead of being normal

In this case, the renal disease is Censor7 which prevents T3, total T4, and free T4 from having their normal levels. The medication and termination of the renal disease make up Censor8 which inhibits Censor7 and makes free T4, total T4 and T3 have constant levels again.

HEPATIC DISEASES (CHRONIC)

In a normal patient with a hepatic disease, there could be an increase of free and total T4 and a decrease of total T3:

-Free T4 normal or increased instead of being normal

-Total T4 normal or increased instead of being normal

-Total T3 decreased instead of being normal

In this case, the hepatic disease is Censor9. It prevents T3, total T4 and free T4 from reaching their normal levels. The medication and termination of the hepatic disease make up Censor10 which inhibits Censor9 and allows free T4, total T4, and T3 to reach their normal levels again.

INFECTIONS

In a normal patient or one with hyperthyroidism, who has a severe infection, we observe the following variations:

Normal Patient

-T3 is decreased instead of normal

-Total T4 is normal or decreased instead of normal

-Free T4 is normal or increased instead of normal

Patient with Hyperthyroidism

-T3 is normal or decreased instead of increased

-T4 is normal or increased instead of increased

The infection prevents T3 and T4 from increasing. The infection is Censor11 and anti-biotics that inhibit Censor11 constitute Censor12. The final result of the two Censors is that the real case of hyperthyroidism appears again with increased levels of T3 and T4.

MALNUTRITION

In a patient with hyperthyroidism who has also fasted for a long time and has nutritional problems, the same phenomenon happens as with infections:

-Normal Patient

-T3	is decreased instead of normal
-Total T4	is decreased instead of normal
-Free T4	is normal or increased

-Patient with Hyperthyroidism

-T3 is normal or decreased instead of increased

-T4 is normal or increased instead of increased

The malnutrition prevents T3 and T4 from being increased. Malnutrition is Censor13 and the food which inhibits Censor13 (malnutrition) is Censor14. After the effects of Censor18, hyperthyroidism is present; T3 and T4 are increased and the other characteristic symptoms are back again.

ANDROGEN USE

In a patient with androgen use, the following state of decrease for a normal patient or a patient with hyperthyroidism is observed:

-Normal Patient

-T3	is decreased instead of normal
-Total T4	is decreased instead of normal
-Free T4	is normal or increased

-Patient with Hyperthyroidism

-T3 is normal or decreased instead of increased

-T4 is normal or increased instead of increased

The androgen use prevents T3 and T4 from increasing. The androgen use is Censor15 and the end of androgen use that inhibits Censor15 (androgen use) is censor16. After the effects of Censor16, hyperthyroidism is present; T3 and T4 are increased and the other characteristic symptoms are back again.

PREGNANCY

Pregnancy produces a clinical state of hyperthyroidism as follows:

-Total T4	increases instead of being normal
-Bound T4	increases instead of being normal
-Total T3	increases instead of being normal
-Bound T3	increases instead of being normal
-Free T4	normal
-Free T3	normal

Because pregnancy produces changes in the normal amounts of the above secretions, one could make a diagnosis of hyperthyroidism, which is not the real case. Here, pregnancy is Censor17 which prevents the secretions from being at normal levels. The "birth" is Censor18 which inhibits Censor17 and allows the secretions to reach their normal levels again.

ORAL CONTRACEPTIVE

Birth control pills have exactly the same effect as estrogen and pregnancy, and produce a clinical state of hyperthyroidism as follows:

-Total T4	increases instead of being normal
-Bound T4	increases instead of being normal
-Total T3	increases instead of being normal
-Bound T3	increases instead of being normal
-Free T3	normal
-Free T4	normal

Birth control pills could lead to an incorrect diagnosis of hyperthyroidism (T3 and T4 are increased). The birth control pill is Censor19, which prevents T3 and T4 from being at their normal levels. The stopping of birth control pill usage is Censor20 which inhibits Censor19 and allows T3 and T4 to be at normal levels again.

OVEREATING

Overeating, an opposite state of malnutrition, also produces a clinical state of mild hyperthyroidism with:

-Total T4	increases instead of being normal
-Bound T4	increases instead of being normal
-Free T4	increases instead of being normal
-Total T3	increases instead of being normal
-Bound T3	increases instead of being normal
-Free T3	increases instead of being normal

Overeating creates a real situation of hyperthyroidism (although it is not the case). Overeating is Censor21. The cure from overeating is Censor22 that inhibits Censor21 and creates a normal situation for releasing the hormones of the thyroid again.

10. Acknowledgments

Many people commented on the contents of this paper, made valuable suggestions and contributed to its publication. I am grateful to all of them and particularly to: Peter Andreae, Pierre le Beux, Randy Davis, Rhonda Goddard, Michel De heaulme, Marvin Minsky, Mark Molitch, Ramesh Patil, Gloria Rudisch, Warner Slack, Gerald Jay Sussman and Peter Szolovits.

11. References

* 1-Blancher, R., "Le Raisonnement," P.U.F. Paris, 1973.

* 2-Cavalieri, R.R., Rapoport, M.B., "Impaired Peripheral Conversion of Thyroxine To Triiodothyronine," Annual Review of Medicine, 1977.

* 3-DeGroot, L.J., Stanbury, J.B., "The Thyroid and Its Diseases," Fourth Edition, 1975.

* 4-Davis, M., "The Mathematics of Non-Monotonic Reasoning," Artificial Intelligence Volume 13 Number 1,2 April 1980.

* 5-Davis, R., "Teiresias: Applications of Meta-Level Knowledge," in Knowledge-Based Systems in Artificial Intelligence, edited by Randall Davis and Douglas B. Lenat, McGraw-hill Book Company, New York.

* 6-De Kleer, J., "causal and Teleological Reasoning in Circuit Recognition," Report TR-529, MIT, Cambridge, MA Artificial Intelligence Laboratory, 1979.

* 7-Dietterich, T.G., and R.S. Michalski., "Inductive Learning of Structural Descriptions," Artificial Intelligence, vol. 16, no. 3, 1981.

* 8-Forbus, K.D., "Qualitative Process Theory," Report AIM-664, Artificial Intelligence Laboratory, MIT, Cambridge, MA, 1982.

* 9-Gentner, D., "Structure-Mapping: A Theoretical Framework for Analogy," Cognitive Science, vol. 7 no. 2, 1983.

* 10-Gorry, G.A., Silverman, H., and Pauker, S.G., "Capturing Clinical Expertise: A Computer Program that Considers Clinical Responses to Digitalis," American Journal of Medicine, March 1978.

* 11-Ingbar, S.H., and Braverman, L.E., "Active Form of the Thyroid Hormone," Annual Review of Medicine, 1976.

* 12-Jackson, I., "Medical Progress: Thyrotropin-Releasing Hormone," New England Journal of Medicine, January 1982.

* 13-Kulikowski, C.A., and S.M., Weiss, "Representation of Expert Knowledge for Consultant," in Artificial Intelligence in Medicine, edited by Peter Szolovits, Westview Press, Boulder, CO, 1982.

* 14-Linquette, M., "Endocrinologie, Semiologie Physiopathologique," Editions Balliere, Paris (6) 1975.

* 15-Mansour, H., "A Structural Approach to Analogy," MIT AI Memo No 747 November, 1983.

* 16-Mansour, H., "Techniques de raisonnement par analogie pour la prise de decision cliniques." COGNITIVA 85 : De l'intelligence artificielle aux biosciences, 1985, Paris.

* 17-Mansour, H., "The Use of Censors and Reasoning by Analogy to Aid in the diagnosis of Thyroïd Diseases," MIE-85 : Sixth International Congress on Medical Informatics, 1985, Helsinki.

* 18-Mansour, H., "Censors and Analogy in the Diagnosis of Thyroid Diseases," International Working Conference Computer-Aided Medical Decision-Making, 1985, Prague.

* 19-Mansour, H., Molitch, M., "A New Strategy for Clinical Decision Making : Censors and Neuroendocrinological Diseases." Accepted Paper : Computers in Biology and Medicine An International Journal, Washington, D.C. 20007, U.S.A.

* 20-Martin, J.B., Reichlin, S., and Brown, G.M., "Clinical Neuroendocrinology, Contemporary Neurology Series," 1977.

* 21-McCarthy, J., "Circumscription- A Form of Non-Monotonic Reasoning," Artificial Intelligence, Volume 13 Number 1,2 April 1980.

* 22-McDermott, D., and Doyle, J., "Non-Monotonic Logic 1," Artificial Intelligence, Volume 13 Number 1,2 April 1980.

* 23-Michalski, R.S., J.G., Carbonell and T.M., Mitchell (editor), "Machine Learning-An Artificial Intelligence Approach," Tioga Publishing Company, Palo Alto, CA, 1983.

* 24-Minsky, M., "Jokes and the Logic of the Cognitive Unconscious," MIT AI Memo November, 1980.

* 25-Newell, A., and Simon, H., "A Human Problem Solving," Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1972.

* 26-Patil, R. S., Szolovits, P. and Schwartz, W. B., "Causal Understanding of Patient Illness in Medical Diagnosis," Proc. Seventh Intl. Joint Conf. on Artificial Intelligence, University of British Columbia, Vancouver B. C., Canada.

* 27-Patil, R. S., "Causal Representation of Patient Illness for Electrolyte and Acid-Base Diagnosis," Ph.D. thesis, Dept. of Electrical Engineering and Computer Science, MIT Lab for Comp. Sci., Cambridge, Mass., (Oct. 1981)

* 28-Pople, H.E., Jr., "Heuristic Methods for Imposing Structure on Ill-structured problems: The structuring of Medical Diagnostics," in Artificial Intelligence in Medicine, edited by Peter Szolovits, Westview Press, Boulder, CO, 1982.

* 29-Reiter, R., "A Logic for Default Reasoning," Artificial Intelligence, Volume 13 Number 1,2 April 1980.

* 30-Schimmel, M., and Utiger, R.D., "Thyroidal and Peripheral Production of Thyroid Hormones; Review of Recent Findings and Their Clinical Implications," Annals of Internal Medicine, 1977.

* 31-Schwartz, W.B., "Medicine and the Computer: The Promise and Problems of Change," New England Journal of Medicine, 1970.

* 32-Shortliffe, E.H., "Knowledge Engineering for Medical Decision Making: A Review of Computer-Based Clinical Decision Aids," Proceeding of the IEEE, 1979.

* 33-Szolovits, P., and Pauker, S.G., "Computers and Clinical Decision Making: Whether, How, and For Whom?," Proceeding of the IEEE, 1979.

* 34-Werner, S., and Ingbar, S.H., "The Thyroid: A Fundamental and Clinical Test," Fourth Edition, 1978.

* 35-Weyhrauch, R.W., "Prolegomena to a theory of Mechanized Formal Reasoning," Artificial Intelligence Volume 13 Number 1,2 April 1980.

* 36-Winograd, T., "Extended Inference Modes in Reasoning by Computer Systems," Artificial Intelligence Volume 13 Number 1,2 April 1980.

* 37-Winston, P.H., "Learning New Principles from Precedents and Exercises," Artificial Intelligence, vol.10, no. 2, 1982.

* 38-Winston, P.H., "Artificial Intelligence," Second Edition, Addison-Wesley,1984.