# THE MEDICAL EXPERT SYSTEM CADIAG-2, AND THE LIMITS OF REFORMULATION BY MEANS OF FORMAL LOGICS

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## *Abstract*

*The medical expert system Cadiag-2 is characterized by its ability to process not only definitely true or false, but also indeterminate (vague or uncertain) information. To process indeterminate information is, on the other hand, the main purpose of t-norm-based fuzzy logics. Thus, for the advancement of a system like Cadiag-2, we should be able to benefit from the extensive possibilities in the field of fuzzy logics, which has developed in recent years considerably. To do so, we have reviewed both concepts – the one underlying Cadiag-2, the other underlying fuzzy logics – thoroughly in a comparative way. It turned out that there are indeed in certain respects amazing similarities; some fundamental differences, however, cannot be easily overcome.*


## 1. Introduction

The aim of this paper is to describe the inference mechanism of Cadiag-2, a medical expert system based on fuzzy technology, in a framework which comes very close to the formalism of t-norm-based propositional fuzzy logics. Our work aims at a formal analysis of the system. Such an analysis is the indispensable basis for an understanding and a justification of the underlying concept, then for modifications and improvements of the inference engine, and finally for the consistency checking of the comprehensible knowledge base, which by today has not been done by automated means.

### 1. 1. The medical expert systems Cadiag

Cadiag – the acronym meaning computer-assisted diagnosis – refers to a series of medical expert systems which have been developed by Prof. K.-P. Adlassnig and his colleagues at the University of Vienna Medical School from the early 80's on and which are today a central subject of research at the Institute for Medical Expert and Knowledge-Based Systems at the Medical University of Vienna [1,2,3]. The general scope is to support the medical personnel in interpreting a patient's symptoms, signs, laboratory test results, and clinical findings, and in generating a complete clinical differential diagnosis. For the performance of these systems, see, e. g., [4].

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The first system, Cadiag-1, was based on three-valued logic. This means that a medical entity, like a symptom or a diagnosis, was specified in one out of three ways: as true, false, or undetermined. Accordingly, the inference engine of this system resembled classical propositional logic.

The usability of any expert system based on a two- or three-valued logic is limited. Namely, to decide if a symptom applies in practice or not, can be delicate or even impossible; a symptom is usually a vague property. In accordance with a presently quite popular direction in philosophy, we call a property vague if there are borderline cases among the objects of reference. For instance, a property like “having high fever” or “suffering from strong abdominal pain” can not be appropriately assigned a *yes* or a *no* if the actual state of the patient is neither confirming nor excluding.

To deal with such situations, the successor system Cadiag-2, for whose comprehensive specification we refer to [6], allows for an extended way to evaluate properties. A symptom may be assigned not only 0, meaning *false*, or 1, meaning *true*, but in addition any real value in between these two values if a tendency is to be expressed. So for instance, 0.2 means for a symptom to hold only weakly; to assign to a symptom the value 0.9, in contrast, means that the actual state of the patient is in a significantly better, although still not perfect, accordance with the statement that the symptom holds.

Cadiag-2 assigns truth values in three different contexts: to symptoms in order to express the degree of compatibility, to diagnoses in order to express the degree of certainty, and finally to implications in order to treat non-strict causal relationships. Consider the following easy example, cited from [3].

Example of a rule from the Cadiag-2 knowledge base

IF *suspicion of liver metastases by liver palpation*
THEN *pancreatic cancer*
with the degree 0.55.

This rule works as follows. If, due to a liver palpation, there is the evident suspicion of liver metastases, we associate to the statement “suspicion of liver metastases by liver palpation” the value 1; in this case, we assign to the diagnosis “pancreatic cancer” a degree of certainty of 0.55.

If the mentioned suspicion is not so clear, but still quantified by a value of at least 0.55, the conclusion will be the same.

If a suspicion is present, but to a degree of less than 0.55, say 0.2, then the degree of certainty about the diagnosis “pancreatic cancer” will be degraded to 0.2.

The systems Cadiag-3 and Cadiag-4 use an even much more sophisticated set of truth values for medical entities. These systems, however, will not be treated in this note.

### 1. 2. Fuzzy logics

Rather independently from possible applications, the field of fuzzy logics has developed considerably during the last ten years. A milestone is the monograph [8] of P. Hájek from the Czech Academy of Sciences in Prague. Basic information on fuzzy logics can be found there.

A fuzzy logic, understood as a formal logical calculus, deals with a number of propositions and their mutual logical interrelations. These propositions are not considered with respect to their content; they are treated just like an entity which can hold or not. However, what makes a logic a fuzzy logic, is the fact that the propositions are not assumed to be either fully true or fully false; they can be assigned any truth value from the set [0,1] of real numbers between 0 and 1.

Now, there are dozens of fuzzy logics; for us, the fuzzy logics with so-called evaluated syntax [9] are most interesting. With these logics, we never consider a proposition alone, but always together with a specific truth value;

$$(\varphi, t)$$

denotes the (possibly vague) property $\varphi$ together with a real value $t \in [0,1]$ expressing to which degree $\varphi$ holds.

In Hilbert-style formalizations of classical propositional logics, we have the *modus ponens* as our inference rule: From $\varphi$ and $\varphi \to \psi$, conclude $\psi$. In fuzzy logics with evaluated syntax, we typically have the following analogous rule, called the *generalized modus ponens* [7]:

$$\text{(gmp)} \qquad \frac{(\varphi, t) \quad (\varphi \to \psi, d)}{(\psi, t * d)}$$

where $*$ denotes an operation on [0,1] combining two truth values, for instance, by selecting the smaller one of the two values or by multiplying them. This rule can be interpreted in the following way: Assume that $\varphi$ holds to the degree $t$; assume furthermore that $\varphi$ implies $\psi$ to the degree $d$; then we can conclude that $\psi$ holds to the degree $t * d$. We shall see that this rule perfectly reflects the mode of operation of Cadiag-2.

## 2. Cadiag-2 – a fuzzy logic?

We now return to the question posed at the beginning. Can Cadiag-2 be understood as a particular fuzzy logic? In this case, the full apparatus of formal logics which has been developed in this field during the last decade, could be applied. We shall exhibit a partly positive and partly negative answer.

In a recent joint work with A. Ciabattoni, we have formulated the inference mechanism of Cadiag-2 in the style of a logical calculus, called *Cadiag logic*, or `CadL` for short. We cannot explain the details here; the formal apparatus will be explained in a forthcoming paper [10]. We concentrate here on the qualitative aspects.

The main inference rule of our calculus `CadL` is the following:

$$\text{(c)} \qquad \frac{(\varphi, t) \quad (\varphi \to \psi, d)}{(\psi, t \wedge d)}$$

where $\varphi$ is, e.g., a symptom or a logical combination of symptoms, $\psi$, e.g., refers to a specific disease, and $t$, $d$ are non-zero truth values. Moreover, $\wedge$ denotes the infimum operation, that is, $t \wedge d$ is the smaller of the two values $t$ and $d$.
It is evident that (c) coincides with (gmp), the generalized modus ponens, perfectly; we just have to put $* = \wedge$. More generally, we may say that, on the syntactical level, a good amount of coincidence between Cadiag-2 and fuzzy logic applies.

For comparative purposes, we should oppose `CadL` to a specific fuzzy logic in the sense of [8]. We have to specify the fuzzy logic which comes closest to the concept underlying Cadiag-2.

The procedure is straightforward. Namely, a fuzzy logic is based on a specific semantics, that is, on a specific interpretation of its symbols. In the typical case, propositions are interpreted by real values between 0 and 1; the conjunction is interpreted by a so-called t-norm, an example of which is the mentioned operation $\wedge$; and an implication connective is interpreted in a way that $\alpha \to \beta$ is true exactly if $\alpha$ has a smaller truth value than $\beta$.

These ideas are compatible with the concepts underlying Cadiag-2. The t-norm used is $\wedge$. The fuzzy logic based on this semantics, will be called *Gödel-Zadeh logic*, or `GZL` for short. `GZL` is a variant of a logic discussed in [5]; `GZL` comes close to the well-known Gödel logic [8], and also resembles the formalism proposed by Zadeh in [11].

Note that `GZL` and `CadL` both have the same purpose — to emulate Cadiag-2; they are, however, defined in different ways. Namely, `CadL` was defined purely syntactically, by providing a set of rules emulating the rules of Cadiag-2. In contrast, `GZL` is the logic deriving all what follows from a set of statements on base of a specific meaning of these statements. So it might not be surprising that `GZL` does not coincide with `CadL`.

The relationship can in fact be stated as follows: All statements and inferences of `CadL` can be translated to propositions and proofs in `GZL`; and what can be inferred in `CadL` can also be proved in `GZL`. The converse, however, does not hold: Given a set of propositions translated from `CadL`, `GZL` can, in general, infer more information than `CadL`. The fuzzy logic `GZL` is strictly stronger than Cadiag-2.

The challenge is to explain what makes `GZL` stronger. An exact formal characterization seems impossible, but on an informal level, the following can be said in view of the two calculi `CadL` and `GZL`.

1. GZL proves all what holds with respect to the interpretation by truth values. So for instance, for a pair **Fehler! Es ist nicht möglich, durch die Bearbeitung von Feldfunktionen Objekte zu erstellen.**, we always have that either **Fehler! Es ist nicht möglich, durch die Bearbeitung von Feldfunktionen Objekte zu erstellen.** or **Fehler! Es ist nicht möglich, durch die Bearbeitung von Feldfunktionen Objekte zu erstellen.**; in the calculus GZL, we can accordingly express that “either fact 1 holds stronger than fact 2, or the other way round.”
2. In contrast, CadL allows only “straightforward” argumentation, and we cannot change to the metalevel. It is impossible to argue about logical relationships, that is, a sentence like “fact 1 holds stronger than fact 2” cannot be part of a more complex statement.

## 3. Conclusion

It is possible to formulate the mode of operation of Cadiag-2 by a formal logical calculus, called `CadL` and resembling common proof systems for fuzzy logics. Furthermore, the calculus `GZL` is the fuzzy logic based on the same semantics like Cadiag-2. It turns out that `GZL` infers all what can be inferred in `CadL`, and `GZL` is strictly stronger.

One may ask if Cadiag-2 should be made stronger by means of the possibilities offered by the fuzzy logical calculus `GZL`. According to our present opinion on this delicate matter, we recommend to be cautious. A problem is that proofs of `GZL` are just sound with respect to the chosen interpretation; but they are in general not translatable to a comprehensible argumentation and for this reason not always useful. We have opted to check possible modifications of the logic instead.

We may summarise that the medical expert systems Cadiag on the one hand and t-norm based fuzzy logics on the other hand, are conceptually very closely related; the underlying ideas are the same in most respects. There are furthermore differences which cannot be easily overcome. By choosing mutually compatible presentations, we were able to exhibit both the common ground and the differences in a clear way.

It will be our next step to introduce more flexible concepts to logic in order to cope with the particular needs of Cadiag-2 and all other medical expert systems which deal with vague data and which are based on the idea that all results need to justified by a chain of convincing arguments.

## 4. Literature

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