Fuzzy Temporal Profiles: A Model for the Representation and Recognition of Signal Patterns

Graduated: Paulo Félix
Departamento de Electrónica y Computación
Universidad de Santiago de Compostela

Advisor: Senén Barro Ameneiro
Departamento de Electrónica y Computación
Universidad de Santiago de Compostela

Abstract

One of the first aims of Artificial Intelligence is the development of models and systems that solve problems relative to the interpretation of a certain environment, trying to simulate those representation and reasoning schemes inherent to the human being. The purpose is to automatize some of the tasks that experts habitually carry out, so that the result is not distinguished from the one they would have obtained. In the thesis summarized here, we propose a new model, which we have named Fuzzy Temporal Profile (FTP), for the representation of vague knowledge and the reasoning on the evolution of a physical parameter in time. This model has been put into practice in an intelligent supervision system of patients hospitalized in Intensive Coronary Care Units (ICCU).

Our proposal belongs to the set of structural methods for the recognition of patterps, in such a way that a segmentation of the input data is made; that later is contrasted with a reduced set of the elements that define the pattern. The objective is to manage those problems in which explicit information about the pattern morphology is available, and where the knowledge nature is fundamentally descriptive.

One of the fundamental ideas on which the FTP model is based is the one of *modeling the flexibility that characterizes the human knowledge,* that is, we try to capture as far as possible the richness of nuances contained in descriptions made by the experts. In order to do so, the FTP is based on the *constraint network* formalism and on the *fuzzy set theory*. The former supplies a representation structure that facilitates the computational projection of a linguistic description. The latter allows the manipulation of vagueness and uncertainty, which are characteristic of the terms used in natural language.

1 The FTP model

A Fuzzy Temporal Profile (FTP) (Félix P., *et al.*, 1999b) is defined as a network of relations between a set of especially significant points on the evolution of a certain parameter. On one hand, these relations fix the temporal distance, increase in value and slope between each pair of these points, and on the other hand, allow the modelling of the behaviour of the evolution fragment between them.

Model Definition

Each significant point $X = <V, T>$ is defined as a pair of variables: V represents an unknown value of the physical parameter, and T represents an unknown instant of time. In absence of any constraint, the variables V and T can take any precise value v and t, respectively.

A constraint $R_{ij} = <D_{ij}, L_{ij}, M_{ij}, S_{ij}>$ on two significant points X_i and X_j is a 4-tuple formed by a fuzzy duration D_{ij}, that restricts the domains of the possible values of the variables V_i and V_j; a fuzzy increment L_{ij}, that restricts the domains of the possible values of the variables T_i and T_j; a fuzzy slope M_{ij}, that jointly restricts the domains of the possible values of the variables V_i, V_j, T_i and T_j; and a descriptor S_{ij} of the profile evolution between the two significant points.

A Fuzzy Temporal Profile $N=\{X,R\}$ is defined as a finite set of significant points $X=\{X_i, X_j, ..., X_N\}$ and a finite set of constraints $R=\{<D_{ij}, L_{ij}, M_{ij}, S_{ij}>, 0 = i,j = N\}$ between these points (Figure 1).

between two significant points takes place, as it is the case of *"... throughout the following fifteen minutes the temperature rises moderately ten degrees"* or *"during the last two hours the temperature is high"* (Felix P. et al, 1998). With the purpose of incorporating the representation of the evolution between each of the two significant points, we have modeled an expandable set of characteristic evolutions associated to different semantics, and whose assignment is made by means of the constraint S_{ij}, so that the compatibility between the section descriptor and a fragment of the temporal evolution of a physical variable can be calculated. This section descriptor is modeled by means of a fuzzy set that shows vagueness and imprecision that characterizes the experts' idea on the desired evolution of the physical parameter under study (Figure 2).
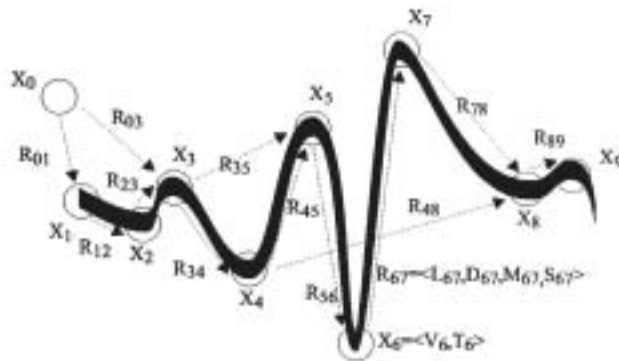

Figure 1: An intuitive idea of an FTP and a possible network that describes it

The constraints on the duration, increase in value and the slope are defined by means of normalized and unimodal possibility distributions, and enable us to model the relations between a set of signal events of special significance for the expert user, which we can find in sentences of the type of *"shortly after the temperature is much more higher"*.

In the representation of an FTP, we have attempted to model those qualitative relations that appear in the bibliography. Thus, we represent between instants those of convex point algebra (Vilain M. y Kautz H. 1986), or between intervals, those defined by Allen (Allen J., 1984). In addition, a representation based on fuzzy sets allows the model to capture the imprecision present in the quantitative relations between temporal facts, which can be found in expressions of the type of *"approximately 5 minutes later"*.

In addition, the natural language allows the expression of a set of descriptions of the manner in which the evolution
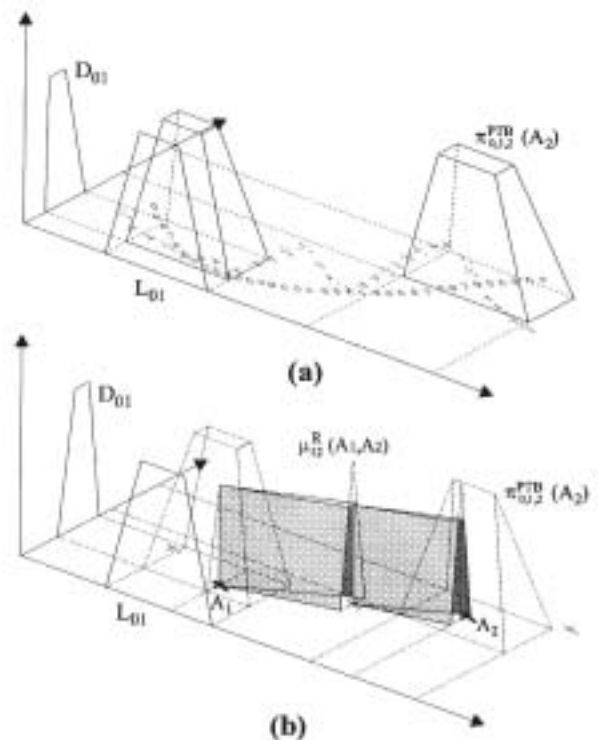

Figure 2: This figure shows the representation of two semantics of evolution in the FTP model. In a) the semantics of sentences of the type "some time later the temperature is higher" is modeled, where the trajectory of the physical parameter between the ends does not matter. In b) the semantic of sentences of the type "throughout the following minutes, the temperature rises slightly" is modeled.

Analysis of the Consistency of the FTP Information

It is made by means of a set of techniques aiming at its *minimization*. Due to the linguistic nature of the FTP acquisition, it is foreseeable that its description contains redundant or inconsistent information. We will call FTP minimization the process by which we eliminate from the domain of each variable those values that are incompatible with the constraints on this variable, in order to obtain an FTP in which the relations are defined in the most precise way. In addition, in this minimization process, the presence of inconsistent information in the network will be detected. We have demonstrated that the problem of minimizing an FTP is NP-complete and, as a result, we have developed a set of algorithms that assure local levels of consistency: what we call *path consistency*, and *section consistency*. In addition, we have proposed a different topology simpler than the general one, that defines what we call *Sequential Fuzzy Temporal Profile*, and whose consistency, following a predetermined order in the signal segmentation, is assured with a computational complexity $O(N^3)$.

Development of an FTP Recognition tool

It consists of a set of algorithms that carry out the recognition (matching) task of those profiles defined by the expert on the real evolution of a certain parameter. The developed algorithms are based on the concept of optimal solution, that supposes the search, on a signal, of network solutions: sets of assignments to the significant points that are compatible in the greatest degree possible with the network constraints. This optimal solution is constructed by means of a search tree, where each one of the leaves is given by an assignment to all the significant points of the FTP, following the typical *first in depth* search method. Due to the theoretical high computational complexity of this process some heuristics have been added in order to speed up the recognition task, based on the properties of the signals on which the recognition will be carried out, or in the properties of the FTP to be detected. In addition, other questions like FTP recognition on signals with loss of information are discussed: signal fragments whose values have not been acquired or have been invalidated (presence of artifacts, for example).
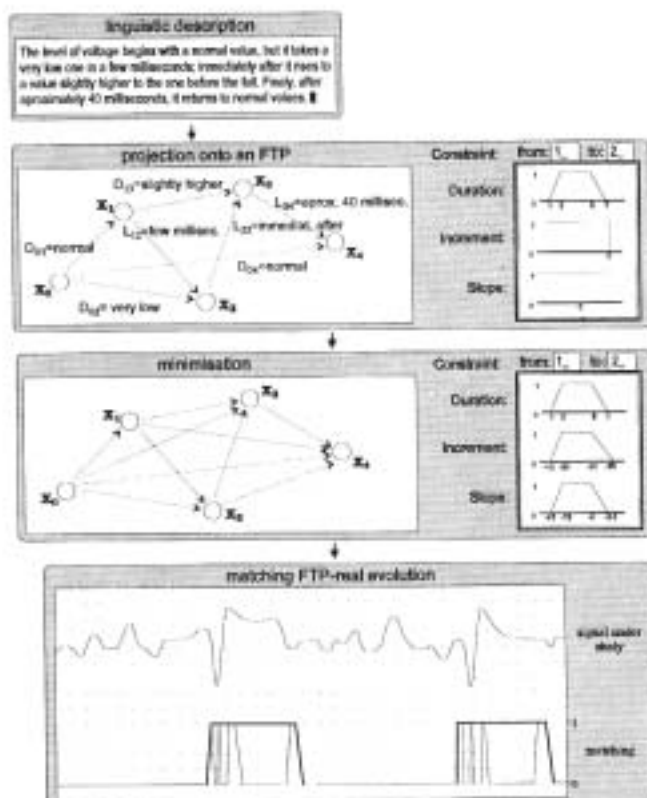

Figure 3: Example of the different stages setting up an application of the Fuzzy Temporal Profile model.

Knowledge Linguistic Acquisition

Although the FTP model is not tied to a certain form of information acquisition, in this work we have wagered for a linguistic acquisition. From this point of view, the FTP constitutes a proposal for the modeling of the semantics of some expressions of the natural language that describes the temporal evolution of a physical parameter. We have tried to obtain an artificial language (Félix P., *et al.*, 1999b) in a register as close as possible to that used by human experts to communicate their knowledge. This language, generalization of a previous work of Barro *et al.* (Barro S., *et al.*, 1994), permits the evolution description of a physical parameter and its projection in terms that define the FTP model. It is based in the BNF (Backus-Naur form) metalanguage, and it may be easily merged in the main structure of the European pre standard TSMI-CEN/TC251 for the representation of temporal problems in computerized medical environments (Ceusters W., *et al.*, 1997).

Implementation of the FTP Model in an Intelligent Supervision System in ICCU

Lastly, we propose the implementation of the Fuzzy Temporal Profile model in a recognition agent, integrated in a signal perception specialist system (Fraga S., et al., 1998), which also forms part of an intelligent patient supervision system for Intensive Coronary Care Units (ICCU). The implementation of this system is made on a recursive structure of specialists, based on blackboard architecture. Also, the integration of FTP in a representation scheme of temporal information is shown, based equally on the formalism of constraint networks, and that shows the set of temporal relations between the different

pieces of reasoning: hypothesis, manifestations, implied hypothesis,... The work proofs how the wager for the formalism of constraint networks allows the obtainment of a temporal information abstraction tool; and how this tool makes easier the integration in the diagnostic process of the information coming from the perception specialist.

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