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The following papers were not included in their appropriate categories due to unforeseen last minute changes in the program.

TEMPORAL FUZZINESS
IN COMMUNICATIONS SYSTEMS

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ABSTRACT

Communication systems are real-time deterministic, well defined systems that transport voice/data signals from point A to point B reliably. However, the transmitted signal is subject to significant distortion by the very harsh environment, the medium, and the system itself. Despite this, data reaches its destination crispily or error-free. To achieve the high quality of error-free data, mechanisms that affect the quality of signal are addressed a priori and countermeasures are developed so that the potentially "fuzzifiers" are removed or "de-fuzzified". Here, the fuzzification-defuzzification process of the signal in real-time communication systems is addressed in the context of *temporal fuzziness* or fuzziness in the time domain. Temporal fuzzy factors that affect the operation of communication systems and their signal transmission are illustrated, analyzed, and the de-fuzzification process is discussed.

1. INTRODUCTION

Communication systems are real-time deterministic, well defined systems that transport voice/data from point A to a remote point B reliably.[1] Between the two points, a number of communication systems are inter-networked. A communication system, macroscopically, appears to be a synchronous real-time, deterministic system. However, microscopically, it is a distributed operating system that consists of many concurrent (micro)-programmed sequential processors (or ASICs) to control its many operations that describe its internal structure and protocol specification.

Fuzziness in communication systems may sound like a paradox. To understand this paradox, let us follow a signal departing from point A, with destination point B. As it departs, an adventurous travel begins: it is subject to algorithmic manipulations (equalization, digital processing, analog to digital conversion), to transformations (sound to electronic, to photonic, to electromagnetic waves), it suffers from external influences (electromagnetic, environmental), etc. The result is a distorted or *fuzzy* signal. To date, sophisticated techniques have been developed to de-fuzzify (or recover) a fuzzified signal, documented in many transmission and information textbooks.[2]

In addition to algorithmic and environmental influencies to transmitted data, there is another serious contributor to data integrity, the system itself. The technology used in the system, its architecture, its implementation, the networking and the interface specifications, all affect data integrity. In addition, a large number of discrete events take place that may influence the integrity of the signal and the system's transmission efficiency. For example, when a request to initiate a call is made, there is a stupendous number of events that take place. A request to initiate a call must successfully be detected. A large number of network communications transactions must successfully take place for a communication path from point A to point B in the network to be established. Moreover, during data transmission, data may either be corrupted or partially lost due to system misbehavior: the system may loose temporarily synchronization, some critical part may become marginal, etc.; i.e. some condition emerges that fuzzifies data. Consequently, a robust system design should be able to either avoid data corruption or be able to detect data corruption and restore. In this case, a number of de-fuzzification (and error correction) processes take place, transparent to the user. This paper focuses on the third source of data fuzzification.

2. THE LOGICS PUZZLE

The traditional **combinatorial** logic is a static crisp boolean (0-1) logic; similarly, **sequential** logic is a boolean logic that decides the *next* event or state from the current one; hence this is also considered a crisp static logic. On the other hand, *fuzzy logic*[3] is a non-crisp logic where the variables, in contrast to boolean, are *fuzzy*; nevertheless, this logic is also static. The **temporal logic**[4] is an extension of the traditional logic where the *notion* of time or the *time interval* is a key variable. However, temporal logic is also a crisp logic. Mapping the different logic algebras in a matrix, see figure 1, the puzzle piece missing is under FUZZY and TEMPORAL. This logic, recently formulated[5], is known as **Temporal Fuzzy Logic.**

	STATIC	DYNAMIC
CRISP	B_L	T_L
FUZZY	F_L	?

B_L = Binary logics
T_L = Temporal logic
F_L = Fuzzy logic

Figure 1. The Logics Puzzle

3. FUNDAMENTALS OF TEMPORAL FUZZY LOGIC

Temporal Fuzzy Logic addresses the type of propositional logic where statements are not *crisp*, in contrast to binary (yes-no, 1-0) logic, but with a lot of uncertainty,[6] and time-variant. As an example, consider the statement: *If runner A is fast, runner B is faster than A, and runner C is slower than B, then, what is the relationship between runners A and C?*

Now, assume that at some specified initial time, the normalized speed profiles or membership functions of runners are SLOW, MODERATE, and FAST, as shown in figure 2 (solid lines). Now, in contrast to many other examples seen in the literature, all parameters in this example are functions of time, such as performance of runners and population of runners. Hence the distributions that define SLOW, MODERATE and FAST are functions of time. I.e., the membership functions are functions of time.

In real life, numerous other time dependant membership functions may found. It is not overstated If I'd say that most real life cases are functions of time (this is an ancient philosopher's discovery). Temporal fuzzy logic assumes such functions.

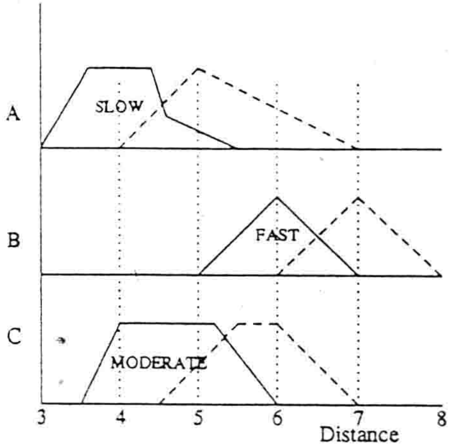

Figure 2. Membership Functions:
Speed Profiles at t=0 (solid) and t=T>0 (dashed)"

In temporal fuzzy logic the membership function is expressed by:

$$\mu_{\tilde{F}}(x,t) \tag{1}$$

and, the grade of membership of $\mu_{\tilde{F}}(x,t)$ at $t=t_i$ by:

$$\mu_{\tilde{F}}(x_i,t_i) \tag{2}$$

Here, we consider normalized fuzzy logic only, hence:

$$\sup_{x \in E} r\,\mu_{\tilde{F}}(x,t) = 1 \tag{3}$$

In addition, Temporal Fuzzy Logic defines a rate of confidence $\Re$ (see Appendix). The rate of confidence is used to further increase certainty during the de-fuzzification process. It is also an index of the **trend** of events. The language herein, although similar to other logics, uses additional symbolism. Appendix A lists the temporal fuzzy operators and their meaning.

A typical linguistic statement in temporal fuzzy logic is also expressed with **If ... Then** statements as in regular fuzzy logic, however, the essence of time is explicitly stated as follows:

If
  A is almost true at t=i
and
  B is almost false at t=i+2
then
  F at t=i+3

where F is an activity, and t is the dimension of time measured in small equal discrete increments, or small equal intervals. Discrete time is a mathematical convenience that allows for algorithmic description and the usage of a clock for the problem at hand. Thus, i+2 means two time intervals (or two clock ticks) latter than i.

Using temporal fuzzy logic symbolism as in Appendix A, the above statement is expressed by:

$$[M^{\alpha}\mu_A(x,t_i)]\,W^2\varnothing[M_{\alpha}\wedge(1-\mu_B(x,t_{i+3}))]\rightarrow\bigcirc F \qquad 4$$

In the above, the first bracket evaluates the grade of membership at point x_i, and at time t_i and stores it in location α. Then, it waits for two intervals doing nothing: $W^2\varnothing$), and then, in the second bracket, a number of events take place: it computes the grade of membership B at instant i+3, it computes the almost true value of μ_B, it recalls the value of μ_A from location α, and it computes the intersection of the two memberships. Finally, if the result is true (as expected), execution of F is the next event.

The difference between the linguistic statements and equation 4 is that the latter expresses the problem statement in a mathematical notation whereby the grade of memberships are explicitly calculable in the time domain. In fact, relation 4 "designs" a virtual circuit that computes the problem at hand.

4. TEMPORAL FUZZINESS IN COMMUNICATIONS SYSTEMS

In communication systems time plays a significant role in the de-fuzzification process of signals. Then, based on the rules of the particular problem and the previous (history) and/or current grades of memberships, inferences are made and certain control activities take place.

The next section briefly describes a communication system, where the On-Hook/Off-Hook process takes place, as one of the fuzzification influencies in data handling.

4.1 A Voice/Data Communication System

The communication system under consideration, in principle, consists of the following major functions, figure 3:

- **Channel units:** each terminates an analog voice or digital data signal. Analog voice is pulse code modulated (PCM) at 64 Kbps.
- **The On-Hook/Off-Hook Detector:** This circuitry detects the state of the external apparatus (i.e. telephone, modem). When the apparatus goes Off-Hook, it is sensed by the detector.
- **A time compressor/multiplexer:** A number of 64 Kbps PCM signals are time compressed and multiplexed into a higher bit rate; this is known as *time division multiplexing* (TDM).
- **The High-speed interface unit:** it synchronizes to the received bit-stream from a remote system, and it transmits/receives high-speed bipolar signals.
- **A Time-Slot Interchanger (TSI):** it constitutes a space-time crosspoint of multiplexed channels.
- **The Controller:** it controls the flow through the cross-connect dynamically, it monitors the system performance, it provisions the various units of the system, it provides maintenance and telemetry, it monitors the operation of the system and it executes call processing based on the On-Hook/Off-Hook state of the channel units.

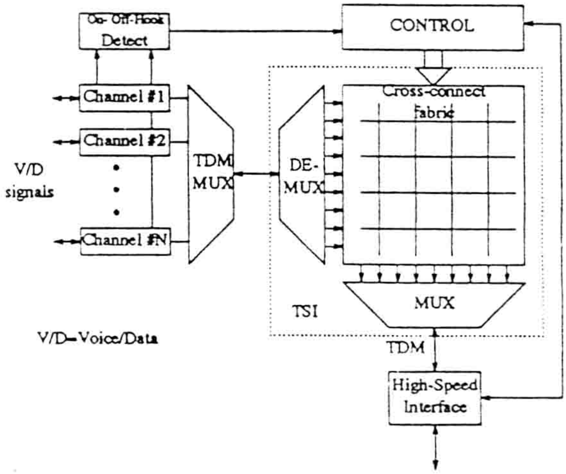

Figure 3. Functional Architecture of the TDM System

4.2 On-Hook or Off-Hook?

The TDM system described above detects transitions from the On-Hook to Off-Hook state of the channels. Initially, this transition may exhibit a degree of uncertainty in the time domain; hence, it is a temporal fuzzy variable. When this condition is defuzzified, i.e. the system is certain of the transition, then it requests from the network an end-to-end communication path. Figure 4a illustrates a continuous linear function of the On-to-Off-Hook state where the x-axis, although in the time domain, represents cumulative time, and figure 4b the diagrammatic representation of the fuzzy change of state in three sequential confidence levels, or membership functions, Low, Medium, and High. In our application, the controller determines the confidence level of all three different time intervals (see rules); hence temporal fuzzy logic is transformed to temporal combinatorial fuzzy logic.

Prior to requesting a communication path, the system constructs a time-dependency (or history) of that state for a predetermined period of time. Then, depending on the membership grades within that time period it decides whether a path should be requested or not. This process is also repeated when a voice/data channel becomes inactive, or "On-Hook"; in this case the path is disconnected.

4.2.1 Temporal fuzzification: As an example, consider that a telephone goes Off-Hook. This represents a change in the telephone state from a logic 1 to logic 0. Now, for many reasons, that are beyond the purpose of this paper, the change of state may be uncertain, i.e. the state may change temporarily, or it may oscillate for a very short period and then reach a steady state. Hence, there is temporal fuzziness in the change of state of the telephone, and in the decision making process of the system. Hence the question: to what degree is the telephone Off-Hook? Figure 5 illustrates a situation of temporal fuzziness with respect to the change of state from On-to-Off-Hook and also the degree of confidence of the change of state. Here, we consider the case where the degree of confidence is a linear function of time, (see also figure 4).

The function of the temporal fuzzy signal is described by:

$$F(t) = \sum_{ij} r^i_H(t) + r^j_L(t) \qquad 4$$

where $r^i_H(t)$ is a random number that indicates the i_{th} length (in time units) at state 1, and $r^j_L(t)$ is the j_{th} length at state 0. In our particular case, t takes discrete values (in increments of 10 msecs). For example, $r^2_H(t)=50$ indicates that the second high level segment is 50 msecs.

4.2.2 Rules and Temporal Defuzzification: In our communication system, for robustness, we have set simple defuzzification rules. Here, the rules of the temporal fuzzy problem in linguistic statements are:

```
1. If L & $\bar{M}$ then,
     if $r_H$ & $\bar{r}_L$,
     then, next
       if $\Re > 0$ then,
   repeat 1 until $\Re$=0 (or L=1),
   else t=0,

2. If M & previous L then,
     if $r_H$ & $\bar{r}_L$,
     then, next
       if $\Re > 0$ then,
     repeat 2 until $\Re$=0 (or M=1),
     else t=0, go to 1

3. If H & (previous) M & (previous) L, then,
     if $r_H$ & $\bar{r}_L$,
     then, next
       if $\Re > 0$ then,
     repeat 3 until $\Re$=0 (or H=1),
     then, next
     declare Off-Hook steady state and request a communication path
     else t=0, go to 1
```

where L=Low, M=Medium, H=High, &=AND operator and $\Re$ = rate of confidence.

The above linguistic statements are expressed with temporal fuzzy notation as:

$$\Phi_{\mu_L(x,t_1)\wedge(\mu_{\bar{M}}(x,t_1)}[\bigcirc(r_H \wedge \bar{r}_L \wedge \Re > 0 U \Re = 0)]. \rightarrow$$
$$\bigcirc[\Phi_{\mu_M(x,t_{1+\Delta})\wedge(\mu_L(x_\Delta,t_\Delta)}[\bigcirc(r_H \wedge \bar{r}_L \wedge \Re > 0 U \Re = 0)]]. \rightarrow$$
$$\bigcirc[\Phi_{\mu_H(x,t_{1+\delta})\wedge\mu_L(x_\delta,t_\delta}[\bigcirc(r_H \wedge \bar{r}_L \wedge \Re > 0 U \Re = 0)]] \rightarrow \bigcirc F_{Off-Hook}$$

where $F_{Off-Hook}$ is the final activity **declare Off-Hook state valid.** This activity invokes a request for a communication path.

When the path has been requested, assigned and connected, and when the state changes from Off-Hook to On-Hook, then the reverse process takes place, and the path is de-assigned and disconnected.

5. SUMMARY

In this paper, linear temporal fuzziness encountered in data/voice communication systems has been identified and analyzed, and the rules and the de-fuzzification process described. The temporal fuzzy logic has been briefly described and it has been applied in the exemplar communication system. In addition, expressions that describe the threshold conditions that should be met to defuzzify, infer and control the data flow, beyond doubt, have also been developed. Identifying *fuzzifiers*, i.e. factors that fuzzify data, and incorporating de-fuzzification mechanisms in the system, an assurance is made of the robust signal/data processing and safe data transport from point A to point B, a requirement and a characteristic of communication systems.

6. APPENDIX: TEMPORAL FUZZY OPERATORS

1. **The Rate of Confidence:** It indicates the direction of confidence of a fuzzy variable in the time domain. This is expressed by:

$$\Re_{\tilde{F}} = -\eta \frac{\mu_{\tilde{F}}(x_i) - \mu_{\tilde{F}}(x_{i+1})}{\delta t} \mu_{\tilde{F}}(x_i)$$

where x_i and x_{i+1} are the values of x measured at time points t_i and t_{i+1} and η is a scalar, the confidence index.

2. The Time Expansion Operator, D^{λ}: Then,
   $\overset{\lambda}{\tau} = D^{\lambda}\tau = (\lambda\tau)_{time-units}$
3. The Time Compression Operator, D_{λ}: Then,
   $\underset{\lambda}{\tau} = D_{\lambda}\tau = (\frac{\tau}{\lambda})_{time-units}$
4. The '$\bigcirc$' for **next**, i.e. $\bigcirc\mu_A(x,\tau)$: $\mu_A(x,\tau)$ becomes true at the next instance or at the next tick of a clock.
   Then, $\bigcirc\mu_A(x,\tau_i)=\mu_A(x,\tau_{i+1})$
5. The '$\Box$' for **henceforth**; i.e. $\Box\mu_A(x,t_i)$: $\mu_A(x,t_i)$ will be true henceforth, or for i=i,i+1,...
6. The "$\Diamond$" for **eventually**; i.e. $\Diamond\mu_A(x,t)$: $\mu_A(x,t)$ eventually will be true.
7. The "U" for **until**; i.e. $\mu_A(x,t)U\mu_B(x,t)$: $\mu_A(x,t)$ will be true until $\mu_B(x,t)$ is.
8. The "$\wp$" for **precedes**; i.e. $\mu_A(x,t_i)\wp\mu_B(x,t_j)$, $i \leq j$: $\mu_A(x,t_i)$ will be true prior to $\mu_B(x,t_i)$
9. "$\Delta=$" for **event**; $\Delta=\mu_A(x,t)$: the event $\mu_A(x,t)$ is about to occur.
10. The "∂" for **while**; i.e. $\mu_A(x,t)\partial\mu_B(x,t)$: $\mu_A(x,t)$ will become true *iff* $\mu_B(x,t)$ is true and it stays true for as long as $\mu_B(x,t)$ is true.
11. The "¢" for **concurrence**; i.e. $\mu_A(x,t)$¢$\mu_B(x,t)$: when $\mu_A(x,t)$ becomes true then (synchronously) $\mu_B(x,t)$ becomes true; the reverse is also true.
12. The "**W**" for **wait**; i.e. **W** $\mu_A(x,\tau_i)$: calculate the grade of membership $\mu_A(x,\tau_i)$ and wait ~~until another condition terminates~~ the validity of this operator.
13. The "W^n" for **wait for n**; i.e. $W^n\mu_A(x,t_i)$: wait for n consecutive intervals and calculate the grade of membership $\mu_A(x,t_i)$.
14. The "$\overset{n}{\rightarrow}$" for **shift-in n times**; i.e. $[\mu_A(x_i,t_i)]\overset{n}{\rightarrow}X$: shift the grades of membership $\mu_A(x_i,t_i)$ n consecutive times in X, where $X=\{x_1,...,x_m\}$, $n \leq m$.
15. The "$\alpha\{\ \}$" for **contents** of α location; i.e. $\alpha\{x_i\}$: the contents of α are x_i.
16. The "M^{α}" for **store in address** α; i.e. M^{α} $\mu_A(x_i,t_i) = \alpha\{\mu_A(x_i,t_i)\}$: store the value of $\mu_A(x_i,\tau_i)$ in location α.
17. The "M_{α}" for **recall from address**; i.e. M_{α}: get the contents from location α. If $\alpha\{\mu_A(x_i,t_i)\}$, then: $M_{\alpha} = \mu_A(x_i,t_i)$,
18. The "$\varnothing$" for **null** or **empty set**.
19. The "$L^n[.]$" for **loop**; i.e. $L^n[F_{op}]$: do $[F_{op}]$ recursively n times, where $[F_{op}]$ is a predefined fuzzy operation.
20. The "$\Phi^n[.]$" for **while do**; i.e. $\Phi^n_A[F_{op}]$: while A is true do F_{op} n times recursively,
21. the equality of A^i with B^j: Then,
    $A^i = B^j \leftrightarrow \mu_A(x,t_i) = \mu_B(x,t_j)$
22. the containment of A^i in B^j: Then,
    $A^i \subset B^j \leftrightarrow \mu_A(x,t_i) \leq \mu_B(x,t_j)$
23. the complement of A: Then,
    $\bar{A} = (compl.)A \leftrightarrow \mu_{\bar{A}}(x,t_i) = 1-\mu_A(x,t_i)$
24. the union of A^i and B^j: Then,
    $A^i \cup B^j \leftrightarrow \mu_{A^i \cup B^j}(x,t) = \max\{\mu_A(x,t_i),\mu_B(x,t_j)\}$
25. the intersection of A^i and B^j: Then,
    $A^i \cap B^j \leftrightarrow \mu_{A^i \cap B^j}(x,t) = \min\{\mu_A(x,t_i),\mu_B(x,t_j)\}$

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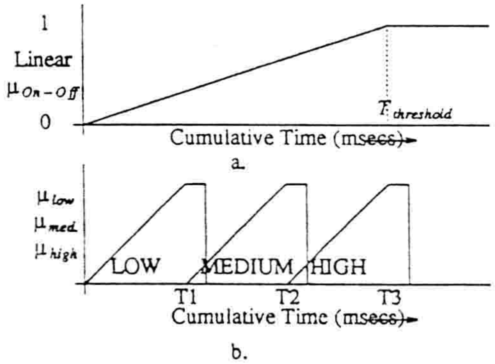

Figure 4. Membership Functions of the On-to-Off-Hook State

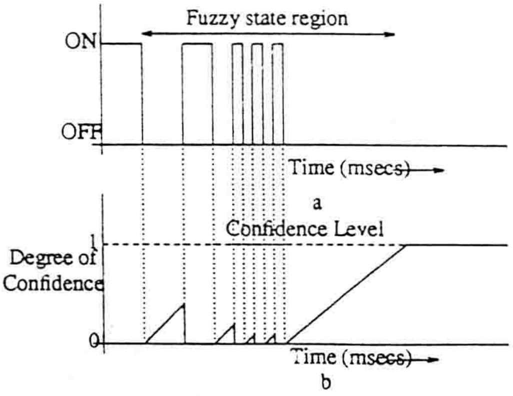

Figure 5. a. Temporal Fuzzy Signal and b. Certainty Level

Determining Overlap of Classes in the n-dimensional Boolean Space

Antônio de Pádua Braga[1] and Igor Aleksander

Abstract — **This paper presents a solution to the problem of determining the distribution of the n-dimensional Boolean space in relation to two arbitrary patterns which are separated by a fixed distance *h* in such space. The estimation of such distribution allows the evaluation of the amount of overlap between the two corresponding *r-spheres*, which is a measure of the correlation between the classes determined by the patterns. This work is significant for applications in pattern recognition as well as for works on storage capacity and retrievability of patterns in Boolean neural networks.**

I. INTRODUCTION

Sphere packing has been concerning scientists in the field of Information Theory since the late 40's and early 50's when the first works were published on the subject [1]. The problem in sphere packing is to determine how n code words, which represent the centres of the spheres, can be located in the Euclidean Space E^n so that the n correspondent congruent spheres of radius r (or *r-spheres*) do not overlap and cover as much of E^n as possible. The aim of the research in Information and Coding Theory is therefore to determine the representation of the n code words in such a way that the n congruent and disjoint spheres have maximum volume.

In most cases in the Neural Networks field there is not freedom to represent elements of the training set as code words in order to maximise sphere's volume. Elements of the training set are determined by the problem under study and can be located anywhere in E^n. Nevertheless, the knowledge of the amount of overlap between two arbitrary spheres is an important issue when determining the storage capacity and retrievability of patterns in Boolean Neural Networks [2,3,4,5,6]. The overlap in this case, gives an idea of which is the percentage of the whole space that is *dubious* in relation to the centres of the two *r-spheres*.

The aim of this paper is to present some ideas to allow the prediction of the amount of overlap between two *r-spheres* in the n-dimensional Boolean space. The results enable a comparision with the previous work of Kanerva on the same subject [2,3]. Such comparision shows that for small values of r, the results of the two models are similar and quite accurate but, when r is large, the model presented here tends to be more precise when compared with computer results. Kanerva's model of Sparse Distributed Memory (SDM) uses small *r-spheres* and the expressions developed for that model are quite precise in the range of r demanded to prove the ideas behind SDM. The work presented here extends the one developed for SDMs in the sense that it is precise in the whole range of variation of r, being useful for SDMs as well as for any other model of Boolean Neural Networks.

II. THE THIRD SIDE OF THE TRIANGLE

The problem addressed in this section is known as the "problem of the third side of the triangle" [2,3], due to the geometrical analogy which exists between a triangle in a plane and the relative distances among three arbitrary points in the Boolean space. It is important to note that Hamming instead of Euclidean Distances are used as metric measures in this work. Although the rules of Euclidean Geometry cannot be directly applied to solve the problem, the geometrical analogy shown in Figure 1 helps to visualise it.

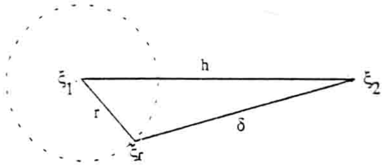

Figure 1. Geometrical view of the "problem of the third side of the triangle". What is the distribution of δ ?

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