Using Linguistic Petri Nets for the generation of linguistic descriptions

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- The Oreto research group was created at the Escuela Superior de Informática of the University of Castilla-La Mancha, in **Ciudad Real (Spain) in 1997**.
- Its initial objective was the **application of knowledge in artificial intelligence techniques to different fields** and activities.
- We have applied techniques such as non-classical logic (**fuzzy**), **approximate reasoning**, and **qualitative and linguistic modeling**.

Oreto Group Members

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Research lines

- **Fuzzy systems**: Description, modeling and development of complex, vague and uncertain systems within the framework of fuzzy logic, fuzzy sets and approximate reasoning.
- **Recognition of actions and events**: Identification of incorrect actions in some activities.
- **Linguistic models of systems**: Qualitative modeling of systems, time series, and events through the construction of linguistic descriptions.
- **Linguistic descriptions**: Generation of linguistic descriptions for indexing events and actions for efficient recovery of temporary sections of sensor information.

Research lines

- **Swarm Intelligence**: The induction of complex classifiers in large databases through partitioning techniques and specialization of classifiers.
- **Aggregation and fusion of information**: The acquisition, aggregation and fusion of data from multiple physical sensors and video cameras.

- Today there are **a lot of information** to show to users.
- **Data** are usually provided to users **in the form of tables and graphical representations**.
- The user has to afford an **analysis process** which is often very **complex and hard to do**.
- In some cases this analysis is impossible, specially the case for **non-expert users** which **don't have the necessary background and skills**.
- A natural language based solution for obtaining information from data has been provided in the last fifteen years by the so-called **Data-to-text systems**.

- Data-to-text systems are motivated by the belief that (brief) **linguistic descriptions of datasets may in some cases be more effective** than more traditional presentations of numeric data, such as tables, statistical analyses, and graphical visualizations.
- Linguistic descriptions can be delivered in **some contexts where visualizations are not possible**, such as text messages on a mobile phone, or when the user is visually impaired.

Linguistic description

Automatic generation of a brief text that describes a dataset providing the necessary information for an final user.

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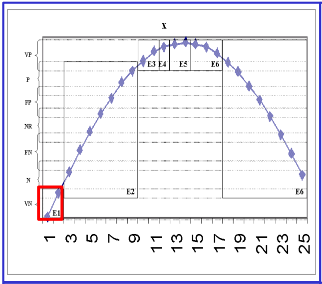
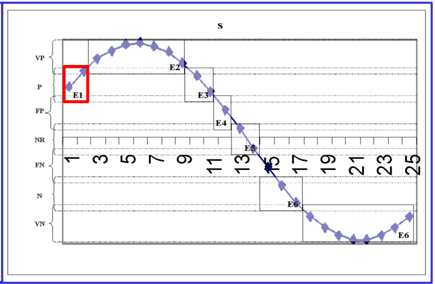
- A **TFM is formed by Temporal Fuzzy Rules (TFRs)** that represents consecutive time points which have their output values close to each other.
- TFMs represent the **time evolution of the system by means of the order of the TFRs**.

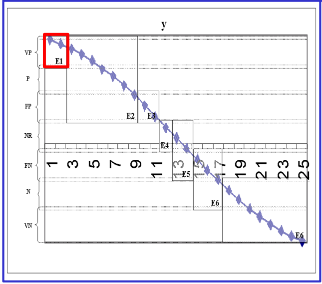
Reference

Juan Moreno Garcia, Luis Rodriguez Benitez, Juan Giralt, Ester del Castillo. **The generation of qualitative descriptions of multivariate time series using fuzzy logic**. Applied Soft Computing, 23, pages 546-555, 2014.

Rule	TFRs	X	Y	S
$R1$	$R^{1,2}$	$\{VN\}$	$\{VP\}$	P
$R2$	$R^{3,9}$	$\{N \text{ to } P\}$	$\{FP \text{ to } VP\}$	VP
$R3$	$R^{10,11}$	$\{VP\}$	$\{FP\}$	P
$R4$	$R^{12,12}$	$\{VP\}$	$\{NR\}$	FP
$R5$	$R^{13,14}$	$\{VP\}$	$\{NR \text{ to } FN\}$	NR
$R6$	$R^{15,17}$	$\{VP\}$	$\{FN \text{ to } N\}$	N
$R7$	$R^{18,25}$	$\{N \text{ to } VP\}$	$\{VN \text{ to } N\}$	VN







Rule	*TFRs*	X_1	X_2	Y
$R1$	$R^{1,2}$	$\{VN\}$	$\{VP\}$	P
$R2$	$R^{3,9}$	$\{N \text{ to } P\}$	$\{FP \text{ to } VP\}$	VP
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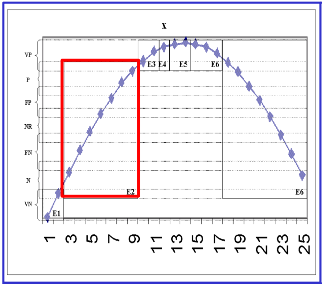
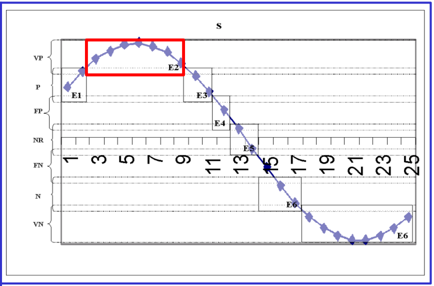
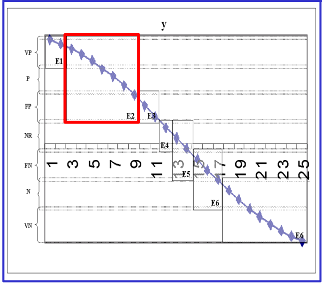
$R4$	$R^{12,12}$	$\{VP\}$	$\{NR\}$	FP
$R5$	$R^{13,14}$	$\{VP\}$	$\{NR \text{ to } FN\}$	NR
$R6$	$R^{15,17}$	$\{VP\}$	$\{FN \text{ to } N\}$	N
$R7$	$R^{18,25}$	$\{N \text{ to } VP\}$	$\{VN \text{ to } N\}$	VN







Rule	*TFRs*	X_1	X_2	Y
*R*1	$R^{1,2}$	$\{VN\}$	$\{VP\}$	P
*R*2	$R^{3,9}$	$\{N \text{ to } P\}$	$\{FP \text{ to } VP\}$	VP
*R*3	$R^{10,11}$	$\{VP\}$	$\{FP\}$	P
*R*4	$R^{12,12}$	$\{VP\}$	$\{NR\}$	FP
*R*5	$R^{13,14}$	$\{VP\}$	$\{NR \text{ to } FN\}$	NR
*R*6	$R^{15,17}$	$\{VP\}$	$\{FN \text{ to } N\}$	N
*R*7	$R^{18,25}$	$\{N \text{ to } VP\}$	$\{VN \text{ to } N\}$	VN

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- The **input variables** of a TFM take **intervals** as values, and the TFM **output variable** takes a **label** as its value.
- A set of TFRs comprise a TFM, where **each rule reflects the cause–effect relation between the output variable and the input variables**.
- TFR obtains the time intervals associated to the **output labels defined a priori by the expert**.
- TFRs are ordered. This **sequentiality establishes a relation between the time and the cause–effect relation reflected in the rules**.

A template and two consecutive rules ($R^{t_i,t'_i} = \{S^i_m, E^i, B^i\}$ and $R^{t_{i+1},t'_{i+1}} = \{S^{i+1}_m, E^{i+1}, B^{i+1}\}$) are used to acquire knowledge. The template is

> *From the instant T_i until T_{i+1} an INC/DEC occurs from LB^i to LB^{i+1} due to*
> *an $DEC/EQUAL/INC$ in X_1 'from IL_1 to FL_1' and*
> *... and*
> *a $DEC/EQUAL/INC$ in X_m 'from IL_m to FL_m'.*

Here, LB^i, LB^{i+1}, IL_j (initial label), and FL_j (final label), are labels.

Example

From the instant *4* until *7* an $increment$ occurs from M to H due to an $equal$ in X_1 'from VH to VH' and an $increment$ in X_2 'from L to FL' and an $increment$ in X_3 'from M to FH'.

TFRs	X_1	X_2	X_3	Y
$R^{1,1}$	$\{VH\}$	$\{VL\}$	$\{VH\}$	VL
$R^{2,3}$	$\{VH\}$	$\{VL, L\}$	$\{M, FL\}$	L
$R^{4,5}$	$\{VH\}$	$\{L\}$	$\{M, FL\}$	M
$R^{6,7}$	$\{VH\}$	$\{L, FL\}$	$\{FH\}$	H
$R^{8,15}$	$\{M\ to\ VH\}$	$\{VL\ to\ FL\}$	$\{FH\ to\ VH\}$	VH
$R^{16,17}$	$\{FL\}$	$\{VL\}$	$\{VH\}$	H
$R^{18,18}$	$\{L\}$	$\{VL\}$	$\{VH\}$	M
$R^{19,20}$	$\{L\}$	$\{VL\}$	$\{VH\}$	L
$R^{21,28}$	$\{VL\}$	$\{VL, L\}$	$\{FH, VH\}$	VL
$R^{29,37}$	$\{VL\ to\ FH\}$	$\{FL\ to\ VH\}$	$\{VL\ to\ M\}$	L
$R^{38,51}$	$\{FH\ to\ VH\}$	$\{VL\ to\ VH\}$	$\{FL\ to\ H\}$	VL

TFRs	X_1	X_2	X_3	Y
$R^{4,5}$	$\{VH\}$	$\{L\}$	$\{M, FL\}$	M
$R^{6,7}$	$\{VH\}$	$\{L, FL\}$	$\{FH\}$	H

From the instant 4 until 7 an $increment$ occurs from M to H due to an $equal$ in X_1 'from VH to VH' and an $increment$ in X_2 'from L to FL' and an $increment$ in X_3 'from M to FH'.

representation

$<< 4, 7 >, < M, H, INC >, << VH, VH, EQUAL >, < L, FL, INC >, < M, FH, INC >>>$

TFRs	X_1	X_2	X_3	Y
$R^{4,5}$	$\{VH\}$	$\{L\}$	$\{M, FL\}$	M
$R^{6,7}$	$\{VH\}$	$\{L, FL\}$	$\{FH\}$	H

From the instant 4 until 7 an $increment$ occurs from M to H due to an $equal$ in X_1 'from VH to VH' and an $increment$ in X_2 'from L to FL' and an $increment$ in X_3 'from M to FH'.

representation

$<< 4, 7 >, < M, H, INC >, << VH, VH, EQUAL >, < L, FL, INC >, < M, FH, INC >>>$

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$R^{4,5}$	$\{VH\}$	$\{L\}$	$\{M, FL\}$	M
$R^{6,7}$	$\{VH\}$	$\{L, FL\}$	$\{FH\}$	H

From the instant 4 until 7 an $increment$ occurs from M to H due to an $equal$ in X_1 'from VH to VH' and an $increment$ in X_2 'from L to FL' and an $increment$ in X_3 'from M to FH'.

representation

$<< 4, 7 >, < M, H, INC >, << VH, VH, EQUAL >, < L, FL, INC >, < M, FH, INC >>>$

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$R^{4,5}$	$\{VH\}$	$\{L\}$	$\{M, FL\}$	M
$R^{6,7}$	$\{VH\}$	$\{L, FL\}$	$\{FH\}$	H

From the instant 4 until 7 an $increment$ occurs from M to H due to an $equal$ in X_1 'from VH to VH' and an $increment$ in X_2 'from L to FL' and an $increment$ in X_3 'from M to FH'.

representation

$<< 4, 7 >, < M, H, INC >, << VH, VH, EQUAL >, < L, FL, INC >, < M, FH, INC >>>$

TFRs	X_1	X_2	X_3	Y
$R^{4,5}$	$\{VH\}$	$\{L\}$	$\{M, FL\}$	M
$R^{6,7}$	$\{VH\}$	$\{L, FL\}$	$\{FH\}$	H

From the instant 4 until 7 an $increment$ occurs from M to H due to an $equal$ in X_1 'from VH to VH' and an $increment$ in X_2 'from L to FL' and an $increment$ in X_3 'from M to FH'.

$s^{4,5}_{6,7}$ representation

$<< 4, 7 >, < M, H, INC >, << VH, VH, EQUAL >, < L, FL, INC >, < M, FH, INC >>>$

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Reference

J. Moreno-Garcia, J. Abián-Vicén, L. Jimenez-Linares, L. Rodriguez-Benitez. **Description of multivariate time series by means of trends characterization in the fuzzy domain**. Fuzzy Sets and Systems, 285, 118-139, 2016.

Definition

TREND: A set of consecutive TFRs where the output variable indicates the same direction.

- Types of trends:
  - Decreasing trends (DEC or $\downarrow$).
  - Flat trends ($FLAT$ or $\leftrightarrow$).
  - Increasing trends (INC or $\uparrow$).
- Requirements of the method:
  1. Manage trends based on the output variable.
  2. Allow working with trends in a specific variable.

Figure: Example of a MTS modelled using a TFM

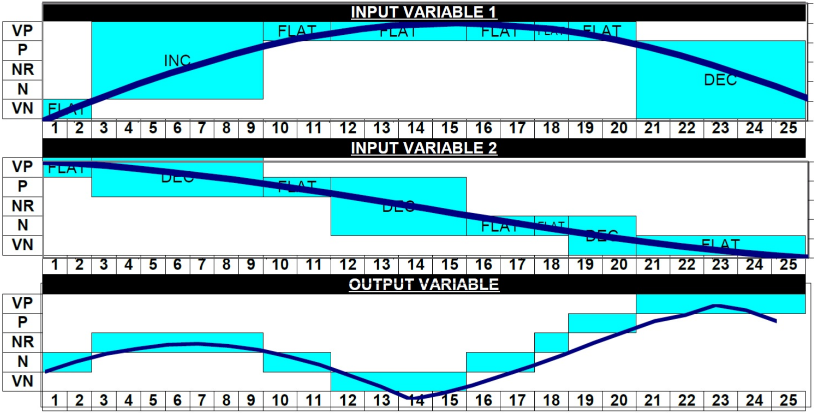
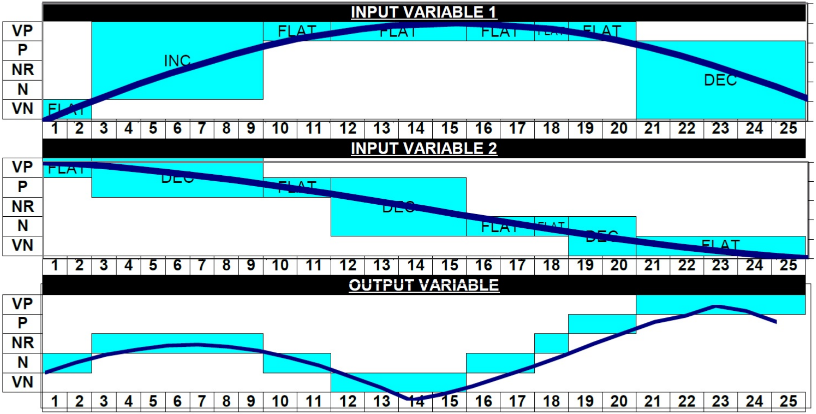
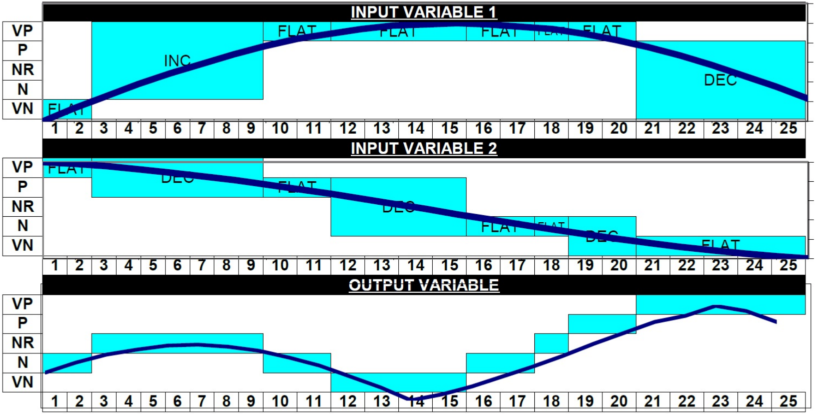


Table: Example of a set of trends.

TFRs	X_1	X_2	Y	Trend	Type
$R^{1,2}$	$\{VN\}$	$\{VP\}$	N	T_1	INC
$R^{3,9}$	$\{N\ to\ VP\}$	$\{P\ to\ VP\}$	NR		
$R^{3,9}$	$\{N\ to\ VP\}$	$\{P\ to\ VP\}$	NR	T_2	DEC
$R^{10,11}$	$\{VP\}$	$\{P\}$	N		
$R^{12,15}$	$\{VP\}$	$\{N\ to\ P\}$	VN		
$R^{12,15}$	$\{VP\}$	$\{N\ to\ P\}$	VN	T_3	INC
$R^{16,17}$	$\{VP\}$	$\{N\}$	N		
$R^{18,18}$	$\{VP\}$	$\{N\}$	NR		
$R^{19,20}$	$\{VP\}$	$\{VN\ to\ N\}$	P		
$R^{21,25}$	$\{VN\ to\ P\}$	$\{VN\}$	VP	T_4	FLAT



$trend_1$	type	INC
	TOV^1	$N_{1,2}$, $NR_{3,9}$
	TIV_1^1	$[VN]^{\leftrightarrow}_{1,2}$, $[N..VP]^{\uparrow}_{3,9}$
	TIV_2^1	$[VP]^{\leftrightarrow}_{1,2}$, $[VP..P]^{\downarrow}_{3,9}$



	type	DEC
$trend_2$	TOV^2	$NR_{3,9}$, $N_{10,11}$, $VN_{12,15}$
	TIV_1^2	$[N..VP]^{\uparrow}_{3,9}$, $[VP]^{\leftrightarrow}_{10,11}$, $[VP]^{\leftrightarrow}_{12,15}$
	TIV_2^2	$[VP..P]^{\downarrow}_{3,9}$, $[P]^{\leftrightarrow}_{10,11}$, $[P..NR]^{\downarrow}_{12,15}$

- This structure allows us to **find out information using a "set of events"** (they can be designed with the colaboration of a expert) that characterizes the MTS is selected. These events allow generating an appropriate description.
- **Examples**:
  1. **Relative to a single value**: In this case, an event can describe situations such as "if the final value for this variable is medium..." or "if this variable reaches a minimum or a maximum, then...".
  2. **Involving two values**: The following sentences are examples of this case, "this phase should not be extended in time..." or "if in this variable two very similar maxima appear, ...".
- A **formal syntax and semantic have been designed** to find out this information.

Reference

J. Moreno-Garcia, L. Rodriguez-Benitez, L. Jimenez-Linares, G. Triviño. IEEE Transactions on Fuzzy Systems. **A Linguistic Extension of Petri Nets for the Description of Systems: An Application to Time Series**, 27(9), 1818-1832, 2019.

- A widely used tool to model linguistic concepts is **fuzzy logic**. It has been successfully applied in **linguistic description**.
- **Granular Linguistic Model of Phenomena (GLMP)** generates linguistic descriptions that consist of several linguistic expressions appropriately combined to describe the meaning of the available data in a specific application context.

- **Petri Nets (PNs)** can detect events and manage the input flow, thus providing the necessary tools to synchronize and coordinate the system.
- A new method to **generate linguistic descriptions with an operation similar to PNs** and inspired by GMLP is detailed.
- The presented approach **maintains the operation of PNs**, while **adding the necessary mechanism to generate linguistic descriptions**.
- The different **linguistics elements are added to the places and transitions** of the PNs.
- This extension is called **linguistic PNs (LPNs)**. It is a mathematical language to generate linguistic descriptions of systems.

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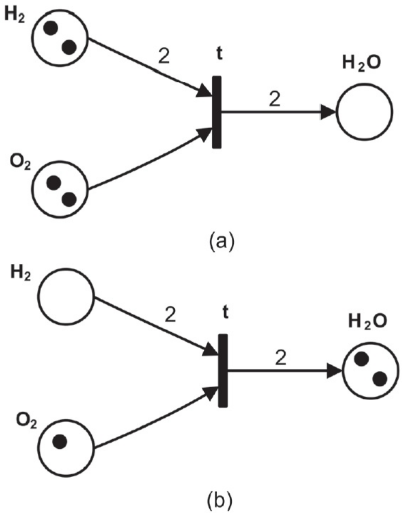
- PNs provide a **mathematical language** usually employed to model distributed systems.
- It is represented by means of a graph that can have the following two types of nodes: **transitions and places**.
- There are **arcs (represented by arrows)** indicating which places are preconditions and/or postconditions of the transitions.
- The **marked PN** is one of the most used PNs.

- A **marked PN** is a tuple $\{P, T, A, M_0\}$ where:
  - P is a nonempty finite **set of places**.
  - T is a nonempty finite **set of transitions**.
  - A is a **set of arcs** $A \subseteq (P \times T) \cup (T \times P)$ where $(P \times T) \in A$ are input arcs and $(T \times P) \in A$ are output arcs.
  - M_0 is the **initial mark of the net**.
- The transitions have associated events representing **logical functions (conditions)** of the input variables.
- A **transition** is ready to be **fired** when **all of its input places have a token in them**.
- If it is enabled and the logical function is fulfilled, then the transition is fired by **removing a token from the input places**; then **a new token is generated for each one of its output places**.


H2
2
t
H2O
2
O2
(a)
H2
2
t
H2O
2
O2
(b)

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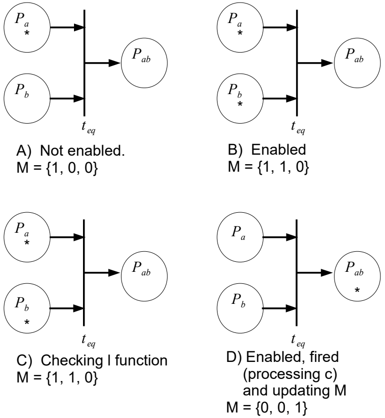
$LPN = \{P, T, M\}$ where:

- P is a nonempty **set of linguistic places** where each place $P_i = \{E_i, W_i, Alg_i\}$ is:
  - E_i is an **ordered set of sets of linguistic labels** E_{i_j}.
  - W_i is a **set of sets of membership grades** W_{i_j}.
  - $Alg_i = \{Tpt_i, V_i\}$ is **an algorithm that generates as output a linguistic description using template** Tpt_i based on E_i, W_i, and V_i (a set of variables).
- T is a nonempty **set of processing transitions** where each transition $T_i = \{I_i, O_i, l_i, c_i\}$ is:
  - I_i is the **set of input places for the transition** T_i.
  - O_i is the **set of output places for** T_i.
  - l_i is the **logical function** that checks if the transition must be fired and when this happens, O_i is computed using function c_i.
  - c_i is the **function needed to compute** O_i when the transition is fired.

- M is **a state vector indicating what the marking is at this instant** and $M_0 = [m_1, m_2, ..., m_{|P|}]$ is the initial marking.

Example: A LPN that counts the number of times the two systems, a and b, take similar temperature values.



$P_i = \{E_i, W_i, Alg_i\}$ taken i values a and b

Cs	Value	Comments
E_i	$\{low, medium, high\}$	Each e_j is a linguistic label
W_i	$\{w_{i_1}, w_{i_2}, w_{i_3}\}$	Calculated using the function c of its previous transition
Alg_i	$<>$	No template or variables were needed in this place

$t_{eq} = \{I_{eq}, O_{eq}, l_{eq}, c_{eq}\}$ where:

- $I_{eq} = \{P_a, P_b\}$.
- $O_{eq} = \{P_{ab}\}$.
- $l_{eq} = (EQUAL(p_a, p_b)) \wedge (w_{a_{p_a}} > \alpha) \wedge (w_{b_{p_b}} > \alpha)$

  where $p_a = argmax_{j \in |W_a|} w_{a_j}$, $p_b = argmax_{j \in |W_b|} w_{b_j}$ *and* α *is used as a threshold parameter.*

- c_{eq} gives values to the components of $P_{a,b}$:
  - $E_{ab} = \{Low, Medium, High\}$.
  - $W_{ab} = \{w_{ab_1}, w_{ab_2}, w_{ab_3}\}$ where every $w_{ab_j} = w_{ab_j} = min(w_{a_j}, w_{b_j})$.
  - $V_{ab}^N = V_{ab}^N + 1$ since a new case of similar temperatures has been detected.

$$P_{ab} = \{E_{ab}, W_{ab}, Alg_{ab}\}$$

Cs	Value	Comments
E_{ab}	$\{low, medium, high\}$	Each e_i is a linguistic label
W_{ab}	$\{w_{ab_1}, w_{ab_2}, w_{ab_3}\}$	Calculated using the function c_{eq}
Alg_{ab}	$\{Tpt_{ab}, V_{ab}\}$	The algorithm and its variables
Tpt_{ab}	The two systems have had the same temperature $V_{ab}^N \in V_{ab}$ times	The used template
V_{ab}	$\{V_{ab}^N\}$	V_{ab}^N contains the number of times this situation has been detected

Let us assume:

1. $M = [1, 1, 0]$, $\alpha = 0.6$ and $V_{ab}^{N} = 3$.
2. $P_a = \{E_a, W_a, Alg_a\} = \{\ \{Low, Medium, High\}, \{0.8, 0.2, 0\}\ , <>\}$.
3. $P_b = \{E_b, W_b, Alg_b\} = \{\ \{Low, Medium, High\}, \{0, 0.3, 0.7\}, <>\}$.

Example 1

- As $p_a \neq p_b$ $(1 \neq 3)$, $(w_{a_1} > \alpha)$ and $(w_{b_3} > \alpha)$, t_{eq} **is not fired**.
- **The designed LPN must contain another transition that is enabled and such that its function l evaluates to true.** Then **it will be fired** and the **markers of P_a and P_b will be displaced** to the output places of that transition.

logical function l

$$l_{eq} = (EQUAL(p_a, p_b)) \wedge (w_{a_{p_a}} > \alpha) \wedge (w_{b_{p_b}} > \alpha)$$

where $p_a = argmax_{j \in |W_a|} w_{a_j}$, $p_b = argmax_{j \in |W_b|} w_{b_j}$ and α is used as a threshold parameter.

Let us assume:

1. $M = [1, 1, 0]$, $\alpha = 0.6$ and $V_{ab}^{N} = 3$.
2. $P_a = \{E_a, W_a, Alg_a\} = \{\ \{Low, Medium, High\}, \{0.2, 0.8, 0\}, <>\}$.
3. $P_b = \{E_b, W_b, Alg_b\} = \{\ \{Low, Medium, High\}, \{0, 0.7, 0.3\}, <>\}$.

Example 2

- As $p_a = p_b\ (2 = 2)$, $(w_{a_2} > \alpha)$ and $(w_{b_2} > \alpha)$, t_{eq} is fired.

logical function l

$$l_{eq} = (EQUAL(p_a, p_b))\ \wedge\ (w_{a_{p_a}} > \alpha)\ \wedge\ (w_{b_{p_b}} > \alpha)$$

where $p_a = argmax_{j \in |W_a|} w_{a_j}$, $p_b = argmax_{j \in |W_b|} w_{b_j}$ *and* α *is used as a threshold parameter.*

Let us assume:

1. $M = [1, 1, 0]$, $\alpha = 0.6$ and $V_{ab}^{N} = 3$.
2. $P_a = \{E_a, W_a, Alg_a\} = \{\ \{Low, Medium, High\}, \{0.2, 0.8, 0\}, <>\}$.
3. $P_b = \{E_b, W_b, Alg_b\} = \{\ \{Low, Medium, High\}, \{\{0, 0.7, 0.3\}, <>\}$.

Example 2

- The function c_{eq} assigns the places of the output to $P_{ab} = \{E_{ab}, W_{ab}\} = \{\{Low, Medium, High\}, \{0, 0.7, 0\}\}$ and V_{ab}^{N} is incremented by 1 ($V_{ab}^{N} = 4$).
- M is updated to $[0, 0, 1]$ when t_{eq} is fired.
- The following description is then generated: "The two systems have had the same temperature four times."

computation function c

c_{eq} gives values to the components of $P_{a,b}$:

- $E_{ab} = \{Low, Medium, High\}$.
- $W_{ab} = \{w_{ab_1}, w_{ab_2}, w_{ab_3}\}$ where every $w_{ab_j} = w_{ab_j} = min(w_{a_j}, w_{b_j})$.
- $V_{ab}^{N} = V_{ab}^{N} + 1$ since a new case of similar temperatures has been detected.

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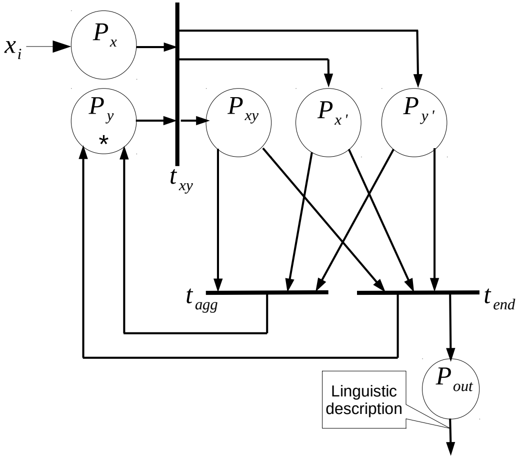
Let $X = \{x_1, x_2, \ldots, x_m\}$ be a TS.



$$P_x = \{E_x, W_x, Alg_x\}$$

Cs	Value	Comments
E_x	$\{e_1, e_2, \ldots, e_m\}$	Each e_i is a linguistic label
W_x	$\{w_{x_1}, \ldots, w_{x_m}\}$	Each w_{x_i} is computed using Equation 1, i.e., x_i is fuzzified. $w_{x_j} = \mu_{e_j}(x_i)\ \forall j \in [1..m]$ (1)
Alg_x	$\{Tpt_x, V_x\}$	The template and its variables
Tpt_x	$<>$	Empty template
V_x	$\{V_x^i\}$	V_x^i is used to contain the instant that this place represents.

$$P_{xy} = \{E_{xy}, W_{xy}, Alg_{xy}\}$$

Cs	Value	Comments
E_{xy}	$\{e_1, e_2, \ldots e_m\}$	
W_{xy}	$\{w_{xy_1}, \ldots, w_{xy_m}\}$	Computed by t_{xy} using Equation 2 $$w_{xy_j} = \left((1-\alpha) * w_{x_j}\right) + \left(\alpha * w_{y_j}\right) \quad (2)$$ *where* $\alpha \in [0, 1]$ *and* $j \in [1..m]$.
Alg_{xy}	$\{Tpt_{xy}, V_{xy}\}$	The template and its variables
Tpt_{xy}	The value e_i holds from the instant V_{out}^{ini} to the instant V_{out}^{fin}	The template
V_{xy}	$\{V_{xy}^{ini}, V_{xy}^{fin}\}$	V_{xy}^{ini} and V_{xy}^{fin} are used to represent the initial time and the final time that determines the time interval. V_{xy}^{ini} takes the value V_y^{ini}, the first instant of P_y, and V_{xy}^{fin} is assigned to the instant that P_x represents, V_x^i.

$$t_{xy} = \{I_{xy}, O_{xy}, l_{xy}, c_{xy}\}$$

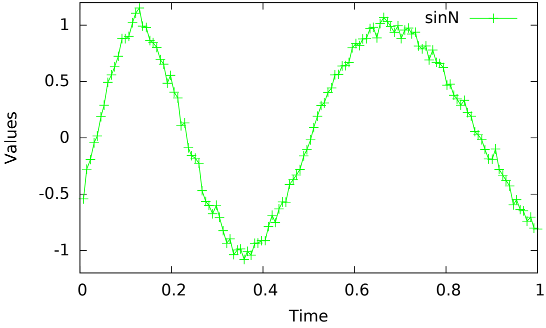
Cs	Value
I_{xy}	$\{P_x, P_y\}$
O_{xy}	$\{P_{x'}, P_{y'}, P_{xy}\}$
l_{xy}	no condition
c_{xy}	copies P_x and P_y to $P_{x'}$ and $P_{y'}$, respectively. It generates P_{xy}

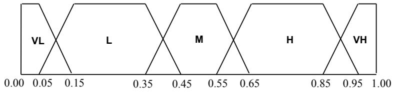
$$t_{agg} = \{I_{agg}, O_{agg}, l_{agg}, c_{agg}\}$$

Cs	Value
I_{agg}	$\{P_{x'}, P_{y'}, P_{xy}\}$
O_{agg}	$\{P_y\}$
l_{agg}	$$EQUAL(p_{y'}, p_{xy}) \quad (3)$$ where $p_{y'} = argmax_{j\in\|W_{y'}\|} w_{y'_j}$ and $p_{xy} = argmax_{j\in\|W_{xy}\|} w_{xy_j}$
c_{agg}	P_{xy} is copied into P_y.

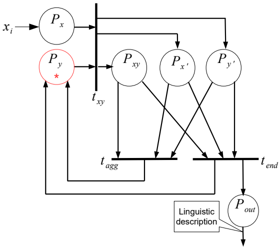
$$t_{end} = \{I_{end}, O_{end}, l_{end}, c_{end}\}$$

Cs	Value
I_{end}	$\{P_{x'}, P_{y'}, P_{xy}\}$
O_{end}	$\{P_{out}, P_y\}$
l_{end}	$$NOT\_EQUAL(p_{y'}, p_{xy}) \quad (4)$$ where $p_{y'} = argmax_{j\in\|W_{y'}\|} w_{y'_j}$ and $p_{xy} = argmax_{j\in\|W_{xy}\|} w_{xy_j}$
c_{end}	P_y is copied to P_{out} and P_x to P_y to start a new iteration.

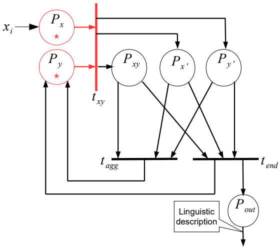

sinN
Values
Time
1
0.5
0
-0.5
-1
0
0.2
0.4
0.6
0.8
1


VL
L
M
H
VH
0.00
0.05
0.15
0.35
0.45
0.55
0.65
0.85
0.95
1.00

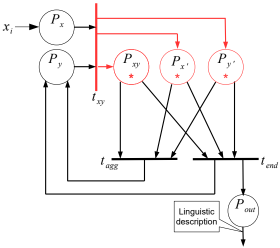
Block A) P_y: $W_y = \{0, 1, 0, 0, 0\}$, $V_y^{ini} = 1$, $V_y^{fin} = 1$		
The example $x_2 = 0.359$ arrives		
P_x	$W_x = \{0, 0.91, 0.09, 0, 0\}$ and $M = [1, 1, 0, 0, 0, 0]$	
t_{xy}	$e\&f$	P_x and P_y are marked, and l_{xy} has no condition
	c_{xy}	P_{xy}: $W_{xy} = \{0, 0.97, 0.03, 0, 0\}$, $V_{xy}^{ini} = 1$, $V_{xy}^{fin} = 2$
		$P_{x'}$ and $P_{y'}$ are copied from P_x and P_y
		$M = [0, 0, 1, 1, 1, 0]$
t_{agg}	e	P_{xy}, $P_{x'}$ and $P_{y'}$ are marked
	l_{agg}	$E(argmax(W_{y'}), argmax(W_{xy})) = E(2, 2) = true$
	c_{agg}	P_y: $W_y = \{0, 0.97, 0.03, 0, 0\}$, $V_y^{ini} = 1$, $V_y^{fin} = 2$
		the new marking is $M = [0, 1, 0, 0, 0, 0]$.



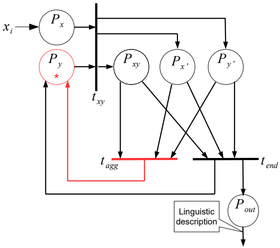
Block A) P_y: $W_y = \{0,1,0,0,0\}$, $V_y^{ini} = 1$, $V_y^{fin} = 1$		
The example $x_2 = 0.359$ arrives		
P_x	$W_x = \{0, 0.91, 0.09, 0, 0\}$ and $M = [1, 1, 0, 0, 0, 0]$	
t_{xy}	$e\&f$	P_x and P_y are marked, and l_{xy} has no condition
	c_{xy}	P_{xy}: $W_{xy} = \{0, 0.97, 0.03, 0, 0\}$, $V_{xy}^{ini} = 1$, $V_{xy}^{fin} = 2$
		$P_{x'}$ and $P_{y'}$ are copied from P_x and P_y
		$M = [0, 0, 1, 1, 1, 0]$
t_{agg}	e	P_{xy}, $P_{x'}$ and $P_{y'}$ are marked
	l_{agg}	$E(argmax(W_{y'}), argmax(W_{xy})) = E(2,2) = true$
	c_{agg}	P_y: $W_y = \{0, 0.97, 0.03, 0, 0\}$, $V_y^{ini} = 1$, $V_y^{fin} = 2$
		the new marking is $M = [0, 1, 0, 0, 0, 0]$.



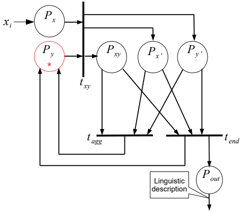
Block A) P_y: $W_y = \{0,1,0,0,0\}$, $V_y^{ini} = 1$, $V_y^{fin} = 1$		
The example $x_2 = 0.359$ arrives		
P_x	$W_x = \{0, 0.91, 0.09, 0, 0\}$ and $M = [1,1,0,0,0,0]$	
t_{xy}	$e\&f$	P_x and P_y are marked, and l_{xy} has no condition
	c_{xy}	P_{xy}: $W_{xy} = \{0, 0.97, 0.03, 0, 0\}$, $V_{xy}^{ini} = 1$, $V_{xy}^{fin} = 2$
		$P_{x'}$ and $P_{y'}$ are copied from P_x and P_y
		$M = [0,0,1,1,1,0]$
t_{agg}	e	P_{xy}, $P_{x'}$ and $P_{y'}$ are marked
	l_{agg}	$E(argmax(W_{y'}), argmax(W_{xy})) = E(2,2) = true$
	c_{agg}	P_y: $W_y = \{0, 0.97, 0.03, 0, 0\}$, $V_y^{ini} = 1$, $V_y^{fin} = 2$
		the new marking is $M = [0,1,0,0,0,0]$.



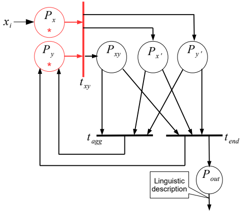
Block A) P_y: $W_y = \{0, 1, 0, 0, 0\}$, $V_y^{ini} = 1$, $V_y^{fin} = 1$		
The example $x_2 = 0.359$ arrives		
P_x	$W_x = \{0, 0.91, 0.09, 0, 0\}$ and $M = [1, 1, 0, 0, 0, 0]$	
t_{xy}	$e\&f$	P_x and P_y are marked, and l_{xy} has no condition
	c_{xy}	P_{xy}: $W_{xy} = \{0, 0.97, 0.03, 0, 0\}$, $V_{xy}^{ini} = 1$, $V_{xy}^{fin} = 2$
		$P_{x'}$ and $P_{y'}$ are copied from P_x and P_y
		$M = [0, 0, 1, 1, 1, 0]$
t_{agg}	e	P_{xy}, $P_{x'}$ and $P_{y'}$ are marked
	l_{agg}	$E(argmax(W_{y'}), argmax(W_{xy})) = E(2, 2) = true$
	c_{agg}	P_y: $W_y = \{0, 0.97, 0.03, 0, 0\}$, $V_y^{ini} = 1$, $V_y^{fin} = 2$
		the new marking is $M = [0, 1, 0, 0, 0, 0]$.



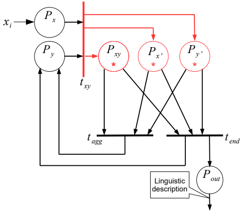
Block D) P_y: $W_y = \{0, 0.55, 0.45, 0, 0\}$, $V_y^{ini} = 1$, $V_y^{fin} = 4$		
The example $x_5 = 0.491$ arrives		
P_x	$W_x = \{0, 0, 1, 0, 0\}$ and $M = [1, 1, 0, 0, 0, 0]$	
t_{xy}	$e\&f$	P_x and P_y are marked, and l_{xy} has no condition
	c_{xy}	P_{xy}: $W_{xy} = \{0, 0.37, 0.63, 0, 0\}$, $V_{xy}^{ini} = 1$, $V_{xy}^{fin} = 5$
		$P_{x'}$ and $P_{y'}$ are copied from P_x and P_y
		$M = [0, 0, 1, 1, 1, 0]$
t_{end}	e	P_{xy}, $P_{x'}$ and $P_{y'}$ are marked
	l_{end}	$NOT\_E(2, 3) = true$
	c_{end}	P_y: $W_y = \{0, 0, 1, 0, 0\}$, $V_y^{ini} = 5$, $V_y^{fin} = 5$
		P_{out} is copied from P_{xy}
		the new marking is $M = [0, 1, 0, 0, 0, 1]$.



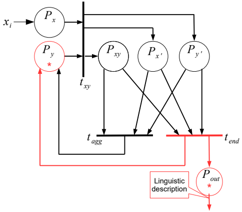
Block D) P_y: $W_y = \{0, 0.55, 0.45, 0, 0\}$, $V_y^{ini} = 1$, $V_y^{fin} = 4$		
The example $x_5 = 0.491$ arrives		
P_x	$W_x = \{0, 0, 1, 0, 0\}$ and $M = [1, 1, 0, 0, 0, 0]$	
t_{xy}	$e\&f$	P_x and P_y are marked, and l_{xy} has no condition
	c_{xy}	P_{xy}: $W_{xy} = \{0, 0.37, 0.63, 0, 0\}$, $V_{xy}^{ini} = 1$, $V_{xy}^{fin} = 5$
		$P_{x'}$ and $P_{y'}$ are copied from P_x and P_y
		$M = [0, 0, 1, 1, 1, 0]$
t_{end}	e	P_{xy}, $P_{x'}$ and $P_{y'}$ are marked
	l_{end}	$NOT\_E(2, 3) = true$
	c_{end}	P_y: $W_y = \{0, 0, 1, 0, 0\}$, $V_y^{ini} = 5$, $V_y^{fin} = 5$
		P_{out} is copied from P_{xy}
		the new marking is $M = [0, 1, 0, 0, 0, 1]$.



Block D) P_y: $W_y = \{0, 0.55, 0.45, 0, 0\}$, $V_y^{ini} = 1$, $V_y^{fin} = 4$		
The example $x_5 = 0.491$ arrives		
P_x	$W_x = \{0, 0, 1, 0, 0\}$ and $M = [1, 1, 0, 0, 0, 0]$	
t_{xy}	$e\&f$	P_x and P_y are marked, and l_{xy} has no condition
	c_{xy}	P_{xy}: $W_{xy} = \{0, 0.37, 0.63, 0, 0\}$, $V_{xy}^{ini} = 1$, $V_{xy}^{fin} = 5$
		$P_{x'}$ and $P_{y'}$ are copied from P_x and P_y
		$M = [0, 0, 1, 1, 1, 0]$
t_{end}	e	P_{xy}, $P_{x'}$ and $P_{y'}$ are marked
	l_{end}	$NOT\_E(2, 3) = true$
	c_{end}	P_y: $W_y = \{0, 0, 1, 0, 0\}$, $V_y^{ini} = 5$, $V_y^{fin} = 5$
		P_{out} is copied from P_{xy}
		the new marking is $M = [0, 1, 0, 0, 0, 1]$.



Block D) P_y: $W_y = \{0, 0.55, 0.45, 0, 0\}$, $V_y^{ini} = 1$, $V_y^{fin} = 4$		
The example $x_5 = 0.491$ arrives		
P_x	$W_x = \{0, 0, 1, 0, 0\}$ and $M = [1, 1, 0, 0, 0, 0]$	
t_{xy}	$e\&f$	P_x and P_y are marked, and l_{xy} has no condition
t_{xy}	c_{xy}	P_{xy}: $W_{xy} = \{0, 0.37, 0.63, 0, 0\}$, $V_{xy}^{ini} = 1$, $V_{xy}^{fin} = 5$
t_{xy}	c_{xy}	$P_{x'}$ and $P_{y'}$ are copied from P_x and P_y
t_{xy}	c_{xy}	$M = [0, 0, 1, 1, 1, 0]$
t_{end}	e	P_{xy}, $P_{x'}$ and $P_{y'}$ are marked
t_{end}	l_{end}	$NOT\_E(2,3) = true$
t_{end}	c_{end}	P_y: $W_y = \{0, 0, 1, 0, 0\}$, $V_y^{ini} = 5$, $V_y^{fin} = 5$
t_{end}	c_{end}	P_{out} is copied from P_{xy}
t_{end}	c_{end}	the new marking is $M = [0, 1, 0, 0, 0, 1]$.



DN	Linguistic Description
1	The value L holds from the instant 0 to the instant 0.023
2	The value M holds from the instant 0.023 to the instant 0.054
3	The value H holds from the instant 0.054 to the instant 0.108
4	The value VH holds from the instant 0.108 to the instant 0.146
5	The value H holds from the instant 0.146 to the instant 0.215
6	The value M holds from the instant 0.215 to the instant 0.254
7	The value L holds from the instant 0.254 to the instant 0.323
8	The value VL holds from the instant 0.323 to the instant 0.408
9	The value L holds from the instant 0.408 to the instant 0.492
10	The value M holds from the instant 0.492 to the instant 0.531
11	The value H holds from the instant 0.531 to the instant 0.646
12	The value VH holds from the instant 0.646 to the instant 0.731
13	The value H holds from the instant 0.731 to the instant 0.854
14	The value M holds from the instant 0.854 to the instant 0.915
15	The value L holds from the instant 0.915 to the instant 1

- This LPN could be represented by a "**black box**" with a single input, the TS X, and one output, P_{out}.
- **It can be used as a module**, which is called the *Time Series Processing Module* (TSPM).

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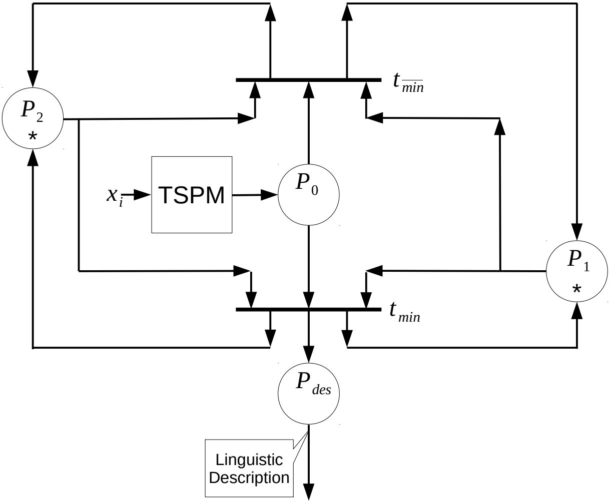

t
min
P 2
*
x i
TSPM
P 0
P 1
*
t min
P des
Linguistic
Description

P_0

Cs	Value
E_0	$\{very\ low, low, middle, high, very\ high\}$
W_0	$\{w_{0_1}, w_{0_2}, \ldots, w_{0_5}\}$
Alg_0	$\{Tpt_0, V_0\}$
Tpt_0	Not used.
V_0	$\{V_0^{ini}, V_0^{fin}\}$

P_{des}

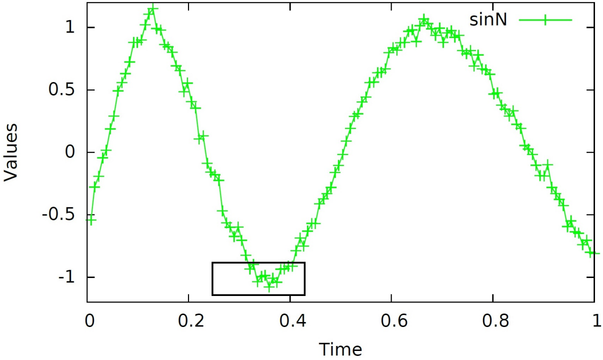
Cs	Value
E_{des}	$\{very\ low, low, middle, high, very\ high\}$
W_{des}	$\{w_{des_1}, w_{des_2}, \ldots, w_{des_5}\}$
Alg_{des}	$\{Tpt_{des}, V_{des}\}$
Tpt_{des}	There is a local minimum with the value $e_i \in E$ from the instant V_{des}^{ini} to the instant V_{des}^{fin}.
V_{des}	$\{V_{des}^{ini}, V_{des}^{fin}\}$

$$t_{min} = \{I_{min}, O_{min}, l_{min}, c_{min}\}$$

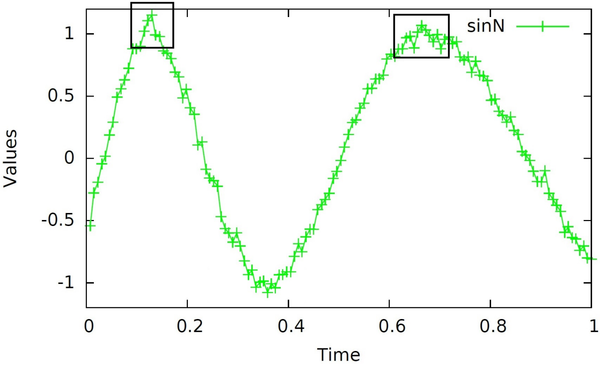
Cs	Value or Action
I_{min}	$\{P_0, P_1, P_2\}$
O_{min}	$\{P_0, P_1, P_2\}$
l_{min}	$(p_1 < p_2)$ and $(p_1 < p_0)$, where $p_i = argmax_{j\in\vert W_i\vert} w_{i_j}$.
c_{min}	transfers P_1 to P_2, P_0 to P_1 and, P_0 to P_{des}

$$t_{\overline{min}} = \{I_{\overline{min}}, O_{\overline{min}}, l_{\overline{min}}, c_{\overline{min}}\}$$

Cs	Value or Action
$I_{\overline{min}}$	$\{P_0, P_1, P_2\}$
$O_{\overline{min}}$	$\{P_0, P_1, P_2\}$
$l_{\overline{min}}$	NOT(l_{min})
$c_{\overline{min}}$	copies P_1 to P_2 and P_0 to P_1



There is a local minimum with the value *very low* from the instant 0.323 to the instant 0.408.



- There is a local maximum with the value *very high* from the instant 0.108 to the instant 0.146.
- There is a local maximum with the value *very high* from the instant 0.646 to the instant 0.731.

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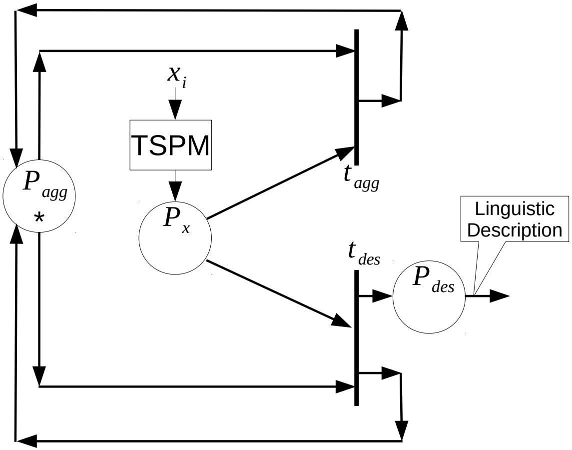
x_i
TSPM
P_{agg}
*
P_x
t_{agg}
t_{des}
P_{des}
Linguistic Description

$$P_x = \{E_x, W_x, Alg_x\}$$

Cs	**Value**
E_x	$\{very\ low, low, middle, high, very\ high\}$
W_x	$\{w_{x_1}, w_{x_2}, \ldots, w_{x_5}\}$
Alg_x	$\{Tpt_x, V_x\}$
Tpt_x	$<>$
V_x	$\{V_x^{ini}, V_x^{fin}\}$

$$P_{agg} = \{E_{agg}, W_{agg}, Alg_{agg}\}$$

Cs	Value
E_{agg}	$\{-very\ \ high, -high, -middle, -low, -very\ \ low, very\ low, low, middle, high, very\ high\}$
W_{agg}	$\{w_{agg_{-5}}, \ldots, w_{agg_{-1}}, w_{agg_1}, \ldots, w_{agg_5}\}$
Alg_{agg}	$\{Tpt_{agg}, V_{agg}\}$
Tpt_{agg}	$<>$
V_{agg}	$\{V_{agg}^{ini}, V_{agg}^{fin}\}$

$$P_{des} = \{E_{des}, W_{des}, Alg_{des}\}$$

Cs	Value
E_{des}	$\{-very\ \ high, -high, -middle, -low, -very\ \ low, very\ low, low, middle, high, very\ high\}$
W_{des}	$\{w_{des_{-5}}, \ldots, w_{des_{-1}}, w_{des_1}, \ldots, w_{des_4}\}$
Alg_{des}	$\{Tpt_{des}, V_{des}\}$
Tpt_{des}	There is a V_{des}^{type} trend from $V_{des}^{L_{ini}}$ to $V_{des}^{L_{fin}}$ during the interval V_{des}^{ini} to V_{des}^{fin}
V_{des}	$\{V_{des}^{ini}, V_{des}^{fin}, V_{des}^{L_{ini}}, V_{des}^{L_{fin}}, V_{des}^{type}\}$

1. Oreto Group
2. Introduction to linguistic description
3. Obtained representation from a TFM
   - Temporal Fuzzy Models
   - Properties of TFMs
   - Multivariate time series representation
4. Linguistic Petri Nets
   - Petri Nets
   - Linguistic Petri Nets
   - Designing a LPN to Describe a TS
   - Describing minima and maxima
   - Describing the trends of a TS
5. **Conclusions and future works**

CONCLUSIONS:

- A new extension of PNs, called LPNs, has been presented.
- LPNs have demonstrated their ability to detect events and to describe them as desired.
- As an example a LPN to generate the linguistic descriptions of TSs has been exposed.
- The detection of trends, maxima, and minima is performed, while noise must be treated in the correct way.

FUTURE WORKS:

- We shall improve the algorithm to generate descriptions in places. To do this, we shall formalize the way of designing the algorithm and its variables.
- Functions l and c also could be formalized to provide a formal way to present these functions.

Using Linguistic Petri Nets for the generation of linguistic descriptions

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University of Castilla-La Mancha

2019-October-03