Advances in Pattern Recognition

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Editorial

This year, the ninth Mexican Conference on Pattern Recognition 2017 (MCPR 2017, June 21-24) was jointly organized by the Computer Science Department of the National Institute for Astrophysics Optics and Electronics (INAOE); with the consent of the Mexican Association for Computer Vision, Neurocomputing and Robotics (MACVNR) and the International Association of Pattern Recognition (IAPR). MCPR 2017was the ninth event in the series, MCPR conferences aim to provide a forum for the exchange of scientific results and new knowledge, as well as promoting co-operation among international research groups in Pattern Recognition and related areas.

The fifth MCPR Postgraduate Students' Meeting (MCPR2017-PSM) allowed discussing research works from both Master and PhD students in order to receive feedback from experienced researchers and advices for future directions, as well as promoting their participation in conference events.

This volume contains original contributions selected through a reviewing process by our Program Committee. These contributions are derived from either Master or PhD students' researches about Pattern Recognition and related areas. We cordially thank all authors for their submitted contributions as well as the Program Committee for their valuable comments to authors.

We hope this RCS volume will be useful to the reader interested in Pattern Recognition and related areas, and hope that MCPR2017-PSM will provide a fruitful forum to enrich the collaboration between Master/PhD students and the community related to Pattern Recognition.

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Supervised Classification Based on Copula Functions

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Abstract. This paper exposes the research being done about the incorporation of copula functions in supervised classification. It is shown, by means of pixel classification, the advantages that modeling dependencies provides to supervised classification and the benefits of doing it through copula functions which are not limited to linear dependencies. The experiments executed so far, show positive results by having improved the performance of the classifiers that do not have copulas incorporated.

Keywords: Pixel classification, Dependence structure, Likelihood function.

1 Introduction

Classification is commonly used nowadays in several sectors like industry and healthcare, among others. There are different kinds of classification and we are working with supervised classification, whose main objective is to group similar objects into different categories based on their features. The categories or classes and the features of the objects that are part of those classes, are known in advance due to some training data that provides the classifier with important information to later, identify the test objects which we want to classify, their category is unknown.

The use of copula functions has increased considerably in classification, thanks to the flexibility that they provide by being able to model different kinds of dependence structures. Copula theory, introduced by [1] to separate the effect of dependence from the effect of the marginal distributions in a joint distribution, allows us to model non-linear dependencies.

This work proposes to use copula functions for solving supervised classification problems. By using gaussian kernels and copula functions whose parameter of dependence is selected with the help of the maximum likelihood method, we intend to observe an improvement in the performance of classifiers.

The paper is organized in the following way: in Section 2, the methodology followed to resolve the research problem is exposed along with some definitions and theorems that help to understand the approach, in Section 3, we describe the main contribution, Section 4 presents the results obtained so far and Section 5 contains the conclusions.

2 Research Methodology

2.1 Copula Functions

Copula functions' main objective in this research is to model dependencies. We take advantage of the association among features when classifying. The separation between marginal distributions and a dependence structure provides flexibility even when the marginals are not the same type.

Definition 1. *A copula function is a joint distribution function of standard uniform random variables. That is,*

$$C(u_1, u_2, \dots, u_d) = Pr[U_1 \leq u_1, U_2 \leq u_2, \dots, U_d \leq u_d],$$

where, $U_i \sim U(0,1) for\ i = 1,2, \dots d.$

Theorem 1(Sklar's theorem). *Let F be a d-dimensional distribution function with marginals* $F_1, F_2, \dots, F_d$*, then there exists a copula* C *such that for all x in* $\overline{\mathbb{R}}^d$,

$$F(x_1, x_2, \dots, x_d) = C\big(F_1(x_1), F_2(x_2), \dots, F_d(x_d)\big) ,$$

where $\overline{\mathbb{R}}$ *denotes the extended real line* $[-\infty, \infty]$*. If* $F_1(x_1), F_2(x_2), \dots, F_d(x_d)$ *are all continuous, then* C *is unique. Otherwise,* C *is uniquely determined on* $Ran(F_1) \times Ran(F_2) \times \dots \times Ran(F_d)$*, where* Ran *stands for the range.*

Due to Sklar's theorem, any d-dimensional density can be represented as:

$$f(x_1, x_2, \dots, x_d) = c\big(F_1(x_1), F_2(x_2), \dots, F_d(x_d)\big) \times \prod_{i=1}^{d} f_i(x_i) \ . \quad (1)$$

where c is the density of the copula C, $F_i(x_i)$ is the marginal distribution function of random variable x_i, and $f_i(x_i)$ is the marginal density of variable x_i. Equation (1) shows that the dependence structure is modeled by the copula function.

In this paper, we work with the following two-dimensional parametric copula functions: Independent, Ali-Mikhail-Haq (AMH), Clayton, Farlie-Gumbel-Morgenstern (FGM), Frank, Gaussian and Gumbel. Fig. 1 shows the dependence structure for each copula and, as can be seen, the dependence structure is different for each copula. Some of these copulas are able to model positive and negative dependencies. The reader interested in copula theory is referred to [2]. The density functions of these copulas are shown in Table 1.

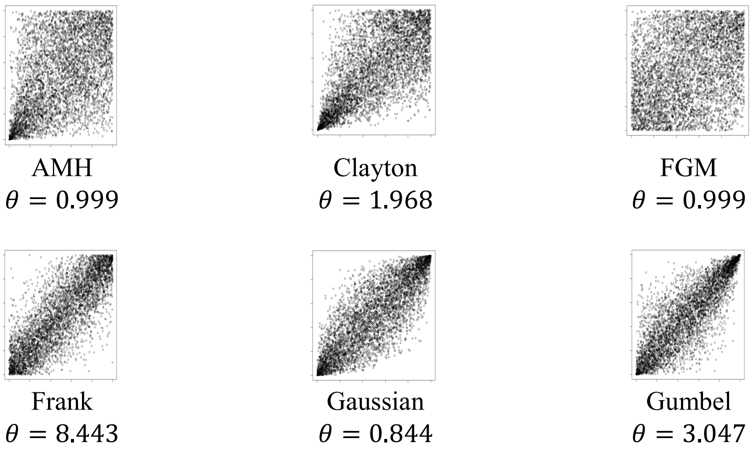


Fig. 1. Dependencies structure with different θ values

The parameter θ, the dependence parameter, of a bivariate copula function can be estimated through the maximum likelihood method (ML). The one-dimensional log-likelihood function, see Equation 2, is maximized and we use its optimal value as parameter since it has better properties than other estimators as explained in [3]:

$$\ell(\theta; \{(u_{1i}, u_{2i})\}_{i=1}^{n}) = \sum_{i=1}^{n} \log\big(c(u_{1i}, u_{2i}; \theta)\big). \tag{2}$$

2.2 Bayes Theorem

There are probabilistic and non probabilistic classifiers, the first ones use probabilistic distributions like bayesian networks, the multivariate normal or even the ones based on copula functions, the non probabilistic classifiers exclude the use of probability on them as neuronal networks or support vector machines.

As we have explained, we study a probabilistic classifier and to do so we have employed Bayes theorem [4], shown in Equation (3), which proposes the estimation of conditional probability of an event “A”, given “B” but we need to know in advance the conditional probability of “B” given “A”:

$$P(A|B) = \frac{P(B|A) \times P(A)}{P(B)}. \tag{3}$$

That way, for our purposes, it is possible to know the probability that an object belongs to a group (A) given some features (B) because we know in advance the conditional probability of an object that has certain features (B) when it does belong to a class (A).

Table 1. Bivariate copula densities

Copula	Description
Independent	$c(u_1,u_2)=1$
AMH	$c(u_1,u_2;\theta)=\frac{1+\theta(u_1+u_2+u_1u_2-2)-\theta^2(u_1+u_2-u_1u_2-1)}{\left(1-\theta(1-u_1)(1-u_2)\right)^3}\;;\theta\epsilon[-1,1)$
Clayton	$c(u_1,u_2;\;\theta)=(1+\theta)(u_1u_2)^{-\theta-1}\left(u_1^{-\theta}+u_2^{-\theta}-1\right)^{-2-\frac{1}{\theta}};\theta\epsilon[-1,\infty)\backslash\{0\}$
FGM	$c(u_1,u_2;\theta)=1+\theta(1-2u_1)(1-2u_2);\;\theta\epsilon[-1,1]$
Frank	$c(u_1,u_2;\theta)=\frac{-\theta(e^{-\theta}-1)e^{-\theta(u_1+u_2)}}{\left((e^{-\theta u_1}-1)(e^{-\theta u_2}-1)+(e^{-\theta}-1)\right)^2};\;\theta\epsilon(-\infty,\infty)\backslash\{0\}$
Gaussian	$c(u_1,u_2;\theta)=(1-\theta^2)^{-\frac{1}{2}}exp\left(-\frac{(x_1^2+x_2^2-2\theta_{x_1x_2})}{2(1-\theta^2)}+\frac{(x_1^2+x_2^2)}{2}\right);\;\theta\epsilon(-1,1)$ $where\;x_1=\Phi^{-1}(u_1)\;and\;x_2=\Phi^{-1}(u_2)$
Gumbel	$c(u_1,u_2;\theta)=\frac{exp\left(-(\tilde{u}_1^\theta+\tilde{u}_2^\theta)^{\frac{1}{\theta}}\right)}{u_1u_2}\frac{(\tilde{u}_1\tilde{u}_2)^{\theta-1}}{(\tilde{u}_1^\theta+\tilde{u}_2^\theta)^{2-\frac{1}{\theta}}}\left((\tilde{u}_1^\theta+u_2^\theta)^{\frac{1}{\theta}}+\theta-1\right);\theta\epsilon[1,\infty)$ $where\;\tilde{u}_1=-\ln(u_1)\;and\;\tilde{u}_2=-\ln(u_2)$

Reasoned on Bayes theorem, there is the naive Bayes classifier [4], which, is based on applying Bayes' theorem, but assuming that each feature is independent of any other feature, meaning, it does not take into account the association that may exist between its features, an example considering three features (b_1,b_2,b_3) can be seen in Equation 4:

$$P\left(A\middle|(b_1,b_2,b_3)\right)=\frac{P(b_1|A)P(b_2|A)P(b_3|A)P(A)}{P(b_1,b_2,b_3)}. \quad (4)$$

However there are also the classifiers by dependency, as shown in Equation (5), that, unlike the previous ones, they consider the association between features of the objects, notice that for Equation 5 we also consider only three features:

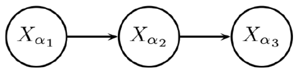
$$P\left(A\middle|(b_1,b_2,b_3)\right)=\frac{c(F_1(b_1),F_2(b_2),F_3(b_3)|A)\times\prod_{i=1}^{3}f_i(b_i|A)\times P(A)}{P(b_1,b_2,b_3)}. \quad (5)$$

3 Main Contribution

As mentioned before, copula functions can model dependencies among variables; the plan in this paper is to use a graphical model as a tool to identify the most important dependencies. The dependence structure is based on a chain model which, for a d-dimensional continuous random vector represents a probabilistic model with density:

$$f_{chain}(x) = f(x_{\alpha 1}) \prod_{i=2}^{d} f\left(x_{\alpha i} | x_{\alpha(i-1)}\right). \tag{6}$$

where $\alpha = (\alpha_1, \ldots, \alpha_d)$ is a permutation of the integers between 1 and d. An example of a chain graphical model for a three dimensional vector is shown in Fig. 2.



$$f_{chain}(x) = f(x_{\alpha 1}) f(x_{\alpha 2} | x_{\alpha 1}) f(x_{\alpha 3} | x_{\alpha 2})$$

Fig. 2. Joint distribution over 3 variables represented by a chain graphical model

As presented in [5], the permutation α is unknown and the chain graphical model must be learnt from data. A way of choosing the permutation α is based on the Kullback-Leibler divergence(D_{KL}). This divergence is an information measure between two distributions. It is always non-negative for any two distributions, and zero if and only if the distributions are identical. Hence, the D_{KL} can be interpreted as a measure of the dissimilarity between two distributions. The goal is to choose a permutation α that minimizes the D_{KL} between the true distribution $f(x)$ of the data set and the distribution associated to a chain model, $f_{chain}(x)$, as shown in Equation (6).

The use of copula functions is becoming popular in machine learning as mentioned in [6]; the novel proposal is to employ them along with a graphical model and to not limit the investigation to only one copula function (gaussian copula) as done in previous works [7] and [8].

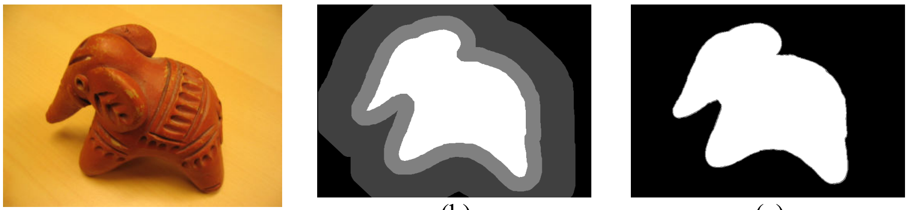
The main contribution in this research is the use of 6 different copulas to select the one that fits the most; this selection is done with a probabilistic model.

4 Achieved Results

During this research, we have been experimenting with pixel classification. From RGB images and having two established groups: background pixels and foreground pixels, we have used the features extracted from training data in order to get a conclusion on test data.

A color image can be represented in a 3-dimension matrix to keep data for red (R), green (G) and blue (B) colors, this is the information that is used as the attributes of each pixel to classify them.

Some classifiers have been computationally implemented; two of them using a normal distribution, from the density, some results have been obtained. We have worked with 50 images from Microsoft repository that can be found online [9]. The database provides 3 different images for each picture: the first one is the color image from where the RGB information is extracted, the second image in gray scale has the training data for both classes and test data, the third image is correctly classified and it is the image that has allowed us to evaluate the performance of the implemented classifiers, in Fig. 3, an example of the images is shown.



(a) (b) (c)

Fig. 3. (a) Color image. (b) Image with the training data for background (dark gray), foreground (white) and test data (gray). (c) Correctly classified image, background (black) and foreground (white)

Three measures, accuracy, sensitivity and specificity, are used to evaluate the performance of the classifiers. We used foreground as positive class and background as negative. As explained in Fig. 4, with the formulas used, the accuracy is calculated to reflect the percentage of correctly classified pixels, sensitivity shows the positive class pixels correctly classified and specificity, the negative class pixels that were correctly classified.

		Truth	
		Positive	Negative
Model	Positive	tp	fp
	Negative	fn	tn

$$accuracy = \frac{tp + tn}{tp + fp + fn + tn}$$

$$sensitivity = \frac{tp}{tp + fn}$$

$$specificity = \frac{tn}{tn + fp}$$

(a) (b)

Fig. 4. (a) Confusion matrix for binary classification, tp stands for true positive, fp is false positive, fn is false negative and tn is true negative. (b) Definition for accuracy, sensitivity and specificity used for this research

At first, we classified some images using normal distribution; the classification was made in two cases: without taking into account the association among the features and taking into account the dependencies or association among them.

It is shown in Fig. 5, the results obtained in the first experiment with a normal distribution and independence between features (b).

The evaluation measures of the classification with normal distribution and independence are: Accuracy - 86.67%, Sensitivity - 97.50% and Specificity - 77.80%.

(a) (b) (c)

Fig. 5. (a) Correctly classified image. (b) Image classified with normal density and independence between features. (c) Image classified with normal density and dependence between features

The same image was classified taking into account the dependency among the features, as can be seen in Fig. 5 (c) and the results were: Accuracy - 90.24%, Sensitivity - 98.85%, Specificity - 83.19%.

From Fig. 5, we have seen that the association among the attributes of an object can provide an improvement in supervised classification, to further, we experimented with 30 images from [9], the same classification that we used in the images above, with normal distribution. We noticed a trend and the next step was to try gaussian kernels instead of normal distribution and classify 50 images instead of 30.

One of the advantages of using gaussian kernel is the flexibility that they provide, we employed this flexible marginal distribution with independence at first, the results are shown in Fig. 6 (b).

The evaluation measures for the image shown in Fig. 6 (b) which was classified with gaussian kernel density and independence among features are: Accuracy - 86.01%, Sensitivity - 99.44%, Specificity - 75.02%.

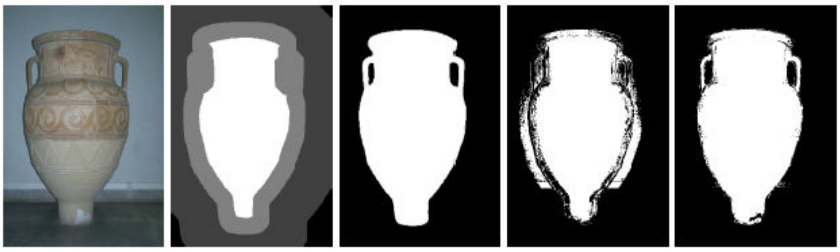
The next step was to incorporate copula functions in classifiers with gaussian kernel distribution; the main objective is to model dependency among the attributes. In order to cover a considerable amount of models, we worked with six different copulas, the ones mentioned before (Table 1).

Through the extraction of the copula parameter using maximum likelihood, the classification was done for 50 images with all six copulas; in Fig. 6 (c) is the classification of the figure we have been showing, with Clayton copula. Another image from database that has been classified using copula functions is shown in Fig. 7.

The images shown as example here, have been classified using AMH, Clayton, Frank, FGM, Gaussian and Gumbel copulas, however we only included their classification using one copula, Clayton in the first example and Frank in the second one to exemplify the results. The use of images is helpful to notice the differences and improvements between one classification and another.

(a) (b) (c)

Fig. 6. (a) Correctly classified image. (b) Image classified with kernel density and by independence. (c) Image classified by Clayton copula



(a) (b) (c) (d) (e)

Fig. 7. (a) The color image. (b) Image with training and test data. (c) Correctly classified image. (d) Image classified with kernel density and by independence. (e) Image classified by Frank copula

Table 2. Evaluation measures represented in percentages

Copula Model	**Accuracy** Mean	Std. Dev.	**Sensitivity** Mean	Std. Dev.	**Specificity** Mean	Std. Dev.
Independent	79.4	10.8	77.3	16.6	81.3	13.6
AMH	82.9	9.5	80.7	15.9	84.7	11.9
Clayton	86.0	8.5	81.6	16.4	89.5	9.2
FGM	80.9	9.8	78.9	16.5	82.5	13.2
Frank	87.7	7.1	87.1	12.2	88.1	9.0
Gaussian	86.0	10.6	87.1	11.0	85.0	18.6
Gumbel	86.7	8.2	87.0	10.9	86.5	13.2

However, from 50 classified images we summarized the measure values obtained by the classifiers when copulas were incorporated, in Table 2, we can visualize these results and observe the improvements. All copulas had a better behavior than the independent copula which represents no association among features; an ANOVA test for comparing the accuracy mean among the classifiers was performed in [5]. The test reports a statistical difference between Clayton, Frank, Gaussian and Gumbel copula functions with respect to the Independent copula$\left(p\text{-value} < 0.05\right)$. The major difference in accuracy with respect to the independent copula is given by the Frank copula.

Accuracy, as can be seen in Fig. 4, shows the amount of pixels that were classified correctly.

5 Conclusions

In this paper, we showed some of the advantages of incorporating copula functions in supervised classification. By using a chain graphical model and modeling dependencies through copula functions we have shown the improvements that classification can have. Thanks to the graphical model we are able to identify the most important dependencies between the attributes of an object.

The results in pixel classification were satisfactory in accuracy, sensitivity and specificity having two classes and 3 attributes. Since the experiments performed so far have been with images, the classification is visually observable and is possible to easily notice the improvements.

From evaluation measures, we can notice that some copulas have had a better performance than others because they modeled the images from database in a better way. We proposed the use of 6 copulas from which we have obtained different results but all of them, compared with the independent copula, have improved the classification results.

As future work it has been planned to select copulas based on the maximum likelihood, meaning that, instead of using only one copula when classifying, use a combination of the "best" dependencies of all 6 copulas. We are also interested in experimenting with non parametric copulas and, from a statistics perspective, with a more random set of training and test data. The classifier based on copula functions must be proved in other datasets, compared with other classifiers and it is necessary to perform more experiments in order to have a better understanding on its advantages and limitations.

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Facial Expression Recognition Using Interpolation Features

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Abstract. In this work, a methodology for classifying emotions (such as happiness, anger and surprise) based on face images is proposed. This methodology consist of three stages: in the pre-processing stage, edge detectors and threshold algorithms are used in order to find edge information about ROIs; in the second stage (feature extraction) numeric information of pre-processing images is extracted via interpolation methods; finally, in the classification stage supervised learners such as Neural Networks, Support Vector Machines and Naïve Bayes are tested. According to the results, our approach has acceptable accuracy in order to recognize emotions.

Keywords: Facial expression recognition, Face image pre-processing, Image segmentation, Supervised classification.

1 Introduction

Nowadays, data processing is an active research area in computer science, where subfields such as image processing is the baseline of computer vision. An application of computer vision is Facial Expression Recognition (FER) for detecting mental disorders, emotions, whether somebody is lying, among others [1]. A FER system detects six universal emotions (anger, happiness, disgust, surprise, sadness and fear) introduced by Paul Ekman in 1994 [2].

A FER system includes different stages (Fig. 1), starting with the pre-processing one where the input images (commonly in RGB color model) are processed applying different edge detectors and image filters in order to find descriptive data from the Regions of Interest (ROIs) in face images (eyebrows, eyes, mouth and nose). The next stage is the feature extraction, where the obtained information from pre-processing stage is used to get numeric information about ROIs. Finally, it is possible to use machine learning algorithms with the aim to classify new face images [3].

Several FER approaches have been reported in the literature, some of them based on Local Binary Pattern (LBP), using a histogram of the intensity values around a pixel to classify emotions via Support Vector Machines (SVM) [4]. Other approach is based on edge detection and parallel computing with CUDA (Compute Unified Device Architecture), in this work a CUDA implementation is used to detect borders for segmenting ROIs, then different points from each ROI were used for classification via SVM [5]. Sebe et al. [7] report a comparison among classifiers to determine emotions, particularly: Bayesian networks, nearest neighbors, decision threes and Naïve Bayes; according to the reported experiments, the best accuracy was obtained by k-nearest neighbors.

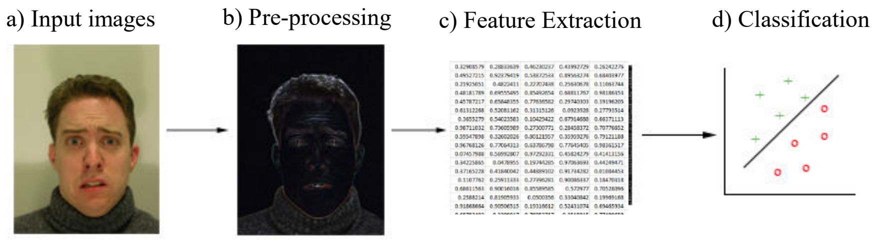

Fig. 1. FER process a) input images in RGB color model or gray scale (face image extracted from [8]); b) image pre-processing applying edge detectors and filters in order to get descriptive information from the ROIs; c) feature extraction getting numeric data from pre-processing stage; d) classification process using data extracted on c) to get a model found by a classifier

In recent years, deep learning approaches have been proposed in order to get a higher accuracy in classification stage. A method based on Convolutional Neural Networks (CNN) is proposed by Wen G. et al. [9], they use four datasets resizing each image to 48 x 48 pixels, then these images are used as input of the CNN. Other approach uses ROIs such as nose, eyes, mouth or landmarks from these ROIs as input of a CNN, finally a good performance in classification stage is reported [10, 6]. Deep belief networks have been also applied to facial expression recognition where face images are split and those are the input of the learners (SVM and Adaboost classifiers) [11].

In this paper we propose a method for detecting three of the six universal emotions (anger, happiness and surprise), based on eyebrows and mouth features extracted via interpolation polynomials as descriptive information of ROIs. Finally, classification algorithms such as Neural Networks (NN) with feed forward architecture, SVM and Naïve Bayes were tested in order to compare their performance.

This paper is structured as follows: section 2 introduces the proposed methodology and each stage of the process is described; in section 3 the results of the classification process are shown; finally in section 4 the conclusions and future work are addressed.

2 Facial Expression Recognition Methodology

The proposed methodology is shown in Fig. 1, we assume that inputs are images in RGB color model. In feature extraction stage, eyebrows and mouth are processed because these ROIs provide information about facial expressions. Points and coefficients found with interpolated polynomials are used as features of the ROIs. Finally, in the classification process SVM, NN and Naïve Bayes are trained in order to test their performance for classifying emotions. In the following sections each stage of our methodology is described.

2.1 Pre-processing

The pre-processing stage is based on edge detectors (such as gradient in different directions) and threshold operators (like Otsu [12]) in order to obtain intensity transition information from ROIs. In addition, unsupervised learners using RGB color model are tested for segmenting ROIs.

The RGB color model can be seen as a three-dimensional space, each one of the axis represents a color channel in the model (Red, Green and Blue), the intensity values of each pixel is denoted as a vector of three values, then a clustering algorithm can be used to segment images; face images can be segmented via clustering algorithms because of intensity values of the ROIs (in some cases) could be different respect to other regions. For the experimentation in this stage, different clustering algorithms are used (DBScan [13], OPTICS [14] and CLARANS [15]). We use as input, images from the MMI facial expression database [8]. As first step we find the face region through Viola & Jones algorithm [16], then the images are resized to 100 x 100 pixels. Before applying the clustering algorithms, a pre-processing stage by smoothing filters (median and mean) and automatic contrast adjustment considering frequency values higher than the 5% of the number of pixels in the image is applied.

In clustering process we apply three algorithms: DBscan, an algorithm based on detecting dense regions taking into account a minimum number of points to consider a region as dense (*min*) and a value (*e*) that is used to define the radius for the region; OPTICS works in a similar way as DBscan does, but OPTICS is order-based to analyze the regions. For both clustering algorithms in our experiments, *min* and *e* values were fixed to 3 and 5 respectively. Other applied clustering algorithm is CLARANS, this algorithm consist of analyzing sets of centroids, in this algorithm the number of clusters is five, the neighbors analyzed (sets that vary in at least one element) is three and the local minimum (used as stop condition) is one hundred. In Fig. 2 it can be seen the clustering results of each one of the algorithms applied over some images taken from the MMI database without applying a pre-processing, on the other hand, Fig. 3 shows the same images with a pre-processing stage consisting of apply smoothing filters (mean and median) and automatic contrast adjustment, due this contrast adjust noise is highlighted in the histogram. For both images (Fig. 2 and Fig. 3), the first row shows the input images, in the second row it is shown the output of DBscan algorithm. The output of CLARANS can be seen in the third row. Finally, in the fourth row the output of OPTICS algorithm is presented.

In general, clustering algorithms have not a good performance in order to get descriptive information about the ROIs, for this reason a different approach must be proposed to get better information about ROIs in face images.

In order to get a better performance than the experiments with the clustering algorithms for extracting ROIs, edge detectors and thresholding approaches were used to get information about eyebrows and mouth regions, for mouth region gradient edge detection in two directions (vertical and horizontal) is applied, finding the distance between these values, then the image is denoised using its histogram and only the frequency values higher than the mean are selected, then a binarization process (*x'=0 if x<threshold, otherwise x'=255*) with *threshold=127* is applied. Finally, the black regions in the binary images are detected via metrics as density (black pixels respect to a rectangular area) and the rectangular area of the cluster related to original image size are considered to find the ROI in the image.

For eyebrow segmentation a different approach need to be improved, in this process a closing morphological operation is applied to smooth the border and remove thin holes in eyebrow region, then an operator is used to remove the shadow between eye and eyebrow, this consist in a threshold value, just considering higher values than this threshold over which sine function is applied, after that Otsu thresholding is carried out. Finally, the same process implemented for detecting regions in mouth is used for the eyebrow case.

In Fig. 4 the segmentation results of the approach described in the above paragraphs are shown, for each image the result for mouth and eyebrow regions is presented with a binary image. The segmented ROIs will be used in the next stage in order to extract numeric values for training a classifier.

2.2 Feature Extraction

In this stage two sets of features are extracted, for mouth region two quadratic polynomials are interpolated, one for the upper part and one for the lower part of the mouth. On the other hand, for eyebrow region only one cubic polynomial is found. The polynomials are found with the Newton divided differences method [17].

In Fig. 5 the process to obtain the features is depicted. The points are transferred to the origin with a vector and the coefficients for each region are found (CF, Coefficient Features), then other set of features are extracted from the polynomial, ten points with each polynomial are found (PF, Point Features). This two sets of features are used in the next stage in order to train a classifier.

2.3 Classification

In the classification process a supervised learner is used to get a model, in this stage we use three different learners for numeric attributes: Naïve Bayes, SVM and NN, which were trained using the features described in the section 2.2.

3 Experimental Results

In this section, the results of the classification process are presented, we use Naïve Bayes, SVM and NN learners and three of the six universal emotions are classified. The training set contains 42 instances for happiness, 17 instances for anger and 20 instances for surprise. For testing the accuracy results, 5-fold-cross-validation is applied in these experiments, all the attributes are normalized via z-score method.

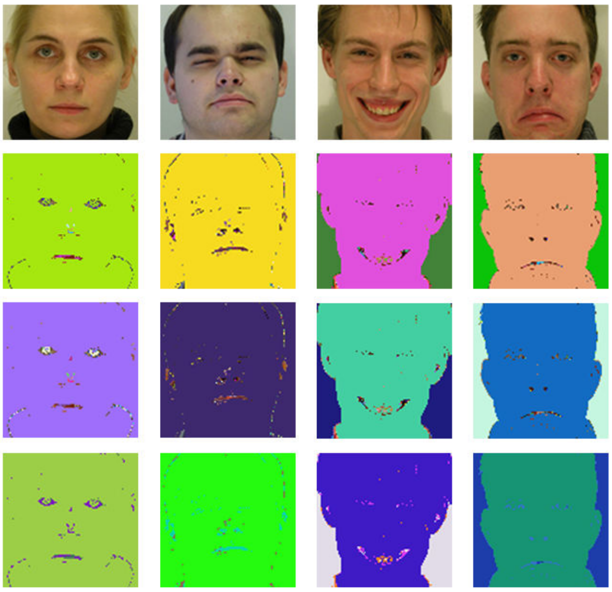

Fig. 2. Obtained results applying clustering algorithms without a pre-processing stage: first row shows input images; second row output of DBscan; in the third row CLARANS result can be seen; OPTICS result images are shown in fourth row

Fig. 3. Results of clustering algorithms applied over pre-processed images. The first row shows the input images; the other three rows show the results of clustering algorithms: second row OPTICS; third row CLARANS; fourth row BDscan

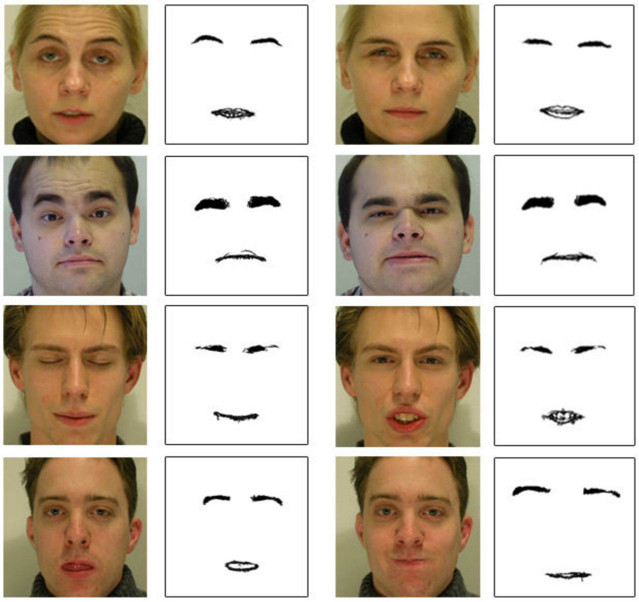

Fig. 4. ROIs (eyebrow and mouth) segmentation results of some images taken from MMI database

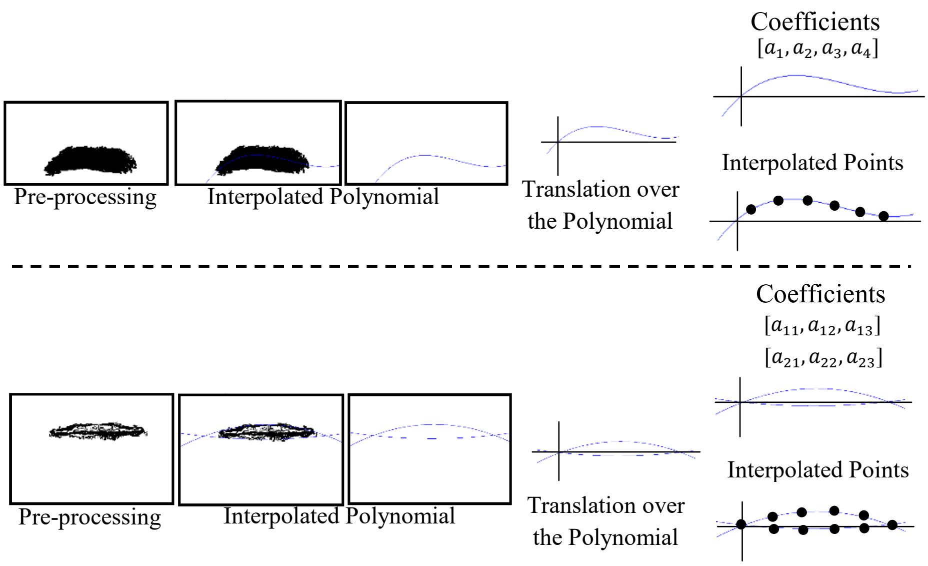

Fig. 5. Feature extraction for eyebrows and mouth regions based on interpolation polynomials

In order to get a better training for the Neural Network (feed forward architecture), different parameter values such as momentum, learning rate and neurons in the hidden layer were tested.

Our first experiment with the NN classifier uses as input the PF set explained in section 2.2. In Table 1 some of the tested parameters such as epochs, number of neurons in the hidden layer (in the experiments one hidden layer is used), momentum and learning rate are shown with their accuracy.

Table 1. Best experimented parameters for the NN classifier with PF

Epochs	Neurons in the hidden layer	Momentum	Learning Rate	Accuracy
500	**39**	**0.3**	**0.06**	**92.4%**
500	**44**	**0.4**	**0.06**	**92.4%**
500	41	0.1	0.27	91.8%
1000	45	0.16	0.58	92.3%
1500	45	0.11	0.6	91.9%

It can be seen that the first two rows in Table 1 the accuracy is 92.4%, there is a difference in the confusion of the emotions, the confusion matrix for the two set of parameters can be seen in Fig. 6, where H=Happiness, A=Anger and S=Surprise. The confusion matrices in Fig. 6 have the same accuracy, in Fig 6a some S cases are classified as A, meanwhile in Fig. 6b some cases S are confused with H and A.

	H	A	S
H	42	0	0
A	1	14	2
S	0	3	18

a)

	H	A	S
H	42	0	0
A	1	14	2
S	1	2	17

b)

Fig. 6. Confusion matrices for experimented parameters with NN classifier and PF: a) parameters for the first row in Table 1; b) parameters for the second row in Table 1

The confusion matrices shown in Fig. 7 were obtained by classifying emotions using our best Neural Network configuration; Fig. 7a and 7b shows the confusion matrices for two experiments where NN is trained with CF, and the two best parameters described in Table 2, rows 3 and 1 respectively. Based on these results, it is possible to conclude that the best performance is obtained using PF as input features.

Table 2. Best experimented parameters for the NN classier with CF

Epochs	Neurons in the hidden layer	Momentum	Learning Rate	Accuracy
500	41	0.01	0.11	83.54%
500	36	0.13	0.04	82.53%
1000	**36**	**0.14**	**0.04**	**84.81%**
1000	45	0.39	0.08	79.74%
1500	35	0.18	0.15	78.48%

a)

	H	A	S
H	41	1	0
A	4	10	3
S	2	2	16

b)

	H	A	S
H	41	1	0
A	6	8	3
S	2	1	17

Fig. 7. Confusion matrices for experimented parameters with NN classifier and CF: a) parameters for the third row in Table 2; b) parameters for the first row in Table 2

For SVM classifier the polynomial and RBF kernel were tested. In Fig. 8 it is shown the results of the experiments with SVM classifier, Fig. 8a and Fig. 8b shows the confusion matrices for PF; in Fig. 8c and Fig. 8d CF are used; in Fig. 8a and Fig. 8c a polynomial kernel is applied, finally Fig. 8b and Fig. 8d show the results using a RBF kernel. The best accuracy obtained by SVM was 89.87%, which is reached when using PF as training inputs and polynomial kernel.

a)

	H	A	S
H	42	0	0
A	1	14	2
S	2	3	15

b)

	H	A	S
H	42	0	0
A	15	0	2
S	16	0	4

c)

	H	A	S
H	42	0	0
A	11	5	1
S	0	3	18

d)

	H	A	S
H	42	0	0
A	17	0	0
S	20	0	0

Fig. 8. Results with SVM classifier using as training inputs: a) PF with polynomial kernel; b) PF with RBF kernel; c) CF with polynomial kernel; d) CF with RBF kernel

Finally, Naïve Bayes classifier is used for the experiments, in Fig. 9 it can be seen the confusion matrices for the two sets of features, in Fig. 9a and Fig. 9b, PF and CF were used as input respectively. The highest accuracy (84.81%) for Naïve Bayes classifier is obtained using PF as input. Additionally, in Fig 10 the histogram of the accuracies obtained in our experiments is depicted, where it is clear that the best accuracy was obtained by NN using PF as features.

a)

	H	A	S
H	38	4	0
A	0	11	6
S	0	2	18

b)

	H	A	S
H	36	6	0
A	5	10	2
S	0	3	17

Fig. 9. Naïve Bayes classifier results: a) point features; b) coefficient features

4 Conclusions

In order to classify emotions from face images a method based on thresholding and border extraction for pre-processing stage is proposed. Other methods based on clustering algorithms such as OPTICS, CLARANS and DBscan are tested, but these approaches have not a good performance in order to get ROIs information.

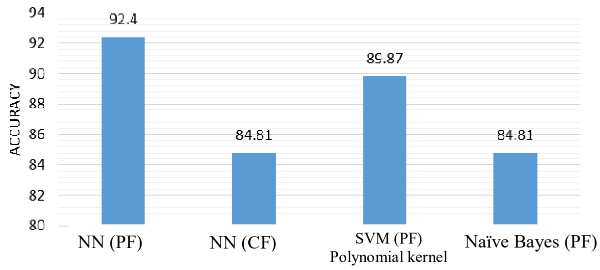

Fig. 10. Histogram with the best accuracy of experimented learners

Features such as coefficients of divided differences of Newton method and points of each ROIs was used to train the classifiers such as SVM, Naïve Bayes and Neural Networks, the best accuracy was obtained by Neural Networks using as training input the features extracted by our proposed approach. To get the accuracy of the NN some parameters were fixed such as momentum, learning rate, neurons in the hidden layer or number of epochs to get acceptable accuracy.

As future work, additional features from ROIs will be extracted in order to get a higher accuracy and less confusion in the classification stage, the six universal emotions will be classified using other learners. Finally, a database (considering the six emotions and the neutral one) will be created in order to have a database containing high quality face images. Other pre-processing method will be also explored in order to get a better performance via clustering algorithms approach.

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Proposal for Automatic Extraction of Taxonomic Relations in Domain Corpus

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Abstract. This paper addresses the study in the Natural Language Processing area focused on the analysis and automatic extraction of taxonomic relations in domain corpus. In addition, a methodology is proposed emphasizing the automatic extraction by patterns and methods of grouping as the formal concepts analysis. This work considers the validation of the proposal through the information provided by task #13 of SemEval 2016 and by manual validation by domain experts.

Keywords: Hyponym, Hyperonym, Taxonomic extraction, taxonomy automatic extraction.

1 Introduction

Today many natural language processing applications make use of thesaurus, word lists or taxonomically classified terms used to represent concepts, such as the WordNet system [5], which serves as a dictionary of lexical knowledge for processing of the semantics of words and documents.

Building such taxonomies can be a difficult and extremely slow task. Thus, there has been a growing interest in finding methods that can learn taxonomic relationships and construct semantic hierarchies automatically [15].

Concept hierarchies (taxonomies) are important because they enable the structuring of information by categories. Relationships of "Is-a" type are an important problem in the construction of taxonomies, so the automatic acquisition of such relationships can be used to construct a taxonomy and even an ontology.

According to the Oxford dictionaries a hyponym is a word of more specific meaning than a general or superordinate term applicable to it, contrasted with hypernym which is a word with a broad meaning constituting a category into which words with more specific meanings fall. A noun is a word used to identify any of class of people, places or things, or to name a particular one of these.

This research has as its origin the task #13 of SemEval-2016 called Taxonomy Extraction Evaluation (TexEval-2) [3]. This task provides a corpus that is Wikipedia and is divided into four subtasks: Construction of taxonomy, Identification of hypernym, Multilingual taxonomy construction, Multilingual taxonomy identification.

Specifically, this paper addresses the first two subtasks focusing first on the identification of hyponymy through two approaches to be addressed in the following sections, identification by patters and formal concepts analysis.

The content of this paper is structured as follows, section 2 discusses the relation work of extracting taxonomic relations through patterns, formal concepts analysis among others. Section 3 mentions the proposed methodology divided into three phases, section 4 details the conclusions of this work.

2 Related Work

There is previous work in which lexical-syntactic patterns are used to identify and evaluate taxonomic and non-taxonomic relationships in domain corpus [17],[20]. As well as the identification of ontological relationships using formal concepts analysis [18], [19] and [20].

Some authors such as Pachenko et. al. [9] use a methodology based on dictionaries and use DBPedia and Wikipedia as corpus, as well as lexical resources such as Wordnet for extraction of taxonomic relationships. On the other hand, [8] uses a pattern-based technique, applying it to unstructured text and using the Wordnet lexical resource in the same way. While [12] used a standards-based methodology, in which it does not specify its corpus, but the Hearts patterns in table 1 are applied.

Table 1. Heart's lexical patterns

Pattern
A, and other B
A, or other B
A is a B
B, such as A
B, including A
B, especially A
B, particularly A
B, for example A
B, among which A

In Maitra et al [7] made a system called JUNLP which is based on two modules of detection of hyperonyms, the first deals with the semantic relations that can be found for a term and use BabelNet for the extraction of relations of hyponymy. BabelNet is a semantic network that connects concepts and named entities with a large network of semantic relationships. The second module attempts to identify subtrees present in the list of terms that may be a possible hyperonym for that term.

Pachenko et al [10] created a system called TAXI (Taxonomy Induction) for the extraction of taxonomic relations. His methodology is based on two sources of evidence, substring matches and Hearts patterns. They analyze all Wikipedia in search of the Hearts patterns and extract those relationships and make use of another corpus like GigaWord, ukWac and CommonCrawl.

Pocostales Joe [11] create a semi-supervised system called NUIG-UNL that finds hyperonym candidates for nouns by representing them as distribution vectors. This method assumes that hyperonyms can be induced by adding a compensation vector to the corresponding hyponym generated by GloVe. The vector is obtained as the average of the compensation between 200 pairs of hyponym / hyperonyms in the same space of the vector.

According to Tan et al.[16] frequently multi-word hyponym are constructions that contain another word that functions in the same way as a part of the same word. For example, "Apple pie" is essentially a "pie". This system explored the number of terms that are the same way. (multi-word) in English.

Cleuziou et al. [4] created a semi-supervised method for the acquisition of lexical taxonomies based on genetic algorithms. It is based on pre-topology theory that provides a powerful formal model of semantic relationships and transforms a list of terms into a space of structured terms in combination with different criteria of discrimination. In particular, rare but precise pieces of knowledge are used to parameterize the different criteria by defining the pre-topological term space. A structural algorithm is used to transform the pre-topological space into a lexical taxonomy.

Unlike the previously described works, the contribution of the methodology proposed in this paper will provide a list of syntactic lexical patterns that we consider can be used in different domains.

3 Proposed Methodology

The proposed methodology to be followed consists of three sequential phases which are described below and are shown graphically in Fig 1.

1. Information preprocessing: Development of an information preprocessing system that allows the processing of the corpus Wikipedia, in this phase it is also considered the preprocessing of the corpus, remove punctuation, special symbols and convert all words to lowercase.
2. Proposed models: Development and implementation of models that allow the extraction of hyponym / hyperonym taxonomic relations in domain corpus through patterns and formal concepts analysis.
3. Evaluation: The evaluation measures used in this phase are: precision and recall, in addition to manual validation by domain experts.

3.1 Phase 1- Information Preprocessing

For the first phase it is necessary to process Wikipedia in such a way that it can be understood by a computer, which is why we will use "Wikipedia Extractor" developed by Attardi [1], which is a tool that generates a flat text output of the whole database stored on Wikipedia.org. In this case each element stored in Wikipedia like the term "Benemérita Autonomous University of Puebla" in Wikipedia has as URL: https://en.wikipedia.org/wiki/Benem%C3%A9rita_Univesidad_Aut%C3%B3noma_de_Puebla . Its contents are taken as a document which is stored in XML format.

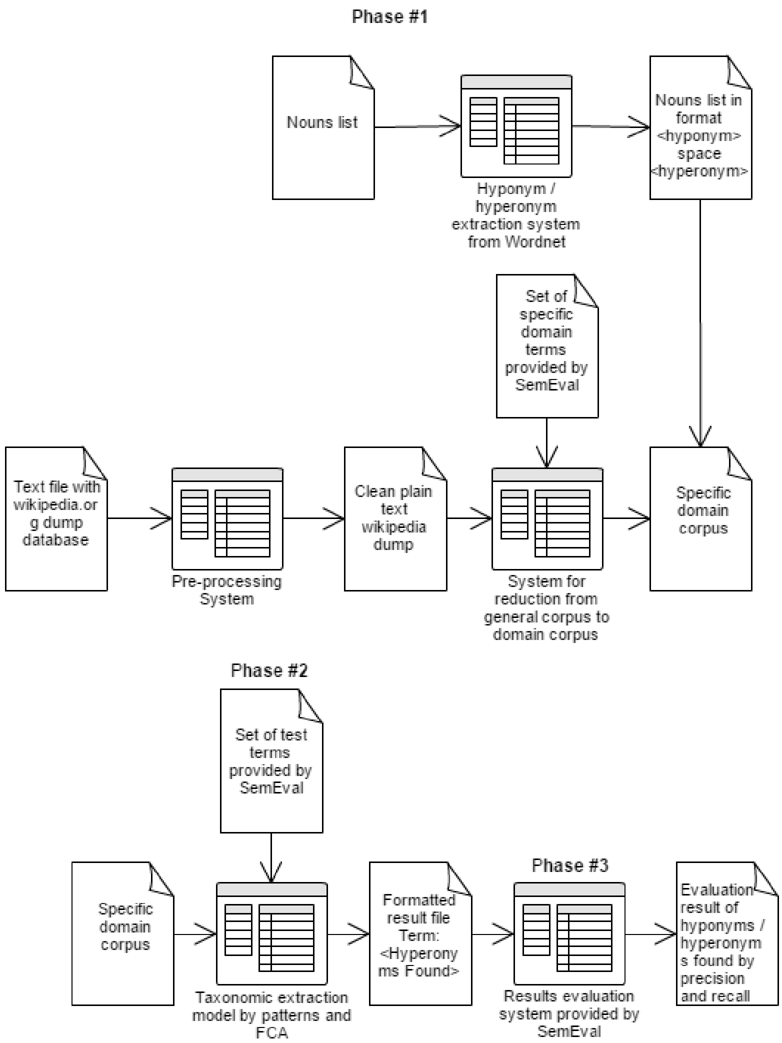

Fig. 1. General System Methodology

The steps to follow by the information preprocessing system are as follows:

1. All corpus words will be converted to lowercase.
2. Punctuation, special characters and numbers will be removed from all documents.
3. The output will be a clean corpus.

The information retrieval system will perform these steps.

4. As input it will receive the list of nouns proposed by SemEval for a specific domain and the corpus obtained in step 3.
5. For the generation of the domain sub-corpus we will only consider the Wikipedia articles in which the nouns proposed by SemEval appear.

6. The system will return the reduced corpus for the domain of the lists of nouns that had as input.

3.2 Phase 2 – Proposed Models

In this phase, we consider two approaches for the extraction and identification of hyperonymy and hyponymy type relations: an approach based on lexical-syntactic patterns and grouping of entitites by FCA (Formal Concepts Analysis). These approaches are presented below.

3.2.1 Lexical-Syntactic Patterns

We propose a model for the extraction of this type of relations using patterns, these patterns will also be extracted automatically but filtered manually and the methodology would be the following.

1. Obtain the list of nouns of SemEval for the domain to be processed.
2. Having a list of all the nouns of the domain to be processed, request to a lexical knowledge base like Wordnet the hyperonym of each noun, with the tuple obtained of type: <extracted noun>:<hyperonym identified by Wordnet>
3. It is proposed to make a limitation of the domain corpus to documents in which the extracted noun and the hyperonym appears identified at a maximum distance of "K" words.
4. With regular expressions, it is proposed the extraction of everything that is between the extracted noun and the identified hyperonym, always remembering that what is in the middle of both should be of a window width of size "K" and this would become a candidate pattern.
5. To reduce margin of error of the patterns that may not always be correct, we will take in consideration only those candidate patterns that have more frequency in the documents and those will be validated by an expert.

An example is the following: In the list of nouns extracted from the whole subcorpus we get the word "Lion", we request WordNet its hyperonym and WordNet gives us that it is "Animal" so now we look in the corpus where the words "Lion" and "Animal" appear. We get the sentence "Lion is an Animal", we extract "is an" and it becomes a candidate pattern. If this pattern is repeated in several relationships, it is taken as an candidate pattern for the extraction of taxonomic relations, we take all patterns that repeat at least two times as a candidate pattern for a subsequent expert manual validation.

3.2.2 FCA – Formal Concepts Analysis

Formal concepts analysis (FCA) is a method of data analysis that describes the relationships between a particular set of objects and a particular set of attributes [2].

It allows data analysis methods to formally represent knowledge and produces two types of outputs for an input data. A reticle of concepts and a collection of attributes implications. The lattice is a formal collection of input data concepts order hierarchically by a sub-concept – super-concept relationship. The implication attribute describes a valid dependence of the data [18]. From a philosophical point of view a concept is the unit of thoughts composed of two parts, extension and intension, the extension covers all the objects or entities belonging to the concept, whereas the intention encompasses all attributes or properties valid for all those objects [21].

Formal concepts analysis provides a methodology for deriving a hierarchy of concepts (such an ontology) from a collection of objects and the properties they verify.

Each concept of the hierarchy obtained simulates a set of objects that share the same values for a certain set of properties or attributes [14].

For the development of this approach we propose a model that allows the construction of the hierarchy of concepts in which the collection of objects defined in the previous paragraph will be the data provided by the SemEval that is, the terms of plants and vehicles domains.

As mentioned above, each concept must meet a set of properties of attributes and with this information we can conclude that concepts share the same sets of attributes or properties and are manifesting some kind of taxonomic relationship.

Some attributes or characteristics proposed are the following: Verb and subject, Verb and object, Verbs, Prepositions, Placements, Nouns and adjectives, Punctuation marks.

3.3 Results Evaluation

Once the results of the application of the proposed models for the automatic extraction of hyponym / hyperonym relations have been obtained, it is necessary to evaluate them. As mentioned before, the evaluation is with the precision and recall measures [6]. In addition to validation by human experts.

4 Partial Results

SemEval-2016 provides test data for the evaluation of the proposal to be made by the participants. It provides concepts that deal with taxonomies already made, for example concepts of a manual taxonomy of vehicles, concepts of vehicles obtained from WordNet, concepts of plants of a manual taxonomy and concepts of plants obtained from Eurovoc and WordNet.

Since the Wikipedia database has a size of 53 GB, it is necessary to limit that corpus by means of an information retrieval system. It was decided to limit it to only the documents in which the terms that task # 13 that the SemEval-2016 provided appear and to obtain two specific domain corpus based on Wikipedia one containing the terminology of the vehicles domain and another one of the domain of plants. Both are described in table 2. On the left side we have the SemEval input nouns, total corpus lines and the total words in the plant corpus, on the right side we have the exact same parameters for the vehicle corpus.

Table 2. Properties of the two sub-corpus

Plants Corpus		Vehicle Corpus	
SemEval Input Nouns	513	SemEval Input Nouns	95
Total Corpus Lines	5000000	Total Corpus Lines	1781497
Total Corpus Words	131129942	Total Corpus Words	188093785

Table 3. Examples of hyponims / hyperonims of the SemEval proposed nouns

Plants Corpus		Vehicle Corpus	
Hyponym	Hypernym	Hyponym	Hypernym
senna	shrub	water scooter	motorboat
eelgrass	water plant	coach	car
guava	edible fruit	rocket	vehicle
eelgrass	aquatic plant	chariot	transport

Table 4. The 14 first patterns obtained by processing the plants and vehicle corpus

Plants Corpus		Vehicle Corpus	
Pattern	Frequency	Pattern	Frequency
to	1906	the	1434
and	1323	and	1493
or	563	a	665
at the	491	or	530
of	444	to	356
the	411	s	139
in the	361	by	119
a	281	and a	73
is a	244	was	68
is	173	on a	68
at	159	on the	64
and other	150	is a	57
like	130	of the	55
is a species of	84	and the	51

Table 5. Intersection of previous results with the lower frequency and some examples

Patterns Intersection		Vehicle Examples	Plant Examples
and	1295	hydrogen fuel cell-powered concept **car and sport utility** vehicle	It makes a good container **plant and ornamental tree**.
or	530	A limousine, executive **car or sport utility** vehicle is usually selected.	Some rooms were used as kitchens or pantries due to the fact of the large number of animal bones found inside, other room was used to store liquids (oil, wine or honey) in big containers or dolia and other rooms were used to store **grain or cereal** in pieces of pottery
the	411	Two would no longer be able to **lift the rocket** to launch altitude.	Lemon basil is **the** only basil used much in Indonesian cuisine
to	356	The princess had him come into the **coach to drive** back	A report by General Robert E. Lee on August 22, 1864, stated that **corn to feed** the Southern soldiers was exhausted.
is a	57	A **rocket is a pyrotechnic firework** made out of a paper	The African yam **bean is a legume** that is rich in protein and starch and an important source of calcium and amino acids.
by	40	heavy goods vehicles, and **public transport by coach** and bus	It contains the single species Eastwoodia elegans, a flower known **by** the common name yellow mock aster or yellow aster.
‘s	38	Because the rocket**'s** engine could withstand high heat	The plant**'s** flowers and fruits get set in about 10 to 11 months time followed by a maturity period of about 7–8 months and then harvested in about 18 months.
and the	35	The Inyo, as well as the express **car and the passenger car**, originally served the Virginia and Truckee Railroad in Nevada.	Predominating plants include the Moriche **Palm and the tree** "Caraipa llanorum". The dominant vegetation on the non-flooded savannas is grass.
on the	31	It is the range of 89-93% of mean state of charge which means as the **blades on the flywheel** turn, energy is being stored up between 89-93% of the given output.	Some family members use also an **oak leaf on the tree** trunk.

In the second phase of the first approach proposed for the extraction of patterns, the first step is to obtain hyponyms / hypernyms from the list of nouns proposed by semeval. Table 3 illustrates some of the results obtained by wordnet, these are extracted to have a base of patterns.

In table 4 we can observe the results obtained when executing the algorithm of the first approach. In column one and two the results are shown with the nouns of the plant domain and the remaining columns correspond to the results obtained for the domain of vehicles.

We decided to make an intersection of the previous results to get some generality of the patterns. In table 5 we show some examples of the extracted relations with some of the previous obtained patterns including the context of the full sentence, the first column is the pattern, second one is the lower frequency on both corpus, 3rd and 4th columns are vehicle examples and plant examples respectively.

The evaluation measure used is: Presicion, P = [Correct ISA] / [Sample]. Where sample is the input domain that can be plants or vehicles. In the case of the plants domain the total nouns with its hyponym / hyperonym relationship is 513, and we made a quick review of the reduced corpus and find out that we have 325 relationships found in the subcorpus so thats 58.03% of accuracy relationships found.

These are partial results as we need to make a test with the extracted general patterns to find out more relationships not limited by our first Wordnet output and check its validity with a domain expert.

5 Conclusions

As we can observe the results obtained as far as the patterns are very similar, we can find the same patterns with the execution of the first methodology in a corpus as well as in the other. It is planned to make a union of both results to join all the patterns that may be different and the patterns that are repeated add the number that were repeated in each corpus to take them to the top positions in the list of candidate patterns.

We can see that in the list there are already validated patterns by authors, such as the Hearst patterns, with finding them in the first positions we can intuit that the proposed methodology is valid and works also this work may be considered as a complement for the Hearst patterns previously described in the related work.

The Web has profoundly changed the way we communicate, do business, and do our work. You have access to millions of resources in different languages regardless of where we are today.

The problem of the Web is that the content / resources that we can find grows faster than we can classify it, thanks to the semantics in the Web, the software is able to process its content, reason with it, combine it and make logical deductions To solve everyday problems automatically.

This research proposes a system that can detect and extract hyponymic / hyperonymic taxonomic relations in flat texts (non-structurally) automatically. By ordering this hierarchical taxonomy (hierarchical), it would be classified semantically and could facilitate its access and understanding by other computer systems that require this type of information that is structured semantically.

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Backpropagation Neural Network for the Prediction of PM_{10} Contamination Data

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Abstract. The prevention of respiratory diseases caused by high air pollution rates is an important issue in big cities, where industrialization and overpopulation cause an increase in allergenic particles that aggravate the disease of allergic rhinitis and asthma, especially in childhood. The problem lies in the disinformation of the population about air quality and the preventive measures to be taken in order to avoid deterioration in health. In this paper, data are monitored by a sensor network that registers the most abundant allergen, called PM_{10}, for the city of León, Guanajuato. An artificial neural network (ANN) with a supervised Backpropagation training is used to predict future data until a minimum error is reached. The proposed methodology generates efficient results, measured in the error of the solutions and in execution time.

Keywords: Sensor network, Artificial neural network, Backpropagation training, Climate data prediction.

1 Introduction

One of the main causes of respiratory diseases, which generates great concern for big cities, is the air emission of pollutants, caused by various human activities, including industry [1, 2]. The use of non-renewable resources in the production of energy, such as oil or coal, generates important emissions of sulfur dioxide (SO2), carbon monoxide (CO), among others. On the other hand, the means of transport used in daily life are another alarming source of pollution. A large part of these pollutants emitted into the environment is generated by cars [3]. According to the United Nations, there are currently around 7 billion people in the world [4, 5], which represents an enormous source of pollution, aggravating the problem as people tend to migrate to big cities or the cities continue to expand, which leads to a higher emission of pollutants that deteriorate air quality. According to data from the "Consejo Nacional de Población" (CONAPO), 72.3% of the population in Mexico lives in metropolitan areas. In addition, according to the United Nations (UN), in the next 10 years rural populations will begin to decline significantly [6]. All this causes that the health of the people, in the big cities, are going to deteriorate more and more. Allergens are those particles that can cause and/or aggravate allergies. The main allergens found in the air are ozone (O3), sulfur dioxide (SO2), carbon monoxide (CO), lead (Pb), particulate matter (PM2.5 and PM10), among others [7, 8].

Constant monitoring of air quality using sensor networks [9] allows people, who suffer allergies, to be informed about the environmental conditions, in order to take pertinent actions and avoid a deterioration in health. In the city of León, Guanajuato, there is the monitoring of air quality by the "Instituto de Ecología del Estado" (IEE). IEE has the "Sistema de Monitoreo de Calidad del Aire del Estado de Guanajuato" (SIMEG), a system that is made up by three fixed monitoring stations, distributed in the city of León. This paper makes use of the data generated by one of the three stations of the SIMEG, which is called "Cámara de la Industria del Calzado del Estado de Guanajuato" (CICEG) [10]. This station generates measurements of pollutant allergens PM, O3, NO2, SO2, NO2 and CO. These allergens (also Pb) fall into the category of major air pollutants [11].

In the present work, in order to obtain further information, as exact as possible, about the updated level of air quality in the environment, a Backpropagation Neural Network (BP-ANN) is used to predict the future data of allergens, obtained by the sensor network installed at the CICEG station. ANNs are a tool that has proved effective in predicting future data. In [12], a BP-ANN is used for the short-term prediction of wind energy. In [13], good predictions in the stock market are obtained.

The rest of this article is organized as follows: Section 2 presents theoretical concepts used in the elaboration of this work. Section 3 shows the methodology. Section 4 shows the results that were obtained and finally, section 5, shows the conclusions.

2 Theoretical Framework

2.1 Air Quality Index (AQI)

The AQI is an indicator of daily air quality, which shows how clean the air around us is, and what are the effects by such air quality. AQI measurements range goes from 0 to 500 ppb. These measurements are divided into five categories (Good, Moderate, Unhealthy for Sensitive Groups, Unhealthy, Very Unhealthy and Dangerous), that are determined depending on the level of pollutant in a higher proportion [14]. The AQI focuses on the measurement of five major air pollutants: SO2, CO, NOx, PMx and O3. The level of air quality, determined by the AQI [15], is generated by the Equation 1:

$$I_p = \frac{I_{HI} - I_{LO}}{BP_{HI} - BP_{LO}}(C_P - BP_{LO}) + I_{LO}. \quad (1)$$

Where I_p is the air quality index, C_P is the concentration of pollutant observed, I_{HI} is the breakpoint AQI greater than C_P observed, I_{lo} is the breaking point AQI less than C_P observed, BP_{HI} is the breakpoint of pollutant greater than C_P observed and BP_{LO} is the breakpoint of pollutant less than C_P observed. The AQI breakpoints are shown in Table 1, which are replaced in the Equation 1 to know the air quality index.

Table 1. AQI classification and breakpoints

Category	Minor Breakpoint	Major Breakpoint	Category color
Good	0	50	Green
Moderate	51	100	Yellow
Unhealthy for Sensitive Groups	101	150	Orange
Unhealthy	151	200	Red
Very Unhealthy	201	300	Purple
Dangerous	301	500	Brown

For the breakpoints of the pollutants, the air quality semaphore published in the “Informe de Estado y Tendencia de la Calidad del Aire Guanajuato 2014” was used [10]. The breakpoints for pollutants obtained by the CICEG station are shown in Table 2.

Table 2. Classification of the five main pollutants, sensed by the CICEG station, with its units of measures

Pollutant	PM_{10}	O_3	SO_2	NO_2	CO
Unit of Measurement	$\mu g/m^3$	Ppb.	Ppb.	Ppb.	Ppm.
Good	0-54	0-64	0-99	0-198	0-9
Satisfactory	55-74	65-69	100-109	190-209	9-10
Not Satisfactory	75-174	70-130	110-174	210-315	11-15
Bad	175-274	131-184	175-239	316-420	16-22
Very Bad	>275	>185	>240	>420	>22

2.2 Backpropagation Artificial Neural Network (BP-ANN)

Backpropagation was introduced in 1986, by Rumelhart, Hinton and Williams. This is a type of gradient descent [16], because it uses the calculation of the gradients of a neural network to adjust the weights [17]. Due to the advantages offered by this ANN modality, it is one of the most used [12].

The activation function used for the ANN is the sigmoid. This activation function has a good performance when the data for the training are positive, in a range of values between 0 and 1 [17]. The Equation 2 shows the sigmoid function:

$$f(x) = \frac{1}{1 + e^{-x}}. \quad (2)$$

In order to comply with the network requirement, a normalization of the values was performed, placing them in a range between 0 and 1, through the Equation 3 [18]:

$$y_i = \frac{d - x_{min}}{x_{max} - x_{min}}. \quad (3)$$

Where d, is the data to normalize, x_{max} is the maximum value in the data series and x_{min} the minimum value. A total number of epochs was determined as the stopping criterion, in addition to an stop error [19], which is measure by the Equation 4:

$$Error = (y_i - f(x_i))^2. \quad (4)$$

Where y_i, are the known data, and $f(x_i)$ the data calculated by the BP-ANN.

2.3 Particulate Matter (PM_{10})

PM are inhalable particles, with diameters that are generally 10 micrometers and smaller. These particles can be breathed but remain on the nose, this can cause nasal obstruction among other inconveniences [20]. Figure 1 [21], shows an illustration of this pollutant.

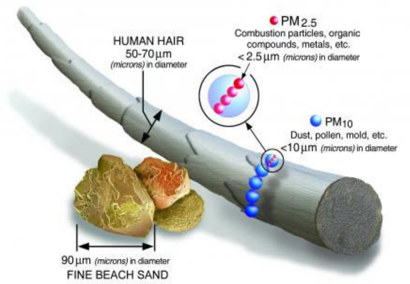

Fig. 1. Size of the PM_{10} particle

These particles are emitted directly from a source, such as construction sites, power plants, industries and automobiles. Also, are formed in the atmosphere as a result of complex reactions of chemicals. Exposure to such particles can affect both your lungs and your heart, and a variety of problems, as nonfatal heart attacks, irregular heartbeat, aggravated asthma, among others [21].

3 Methodology

This work was supported by the IEE, which facilitated the collection of the database generated by the CICEG station, located in the city of León. The database has 63, 913 records: from January 1, 2010 to March 31, 2017. In addition to the measurement of five pollutants (PM_{10}, O_3, NO_2, SO_2, NO_2 and CO), the database has the information of "Year, Month, Day, Time and Temperature". In this work, the data corresponding to the pollutant PM were taken, due to the fact that this pollutant is the most prevalent in the area, and dictates the AQI level for the CICEG station. Table 3 shows how the database is constituted.

Table 3. Database of levels for the five different contaminants, generated by the CICEG station

Date	Hour	O_3	SO_2	NO_2	CO	PM_{10}	Temperature
1/1/2010	0	7.02	10.40	151	3	362	14
1/1/2010	1	8.04	17.2	95	2.8	498	16
1/1/2010	2	10	18	101	3.3	490	17
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
31/03/2017	21	9.24	16.1	90	2.14	82	22
31/03/2017	22	9.01	15.68	101	2.32	101.05	21.35
31/03/2017	23	8.77	15.06	85	1.86	90.34	20.98

First, the data from 8, 9 and 10 hours were selected, due to the pollutant was most present on that hours, and there is more urban mobility in the area. Figure 2, shows the behavior of PM10 pollutant measurements.

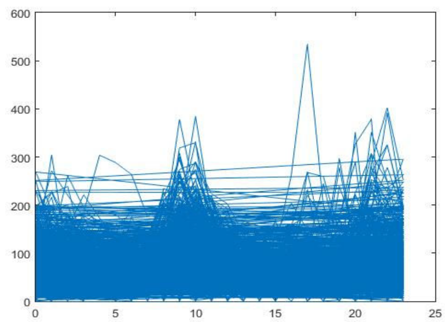

Fig. 2. Behavior PM_{10} pollutant measurements

We took one year of measurements for each hour; these correspond to data from March 1, 2016 to March 31, 2017. With these data we predict the level of pollutant of the selected hours to April 1, 2017. In total, we obtained 396 measurement data per hour. Figure 3, shows the methodology used.

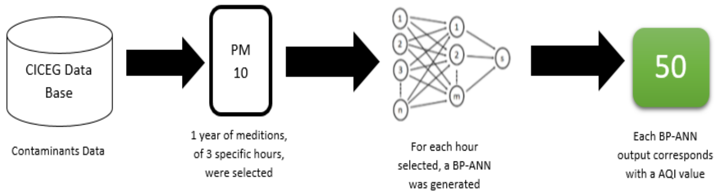

Fig. 3. Methodology used

For each hour selected for prediction, a BP-ANN was generated. Each of the values of the variables introduced in the input layer was normalized to satisfy the requirements of the network, through the Equation 3. The configuration that was used in the ANN is shown in the Table 4.

Table 4. Neural network configuration

Variable	Epochs	Entry/Hidden/Output Layer Neurons	Stop criterion	Learning rate	Weights
PM10	50000	316/310/1	0.001	0.03	-2 to 2

For training process, we took 396 data, which corresponds with 396 days of measurements from March 1, 2016 to March 31, 2017. Of these, 316 were taken for training; each value corresponds to an input neuron of the BP-ANN. The remaining 80 data were taken for testing, and thus performed the calibration of the weights. The output of the BP-ANN was compared with a value already known until reaching the stop criterion (0.001) or a specified number of epochs. We performed 35 runs, obtaining the median of the results, as a parameter to know the efficiency of the prediction.

This configuration shown in Table 4 was selected according to the best results given by previous experimentation, using different parameters. Once the value of the contaminant introduced into the ANN is obtained, the inverse process is done to the normalization, making use of the Equation 6, which is obtained by the Equation 3:

$$d = y * (x_{max} - x_{min}) + x_{min}. \quad (6)$$

Where y, is the normalized data, x_{max} is the maximum value in the standardized data set and x_{min} the minimum. Once the data is obtained in its original form, it is entered into the system through Equation 1, and thus knows the level of air quality. These levels of air quality are compared to each other to determine which the one that generates a higher AQI is.

4 Results

Once the network was trained, for the validation process, we add a vector whose output was not known by the network. The output not known, corresponded to the following day April 1, 2017 to those selected for training and testing. The validation data is known to verify the efficiency of the BP-ANN. Due the output of the network is a normalized data; the Equation 6 is used to know the real data and compare it. Table 5 shows the results of the experiments carried out in the prediction of the selected data from the CICEG station with the BP-ANN.

Table 5. Result of the 35 runs performed with the neural network

Hours	8	9	10
Real	53.71	88.96	83.19
Neural Network Output	52.80	87.45	85.10

The values of the pollutants were replaced in the Equation 1, in order to know which the one that determines the level of air quality is. Table 6 shows the results.

Table 6. AQI value for the results of the neural network experiments shown in Table 5

Hour	8	9	10
AQI	48.88	107.16	105.99
Category	Good	Sensitive Groups	Sensitive Groups

The behavior of the observed error in the training process of the BP-ANN, is observed in Figure 4.

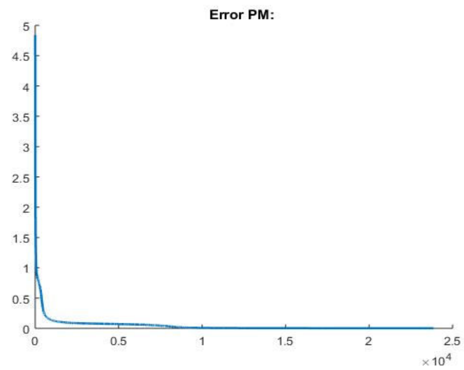

Fig. 4. Error behavior in the training process of the BP-ANN

As is shown in Table 6, the highest value AQI index was the PM_{10} for the 9 hours. Because the AQI index is taken on the basis of the pollutant that is most in the environment, the AQI predicted would be 107.16, which equates to the air quality category “Unhealthy for Sensitive Groups".

5 Conclusions

In this paper, the effectiveness of BP-ANN to predict has been demonstrated once again. As can be seen in Table 5, the values obtained at the output of the neural network are very close to the actual values (not known by the neural network) of the PM_{10} pollutant measured by the CICEG station. The system is effective, because the results allow having confidence in the predictions of the neural network.

It is important to mention that the values of the pollutant measurements obtained by the CICEG station vary greatly from one hour to another, due to factors such as traffic levels, work schedules in factories near the station, climatic conditions, among others. As this can vary (for better or for worse) from one hour to another, the system is also able to send alerts based on the observations of the station. It is expected with this to encourage people suffering from respiratory diseases, to be more aware of the air quality of the environment in which they develop. Based on the opinion of experts, the problem of pollution is something that will continue to exist and will continue to be a focus of attention for society, and by staying informed you can create awareness to take more care of the environment.

As future work, it is proposed to perform the processing of the databases generated by the other stations located in the city of León, and thus to have a general overview of the level of air quality in the city. Also, it is proposed to use other prediction tools such as least square data adjustment, and to perform experiments to see which offers better performance in prediction and computational cost or other features that help to streamline the prediction system. Besides, use sensors that allow us to know the quality of the air indoors, due that depending on indoor pollutants it can even lead to the generation of seasonal asthma and other diseases.

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Reasoning in Context-Aware Systems with Modal Logics

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Abstract. Context-aware systems are ubiquitous computing systems capable to adapt their behavior according to a dynamical changing environment. The development of reasoning and modeling techniques of context information have resulted a challenging task due to the inherent complexity of dynamical systems. In particular, modeling time and location context information have been so far constrained in current formalisms for context-aware computing due to expressive and computational limitations. Due to the well-known balance of expressive power and efficient reasoning algorithms associated to modal logics, we propose in the current work the use of expressive modal logics as a reasoning framework for context-aware pervasive systems. In particular, we describe a consistency model for a context-aware communication system. The consistency of this model is characterized in term of the satisfiability of the μ-calculus (an expressive modal logic).

Keywords: Context-Aware Systems, Automated reasoning, Modal logics.

1 Introduction

Context-aware systems are flexible and adaptable to the context of information [6]. Due to the inherent huge amount of context variables in these systems, developing a context-aware system tends to be a very complex task for developers. In order to help reduce complexity and improve the maintenance and scalability in context-aware systems, it then is necessary to use modeling and reasoning techniques.

Basic modal logic K is an extension of propositional logic with necessitation and possibility operators [7]. Many extensions of K, such as linear temporal logic (LTL), propositional dynamic logic (PDL), computational tree logic (CTL), description logics (DLs), etc., have been successfully used as reasoning frameworks in a wide rage of domains, such as program analysis, knowledge representation, databases, programming languages, etc. Due to the well-known balance of expressive power and efficient reasoning algorithms associated to modal logics [12], we propose in the current work the use of expressive modal logics as a reasoning framework for context-aware pervasive systems.

1.1 Motivations and Related Works

One of the early approaches when modeling context aware systems is described in [10]. In this paper, it is described a context-aware communication system in terms of CML (object role modeling [9]) models. In particular, the input of the system consists of communication preferences for a set of persons and communication constraints for a set of locations. The system outputs a ranked set of communication channels suggestions satisfying preferences and location constraints. However, there is no guarantee the communication system is consistent, that is, whether communication preferences and location constraints allow any communication at all. In the current paper, we describe a consistency checker of the context-aware communication system. More precisely, we model the system in terms of μ-calculus formulas, an expressive modal logic. Where if the formula is satisfiable, then the communication system is consistent, otherwise, the system is not consistent.

In [5], several spatial modeling approaches are described: set-based, hierarchical, graph-based, and hybrids. These approaches can model, with some limitations, several kind of spatial queries: position, nearest neighbor and range. One major limitation with these approaches is concerning time modeling. Since expressive modal logics have been successfully used as reasoning frameworks in the context of arithmetic constraints [3], which implies spatial modeling via euclidean distance, we believe that these expressive logics can also be used in the setting of spatial modeling, together with time modeling.

More recently, ontology-based modeling has gained a lot of attention in the pervasive computing community [11, 8, 13]. Ontologies are described in terms of the OWL(2) (Web Ontology Language) [2]. OWL(2) has been successfully studied and developed as a reasoning framework in the knowledge representation setting [1]. Since context information can be seen as a particular kind of knowledge, several proposed for context-aware modeling have been described, first in terms of the first version of OWL [8, 13], then with the last version OWL2 [11]. Although, OWL2 can model complex human activities, it still has some limitations with respect to spatial modeling. Since OWL(2) is in principle a Description Logic, which itself can be seen as member of the modal logic family [4], we believe extension of OWL2 with arithmetic constraints can be used for spatial modeling.

In Section 2, we describe the modal μ-calculus, then in Section 3, we provide a consistency model for a context-aware communication system. Finally in Section 4, we give a brief summary of the paper and discuss further research perspectives.

2 The μ-calculus on Trees

In this section, we introduce the μ-calculus with converse, an extension of modal logic with and least and greatest fixed-points. Also converse modalities are included. Formulas are interpreted over finite unranked trees.

Before definining the set of fomulas, we consider a fixed alphabet composed by three sets $PROP$, MOD and Var, where $PROP$ is a set of proposition, $MOD = \{1, 2, 3, 4\}$ is a set of modalities, and Var is a set of variables.

Definition 1 (Syntax). *The set of μ-calculus formulas is defined by the following grammar:*

$$\varphi ::= p \mid X \mid \neg\varphi \mid \varphi \vee \psi \mid \langle m\rangle\varphi \mid \mu X.\varphi$$

Where p is a proposition, m a modality, and X is a variable.

We assume variables can only occur bounded and in the scope of a modality.

Formulas are interpreted as node subsets in unranked trees. We then now define tree structures in style of Kripke. A tree structure K or simply a tree is defined as a tuple (N, R, L) where:

- N is a set of nodes;
- R is a family of binary relations R^m among nodes $(N \times N)$ forming a tree shape, that is, R^1 denotes the first child relation, R^2 the following (right) sibling, R^3 the parent, and R^4 the previous (left) sibling, we often write $n' \in R(n, m)$ instead of $(n, n') \in R^m$; and
- L is a function labeling $L : N \to 2^{PROP}$.

We give a formal description of formula semantics.

Definition 2 (Semantics). *Consider a tree K and a valuation $V : Var \to 2^N$. Formulas are interpreted as follows:*

$$\begin{aligned}
[\![p]\!]^K_V &= \{n \mid p \in L(n)\}\\
[\![\neg\varphi]\!]^K_V &= N \setminus [\![\varphi]\!]^K_V\\
[\![\varphi \vee \psi]\!]^K_V &= [\![\varphi]\!]^K_V \cup [\![\psi]\!]^K_V\\
[\![\langle m\rangle\varphi]\!]^K_V &= \{n \mid R(n, m) \cap [\![\varphi]\!]^K_V \neq \emptyset\}\\
[\![X]\!]^K_V &= V(X)\\
[\![\mu X.\varphi]\!]^K_V &= \bigcap\{N' \mid [\![\varphi]\!]^K_{V[^{\mu X.\varphi}/_X]} \subseteq N'\}
\end{aligned}$$

A formula ϕ is satisfiable, if and only if, there is a tree such as the interpretation of ϕ over the tree is not empty, that is $[\![\phi]\!]^K_V \neq \emptyset$. If a tree K satisfies a formula ϕ, we say K is a model of ϕ.

Intuitively, propositions are used as labels for nodes, negation $(\neg)$ is interpreted as set complement, disjunctions are interpreted as set union. Modal formulas $\langle m\rangle\phi$ hold in nodes where there is an m-adjacent node supporting ϕ. The least fixed-point is intuitively interpreted as a recursion operator.

Notation: $\phi \wedge \varphi := \neg(\neg\phi \vee \varphi)$, $[m]\phi := \neg\langle m\rangle\neg\phi$, $\nu x.\phi := \neg\mu x.\neg\phi[^x/_{\neg x}]$, $\top := p \vee \neg p$, and $\bot := \neg\top$.

Example 1. Consider for instance the following formula: $\langle 1\rangle p_2 \wedge p_1$. This formula holds in nodes named p_1 with a child named p_2. In Figure 1, there is a graphical representation of tree model for $\langle 1\rangle p_2 \wedge p_1$.

The fixed-point operator is intuitively interpreted as a recursion operator, consider for instance $\mu X.(p_3 \vee \langle 1\rangle X) \wedge \langle 1\rangle p_2 \wedge p_1$. This formula holds in a p_1 node with a descendant p_3 and a child p_2. The tree in Figure 1 is also a model for $\mu X.(p_3 \vee \langle 1\rangle X) \wedge \langle 1\rangle p_2 \wedge p_1$.

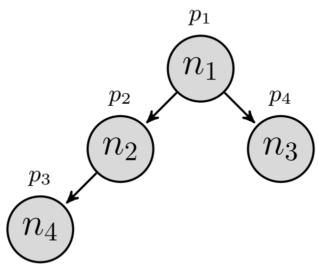

Fig. 1. Tree model for $\langle 1\rangle p_2 \wedge p_1$ and $\mu X.(p_3 \vee \langle 1\rangle X)$

3 Consistency of a Context-Aware Communication System

In this section, we describe a μ-calculus characterization of a context-aware communication system [10]. The input of the communication system consists of a set of user communication preferences, a set of location communication constraints, and a schedule describing when users are at a specific location. Communication can be synchronous or asynchronous. For instance, let say the communication system is composed by two users, whose communications preferences consists of e-mail and chat, and e-mail and phone, respectively. e-mail and chat imply asynchronous communication, and phone implies synchronous communication.

It is then easy to see that user 1 can start communication asynchronously with user 2. However, it may be the case that according to the schedule, user 2 will be located at places where e-mail is not available. Furthermore, user 2 may have access to e-mail but only before user 1. In this two cases, we say the communication system is not consistent because constrains forbid communication. The μ-calculus formula characterizing the system is satisfiable, if and only if, the system is consistent.

Formally, we describe the input of the system as sets.

Definition 3 (System input).

- *The set of communication channels* $CH = \{c_1, \ldots, c_n\}$ *is divided in asynchronous and synchronous, that is,* $CH = AC \cup SC$ *and* $AC \cap SC = \emptyset$.
- *The set of user preferences (restrictions)* PC *is composed by pairs* (p, c), *Where* p *is a user proposition, and* c *is a communication channel.*
- *The set of communication constraints for locations* PL *is composed by pairs* (l, c), *where* l *is a location proposition and* c *is a communication channel.*
- *The schedule is defined as the following set:* $SCH = \{(p, t, l) \mid p$ *is a user proposition,* t *is a time proposition,* l *is a location proposition*$\}$.

In order to semantically define the consistency of the communication system, we define a consistency model.

Definition 4 (System consistency model). *Given a set of communication channels* CH, *a set of user preferences* PC, *a set of location constraints* PL, *and* *a schedule SCH, we define the consistency model $CModel(CH, PC, PL, SCH)$ as a tree structure (N, R, L), as follows:*

- *there is one node for the root $r \in L(n)$;*
- *one node for each time proposition $t_i \in L(n_{t_i})$ $(i = 1, \ldots, k_1)$, which are the children of the root, that is, $R(n, 1) = n_{t_1}$, $R(n_{t_j}, 2) = n_{t_{j+1}}$ $(j = 1, \ldots, k_1 - 1)$;*
- *each time node has one child per location, that is, $l_j \in L(n_{l_{i,j}})$ and $R(n_{t_i}, 1) = n_{l_{i,1}}$ and $R(n_{l_{j,s}, 2}) = n_{j,s+1}$, where $i = 1, \ldots, k_1$, $j = 1, \ldots, k_2$ and $s = 1, \ldots, k_2 - 1$;*
- *each location node has one child per channel available, that is, $c_s \in L(n_{i,j,w})$, $R(n_{l_{i,j}}, 1) = n_{c_{i,j,1}}$ and $R(n_{c_{i,j,w}}, 2) = n_{c_{i,j,w+1}}$, where $i = 1, \ldots, k_1$, $j = 1, \ldots, k_2$, $s = 1, \ldots, k_3$ and $w = 1, \ldots, k_3 - 1$; and*
- *each channel node has one child per user with that channel preference, that is, $u_w \in L(n_{c_{i,j,s}})$, $R(n_{c_{i,j,s}}, 1) = n_{u_{i,j,1}}$ and $R(n_{u_{i,j,z}}, 2) = n_{u_{i,j,z}}$, where $i = 1, \ldots, k_1$, $j = 1, \ldots, k_2$, $s = 1, \ldots, k_3$, $w = 1, \ldots, k_4$ and $z = 1, \ldots, k_4 - 1$.*

Intuitively, a consistency model is tree of 5 levels: the first level is the root; the second is composed by the time lapses considered in the schedule; the third level contains the locations; the communication channels available at a particular location compose the fourth level; and the last level contains the users associated to each communication channel. In Figure 2 it is depicted a graphical representation of a consistency communication model.

In order to define the consistency of the communication system, we define the following relations in a tree (N, R, L): a node n_1 is a child of a node n_2, written $child(n_1, n_2)$, if and only if, $R(n_1, 1) = n_2$ or there is a non empty sequence $R(n_1, 1) = n'_1, R(n'_1, 2) = n'_2, \ldots, R(n'_i, 2) = n_2$; a node n_1 is a descendant of a node n_2, written $descendant(n_1, n_2)$, if and only if, there is a non empty sequence of nodes $n'_1, n'_2, \ldots, n'_i$, such that $child(n_1, n'_1)$, $child(n'_1, n'_2)$, …, $child(n'_i, n_2)$; and a node n_2 is a following sibling of a node n_1, written $fsibling(n_1, n_2)$, if and only if, n_1 is the same than n_2 or there is a (possibly empty) sequence of nodes $R(n_1, 2) = n'_1$, …, $R(n'_i, 2) = n_2$.

Definition 5 (System consistency). *Given a consistency model $CModel$, we say user u_1 can communicate with user u_2, if and only if,*

- *(Synchronously) there is a channel node n_c, such that $child(n_c, n_{u_1})$ and $child(n_c, n_{u_2})$, and there is a time node n_t, such that $descendant(n_t, n_c)$, $descendant(n_t, n_{u_1})$ and $descendant(n_t, n_{u_2})$;*
- *(Asynchronously) there is a channel node c_c, such that $child(n_c, n_{u_1})$ and $child(n_c, n_{u_2})$, and there are two time nodes n_{t_1} and n_{t_2}, such that $fsibling(n_{t_1}, n_{t_2})$, $descendant(n_{t_1}, n_c)$, $descendant(n_{t_2}, n_c)$, $descendant(n_{t_1}, n_{u_1})$ and $descendant(n_{t_2}, n_{u_2})$.*

Synchronous communication among two users occurs in the system consistency model when the user nodes are children of the same communication channel node and descendants of the same time node. Asynchronous communication relax the time restriction: the user node who starts communication must be a

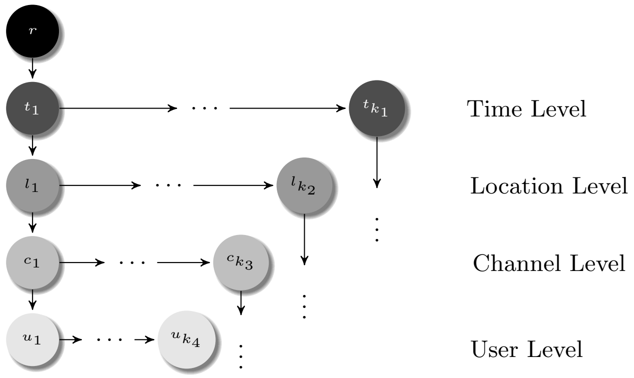

Fig. 2. Graphical representation of a consistency communication model

descendant of a time node, which is a previous sibling of the ancestor time node of the other user node.

We now define a logic formula that it is only satisfiable in a consistency model. To this end, we first define some notation: $\langle m\rangle^0\phi := \phi$, $\langle m\rangle^1\phi := \langle m\rangle\phi$, $\langle m\rangle^i\phi := \langle m\rangle^{i-1}\langle m\rangle\phi$, where m is modality and i is the natural number.

We now describe a characterization of the consistency model in terms of a μ-calculus formulas.

Definition 6 (Consistency formula). *Given a system input CH, PC, PL and SCH, and a communication type $tc \in \{syn, asyn\}$, syn for synchronous and asyn for asynchronous, we define the consistency formula as follows:*

$$N_1(tc) := \langle 1\rangle(t_1 \wedge N_2(tc, t_1) \wedge \bigwedge_{i=2}^{k_1} \langle 2\rangle^{i-1}(t_i \wedge N_2(tc, t_i)) \wedge \neg\langle 2\rangle^{k_1}\top)$$

$$N_2(tc, t) := \langle 1\rangle(l_1 \wedge N_3(tc, t, l) \wedge \bigwedge_{i=2}^{k_2} \langle 2\rangle^{i-1}(l_i \wedge N_3(tc, t, l)) \wedge \neg\langle 2\rangle^{k_2}\top)$$

$$N_3(tc, t, l) := \begin{cases} \neg\langle 1\rangle\top & h(tc, t, l) = 0) \\ F_3(tc, t, l) & h(tc, t, l) \geq 1) \end{cases}$$

$$F_3(tc, t, l) := \langle 1\rangle(c_1 \wedge N_4(tc, t, l, c_1) \wedge \bigwedge_{i=2}^{h(tc,t,l)} \langle 2\rangle^{i-1}(c_i \wedge N_4(tc, t, l, c_i)) \wedge \neg\langle 2\rangle^{h(tc,t,l)}\top)$$

$$N_4(tc, t, l, c) := \begin{cases} \neg\langle 1\rangle\top & k(tc, t, l, c, p) = 0) \\ F_4(tc, t, l, c) & h(tc, t, l, c, p) \geq 1) \end{cases}$$

$$F_4(tc, t, l, c) := \langle 1\rangle(p_1 \wedge \bigwedge_{i=2}^{k(tc,t,l,c,p)} \langle 2\rangle^{i-1}p_i \wedge \neg\langle 2\rangle^{k}\top)$$

Where k_1 is the number of time propositions in the schedule, k_2 is the number of locations, $h(tc, t, l) = |\{c \in tc \mid (l, c) \in PL\}|$ is the number of communication channels of type tc at a particular location l, and $k(tc, t, l, c, p) = |\{c \in tc \mid (p, t, l) \in SCH, (p, c) \in PC\}|$ is the number of users with a communication channel c as a preference.

Lemma 1. *Given a system input channels, PC, PL, SCH, the consistency formula is satisfiable by the consistency model only, that is, $[\![N_1(tc)]\!]_V^K \neq \emptyset$, if and only if, N is $CModel$.*

We now define a characterization formula for each type of communication.

Definition 7 (Synchronous communication). *The characterization formula $SC(u_1, u_2)$ corresponding to a synchronous communication from user u_1 to u_2 is defined as follows:*

$$
\begin{aligned}
SC(u_1, u_2) :=& \bigvee_{i=1}^{k} F_{SC}(u_1, u_2, c_i)\\
F_{SC}(u_1, u_2, c_i) :=& \langle 1\rangle(\mu T.(\langle 1\rangle(F(u_1, c_i) \wedge F(u_2, c_i)) \vee \langle 2\rangle T))\\
F(u, c) :=& \mu L.(\langle 1\rangle(\mu C.(c \wedge \langle 1\rangle(\mu P.u \vee \langle 2\rangle P)) \vee \langle 2\rangle C)) \vee \langle 2\rangle L)
\end{aligned}
$$

Where k is the number of synchronous communication channels.

Definition 8 (Asynchronous communication). *The characterization formula $AC(u_1, u_2)$ corresponding to a synchronous communication from user u_1 to u_2 is defined as follows:*

$$
\begin{aligned}
AC(u_1, u_2) :=& \bigvee_{i=1}^{k} F_{AC}(u_1, u_2, c_i)\\
F_{AC}(u_1, u_2, c_i) :=& \langle 1\rangle(\mu T.(\langle 1\rangle F(u_1, c_i) \wedge \mu T'.(\langle 1\rangle F(u_2, c_i) \vee \langle 2\rangle T') \vee \langle 2\rangle T))
\end{aligned}
$$

Where k is the number of asynchronous channels and F is defined in Definition 7.

Now, from Lemma 1, it follows the consistency theorem.

Theorem 1. *Given an input system channels, PC, PL and SCH, user u_1 can communicate with user u_2 (according with Definition 5), if and only if,*

- *(synchronously) $N_1(syn) \wedge SC(u_1, u_2)$ is satisfiable;*
- *(asynchronously) $N_1(asyn) \wedge AC(u_1, u_2)$ is satisfiable.*

We now describe an example of the system input. We show in two cases when the system is consistent and inconsistent.

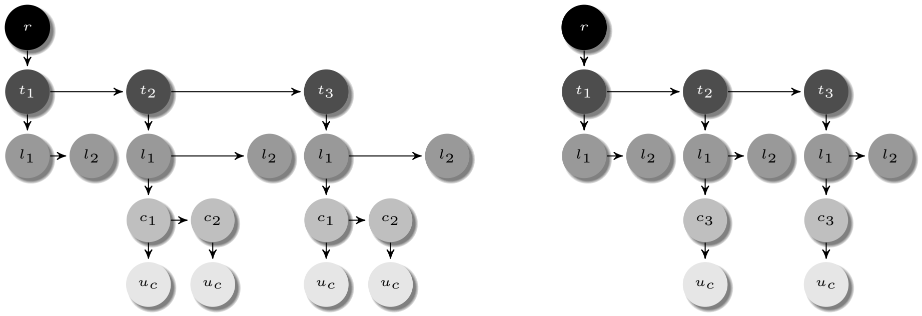

Fig. 3. The inconsistent CModel A is the synchronous communication, the formula is $root \wedge N_1(tc) \wedge SC(u_c, u_y)$ and the inconsistent CModel B is the asynchronous communication and the formula is $root \wedge N_1(t_c) \wedge AC(u_c, u_y)$. Where r is the root, c_1 is the mobile call, c_2 is landline, c_3 is the message, l_1 is the office and l_2 is the warehouse

Table 1. Schedule of users within the company

Schedule			
User	Preferences	Location	Time
u_y	mobile call and message	Warehouse	t_1, t_2 and t_3
u_c	mobile call, landline and message	Office	t_2 and t_3

Example 2. We consider the Table 1 where user u_y arrives at t_1 to the warehouse and user u_c arrives at t_2 to the office also this table shows user preferences and the location where they will be. Consistent system input.

- The set of communication channels is $CH = \{mobile\ call, landline, message\}$.
- The set of user preferences is $PC = \{(u_y, mobile\ call), (u_y, message), (u_c, mobile\ call), (u_c, message), (u_c, landline)\}$
- The set of communication constraints for location is $PL = \{(Warehouse, mobile\ call), (Warehouse, message), (Office, mobile\ call), (Office, landline), (Office, message)\}$
- The shedule is the following set: $SCH = \{(u_y, t_1, Warehouse), (u_y, t_2, Warehouse), (u_y, t_3, Warehouse), (u_c, t_2, Office), (u_c, t_3, Office)\}$

Inconsistent system input. Now consider where the user u_y has no preferences, we are based on the previous sets, the inconsistent system sets are as follows.

- The set of user preferences is $PC = \{(u_c, mobile\ call), (u_c, message), (u_c, landline)\}$

Example 3. We now present the $CModel(CH, PC, PL, SCH)$.

- The tree has a root (r).
- The time nodes are three t_1, t_2 and t_3 children of r.
- Each time node has two child nodes Office and Warehouse.

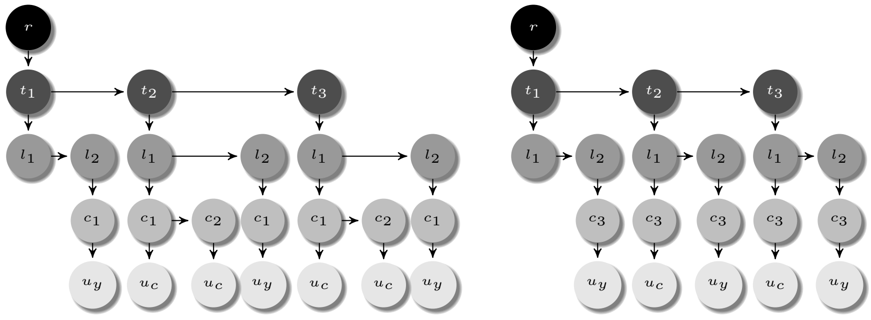

Fig. 4. The CModel A is the synchronous communication, the formula is $root \wedge N_1(tc) \wedge SC(u_c, u_y)$ and the CModel B is the asynchronous communication and the formula is $root \wedge N_1(t_c) \wedge AC(u_c, u_y)$. Where r is the root, c_1 is the mobile call, c_2 is landline, c_3 is the message, l_1 is the office and l_2 is the warehouse

– Each location node has two synchronous channels (mobile call and landline) and an asynchronous channel (message).
– Each channel node has one user (u_y and u_c), which are essential to the user's preference.

In the Figure 4 it is observed the CModel for the consistent system with synchronous and asynchronous communication. Now in the Figure 3 is observed the CModel for the inconsistent system with synchronous and asynchronous communication. In this figure we observe that the user u_y does not appear in the CModel, this is because he has not preferences.

Example 4. According with Definition 6, we present $N1(syn)$ only one example when the system is consistent and uses a synchronous communication.

$$\begin{aligned} N_1(t_c) :=& t_1 \wedge N_2(t_c, t_1) \wedge \langle 2 \rangle (t_2 \wedge N_2(t_c, t_2)) \wedge \langle 2 \rangle \langle 2 \rangle (t_3 \wedge N_2(t_c, t_3)) \\ & \wedge \neg \langle 2 \rangle \langle 2 \rangle \langle 2 \rangle \top \\ N_2(t_c, t_2) :=& \langle 1 \rangle (l_1 \wedge N_3(t_c, t_2, l_1) \wedge \langle 2 \rangle (l_2 \wedge N_3(t_c, t_2, l_2)) \wedge \neg \langle 2 \rangle \langle 2 \rangle \top) \\ N_3(t_c, t_2, l_1) :=& \langle 1 \rangle (c_1 \wedge N_4(t_c, t_2, l_1, c_1) \wedge \langle 2 \rangle (c_2 \wedge N_4(t_c, t_2, l_1, c_2)) \wedge \neg \langle 2 \rangle \langle 2 \rangle \top) \\ N_4(t_c, t_2, l_1, c_1) :=& \langle 1 \rangle (u_c \wedge \neg \langle 2 \rangle \top) \end{aligned}$$

Where c_1 is the mobile call, c_2 is landline, l_1 is the office, l_2 is the warehouse and t_c is syn.

Example 5. When a user u_c wishes to contact the user u_y. Then, according to Definition 7 we present an example of synchronous communication.

$$\begin{aligned} F_{SC}(u_c, u_y, c_1) :=& \langle 1 \rangle (\mu T.(\langle 1 \rangle (F(u_c, c_1) \wedge F(u_y, c_1) \vee \langle 2 \rangle T)) \\ SC(u_c, u_y) :=& F_{SC}(u_c, u_y, c_1) \end{aligned}$$

Where c_1 is mobile call. This example shows the mobile call channel. This channel is the only in common for the two users. In this case it is possible to communicate between the two users. In the case where the user does not have preferences the system is inconsistent.

4 Conclusions

In this paper, we proposed the use of expressive modal logics as a reasoning framework of context-aware systems. In particular, we described a consistency model for a context-aware communication system [10, 6]. This model is characterized in terms of the satisfiability of the modal μ-calculus.

As further research perspectives, we believe extensions of the μ-calculus, such as inverse programs, nominals and graded modalities, can be used to model time and location context information, a crucial expressive-computational bottleneck when reasoning in context-aware sytems [6].

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A Proposal for Domain Ontological Learning

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Abstract. In this paper, the population ontology problem is addressed and a semiautomatic methodology for ontology learning is proposed. In this work a study of advances in this research area is presented, which is divided according with the aim of the ontology and the class extraction, creation, or population. Based on this study, an initial proposal for ontology semiautomatic population is introduced. This initial proposal consists of four general steps: class extraction, creation, population and evaluation, where the population step is the main objective of this research. As future work, this methodology is intended to be applied to pedagogic domain, specially to classroom learning tools.

Keywords: Ontology learning, Semiautomatic population, Pedagogy domain, Ontology creation, NLP.

1 Introduction

In recent years, the available information has increased exponentially; thus, information science researchers propose strategies to develop processes and generate answers according to the user requirements in Information Processing Systems (IPS) [1]. The classic techniques of information retrieval cannot resolve problems like heterogeneity and ambiguity of web information. It is necessary to develop new semantics approaches to improve actual research, for example ontologies.

Ontologies can be used for purposes such as structure knowledge in taxonomies, vocabulary manage, natural language processing applications, searches, recommendation systems, and e-learning among others [2, 3, 4]. Ontologies can model interaction systems between users and their environment, since to its property to manage complex knowledge in reusable formal representations.

Ontology is a formal, explicit specification of a shared conceptualization. Their classes, relationships, constraints and axioms define a common vocabulary to share knowledge [5]. The ontology construction process can be manual or automatic, if it is automatic, the process is called "Ontology learning" and include: relevant terminology acquisition, synonyms extraction, concepts formation, hierarchical organization of elements, relationships learning, properties, attributes, with their rank and domain, hierarchical organization of relationships, instantiation of schema axioms, and arbitrary axioms definition [6]. In the manual construction process, a domain expert is necessary for model formalization; but generally, it is difficult to transmit their knowledge and the proper way to formalize it [7]. Ontology population is carried out in the previously defined last steps; these steps look for identifying instances of non-taxonomic relationships and properties of ontology classes. A generic methodology for automatic population include candidate instances identification using natural language processing techniques, classifier construction with machine learning and information extraction and new instances classification [8].

In this paper the population ontology problem is addressed and a semiautomatic methodology for ontology learning is outlined; for experiments, the pedagogic domain will be used. The article is organized in 4 sections following described. Section 2 introduces the population problem as well as the relevance to the selected domain. Section 3 presents an analysis about the related works, this section is divided in extraction features, creation and population subsections. Finally, section 4 presents conclusions and a general description about the proposed methodology.

2 Research Problem

The ontology construction process can be performed in a semiautomatic or automatic way from a set of initial data, which can be a text corpus in natural language. An automatic process involves artificial intelligence techniques and not human intervention, the semi-automatic process involves the human intervention in any process step. The idea is to start from a set of texts and relate their grammatical features with ontological entities. This relationship can be not flexible; however, there are exceptions where Natural Language Processing (NLP) techniques allow achieving a good texts representation through ontologies.

Currently, the ontology creation process is a critical process, which can be done manually but involves much time and resources, on the other hand, works about population process use specific domains and manual evaluation. Thus, in the present research a methodology for semi-automatic population of ontologies is outlined.

The main objective is to design an ontology in the pedagogical domain and then, to propose a methodology for its semi-automatic population using NLP techniques in unstructured texts. In the creation and population stages, it is necessary to use a specific domain for implementing the methodology and carrying out evaluation metrics; therefore, the pedagogical domain is used for initial experiments.

In researchers about this domain, the authors present manual ontologies, and the focus is in creation, not in population process. Figure 1 shows a Venn diagram including main works revised being divided according to the ontology focus: applied to e-learning or classroom classes. Also the figure presents concepts in a specific topic or as a tool to facilitate the learning process among lecturer and students.

The proposed work is in the dark area (intersection between face to face domain and ontology building as a tool). This last area is addressed in most of the works, but always using a manual construction, thus, the research takes relevance in the proposal of a semiautomatic approach. In section 3, scientific literature about semiautomatic population is discussed.

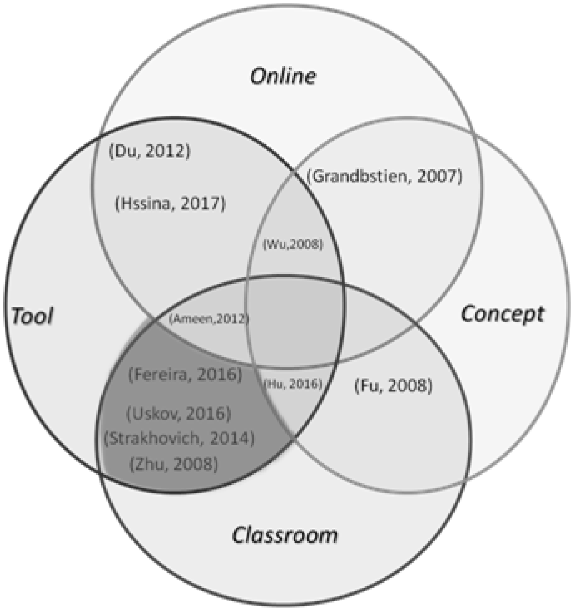

Fig. 1. Researches in pedagogy domain

3 Related Work

Figure 2 relates research topics, besides the techniques and methods used in each stage. The works are presented as follows, and the evaluation analysis is done in each paper of the others subsections.

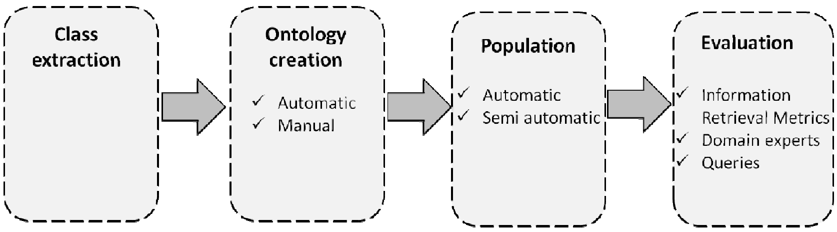

Fig. 2. Art state workflow instead

3.1 Class Extraction

Ontologies for the Use of digital learning Resources and semantic Annotations on Line (OURAL) project is present in [9], the project includes people from several disciplines (educational science, computer science, and cognitive psychology) building e-learning services. The authors present the extracted class using NLP techniques in unstructured texts about learning situation. Educational domain was also analyzed in [10], but its application was into Chinese language.

Others works like [11] present methods for semi-automatic class extraction using a database of Spanish verbs, diathesis alternations and syntactic-semantic schemes (ADESSE tool) [12], where the semantic extracted patterns are the classes. This methodology was applied in educational domain and replicated in financial domain in [13]; in both works, the class extraction was completed with the domain expert opinion. A method for class extraction using linguistic patterns and NLP metrics such as morphological labeling is presented in a recent research [14].

3.2 Ontology Creation

Table 1 summarizes the work done, in conjunction with the domain used in addition to the construction method.

Table 1. Researches on ontologies creation

Method	Domain
Automatic	[15] Painters biographies [16] Technical and medical texts [17] FIFA [7] EOLSS Collection
Manual	[18] News about the basic level education [19] Material for teaching English [20] Online Course Manuals [2] Computing [21] Online education [22] Software engineering courses [23] Courses offered by a university [24] Intelligence Levels [25] Books for level K12 [26] E-learning

Artequackt project, a system of biographies according to the user parameters, is presented in [15]; it is a pilot test where the ontology was created automatically using WordNet tool (https://wordnet.princeton.edu/). Others works such as [16] and [17] show building process using episode extraction in an unstructured texts domain, the authors use International Federation of Association Football (FIFA) news and also use information retrieval techniques (precision and recall) for evaluation. A new methodology to automatically build ontologies from Spanish unstructured texts is proposed in [13], the authors describe three stages: concepts search, relations extractions and ontology construction process. Finally, [7] presents a similar approach than [13] but with a deep semantic analysis (multilingual scenarios); the authors use anaphora resolution techniques, clustering and extraction of lexical-syntactic patterns.

The research which report ontologies manually constructed is based in the domain and evaluation, since the domain used for this proposal, mainly analyzes the works in pedagogical domain. [18] and [4] present an ontology for event recognition using 2000 papers about news in the academic life; the authors use pattern extraction and information retrieval metrics.

For improving the classroom learning, authors such as [19] and [25] have proposed techniques based on ontologies. In [19] an ontology for interaction between students and teachers for English language teaching is introduced. On the other hand, [25] proposes an ontology for the internet learning process. In both works is defined an ontology for each entity in the learning process, and the evaluation is conducted with a manual process supervised for domain experts. Other researchers are focused on online education ([20], [2], [21] and recently [26]) where ontologies are manually defined from XML resources available in the Internet, and the evaluation is a manual process too. An ontology created from CASE diagrams for on-line education is presented in [22]; its evaluation is addressed by experts in a manual process.

There are works such as [24] focused on automatic learning; in this paper, an ontology based on the Internet of Things used in a classroom is created, considering the student intelligences. The ontology creation process from the courses information offered in advanced levels is explained in [23], where students can choose courses according with their academic background. Both works present the structure, information, and hierarchy of the classes in a manual way.

3.3 Population

Works reported in literature used an automatic or semi-automatic approach. Table 2 shows them and domains where they were applied.

Table 2. Works on ontologies population

Method	Domain
Automatic	[27] Google text snippets [28] Biomedical [29] Independent [8] Legal and Tourism [6] Academic Profiles
Semi automatic	[4] Scientific papers [18] Scientific papers [30] Geographical locations [31] E-learning SCORM [3] Independent

A method for ontologies population using Google snippets is proposed in [27], the research is based on manual patterns for class assignment and relations, these patterns are consulted at Google where they are analyzed for obtaining new instances. Another method for automated population is proposed in [28], the methodology combines traditional linguistic analysis and technologies for the extraction of textual knowledge; it is based on contextual distance and knowledge gained with semantic roles.

A different work in automatic population is present in [29], where an automatic unsupervised model is created, and for implementation the authors use texts from the Wikipedia tourism domain. The tourism domain and legal corpus were used in [8] for introducing a generic process as automatic population. In these works are used techniques such as grammatical features extraction, named entities, morphological tagger and queries evaluation using WordNet with precision and recall. The academic profiles are explored in [6], where the authors carry out automatic population using curriculums and Spanish papers abstracts; they use a gold built for domain experts in evaluation step.

For semiautomatic approaches, some works uses domain experts too and NLP techniques. A system for semiautomatic population of unstructured text is presented in [4] and [18], in this paper supervised learning with Marmot, Crystal and Badger tools is applied. A weakly supervised approach is described in [30], where a manual analysis is used to generate a syntactic model, and information retrieval metrics for evaluation step. A related research is worked in [31], where hyponymy and hypernym are evaluated by validating and verifying ontological relationships in a restricted domain. A question answering Web system is described in [3], this system combines multiple knowledge bases and a NLP parser for transforming queries in Protocol and RDF Query Language (SPARQL).

The most of research carried out in 3.1, 3.2 and 3.3 is based on domain experts in creation or evaluation steps, the works related to automatic approach focus on creation but not population. This analysis is relevant for the proposed research, since any method for population task is feasible in pedagogical domain and the creation step is manual. For evaluation step, it is necessary to analyze different metrics, such as, accuracy, precision and recall, which have been used by several researchers.

4 Conclusions

This paper addressed the ontology population problem and recent topics related to. The population is carried out in manual or automatic process, but only a few papers deal with automatic or semiautomatic creation and population issue. A four steps proposal in semi-automatic population is ongoing:

-Preprocessing: Considers the corpus creation from pedagogical documents follows by the classes extraction using NLP and information retrieval techniques.

-Creation: The ontology system creation by a semiautomatic approach comprises three single ontologies: learning styles, multiple intelligences and teaching learning strategies.

-Population: Use of NLP techniques and semantic analysis.

-Evaluation: Time, consistency and domain will be evaluated.

As a future work, the proposed methodology will be implemented in the initial domain, but the idea is to extend it to obtain a general methodology applicable to other pedagogy domains.

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Comparative of Interpolators Applied to Depth Images

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Abstract. Interpolators are widely used in image processing because they allow us to estimate the unknown values of sensor measurements. In this research, we present a comparison between commonly used interpolators to evaluate how each affect the behavior of the data, it is studied the problem of interpolation as a means to infer information at a higher frequency through the mathematical description an depth image.

Keywords: Interpolation, Depth images, Frequency.

1 Introduction

Image processing and analysis is currently better known and used for various activities in the world of technology, the type of analysis that is performed and the techniques used are directly linked to the amount of information provided by each image, as well as what needs to be identified through this one.

This information depends in turn on the sampling frequency of the sensor being used; a digital image is constituted by a spatial sampling of a set of sensors represented by a matrix. However, when talking about sampling, the main limitation observed is the sensor acquisition frequency, which in turn is limited due to the characteristics of the phenomenon being sampled. In several occasions to compensate for the limitations above, it is common the use of interpolators, so that we can obtain more information about the phenomenon being analyzed.

Therefore, when using an interpolator it is expected that the information obtained through it will be consistent with the data originally acquired, that is, that it does not deform the nature of the information, since this can directly affect the result of the analysis performed.

Therefore, in this work, we study the problem of interpolation as a means to infer information at a higher frequency. We examined how three different types of interpolators affect the data acquired at a certain frequency. We present experiments with depth images of increased resolution and analyze how much it affects the method of interpolation used in the original image.

2 Theoretical Foundation

There is evidence in the literature of different comparatives between interpolators, however these are based on criteria such as: execution time, precision, clarity of the image, among others [1], [2]. However, for purposes of this work, what is interesting is to know how much it affects or not the use of some interpolator to the original distribution of the depth image.

In this work, three commonly used interpolators are used in image analysis, which are described below.

2.1 Linear Interpolation

One of the most used interpolators is the linear one described in Eq. (1) due to its simplicity. It consists in fitting a line to two given points:

$$g(x) = \frac{b-x}{b-a} f(a) + \frac{x-a}{b-a} f(b). \tag{1}$$

where g (x) denotes that this is a first-degree interpolation polynomial. To interpolate an image, the function is first applied to the x-axis and then to the y-axis.

The advantage of using the linear interpolator is that the implementation is simple, for this reason, the computation time is small compared to other interpolators. Another advantage of the linear interpolation is that the results are more accurate with smaller intervals between the two points. However, in the same way, if the interval is large, the result is more inaccurate. It should also be considered that if the selected points do not correspond to a straight line, the calculated values become incorrect.

2.2 Lagrange Interpolation

The Lagrange interpolation polynomial is a reformulation of Newton's polynomial that avoids the calculation of the divided differences, and is represented by Eq. (2) of polynomial bases of Lagrange (Eq. 3):

$$f(x) = \sum_{j=0}^{k} y_i l_i(x). \tag{2}$$

$$l_j(x) = \prod_{i=0,\ i \neq j}^{n} \frac{x-x_i}{x_j-x_i} = \frac{x-x_0}{x_j-x_0} \cdots \frac{x-x_0}{x_j-x_0} \frac{x-x_0}{x_j-x_0} \cdots \frac{x-x_0}{x_j-x_0}. \tag{3}$$

The Lagrange interpolation grows fast computationally with the increase of the interpolator degree. The polynomial degree varies according to the input points, i.e., if we remove or add points it is necessary to change the degree of the polynomial.

2.3 Basic Splines (B-Splines)

The purpose of this interpolator is to make the interpolation curve smoother and improving the image edges.

The cubic B-spline function is defined in Eq. (4):

$$f(x) = \sum_{k=-\infty}^{\infty} B_{k,n+1}(x) \cdot f(x_k). \tag{4}$$

The three-order B-spline function is as follows:

$$B_{i,3} = \begin{cases} \frac{(x-x_i)^2}{(x_{i+1}-x_i)(x_{i+2}-x)(x-x_{i+1})}. & , x_i \le x \le x_{i+1} \\ \frac{(x-x_i)^2}{(x_{i+1}-x_i)(x_{i+2}-x_i)} - \frac{(x_{i+2}-x)(x-x_{i+1})}{(x_{i+2}-x_{i+1})(x_{i+3}-x_{i+1})}. & , x_{i+1} \le x \le x_{i+2} \\ \frac{(x-x_{i+3})^2}{(x_{i+3}-x_{i+1})(x_{i+3}-x_{i+2})}. & , x_{i+2} \le x \le x_{i+3} \end{cases} \tag{5}$$

The B-spline interpolator has a greater mathematical complexity, because the base functions do not support an explicit expression and change when adjusting the nodes vector.

3 Methodology

For this work and because they are analyzing depth images it is decided to choose two objects that have the following properties.

1. Rigid object of known form, non-deformable.
2. Soft and amorphous object.

This is considered as the most special cases that can be found when acquiring an image through a ToF camera.

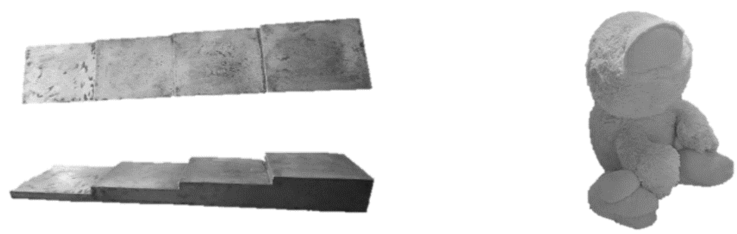


Fig. 1. Objects acquired with the depth sensor

Depth images were acquired with a ToF camera, to reduce the noise generated by the sensor, 250 depth images were acquired and we averaged to estimate the expected value of each pixel.

Were implemented and applied the three interpolators to the acquired images (Linear, Lagrange, and B-spline), increasing the acquisitions two, four, eight and sixteen times, to analyze the effect of each interpolator and each increase over the information provided in the original image.

To describe the original image, we calculated the central moments and compared with the central moments of the interpolated images. The formula of the central moment of order k is described in Eq. (6):

$$\mu_k = E[(X - E[X])^k]. \tag{6}$$

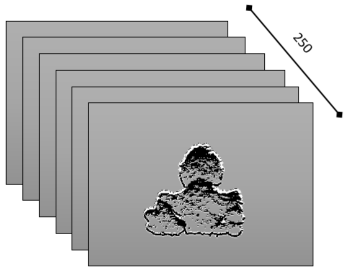


Fig. 2. Frames acquired by object

Where E is the expectation operator and k is the order of the statistical moment that is being calculated.

4 Results

In this section, we present the results obtained by applying the three different interpolators on the acquired original image, both qualitative and quantitative:

In the Figure 3 and 4 the interpolation applied to the original images of the plush doll and the calibration pattern respectively is shown, in both only a fragment of the image is shown as an example so that the effect of the interpolation can be better observed.

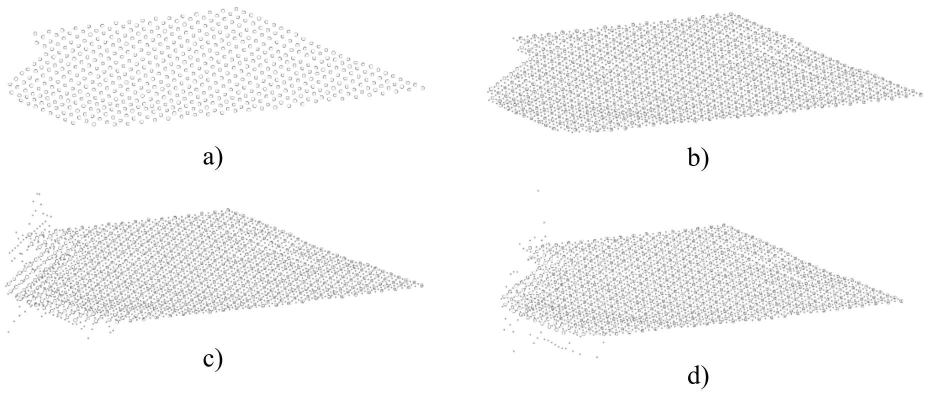


Fig. 3. (a) Original image (plush doll), (b) Image with Linear Interpolator (plush doll), (c) Image with Lagrange Interpolator (plush doll), (d) Image with B-Spline Interpolator (plush doll)

In tables 1-6 we present the descriptors of the first four central moments to compare the interpolated images with the input image. Row OI represents the information obtained from the original image, and the subsequent rows represent the central moments of the interpolated images by increasing the frequency 2, 4, 8 and 16 times the original with each interpolator.

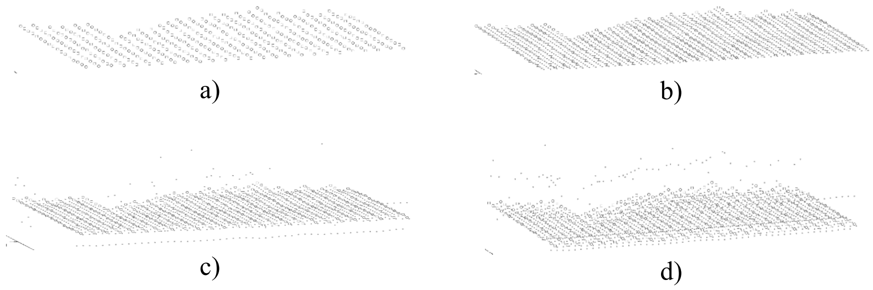


Fig. 4. (a) Original image (pattern depth), (b) Image with Linear Interpolator (pattern depth), (c) Image with Lagrange Interpolator (pattern depth), (d) Image with B-Spline Interpolator (pattern depth)

Figures 5,6 and 7 depict visually how the moments of the scaled images vary more frequently with respect to the original moments of the depth image(plush doll).

Table 1. Linear interpolation (plush doll)

	1st M	2nd M	3rd M	4th M
OI	0.055920057	4567.730957	106484.9375	*76746880*
2x	0.058058724	4518.415039	111223.5469	75409888
4x	0.291386068	4520.250488	111087.3047	75139080
8x	2.15897727	4531.534668	146713.9219	76388360
16x	8.629109383	4570.442383	1114.875366	72706552

Table 2. B-Spline interpolation (plush doll)

	1st M	2nd M	3rd M	4th M
OI	0.055920057	4567.730957	106484.9375	76746880
2x	0.01438925	5114.751465	1607.946045	128895192
4x	0.210121885	5103.547852	28430.24414	129927656
8x	2.253632307	5101.760254	7790.346191	129600160
16x	7.980696201	5140.467285	149802.7813	132150752

Table 3. Lagrange interpolation (plush doll)

	1st M	2nd M	3rd M	4th M
OI	0.0559200569987	4567.73095703125	106484.937500000	76746880
2x	0.0138180907815	5374.58984375000	242783.953125000	261666128
4x	0.2379906475543	5420.54345703125	230595.296875000	246231024
8x	2.1160101890564	5416.71679687500	186943.125000000	241594672
16x	8.2407598495483	5457.23486328125	352931.562500000	250968080

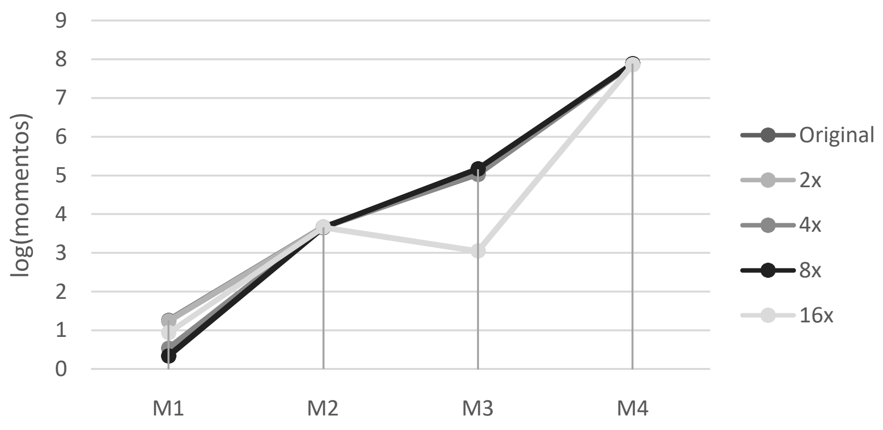


Fig. 5. Lineal interpolator

In Figure 5 it is observed that the linear interpolator for this type of images, offers good results, however, when we scale 16x the original data a considerable variation is observed for the moment 3.

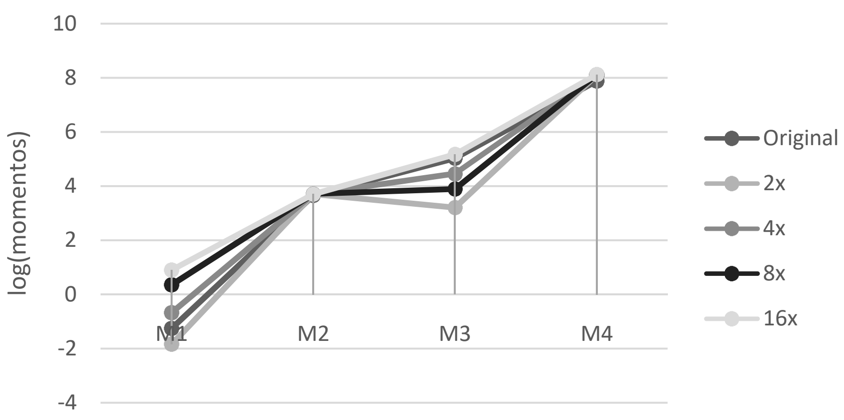


Fig. 6. B-Spline interpolator

Both the B-Spline interpolator and the Lagrange interpolator, from scaling 2x, show a noticeable variation with respect to the original data; however, the B-Spline interpolator as seen in Figure 6 varies more than the Lagrange interpolator Figure 7 for moment 3.

Figures 5, 6 and 7 depict visually how the moments of the scaled images vary more frequently with respect to the original moments of the depth image(pattern of depth).

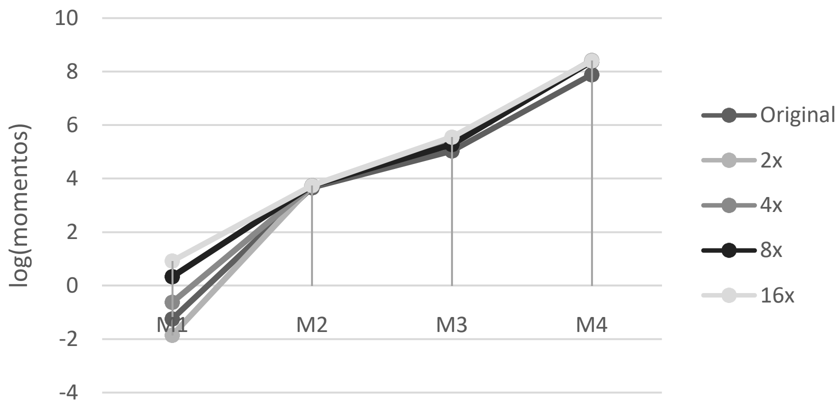


Fig. 7. c) Lagrange interpolator

Table 4. Liner interpolation (pattern of depth)

	1st M	2nd M	3rd M	4th M
OI	0.0001281092700	60.22936633	569.4663696	11182.77637
2x	0.0001294422447	62.19714737	555.3723755	10825.80664
4x	0.000847409	63.29848484	524.324462890	10410.88477
8x	0.00371421	65.824699401	763.623840332	13556.16309
16x	0.047592497	84.282928466	1455.68054199	27358.07422

Table 5. B-Spline interpolation (pattern of depth)

	1st M	2nd M	3rd M	4th M
OI	0.0001281092700082	60.22936630249	569.46636962890	11182.7763
2x	0.0092535801231861	3264.8283691406	612950.50000000	174173216
4x	0.0305372662842274	3582.5812988281	626727.62500000	171449104
8x	0.204221203923225	3606.1777343750	628083.93750000	172152064
16x	3.49978852272034	3622.1728515625	588958.06250000	163265120

Table 6. Lagrange interpolation (pattern of depth)

	1st M	2nd M	3rd M	4th M
OI	0.0000000	0.0060229	0.0569466	1.1182776
2x	0.0000000	0.0000562	0.0175613	6.9509043
4x	0.0000000	0.0000605	0.0165664	6.1430662
8x	0.0000000	0.0000608	0.0164137	6.1218336
16x	0.0000000	0.0000609	0.0158865	5.9289088

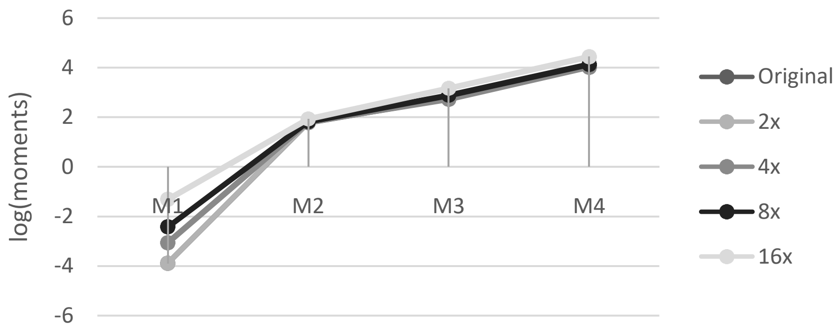


Fig. 8. Lineal interpolator

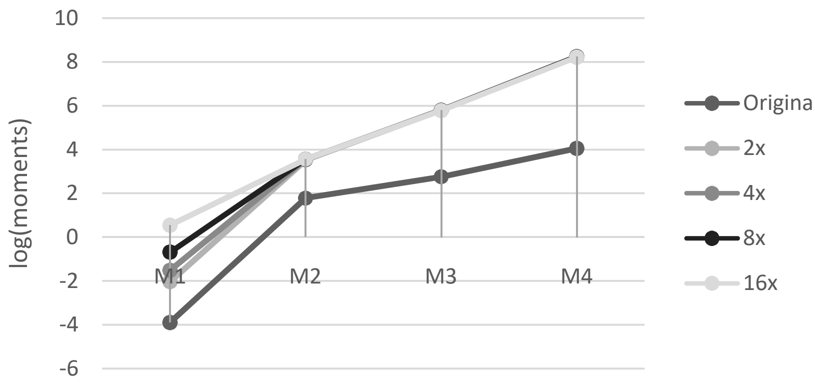


Fig. 9. B-Spline interpolator

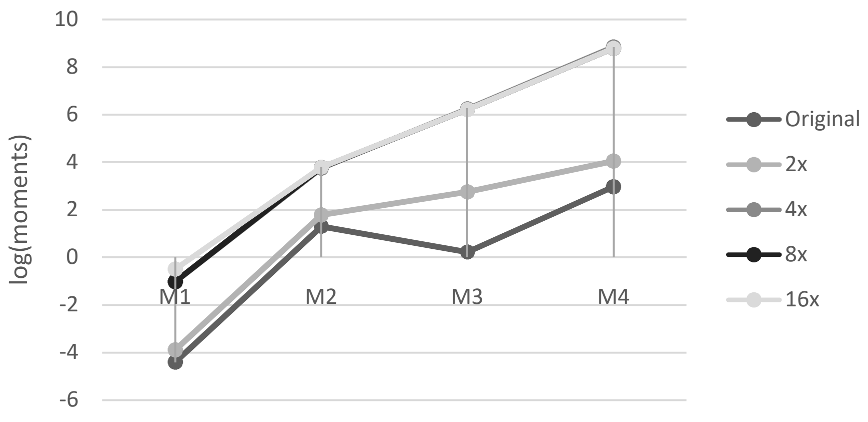
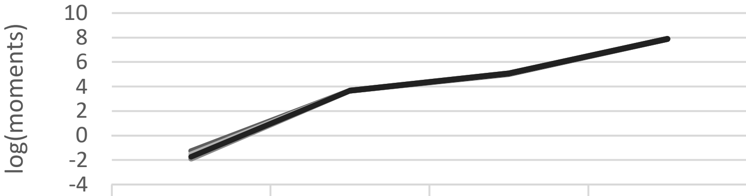
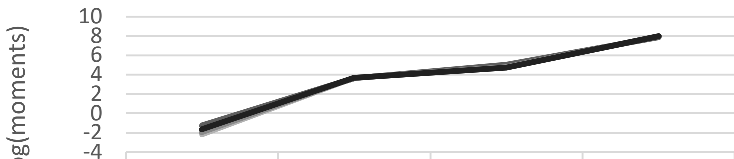


Fig. 10. Lagrange interpolator



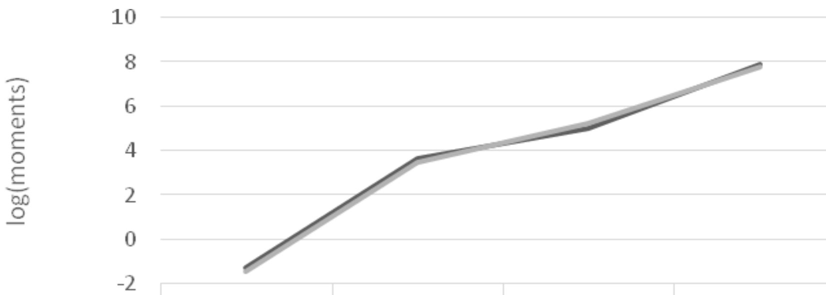
	M1	M2	M3	M4
0.1	-1.252432395	3.659700516	5.02728818	7.885060729
0.2	-1.524917387	3.654256703	5.068531744	7.873274275
0.3	-1.889672726	3.652817907	5.058930548	7.87180081
0.4	-1.723817828	3.653564623	5.062984278	7.872366129

Fig. 11. Linear Interpolation



	M1	M2	M3	M4
0.65	-1.252432395	3.659700516	5.02728818	7.885060729
0.75	-2.189894425	3.683789617	4.75175115	7.981087726
0.85	-1.955890124	3.682649578	4.740365003	7.980698487
0.95	-1.671134563	3.683023852	4.740945296	7.979722859

Fig. 12. B-Spline Interpolation



	M1	M2	M3	M4
Original	-1.252432395	3.659700516	5.02728818	7.885060729
0.2	-1.440779	3.469215642	5.220424223	7.795525155

Fig. 13. Lagrange Interpolation

5 Conclusions

In this project, we performed a comparison between the variation of the central moments initials of a depth image against the central moments obtained from a processed image using three different interpolation methods.

Quantitatively it can be observed that there is variation in the central moments of the original image given the selected interpolator as seen in Tables 1-6; however, it is also observed that it depends on the shape of the object being analyzed.

As can be seen in Fig. 5.6 and 7 it can be seen that the linear interpolator is the one that best fits the original central moments of the image, however, increasing it by 16x for the moment 3 is considerably different from the original.

As observed both the Lagrange interpolator and the B-Spline interpolator are the one that presents the greatest variation with respect to the original information as seen in Figure 6, 7, 9 and 10.

Because of this, the image is scaled with a smaller frequency to be able to visualize where it begins to move away from the original moments Figure 11, 12, 13, so that when processing images of depth from ToF sensors, this is taken into consideration.

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