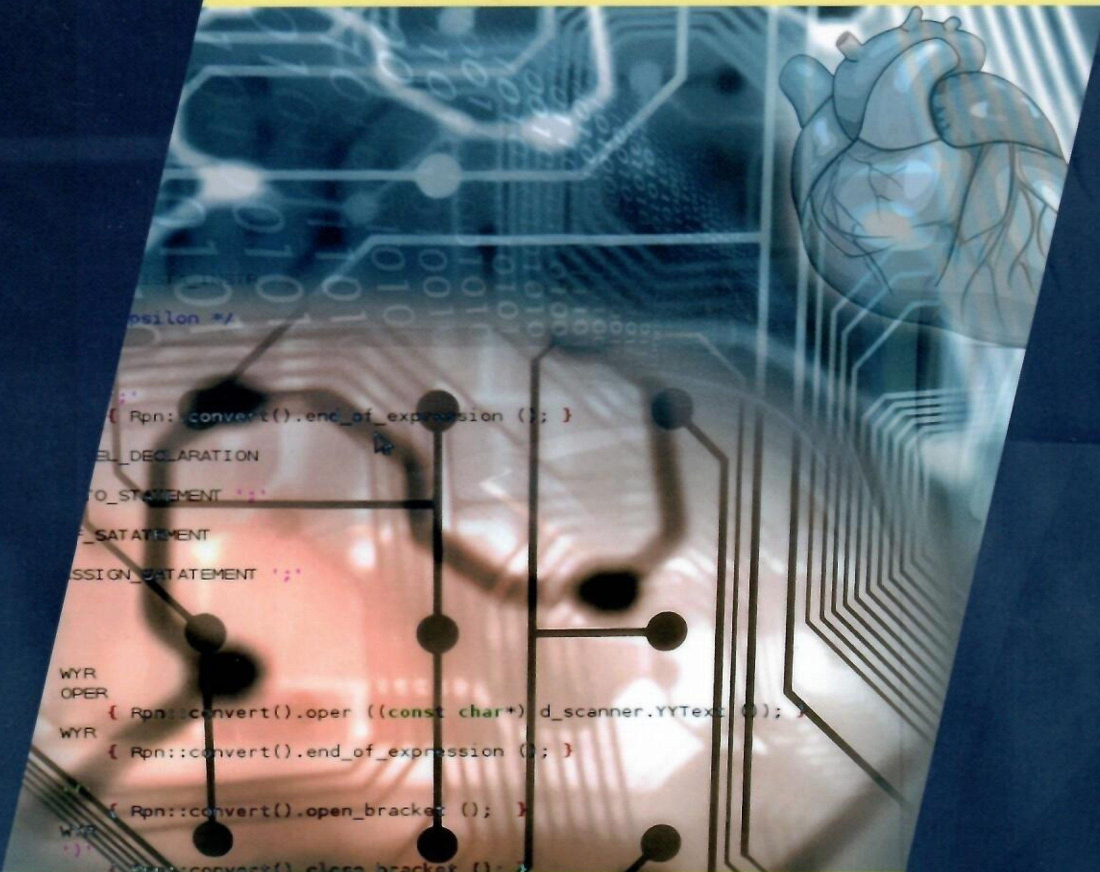

Information Technology in Medical Diagnostics II

Editors:
Waldemar Wójcik, Sergii Pavlov
and Maksat Kalimoldayev

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Preface

For many centuries man has been trying to learn about the state of his health. Initially, in the pre-technological period, he had to rely only on his senses. Then there were simple tools to help the senses. The breakthrough turned out to be the discovery of X-rays, which afforded an insight into the human body. Contemporary medical diagnostics is increasingly being assisted by information technology, which offers, for example, a very thorough analysis of the tissue image or pathology differentiation. It also allows for very early preventive diagnostics. Under the influence of information technology, "classical" diagnostic techniques change and new ones arise. More and more often the same methods can be used for both medical and technical diagnostics. Moreover, methodology inspired by the functioning of living organisms is developed.

This volume is the second one in a series showing the latest advances in information technologies directly or indirectly applied in medical diagnostics. Unlike the previous one, it does not contain closed chapters, but rather extended versions of presentations made during two conferences: XLVIII International Scientific and Practical Conference "Application of Lasers in Medicine and Biology", held in May 2018 in Kharkov, and the International Scientific Internet conference "Computer graphics and image processing, which took place also in May 2018 in Vinnitsa. Although both conferences were organised in Ukraine, the research results presented in this volume are the fruit of the cooperation of Polish, Ukrainian and Kazakh scientists.

We hope that a monograph on technological issues interwoven with medical and biological problems will contribute to better use of the latest research results in practice. We are convinced that the experience and knowledge of the authors of the chapters have influenced the value of this book.

Waldemar Wójcik, Sergii Pavlov & Maksat Kalimoldayev
Lublin, November 2018

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Formalization of the diagnosis of olfactory disorders

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ABSTRACT: At present, many methods of olfactory research are known, but they have a number of shortcomings associated with the lack of standardization in this field and the lack of objectivity of the obtained information. Thus, it is proposed to increase the objectivity of diagnostics of olfactory analyzer disturbances due to the study of respiratory function based on rhinomanometry. The necessity of using linguistic variables and the fuzzy logic apparatus for formalizing the diagnosis of olfactory disorders with the purpose of increasing the objectivity of diagnosis of respiratory and olfactory disturbances is substantiated. The classification of the degree of impaired perception of odors is proposed, which consists of four intervals. The estimation of the accuracy of the developed classification was 92% and was carried out on the basis of the developed model of fuzzy logical inference of the olfactometric research process, which is based on the Mamdani algorithm, the basis for the rules of fuzzy products was formulated. The model contains three input and one output linguistic variable. The prospect of work is the use of interval fuzzy sets, to identify the permissible deviations in the developed classification of the sensitivity of the sense of smell.

1 INTRODUCTION

Olfaction plays a major role in our interaction with the environment. The olfactory system not only acts for the detection of potential dangers in the environment, such as smoke, gas or dusts, but also it influences our nutrition, social behavior, and well-being (Huart & Rombaux 2013).

Today we know a lot of olfactory function testing techniques but there is no single universally accepted universal method due to a number of difficulties associated with the formalization of the subjective component of the process of diagnosing abnormalities in the olfactory analyzer. There is a need to develop new approaches to the diagnosis of olfactory disorders, these approaches can enhance the objectivity of diagnosis.

According to Aristotelian logic, for a given proposition or state we only have two logical values: true-false, black-white, 1–0. In real life, things are not either black or white, but most of the times are grey. Thus, in many practical situations, it is convenient to consider intermediate logical values. The best and most precise description of disease entities uses linguistic terms that are also imprecise and vague. To deal with imprecision and uncertainty, we have at our disposal fuzzy logic. Fuzzy logic introduces partial truth values, between true and false (Torres & Nieto 2006, Smolarz et al. 2010).

Forecasting on the basis of fuzzy logic allows us to describe the cause-effect relationships between the input indicators and a specific forecast or diagnosis in the form of statements in natural language and consequently, makes it possible to conduct a logical formalization of the expert opinion (Huart & Rombaux 2013, Torres & Nieto 2006, Telishevska & Povoroznyuk 2013). Therefore, the methods of fuzzy logic have found wide application in various branches of medicine (Gozhyi & Kalinina 2014), for example in cardiology (Melnik & Goloskokov 2008, Pavlov & Barylo 2017) for determining the localization of the infarction.

A feature of the linguistic variables used in medicine is the complete absence of their numerical value. For example, with back pain, the patient describes his feelings with words like "strong pain" that are difficult to formalize and measure. Traditionally, mathematics uses a clear (clearly defined) property of $P(x)$, that is, properties that are either true or false. Each property defines a set: $\{x|x$ has the property $P\}$.

In 1965, Lotfi Zadeh (Zadeh 1975) proposed a theory explaining how to formalize "fuzzy" properties: a clear property of P can be described by the characteristic function $\mu: X \rightarrow \{0,1\}$. The fuzzy property can be described as a function μ (membership function): $X \rightarrow [0,1]$. The value of $\mu(x)$ indicates the degree to which x has the property (for example, which x corresponds to the degree of pain). An example of the representation of the value of "high fever" in medical science as a fuzzy set is shown in Figure 1 (Zadeh 1975, Phuong & Kreinovich 2000).

In Figure 1, a) if x is greater than 39°C, then membership function $\mu(x)$ of medical concept "High Fever" is 1 i.e. means that x has surely "high fever", b) if x is less than 38.5°C, then membership function $\mu(x)$ of medical concept "High Fever" is 0 i.e. means that x has surely not "high fever", c) if x is in the interval [38.5°C, 39°C], then x has a property "high fever" with some degree in [0,1] (Zadeh 1975).

In addition, the set of values of a variable often depends on the subjective perception of the doctor. It is proposed in (Zamkovoj & Mustetsov 2006, Pavlov & Kozhemiako 2010) to use the non-uniform distribution of the values of linguistic variables on a numerical scale, taking into account their informativeness in the development of medical intelligent decision-making systems.

Also, the fuzzy logic apparatus is used to check the accuracy of the classification. In work (Sharma & Bhagawati 2013), the electron nose was tested for eight different gases namely butanol, acetic acid, acetone, benzene, chloroform, di-chloromethane, ethyl-acetate and sulfuric acid. Experimental results have shown that the accuracy of classification using a fuzzy logic approach can be obtained up to 93.75%. Therefore it can be concluded that in future, such an approach can be applied to other sample gases to check the accuracy of classification. Thus, the use of linguistic variables and fuzzy logic in medicine is an effective tool for improving the quality and objectivity of diagnosis of respiratory and olfactory disorders.

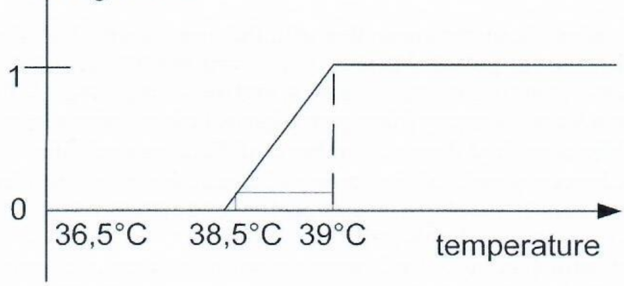

Figure 1. An example of the representation of the membership function of the term "high fever" (Zadeh 1975).

The purpose of this work is to formalize the approach to diagnosing respiratory and olfactory disorders based on the application of linguistic variables of the fuzzy logic apparatus. The objectives of the study are as follows:

1. The process of perception of a person's smell should be presented in the form of a fuzzy logic structure:
   - formulating input and output linguistic variables;
   - formulate a rule base of fuzzy inference system;
   - to develop a model of fuzzy logical inference of olfactometric research;
2. It is necessary to develop the classification of the degree of olfactory disorders.
3. It is necessary to evaluate the accuracy of the classification using the developed model of fuzzy inference.

2 EXPERIMENTAL DEVELOPMENT OF THE STRUCTURE OF THE MODEL OF FUZZY INFERENCE

Assessment of the function of smell is a complex diagnostic process, since it is based on a subjective sense of smell by the patient. To detect violations of the functions of the olfactory analyzer, olfactometry is used. Olfactometry (from Latin Olfacio—sense of smell and other Greek Μετρον – measure, measurement) is a technique that allows to measure the sensitivity of the olfactory analyzer by affecting it with specific odoriferous substances (odor vectors). The purpose of olfactometry, except for the recognition of odors, is the definition of olfactory sensitivity (smell threshold), which accordingly affects the determination of the degree of disturbance of the function of the olfactory analyzer of a person (Abizov & Pavlishin 2013).

Verbal subjective patient responses on the degree of odor perception can be represented as subjective categories. For example, "bad", "good", "poorly", "excellent", "not felt" the smell during the olfactometric examination. Thus, there is a linguistic ambiguity associated with the inaccuracy of the description of the sought value—olfactory sensitivity. Therefore, it is expedient to present the process of perceiving a person's smell in the form of a fuzzy logic structure.

To achieve the goals and objectives we conducted studies using a device for testing respiratory odor disorders, presented in Figure 2 (Avrunin & Zhuravlev 2015a). The work was carried out in cooperation between the Department of Biomedical Engineering of Kharkov National University of Radioelectronics and the Department of Otorhinolaryngology of Kharkov National Medical University.

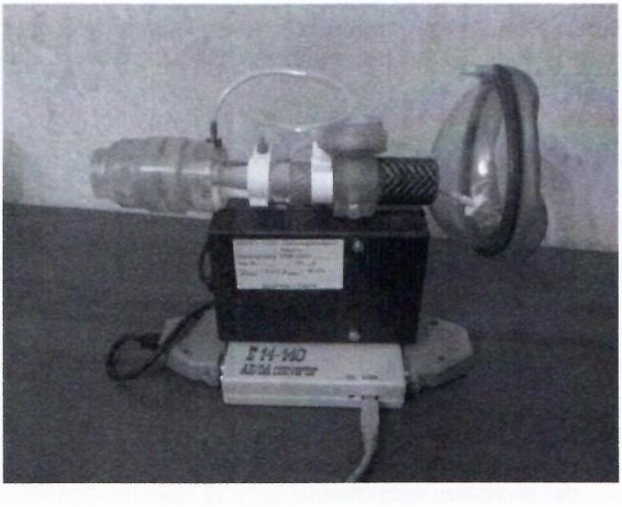

Figure 2. Device for testing olfaction disorders (Avrunin & Zhuravlev 2015a).

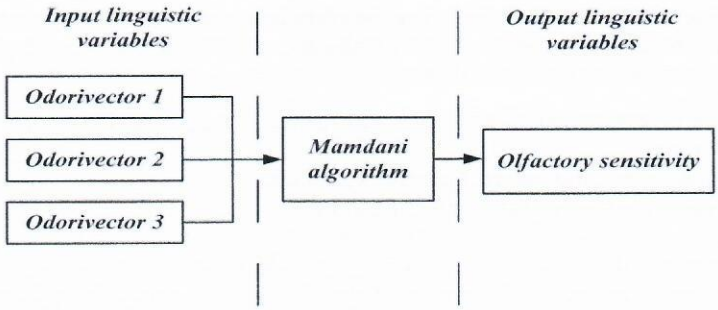

Figure 3. Structure of the model of fuzzy inference "Olfactometry".

During the study of the human olfactory function, the patient is offered a sniff of several different odor vectors. The patient performs respiratory maneuvers with a gradual increase in their intensity and fixes the time of appearance of the threshold of sensation of the odor vector, then calculations of the pneumatic power and energy of breathing are performed. The method of increasing the objectivity of olfactometric studies involves the use of three odor vectors: ammonia, acetic acid, valerian tincture (Avrunin & Zhuravlev 2015b). Thus, it is proposed to use three input linguistic variables and one output for modeling the structure of fuzzy logic inference.

A linguistic variable is an expression of the form:

$$\langle \beta, \mathrm{T}, \mathrm{X}, \mathrm{G}, \mathrm{M} \rangle,$$

where β is the name of the variable, T is the set of values of the linguistic variable, which consists of the names of fuzzy variables, X is the domain of definition of a linguistic variable, G is a syntactic procedure that allows generating new meaningful values from the set, M is a semantic procedure that allows one to put new values into correspondence with a new fuzzy set (Phuong & Kreinovich 2000).

As input parameters of the system of fuzzy inference, we will use linguistic variables: "odorivector_1", "odorivector_2", "odorivector_3", and as output parameters a fuzzy linguistic variable "olfactory_sensitivity". The structure of the fuzzy model for assessing the degree of impairment of the olfactory function is shown in Figure 3. As a term-set of input linguistic variables, we will use: T1 = {excellent, good, poorly, not sensible}, which corresponds to the degree of odor vector sensation by the subject. As the term-set for the output linguistic variable, we will use the set T2 = {"high", "medium", "low", "absent"}. The domain of definition of linguistic variables [0 30] J. Syntactic and semantic procedures are not used.

3 SELECTING THE PARAMETERS OF THE FUZZY LOGIC OUTPUT MODEL

The simulation was carried out using the Mamdani algorithm, since for problems where the explanation is more important, the rationale for the decision taken, according to the work of Shtovba S.D. (Shtovba 2003) will have the advantage of fuzzy models of the Mamdani type in comparison with the use of fuzzy models of the Sugeno type.

In systems where the Mamdani algorithm is used, the following parameters are usually applied (Shtovba 2003, Leonenkov 2005):

- for conjunction – the operation of a minimum;
- for disjunction – the operation of the maximum;
- for implication – the operation of a minimum;
- for aggregation – the maximum operation;
- for defuzzification – the method of the center of gravity (1).

$$
\begin{aligned}
T(A\wedge B) &= \min\{T(A),T(B)\}\\
T(A\vee B) &= \max\{T(A),T(B)\}\\
T(A\supset B) &= \min\{T(A),T(B)\}\\
y &= \frac{\int_{\min}^{\max} x\cdot\mu(x)\,dx}{\int_{\min}^{\max}\mu(x)\,dx}
\end{aligned}
\qquad (1)
$$

where y is the result of defuzzification; x is a variable corresponding to the output linguistic variable "olfactory_sensitivity"; $\mu(x)$ is the fuzzy set belonging to the output variable "olfactory_sensitivity" after the accumulation stage; min and max are respectively the left and right points of the interval of the carrier of the fuzzy set of the output variable "olfactory_sensitivity".

According to the works of M.V. Burtsev, A.I. Povoroznyuk. (Burtsev & Povoroznuk 2010), it is necessary to use the membership function of t, π, or T class, since the vast majority of objects are in a certain limited interval. The formalization of terms can be achieved with the help of a symmetric Gaussian membership function (2), by the direct construction method.

$$
\mu(x) = e^{-\frac{(x-b)^2}{2c^2}} \qquad (2)
$$

where x is a variable, μ the membership function and b, c are parameters.

In direct methods of constructing membership functions, an expert or a group of experts assigns for each $x \in X$ the value of the membership function $\mu(x)$. In the following, the membership function can be refined experimentally on the basis of an analysis of the results of solving specific problems (Shtovba 2003). The membership functions of the terms of the input linguistic variables are shown in Figure 4. The developed base of rules of fuzzy products contains 4 points, weights are equal to 1:

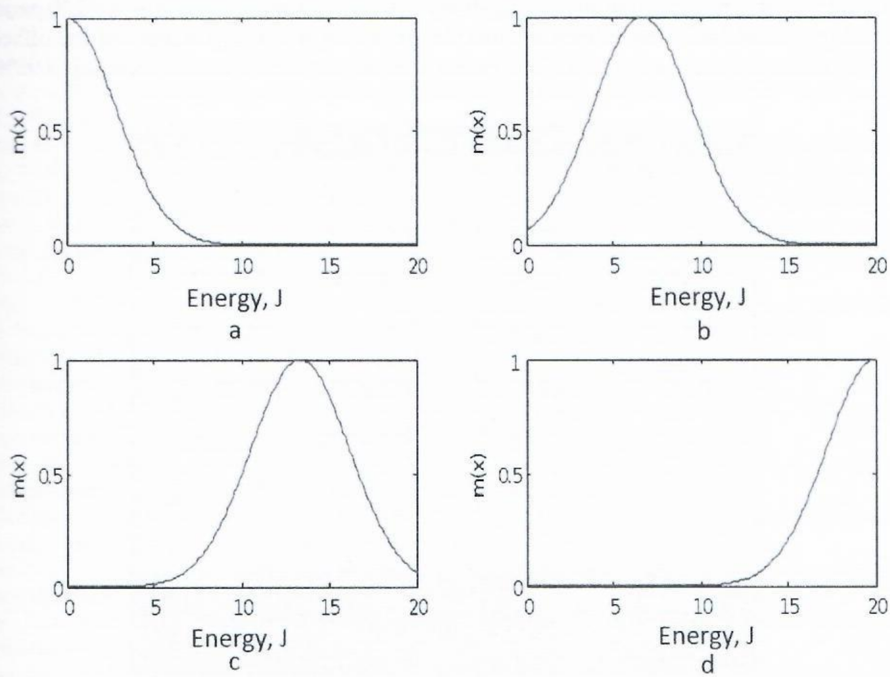

Figure 4. The membership of terms (a is "excellent", b is "good", c is "poorly", d is "not felt") of input linguistic variables.

1. IF "the odorivector 1 is excellent" AND "the odorivector 2 is excellent" AND "the odorivector of 3 is excellent" THEN "the sensitivity of the sense of smell is high".
2. IF "the odorivector 1 is good" AND "the odorivector 2 is good" AND "the odorivector 3 is good" THEN "the sensitivity of the sense of smell is middle".
3. IF "the odorivector 1 is poorly" AND "the odorivector 2 is poorly" AND "the odorivector 3 is poorly" THEN "the sense of smell is low".
4. IF "odorivector 1 is not felt" And "odorivector 2 is not felt" And "odorivector 3 is not felt" THEN "sensibility of smell is absent".

The value of the output linguistic variable is 2.37 for given the values of the input linguistic variables, which corresponds to the interval of the values of the first term of the output variable, that is, the olfactory sensitivity is high.

4 RESULTS AND DISCUSSION

Assessment of the accuracy of classification of the degree of impaired perception of odors. Olfactory sensitivity was determined in 120 patients with nasal aerodynamics and in 100 persons from the control group using the developed model of fuzzy inference of olfactometric research. Figure 5 shows the program for viewing fuzzy inference rules after changing the values of the input variables to [1.5 2.4 1.9] in the interactive programming package MATLAB .

Based on the obtained results, the following classification of the degree of impaired perception of odors is proposed:

$E \leq 2$ J – a conditionally normal sense of smell;
$2 < E \leq 8$ J – the average degree of dysosmia;
$8 < E \leq 16$ J – heavy degree of dysosmia;
$E > 16$ J – is practically complete dysosmia.

The results were confirmed by additional laboratory and clinical studies. These studies were carried out by experts in the oto-rhino-laryngological department of the Kharkiv Regional Clinical Hospital. The experimental results showed that for a sample consisting of 220 patients, the developed model of fuzzy inference showed that the degree of impairment of the olfactory function confirmed the diagnoses for 201 patients, hence the classification accuracy is 92%.

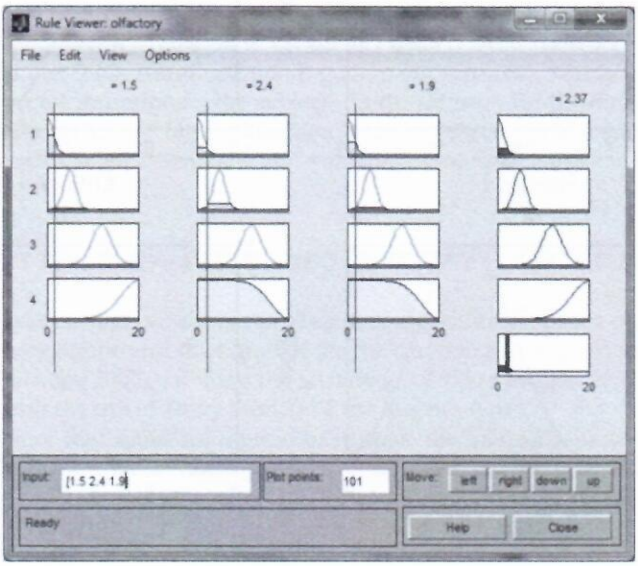

Figure 5. The program for viewing fuzzy inference rules after changing the values of the input variables to [1.5 2.4 1.9].

5 CONCLUSIONS

The use of modern intelligent systems of making decisions makes it possible to make a choice from the list of possible diseases, which will significantly shorten the time for diagnosing olfactory disorders by the doctor and will speed up the process of providing medical care to the patient.

Thus, the process of perception of a person's smell is presented in the form of a fuzzy logic structure: it is suggested to use three input and one output linguistic variables, a base of rules for fuzzy products is formulated, and a model of fuzzy logical inference "Olfactometry" is developed. A classification of the degree of violation of sense of smell, it was found that virtually complete dysosmia occurs when the energy E exceeds 16 J. The accuracy of the classification of the assessment of the degree of violations of the human olfactory function was calculated on the basis of the fuzzy inference model and was 92%.

The prospect of work is the use of interval fuzzy sets to identify the permissible deviations in the developed classification of the sensitivity of the smell, which will improve the accuracy of the diagnosis of olfactory disorders.

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Information Technology in Medical Diagnostics II links technological to medical and biological issues, and will be valuable to academics and professionals interested in medical diagnostics and IT.

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