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Support Allergic Patients, using Models Found by Machine Learning Algorithms, to Improve their Quality of Life.

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***Asbstract*:** Food allergy is a disease that negatively affects quality of life, and in some cases its impact is serious. Diagnosing food allergies prior to exposure to the allergen(s) has significant costs and results in overdiagnosis leading to the avoidance of food to which patients are not allergic. Discovering relationships between features of food allergy data would support patients by finding their food allergens and avoiding the use of costly diagnostics. This paper presents the potential of using machine learning algorithms in discovering these relationships. The data was collected by the medical laboratory Intermedica through tests performed by patients with food allergies. The apriori algorithm is applied to these data. The relationships discovered in our data are implemented in a software application, which also has an interface to enter data about new patients being screened for food allergies. The set of discovered relationships leads to the creation of a list of food allergens for a new patient, which helps them eliminate the molecular allergy test when it is not necessary and as a result, reduce financial costs. The model also supports patients by not eliminating foods that do not harm them, thereby not risking a nutritional deficit.

Keywords: *machine learning algorithms; food allergy; molecular allergy test; apriori algorithm.*

1. Introduction

The term allergy means an oversensitivity to foreign substances that are normally harmless. Alongside any genetic predisposition, numerous nongenetic factors also play a role, such as exposure to the allergen and nutritional condition. The most frequently occurring allergy is a type 1 hypersensitivity reaction in which specific IgE antibodies are formed [1].

A food allergy is an IgE-mediated reaction that leads to symptoms within hours of having ingested the food. Possible symptoms include burning or itching in the oral cavity, nausea, gastrointestinal spasms, diarrhea, and skin rashes. Severe reactions can also lead to asthma attacks, breathlessness, increased heart rate, and panic attacks and confusion. In rare cases, anaphylaxis can occur [2].

Food allergy can significantly affect patients' quality of life. The safest option available today remains the avoidance of food to which they are allergic [3]. The elimination of food allergens, proteins in foods or derivatives that cause abnormal immune responses [4] may lead to the development of nutritional disorders [5]. Information about food allergens is difficult to obtain in many instances, and patients and their caregivers feel forced to develop their own safety strategies, resulting in a higher level of social isolation and discrimination [3]. In some cases, fatal reactions may occur in children, adolescents, or adults who have allergies [6].

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Food allergies are more common in children because their digestive tract and immune system are not fully formed. Most food allergies appear in childhood and can pass as the child grows, such as milk or egg allergies. Childhood food allergy is a serious, potentially life-threatening condition known to substantially impair quality of life among patients and their caregivers [7],[8],[9],[10]. According to the European Academy of Allergy and Clinical Immunology (EAACI), the number of children with allergies in 2011 had doubled in the previous 10 years [11]. In 2011, food allergy was estimated to impact 8% of US children, of which nearly 40% reported a history of severe reactions [7]. About 30% of children with food allergies are allergic to more than one food [12], [13]. In the United States, every three minutes an allergic food reaction sends a sufferer to the emergency room [14]. According to the World Allergy Organization white book of allergies, the prevalence of allergic diseases on a global scale has increased and 20-30% of the world's population is now affected by one or more allergies [15],[16]. Compelling data on developing countries also shows an increase in the prevalence of food allergy [17]. It is expected that such increases will continue in line with the rise in air pollution and ambient temperature. A combination of host and environmental factors determine the intensity of allergic reactions: increased vulnerability can be attributed to various factors including changes in lifestyle, hygiene, diet, and physical activity.

The schemes of food allergy diagnosis start with allergy focused history and include skin prick tests (SPTs) and specific IgE tests (sIgE) [18]. Depending on the case history, patients can be tested for one or several food elements using the skin prick test (SPT) provided they have not used antihistamines in the previous 10 days; this is to ensure that the analysis is completely accurate. It may occur that during the application of the test the patient suffers anaphylaxis, therefore it must be performed in the presence of an

allergist [19]. A positive test result is reliable about 55% of the time, while a negative result is 95% accurate. Positive results suggest that the organism has produced allergic antibodies (IgE) to a certain food element, indicating that the patient is sensitive to this food, although it is not enough to determine the diagnosis. To interpret the results, the doctor takes into account the patient's medical history, particularly any symptoms reported by family members with allergies, and from the SPT results. Results are available within about 30 minutes. A specific IgE test is performed when it is not possible for the patient to perform the skin test; this is used when it is not possible to stop using antihistamines, the patient has eczema, or is very likely to suffer anaphylaxis during the test. It is very important to note that the presence of IgE specific to any food does not constitute a sure diagnosis of allergy, while a negative test does not necessarily eliminate the presence of an allergy. The patient may have a positive result for a certain food but is asymptomatic, that is, not clinically allergic. The opposite also occurs with a negative result is negative despite the patient experiencing symptoms when exposed to the allergen. Therefore, it is very important that testing is performed for the specific suspected allergen based on clinical symptoms, family history, and the patient's response to exposure to those food elements. About 50-60% of SPT skin tests and blood tests for food allergies, such as a specific IgE, give a "false positive" result. This means that the tests provide a positive result even if the patient is not actually allergic to a specific food. [20] The test may detect similar proteins that do not trigger allergic reactions. For example, an individual who is allergic to peanuts may present a positive response to other members of the legume family, such as green beans, even if eating green beans has never been a problem [20]. Component resolved diagnosis (CRD), an approach in which food allergies are utilized to characterize the molecular components of each allergen involved in a specific IgE-mediated response, would help to provide a more accurate diagnosis, and facilitate a more appropriate prognosis regarding the development of tolerance or degree of risk, thus improving patient management [21]. CRD has emerged as a promising diagnostic tool given the limitations of conventional methods in diagnosing food allergies. On the other hand, CRD approaches are expensive [22].

Patients screened for food allergies in medical laboratories usually undergo a skin prick test (SPT) or blood tests. The data recorded by Intermedica medical laboratory during tests performed on patients with food allergies include details about the following: gender; allergies to hazelnuts, peanuts, nuts, almonds, milk, egg white, egg yolk, potatoes, celery allergy, carrots, tomatoes, peaches, apples, soy, wheat flour, sesame, rye flour; and familial characteristics such as Sister/Brother, allergic Sister/Brother, and Allergic Parents. Discovering relationships within these characteristics lead to the creation of a list of food allergens for a given patient. These discovered relationships could be used to create a list of food allergens for new patients screened for food allergies.

Machine learning, which aims to teach computers how to learn and act without being explicitly programmed [23] could be used to discover relationships in the data feature for patients with food allergies. Machine learning algorithms are used by Data Mining, known also as the process of learning from experience by analyzing historical data, to gather data [24],[25]. Applications and examples of machine learning include Social Media Analysis [26], Product Recommendation [27], Image Processing and Pattern Recognition [28],[29],[30],[31], Natural Language Processing [32], Insurance Claim Analysis [33], Bioinformatics and Medical Diagnosis [34],[35], Search Engines [36], Financial Market Analysis [37], and so on. Machine learning, because it is merely a scientific approach to problem solving, has almost limitless applications [23]. One approach to problem solving in machine learning is "association", which finds potentially useful relationships in data features. Apriori algorithm is the most well-known algorithm of this approach. This algorithm is used to discover relationships in our data features, which are implemented in an application that is user friendly and can be used by medical laboratory personnel to generate a list of food allergens for a new patient being screened for a food allergy. The list of food allergens could be cross checked with those resulting from a skin prick test (SPT) or blood test in new patients. Because 50-60% of SPT skin tests and specific IgE blood tests give a "false positive" result, the costly CRD diagnostic tool will be suggested if the list resulting from the skin prick test (SPT) or blood tests contains food allergens that do not occur in the list arising from discovered relationships. The CRD diagnostic tool will not be suggested if food allergens are present in the list resulting from SPT or blood tests that are found in the discovered relationships, as a result of reducing the costs of food allergy diagnostics before allergen(s) exposure. The patient is also supported by not allowing overdiagnosis and as a result not eliminating foods to which they are not allergic but which result in false positives. This solution contributes to the improvement of quality of life for patients.

2. Methods and Data

Several methods were used in the study to achieve the final goal. Initially, the literature study was carried out based on books and scientific articles with the aim of obtaining information and the latest findings on data mining that use machine learning algorithms to mine historical data, food allergies, the effects of allergies on patients and their lives, as well as the use of data mining to help allergic patients. One of the approaches to discover knowledge in data, using machine learning algorithms, is to use rule-based methods that discover and generate rules to store, manipulate or apply [38], [39]. Rules are typically in the form If ... Then … and are used for classification: where we are provided with classified data, from which we expect to learn how to classify new cases or associations: where we are interested in the relationship between each feature of the data. Numerous experiments using machine learning algorithms that discover rules were undertaken on the collected data to ascertain useful knowledge.

2.1 Data

The data used in the study were provided by the medical laboratory Intermedica. These data are records for patients who were tested for food allergies with blood specific IgE or molecular allergy tests. The dataset contains 155 instances and 21 attributes. features. Features of our data are gender {M/F}, allergies to hazelnuts {positive/negative}, peanuts {positive/negative}, nuts {positive/negative}, almonds {positive/negative}, milk {positive/negative}, egg white {positive/negative}, egg yolk {positive/negative}, potatoes {positive/negative}, celery {positive/negative}, carrots {positive/negative}, tomatoes {positive/negative}, peaches {positive/negative}, apple {positive/negative}, soy {positive/negative}, wheat flour {positive/negative}, sesame {positive/negative}, rye flour {positive/negative}, Sister/Brother {Yes/No}, Allergic Sister/Brother {Yes/No}, Allergic Parents{no/one/two}. A study published by the Environmental Research and Public Health Institution in Australia found that family factors were determined to be essential in the occurrence of food allergies in patients [40].

Among these factors, it was found that the number of sisters and brothers, whether they or the parents are also allergic, was a determinant for food allergy.

2.2 Data Transformation

There are many negative values compared to positive values in features about food allergies. Table 1 presents the percentage of people in each milk allergy category.

Table 1. Percentage of people in each milk allergy category.

Milk Allergy	Number of people in this category	Percentage of people in this category
Positive	6	3.87%
Negative	149	96.13%

Such an imbalance in categories of a target feature, considered as the class in data, is a challenging problem in the field of machine learning and data mining [41]. A filter to balance categories of this feature is applied in cases in which we generated rules where one of our data features is a target. An irrelevant feature can significantly degrade the performance of rule-based methods. As a result, we applied the attribute selection in our data.

2.3 Machine Learning Algorithms applied to our data.

Experiments in our data are made by applying Part, C4.5 and Apriori algorithm using Weka, a machine learning software written in the Java programming language, as a tool. Part algorithms discover rules and generate an unrestricted decision list by combining the two major paradigms for rule generation-creating rules from decision trees and the separate-and-conquer rule-learning technique [42]. The C4.5 algorithm is based on the top-down induction of decision trees: ID3 is the best-known and most widely used learning algorithm, and was developed by Ross Quinlan to which procedures to deal with numeric attributes, missing values and noisy data were added. It is used to create a tree structure model, a decision tree that can be converted into a rule set [43]. The apriori algorithm finds frequent item sets via a generate-and-test methodology where longer item sets are formed from shorter ones. After item set generation a set of rules is generated for each item set [44], [45].

2.4 Software application

The software application is created by using open source, free tools. The programming language used for the software is PHP, a widely used, free, and efficient server scripting language, and a powerful tool for making dynamic and interactive Web pages or Web applications. The database used for the software is MySQL, a free and open source widely used relational database management system (RDBMS) [46].

3. Results and discussion

Our dataset is imported to WEKA and Part, C4.5 and Apriori Algorithms are applied. To learn a set of rules from previous data where y is a target feature, the followed steps are:

- The previous data {training examples [x, y] to find an unknown set of rules (f(x)) for y} are provided to the learning algorithm.
- The learning algorithm (Part or C4.5 algorithm) analyses the training examples and produces a set of rules f.
- For each example of data {x,y}(unused in the construction of a set of rules f): x is added to the set of rules f and predicts $\hat{y} = f(x)$.
- The loss L ($\hat{y}$,y) or alternatively ⌈accuracy A($\hat{y}$,y)⌉ is then measured.
- Goal of the learning algorithm: find f that minimizes the expected loss or alternatively maximizes the accuracy.

The 10-fold cross validation technique is used in our study to evaluate how predictive is the set of rules learned with PART and C4.5 algorithms and the accuracy of its measurement. The dataset is divided in 10 parts known as folds. To estimate its accuracy the algorithm is applied 10 times in these folds, where each time 9 are used for training and one for testing. Each of the folds is used once for testing and to average the accuracy results. The algorithm is applied for the eleventh time to the entire dataset to produce the set of discovered rules.
Some of the rules discovered by applying Part Algorithm are as follows:

sesame allergy = negative AND
peanut allergy = negative AND
egg yolk allergy = negative AND
celery allergy = negative then hazelnut allergy = negative
carrots allergy = positive then hazelnut allergy = positive
almond allergy = negative AND
sesame allergy = negative then hazelnut allergy = negative

The set of rules generated from the decision tree found by C4.5 algorithm is shown below:

If sesame allergy = negative
and peanut allergy = positive then hazelnut allergy = positive
If sesame allergy = negative
and peanut allergy = negative
and egg yolk allergy = negative
and celery allergy = negative then hazelnut allergy = negative
If sesame allergy = negative
and peanut allergy = negative
and egg yolk allergy = negative
and celery allergy = positive then hazelnut allergy = positive
If sesame allergy = negative
and peanut allergy = negative
and egg yolk allergy = positive
and| almond allergy = positive then hazelnut allergy = positive
If sesame allergy = negative
and peanut allergy = negative
and egg yolk allergy = positive
and almond allergy = negative then hazelnut allergy = negative
if sesame allergy = positive then hazelnut allergy = positive

Table 2 shows the accuracy of the set of rules found by PART and C4.5 algorithms for the target feature hazelnut allergy in the sub dataset created after applying attribute selection and the class balance filter.

Table 2: Accuracy of PART and C4.5 algorithms

Algorithm	Accuracy
Part	85.9986%
C4.5	84.506%

As we want to create a list of food allergens, these accuracies are not satisfiable. We applied the Apriori algorithm to ascertain

association rules. Confidence is the metric type used in our study to rank and measure the usefulness of the discovered association rules; we set it to 90%. Some of the rules resulted from applying Apriori in our data algorithm are as follows:

- Allergic Sister/Brother = no Allergic Parents=no => egg yolk allergy =negative conf:(1)
- Allergic Sister/Brother = no => egg yolk allergy =negative conf:(0.99)
- Allergic Parents = two => peanut allergy=positive conf:(1)
- Allergic Sister/Brother = no Allergic Parents = two => peanut allergy=positive conf:(1)
- peanut allergy=positive almond allergy=positive => hazelnut allergy=positive conf:(1)
- nuts allergy=positive wheat flour allergy=positive => rye allergy=positive conf:(1)
- almond allergy=positive rye allergy=positive => wheat flour allergy=positive conf:(1)
- rye allergy=positive celery allergy=positive => sesame allergy = positive conf:(1)
- nuts allergy=positive potato allergy=positive => apple allergy=positive conf:(1)
- peanut allergy=positive celery allergy=positive => carrots allergy=positive conf:(1)
- rye allergy=positive => hazelnut allergy=positive sesame allergy = positive conf:(0.98)
- celery allergy=positive => hazelnut allergy=positive conf:(0.96), carrots allergy=positive conf:(0.97)
- nuts allergy=positive => rye allergy=positive apple allergy=positive conf:(1)
- wheat flour allergy=positive => apple allergy=positive conf:(0.99), rye allergy=positive conf:(0.98)
- almond allergy=positive => hazelnut allergy=positive conf:(0.96), soy allergy conf:(0.95)
- potato allergy=positive => peanut allergy=positive conf:(0.98)
- egg yolk allergy = positive => milk allergy=positive conf:(0.95)

The rules produced by the Apriori algorithm are implemented in a software application. Due to the small number of examples in the training dataset and limited number of food allergy features, this software is a prototype. A user-friendly interface allows the user to enter the data for a new patient screened for a food allergy. The data gathered for the new patient also includes that concerning food consumed during/before the allergic reaction. Figure 1 shows a part of this interface. A webpage within the software offers a brief description of how the application works.

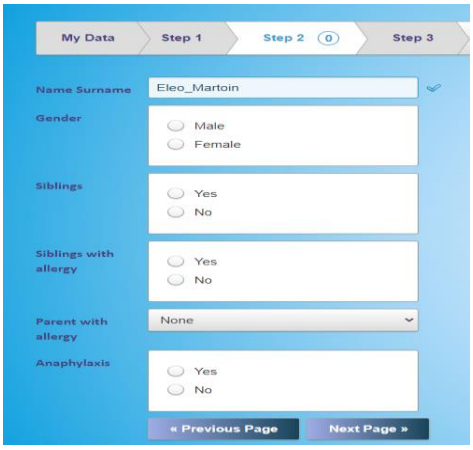

Figure 1. Interface for entering data about a new patient.

4. Conclusion and Future Work

Allergic problems are increasing day to day and result in significant cost to patients who suffer from allergic diseases and a poor quality of life. Data Mining, through Machine Learning algorithms, supports this patient cohort through the discovery of associations of features that lead to the identification of food allergens. The connections discovered through Machine Learning algorithms help to determine if patients should be diagnosed with the CRD tool and the foods they can consume, resulting in lower costs to the patient and improved quality of life. The model found through association rule learning assists the patient in creating a list of food allergens. Based on this knowledge the patient is instructed that they seek diagnosis with the CRD tool if, after performing the SPT test or blood test for a specific food IgE, they also test positive to other food elements not included in the list created based on the association rules. This is undertaken so that the patient does not eliminate foods to which they may not have an allergy, but which provide a positive result due to cross reactions. With the model we found, we improve the patient's life by instructing them to: 1. eliminate the performance of the molecular test if the result of the SPT or food sIgE analysis is positive only in one or several elements displayed in the list created based on the association rules. This helps the patient financially since the molecular test is much more expensive than blood tests, and normally much more expensive than SPT. 2. Avoid eliminating foods that do not harm them and preventing the development of a nutritional deficit, thus providing medical help. In the future, the training data will be enriched with more examples from tests performed by patients with food allergies and more features about other foods that cause allergic reactions. As a result, the set of discovered rules will be more inclusive. Also, in order to expand the study even further in relation to medicine, models can be defined about how to avoid nutritional deficiency in individuals with allergies to more than one food. Seen from the point of view of dietitians, it is an area of great interest for patients with food allergies who, after expensive allergy tests and constant visits to allergists, should be connected with a dietitian. In Albania, the service of a dietitian, even in severe cases, is not offered as a public service. This means that most patients do not fulfil these health needs, thus endangering their health and quality of life.

5. References

[1] L. K. Arruda, D. Solé, C. E. Baena-Cagnani, and C. K. Naspitz, “Risk factors for asthma and atopy,” Curr Opin Allergy Clin Immunol, vol. 5, no. 2, pp. 153–159, Apr. 2005, doi:

10.1097/01.all.0000162308.89857.6c.
[2] P.A. Eigenmann, A.M. Calza, "Diagnosis of IgE-mediated food allergy among Swiss children with atopic dermatitis - PubMed." Pediatr Allergy Immunol. vol. 11, no. 2, pp. 95-100, May. 2000, doi:10.1034/j.1399-3038.2000.00071.x
[3] S. Romagosa Vilarnau, H.A. Brough, S. Schnadt, M. Podestà, R. Åsgård, E. Botjes, F.R. Thordardottir, R.W.R. Crevel, E.N.C. Mills, A. Muraro, S. Arasi, P. Chaslaridis, (2020), "1798|Food detectives: Quality of life, food allergen labelling and EU law" [Online]. Available: https://onlinelibrary.wiley.com/doi/10.1111/all.14509 http://scientific.eaaci.org/site/programme/?1=1&sessiondetail=2937753&abstractdetail=102426&a=eaaci2020dc&trackid=&i=#! https://www.efanet.org/news/31-efa-projects/3914-efa-food-detectives-project
[4] Allergen Bureau. Food Allergen. [Online]. Last accessed: 25.07.2022 Available: https://allergenbureau.net/food-allergens/
[5] R. Meyer, "Nutritional disorders resulting from food allergy in children," Pediatr Allergy Immunol, vol. 29, no. 7, pp. 689–704, Nov. 2018, doi: 10.1111/pai.12960.
[6] T. Umasunthar, J. Leonardi-Bee, M. Hodes, P.J. Turner, C. Gore, P. Habibi, J.O. Warner, R.J. Boyle, "Incidence of food anaphylaxis in people with food allergy: a systematic review and meta-analysis," Clin Exp Allergy, vol. 45, no. 11, pp. 1621–1636, Nov. 2015, doi: 10.1111/cea.12477.
[7]R. S. Gupta, C. M. Warren, B. M. Smith, J. A. Blumenstock, J. Jiang, M. M. Davis, & K. C. Nadeau, "The Public Health Impact of Parent-Reported Childhood Food Allergies in the United States," Pediatrics, vol. 142, no. 6, p. e20181235, Dec. 2018, doi: 10.1542/peds.2018-1235.
[8] S. A. Rudders, S. A. Arias, and C. A. Camargo, "Trends in hospitalizations for food-induced anaphylaxis in US children, 2000-2009," J Allergy Clin Immunol, vol. 134, no. 4, pp. 960-962.e3, Oct. 2014, doi: 10.1016/j.jaci.2014.06.018.
[9] S. M. Jones and A. W. Burks, "Food Allergy," N Engl J Med, vol. 377, no. 12, pp. 1168–1176, Sep. 2017, doi: 10.1056/NEJMcp1611971.
[10] S. A. Bock, A. Muñoz-Furlong, and H. A. Sampson, "Further fatalities caused by anaphylactic reactions to food, 2001-2006," J Allergy Clin Immunol, vol. 119, no. 4, pp. 1016–1018, Apr. 2007, doi: 10.1016/j.jaci.2006.12.622.
[11] The European Academy of Allergy and Clinical Immunology, (2011) [Online]. Last accessed: 25.07.2022. Available: http://hugin.info/146478/R/1490004/425677.pdf
[12] R.S. Gupta, E.E. Springston, M.R. Warrier, B. Smith, R. Kumar, J. Pongracic, J.L. Holl, "The prevalence, severity, and distribution of childhood food allergy in the United States," Pediatrics, vol. 128, no. 1, pp. e9-17, Jul. 2011, doi: 10.1542/peds.2011-0204.
[13] The Nourished Child. (2019). Multiple Food Allergies: 7 Dangers for Children. [Online]. Last accessed 25.07.2022. Available: https://thenourishedchild.com/multiple-food-allergies-7-real-nutrition-risks-kids/.
[14] S. Clark, J. Espinola, S. A. Rudders, A. Banerji, and C. A. Camargo, "Frequency of US emergency department visits for food-related acute allergic reactions," J Allergy Clin Immunol, vol. 127, no. 3, pp. 682–683, Mar. 2011, doi: 10.1016/j.jaci.2010.10.040.
[15] R. Pawankar, "It's time for an evolution," Asia Pac Allergy, vol. 11, no. 1, p. e11, 2021, doi: 10.5415/apallergy.2021.11.e11.
[16] R. Pawankar, G.W. Canonica, S.T. Holgate, R.F. Lockey, M. Blaiss, The WAO White Book on Allergy (Update. 2013) [Online] Last Accessed: 01.08.2022, Available: https://www.worldallergy.org/UserFiles/file/WhiteBook2-2013-v8.pdf
[17] W. Loh and M. L. K. Tang, "The Epidemiology of Food Allergy in the Global Context," Int J Environ Res Public Health, vol. 15, no. 9, p. E2043, Sep. 2018, doi: 10.3390/ijerph15092043.
[18] S. H. Sicherer and H. A. Sampson, "Food allergy: A review and update on epidemiology, pathogenesis, diagnosis, prevention, and management," Journal of Allergy and Clinical Immunology, vol. 141, no. 1, pp. 41–58, Jan. 2018, doi: 10.1016/j.jaci.2017.11.003.
[19] NHS, National Health Service (UK). Food allergy: Diagnosis. [Online]. Last accessed: 25.07.2022. Available: https://www.nhs.uk/conditions/food-allergy/diagnosis/
[20] Food Allergy Research & Education (FARE). Blood Tests. [Online]. Last accessed: 25.07.2022. Available: https://www.foodallergy.org/resources/blood-tests
[21] E. Calamelli, L. Liotti, I. Beghetti, V. Piccinno, L. Serra, and P. Bottau, "Component-Resolved Diagnosis in Food Allergies," Medicina (Kaunas), vol. 55, no. 8, p. E498, Aug. 2019, doi: 10.3390/medicina55080498
[22] J. Flores Kim, N. McCleary, B. I. Nwaru, A. Stoddart, and A. Sheikh, "Diagnostic accuracy, risk assessment, and cost-effectiveness of component-resolved diagnostics for food allergy: A systematic review," Allergy, vol. 73, no. 8, pp. 1609–1621, Aug. 2018, doi: 10.1111/all.13399.
[23] DeepAI. Machine Learning. [Online]. Last accessed:25.07.2022. Available: Machine Learning Definition | DeepAI
[24] Ian H. Witten, Eibe Frank, Mark A. Hall, Christopher Pal, "What's it all about?" in Data Mining Practical Machine Learning Tools and Techniques, 4th ed. Burlington, Massachusetts, USA: Morgan-Kaufmann, 2017, pp. 3-9.
[25] Jiawei Han, Micheline Kamber, Jian Pei, "Introduction" in Data Mining: Concepts and Techniques (The Morgan Kaufmann Series in Data Management Systems), 3rd ed. Burlington, Massachusetts, USA: Morgan-Kaufmann, 2011, pp. 1-24.
[26] B. T.K., C. S. R. Annavarapu, and A. Bablani, "Machine learning algorithms for social media analysis: A survey," Computer Science Review, vol. 40, p. 100395, May 2021, doi: 10.1016/j.cosrev.2021.100395.
[27] J. Patil, H. Kadwe, P. Thakhre, S. Manna, and P. S. Gavhane, "Product Recommendation using Machine Learning Algorithm - A Better Appoarch," International Journal of Engineering Research & Technology, vol. 8, no. 11, Dec. 2019, doi: 10.17577/IJERTV8IS110314.
[28] J. Matuszewski and A. Rajkowski, "The use of machine learning algorithms for image recognition," in Radioelectronic Systems Conference 2019, Feb. 2020, vol. 11442, pp. 412–422. doi: 10.1117/12.2565546.
[29] I. Cinar and M. Koklu, "Classification of Rice Varieties Using Artificial Intelligence Methods", Int J Intell Syst Appl Eng, vol. 7, no. 3, pp. 188–194, Sep. 2019.
[30] Y. S. Taspinar, M. Koklu, and M. Altin, "Fire Detection in Images Using Framework Based on Image Processing, Motion Detection and Convolutional Neural Network", Int J Intell Syst Appl Eng, vol. 9, no. 4, pp. 171–177, Nov. 2021.
[31] I. A. Ozkan and M. Koklu, "Skin Lesion Classification using Machine Learning Algorithms", Int J Intell Syst Appl Eng, vol. 5, no. 4, pp. 285–289, Dec. 2017.
[32] J. Ive, "Natural Language Processing: A Machine Learning Perspective by Yue Zhang and Zhiyang Teng," Computational Linguistics, vol. 48, no. 1, pp. 233–235, Mar. 2022, doi: 10.1162/coli_r_00423.
[33] K. S. Patil, "A Survey on Machine Learning Techniques for Insurance Fraud Prediction," Helix, vol. 8, no. 6, pp. 4358–4363, Oct. 2018, doi: 10.29042/2018-4358-4363.
[34] D. Pavithra and J. A.N., "A Study On Machine Learning Algorithm In Medical Diagnosis," International Journal of Advanced Research

in Computer Science, vol. 9, Aug. 2018, doi: 10.26483/ijarcs.v9i4.6281.

[35] I. Kumar, S. P. Singh, and Shivam, "Machine learning in bioinformatics," in Bioinformatics, Elsevier, 2022, pp. 443–456. doi: 10.1016/B978-0-323-89775-4.00020-1.

[36] P. Rai, S. Prabhumoye, P. Khattri, L. Sandhu, and S. Kamath S, "A Prototype of an Intelligent Search Engine Using Machine Learning Based Training for Learning to Rank," Jun. 2014, vol. 27. doi: 10.1007/978-3-319-07353-8_9.

[37] B. Henrique, V. Sobreiro, and H. Kimura, "Literature Review: Machine Learning Techniques Applied to Financial Market Prediction," Expert Systems with Applications, vol. 124, Jun. 2019, doi: 10.1016/j.eswa.2019.01.012.

[38] G. W. Bassel, E. Glaab, J. Marquez, M. J. Holdsworth, and J. Bacardit, "Functional Network Construction in Arabidopsis Using Rule-Based Machine Learning on Large-Scale Data Sets[C][W][OA]," Plant Cell, vol. 23, no. 9, pp. 3101–3116, Sep. 2011, doi: 10.1105/tpc.111.088153.

[39] GECCO: Genetic and Evolutionary Computation Conference, Denver, Colorado, USA (July 20-24, 2016), Tutorials: Introducing rule-based machine learning: capturing complexity, [Online] Last accessed 25.07.2022, Available: http://gecco-2016.sigevo.org/index.html/Tutorials#id_Introducing%20rule-based%20machine%20learning:%20capturing%20complexity

[40] J. J. Koplin et al., "The Impact of Family History of Allergy on Risk of Food Allergy: A Population-Based Study of Infants," Int J Environ Res Public Health, vol. 10, no. 11, pp. 5364–5377, Nov. 2013, doi: 10.3390/ijerph10115364.

[41] K. Cheng, C. Zhang, H. Yu, X. Yang, H. Zou, and S. Gao, "Grouped SMOTE With Noise Filtering Mechanism for Classifying Imbalanced Data," IEEE Access, vol. 7, pp. 170668–170681, 2019, doi: 10.1109/ACCESS.2019.2955086.

[42] E. Frank and I. H. Witten, "Generating accurate rule sets without global optimization," University of Waikato, Department of Computer Science, Working Paper, Jan. 1998. Accessed: Aug. 01, 2022. [Online]. Available: https://researchcommons.waikato.ac.nz/handle/10289/1047

[43] S. Salzberg, "Book Review: C4.5: Programs for Machine Learning by J. Ross Quinlan. Morgan Kaufmann Publishers, Inc., 1993," Machine Learning, 2004, doi: 10.1023/A:1022645310020.

[44] R. Agrawal, and R. Srikant: Fast Algorithms for Mining Association Rules in Large Databases. In: 20th International Conference on Very Large Data Bases, 478-499, 1994.

[45] B. Liu, W. Hsu, and Y. Ma, "Integrating Classification and Association Rule Mining," In: Fourth International Conference on Knowledge Discovery and Data Mining, 80-86, 1998.

[46] Jon Duckett, PHP & MySQL: Server-Side Web Development, Hoboken, New Jersey, USA: Wiley, 2022.