Algorithm Analysis and Assessment of the Information Objects in Adaptive Systems

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Abstract. Analysis and assessment of the state of information objects is an urgent task in adaptive systems. Information about the current state of the system, its constituent components, the object of observation can be used in the decision-making process or in the implementation of control algorithms. However, an information object can have a complex structure or be characterized by many features, among which it is difficult to distinguish the main components. Therefore, an algorithm for analyzing and assessing the state of information objects is proposed, based on obtaining the compressed state of objects using neural networks. The resulting compressed state sufficiently characterizes the original object, but has a lower dimension. This can be used to speed up the analysis and assessment process and improve its accuracy in adaptive systems.

1. Introduction

Adaptive systems are used in many subject areas to ensure full functioning under various environmental conditions and behavior of the observed object [1-3]. Examples of such systems are automatic control systems, decision support systems, data analysis and processing systems. Adaptive systems are in demand in industry, robotics, in the automation of human activity, as well as in the implementation of information systems that adapt to the needs of various categories of users.

The implementation of the adaptive system includes the solution of problems of analysis and processing of information objects. An information object can be understood as an object of observation, operators or users of the system, components of the external environment. If the adaptive system operates in real time, then the urgent task is to ensure a high level of productivity of the process of analysis and information processing [4]. Since the structure of information objects can be represented by a large amount of data, one of the urgent tasks is the development of methods for analyzing and evaluating information objects, their state at the current time. To simplify this process, it makes sense to consider not the entire state of the information object, but some of its component or condensed representation [5, 6]. Such a compressed state is an abstract information entity that stores the main features of an information object, which makes it possible to speed up the comparative analysis of objects, determine new relationships between them, as well as carry out their encoding and subsequent decoding based on the available compressed representation [6, 7].

One of the promising approaches to obtaining compressed states of objects is machine learning algorithms, for example, neural networks [8, 9]. Autoencoders are especially effective in solving this problem - neural networks, which, based on the input data, form some coded representation, from
which the original data is then recreated. Thus, you can generate pictures, remove noise from video and images.

Compression and assessment of the state of objects are investigated in the work [7]. The authors have proven that the dynamic characteristics of objects and changes in their properties can be efficiently modeled and processed using compressed or sparse representations. The hidden layers of the autoencoder can be used to obtain such representations.

Convolutional neural networks and autoencoders really show high efficiency when processing complex objects, images. For example, in [10], a method for improving the image quality for surveillance cameras is considered. Similar tasks were considered in the study [11]: improving the quality of recognition, detecting objects, removing the background image, as well as shadows from objects, which makes it possible to increase the accuracy of positioning cars on traffic images.

However, the use of autoencoders requires the development of an appropriate neural network architecture based on the analysis of the structure of the initial information object, a selection of the value of the latent representation, which can ensure the correct restoration of the object.

Analysis of practical approaches to the automated selection of the structure of neural networks made it possible to single out the following software solutions: AutoKeras [12], DEvol [13, 14], AutoSklearn [15], Google AutoML [16], AutoGAN [17]. Each of the tools uses its own approaches to find the optimal settings and architectures of neural networks: Bayesian optimization of network parameters (AutoSklearn, AutoKeras), genetic programming (DEvol), controllers based on neural networks (Google AutoML, AutoGAN). However, these methods do not allow solving the problem of compressing the state of information objects in an automatic mode, since they do not support the autoencoder mechanism. This makes the task of developing an automated approach to generating the compressed state of objects relevant in scientific and practical terms.

Within the framework of this article, we consider an algorithm for analyzing and assessing the state of information objects, based on the use of neural networks and allowing to obtain a concise representation of the state of an information object of an adaptive system.

2. Algorithm for analyzing and assessing the state of information objects

Let us formulate the research problem. Let an information object \( X = (x_1, \ldots, x_n) \) represented by a multidimensional vector \( Y = (y_1, \ldots, y_m) \) of some feature values be given in an adaptive system. The multidimensional vector \( X \) will be called the compressed representation of the vector, and \( m < n \). Then, to solve the problem of compressing the state of an information object \( X \) for subsequent analysis and evaluation, it is necessary to assign a vector \( X \) to the vector \( Y \).

To solve this problem, an algorithm for analyzing and assessing the state of an information object has been developed. Let's represent it in the form of a block diagram (figure 1).

Let us consider the stages of the developed algorithm and the mathematical description of the process of compressing the state of an information object.

The first stage implements preliminary processing of the information object \( X \). For this, operations of normalization, translation into tokens, vectorization and others are performed, if necessary [18]. The dimension \( n \) of the state vector \( X \) of the information object is determined.

Based on the structure of the initial data vector \( X \), the structure of the neural network is selected. The architecture is based on the use of dense layers of neurons, as well as convolutional (for images), recurrent (for text data), alignment and forgetting layers (to reduce the likelihood of overfitting). Next, the primary choice of the size \( m < n \) of the compressed state vector \( Y \) of the information object is carried out.

The neural network architecture is AutoEncoder. This architecture allows mapping \( X \rightarrow X \) with an error \( \varepsilon \). The AutoEncoder architecture assumes the presence of a hidden layer \( H \) formed at the output of the encoder and used at the input of the decoder to restore the original vector \( X \). Thus, having trained AutoEncoder on some choice of vectors, you can use as the compressed state \( Y = H \) for each of these vectors.
Figure 1. Algorithm for analyzing and assessing the state of information objects.

With this approach, the vector $Y$ of the compressed representation has a smaller or comparable dimension and a smaller size $m$, determined by the network architecture. During training, you can sequentially increase the size $m$ until the error becomes less than $\varepsilon$.

The resulting compressed state $Y$ can be used to solve analysis or data processing problems instead of the original state $X$.

Thus, the presented algorithmic and mathematical support allows solving the problem of analyzing and assessing the state of an information object.

3. Practical implementation of the algorithm in adaptive systems
The practical implementation of the algorithm is based on the use of the Python programming language, the Keras machine learning library and the TensorFlow framework [19]. The program code includes the following procedures:

- determination of the dimension of the initial data;
- preprocessing, if necessary - data normalization and tokenization;
- search for the optimal architecture of the neural network;
- implementation of the neural network training procedure;
- using a neural network to determine the compressed state of an information object, or to restore it from a compressed state.
Datasets MNIST (images of numbers), HEC (measurements of energy consumption [20]), Adult (analysis of wages [21]) and HAR (analysis of human movements [22]) were used to evaluate the algorithm. In accordance with the developed algorithm, it is necessary to estimate the dimension of the state of information objects from each dataset, carry out preliminary data processing, and then select the dimension of the compressed state.

Figure 2 shows the dimension of the initial state of information objects, the compressed state and the value of the state compression, expressed as a percentage. The value of the compressed state was chosen experimentally during iterative increase until an acceptable accuracy of the neural network is achieved.

The greatest effect of dimensional change can be noted on the MNIST and HAR datasets. This is due to the large dimension of the original information objects. In the case of MNIST images, theoretically, the value of the compressed state can be 1, since this is sufficient for the distribution of 10 classes of numbers, however, in the course of experimental studies, such a strong compression did not always show satisfactory results. Thus, the selected dimensions of compressed states will reduce the size of the state of information objects by 85 - 98%.

![Figure 2. The dimension of the initial and compressed states of information objects.](image)

Further, the search for the optimal neural network architecture for each type of information objects is carried out. Figure 3 shows the values of the mean square error at the beginning of training the neural network and at the end (after the selection of the optimal structure).

The search for the structure of the neural network took an average of 120 to 600 seconds. Thus, in the process of searching for the optimal structure of the neural network, the error decreased on average by 54%.
Next, let us estimate how the compressed information object corresponds to the original one. To do this, we will carry out the process of encoding and decoding for an example from each dataset. Comparison of the original and reconstructed objects is shown in figure 4. The visual analysis of the results obtained can be considered satisfactory - the structure of the object and its contents correspond to the original objects.

Taking into account the sufficient accuracy of restoring the information object, the result can be considered acceptable. The resulting compressed states of information objects can be used to improve the performance of the process of analyzing and evaluating information objects of adaptive systems.

### Figure 3. Mean square error values of initial and final neural network architectures.

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| Dataset | Original object | Restored object |
|---------|-----------------|----------------|
| MNIST   | 4.46, 0.13, 234.6, 19.0, 0.0, 37.0, 16.0 | 4.7, 0.02, 236.2, 20.2, 0.0, 32.8, 16.5 |
| HEC     | 0.35, 2.0, 0.15, 5.0, 0.6, 1.0, 10.0, 1.0, 0.0, 0.0, 0.0, 0.39, 0.0, 1.0 | 0.33, 2.3, 0.13, 4.60, 0.64, 0.82, 6.51, 1.20, 0.07 0.0, 0.0, 0.0, 0.45, 0.30 0.99 |
| Adult   | 0.03, 0.0, -0.02, -0.2, -0.36, -0.6, -0.24, -0.41, -0.64... | 0.03, 0.05, 0.02, -0.13, -0.34, -0.54, -0.14, -0.41, -0.59... |
| HAR     | 0.03, 0.0, -0.02, -0.2, -0.36, -0.6, -0.24, -0.41, -0.64... | 0.03, 0.05, 0.02, -0.13, -0.34, -0.54, -0.14, -0.41, -0.59... |

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**Figure 4.** Comparison of original and restored information objects.

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4. **Conclusion**

The paper considers the problem of analyzing and assessing the state of information objects, which can be used in adaptive systems in management and decision-making processes. The structure of the state of an information object can have a high dimension, which makes it difficult to process, analyze and evaluate.

To solve this problem and speed up the process of analyzing and evaluating information objects in adaptive systems, an algorithm based on the use of neural networks of autoencoders is proposed. The
mathematical description of the algorithm in the notation of set theory is presented. The practical implementation of the algorithm and its testing on several types of information objects are considered. As a result of experimental studies, it was found that the proposed approach allows restoring the states of information objects from compressed states with sufficient accuracy. The amount of compression varies depending on the structure of the object from 85 to 98%. The results obtained can be used in various adaptive control systems, decision support, data analysis and processing to reduce the complexity of the structure of the state of information objects.

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