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К СОЗДАНИЮ МЕТРИЧЕСКОГО ПРОСТРАНСТВА ОБРАЗА СЕЛЬСКОХОЗЯЙСТВЕННОГО ОБЪЕКТА

Куценогий П.К., Каличкин В.К.
Сибирский федеральный научный центр агробиотехнологий Российской академии наук
Новосибирская область, р.п. Краснообск, Россия

Представлен анализ различных подходов к прогнозированию сложных многофакторных систем в условиях неопределенности внешних условий. Данные подходы необходимо развивать с целью создания адекватных моделей сельскохозяйственной деятельности для целей ее эффективного планирования и управления. Отличительная особенность сельскохозяйственного производства – критическая зависимость от факторов внешней среды, которые не поддаются точному прогнозированию. Используемые для решения данной задачи в настоящее время регрессионное моделирование и анализ временных рядов в сложных случаях не дают адекватный прогноз динамики сельскохозяйственного объекта. В качестве подхода предлагается использовать построение «образа» системы. Данный подход относится к «природоподобным», так как моделирует способ принятия решения специалистом на основе накопленного опыта и интуиции. Ключевым параметром этого построения будет корректный выбор метрики (системы координат). Данный подход проиллюстрирован примером создания образа двухмерного явления в одномерной системе координат. В результате под образом понимается изображение реальности в векторном пространстве определенной размерности. Образ в представлении авторов – отображение реальности в искусственно созданной метрике, более доступное пониманию и анализу, но сохраняющее основные (важные) черты и функции исходного объекта. Методы искусственного интеллекта можно рассматривать в качестве инструментов для создания и анализа образов. Важной характеристикой образа является его прогностическая сила, т.е. возможность для использования образа с целью прогнозирования состояния реального объекта в будущем периоде. Образ сохраняет свою прогностическую силу, если прогноз, полученный с использованием данного образа, соответствует данным, полученным при наблюдении за реальным объектом. Образ формируется в подходящей метрике для решения конкретной задачи. Ключевым метрическим параметром образа сельскохозяйственной деятельности, пригодного для целей прогнозирования, является минимальная размерность используемого векторного пространства, при котором сохраняется прогностическая сила образа для решения поставленной задачи.

Ключевые слова: образ системы, моделирование процессов, прогнозирование, искусственный интеллект, размерность метрического пространства

CREATION OF THE SPATIAL METRIC FOR THE IMAGE OF AN AGRICULTURAL OBJECT

Kutsenogii P.K., Kalichkin V.K.
Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences
Krasnoobsk, Novosibirsk Region, Russian Federation

The analysis of various approaches to forecasting complex multifactorial systems in conditions of uncertainty of external conditions is presented. It is necessary to develop these approaches in order to create adequate models of agricultural activities for their effective planning and management. A distinctive feature of agricultural production is a critical dependence on environmental factors, which cannot be accurately predicted. Regression modeling and analysis of time series used at present to solve this problem in difficult cases do not result in an adequate forecast of the dynamics of an agricultural object. As an approach, it is proposed to use the construction of the "image" of the system. This approach is classified as "nature-like", as it simulates a way of decision-making by a specialist on the basis of accumulated experience and intuition. The key parameter of this construction will be the correct choice of the metric (coordinate system). This approach is illustrated by an example of creating an image of a two-dimensional phenomenon in a one-dimensional coordinate system. As a result, an image is understood as an image of reality in a vector space of a certain dimension. The image in the authors' view is a reflection of reality in an artificially created metric, more suitable for understanding and analysis, but retaining the main (important) features and functions of the original object. Artificial intelligence techniques can be seen as tools for image creation and analysis. An important characteristic of an image is its predictive power, i.e. the ability to use the image in order to predict the state of a real object in the future period. An image retains its predictive power if the forecast obtained using this image corresponds to the data obtained when observing a real object. The image is formed in a suitable metric for solving a specific problem. The key metric parameter of the image of agricultural activity, suitable for forecasting purposes, is the minimum dimension of the vector space used, at which the predictive power of the image is retained to solve the problem.

Keywords: system image, process modeling, forecasting, artificial intelligence, spatial metric dimension

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The creation of an image of an object, process or phenomenon in science is associated primarily with two disciplines - modeling and forecasting. It is believed that all cognition is modeling [1, 2]. A model is an artificially created system that reflects the similarity of structure and function to the original system, but which always simplifies and distorts the original. At the same time, simplification is necessary due to a great complexity of the agricultural system and the accumulated knowledge about its functioning. The adequacy of models of agricultural systems is limited by the complexity of the mathematical description and their nonstationarity, which manifests itself in their evolution in time. Consequently, model and modeling, regardless of methods (approaches), are of limited value and diffusion. To this it should be added that modeling is developed in the academic environment and is poorly used by production specialists. Mathematical modeling of agricultural processes and objects (for example, the management of the production process of plants) is, in fact, a “thing in itself”.

In turn, computer modeling is currently developing towards the processing of big data and their visualization (creation of images), since it is this process of data transformation that is most easily perceived by a person [3]. Within this paradigm, virtual reality (VR) and augmented reality (AR) technologies are most promising in simplifying the process of perception and understanding of data, as well as decision support processes [4]. At the same time, according to N.N. Shabrov[1], the solution of extraordinary problems cannot be provided with a set of previously developed multipurpose models due to their inadequacy or ineffective scaling of computations. Solving such problems requires the development of unique models and equations of state of the object, as well as the development of numerical solution schemes. In this regard, simulation is carried out using supercomputers. Simulation on supercomputers generates ultra-large-scale amounts of data, the analysis and interactive visualization of which in virtual environment systems in real time, in turn, also requires the use of supercomputer computing. The amounts of data on the petabyte level (10^{15} bytes) are created in the process of simulation with computing systems performance on the level of petaflops (10^{15} operations per second). At the same time, to visualize volumes of data of the Petabyte level, both new technologies for analysis and visualization of results are required, as well as new software and hardware visualization tools[2].

In Russia, a national technological platform is currently being formed for the creation and development of supercomputer technologies, even of the exoflop class [3]. However, it is worth assuming that in the near future the solution of agricultural problems (note that they are extraordinary) is hardly possible on this technological platform. Business and the state are interested in it, but at present there are no researchers in Russia capable of solving this problem at a high professional level (agricultural science and education have not prepared such researchers).

The creation of forecasting methods is one of the main problems of science, and perhaps the most difficult of them. The most common forecasting in agriculture is based on the use of a factorial regression model [5–7]. However, it is impossible to include all the factors influencing the studied indicator, for example, the yield of crops in any regression model. Firstly, some of the factors are generally unknown, since our knowledge does not have the status of absolute truth. Secondly, some of the factors are theoretically known, but in practice there is no sufficiently reliable information on them. Thirdly, if the number of well-known factors is large, then all of them cannot be included in the regression equation based on mathematical constraints (excess of the number of factors over the sample size, multicollinearity [8, 9], heteroscedasticity) [10, 11].

Another common method is time series analysis, in which forecasting is carried out according to the trend [12-14]. This method also has disadvantages, namely: the implicitness of the dynamics factors hidden behind the "period number" deprives the researcher of the opportunity to take into account the expected leap in the development of a particular factor. It is not possible to simulate different forecast options for different combinations of factor values, which is usually done when doing the forecasting using a regression model with controlled factors. The outlook for the trend has the traits of fatalism, as it were.

Consequently, regression modeling and analysis of time series in difficult cases do not provide an adequate forecast of the dynamics of an agricultural object. Nevertheless, a person makes decisions and most often they turn out to be successful. Something faintly perceptible, intuitive, not subject to strict formalization prompts a person to make the right decision. In our opinion, this intuitive, created by the subjective experience of a person, appears in his head as a certain image of the result of an action, and the action itself appears as an image.

[1]Shabrov N.N., Kiev V.A., Kuzin A.K. Virtual environment systems - key technologies for analyzing the results of supercomputer modeling // Supercomputer days in Russia: conference materials, 2015. pp. 428–435.

[2]Shabrov N.N., Orlov S.G., Kuzin A.K., Suetov A.E. Parallel computer technologies in virtual environment systems. Goals and objectives // Supercomputer technologies in science, education and industry: materials of the conf. M.: Publishing house of Moscow State University, 2011. P. 669–671.

The axiom of understanding the image in modern philosophy and psychology has been the definition of the image given by G.V. Hegel[3], "... reveals to our eyes not an abstract essence, but its concrete reality ...". In cognitive science, an image is understood as “a representation in the mind of a non-present object or event” [15]. The main task of the image is to preserve the events and phenomena of reality in the memory in the form of some kind of “picture in the head”, “projection of the scenes from the real world”.

From the point of view of using an image as a publicly available tool, and not just a “picture in the head” of an individual subject, the definition “projection of a scene from the real world” is more appropriate. This projection is always carried out in some metric. For example, cinematography of the last century (not 3D) is a projection of a visual image onto a flat screen, i.e. a two-dimensional image of a three-dimensional world. The same applies to the art of painting. If an image is a "picture" corresponding to some original, then the dimension of the space of the picture and the dimension of the space of the original do not necessarily coincide at all. Nevertheless, the image that is required and has practical significance should allow one to get an adequate idea of the original and have a predictive power. In other words, an adequate image reflects the characteristics of the original necessary for forecasting, or in another way: it is possible to accurately (with acceptable accuracy) identify the original on the basis of the image. So, from a photograph, you can identify a person with almost 100% probability by the signs of their appearance, although a photograph is a two-dimensional image, and a person's appearance is a function of three-dimensional space. Moreover, identification can be made close to 100% from black and white photography, although a person's face has the entire color spectrum. This example shows that for the "identification" function, it is sufficient to create an image of an object in space, the dimension of which is much less than the possible dimension of the space required for an accurate description of the object.

The same should be applied to the description of agricultural activities. For an accurate and full-scale description of such processes, a multiparameter (multidimensional) description is required. There is a huge variety of interacting factors that ultimately lead to the final result of the activity. Taking into account all possible factors, much less, their accurate forecasting, is an unsolvable task. However, is it really necessary to create the most detailed possible image in the most complex and complete metric to adequately describe the situation and predict the result?

The purpose of the study is to determine the image of an agricultural object as a tool for adequate forecasting, to consider the concepts of the required and possible detailing of the image based on the specifics of the problem being solved and to determine the key metric space of the created image.

In psychology, the image is understood as a reflection of reality in the form of an integral structure, which becomes the content of the human psyche. This nature-like and anthropocentric approach can be developed by modeling images of real objects as it happens in artificial neural networks. However, there is also a slightly different approach. An object model is created in order to predict events associated with a given object that have never actually occurred, based on previous similar or analogous experiences. It should be emphasized that if an exact repetition of the conditions of an experiment is possible, as postulated in physics, then it is possible to accurately predict the result of a given experiment solely on the basis of experience. If the repetition of the experimental conditions is impossible or these conditions are initially underdetermined, then in any case it is necessary to build a model with a number of assumptions and predict the result based on this model. Thus, another definition of an object's image is a model that allows one to predict the state of a given object with an acceptable degree of accuracy (reliability).

[3]Gegel G.V. Aesthetics. T. 1.M.: Art, 1968.311 p.

The second (physical) definition of "image" intersects with the first in the part in which the image, which is a reflection of reality in the human psyche, as well as the numerical model, is subject to "improvement" as knowledge about the object is accumulated. Simple examples are appropriate here. One person's first impression of another person is an image that predicts behavior. What can you expect from this particular person in a given situation? As the experience of interacting with a person in various situations is accumulated, the first impression may turn out to be erroneous, and a more perfect model of prediction (the image of another person's personality) appears, which offers more accurate options for behavior in certain situations. The example with human behavior is quite typical, since it describes a very complex object with a large number of factors affecting the final result.

The image or "predictive model" of agricultural activity unambiguously refers to the activity that occurs under the influence of a large number of factors that have a critical impact on the final results of the ongoing processes, while a number of factors are subject to strong variability, others are generally undefined. Agricultural activity is associated with the life cycles of biological objects: plants and animals. The development and death of these biological objects depends both on the properties of the objects themselves, encoded in the genome, and on external conditions. One of the most significant external conditions that determine the development of plants is the weather in the form of a set of meteorological indicators: temperature, illumination, precipitation, wind speed, etc. It is important to realize that the concept of "weather" hides a very wide range of parameters of the state of the atmosphere, hydrosphere and soil at the point of measurement and at the point in time when measurements are taken. Often, when trying to create a predictive model of agricultural activity, they try to find a way to predict the weather for the period for which it is necessary to obtain a forecast of crop yields. Long-term weather forecasts are always values obtained with some degree of probability. Another factor to take into account: the current weather conditions at the time of observation (current experiment) will never be exactly the same. From the point of view of physical modeling, this means that it is impossible to reproduce the conditions of the experiment in order to verify the truth of the observations made at the current stage. It is not just the fact of the presence of difficultly predictable conditions that is important, but the fact of the underdetermination of these conditions that is important, since the only thing that is known for sure is that these conditions (especially in the time base) will never be repeated.

Any end result that we want to achieve can be represented in the form of an image. In fact, depending on the "completeness", the image allows simulating the result in the process of a mental (for a person) or numerical experiment in the case of creating a numerical virtual image. The image is placed in the boundary conditions that meet the expectations and produces a predictive result. Just like a person who can navigate in an environment that is not entirely familiar to them, relying on accumulated experience and the corresponding logical constructions, researchers expect the result that most closely matches the observed reality in the presence of incomplete or underdetermined boundary conditions from a qualitatively constructed image. The more "complete" the image being created, the less requirements it will impose on the number and accuracy of the input parameters used. From the point of view of human activity, this is what is called "experience."

An image is an artificially created reality that we should strive for (or should we predict?). Or is it a model with predictive power? By the concept of an image we mean the existing picture, which, being supplemented by conditions (assumed), gives the expected result. A correctly created image should be minimally sensitive to the accuracy of determining conditions in the future periods. How do we define the "quality" of an image? After an event occurs, reality can be correlated with a forecast. The conditions are no longer modeled or predicted, but have occurred in fact. In this situation, the observer has the actual value of the projection and can compare it with the prediction based on the pre-built image. The better the match, the better the image will be created. If the match does not fit into the specified range, the image will be corrected. There is an accumulation of experience, in accordance with which the image is corrected. Ideally, the image tends to a certain limiting case, when further accumulation of experience no longer leads to a more accurate description. The accuracy of predictions no longer increases with the number of tests performed and the number of adjustments made. This may also be due to the underdetermination of the conditions in which physical reality exists, the image of which is created by the researcher. In this case, the image must be accepted as adequate to reality to an achievable extent, and it is to this image that the researcher (observer) strives.

This approach is similar to the one used to "train" neural networks in machine learning. In this case, a neural network can be considered as a model capable of predicting the result of interest to the researcher after a certain setting or training. Within the model, certain degrees of freedom remain, namely: the weighting coefficients of signals transmitted from one layer of the network to the next in order to activate the functions of virtual neurons of the next layer. Given a sufficient number of training examples, i.e. sets of conditions and known results corresponding to these conditions, training takes place, which is the selection of weight coefficients so that the model adequately reproduces the entire array of training examples. We will dwell on the degree of adequacy below. Now let's consider the case when the training fails to complete successfully. There may be several reasons for this:

– insufficient number of training examples. It is not difficult to test this hypothesis if there is a possibility of further accumulation of experience. If it is possible to continue experiments in new conditions and as experience is gained, the accuracy of subsequent predictions increases, then the model (image) is adequate, but initially there was not enough data. As data accumulates, the image (model) is refined, but up to a certain limit inherent in the very structure of the image or model. Further data accumulation becomes redundant;

– inadequacy of the very structure of the image or model to the task at hand. If the accuracy of the predictions does not increase with the accumulation of data, it is necessary to modify the model itself. Probably, initially there are not enough degrees of freedom in it or they are inadequately defined;

– it is possible that the problem, in principle, cannot be solved with the help of some kind of modeling, or there is no adequate image describing the reality in the conditions essential for the process. This result arose, most likely, due to the initially high expectations of the researcher from the created image and an incorrectly formulated problem.

Let's consider this problem in more detail. The key question is the following: how detailed should and can be the image that we strive to create to simulate real physical or biological processes? The paradox, but in this case, "better" can be "worse". The predictive power of an overly detailed image may be obviously worse than that of an image with a lot of assumptions and generalizations. In the field of artificial intelligence and machine learning, this paradox is described in terms of "overfitting model". Let's explain the essence of the problem with an example.

Let's imagine that it is necessary to determine the personality of a person from a photograph. You can have a very clear, detailed digitized photograph and build upon it. Based on this photograph, we create a detailed digital image of this person, taking into account all the details of the existing photograph. Then, to identify a person, it will be necessary to take exactly the same photo, in the same angle and resolution. Most likely, it will not be possible to accurately reproduce the picture, and the machine algorithm will assert that any of the photographs presented does not correspond to the original, including photographs in which a person is captured from the original photograph used as the original image or model. This very accurate model has a predictive power of zero, since it will give a negative answer with a 100% probability when identifying any person (including the correct one).

Now let's try to "rough" the image, using not all the data of the digitized photograph. We will develop a system of ratios describing the main features of the face: the ratio of the length of the nose to the distance between the tip of the nose and the chin, the ratio of the width and height of the forehead, the ratio of the length of the mouth and the distance between the eyes, etc. Having identified, for example, 100 such parameters that can be determined from photographs of a person, in fact, we will create a new metric in which the photograph can be transformed. Once the snapshot is encoded in the new metric, the amount of data used and stored is drastically reduced. To create an image of a person's face in the new metric, it is better to use not one accurate high-resolution image, but many images, albeit of poor quality. The use of multiple images will allow you to take into account the features of the facial expressions of each individual person when photographing. The dimension of the metric can be 100, and it can be more or less. The larger the dimension, the more accurately we will cut off incorrect images. However, we can immediately say that even a very rough model or image gives a nonzero probability of obtaining the correct result: with some finite probability, such an image will correspond to the real sought-for person. Since the probability of finding the correct person in the case of an overtrained model is immediately estimated by us as equal to zero, any finite probability of getting the correct answer is infinitely better in terms of the predictive power of the image or model. In the given example, it can be seen that a rough image can be significantly better than an attempt to create an accurate image as applied to a specific task.

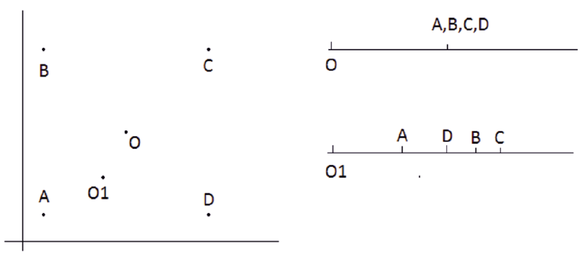
It follows from the above that the image we are striving for is not an idealized description that is as close as possible to the picture of the world we represent, but the model that, when adequate boundary conditions are imposed on it, will give the predicted value of the quantity of interest with the maximum possible (permissible) accuracy. From this point of view, the determination of the limits of the minimum permissible limits of the spread of predicted values in relation to a specific problem is the most important issue to be solved when constructing predictive images or models.

The process of “coarsening” an image for the purposes of its practical use can be represented in the form of a formal mathematical problem of finding the minimum possible dimension of the space for representation. Some authors [16] describe as a way of visualizing an object from n-dimensional space, its projection into a space of a lower dimension. In fact, this is the only practically working approach. So, when we talk about "visualization", we mean that the image can be presented in a graphical representation that is convenient for perception. However, a person is able to visually perceive objects in the form of two- and three-dimensional images. It is quite difficult, even with a highly developed imagination, to imagine a four-dimensional object. The next visualization task when choosing a projection into two- or three-dimensional space is the choice of a metric in which the observer can adequately assess a real (multidimensional) object, seeing only its “image” or projection into a space of a lower dimension. In the cited work [16], the measure of adequacy is assessed by such a criterion as the ability of the operator of a complex technical system, described by many parameters, to correctly assess its technical condition and retell, if necessary, the occurrence of an emergency situation. In this case, we have a specific application of the predictive power of the image. The system is generally described in n-dimensional space: the number of parameters, each of which can be measured in a wide range of values, is quite large. The system operator is able to quickly perceive only the two-dimensional image displayed on the display. The correct choice of the axes (two-dimensional metric) of the image will allow the operator to distinguish in this picture a situation that predicts the possible emergency behavior of the system.

The criticality of the choice of the metric for the purpose of using the image in the future for solving practical problems can be illustrated by an elementary (naive) example. The figure shows 4 points (objects) A, B, C, D in the original two-dimensional space. It is proposed to choose a metric for one-dimensional representation of objects. Let us choose as a metric the distance of each of the points to some center O. If, as a reference point, we select a point O in the center of the square formed by the points ABCD, then in the new one-dimensional space it will be seen that all objects are equidistant from O. Therefore, in the original (true) space, you can arrange objects on a circle. However, information about the equidistance of points along the circle will be lost, which is an example of the cost of reducing the dimension of the image in comparison with the original representation. This fact indicates that the choice of a metric for creating an adequate image also depends on the formulation of the problem for the solution of which the image is created.

Let's consider this elementary example from the point of view of incorrect choice of metric for creating an image in n – 1-dimensional space. If you choose not point O, but point O1 as the starting point of the new metric, the display of objects in the new space will look like a strange distribution, in which it is difficult to see the system and draw any conclusions about the objects in the original representation.

The described example is not an image of the future of the system, but an image of its present state, which makes it possible to reflect



Пример создания одномерного образа расположения четырех объектов в двухмерном пространстве

An example of creating a one-dimensional image of the location of four objects in two-dimensional space

the main features associated with the development of the situation, or with the dynamics of the development of the system in a certain time perspective. It is this approach that makes it possible to move on to predicting the behavior of complex systems in the future.

As noted above, a complete forecast in the initial metric (reference coordinates of the description) becomes impossible due to the abundance of factors, some of which cannot be taken into account. Simplification of the metric while preserving the possibility of identifying the image is the ability to take into account precisely important and significant factors, including those that critically affect the behavior of the system. By simplifying the picture, it is possible to preserve the predictive power of the created image.

The image is formed on the basis of knowledge about the potential capabilities of the object, immersed in conditions. In general, the forecasting problem can be formulated as obtaining an image of a finite system for a time point T, having a certain set of data about the system at times preceding time T. The concept of an “image” is inextricably linked with the concept of an “observer”. When it comes to forecasting, very specific parameters of the image of interest to the observer are important. If we are talking about a picture, he is interested in portrait similarity with the desired object or subject, about agricultural activity - for example, the possible expected yield of specific crops and the necessary actions to obtain it. We are talking about an image in a specific "metric" or coordinate system. This is where the “observer” arises, since the image is created in accordance with the technical assignment of the observer and includes parameters that are important to him. The observer is interested in a specific forecast for specific parameters of the system. The choice of the optimal metric occurs precisely for the purpose of solving the problem posed by the observer. If the task is to create an image suitable for predicting the state of the system, it is necessary to take into account how many and what parameters of the system must be described, as well as on which external conditions the dependence is critical and which external conditions can and which cannot be adequately predicted in the time perspective of interest.

For example, the task is to obtain a forecast of agricultural activity in the future. The critical parameters influencing the result are the weather conditions of the future period, the weather conditions of the previous period and the set of agricultural technologies used for the cultivation of the studied crop. The most unpredictable parameters are the weather parameters of the future period. Accordingly, an adequate predictive model should be built in the form of an image of the future period in such a metric in order to have minimal sensitivity to changes in parameters describing the current weather.

The dimension of the image space can be limited by the dimension of the available array of source data, on the basis of which this image is supposed to be created. The problem of finding the optimal dimension, or the optimal "metric" of the image, in itself is undoubtedly important.

Almost all artificial intelligence or machine learning methods (in a narrower sense) are reduced to representing the original data array in space with a constructed metric in such a way as to reveal hidden patterns encoded in the data itself, but not obvious in the original metric. The main advantage of such approaches is that the system itself selects the metric in which the presentation looks in the most obvious way. The choice of this metric is the key task of building an image, which is illustrated in the figure.

Any final result, including the result of agricultural activity, described in the future forecast period, can be represented in the form of an image. An image is a display of reality in an artificially created metric, more accessible to understanding and analysis, but retaining the main (important) features and functions of the original object.

An image is the state of an object in the future, which is supposed to be used for prognostic purposes based on knowledge about the potential capabilities of an object immersed in conditions (for example, a separate agrometeorological resource, yield, etc.). By image we mean the existing objective reality modeled using a set of vectors. Artificial intelligence methods can be considered as tools for creating and analyzing the generated images.

When creating an image of an agricultural object (activity), there are a number of objective restrictions on the maximum permissible detailing associated with the underdetermination of the conditions in which the activity will be reproduced. The underestimation of the details (information) available to the researcher when creating the image leads to a decrease in the accuracy of the forecast based on it. An attempt to create an image with more detail than the object of research allows leads to unstable behavior of the image, inadequate conclusions based on it and an unnecessary waste of computational resources. The key metric parameter of the image of an agricultural object (activity) suitable for forecasting purposes is the minimum dimension of the space of the created image, which retains its predictive power for solving the problem.

СПИСОК ЛИТЕРАТУРЫ

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Информация об авторах

Куценогий П.К., кандидат физико-математических наук, ведущий научный сотрудник; e-mail: peter@kutsenogiy.ru

(✉) **Каличкин В.К.,** доктор сельскохозяйственных наук, профессор, главный научный сотрудник; **адрес для переписки**: Россия, 630501, Новосибирская область, р.п. Краснообск, а/я 463; e-mail: kvk@ngs.ru

Author Information

Peter K. Kutsenogii, Candidate of Science in Physics and Mathematics, Lead Researcher, e-mail: peter@kutsenogiy.ru

(✉) **Vladimir K. Kalichkin,** Doctor of Science in Agriculture, Professor, Head Researcher; **address:** PO Box 463, SFSCA RAS, Krasnoobsk, Novosibirsk Region, 630501, Russia; e-mail: kvk@ngs.ru

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