Perceiving the Pattern

Pattern recognition plays a central role in astronomy, but it is also expedient when dealing with multimedia data and in medicine. Researchers working with **Gregor Morfill** at the **Max Planck Institute for Extraterrestrial Physics** in Garching have developed a particularly reliable method for such recognition.

TEXT **CHRISTIAN BUCK**

Bartók, Beethoven or Brahms? Wolfram Bunk's computer knows the answer – because the physicist and his co-workers at the Max Planck Institute for Extraterrestrial Physics in Garching, near Munich, have converted a conventional Apple notebook into a music expert. The technology is known as audio fingerprinting, and it is even possible to watch it in action: As soon as Wolfram Bunk retrieves a piece of music from the computer's memory, the analysis begins and the screen comes alive. Blocks of color in different shades of red on the monitor represent classical composers like Beethoven, Mozart and Vivaldi, but also rock musicians like Peter Gabriel and bands like Genesis and Pink Floyd.

The music has barely started when white bars begin their analytical dance across the red areas: the higher the amplitude, the more typical the piece is for a specific artist. It doesn't take long before one bar dominates and the others become smaller and smaller – the computer has obviously hit on something. "After an approximately 30-second sound bite, the system recognizes the composer in about 90 percent of cases," explains Bunk. In this case, its diagnosis is Beethoven. A direct hit!

Audio fingerprinting involves the interplay of music and mathematics – two things that have been considered to be closely related ever since Pythagoras. The Greek philosopher reflected on musical intervals and simple number ratios. Bunk and his colleagues Thomas Aschenbrenner and Roberto Monetti from the Max Planck Institute in Garching have developed a method that is able to extract characteristic attributes and qualities from pieces of music – similar to fingerprints, which are typical of a particular person. The analysis involves breaking down 0.1-second sections of the musical works into their frequencies – their spectrum – and analyzing them for typical characteristics.

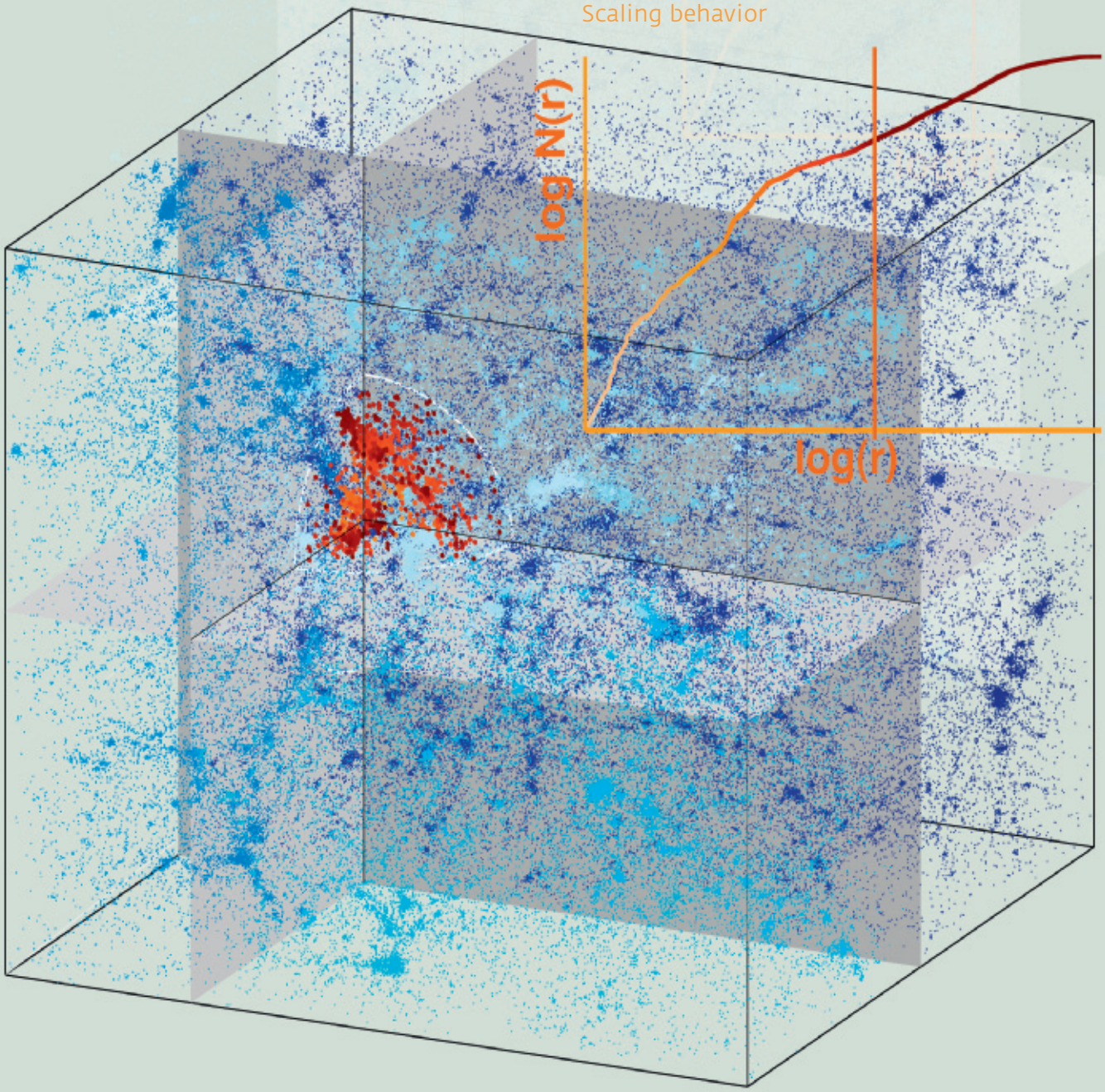
TYPICAL MUSIC SNIPPETS

"This results in up to ten representative spectra being assigned to each piece," says Bunk. "If the system is now asked to recognize a new composition, the computer also calculates the audio characteristics for that piece in real time." It simultaneously searches the computer database for similarities that the system can use to assign an unknown piece to a composer. Since the prototype spectra are so short, the volume of data is low and the computer can recognize the composer in a very short time.

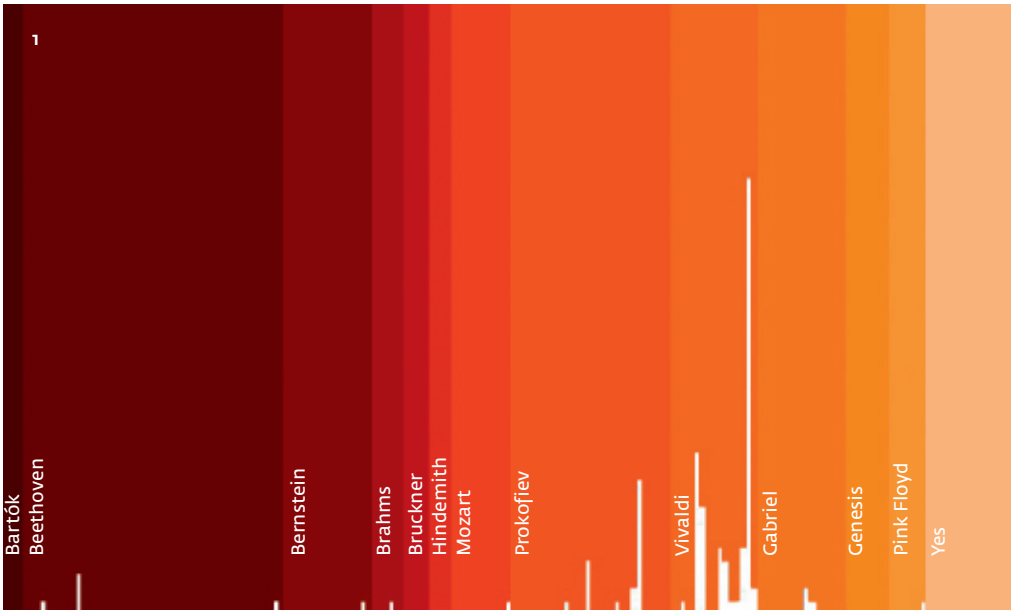
"The fact that the system can tell different composers apart is probably due to the typical instruments used and other sound characteristics of the individual composers," believes Bunk. "Melodies are not important because the analysis uses a timescale that is shorter than the melody formation." The audio snippets analyzed are simply too short to allow inferences to be drawn about the melody.

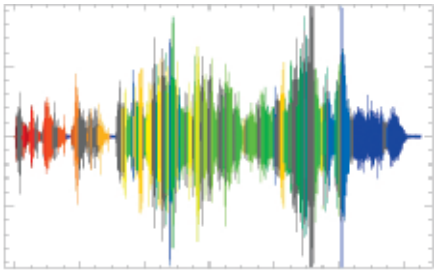
The great art consists in selecting the right representatives for a piece of music. "Spectra chosen at random do not usually contain the necessary information," says Bunk. "What is needed is a method for identifying the best fingerprints." This is where the competence of the Garching-based researchers comes into play – since astrophysics uses sophisticated methods of data analysis and statistics to interpret measured data. >

Illustration: MPI for Extraterrestrial Physics



A point and its environs: In a simulated galaxy distribution, the scientists study the structure with the help of the scaling index method. Starting from the point of intersection of the coordinate system, they determine the galaxy distribution N as a function of the radius R. From the graph at top right, they identify the scaling behavior. The procedure is repeated for each point and allows conclusions to be drawn about the distribution pattern.





Music in color: In this excerpt from Vivaldi's *Four Seasons*, prototypical sound characteristics are marked in color.

The scientists originally planned to develop measures for the inhomogeneous distribution of matter in the universe. Astronomers use observation data, for example from telescopes or satellites, to help them reconstruct the visible universe – that is, the distribution of galaxies and clusters of galaxies – in three dimensions. This is the basis for assessing the quality of different cosmological models by means of observations. Their aim is not to compare the positions of individual stars in theory and in reality. "We are more interested in a statistical comparison of the large-scale distribution of cosmological structures between the model and observations," says Bunk. "This automatically raises the question of how global properties of point distributions can be characterized."

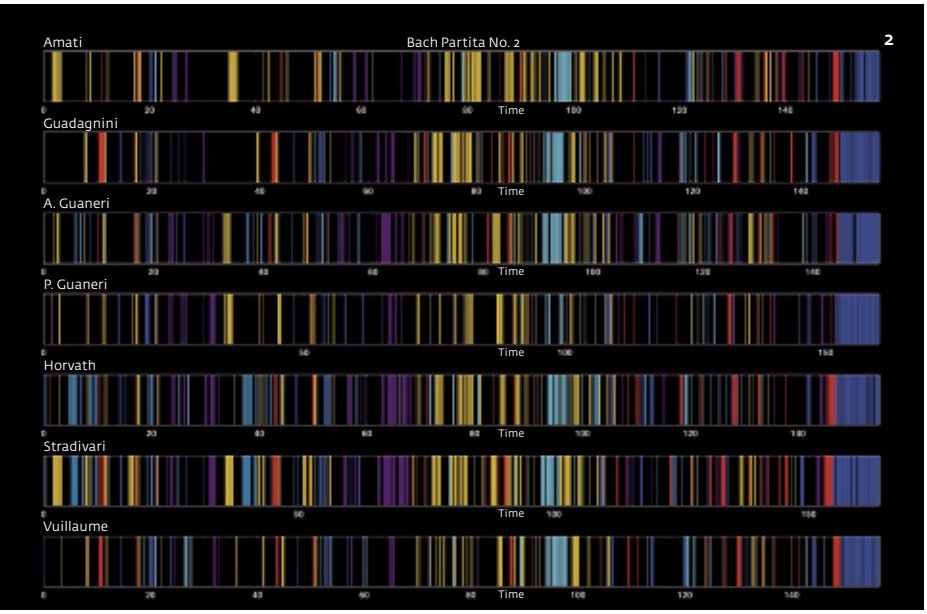
A PATTERN GIVES AN INDICATION OF ITS CAUSE

This sounds abstract, but can easily be transferred to everyday experiences. Bunk rephrases the principle as follows: "If grains of sand are distributed in different ways over a surface, driven by water or wind, for example, characteristic patterns evolve. It is totally irrelevant where the individual grains are – what counts are the global characteristics of these patterns that can then be used to ascertain how the sand grains were distributed." In this way, in astrophysics, researchers can compare the results of different cosmological theories that differ, for example, in their models for the gravitational force or the contributions from dark matter and dark energy.

These comparisons have their basis in mathematical disciplines such as statistics, information theory, topology, group theory and graph theory. Bunk and his colleagues use these methods to develop new ways of gathering information, or mining data – data mining is another name for pattern recognition, or the recognition of rules in extensive data sets. Since the subject is so important in its theoretical and practical ramifications, a total of seven staff members at the Max Planck Institute in Garching are engaged in this field.

The scaling index method is one of the various methods the Max Planck researchers use to characterize patterns – a method they developed and have since patented. Researchers can use it to break down a point distribution into clusters according to its dimensionality. The dimension of these clusters is expressed by the scaling index alpha: "A compact clustering of points at a certain position yields a value

Illustrations: MPI for Extraterrestrial Physics (2)



1 That can only be Vivaldi: The white bars signalize the greatest concordance with the Baroque composer, but also similarities with Prokofiev.

2 Bar code for string music: A soloist plays a Bach partita with seven different violins. The characteristic sound properties result in similar patterns of colored bars.

close to zero," explains Bunk. "A line consisting of points yields a value close to one – and so on." A purely random distribution of points always results in an alpha value that is the dimension of the space in which it is embedded – so if the points are arbitrarily distributed on a two-dimensional plane, alpha has the value two. "We then characterize the patterns by analyzing the frequency distribution of the scaling indices, which can be interpreted as a type of structural spectrum," explains Wolfram Bunk. In this way, cosmological structures can be resolved into different structural elements, for example.

From a mathematical point of view, digitalized multimedia data also consist of point distributions that can be analyzed with the aid of pattern recognition. Consequently, it is possible to use astrophysical methods to remove, or at least reduce, interfering noise from images or music. In the statistical sense, it can be determined whether each pixel of an image belongs to a structure – the real signal – or represents pure noise, for example. "The noise pixels can thus be removed and an interpolation or other methods can be used to at least partially reconstruct the image or a photo from the remaining pixels," explains Bunk, who immediately demonstrates the point and frees the picture of a pretty woman from its interfering junk data. "Other applications can be found in automotive manufacturing, such as characterizing the roughness of cylinder surfaces in combustion engines."

And also in the analysis of music: In this case, the researchers use a clustering method and analyze sound spectra instead of the structural spectra. After the computer has broken down the short audio snippets into their individual frequency spectra, it calculates specific distance measures between the spectra. This shows how similar or dissimilar they are. They are then subdivided into classes – clusters whose members are similar. A representative can now be selected from each cluster. In this way, a complete piece of music can be represented by a sequence of characteristic sounds as they are used in the recognition algorithm, and its sound structure can be characterized and recognized.

But the digital sound expert can do more than just identify the composer of unknown works. If a work is already in the database, the computer recognizes it even when it is a different interpretation. The researchers can also use audio fingerprinting to distinguish between different conductors – the system can even identify the violins of famous instrument makers. It also supplies many other surprising insights: a piece by Vivaldi causes the bars to flicker not only for Prokofiev, but also for the rock group Pink Floyd; and Brahms also causes movement with Genesis and Peter Gabriel. It seems there have been unexpected similarities over the centuries – which no one would likely have realized without audio fingerprinting.

MUSIC RECOGNITION IDENTIFIES TV COMMERCIALS

"Although there is as yet no commercial partner for the system, it has been tested in automatically recognizing TV advertisements by their soundtrack alone," says Bunk. Something that has strong practical use – after all, TV advertising customers would like to know whether their expensive commercials have actually been aired. At present, this is monitored by individuals who must spend hours watching videotapes in fast-forward mode. In the future, this monotonous task can be performed by computers and pattern recognition. "The system could later also be used for voice recognition, for example for access control," says Bunk. The police are also interested in the technology – the

Illustration: MPI for Extraterrestrial Physics

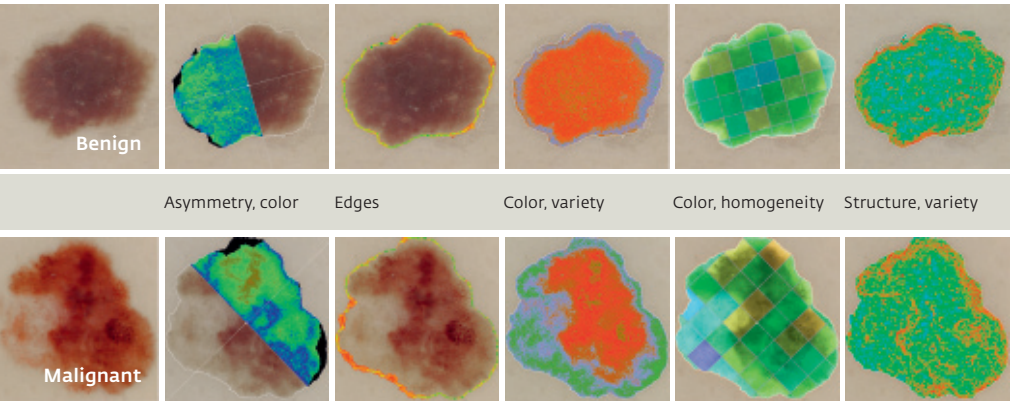
» Characteristic properties can be extracted from pieces of music – similar to fingerprints, which are typical of a particular person.

Bavarian State Criminal Police Office (LKA) has already contacted the team in Garching, but it is not yet clear whether audio fingerprinting can actually be used to identify the voices of suspects.

The system has, however, provided tangible benefits in medicine for many years: pattern recognition from Garching helps dermatologists identify melanomas in time. Currently, doctors usually use a dermatoscope, a reflected-light microscope with tenfold magnification, for preventive checkups. "But even with the dermatoscope, diagnosis is difficult – the dermatologist still needs a lot of experience," explains Wilhelm Stolz, Senior Consultant at the clinic for dermatology, allergology and environmental medicine at Munich-Schwabing Municipal Hospital. "This is mainly a problem for doctors who see fewer than 10 to 20 patients with a melanoma per year." Moreover, it is not always entirely clear whether a mark on the skin is malignant or benign. "Some patients also have a large number of moles that cannot all be removed as a prophylactic measure," says Stolz.

Here, pattern recognition can help make the results more objective and avoid unnecessary surgeries. Working with computer scientist Wolfgang Abmayr from the University of Applied Sciences – München and experts from the Max Planck Institute, Stolz has therefore developed the DermoGenius: a video camera that takes pictures of the suspicious skin areas and transmits them to a computer that uses pattern recognition to identify melanomas. Important characteristics of the malignant tumors are asymmetry, a large number of different colors, and a variety of structural components. They are analyzed by the computer, which then supplies a diagnosis with a sensitivity of 95 percent. A further advantage of the DermoGenius is that the temporal development of suspicious skin pigment alterations can be traced, since all images are saved and can be compared quantitatively.

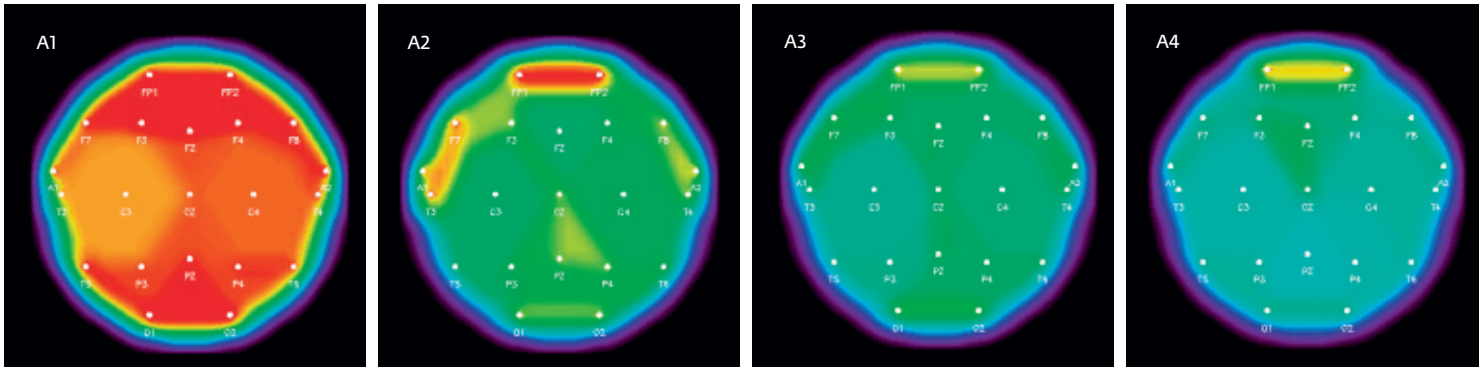
A malignant melanoma differs from a benign alteration in numerous traits: in the variety of structure and color, the homogeneity and asymmetry of the color and the appearance of the edges.



ELECTRONIC ASSISTANT WITH POWERS OF PERSUASION

"An expert is always as good as the DermoGenius, but the computer is usually better than a less experienced doctor," says Stolz, describing the usefulness and limits of the system. "In some cases, it is also easier to persuade a patient to agree to an excision if, in addition to the doctor, the computer also provides an unambiguous diagnosis." However, in cases of doubt, a person must always decide; the computer plays only a supporting role. The system is thus particularly interesting for dermatologists with their own offices: in a hospital, it is usually easy for the doctor to consult

Photo: MPI for Extraterrestrial Physics



Successful therapy: In epilepsy the nerve cells in different areas fire in synch (red). In the course of treatment this synchronization diminishes markedly (blue).

a colleague and ask for his or her opinion; when this isn't possible, the DermoGenius is an available expert in the form of a computer. The instrument is currently being manufactured by Biocam in Regensburg, and is already employed in many doctors' offices.

Another very promising development from Garching is not yet that advanced, but it is well on the way: For a number of years, the researchers have been working with Stephan Springer, a specialist in child and youth psychiatry and psychotherapy at the Heckscher Clinic in Munich, on the analysis of electroencephalograms (EEG). "The visual evaluation of an EEG with about 16 to 20 channels has limitations, because the signal is a discontinuous mixture of different frequencies, patterns and event-correlated graphoelements," explains Springer. "But it's remarkably suitable for a mathematical analysis."

It can assist in evaluating signal characteristics that a person cannot perceive visually. In an EEG, there is a basic activity with a frequency of about 10 hertz, and many other frequencies that result in a very confusing overall image. "After many years of experience, a doctor can develop a "feel" for frequency changes, frequency mixing and patterns, and then, at best, notice stronger deviations, while smaller changes cannot be detected visually," says Springer. In the minutes before an epileptic seizure, for example, the oscillation amplitude becomes smaller, while the frequency increases. This indicates that inhibitions are being reduced in the brain and a seizure is developing, possibly connected with unconsciousness. The most important goal of earlier mathematical EEG analyses was to extend the time for predicting a seizure.

STRIKING INTERACTION BETWEEN BRAIN HEMISPHERES

The first step of the collaboration with Wolfram Bunk and his colleagues involved analyzing the EEGs of a twelve-year-old patient from whom many EEG recordings over several years were available. He suffered from frontal lobe epilepsy, which is persistent and very difficult to treat. Moreover, with this type of epilepsy, the doctors can visually identify very little between seizures. It was thus obvious to look for conspicuous patterns in the brain waves measured, and to link them to the development of the clinical picture that the doctors had arrived at.

A successful move: "The investigations have shown that, in this patient, the interactions between the left and the right cerebral hemispheres revealed distinct changes compared with a group of children with no symptoms," reports Springer. Strong interactions between the front and rear cerebral regions are normal – presumably because they are connected by numerous nerves. There are only a few defined paths between the two hemispheres of our brain, however, and this is why the unusual activities point to a connection to epilepsy. "The fact that it would not have been possible to recognize these interactions visually makes pattern recognition very valuable," says the expert, and points to further evidence: "The occurrence and the decline of the conspicuous events happened at approximately the same time as the occurrence and the improvement of the severe psychiatric abnormalities connected with the epilepsy."

The next step will be to investigate three different groups consisting of around 20 young patients each: healthy children, children with autism and children with epilepsy and autism. Autistic children are much more likely to suffer from epilepsy than healthy children, and the doctors now hope that pattern recognition will help them speed up the identification of the correct therapy – to treat both the epileptic seizures and the accompanying symptoms. First results are expected starting this fall.

BETTER CONTROL OVER THERAPY

Apart from new insights concerning the neurophysiological causes of the symptoms, the doctors also expect to be better able to control the success of an epilepsy therapy. "At present, there is a choice of more than 20 different

Photo: MPI for Extraterrestrial Physics

» Pattern recognition has proven to be an ideal diagnostic tool for epilepsy – better than other approaches that have previously been tried in this field.

medications, and the optimum combination of active ingredients must be found for each individual patient," explains Springer. "Today, it usually takes several months to optimize the therapy." For the children concerned, this means that their quality of life suffers and that they miss out on important learning phases. And if the therapy is not ideal, the young patients also suffer from side effects, such as a reduced ability to speak, concentration problems and emotional difficulties.

In the future, pattern recognition can also be used to examine adults. The conditions here are even easier. Children's brains are still maturing during their development, which causes the EEG to change as well. This is not the case with adults. "To sum things up, it can be said that pattern recognition methods have proven to be an ideal diagnostic tool compared with other approaches that have previously been tried in this field," says Springer. One advantage of the method is that it is also relatively unaffected by artifacts – that is, variations in the EEG that are caused, for example, by movements of the patient and that have nothing to do with an epileptic seizure.

So what does astrophysics have in common with Beethoven or even with epilepsy? It sounds like a riddle – but it is one that the Garching-based researchers are solving in two ways. Pattern recognition is in demand in many fields, and it reveals hidden similarities – not only between Vivaldi and Prokofiev. ◂

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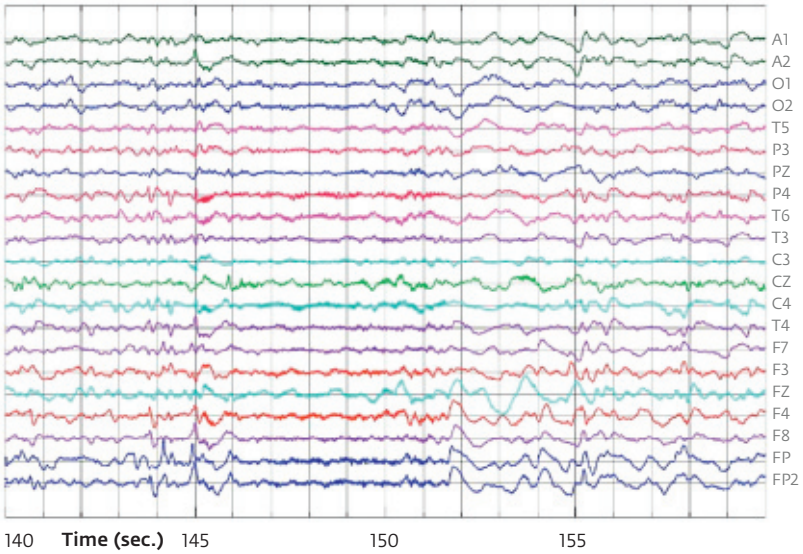

Even an experienced doctor will find it difficult to recognize the pattern of an imminent epileptic seizure on the EEG. Methods developed by the astrophysicists in Garching will help improve prediction somewhat.

GLOSSARY

Pattern recognition
Looks for regularities, repetitions or similarities in a large volume of data describing things like planar, spatial or acoustic structures.

Scaling index method
The scaling index indicates how points in a given area are distributed. The frequency distribution of the scaling index characterizes the pattern.

Clustering method
Audio snippets of a composer, for instance, are clustered into similar sound spectra. An unknown piece of music is compared with representatives of the clusters.

Electroencephalography (EEG)
Electrodes attached to the head measure voltage fluctuations on the surface of the head. These measurements give an indication of the electrical activity in the brain.

Illustration: MPI for Extraterrestrial Physics