Four Scientific Approaches to Pattern Recognition

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Abstract

Two opposite ways to build a scientific description of the world are the Platonic and Aristotelean approaches. In the area of pattern recognition they may be applied to both, external examples, as well as to our own internally observed recognition abilities. Consequently, four scientific approaches to pattern recognition may be distinguished. They are explained here and illustrated by some examples. Finally, a few problems and fruits of their interaction are discussed.

1. Introduction

Pattern recognition is the ability to generalize from observations. We see an object with a particular shape, color and flavour and know that it is an apple. Thereby we generalize from the specific observation {*shape, color, flavour*} to the general concept of *apple*. On a higher level we find the ability to *learn* a concept from a set of examples. For instance, after we have visited some Roman and Gothic churches and inspected their architectures, we are able to recognize other churches in these categories. It may be helpful when somebody points us out what are the Roman churches and what are the Gothic ones, but even without that we may find the existence of these two categories and build up a good feeling of the underlying concepts.

The ability of pattern recognition is primarily human as it is related to the recognition or definition of a concept. This holds even more strongly for the construction of artificial pattern recognition systems. They simulate the ability by the creation of a physical model. Within a given, restricted application, however, such an artificial system may be preferred over mobilizing humans because of speed, accuracy, robustness, etcetera. The *technical realization* of artificial pattern recognition devices may thereby have economic and social advantages. The *design* of such systems demands scientific knowledge of the human pattern recognition ability. Moreover, the realization and evaluation of the use of such systems may increase this knowledge further.

The above shows that a distinction can be made between the scientific study of pattern recognition as the ability to generalize from observations and the applied technical area of the design of artificial pattern recognition devices, without neglecting the fact that each one may highly profit from the other. In this paper we will focus on the scientific aspects, i.e. how we may gain knowledge on the way pattern recognition systems work and how descriptions can be made such that these may be used for building artificial recognition devices.

In this paper we will discuss and relate some possible well-known scientific approaches to pattern recognition. In particular we like to point out how these approaches differ due to fundamental differences in the scientific points of view from which they arise. As a consequence they are often studied in distinct traditions based on different paradigms. We will try clarify the under-

lying cause for the pattern recognition field. The reader should realize that these are still unfinished thoughts that may grow further in discussions. It is the purpose of this paper to stimulate that.

In science new knowledge is phrased in terms of existing knowledge. The starting point of this process is set by generally accepted, evident views or facts that cannot be explained further. These fundaments, however, are not the same for all researchers. Different types of approaches may be distinguished that are caused by differences in starting points. It is almost a type of taste from where a particular researcher starts. As a consequence different 'schools' may arise. At the end, however, someone may try to integrate scientific results originating from different approaches into a single pattern recognition device. Sometimes it causes confusion how these results can be combined and where they essentially differ. Sometimes the combination of results of different approaches appears to be fruitful, not only for the technical realization, but also for the scientific understanding by the researcher that broadens his horizon of allowable starting points.

In this paper we will describe four approaches to pattern recognition. They arise from two different dichotomies of starting points, described in the sections 2 and 3. In section 4 the four resulting approaches are described. Next some examples will be discussed illustrating the problems of the interaction of different approaches.

2. The Platonic and the Aristotelean viewpoints

The main difference in starting points for almost each scientific area are the so called Platonic and the Aristotelean view points. In a first attempt they may be understood as top-down and bottom-up ways of building knowledge.

The *Platonic approach* starts from generally accepted concepts and global ideas of the world. They constitute a coherent picture in which many details are not yet defined. The primary task of the researcher using this approach is to recognize in his observations of the world the underlying concepts and ideas that are already accepted by him. Many theories of the creation of the universe or the world are based on this, e.g. the drifts of the continents or the dieing out of the mammoths: it is not the result of reasoning starting from observations, but merely a more or less convincing global theory (depending on the listener!) that seems to extrapolate far beyond the hard facts. For the Platonic researcher, however, it is not an extrapolation, but an adaptation of previous versions of the theory to new facts. That is the way this approach works: existing ideas, used for a long time, are gradually adapted to new incoming observations. This is not based on an essential change, but on finding better, more appropriate definitions and explanations. On the highest level theories remain as they are for a long time. What changes is how observations are explained by them.

In the Aristotelean approach the observations are of primary interest. Scientific descriptions stay as closely as possible to them. It is avoided to speculate on larger, global theories that go beyond the facts. The observations are always the ground from which the researcher builds his knowledge. Consequently, his theories are not global, nor do they constitute high level descriptions.

A famous guideline in this approach is the so-called Occam's razor: avoid theories that are more complex than strictly needed for explaining the observations. Arguments may arise, however, on what is more complex, as this depends, for instance, on the type of mathematics that is used.

The choice for a particular approach is free, or, if one likes, determined on non-scientific, for instance political grounds. Nobody can judge for somebody else what his basic truth is. Against the Aristoteleans may be held that they don't see the big picture. The Platonic researchers on the other hand, may be blamed for building castles in the air.

3. The internal and the external theatre

The research topic of the science of pattern recognition, i.e. the generalization of observations, is highly connected to science itself. Science is in the end a brief explanation summarizing the observations, i.e. a generalization of them. Such an explanation may primarily be observed by the researcher in his own thinking. Pattern recognition research can thereby be performed by introspection. The researcher inspects himself how he generalizes from observations. The basis of this generalization is constituted by the primary observations. This may be an entire object ('I just see that it is an apple') or its attributes ('it is an apple because of its color and shape').

The second theatre in which pattern recognition can be observed is by inspecting others while they perform a pattern recognition task, e.g. when they recognize an apple. Now the researcher tries to find out by experiments and measurements how the subject decides for an apple on the basis of the stimuli presented to his senses. He thereby builds a model of the entire subject, from senses until decision making.

Both approaches result into a model. In the external approach, however, the senses may be included in this model. In the internal approach this is not possible, or just very partially. We are usually not aware of what happens in our senses. Introspection thereby start by what they offer to our thinking. As a consequence, models based on the internal approach have to be equipped externally with (artificial) senses, i.e. with sensors.

4. Four Approaches

Combining the two dichotomies as presented in the sections 2 and 3 the following four approaches can be distinguished.

1. Introspection by a Platonic viewpoint. We will call this the *spiritualistic* approach.
2. Introspection by an Aristotelean viewpoint. We will call this the *realistic* approach.
3. Extrospection by an Aristotelean viewpoint. We will call this the *materialistic* approach.
4. Extrospection by a Platonic viewpoint. We will call this the *idealistic* approach.

These four approaches will now be discussed separately in the following subsections. We will identify some known procedures and techniques that may be related to these. See also the figure on the next page.

4.1 The spiritualistic approach

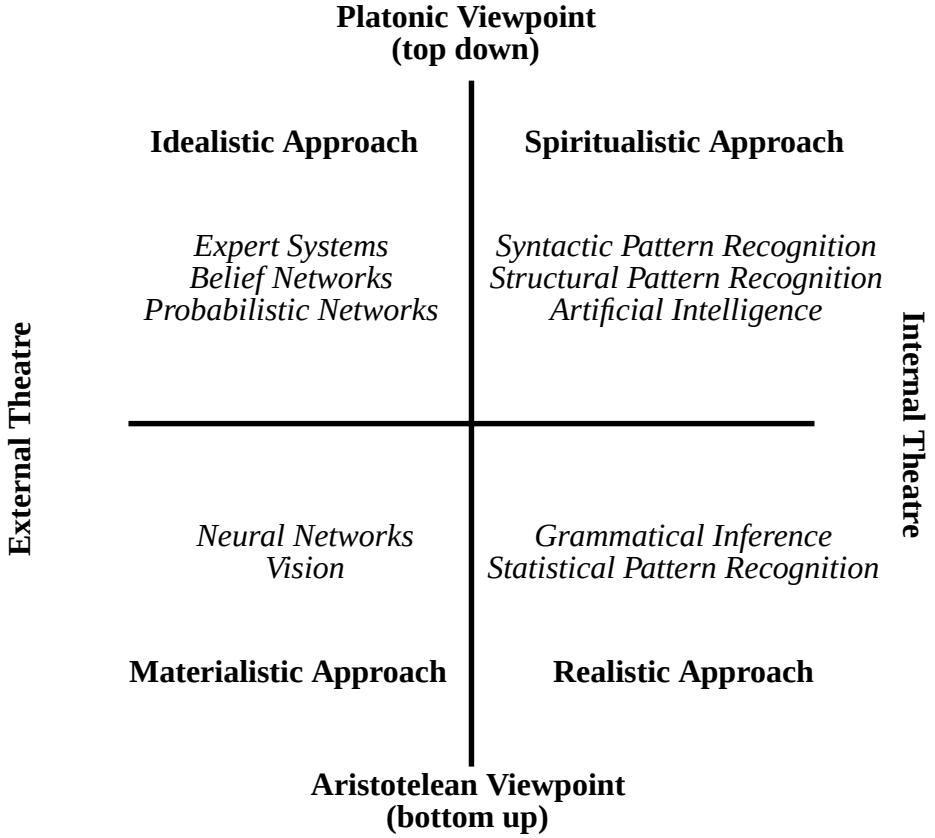
This is defined as introspection from a Platonic viewpoint. The researcher thereby starts from global ideas on how pattern recognition systems may work and tries to verify them in his own thinking and reasoning. He thereby may find, for instance, that particular color / shape combi-

nations are sufficient for him to decide for an apple. More generally he may discover that he uses particular reasoning rules operating on a fixed set of possible observations. The so called *syntactic* and *structural* approaches to pattern recognition thereby belong to this area, as well as *artificial intelligence* in its restricted definition of artificial reasoning. (We realize that sometimes a much broader definition is used in which the superset of all approaches discussed here, constitutes just a subset of artificial intelligence).

4.2 The realistic approach

If the researcher leaves the Platonic viewpoint and concentrates on observations, but still uses introspection, he wonders what he should do with just a set of observations without any framework. An important shift that is related with this is the nature of observations. Observations as 'round', 'egg-shaped' or 'gold colored' may be judged as recognitions in themselves. A researcher trying to understand the process of recognition needs to explain these high level observations from more low-level outcomes of senses. He is, however, not able to observe them directly. One possibility is to study the outcomes of artificial senses, i.e. of sensors. He now may decide to study how he would generalize from their numerical outcomes. Most likely this is not physiologically correct, but this is unimportant from the internal viewpoint, as the researcher still observes how he himself generalizes from low level observations.

Generalization from numbers is traditionally done by statistics. The realistic approach thereby includes the area of *statistical pattern recognition*. If the low-level inputs are not expressed in numbers, but in attributed observations as 'red, egg-shaped', then the generalization may be based on *logical* or *grammatical inference*. As soon, however, as the structure of objects or at-



tributes is not generated from the observations, but derived (postulated) from a formal global description of the application knowledge, e.g. using *graph matching*, the approach is effectively top-down and thereby spiritualistic or idealistic.

4.3 The materialistic approach

We now leave the internal theatre and concentrate on research that is based on the external study of the pattern recognition abilities of humans or their brains and senses. If this is done in a bottom-up way, the Aristotelean approach, then we are in the area of low-level modelling of senses, nerves and possibly brains. These models are based on the physical and physiological knowledge or cells and the proteins and minerals that constitute them. This is thereby called the materialistic approach.

Senses themselves usually don't directly generalize from observations. They may be constructed, however, in such a way that on a higher level this process is strongly favoured. For instance, the way the eye, and in particular the retina is constructed, is advantageous for the detection of edges and movements and for finding interesting details in the global, overall picture. The area of *vision* thereby profits from this approach.

On a level more close to the brain it is studied how nerves process the signals they receive from the senses. Somehow this is combined to a generalization of what is observed by the senses. Models of systems of multiple nerves are called *neural networks*. They appeared to have a good generalization ability and are thereby also used in technical pattern recognition applications in which the physiological origin is not relevant.

4.4 The idealistic approach

When we go up in the external theatre and replace the observations as the starting point by ideas, we are in the area of the idealistic approach. Here one still tries to model externally given pattern recognition systems, but now in a top-down manner. An example is the field of *expert systems*: by interviewing experts in a particular pattern recognition task, it is attempted to investigate what rules he uses and in what way he is using observations. Also *belief networks* and *probabilistic networks* belong to this area as far as they are defined by experts and not learned from observations.

The idealistic approach can be distinguished from the materialistic approach by the fact that it is in no way attempted to model the system in a physical or physiological realistic way. The building blocks are the ideas, concepts and rules, as they live in the researcher. They are adapted to the application by external inspection of an expert. If this is done by the researcher internally by introspection, we have closed the circle and are back at the spiritualistic approach.

5. Examples of interaction

The four approaches presented in the previous section are four ways to study the science of pattern recognition. Resulting knowledge is valid for those who share the same starting point. If the results are used for building artificial systems then there is, of course, no reason to restrict oneself to a particular approach. Any model that works may be useful. There are, however, certain

problems in combining different approaches. These may be caused by differences in culture, in assumptions, in targets, etcetera. We will restrict to two examples, one for each of the two dichotomies.

The neural networks as developed by the materialistic approach constitute a technique that within the area of statistical pattern recognition (in the realistic approach) can be used as an alternative for the traditional classification methods. It took, however, almost ten years before neural networks were fully appreciated in statistical pattern recognition after their introduction around 1985. During the same period the neural network community suffered from lack of knowledge of the competing classification procedures. One of the basic misunderstandings in the realistic approach was its dominating paradigm stating that learning systems should never be larger than strictly necessary, following the principle of Occam's razor. It could not be understood how largely oversized systems as neural networks would ever be able to generalize and did not start to adapt themselves to peculiarities in the data (so-called overtraining). In the neural network community it was during the same period evident that the larger the neural network the better, as a brain with more neurons would perform better in learning than a brain with less. When this contradiction was finally solved, the area of statistical pattern recognition was enriched with a new set of tools. Moreover, some principles could be formulated from which pattern recognition can be understood, that would only have been found otherwise with great difficulties.

In general it may be expected that the internal approach profits from results in external world. It is possible that thinking, the way we generalize from observations, changes after it is established how this works in nature. For instance, once we have learned how a specific expert solves his problems, this may be used more generally and thereby become a rule in structural pattern recognition. The entire external theatre may thereby be used to enrich the internal one.

A direct fertilization between the Platonic and Aristotelean approaches is very difficult. It is still one of the major challenges in science as a whole to formalize the growth of existing knowledge by new observations. This is similar to the problems in computing the macroscopic effects due to changes in the microscopic physical description. The computational complexity of an integration of higher level knowledge due to low level observations is enormous. The cause is that we hardly ever find sufficient observations and the power to combine them such that the result may compete with the high level knowledge we already have. There is, however, also a more fundamental problem: how can we express the uncertainty in higher level knowledge in such a way that it may be changed (upgraded?) by low level observations? Put it differently: knowledge is very often structural and has thereby a qualitative nature, while on the lowest level observations are often treated as quantitative.

6. Discussion

At the end, a basic difficulty should be pointed out. Pattern recognition as defined by generalization from observations is in fact an Aristotelean process. The question may be raised whether this can be really understood from the Platonic viewpoint: is it really possible to understand how this works from the starting point of global ideas, so from generalization themselves? If we go back to the examples that are given in the sections on the spiritualistic and idealistic approaches, like structural pattern recognition and expert systems, then it has to be concluded that they don't

describe the generalization process, but merely how to use a given generalization (internally or externally) for handling new observations. It is the authors belief that there is a fundamental difficulty for the Platonic soul to gain a scientific understanding of the pattern recognition ability.

The main point of this paper is to make clear that, like everywhere else in science, also in the science of pattern recognition different approaches may exist. These approaches describe the process of generalization from observations in different ways using different starting points. There is no right or wrong, no better or worse in adopting an approach. These starting points are equally valid. Considered as a whole they may result in more understanding. At the moment, however, the focus is changed from a scientific understanding to the application of the scientific results, i.e. to the construction of artificial pattern recognition devices, then, depending on the application, different approaches may be preferred. In that case, one approach may be better suited than another.

This discussion is based on a presentation by the author that appeared already partially in print [1]. This printed version, however, just contained the technical issues of the presentation. The more philosophical ones are published here for the first time. The author has pointed out on several occasions that there is a fundamental difference in approach between the traditional statistical pattern recognition field and the neural network area, e.g. see [2]. The problem of the integration of knowledge based systems with those that learn from observations has been described by Perlovsky [3]. He and also Watanabe [4] point out the differences between the Platonic and Aristotelean viewpoints. The names given here, in section 4, to the four approaches, are inspired by a lecture of Rudolf Steiner [5]. The parallel existence of different, equally valid scientific approaches is directly related to the concept of paradigms as introduced by Kuhn [6].

7. Acknowledgement

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8. References

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