Some Contributions by Zdzisław Pawlak

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Commemorating the life and work of Zdzisław Pawlak[⋆]

If we classify objects by means of attributes,
exact classification is often impossible.
– Zdzisław Pawlak, January 1981.

Abstract. This article celebrates the creative genius of Zdzisław Pawlak. He was with us only for a short time and, yet, when we look back at his accomplishments, we realize how greatly he has influenced us with his generous spirit and creative work in many areas such as approximate reasoning, intelligent systems research, computing models, mathematics (especially, rough set theory), molecular computing, pattern recognition, philosophy, art, and poetry. Pawlak's contributions have far-reaching implications inasmuch as his works are fundamental in establishing new perspectives for scientific research in a wide spectrum of fields. His most widely recognized contribution is his brilliant approach to classifying objects with their attributes (features) and his introduction of approximation spaces, which establish the foundations of granular computing and provides an incisive approach to pattern recognition. This article attempts to give a vignette that highlights some of Pawlak's remarkable accomplishments. This vignette is limited to a brief coverage of Pawlak's work in rough set theory, molecular computing, philosophy, painting and poetry. Detailed coverage of these as well as other accomplishments by Pawlak is outside the scope of this commemorative article.

1 Introduction

This article commemorates the life, work and creative genius of Zdzisław Pawlak. He is well-known for his innovative work on the classification of objects by means of attributes (features) and his discovery of rough set theory during the early

⋆ Professor Zdzisław Pawlak passed away on 7 April 2006.

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1980s (see, e.g., [7,19,24]). Since the introduction of rough set theory, there have been well over 4000 publications on this theory and its applications (see, e.g., [33,35]). One can also observe a number of other facets of Pawlak's life and work that are less known, namely, his pioneering work on genetic grammars and molecular computing, his interest in philosophy, his lifelong devotion to painting landscapes and waterscapes depicting the places he visited, his interest and skill in photography, and his more recent interests in poetry and methods of solving mysteries by fictional characters such as Sherlock Holmes. During his life, Pawlak contributed to the foundations of granular computing, intelligent systems research, computing models, mathematics (especially, rough set theory), molecular computing, knowledge discovery as well as knowledge representation, and pattern recognition.

This article attempts to give a brief vignette that highlights some of Pawlak's remarkable accomplishments. This vignette is limited to a brief coverage of Pawlak's works in rough set theory, molecular computing, philosophy, painting and poetry. Detailed coverage of these as well as other accomplishments by Pawlak is outside the scope of this commemorative article.

The article is organized as follows. A brief biography of Zdzisław Pawlak is given in Sect. 2. Some of the very basic ideas of Pawlak's rough set theory are presented in Sect. 3. This is followed by a brief presentation of Pawlak's introduction of a genetic grammar and molecular computing in Sect. 4. Pawlak's more recent reflections concerning philosophy (especially, the philosophy of mathematics) are briefly covered in Sect. 5. Reflections on Pawlak's lifelong interest in painting and nature as well as a sample of paintings by Pawlak and a poem coauthored by Pawlak, are presented in Sect. 6.

2 Zdzisław Pawlak: A Brief Biography

Zdzisław Pawlak was born on 10 November 1926 in Łódź, 130 km south-west from Warsaw, Poland [40]. In 1947, Pawlak began studying in the Faculty of Electrical Engineering at Łódź University of Technology, and in 1949 continued his studies in the Telecommunication Faculty at Warsaw University of Technology. Starting in the early 1950s and continuing throughout his life, Pawlak painted the places he visited, especially landscapes and waterscapes reflecting his observations in Poland and other parts of the world. This can be seen as a continuation of the work of his father, who was fond of wood carving and who carved a wooden self-portrait that was kept in Pawlak's study. He also had extraordinary skill in mathematical modeling in the organization of systems (see, e.g., [17,21,25]) and in computer systems engineering (see, e.g., [13,14,15,16,18]). During his early years, he was a pioneer in the designing computing machines. In 1950, Pawlak constructed the first-in-Poland prototype of a computer called GAM 1. He completed his M.Sc. in Telecommunication Engineering in 1951. Pawlak's publication in 1953 on a new method for random number generation was the first article in informatics published abroad by a researcher from Poland [10]. In 1958, Pawlak completed his doctoral degree from the Institute of Fundamental Technological

Research at the Polish Academy of Science with a Thesis on *Applications of Graph Theory to Decoder Synthesis*. In 1961, Pawlak was also a member of a research team that constructed one of the first computers in Poland called UMC 1. The original arithmetic of this computer with base "-2" was due to Pawlak [11]. He received his habilitation from the Institute of Mathematics at the Polish Academy of Sciences in 1963. In his habilitation entitled *Organization of Address-Less Machines*, Pawlak proposed and investigated parenthesis-free languages, a generalization of polish notation introduced by Jan Łukasiewicz (see, e.g., [13,14]).

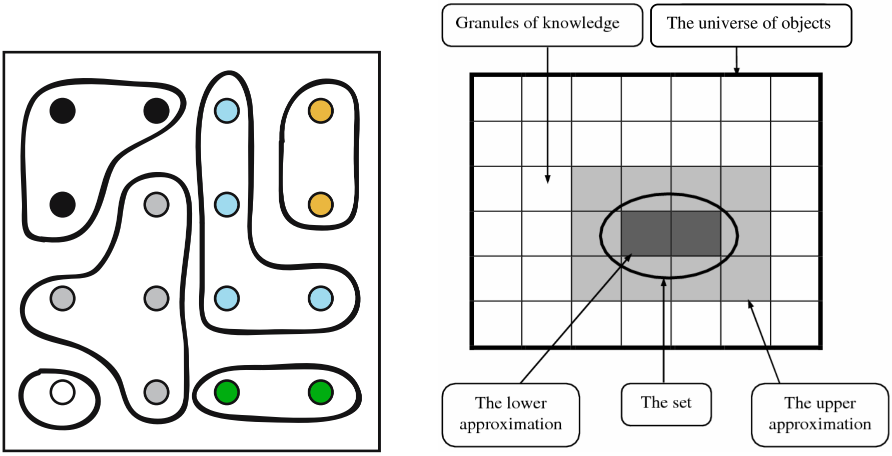
In succeeding years, Pawlak worked at the Institute of Mathematics of Warsaw University and, in 1965, introduced foundations for modeling DNA [12] in what has come to be known as molecular computing [3,12]. He also proposed a new formal model of a computing machine known as the Pawlak machine [18,20] that is different from the Turing machine and from the von Neumann machine. In 1973, he introduced knowledge representation systems [19] as part of his work on the mathematical foundations of information retrieval (see, e.g., [7,19]). In the early 1980s, he was part of a research group at the Institute of Computer Science of the Polish Academy of Sciences, where he discovered rough sets and the idea of classifying objects by means of their attributes [22], which was the basis for extensive research in rough set theory during the 1980s (see, e.g., [5,6,8,23,24,26]). During the succeeding years, Pawlak refined and amplified the foundations of rough sets and their applications, and nurtured worldwide research in rough sets that has led to over 4000 publications (see, e.g., [35]). In addition, he did extensive work on the mathematical foundations of information systems during the early 1980s (see, e.g., [21,25]). He also invented a new approach to conflict analysis (see, e.g., [27,28,30,31]).

During his later years, Pawlak's interests were very diverse. He developed a keen interest in philosophy, especially in the works by Łukasiewicz (logic and probability), Leibniz (*identify of indiscernibles*), Frege (membership, sets), Russell (antinomies), and Leśniewski (*being a part*)). Pawlak was also interested in the works of detective fiction by Sir Arthur Conan Doyle (especially, Sherlock Holmes' fascination with data as a basis for solving mysteries) (see, e.g., [32]).

Finally, Zdzisław Pawlak gave generously of his time and energy to help others. His spirit and insights have influenced many researchers worldwide. During his life, he manifested an extraordinary talent for inspiring his students and colleagues as well as many others outside his immediate circle. For this reason, he was affectionately known to some of us as Papa Pawlak.

3 Rough Sets

A brief presentation of the foundations of rough set theory is given in this section. Rough set theory has its roots in Zdzisław Pawlak's research on knowledge representation systems during the early 1970s [19]. Rather than attempt to classify objects *exactly* by means of attributes (features), Pawlak considered an approach to solving the object classification problem in a number of novel ways. First, in



1.1: Blocks of Objects 1.2: Sample Set Approximation

Fig. 1. Rudiments of Rough Sets

1973, he formulated knowledge representation systems (see, e.g., [7,19]). Then, in 1981, Pawlak introduced approximate descriptions of objects and considered knowledge representation systems in the context of upper and lower classification of objects relative to their attribute values [22,23]. We start with a system $S = (X, A, V, \delta)$, where X is a non-empty set of objects, A is a set of attributes, V is a union of sets V_a of values associated with each $a \in A$, and δ is called a knowledge function defined as the mapping $\delta : X \times A \to V$, where $\delta(x, a) \in V_a$ for every $x \in X$ and $a \in A$. The function δ is referred to as *knowledge function* about objects from X. The set X is partitioned into elementary sets that later were called blocks (see, e.g., [9,38]), where each elementary set contains those elements of X which have matching attribute values. In effect, a block (elementary set) represents a granule of knowledge (see Fig. 1.2). For example, the elementary set for an element $x \in X$ is denoted by $B(x)$, which is defined by

$$B(x) = \{y \in X | \; \forall a \in A \; \delta(x, a) = \delta(y, a)\} \tag{1}$$

Consider, for example, Fig. 1.1 which represents a system S containing a set X of colored circles and a feature set A that contains only one attribute, namely, *color*. Assume that each circle in X has only one color. Then the set X is partitioned into elementary sets or blocks, where each block contains circles with the same color. In effect, elements of a set $B(x) \subseteq X$ in a system S are classified as *indiscernible* if they are indistinguishable by means of their feature values for any $a \in B$. A set of *indiscernible* elements is called an *elementary set* [22]. Hence, any subset $B \subseteq A$ determines a partition $\{B(x) : x \in X\}$ of X. This partition defines an equivalence relation $I(B)$ on X called an *indiscernibility* relation such that $xI(B)y$ if and only if $y \in B(x)$ for every $x, y \in X$.

Assume that $Y \subseteq X$ and $B \subseteq A$, and consider an approximation of the set Y by means of the attributes in B and B-indiscernible blocks in the partition of X. The union of all blocks that constitute a subset of Y is called the *lower approximation* of Y (usually denoted by B_*Y), representing certain knowledge about Y. The union of all blocks that have non-empty intersection with the set Y is called the *upper approximation* of Y (usually denoted by B^*Y), representing uncertain knowledge about Y. The set $BN_B(Y) = B^*Y - B_*Y$ is called the B-boundary of the set Y. In the case where $BN_B(Y)$ is non-empty, the set Y is a *rough (imprecise)* set. Otherwise, the set Y is a *crisp* set. This approach to classification of objects in a set is represented graphically in Fig. 1.2, where the region bounded by the ellipse represents a set Y, the darkened blocks inside Y represent B_*Y, the gray blocks represent the boundary region $BN_B(Y)$, and the gray and the darkened blocks taken together represent B^*Y.

Consequences of this approach to the classification of objects by means of their feature values have been remarkable and far-reaching. Detailed accounts of the current research in rough set theory and its applications are available, e.g., in [32,35,37].

4 Molecular Computing

Zdzisław Pawlak was one of the pioneers of a research area known as molecular computing (see, e.g., ch. 6 on Genetic Grammars published in 1965 [12]). He searched for grammars generating compound biological structures from simpler ones, e.g., proteins from amino acids. He proposed a generalization of the traditional grammars used in formal language theory. For example, he considered the construction of mosaics on a plane from some elementary mosaics by using some production rules for the composition. He also presented a language for linear representation of mosaic structures. By introducing such grammars one can better understand the structure of proteins and the processes that lead to their synthesis. Such grammars result in real-life languages that characterize the development of living organisms. During the 1970s, Pawlak was interested in developing a formal model of *deoxyribonucleic acid* (DNA), and he proposed a formal model for the genetic code discovered by Crick and Watson. Pawlak's model is regarded by many as the first complete model of DNA. This work on DNA by Pawlak has been cited by others (see, e.g., [3,40]).

5 Philosophy

For many years, Zdzisław Pawlak had an intense interest in philosophy, especially regarding the connections between rough sets and other forms of sets. It was Pawlak's venerable habit to point to connections between his own work in rough sets and the works of others in philosophy and mathematics. This is especially true relative to two cardinal notions, namely, sets and vagueness. For the notion of a set, Pawlak called attention to works by Georg Cantor, Gottlob Frege and Bertrand Russell. Pawlak observed that the notion of a set is not only fundamental for the whole of mathematics but also for natural language, where it is commonplace to speak in terms of collections of such things as books, paintings, people, and their vague properties [32].

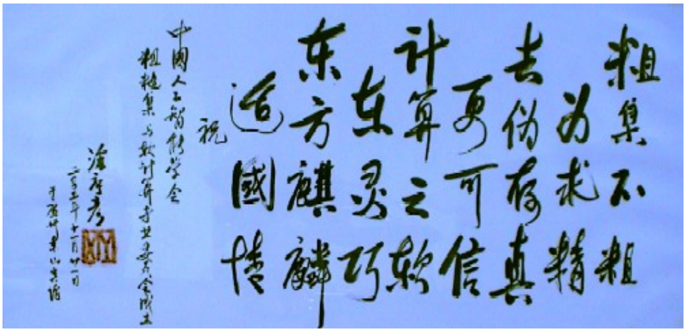


Fig. 2. Poem about Rough Sets in Chinese

In his reflections on structured objects, Pawlak pointed to the work on mereology by Stanisław Leśniewski, where the relation *being a part* replaces the membership relation $\in$. Of course, in recent years, the study of Leśniewski's work has led to rough mereology and the relation *being a part to a degree* in 1996 (see, e.g., [34] cited by Pawlak in [32]).

For many years, Pawlak was also interested in vagueness and Gottlob Frege's notion of the boundary of a concept (see, e.g., [2,4]). For Frege, the definition of a concept must unambiguously determine whether or not an object falls under the concept. For a concept without a sharp boundary, one is faced with the problem of determining how close an object must be before it can be said to belong to a concept. Later, this problem of sharp boundaries shows up as a repeated motif in landscapes and waterscapes painted by Pawlak (see, e.g., Fig. 3.1 and Fig. 3.2). Pawlak also observed out that mathematics must use crisp, not vague concepts. Hence, mathematics makes it possible to reason precisely about approximations of vague concepts. These approximations are temporal and subjective [32].

Professor Zdzisław Pawlak was very happy when he recognized that the rough set approach is consistent with a very old Chinese philosophy that is reflected in a recent poem from P.R. China (see Fig. 2).

The poem in Fig. 2 was written by Professor Xuyan Tu, the Honorary President of the Chinese Association for Artificial Intelligence, to celebrate the establishment of the Rough Set and Soft Computation Society at the Chinese Association for Artificial Intelligence, in Guangzhou, 21 November 2003. A number of English translations of this poem are possible. Consider, for example, the following two translations of the poem in Fig. 2, which capture the spirit of the poem and its allusion to the fact that rough sets hearken back to a philosophy rooted in ancient China.

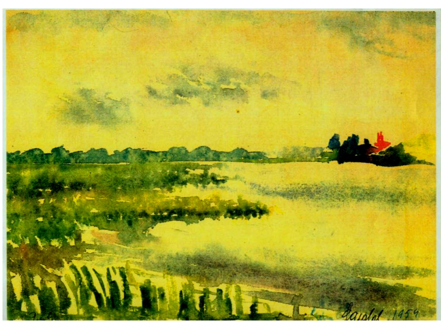
Rough sets are not rough, and one moves towards precision.
One removes the "unbelievable" so that what remains is more believable.
The soft part of computing is nimble.
Rough sets imply a philosophy rooted in China.
Anonymous
8 January 2005

Rough sets are not "rough" for the purpose of searching for accuracy.
It is a more reliable and believable theory that avoids falsity and keeps the truth.
The essence of soft computing is its flexibility.
[Rough Sets] reflect the oriental philosophy and fit the Chinese style of thinking.
Xuyan Tu, Poet
Yiyu Yao, Translator
21 November 2003

The 8 January 2005 anonymous translation is a conservative rendering of the Chinese characters in a concise way in English. The 21 November 2003 translation is more interpretative, and reflects the spirit of an event as seen by the translator in the context of the opening of the Institute of Artificial Intelligence in P.R. China.

6 Painting, Nature and Poetry

Zdzisław Pawlak was an astute observer of nature and was very fond of spending time exploring and painting the woodlands, lakes and streams of Poland. Starting in the early 1950s and continuing for most of his life, Pawlak captured what he observed by painting landscapes and waterscapes. Sample paintings by Pawlak are shown in Fig. 3.1 and Fig. 3.2.



3.1: 1954 Landscape by Pawlak

3.2: 1999 Watercape by Pawlak

Fig. 3. Paintings by Zdzisław Pawlak

In more recent years, Zdzisław Pawlak wrote poems, which are remarkably succinct and very close to the philosophy of rough sets as well as his interest in painting. In his poems, one may find quite often some reflections which most probably stimulated him in the discovery of the rough sets, where there is a focus on border regions found in scenes from nature. A sample poem coauthored by Pawlak is given next (each line of the English is followed by the corresponding Polish text).

Near To
Blisko

How near to the bark of a tree are the drifting snowflakes,
Jak blisko kory drzew płatki śniegu tworzą zaspy,

swirling gently round, down from winter skies?
Wirując delikatnie, gdy spadają z zimowego nieba?

How near to the ground are icicles,
Jak blisko ziemi są sople lodu,

slowing forming on window ledges?
Powoli formujące się na okiennych parapetach?

Sometimes snow-laden branches of some trees droop,
Czasami, gałęzie drzew zwieszają się pod ciężarem śniegu,

some near to the ground,
niektóre prawie do samej ziemi,

some from to-time-to-time swaying in the wind,
niektóre od czasu do czasu kołyszą się na wietrze,

some nearly touching each other as the snow falls,
niektóre niemal dotykają się wzajemnie, gdy śnieg pada,

some with shapes resembling the limbs of ballet dancers,
niektóre o kształtach przypominających kończyny baletnic,

some with rough edges shielded from snowfall and wind,
niektóre o nierównych rysach, osłonięte przed śniegiem i wiatrem,

and then,
i potem,

somehow,
w jakiś sposób,

spring up again in the morning sunshine.
Wyrastają na nowo w porannym słońcu.

How near to ...
Jak już blisko do ...

– Z. Pawlak and J.F. Peters,
Spring, 2002.

The poem entitled *Near To* took its inspiration from an early landscape painted by Pawlak in 1954, which is shown in Fig. 3.1. A common motif in Pawlak's paintings is the somewhat indefinite separation between objects such as the outer edges of trees and sky, the outer edges of tree shadows reflected in water and the water itself, and the separation between water and the surrounding land. The boundaries of objects evident in Pawlak's paintings are suggestive of the theoretical idea of the boundary between the lower and upper approximations of a set in rough set theory. There is also in Pawlak's paintings an apparent fascination with containment of similar objects such as the parts of a tree shadow or the pixels clustered together to represent a distant building (see, e.g., Fig. 3.2). In some sense, the parts of a tree shadow or the parts of the roof of a distant building are indiscernible from each other.

7 Conclusion

This paper attempts to give a brief overview of some of the contributions made by Zdzisław Pawlak to rough set theory, genetic grammars and molecular computing, philosophy, painting and poetry during his lifetime. Remarkably, one can find a common thread in his theoretical work on rough sets as well as in molecular computing, painting and poetry, namely, Pawlak's interest in the border regions of objects that are delineated by considering the attributes (features) of an object. The work on knowledge representation systems and the notion of elementary sets have profound implications when one considers the problem of approximate reasoning and concept approximation.

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