In the history of mankind, Professor Zdzisław Pawlak, Member of the Polish Academy of Sciences, will be remembered as a great human being with exceptional humility, wit and kindness as well as an extraordinarily innovative researcher with exceptional stature. His legacy is rich and varied. Pawlak’s research contributions have had far-reaching implications inasmuch as his works are fundamental in establishing new perspectives for scientific research in a wide spectrum of fields.

Preamble

Professor Pawlak’s most widely recognized contribution is his incisive approach to classifying objects with their attributes (features) and his introduction of approximation spaces, which establish the foundations of granular computing and provide frameworks for perception and knowledge discovery in many areas. 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. 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) \[25\] and his discovery of rough set theory during the early 1980s (see, e.g., \[11,22,25,27\]). Since the introduction of rough set theory, there have been well over 4000 publications on this theory and its applications (see, e.g., \[6,35,36,37,39,71\] and Section \[12\]).

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. \[8\]. Pawlak’s more recent reflections concerning philosophy (especially, the philosophy of mathematics) are briefly covered in Sect. \[9\]. 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. \[10\].

2 Zdzisław Pawlak: A Brief Biography

Zdzisław Pawlak was born on 10 November 1926 in Łódź, 130 km south-west from Warsaw, Poland \[41\]. 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., \[20,24,28\]) and in computer systems engineering (see, e.g., \[16,17,18,19,21\]). During his early years, he was a pioneer in the designing computing machines. In 1950, Pawlak presented the first project of a computer called GAM 1. He completed his M.Sc. in Telecommunication Engineering in 1951. Pawlak’s publication in 1956 on a new method for random number generation was the first article in informatics
published abroad by a researcher from Poland [13]. 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 (see Fig. 1).

The original arithmetic for the UMC1 computer system with base “-2” was due to Pawlak [14]. 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., [16,17]).

In succeeding years, Pawlak worked at the Institute of Mathematics of Warsaw University and, in 1965, introduced foundations for modeling DNA [15] in what has come to be known as molecular computing [3,15]. He also proposed a new formal model of a computing machine known as the Pawlak machine [21,23] that is different from the Turing machine and from the von Neumann machine. In 1973, he introduced knowledge representation systems [22] as part of his work on the mathematical foundations of information retrieval (see, e.g., [11,22]). 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 [25], which was the basis for extensive research in rough set theory during the 1980s (see, e.g., [7,8,12,26,27,29]). 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., [39]). In addition, he did extensive work on the mathematical foundations of information systems during the early 1980s (see, e.g., [21,23]). He also invented a new approach to conflict analysis (see, e.g., [30,31,33,34]).
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., [35]).

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

If we classify objects by means of attributes, exact classification is often impossible.


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 [22]. 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 1973, he formulated knowledge representation systems (see, e.g., [11,22]). 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 [25,26]. We start with a system $S = (X, A, V, \sigma)$, 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 $\sigma$ is called a knowledge function defined as the mapping $\sigma : X \times A \rightarrow V$, where $\sigma(x, a) \in V_a$ for every $x \in X$ and $a \in A$. The function $\sigma$ is referred to as knowledge function about objects from $X$. The set $X$ is partitioned into elementary sets that later were called blocks, 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. 2.2). For example, for any $B \subseteq A$ the $B$-elementary set for an element $x \in X$ is denoted by $B(x)$, which is defined by

$$B(x) = \{y \in X | \forall a \in B \sigma(x, a) = \sigma(y, a)\}$$

(1)

Consider, for example, Fig. 2.1, 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 [25]. Hence,
2.1: Blocks of Objects

The universe of objects

Granules of knowledge

The lower approximation

The set

The upper approximation

2.2: Sample Set Approximation

Fig. 2. Rudiments of Rough Sets

any subset $B \subseteq A$ determines a partition $\{B(x) : x \in X\}$ of $X$. This partition defines an equivalence relation $Ind(B)$ on $X$ called an indiscernibility relation such that $xInd(B)y$ 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. 2.2 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 [35,36,37] (see also Section 12).

4 Approximation

Some categories (subsets of objects) cannot be expressed exactly by employing available knowledge. Hence, we arrive at the idea of approximation of a set by other sets.

One of the most profound, very important notions underlying rough set theory is approximation. In general, an approximation is defined as the replacement of objects by others that resemble the original objects in certain respects [4]. For example, consider a universe \( U \) containing objects representing behaviors of agents. In that case, we can consider blocks of behaviors in the partition \( U/R \), where the behaviors within a block resemble (are indiscernible from) each other by virtue of their feature values. Then any subset \( X \) of \( U \) can be approximated by blocks that are either proper subsets of \( X \) (lower approximation of the set \( X \) denoted \( \tilde{R}X \)) or by blocks having one or more elements in common with \( X \) (upper approximation of the set \( X \) denoted \( RX \))\(^1\). In rough set theory, the focus is on approximating one set of objects by means of another set of objects based on the feature values of the objects [32]. The lower approximation operator \( \tilde{R} \) has properties that correspond closely to properties of what is known as the \( \Pi_0 \) topological interior operator [27,77]. Similarly, the upper approximation operator \( R \) has properties that correspond closely to properties of the \( \Pi_0 \) topological closure operator [27,77]. It was observed in [27] that the key to the rough set approach is provided by the exact mathematical formulation of the concept of approximative (rough) equality of sets in a given approximation space.

5 Approximation Spaces

The key to the presented approach is provided by the exact mathematical formulation, of the concept of approximative (rough) equality of sets in a given approximation space.


In [32], an approximation space is represented by the pair \((U, R)\), where \( U \) is a universe of objects, and \( R \subseteq U \times U \) is an indiscernibility relation (denoted \( \text{Ind} \) as in Sect. 3) defined by an attribute set (i.e., \( R = \text{Ind}(A) \) for some attribute set \( A \)). In this case, \( R \) is an equivalence relation. Let \([x]_R \) denote an equivalence class of an element \( x \in U \) under the indiscernibility relation \( R \), where \([x]_R = \{y \in U : x R y\}\).

In this context, \( R \)-approximations of any set \( X \subseteq U \) are based on the exact (crisp) containment of sets. Then set approximations are defined as follows:

- \( x \in U \) belongs with certainty to \( X \subseteq U \) (i.e., \( x \) belongs to the \( R \)-lower approximation of \( X \)), if \([x]_R \subseteq X\).
- \( x \in U \) possibly belongs \( X \subseteq U \) (i.e., \( x \) belongs to the \( R \)-upper approximation of \( X \)), if \([x]_R \cap X \neq \emptyset\).

\(^1\) In more recent years, the notation \( R^*X, R^\ast X \) has been often used (see, e.g., Sect. 3) to denote lower and upper approximation, respectively, since this notation is more “typewriter” friendly.
x ∈ U belongs with certainty neither to the X nor to U − X (i.e., x belongs to the R-boundary region of X), if [x]_R ∩ (U − X) ≠ ∅ and [x]_R ∩ X ≠ ∅.

Several generalizations of the above approach have been proposed in the literature (see, e.g., \cite{35,36,37} and Section 12). In particular, in some of these approaches, set inclusion to a degree is used instead of the exact inclusion.

6 Generalizations of Approximation Spaces

Several generalizations of the classical rough set approach based on approximation spaces defined as pairs of the form (U, R), where R is the equivalence relation (called an indiscernibility relation) on the non-empty set U, have been reported in the literature. Let us mention two of them.

A generalized approximation space can be defined by a tuple $GAS = (U, N, \nu)$ where $N$ is a neighborhood function defined on U with values in the powerset $\mathcal{P}(U)$ of U (i.e., $N(x)$ is the neighborhood of x) and $\nu$ is the overlap function defined on the Cartesian product $\mathcal{P}(U) \times \mathcal{P}(U)$ with values in the interval [0,1] measuring the degree of overlap of sets. The lower $GAS_*$ and upper $GAS^*$ approximation operations can be defined in a $GAS$ by Eqs. 2 and 3.

$$GAS_*(X) = \{x ∈ U : \nu(N(x), X) = 1\},$$

$$GAS^*(X) = \{x ∈ U : \nu(N(x), X) > 0\}.\tag{2}$$

In the standard case, $N(x)$ equals the equivalence class $B(x)$ or block of the indiscernibility relation $Ind(B)$ for a set of features B. In the case where R is a tolerance (similarity) relation\footnote{Recall that a tolerance is a binary relation $R \subseteq U \times U$ on a set U having the reflexivity and symmetry properties, i.e., $xRx$ for all $x ∈ U$ and $xRy$ implies $yRx$ for all $x, y ∈ U$.}, $\tau \subseteq U \times U$, we take $N(x) = \{y ∈ U : x\tau y\}$, i.e., $N(x)$ equals the tolerance class of $\tau$ defined by $x$. The standard inclusion relation $\nu_{SRI}$ is defined for $X, Y \subseteq U$ by Eq. 4.

$$\nu_{SRI}(X, Y) = \begin{cases} \frac{|X \cap Y|}{|Y|}, & \text{if } Y \neq \emptyset, \\ 1, & \text{otherwise}. \end{cases}\tag{4}$$

For applications, it is important to have some constructive definitions of $N$ and $\nu$.

One can consider another way to define $N(x)$. Usually together with a $GAS$, we consider some set $F$ of formulas describing sets of objects in the universe $U$ of the $GAS$ defined by semantics $\| \cdot \|_{GAS}$, i.e., $\|\alpha\|_{GAS} \subseteq U$ for any $\alpha ∈ F$. Now, one can take the set the neighborhood function as shown in Eq. 5.

$$N_F(x) = \{\alpha ∈ F : x ∈ \|\alpha\|_{GAS}\},\tag{5}$$

and $N(x) = \{\|\alpha\|_{GAS} : \alpha ∈ N_F(x)\}$. Hence, more general uncertainty functions having values in $\mathcal{P}(U)$ can be defined and as a consequence different definitions...
of approximations are considered. For example, one can consider the following definitions of approximation operations in GAS defined in Eqs. 6 and 7.

\[ GAS_\circ (X) = \{ x \in U : \nu(Y, X) = 1 \text{ for some } Y \in N(x) \}, \]
\[ GAS^\circ (X) = \{ x \in U : \nu(Y, X) > 0 \text{ for any } Y \in N(x) \}. \]

There are also different forms of rough inclusion functions. Let us consider two examples.

In the first example of a rough inclusion function, a threshold \( t \in (0, 0.5) \) is used to relax the degree of inclusion of sets. The rough inclusion function \( \nu_t \) is defined by Eq. 8.

\[ \nu_t(X, Y) = \begin{cases} 1, & \text{if } \nu_{SRI}(X, Y) \geq 1 - t, \\ \frac{\nu_{SRI}(X, Y) - t}{1 - 2t}, & \text{if } t \leq \nu_{SRI}(X, Y) < 1 - t, \\ 0, & \text{if } \nu_{SRI}(X, Y) \leq t. \end{cases} \]

One can obtain approximations considered in the variable precision rough set approach (VPRSM) by substituting in (2)-(3) the rough inclusion function \( \nu_t \) defined by (8) instead of \( \nu \), assuming that \( Y \) is a decision class and \( N(x) = B(x) \) for any object \( x \), where \( B \) is a given set of attributes.

Another example of application of the standard inclusion was developed by using probabilistic decision functions.

The rough inclusion relation can be also used for function approximation and relation approximation. In the case of function approximation the inclusion function \( \nu^* \) for subsets \( X, Y \subseteq U \times U \), where \( X, Y \subseteq \mathbb{R} \) and \( \mathbb{R} \) is the set of reals, is defined by Eq. 9.

\[ \nu^*(X, Y) = \begin{cases} \frac{\text{card}(\pi_1(X \cap Y))}{\text{card}(\pi_1(X))}, & \text{if } \pi_1(X) \neq \emptyset, \\ 1, & \text{if } \pi_1(X) = \emptyset, \end{cases} \]

where \( \pi_1 \) is the projection operation on the first coordinate. Assume now, that \( X \) is a cube and \( Y \) is the graph \( G(f) \) of the function \( f : \mathbb{R} \rightarrow \mathbb{R} \). Then, e.g., \( X \) is in the lower approximation of \( f \) if the projection on the first coordinate of the intersection \( X \cap G(f) \) is equal to the projection of \( X \) on the first coordinate. This means that the part of the graph \( G(f) \) is “well” included in the box \( X \), i.e., for all arguments that belong to the box projection on the first coordinate the value of \( f \) is included in the box \( X \) projection on the second coordinate.

The approach based on inclusion functions has been generalized to the rough mereological approach. The inclusion relation \( x \mu_r y \) with the intended meaning \( x \) is a part of \( y \) to a degree at least \( r \) has been taken as the basic notion of the rough mereology being a generalization of the Leśniewski mereology [9,10]. Research on rough mereology has shown the importance of another notion, namely closeness of complex objects (e.g., concepts). This can be defined by \( xcl_{r,r'} y \) if and only if \( x \mu_r y \) and \( y \mu_{r'} x \).
Rough mereology offers a methodology for synthesis and analysis of objects in a distributed environment of intelligent agents, in particular, for synthesis of objects satisfying a given specification to a satisfactory degree or for control in such a complex environment. Moreover, rough mereology has been recently used for developing the foundations of the information granule calculi, aiming at formalization of the Computing with Words paradigm, recently formulated by Lotfi Zadeh [42]. More complex information granules are defined recursively using already defined information granules and their measures of inclusion and closeness. Information granules can have complex structures like classifiers or approximation spaces. Computations on information granules are performed to discover relevant information granules, e.g., patterns or approximation spaces for complex concept approximations.

Usually families of approximation spaces labeled by some parameters are considered. By tuning such parameters according to chosen criteria (e.g., minimal description length), one can search for the optimal approximation space for a concept description.

7 Conflict Analysis and Negotiations

Conflict analysis and resolution play an important role in business, governmental, political and legal disputes, labor-management negotiations, military operations and others. To this end many mathematical formal models of conflict situations have been proposed and studied.

Various mathematical tools, e.g., game theory, graph theory, topology, differential equations and others, have been used for that purpose. In fact, as yet there is no “universal” theory of conflicts. Instead, mathematical models of conflict situations are strongly domain dependent.

Zdzisław Pawlak introduced still another approach to conflict analysis, based on some ideas of rough set theory [30, 31, 33, 34, 37]. Pawlak’s model is simple enough for easy computer implementation and is adequate for many real-life applications.

The approach is based on the conflict relation in data. Formally, the conflict relation can be seen as a negation (not necessarily, classical) of the indiscernibility relation which was used by Pawlak as a basis of rough set theory. Thus, indiscernibility and conflict are closely related from a logical point of view. It turns out that the conflict relation can be used in conflict analysis studies.

8 Molecular Computing

The understanding of protein structure and the processes of their syntheses is fundamental for the considerations of the life problem.


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 [15]). 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., [3,11]).

9 Philosophy

No doubt the most interesting proposal was given by the Polish logician Stanisław Lesniewski, who introduced the relation of “being a part” instead of the membership relation between elements and sets employed in classical set theory.


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 classical notion of a set, Pawlak called attention to works by Cantor, 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 [35].

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., [38] cited by Pawlak in [35]).

For many years, Pawlak was also interested in vagueness and Gottlob Frege’s notion of the boundary of a concept (see, e.g., [25]). 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. 5.1 and Fig. 5.2).
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 \[35\].

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. 3).

The poem in Fig. 3 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 December 2003. A number of English translations of this poem are possible. Consider, for example, the following two translations of the poem in Fig. 3 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.

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**Fig. 3. Poem about Rough Sets in Chinese**

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 December 2003
The 8 January 2005 anonymous translation is a conservative rendering of the Chinese characters in a concise way in English. The 21 December 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.

![Zdzisław Pawlak in Snow Country](image)

**Fig. 4. Zdzisław Pawlak in Snow Country**

## 10 Painting and Nature

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. A picture showing Pawlak during a walk in snow-covered woods is shown in Fig. 4. 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. 5 and Fig. 6.

A common motif in Pawlak’s paintings is the somewhat indefinite separation between objects such as the outer edges of trees and sky (see, e.g., Fig. 5.3, Fig. 6.3 and 6.1). In Fig. 6.1 there is a blurring (uncertain boundary) between the tops of the trees and shrubs against the sky. Notice how the separation between the reeds in the foreground and the water on the far side of the reeds is rather indistinct in Fig. 6.1 (i.e., there is no sharp boundary between the reeds and water). This blurring the boundaries between tree shadows and water is also particularly pronounced in Fig. 6.1 (see, e.g., Fig. 5.3 and 5.4). There is considerable charm in Fig. 5.4 where there is a colorful blending of the tree shadows, 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 roadway bordered by gorse in Fig. 6.3, line of haystacks in a field in Fig. 6.4, distant mountains framed by a border of evergreens and flora in the foreground in Fig. 5.3 as well as in Fig. 6.2 of the parts of a tree shadows shimmering in the water in Fig. 6.1 or the pixels clustered together to represent a distant building (see, e.g., Fig. 5.2). In some sense, the parts of a tree shadow or the parts of the roof of a distant building are indiscernible from each other.

The water shadows can be considered as approximations (substitutions) for the reflected objects in Fig. 5.3 and Fig. 5.4. To see this, try the following experiment. Notice that every pixel (picture element) with coordinates (x, y) has 4 neighbors at (x+1, y), (x-1, y), (x, y+1), and (x, y-1), which constitute what is known as a 4-neighborhood of an image. An image segment is a collection of 4-neighborhood connected pixels with the same color. Let $U$ consist of the color segments in Fig. 5.4 and consider only the shape and color of the segments in $U$. The image segments making up the trees have “reflected” segments in tree shadows in Fig. 5.4. Mask or cover up the image segments contained in the trees.
along the distant shoreline, then segments in the tree shadows can be used to approximate the corresponding segments of the trees shown in Fig. 5.4. To see this, go a step further, repaint the vacant space in the masked area of the painting with image segments from the tree shadows in Fig. 5.4. The new version of the painting will be approximately like the original painting. This approximation will vary depending on the time of day and the length of the tree shadows.

11 Poetry

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. [5.1]

12 Outgrowth of Research by Zdzisław Pawlak

This section briefly introduces the literature in that has been inspired by the Zdzisław Pawlak’s research in rough set theory and applications.

12.1 Journals

Evidence in the growth in the research in the foundations of rough set theory and its many applications can be found in the *Transactions on Rough Sets (TRS)*, which is published by Springer as a journal subline of the Lecture Notes in Computer Science [71]. The *TRS* has as its principal aim the fostering of professional exchanges between scientists and practitioners who are interested in the foundations and applications of rough sets. Topics include foundations and applications of rough sets as well as foundations and applications of hybrid methods combining rough sets with other approaches important for the development of intelligent systems. We are observing a growing research interest in the foundations of rough sets, including the various logical, mathematical and philosophical aspects of rough sets. Some relationships have already been established between rough sets and other approaches, and also with a wide range of hybrid systems. As a result, rough sets are linked with decision system modeling and analysis of complex systems, fuzzy sets, neural networks, evolutionary computing, data mining and knowledge discovery, pattern recognition, machine learning, and approximate reasoning. In particular, rough sets are used in probabilistic reasoning, granular computing (including information granularity calculi based on rough mereology), intelligent control, intelligent agent modeling, identification of autonomous systems, and process specification. A wide range of applications of methods based on rough set theory alone or in combination with other approaches have been discovered in the following areas: acoustics, biology, business and finance, chemistry, computer engineering (e.g., data compression, digital image processing, digital signal processing, parallel and distributed computer systems, sensor fusion, fractal engineering), decision analysis and systems, economics, electrical engineering (e.g., control, signal analysis, power systems), environmental studies, digital image processing, informatics, medicine, molecular biology, musicology, neurology, robotics, social science, software engineering, spatial visualization, Web engineering, and Web mining. The journal includes high-quality research articles accepted for publication on the basis of thorough peer reviews. Dissertations and monographs up to 250 pages that include new research results can also be considered as regular papers. Extended and revised versions of selected papers from conferences can also be included in regular or special issues of the journal (see, e.g., [72,73,74,75]). In addition, articles that have appeared in journals such as *Communications of ACM* [67], *Computational Intelligence* [95], *Fundamenta Informaticae* (see, e.g., [45], *International Journal
of Intelligent Systems [63, 70], Journal of the Intelligent Automation and Soft Computing [56], Neurocomputing [63], and Pattern Recognition Letters [83].

In the period 1997-2002, many articles on rough sets have been published in Bulletin of the International Rough Sets Society [90].

12.2 Conferences

The wide spectrum of research in rough sets and its applications can also be gauged by a number of international conferences. The premier conference of the International Rough Set Society (IRSS) is the International Conference on Rough Sets and Current Trends in Computing (RSCT) was held for first time in Warsaw, Poland in 1998. It was followed by successful RSCTC conferences in Banff, Canada (2000), in Malvern, U.S.A. (2002) and in Uppsala, Sweden (2004) [43, 53, 70, 92, 98]. RSCTC is an outgrowth of a series of annual International Workshops devoted to the subject of rough sets, started in Poznan, Poland in 1992, and then held alternatively in Canada, the USA, Japan and China (RSKD, RSSC, RSFDGrC, RSGrC series). The next RSCT will be held in Kobe, Japan in 2006. The aim of the RSCTC conference is to provide researchers and practitioners interested in new information technologies an opportunity to highlight innovative research directions, novel applications, and a growing number of relationships between rough sets and such areas as computational intelligence, knowledge discovery and data mining, intelligent information systems, web mining, synthesis and analysis of complex objects and non-conventional models of computation.

The IRSS also sponsors two other international conferences, namely, Rough Sets, Fuzzy Sets, Data Mining, and Granular Computing (RSFDGrC) (see, e.g., [51, 82, 86, 87, 91, 93, 95]) and Rough Sets and Knowledge Discovery (RSKD), held for the first time in 2006 in Chongqing, P.R. China [76]. RSFDGrC 2005 [86, 87] was a continuation of international conferences and workshops devoted to the subject of rough sets, held alternatively in Canada, P.R. China, Japan, Poland, Sweden, and the USA. RSFDGrC achieved the status of bi-annual international conference starting from the year of 2003 in Chongqing, P.R. China. This conference encompasses rough sets and fuzzy sets, granular computing, as well as knowledge discovery and data mining. RSKT 2006 [76] provides a forum for researchers in rough sets and knowledge technology. Rough set theory is closely related to knowledge technology in a variety of forms such as knowledge discovery, approximate reasoning, intelligent and multiagent systems design, knowledge intensive computations that signal the emergence of a knowledge technology age. The essence of growth in cutting-edge, state-of-the-art and promising knowledge technologies is closely related to learning, pattern recognition, machine intelligence and automation of acquisition, transformation, communication, exploration and exploitation of knowledge. A principal thrust of such technologies is the utilization of methodologies that facilitate knowledge processing. The focus of the RSKT conference is to present state-of-the-art scientific results, encourage academic and industrial interaction, and promote

3 See http://www.roughsets.org/.
collaborative research and developmental activities, in rough sets and knowledge technology worldwide.

During the past 10 years, a number of other conferences and workshops that include rough sets as one of the principal topics, have also been taken place (see, e.g., [48, 58, 89, 85, 99, 100, 101, 102, 103]).

12.3 Books

During the past two decades, a significant number of books and edited volumes have either featured or included articles on rough set theory and applications (see, e.g., [44, 46, 47, 48, 49, 50, 52, 54, 55, 57, 59, 60, 77, 80, 81, 83, 88, 94, 61, 62, 63, 64, 65, 66, 68]). For example, the papers on rough set theory and its applications in [80, 81] present a wide spectrum of topics. It is observed that rough set theory is on the crossroads of fuzzy sets, theory of evidence, neural networks, Petri nets and many other branches of AI, logic and mathematics. The rough set approach appears to be of fundamental importance to AI and cognitive sciences, especially in the areas of machine learning, knowledge acquisition, decision analysis, knowledge discovery from databases, expert systems, inductive reasoning and pattern recognition.

12.4 Tutorials

In 1991, Zdzislaw Pawlak published a monograph that provides a comprehensive presentation of the fundamentals on rough sets [66]. The book by Pawlak on approximation of sets by other sets that is based on the study of a finite, non-empty sets of objects called universe where each universe is denoted by \( U \), subsets of \( U \) called concepts, attributes (features) of objects, and an indiscernibility relation \( Ind \) that partitions \( U \) into a collection of disjoint equivalence classes (called blocks in Sect. 3). This seminal work by Pawlak was the forerunner of numerous advances in rough set theory and its applications. After 1991, a succession of tutorials have been published that capture the essentials of rough sets and exhibit the growth in research in the theory and applications (see, e.g., [6, 33, 36, 77]).

13 Conclusion

This paper attempts to give a brief overview of some of the contributions made by Zdzislaw Pawlak to rough set theory, conflict analysis and negotiation, 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 conflict analysis and negotiation, 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.

– James F. Peters and Andrzej Skowron
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References

I. Seminal Works


II. Rough Set Literature


http://www.springer.com/east/home/computer/lncs?SGWID=5-164-6-73656-0.


99. IFSA/IEEE Fifth Int. Conf. on Hybrid Intelligent Systems, Rio de Janeiro, Brazil, 6-9 Nov. (2005). See http://www.ica.ele.puc-rio.br/his05/index.html
103. Information Processing and Management of Uncertainty (IPMU) http://www.informatik.uni-trier.de/~ley/db/conf/ipmu/index.html