Some Results on Multigranulation Neutrosophic Rough Sets on a Single Domain

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Received: 11 August 2018; Accepted: 13 September 2018; Published: 19 September 2018

Abstract: As a generalization of single value neutrosophic rough sets, the concept of multi-granulation neutrosophic rough sets was proposed by Bo et al., and some basic properties of the pessimistic (optimistic) multigranulation neutrosophic rough approximation operators were studied. However, they did not do a comprehensive study on the algebraic structure of the pessimistic (optimistic) multigranulation neutrosophic rough approximation operators. In the present paper, we will provide the lattice structure of the pessimistic multigranulation neutrosophic rough approximation operators. In particular, in the one-dimensional case, for special neutrosophic relations, the completely lattice isomorphic relationship between upper neutrosophic rough approximation operators and lower neutrosophic rough approximation operators is proved.

Keywords: neutrosophic set; neutrosophic rough set; pessimistic (optimistic) multigranulation neutrosophic approximation operators; complete lattice

1. Introduction

In order to deal with imprecise information and inconsistent knowledge, Smarandache [1,2] first introduced the notion of neutrosophic set by fusing a tri-component set and the non-standard analysis. A neutrosophic set consists of three membership functions, where every function value is a real standard or non-standard subset of the nonstandard unit interval \([0, 1]\). Since then, many authors have studied various aspects of neutrosophic sets from different points of view, for example, in order to apply the neutrosophic idea to logics, Rivieccio [3] proposed neutrosophic logics which is a generalization of fuzzy logics and studied some basic properties. Guo and Cheng [4] and Guo and Sengur [5] obtained good applications in cluster analysis and image processing by using neutrosophic sets. Salama and Broumi [6] and Broumi and Smarandache [7] first introduced the concept of rough neutrosophic sets, handled incomplete and indeterminate information, and studied some operations and their properties.

In order to apply neutrosophic sets conveniently, Wang et al. [8] proposed single valued neutrosophic sets by simplifying neutrosophic sets. Single valued neutrosophic sets can also be viewed as a generalization of intuitionistic fuzzy sets (Atanassov [9]). Single valued neutrosophic sets have become a new majorly research issue. Ye [10–12] proposed decision making based on correlation coefficients and weighted correlation coefficient of single valued neutrosophic sets, and gave an application of proposed methods. Majumdar and Samant [13] studied similarity, distance and entropy of single valued neutrosophic sets from a theoretical aspect.

Şahin and Küçük [14] gave a subsethood measure of single valued neutrosophic sets based on distance and showed its effectiveness through an example. We know that there’s a certain connection among fuzzy rough approximation operators and fuzzy relations (resp., fuzzy topologies, information...
systems [15–17]). Hence, Yang et al. [18] firstly proposed neutrosophic relations and studied some kinds of kernels and closures of neutrosophic relations. Subsequently they proposed single valued neutrosophic rough sets [19] by fusing single valued neutrosophic sets and rough sets (Pawlak, [20]), and they studied some properties of single value neutrosophic upper and lower approximation operators. As a generalization of single value neutrosophic rough sets, Bao and Yang [21] introduced $p$-dimension single valued neutrosophic refined rough sets, and they also gave some properties of $p$-dimension single valued neutrosophic upper and lower approximation operators.

As another generalization of single value neutrosophic rough sets, Bo et al. [22] proposed the concept of multi-granulation neutrosophic rough sets and obtained some basic properties of the pessimistic (optimistic) multigranulation neutrosophic rough approximation operators. However, the lattice structures of those rough approximation operators in references [19,21,22], were not well studied. Following this idea, Zhao and Zhang [23] gave the supremum and infimum of the $p$-dimension neutrosophic upper and lower approximation operators, but they did not study the relationship between the $p$-dimension neutrosophic upper approximation operators and the $p$-dimension neutrosophic lower approximation operators, especially in the one-dimensional case. Inspired by paper [23], a natural problem is: Can the lattice structure of pessimistic (optimistic) multigranulation neutrosophic approximation operators be given?

In the present paper, we study the algebraic structure of optimistic (pessimistic) multigranulation single valued neutrosophic approximation operators.

The structure of the paper is organized as follows. The next section reviews some basic definitions of neutrosophic sets and one-dimensional multi-granulation rough sets. In Section 3, the lattice structure of the pessimistic multigranulation neutrosophic rough approximation operators are studied. In Section 4, for special neutrosophic relations, a one-to-one correspondence relationship between neutrosophic upper approximation operators and lower approximation operators is given. Finally, Section 5 concludes this article and points out the deficiencies of the current research.

2. Preliminaries

In this section, we briefly recall several definitions of neutrosophic set (here “neutrosophic set” refers exclusively to “single value neutrosophic set”) and one-dimensional multi-granulation rough set.

Definition 1 ([8]). A neutrosophic set $B$ in $X$ is defined as follows: $\forall a \in X$,

$$B = (T_A(a), I_A(a), F_A(a)),$$

where $T_A(a), I_A(a), F_A(a) \in [0, 1], 0 \leq \sup T_A(a) + \sup I_A(a) + \sup F_A(a) \leq 3$. The set of all neutrosophic sets on $X$ will be denoted by $\text{SVNS}(X)$.

Definition 2 ([11]). Let $C$ and $D$ be two neutrosophic sets in $X$, if

$$T_C(a) \leq T_D(a), \quad I_C(a) \geq I_D(a) \quad \text{and} \quad F_C(a) \geq F_D(a)$$

for each $a \in X$, then we called $C$ is contained in $D$, i.e., $C \subseteq D$. If $C \subseteq D$ and $D \subseteq C$, then we called $C$ is equal to $D$, denoted by $C = D$.

Definition 3 ([18]). Let $A$ and $B$ be two neutrosophic sets in $X$,

(1) The union of $A$ and $B$ is a s neutrosophic set $C$, denoted by $A \uplus B$, where $\forall x \in X$,

$$T_C(a) = \max\{T_A(a), T_B(a)\}, \quad I_C(a) = \min\{I_A(a), I_B(a)\}, \quad \text{and} \quad F_C(a) = \min\{F_A(a), F_B(a)\}.$$
The intersection of $A$ and $B$ is a neutrosophic set $D$, denoted by $A \sqcap B$, where $\forall x \in X$,

$$T_D(a) = \min\{T_A(a), T_B(a)\}, \quad I_D(a) = \max\{I_A(a), I_B(a)\}, \quad \text{and} \quad F_D(a) = \max\{F_A(a), F_B(a)\}.$$ 

**Definition 4 ([18]).** A neutrosophic relation $R$ in $X$ is defined as follows:

$$R = \{< (a, b), T_R(a, b), I_R(a, b), F_R(a, b) > | (a, b) \in X \times X\},$$

where $T_R : X \times X \rightarrow [0, 1], I_R : X \times X \rightarrow [0, 1], F_R : X \times X \rightarrow [0, 1]$, and

$$0 \leq \sup T_R(a, b) + \sup I_R(a, b) + \sup F_R(a, b) \leq 3.$$ 

The family of all neutrosophic relations in $X$ will be denoted by $\text{SVNR}(X)$, and the pair $(X, R)$ is called a neutrosophic approximation space.

**Definition 5 ([19]).** Let $(X, R)$ be a neutrosophic approximation space, $\forall A \in \text{SVNS}(X)$, the lower and upper approximations of $A$ with respect to $(X, R)$, denoted by $R(A)$ and $\overline{R}(A)$, are two neutrosophic sets whose membership functions are defined as: $\forall a \in X$,

$$T_{R(A)}(a) = \wedge_{b \in X} (T_R(a, b) \lor T_A(b)), \quad I_{R(A)}(a) = \lor_{b \in X} [(1 - I_R(a, b)) \land I_A(b)],$$

$$F_{R(A)}(a) = \lor_{b \in X} (T_R(a, b) \land F_A(b)), \quad T_{\overline{R}(A)}(a) = \lor_{b \in X} [T_R(a, b) \land T_A(b)],$$

$$I_{\overline{R}(A)}(a) = \wedge_{b \in X} (I_R(a, b) \lor I_A(b)), \quad F_{\overline{R}(A)}(a) = \wedge_{b \in X} [F_R(a, b) \lor F_A(b)].$$

The pair $(R(A), \overline{R}(A))$ is called the one-dimensional multi-granulation rough set (also called single value neutrosophic rough set or one-dimension single valued neutrosophic refined rough set) of $A$ with respect to $(X, R)$. $R$ and $\overline{R}$ are referred to as the neutrosophic lower and upper approximation operators, respectively.

**Lemma 1 ([19]).** Let $R_1$ and $R_2$ be two neutrosophic relations in $X$, $\forall A \in \text{SVNS}(X)$, we have

1. $R_1 \sqcap R_2(A) = R_1(A) \sqcap R_2(A);$
2. $R_1 \sqcup R_2(A) = \overline{R_1(A)} \sqcup \overline{R_2(A)};$
3. $R_1 \sqcap R_2(A) \sqcup R_1(A) \sqcup R_2(A) \sqcup R_1(A) \sqcup R_2(A);$
4. $R_1 \sqcup R_2(A) \sqcap R_1(A) \sqcup R_2(A) \sqcup R_1(A) \sqcup R_2(A).$

3. The Lattice Structure of the Pessimistic Multigranulation Neutrosophic Rough Approximation Operators

In this section, set $M = \{R_1, R_2, \ldots, R_n\} = \{R_i\}_{i=1}^n$ is called a multigranulation neutrosophic relations set on $X$ if each $R_i$ is a neutrosophic relation on $X$. In this case, the pair $(X, M)$ will be called an $n$-dimensional multigranulation neutrosophic approximation space.

**Definition 6 ([22]).** Let $(X, M)$ be an $n$-dimensional multigranulation neutrosophic approximation space. We define two pairs of approximation operators as follows, for all $\forall A \in \text{SVNS}(X)$ and $a \in X$,

$$M^O(A) = (M^O(A), \overline{M^O}(A)), \quad M^P(A) = (M^P(A), \overline{M^P}(A)),$$

where

$$T_{M^O}(a) = \lor_{i=1}^n T_{R_i(A)}(a), \quad I_{M^O}(a) = \wedge_{i=1}^n I_{R_i(A)}(a), \quad F_{M^O}(a) = \wedge_{i=1}^n F_{R_i(A)}(a),$$

$$T_{M^P}(a) = \wedge_{i=1}^n T_{R_i(A)}(a), \quad I_{M^P}(a) = \lor_{i=1}^n I_{R_i(A)}(a), \quad F_{M^P}(a) = \lor_{i=1}^n F_{R_i(A)}(a).$$
Theorem 2. \( \forall \{ F \} \in \Lambda \subseteq n - \text{SVNR}(X) \) where \( M^i = \{ M^i \}_{j=1}^{n} \) and \( \Lambda \) be an index set, we can define union and intersection of \( M^i \) as follows:

\[
\forall \{ M^i \}_{j=1}^{n} \in \Lambda \subseteq n - \text{SVNR}(X), \quad \bigvee_{j=1}^{n} M^i = \left\{ \bigcup_{j=1}^{n} M^i \right\}_{j=1}^{n}, \quad \bigwedge_{j=1}^{n} M^i = \left\{ \bigcap_{j=1}^{n} M^i \right\}_{j=1}^{n},
\]

where

\[
T_{\bigcup_{j=1}^{n} M^i}(a,b) = \bigvee_{j=1}^{n} T_M(a,b), \quad I_{\bigcup_{j=1}^{n} M^i}(a,b) = \bigwedge_{j=1}^{n} I_M(a,b),
\]

\[
F_{\bigcup_{j=1}^{n} M^i}(a,b) = \bigwedge_{j=1}^{n} F_M(a,b), \quad T_{\bigcap_{j=1}^{n} M^i}(a,b) = \bigvee_{j=1}^{n} T_M(a,b),
\]

\[
I_{\bigcap_{j=1}^{n} M^i}(a,b) = \bigvee_{j=1}^{n} I_M(a,b), \quad F_{\bigcap_{j=1}^{n} M^i}(a,b) = \bigwedge_{j=1}^{n} F_M(a,b).
\]

Then \( \bigvee_{j=1}^{n} M^i \) and \( \bigwedge_{j=1}^{n} M^i \) are two multigranulation neutrosophic relations on \( X \), and we easily show that \( \bigvee_{j=1}^{n} M^i \) and \( \bigwedge_{j=1}^{n} M^i \) are infimum and supremum of \( \{ M^i \}_{j=1}^{n} \), respectively. Hence we can easily obtain the following theorem:

Theorem 1. \((n - \text{SVNR}(X), \subseteq, \land, \lor)\) is a complete lattice, \( \bar{X}_n = \{ X_{1n}, X_{2n}, ..., X_{nn} \} \) and \( \overline{\varnothing}_n = \{ \varnothing_n, \varnothing_n, ..., \varnothing_n \} \) are its top element and bottom element, respectively, where \( X_{in} \) and \( \varnothing_n \) are two neutrosophic relations in \( X \) and defined as follows: \( \forall (a,b) \in X \times X, T_{X_{in}}(a,b) = 1, I_{X_{in}}(a,b) = 0, F_{X_{in}}(a,b) = 0 \) and \( T_{\varnothing_n}(a,b) = 0, I_{\varnothing_n}(a,b) = 1, F_{\varnothing_n}(a,b) = 1 \). In particular, \((\text{SVNR}(X), \subseteq, \land, \lor)\) is a complete lattice.

Theorem 2. Let \( M = \{ R_j \}_{j=1}^{1} \) and \( N = \{ Q_i \}_{i=1}^{1} \) be two multigranulation neutrosophic relations on \( X \), \( \forall A \in \text{SVNS}(X) \), we have

\[
\begin{align*}
1) & \quad M \lor N^O(A) \subseteq M^O(A) \sqcup N^O(A), \quad M \lor N^P(A) = M^P(A) \sqcup N^P(A); \\
2) & \quad M \lor N^O(A) \not\supseteq M^O(A) \sqcup N^O(A), \quad M \lor N^P(A) = M^P(A) \sqcup N^P(A); \\
3) & \quad M \land N^O(A) \not\supseteq M^O(A) \sqcup N^O(A) \not\supseteq M^O(A) \sqcup N^O(A), \quad M \land N^P(A) \not\supseteq M^P(A) \sqcup N^P(A) \not\supseteq M^P(A) \sqcup N^P(A); \\
4) & \quad M \land N^O(A) \subseteq M^O(A) \sqcup N^O(A), \quad M \land N^P(A) \subseteq M^P(A) \sqcup N^P(A).
\end{align*}
\]
Proof. We only show that the case of the optimistic multigranulation neutrosophic approximation operators.

(1) \( \forall a \in X \), by Lemma 1 and Definition 6, we have the following:

\[
T_{M\lor N^O(A)}(a) = \bigvee_{i=1}^n T_{R_i\lor \overline{Q}_i(A)}(a) = \bigvee_{i=1}^n T_{R_i(A)\lor \overline{Q}_i(A)}(a)
\]

\[
= \bigvee_{i=1}^n \left[ T_{R_i(A)}(a) \land T_{\overline{Q}_i(A)}(a) \right]
\]

\[
\leq \left[ \bigvee_{i=1}^n T_{R_i(A)}(a) \right] \land \left[ \bigvee_{i=1}^n T_{\overline{Q}_i(A)}(a) \right]
\]

\[
= T_{M^O(A)}(a) \land T_{N^O(A)}(a)
\]

\[
= T_{M^O(A)\lor N^O(A)}(a),
\]

\[
I_{M\lor N^O(A)}(a) = \bigwedge_{i=1}^n I_{R_i\lor \overline{Q}_i(A)}(a) = \bigwedge_{i=1}^n T_{R_i(A)\lor \overline{Q}_i(A)}(a)
\]

\[
= \bigwedge_{i=1}^n \left[ I_{R_i(A)}(a) \lor T_{\overline{Q}_i(A)}(a) \right]
\]

\[
\geq \left[ \bigwedge_{i=1}^n I_{R_i(A)}(a) \right] \lor \left[ \bigwedge_{i=1}^n T_{\overline{Q}_i(A)}(a) \right]
\]

\[
= I_{M^O(A)}(a) \lor I_{N^O(A)}(a)
\]

\[
= I_{M^O(A)\lor N^O(A)}(a),
\]

Hence, \( M \lor N^O(A) \subseteq M^O(A) \lor N^O(A) \).

(2) \( \forall a \in X \), by Lemma 1 and Definition 6, we have the following:

\[
T_{M\land N^O(A)}(a) = \bigwedge_{i=1}^n T_{R_i\land \overline{Q}_i(A)}(a) = \bigwedge_{i=1}^n T_{R_i(A)\land \overline{Q}_i(A)}(a)
\]

\[
= \bigwedge_{i=1}^n \left[ T_{R_i(A)}(a) \land T_{\overline{Q}_i(A)}(a) \right]
\]

\[
\geq \left[ \bigwedge_{i=1}^n T_{R_i(A)}(a) \right] \land \left[ \bigwedge_{i=1}^n T_{\overline{Q}_i(A)}(a) \right]
\]

\[
= T_{M^O(A)}(a) \land T_{N^O(A)}(a) = T_{M^O(A)\land N^O(A)}(a),
\]

\[
I_{M\land N^O(A)}(a) = \bigvee_{i=1}^n I_{R_i\land \overline{Q}_i(A)}(a) = \bigvee_{i=1}^n I_{R_i(A)\land \overline{Q}_i(A)}(a)
\]

\[
= \bigvee_{i=1}^n \left[ I_{R_i(A)}(a) \lor I_{\overline{Q}_i(A)}(a) \right]
\]

\[
\leq \left[ \bigvee_{i=1}^n I_{R_i(A)}(a) \right] \lor \left[ \bigvee_{i=1}^n I_{\overline{Q}_i(A)}(a) \right]
\]

\[
= I_{M^O(A)}(a) \lor I_{N^O(A)}(a)
\]

\[
= I_{M^O(A)\lor N^O(A)}(a),
\]

Hence, \( M \land N^O(A) \supseteq M^O(A) \lor N^O(A) \).
(3) \( \forall a \in X \), by Lemma 1 and Definition 6, we have the following:

\[
T_{M \wedge N^o(A)}(a) = \bigvee_{i=1}^{n} T_{R_\ast \wedge Q_i^\ast (A)}(a) \geq \bigvee_{i=1}^{n} T_{R_\ast \wedge \overline{Q_i^\ast (A)}}(a) = \bigvee_{i=1}^{n} \left[ T_{R_i^\ast (A)}(a) \wedge T_{\overline{Q_i^\ast (A)}}(a) \right] = \left[ \bigvee_{i=1}^{n} T_{R_i^\ast (A)}(a) \right] \wedge \left[ \bigvee_{i=1}^{n} T_{\overline{Q_i^\ast (A)}}(a) \right] = T_{M^O(A)}(a) \wedge T_{\overline{N^O(A)}}(a) \geq T_{M^O(A)}(a) \wedge T_{N^O(A)}(a),
\]

\[
I_{M \wedge N^o(A)}(a) = \bigwedge_{i=1}^{n} I_{R_i^\ast \wedge Q_i^\ast (A)}(a) \leq \bigwedge_{i=1}^{n} I_{R_i^\ast \wedge \overline{Q_i^\ast (A)}}(a) = \bigwedge_{i=1}^{n} \left[ I_{R_i^\ast (A)}(a) \wedge I_{\overline{Q_i^\ast (A)}}(a) \right] = \left[ \bigwedge_{i=1}^{n} I_{R_i^\ast (A)}(a) \right] \wedge \left[ \bigwedge_{i=1}^{n} I_{\overline{Q_i^\ast (A)}}(a) \right] = I_{M^O(A)}(a) \wedge I_{\overline{N^O(A)}}(a) \leq I_{M^O(A)}(a) \wedge I_{N^O(A)}(a),
\]

\[
F_{M \wedge N^o(A)}(a) = \bigwedge_{i=1}^{n} F_{R_i^\ast \wedge Q_i^\ast (A)}(a) \leq \bigwedge_{i=1}^{n} F_{R_i^\ast \wedge \overline{Q_i^\ast (A)}}(a) = \bigwedge_{i=1}^{n} \left[ F_{R_i^\ast (A)}(a) \wedge F_{\overline{Q_i^\ast (A)}}(a) \right] = \left[ \bigwedge_{i=1}^{n} F_{R_i^\ast (A)}(a) \right] \wedge \left[ \bigwedge_{i=1}^{n} F_{\overline{Q_i^\ast (A)}}(a) \right] = F_{M^O(A)}(a) \wedge F_{\overline{N^O(A)}}(a) \leq F_{M^O(A)}(a) \wedge F_{N^O(A)}(a).
\]

Hence, \( M \wedge N^o(A)\) \( \supseteq \) \( M^O(A) \wedge N^o(A)\) \( \supseteq \) \( M^O(A) \cap N^O(A)\).

(4) \( \forall a \in X \), by Lemma 1 and Definition 6, we have the following:

\[
T_{M \wedge N^o(A)}(a) = \bigvee_{i=1}^{n} T_{R_\ast \wedge Q_i^\ast (A)}(a) \leq \bigvee_{i=1}^{n} T_{R_\ast \wedge \overline{Q_i^\ast (A)}}(a) = \bigvee_{i=1}^{n} \left[ T_{R_i^\ast (A)}(a) \wedge T_{\overline{Q_i^\ast (A)}}(a) \right] = \left[ \bigvee_{i=1}^{n} T_{R_i^\ast (A)}(a) \right] \wedge \left[ \bigvee_{i=1}^{n} T_{\overline{Q_i^\ast (A)}}(a) \right] = T_{M^O(A)}(a) \wedge T_{\overline{N^O(A)}}(a) = T_{M^O(A) \cap \overline{N^O(A)}}(a),
\]

\[
I_{M \wedge N^o(A)}(a) = \bigwedge_{i=1}^{n} I_{R_i^\ast \wedge Q_i^\ast (A)}(a) \geq \bigwedge_{i=1}^{n} I_{R_i^\ast \wedge \overline{Q_i^\ast (A)}}(a) = \bigwedge_{i=1}^{n} \left[ I_{R_i^\ast (A)}(a) \wedge I_{\overline{Q_i^\ast (A)}}(a) \right] = \left[ \bigwedge_{i=1}^{n} I_{R_i^\ast (A)}(a) \right] \wedge \left[ \bigwedge_{i=1}^{n} I_{\overline{Q_i^\ast (A)}}(a) \right] = I_{M^O(A)}(a) \wedge I_{\overline{N^O(A)}}(a) \geq I_{M^O(A)}(a) \wedge I_{N^O(A)}(a),
\]

\[
F_{M \wedge N^o(A)}(a) = \bigwedge_{i=1}^{n} F_{R_i^\ast \wedge Q_i^\ast (A)}(a) \geq \bigwedge_{i=1}^{n} F_{R_i^\ast \wedge \overline{Q_i^\ast (A)}}(a) = \bigwedge_{i=1}^{n} \left[ F_{R_i^\ast (A)}(a) \wedge F_{\overline{Q_i^\ast (A)}}(a) \right] = \left[ \bigwedge_{i=1}^{n} F_{R_i^\ast (A)}(a) \right] \wedge \left[ \bigwedge_{i=1}^{n} F_{\overline{Q_i^\ast (A)}}(a) \right] = F_{M^O(A)}(a) \wedge F_{\overline{N^O(A)}}(a) \geq F_{M^O(A)}(a) \wedge F_{N^O(A)}(a).
\]

Hence, \( M \wedge \overline{N^O(A)}\) \( \subseteq \) \( M^O(A) \cap \overline{N^O(A)}\). □

From Theorem 2, we can easily obtain the following corollary:
Corollary 1. Let $M = \{R_i\}_{i=1}^{m}$ and $N = \{Q_i\}_{i=1}^{n}$ be two multigranulation neutrosophic relations set on $X$. If $M \subseteq N$, then $\forall A \in SVNS(X)$,

$$N^O(A) \subseteq M^O(A), \; N^P(A) \subseteq M^P(A), \; \bar{M}^O(A) \subseteq N^O(A), \; \bar{M}^P(A) \subseteq N^P(A).$$

Let $H_p^O = \{\bar{M}^P \mid M \in n - SVNR(X)\}$ and $L_p^O = \{M^O \mid M \in n - SVNR(X)\}$ be the set of pessimistic multigranulation neutrosophic upper and lower approximation operators in $X$, respectively.

- Defined a relation $\preceq$ on $H_p^O$ as follows: $\bar{M}^P \preceq N^P$ if and only if $\bar{M}^P(A) \subseteq N^P(A)$ for each $A \in SVNS(X)$. Then $(H_p^O, \preceq)$ is a poset.
- Defined a relation $\preceq$ on $L_p^O$ as follows: $M^O \preceq N^O$ if and only if $M^O(A) \subseteq N^O(A)$ for each $A \in SVNS(X)$. Then $(L_p^O, \preceq)$ is a poset.

Let $H_p^O = \{\bar{M}^O \mid M \in n - SVNR(X)\}$ and $L_p^O = \{M^O \mid M \in n - SVNR(X)\}$ be the set of optimistic multigranulation neutrosophic upper and lower approximation operators in $X$, respectively.

- Defined a relation $\preceq$ on $H_p^O$ as follows: $\bar{M}^O \preceq N^O$ if and only if $\bar{M}^O(A) \subseteq N^O(A)$ for each $A \in SVNS(X)$. Then $(H_p^O, \preceq)$ is a poset.
- Defined a relation $\preceq$ on $L_p^O$ as follows: $M^O \preceq N^O$ if and only if $M^O(A) \subseteq N^O(A)$ for each $A \in SVNS(X)$. Then $(L_p^O, \preceq)$ is a poset.

Theorem 3. (1) $\forall \{\bar{M}^O_i\}_{i \in I} \subseteq (H_p^O, \preceq)$ and $I$ be a index set, we can define union and intersection of $\bar{M}^O_i$ as follows:

$$\vee_{i \in I} \bar{M}^O_i = \bigvee_{i \in I} \bar{M}^O_i, \; \wedge_{i \in I} \bar{M}^O_i = \bigwedge_{i \in I} \bar{M}^O_i,$$

where $\bigvee_{i \in I} M^O_i = \bigvee_{i \in I} \bar{M}^O_i$, $\bigwedge_{i \in I} M^O_i = \bigwedge_{i \in I} \bar{M}^O_i.$

Then $\vee_{i \in I} \bar{M}^O_i$ and $\wedge_{i \in I} \bar{M}^O_i$ are supremum and infimum of $\{\bar{M}^O_i\}_{i \in I}$, respectively.

(2) $\forall \{\bar{M}^P_i\}_{i \in I} \subseteq (L_p^O, \preceq)$ and $I$ be a index set, we can define union and intersection of $\bar{M}^P_i$ as follows:

$$\vee_{i \in I} \bar{M}^P_i = \bigvee_{i \in I} M^P_i, \; \wedge_{i \in I} \bar{M}^P_i = \bigwedge_{i \in I} M^P_i,$$

where $\bigvee_{i \in I} M^P_i = \bigvee_{i \in I} \bar{M}^P_i$, $\bigwedge_{i \in I} M^P_i = \bigwedge_{i \in I} \bar{M}^P_i.$

Then $\vee_{i \in I} \bar{M}^P_i$ and $\wedge_{i \in I} \bar{M}^P_i$ are supremum and infimum of $\{\bar{M}^P_i\}_{i \in I}$, respectively.

Proof. We only show (1).

Let $M = \bigvee_{i \in I} M_i$, then $M_i \subseteq M$ for each $i \in I$. By Corollary 1, we have $M^P_i(A) \subseteq M^P(A)$ for any $A \in SVNS(X)$. Thus $M^P_i \preceq M^P$. If $M^*$ is a multigranulation neutrosophic relations set such that $M^*_i \preceq M^*$ for each $i \in I$, then $A \in SVNS(X)$, $M^O_i(A) \subseteq \bar{M}^P(A)$. Hence,

$$\bar{M}^P(A) = \bigvee_{i \in I} M^P_i(A) = \bigvee_{i \in I} \bar{M}^P_i(A) \subseteq \bar{M}^P(A).$$

Thus $\bar{M}^P \preceq \bar{M}^P$. So $\vee_{i \in I} M^O_i = \bigvee_{i \in I} M^O_i$ is the supremum of $\{M^O_i\}_{i \in I}$.

Let $Q = \bigwedge_{i \in I} M_i$, then $\forall B \in SVNS(X)$, we have

$$Q^P(B) = \bigwedge_{i \in I} M_i^P(B) \subseteq \bigwedge_{i \in I} \bar{M}^P_i(B) \subseteq \bar{M}^P_i(B).$$
Thus $\overline{Q}^p \leq \overline{M}_i^p$ for each $i \in I$. If $M^*$ is a multigranulation neutrosophic relations set such that $M^p \leq \overline{M}_i^p$ for each $i \in I$, then

$$M^p(A) \subseteq \bigcap_{i \in I} \overline{M}_i^p(A).$$

By the construction of $[\wedge M_i]$, we can easily obtain $M^* \subseteq [\wedge M_i] = Q$. Hence,

$$M^p \leq [\wedge M_i]^p = \overline{Q}^p,$$

So $\wedge M_i^p = [\wedge M_i]^p$ is the infimum of $\{M_i^p\}_{i \in I}$. □

Remark 2. (1) $\forall A \in \text{SVNS}(X)$, $\forall a \in X$, we can calculate that the following formula holds.

$$T_{\overline{O}_N}(a) = 0, \quad I_{\overline{O}_N}(a) = 1, \quad F_{\overline{O}_N}(a) = 1,$$

$$T_{\overline{O_D}}(a) = 1, \quad I_{\overline{O_D}}(a) = 0, \quad F_{\overline{O_D}}(a) = 0.$$

Hence, $\forall M \in n - \text{SVNR}(X)$, $\overline{\overline{O}_N}(a) \subseteq M^p(A)$ and $M^p(A) \subseteq \overline{\overline{O}_D}(A)$. It shows that $\overline{\overline{O}_N} \leq \overline{M}_i^p$ and $\overline{\overline{O}_N} \leq M^p$, i.e., $\overline{\overline{O}_N}$ is the bottom element of $(H_n^p, \leq)$ and $\overline{\overline{O}_D}$ is the bottom element of $(L_n^p, \leq)$. By Theorem 3, we have the following result: Both $(H_n^p, \leq, \wedge, \vee)$ and $(L_n^p, \leq, \wedge, \vee)$ are complete lattices.

(2) Similarly, we can prove that both $(H_n^O, \leq, \wedge, \vee)$ and $(L_n^O, \leq, \wedge, \vee)$ are complete lattices if we can use the generalization formula of

$$\overline{M} \vee \overline{N}^O(A) \equiv \overline{M}^O(A) \cup \overline{N}^O(A)$$

However, by Theorem 2, we known that

$$\overline{M} \vee \overline{N}^O(A) \equiv \overline{M}^O(A) \cup \overline{N}^O(A) \supseteq M \vee N^O(A) \equiv M^O(A) \cap N^O(A).$$

So, naturally, there is the following problem:

How to give the supremum and infimum of the optimistic multigranulation neutrosophic rough approximation operators?

In the one-dimensional case, for convenience, we will use $H = \{\overline{R} \mid R \in \text{SVNR}(X)\}$ and $L = \{\overline{R} \mid R \in \text{SVNR}(X)\}$ to denote the set of neutrosophic upper and lower approximation operators in $X$, respectively. According to Lemma 1, Remark 2 and Theorem 3, we have the following result: both $(H, \leq, \wedge, \vee)$ and $(L, \leq, \wedge, \vee)$ are complete lattices (it is also the one-dimensional case of Reference [23]).

4. The Relationship between Complete Lattices $(H, \leq, \wedge, \vee)$ and $(L, \leq, \wedge, \vee)$

In this section, we will study the relationship between complete lattices $(H, \leq, \wedge, \vee)$ and $(L, \leq, \wedge, \vee)$. Set

$$A = \{\text{SVNR}(X) \mid \forall R_1, R_2 \in \text{SVNR}(X), \overline{R}_1 \leq \overline{R}_2 \iff R_1 \subseteq R_2 \iff R_1 \leq R_2\}.$$

Firstly, we will give an example to illustrate that $A$ is not an empty family.

Example 1. Let $X = \{a\}$ be a single point set, $R_1$ and $R_2$ are two single valued neutrosophic relations in $X$.

(1) If $\overline{R}_1 \leq \overline{R}_2$, then $R_1 \subseteq R_2$. In fact, if $\overline{R}_1 \leq \overline{R}_2$, then $\overline{R}_1(A) \subseteq \overline{R}_2(A)$ for each $A \in \text{SVNS}(\{a\})$. 
Thus, \( \forall a \in X, \)
\[
T_{R_1}(a) \leq T_{R_2}(a), \quad I_{R_1}(a) \leq I_{R_2}(a), \quad \text{and} \quad F_{R_1}(a) \geq F_{R_2}(a).
\]
Moreover, \( T_{R_1}(a, a) \land T_A(a) \leq T_{R_2}(a, a) \land T_A(a), \) \( I_{R_1}(a, a) \lor I_A(a) \leq I_{R_2}(a, a) \lor I_A(a), \) and \( F_{R_1}(a, a) \lor F_A(a) \geq F_{R_2}(a, a) \lor F_A(a). \) Considering the arbitrariness of \( A, \) in particular, take \( A = \{ < a, (1, 0, 0) > \}, \) we have \( T_{R_1}(a, a) \leq T_{R_2}(a, a), I_{R_1}(a, a) \leq I_{R_2}(a, a) \) and \( F_{R_1}(a, a) \geq F_{R_2}(a, a). \)

Hence, \( R_1 \preceq R_2. \)

Similarly, we also can show the following result:

(2) If \( R_1 \preceq R_2, \) then \( R_1 \preceq R_2. \) So, by (1), (2) and Corollary 1, we have \( \SVNR\{\{a\}\} \in A, \) i.e., \( A \) is not an empty family.

Now, we will give the relationship between complete lattices \( (H, \leq, \wedge, \vee) \) and \( (L, \leq, \wedge, \vee). \)

**Proposition 1.** If \( \SVNR(X) \in A, \) then \( [\bigcap_{i \in I} R_i] = \bigcap_{i \in I} R_i = [\bigcup_{i \in I} R_i], \) where \( I \) is a index set, and \( R_i \in \SVNR(X) \) for each \( i \in I. \)

**Proof.** We first show that \( [\bigcap_{i \in I} R_i] = \bigcap_{i \in I} R_i. \) Let \( R \) be a neutrosophic relation in \( X \) such that \( \bigcap_{i \in I} R_i(A) \supseteq R(A) \) for each \( A \in \SVNS(X), \) then \( R \supseteq R \), this is equivalent to \( R \supseteq R \) since \( \SVNR(X) \in A. \) Thus \( [\bigcap_{i \in I} R_i] \supseteq R. \) Moreover, by the construction of \( [\bigcup_{i \in I} R_i], \) we have \( [\bigcap_{i \in I} R_i] \supseteq [\bigcup_{i \in I} R_i]. \) On the other hand, we can show that \( [\bigcup_{i \in I} R_i] \supseteq [\bigcap_{i \in I} R_i] \) for each \( A \in \SVNS(X). \) So

\[
[\bigcap_{i \in I} R_i] = \bigcup\{ R \in \SVNR(X) | \forall A \in \SVNS(X), [\bigcap_{i \in I} R_i(A)] \supseteq R(A) \} \supseteq [\bigcup_{i \in I} R_i].
\]

Hence \( [\bigcup_{i \in I} R_i] = [\bigcap_{i \in I} R_i] \).

Now, we show that \( \bigcap_{i \in I} R_i = [\bigcup_{i \in I} R_i]. \) Let \( R \) be a single valued neutrosophic relation in such that \( \bigcup_{i \in I} R_i(A) \supseteq R(A) \) for each \( A \in \SVNS(X), \) then \( R \supseteq R \), this is equivalent to \( R \supseteq R \) since \( \SVNR(X) \in A. \) Thus \( [\bigcup_{i \in I} R_i] \supseteq R. \) Moreover, by the construction of \( [\bigcup_{i \in I} R_i], \) we have \( [\bigcup_{i \in I} R_i] \supseteq [\bigcup_{i \in I} R_i]. \)

On the other hand, we can show that \( [\bigcup_{i \in I} R_i] \supseteq [\bigcup_{i \in I} R_i] \) for each \( A \in \SVNS(X). \) So

\[
[\bigcup_{i \in I} R_i] = \bigcup\{ R \in \SVNR(X) | \forall A \in \SVNS(X), [\bigcup_{i \in I} R_i(A)] \supseteq R(A) \} \supseteq [\bigcup_{i \in I} R_i].
\]

Hence, \( [\bigcap_{i \in I} R_i] = [\bigcup_{i \in I} R_i] \).

From above proved, we know that \( [\bigcap_{i \in I} R_i] = [\bigcup_{i \in I} R_i] = [\bigcup_{i \in I} R_i]. \) □

**Theorem 4.** If \( \SVNR(X) \in A, \) then \( (\SVNR(X), \subseteq, \cup, \cap) \) and \( (H, \leq, \wedge, \vee) \) are complete lattice isomorphism.

**Proof.** Define a mapping \( \phi_{12} : \SVNR(X) \rightarrow H \) as follows: \( \forall R \in \SVNR(X), \) \( \phi_{12}(R) = R. \) Obviously, \( \phi_{12} \) is surjective. If \( R_1 \equiv R_2, \) notice that \( \SVNR(X) \in A, \) we know that \( R_1 = R_2. \) So \( \phi_{12} \) is one-one. \( \forall \{ R_i \}_{i \in I} \subseteq \SVNR(X) \) and \( I \) be a index set. By Theorem 3 and Proposition 1, we have

\[
\phi_{12}(\bigcup_{i \in I} R_i) = \bigcup_{i \in I} R_i = \bigvee_{i \in I} R_i = \bigvee_{i \in I} \phi_{12}(R_i),
\]

and

\[
\phi_{12}(\bigcap_{i \in I} R_i) = \bigcap_{i \in I} R_i = \bigwedge_{i \in I} R_i = \bigwedge_{i \in I} \phi_{12}(R_i).
\]

Hence, \( \phi_{12} \) preserves arbitrary union and arbitrary intersection. □

From above proved, we know that \( (\SVNR(X), \subseteq, \cup, \cap) \) and \( (H, \leq, \wedge, \vee) \) are complete lattice isomorphism.
Theorem 5. If $\text{SVNR}(X) \in \mathcal{A}$, then $(\text{SVNR}(X), \sqsubseteq, \sqsubset, \sqsupset, \sqsubseteq, \sqsupset)$ are complete lattice isomorphism.

Proof. Define a mapping $\phi_{13} : \text{SVNR}(X) \rightarrow L$ as follows: $\forall \mathcal{R} \in \text{SVNR}(X), \phi_{13}(\mathcal{R}) = \mathcal{R}$. Obviously, $\phi_{13}$ is surjective. If $\mathcal{R}_1 = \mathcal{R}_2$, notice that $\text{SVNR}(X) \in \mathcal{A}$, we know that $\mathcal{R}_1 = \mathcal{R}_2$. So $\phi_{13}$ is one-one. $\forall \{\mathcal{R}_i\}_{i \in I} \subseteq \text{SVNR}(X)$ and $I$ be an index set. By Theorem 3 and Proposition 1, we have

$$\phi_{13}(\bigvee_{i \in I} \mathcal{R}_i) = \bigvee_{i \in I} \phi_{13}(\mathcal{R}_i) = \bigvee_{i \in I} \mathcal{R}_i,$$

and

$$\phi_{13}(\bigwedge_{i \in I} \mathcal{R}_i) = \bigwedge_{i \in I} \phi_{13}(\mathcal{R}_i) = \bigwedge_{i \in I} \mathcal{R}_i.$$

Hence, $\phi_{13}$ preserves arbitrary union and arbitrary intersection. □

From the above proof, we know that $(\text{SVNR}(X), \sqsubseteq, \sqsubset, \sqsupset, \sqsubseteq, \sqsupset)$ are complete lattice isomorphism.

Theorem 6. If $\text{SVNR}(X) \in \mathcal{A}$, then $(H, \sqsubseteq, \sqsubset, \sqsupset, \sqsubseteq, \sqsupset)$ are complete lattice isomorphism.

Proof. Through Theorems 4 and 5, we immediately know that the conclusion holds. We can also prove it by the following way:

Define a mapping $\phi_{23} : H \rightarrow L$ as follows: $\forall \mathcal{R} \in H, \phi_{23}(\mathcal{R}) = \mathcal{R}$. Through Theorems 4 and 5, there must be one and only one $\mathcal{R} \in \text{SVNR}(X)$ such that $\phi_{23}(\mathcal{R}) = \mathcal{R}$ for each $\mathcal{R} \in L$. This shows $\phi_{23}$ is surjective. If $\mathcal{R}_1 = \mathcal{R}_2$, notice that $\text{SVNR}(X) \in \mathcal{A}$, we know that $\mathcal{R}_1 = \mathcal{R}_2$. So $\phi_{23}$ is one-one. $\forall \{\mathcal{R}_i\}_{i \in I} \subseteq H$ and $I$ be a index set. Through Theorem 3 and Proposition 1, we have

$$\phi_{23}(\bigvee_{i \in I} \mathcal{R}_i) = \bigvee_{i \in I} \phi_{23}(\mathcal{R}_i) = \bigvee_{i \in I} \mathcal{R}_i,$$

and

$$\phi_{23}(\bigwedge_{i \in I} \mathcal{R}_i) = \bigwedge_{i \in I} \phi_{23}(\mathcal{R}_i) = \bigwedge_{i \in I} \mathcal{R}_i.$$

Hence, $\phi_{23}$ preserves arbitrary union and arbitrary intersection. So, $(H, \sqsubseteq, \sqsubset, \sqsupset, \sqsubseteq, \sqsupset)$ are complete lattice isomorphism. □

Remark 3. Through Theorems 4–6, we can ascertain that $\phi_{12}, \phi_{13}$ and $\phi_{23}$ are isomorphic mappings among complete lattices. Moreover, the following diagram can commute, i.e., $\phi_{23} \circ \phi_{12} = \phi_{13}$ (see Figure 1).

\[\text{(SVNR}(X), \sqsubseteq, \sqsubset, \sqsupset, \sqsubseteq, \sqsupset) \xrightarrow{\phi_{12}} (H, \sqsubseteq, \sqsubset, \sqsupset, \sqsubseteq, \sqsupset) \xrightarrow{\phi_{23}} (L, \sqsubseteq, \sqsubset, \sqsupset, \sqsubseteq, \sqsupset)\]

Figure 1. Correspondence relationship among three complete lattices.

5. Conclusions

Following the idea of multigranulation neutrosophic rough sets on a single domain as introduced by Bo et al. (2018), we gave the lattice structure of the pessimistic multigranulation neutrosophic rough approximation operators. In the one-dimensional case, for each special SVNR(X), we gave a
one-to-one correspondence relationship between complete lattices \((H, \leq)\) and \((L, \leq)\). Unfortunately, at the moment, we haven’t solved the following problems:

1. Can the supremum and infimum of the optimistic multigranulation neutrosophic rough approximation operators be given?
2. For any set, are \((H, \leq)\) and \((L, \leq)\) isomorphic between complete lattices?

**Author Contributions:** H.Z. provided the idea of the paper and proved the theorems. H.-Y.Z. provided helpful suggestions.

**Funding:** This research received no external funding.

**Acknowledgments:** The work is partly supported by the National Natural Science Foundation of China (Grant No. 61473181, 11771263 and 11671007), the Doctoral Scientific Research Foundation of Xi’an Polytechnic University (Grant No. BS1426), the Construction Funding of Xi’an Polytechnic University for Mathematics (Grant No. 107090701), and the Scientific Research Program Funded by Shaanxi Provincial Education Department (2018).

**Conflicts of Interest:** The authors declare no conflict of interest.

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