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A Characterization of the Annihilators of a Rough Semiring

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***Abstract:** In this paper, the annihilators of a Rough Semiring (T, Δ, ∇) are defined. An equivalence relation is defined on these set of annihilator. It is proved that the set of classes induced by this equivalence relation on the set of annihilators forms a Boolean algebra.*

***Key Words:** Rough Set Theory, Semiring, Annihilators, Ideals.*

I. INTRODUCTION

The Semiring is an algebraic structure which was introduced by H.S. Vandiver in 1934. The concept of Rough set Theory was introduced by Pawlak [6] in 1982 to deal with uncertain [2] information and it is defined as a pair of sets called lower and upper approximations. Some authors approached this Rough set Theory and semiring algebraically. Praba and Mohan [7] discussed the concept of rough lattice and the Characterization of Rough Semiring was discussed in [10]. In [1], authors discussed the ideals of a commutative rough semiring and a characterization for the ideals of a rough semiring in terms of the principal ideals of the rough monoid for a given information system. Zero divisor graph of this rough lattice is constructed [8]. In [9], authors introduced the rough fuzzy ideals of a semiring and rough fuzzy prime ideals of a semiring. In [3], authors constructed the 0-1 matrix M by using Semilattice and they discussed the characterization of the matrix. John D.LaGrange [4] examined the connections between the algebraic and graph-theoretic annihilators and discussed about the Zero divisor graph using these annihilators.

In Section 2, we give the preliminary definitions. In section 3, we define the annihilators of a Rough Semiring (T, Δ,∇). An equivalence relation R_1 is defined on the set of Annihilators and the characterization of these annihilators are described in section 4, we proved that the set of equivalence classes induced by these annihilators forms a Boolean algebra which is isomorphic to the power set of the Boolean algebra. We give the conclusion in section 5.

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II. PRELIMINARIES

In this section, we give the necessary definitions, that are required for the forthcoming sections.

A. Graph Theory

Definition 2.1: (Annihilator) [5] Let S be a commutative semigroup with 0. Given any $a \in S, \mathrm{ann}_s(a) = \{x \in S \mid x \Lambda a = 0\}$.

In general, if $\emptyset \neq A \subseteq S$, then the set $\mathrm{ann}_s(A) = \{\mathrm{ann}_s(a) \mid a \in A\}$ is called the annihilator of A in S.

Definition 2.2: A subset X of U is said to be dominant if $X \cap X_i \neq \emptyset$ for $i = 1,2,3 \ldots, n$.

B. Rough Set Theory

Let = $I = (U, A)$be an information system, where U is a non empty set of finite objects, called the universe and A is a non empty finite set of fuzzy attributes defined by $\mu_a : U \rightarrow [0,1], a \in A$, is a fuzzy set. With any $P \subseteq A$, there is an associated equivalence relation called $IND(P)$ defined as $IND(P) = \{(x, y) \in U^2 \mid \forall a \in P,\ \mu_a(x) = \mu_a(y)\}$. The partition induced by $IND(P)$consists of equivalence classes defined by $[x]_p = \{y \in U \mid (x, y) \in IND(P)\}$. For any $X \subseteq U$, define the lower approximation space $P\_(X)$ such that $P\_(X) = \{x \in U \mid [x]_p \subseteq X\}$. Also, define the upper approximation space $P^-(X)$ such that $P^-(X) = \{\{x \in U \mid [x]_p \cap X \neq \emptyset\}$.

Definition 2.3: Let U be non empty finite set of objects, called universal set. For any $X \subseteq U$, the Rough set corresponding to X is an ordered pair $RS(X) = (P\_(X), P^-(X))$

Definition 2.4: If $X \subseteq U$, then the number of equivalence classes(Induced by $IND(P)$) contained in X is called as the Ind.weight of X. It is denoted by $IW(X)$.

Definition 2.5: Let $X, Y \subseteq U$, The Praba Δ is defined as $X \Delta Y = X \cup Y$ if $IW(X \cup Y) = IW(X) + IW(Y) - IW(X \cap Y)$. If $IW(X \cup Y) > IW(X) + IW(Y) - IW(X \cap Y)$, then identify the equivalence class obtained by the union of X and Y. Then delete the elements of that class belonging to Y. Call the new set as Y. Now obtain X ΔY. Repeat the process until $IW(X \cup Y) = IW(X) + IW(Y) - IW(X \cap Y)$.

Definition 2.6: If $X, Y \subseteq U$, then an element $X \in U$ is called a Pivot element, if $[x]_P \nsubseteq X \cap Y$, but $[x]_P \cap X \neq \phi$ and $[x]_P \cap Y \neq \phi$ and the set of Pivot elements of X and Y is called the Pivot set of X and Y
and is denoted by $P_{X \cap Y}$.

Definition 2.7: Praba ∇ of X and Y is denoted by $X\nabla Y$ and it is defined as $X\nabla Y = \{x\in U \mid [x]_P \subseteq X\cap Y\} \cup P_{X\cap Y}$, where $X, Y \subseteq U$.

Note that each Pivot element in $P_{X\cap Y}$ is the representative of that particular class.

Theorem 1: Let $I = (U, A)$ be an information system, where U be the universal (finite) set and A be the set of fuzzy attributes and T be the set of all rough sets then (T, Δ,∇) is a Semiring is called as a Rough Semiring.

Example-1: Let $U = \{x_1, x_2, x_3, x_4, x_5, x_6\}$ and $X_1 = \{x_1, x_3\}$; $X_2 = \{x_2, x_4, x_6\}$; $X_3 = \{x_5\}$; The Lattice corresponding to this semiring is shown in Figure-1.

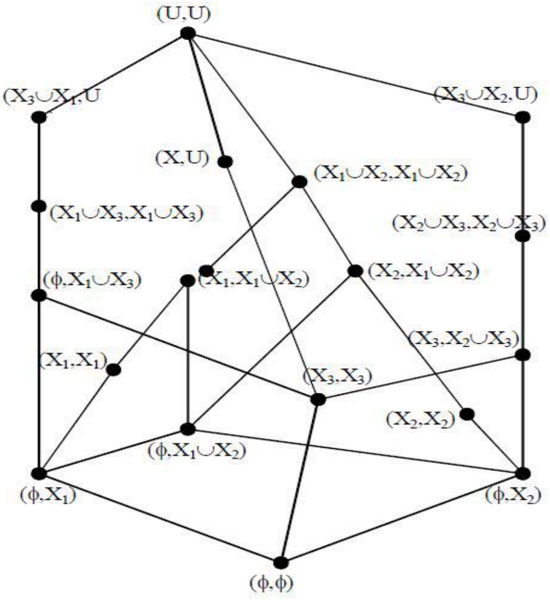

Figure 1 Rough Lattice

Remark: $|T| = 2^{n-m} \times 3^m$, where n is the number of equivalence classes induced by $IND(P)$ and m is the number of equivalence classes whose cardinality is equal to one.

Theorem 2: Let $I = (U, A)$ be an information system. If a subset X of U is not dominant then RS(X) is a zero divisor of the rough semiring (T, Δ,∇).

Theorem 3: Let (T, Δ,∇) be a rough semiring. If a subset X of U is dominant then RS(X) is not a zero divisor in T.

Definition 2.8: Let $I = (U, A)$ be an information system. $U = \cup_{i=r}^{r} X_i$ be the union of equivalence classes induced by $IND(P)$ and $T = \{RS(X) \mid X \subseteq U\}$. Choose a representative X_i from each equivalence class X_i whose cardinality is greater than one. Let $B = \{x_i \mid x_i\in X_i\}$ and $|X_i| > 1\}$ be the pivot set of the information system I consisting of the representative elements of the equivalence classes X_i whose cardinality is greater than one. Let $J = \{RS(X) \mid X \in \mathcal{P}(B)\}$. This subset J of T is called as the set of Pivot Rough Sets on U.

Definition 2.9: Consider the Rough Semiring (T, Δ,∇). A left or right rough ideal of a Rough semiring is a non empty subset J of T such that

(a) $RS(X)\ \Delta RS(Y) \in J$ for all $RS(X), RS(Y) \in J$ and

(b) $RS(X)\nabla RS(Y) \in J$ and $RS(Y)\nabla RS(X) \in J$ for all $RS(Y) \in J$ and $RS(X) \in T$.

Remark: The Pivot rough set (J) is an Rough ideal of the Rough semiring (T, Δ,∇).

Definition 2.10: (Rough Zero Divisor on a Rough Semiring) Let (T, Δ,∇) be a commutative Rough semiring. An element $RS(X) \neq RS(\phi)$ of T is said to be a zero divisor of T if there exist $RS(Y) \neq RS(\phi)$in T such that $RS(X)\nabla RS(Y) = RS(\phi)$ i.e., $RS(X\nabla Y) = RS(\phi)$.

Definition 2.11: (Zero divisor Graph of a Rough Semiring) The zero divisor graph of a rough semiring (T, Δ,∇) is $T(G) = V, E)$ where V is the set of vertices in $T(G)$ consists of non-empty zero divisors i.e., $V = \{RS(X) \in T \mid RS(X) \neq RS(\phi)$ is a zero divisor of $T\}$ and E is the set of edges connecting the elements of V such that there is an edge connecting RS(X) and RS(Y) in V if $RS(X)\nabla RS(Y) = RS(\phi)$. This graph is called as Rough zero divisor graph of the Rough semiring T.

In the following section, we consider U as an non-empty finite set of objects together with an equivalence relation R on U. We call $I = (U, R)$ as an approximation space.

III. ANNIHILATORS OF THE ROUGH SEMIRING

Let $I = (U, R)$ as an approximation space, where U is a nonempty finite set of objects and R is an equivalence relation on U. For any subset X of U, $RS(X)$ is defined by, $RS(X) = (R_{-}(X), R^{-}(X))$ where $R_{-}(X) = \{\, x \in U \mid [x] \subseteq X \,\} = \{x \in U \mid [x] \subseteq X\}$ and $R^{-}(X) = \{\, x \in U \mid [x] \cap X \neq \phi \,\}$. Let us assume that $\{X_1, X_{2,\dots,}X_n\}$are the n equivalence classes, induced by R. Without loss of generality, let us assume that there are m-equivalence classes with cardinality greater that 1. Say $\{X_1, X_{2,\dots,}X_m\}$ and the remaining n-m classes have cardinality equal to 1. Let us assume that they are $\{X_{m+1}, X_{m+2,\dots,}X_n\}$ and $\{x_i \in X_i, 1 \le i \le m\}$ are the pivot elements (representative elements) of the equivalence x class whose cardinality is greater than 1. Let $E = \{X_1, X_{2,\dots,}X_n\}$, $E = \{x_1, x_2, \dots, x_m\}$ and $I = \{x_1, x_2, \dots, x_m, X_{m+1}, X_{m+2,\dots,}X_n\}$, $T = \{RS(X) \mid X \subseteq U\}$, then (T, Δ, ∇) is a semiring called as rough semiring and $|T| = 2^{n-m}x3^m$.

Definition 3.1: Given a Rough semiring (T, Δ, ∇) define a 0-1 matrix by $M(T) = (M)_{XY}$ where

$$(M)_{XY} = \begin{cases} 1 \ if\ RS(X)\Delta RS(Y) \neq RS(\phi) \\ 0 \qquad\qquad\qquad otherwise \end{cases}$$

Note that $M(T)$ is a square matrix of order $2^{n-m}x3^m$.

Definition 3.2: Let(T, Δ, ∇) be a Rough Semiring. Given any $RS(X) \in T$,

$$ann_T(RS(X)) = \{RS(Y) \in T \mid RS(X)\nabla RS(Y) \neq RS(\phi)\}$$

In general, if $\emptyset \neq A \subseteq T$, then the set $ann_T(A) = \cap_{RS(X)\in A} \{ann_T(RS(X))\}$ is called the annihilator of A in T.

Definition 3.3: For any $RS(X) \in T$, define a relation R_1 on T by $R_1 = \{(RS(X), RS(Y)) \in T^2 | ann_T(RS(X)) = ann_T(RS(Y))\}$ then clearly R_1 is an equivalence relation on T and for any $RS(X) \in T, [RS(X)]_{R_1} = \{ RS(Y) \in T \, | ann_T(RS(X)) = ann_T(RS(Y))\}$.

Theorem 4: If $x_1, x_2, \dots, x_m$ are the pivot elements of the equivalence classes whose cardinality is greater than 1 and let $X_{m+1}, X_{m+2,\dots,} X_n$ are the equivalence classes whose cardinality is equal to 1. Then,
(i) $[RS(X)]_{R_1} = \{ RS(x_i), RS(X_i) \, , \; 1 \le i \; \le m\}$
(ii) $[RS(X_i)]_{R_1} = \{ \; RS(X_i) \, , \; m+1 \le i \; \le n\}$
(iii) $[RS(x_i \cup x_j \,)]_{R_1} = \{ RS(x_i \cup x_j \,) \, , RS(X_i \cup$ *xj ,RSXi∪Xj, RSxi∪Xj ,1≤i,j ≤m}*
(iv)$[RS(x_i \cup X_j \,)]_{R_1} = \{ RS(x_i \cup X_j \,) \, , RS(X_i \cup X_j), 1 \le i \le m \, , j \ge m+1\}$

Remark:
In general, if $X = \{x_1 \cup x_2 \cup \; \dots \cup x_r, Y_1 \cup Y_2 \cup \dots \cup Y_k\}$, where r ≤ m and $\{Y_1, Y_2, \dots, Y_k\} \subseteq \; \{X_{m+1}, X_{m+2,\dots,} X_n\}$, then$[RS(x_1 \cup x_2 \cup \; \dots \cup x_r, Y_1 \cup Y_2 \cup \dots \cup Y_k)]_{R_1}$= $\{RS(b_1 \cup$ *b2∪ …∪br,Y1∪Y2∪…∪Yk bi= xi* (or) *Xi, 1≤i≤r}.* From the above results, we can conclude that $T_1 = \{ \, [RS(Y)]_{R_1} \big| RS(Y) \in T \}$. For the example-1, *M(T)* is a 18 × 18 matrix , using the annihilators we can have the reduced matrix which is given below.

$$\begin{array}{c|cccccccc}
 & RS(\phi) & A & B & C & D & E & F & RS(U) \\
\hline
RS(\phi) & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
A & 0 & 1 & 0 & 1 & 1 & 0 & 0 & 1 \\
B & 0 & 0 & 1 & 1 & 0 & 1 & 0 & 1 \\
C & 0 & 1 & 1 & 1 & 1 & 1 & 0 & 1 \\
D & 0 & 1 & 0 & 1 & 1 & 1 & 1 & 1 \\
E & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 \\
F & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\
RS(U) & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1
\end{array}$$

Where
$A = \{RS(x_1), RS(X_1)\} = \; [RS(x_1)]_{R_1}$,
$B = \{RS(x_2), RS(X_2)\} = \; [RS(x_2)]_{R_1}$,
$C = \{ \, RS(x_1 \cup x_2 \,) \, , RS(X_1 \cup x_2 \,), RS(X_1 \cup X_2), RS(x_1 \cup X_2 \,)\} = \; [RS(x_1 \cup x_2 \,)]_{R_1}$
$D = \{ \, RS(X_1 \cup X_3), RS(x_1 \cup X_3 \,)\} = \; [RS(x_1 \cup X_3 \,)]_{R_1}$
$E = \{ \, RS(x_2 \cup X_3), RS(X_2 \cup X_3 \,)\} = \; [RS(x_2 \cup X_3 \,)]_{R_1}$,
$F = \{ \, RS(X_3)\} = \; [RS(X_3 \,)]_{R_1}$

Theorem 5: $[RS(U)]_{R_1}$ = { $RS(U)|$ Y is dominant in U}.
Proof: $[RS(U)]_{R_1} = \{ \, RS(Y) | ann_T(RS(Y)) = ann_T(RS(U))\}$., but U as an universal set contains all the equivalence classes and hence $ann_T(RS(U))$contains the only element $RS(\phi)$.
$\Leftrightarrow ann_T(RS(Y))$ = ann_TRS(∅).
$\Leftrightarrow Y \cap X_i \neq \emptyset \;, \forall i = 1, \dots n.$
⇔ Y is dominant in U.
For any subset X of U, $E_X = \{X_i | X_i \cap X \neq \emptyset, i = 1,2 \dots, n\}$ and $P_X = \{x_i | \, x_i \in X_i \; and \; X_i \not\subset X, X_i \cap X \neq \emptyset\}$. Note that P_X contains the set of a representative elements of the equivalence class which is not completely contain in X but having a non-empty intersection with X. Let $A_{i1,\dots,ik} = \{a_{i1}, a_{i2}, \dots, a_{ik} | a_{ir} = x_i \; (or) X_i\}$ for i = *1, 2, . . . , n.*
$J_{i1,\dots,ik} = \{RS(Y) | Y \in A_{i1,\dots,ik} \,\} \,, J = \{J_{i1,\dots,ik} \, \big| 1 \le r \le n\}.$

Theorem 6: For any $[RS(X)]_{R_1} \in T_1$, $[RS(X)]_{R_1} = J_{i1,\dots,ir}$for some $1 \le r \le n$.

Proof:
Consider $[RS(X)]_{R_1} \in T_1$, then $E_X = \{X_i \in T \, | X_i \cap X \neq \phi\}$. Let us assume that, E_X = $\{Y_1 \cup Y_2 \cup \dots \cup Y_k \subseteq E\}$. Choose a representative element $y_i$belongs to each of the equivalence class in E_X, whose cardinality is greater than 1. Then,we can form the set $A_{i1,\dots,ik}$= $\{a_{i1}, a_{i2}, \dots, a_{ik} | a_{ik} = y_i \; (or) Y_i\}$ for *i = 1, 2, . . . , k.*. Now $J_{i1,\dots,ik} = \{RS(Y) | Y \in A_{i1,\dots,ik} \,\}$. Note, that if any the Y_i is an equivalence class with cardinality = 1, then. Now, we prove that $[RS(X)]_{R_1}$=$J_{i1,\dots,ik}$ $if \; RS(Y) \in [RS(X)]_{R_1}$, then $ann_T(RS(Y)) = ann_T(RS(X))$. This implies X and Y have non-empty intersection with same set of equivalence classes. They are nothing but E_X.
$\Leftrightarrow RS(Y) \in J_{i1,\dots,ik}$.

Theorem 7: For any subset X of U,$ann_T(RS(X)) = \{ RS(Y) \, | Y \; \in \mathcal{P}(E \cup P) - \; (\, E_X \cup P_X)\}$.
Proof:
From [1], RHS is an ideal in *T*.
$ann_T(RS(X)) = \{ \, RS(Z) \, | RS(X) \nabla RS(Z) = RS(\phi)\} \,$.
Therefore, if $RS(Z) \; \in ann_T(RS(X))$, then Z and X, do not have any equivalence class (or) pivot element in common, that means
$\Leftrightarrow Z \; \in \; \mathcal{P}(E \cup P) - \; (\, E_X \cup P_X)$
$\Leftrightarrow RS(Z) \in RHS$.

Example-2:
$ann_T(RS(X_1)) = \{ \, RS(x_1), RS(X_2), RS(X_3), RS(x_2 \cup X_3), RS(X_2 \cup X_3)\}$
= { RS(Y) $|Y \; \in \mathcal{P}((E \cup P) - \; (\, E_X \cup P_X))\}$
Here $E_X = \{ \, X_1\}$ and $P_X = \{x_1\}$
E= $\{X_1, X_2, X_3\}$ and P = $\{ \, x_1, x_2\}$

Theorem 8: For any ideal $J_X, X \subseteq U$ in T.
$J_X = ann_T(RS((E \cup P) - \; (\, E_X \cup P_X)).$
Proof:
If $RS(Y) \in \; J_X$, then $Y \in P(X)$,
To prove that,
$RS(Y) \in ann_T(RS((E \cup P) - \; (\, E_X \cup P_X)$
Consider, $RS(Y) \nabla RS((E \cup P) - \; (\, E_X \cup P_X) = Rs(\phi)$ as X and $(E \cup P) - \; (\, E_X \cup P_X)$do not contain any equivalence class (or) pivot elements in common. Hence the annihilator ideals of the rough lattice $(T \,, \Delta, \; \nabla)$ is completely characterized by the sets E and P.

Theorem 9: $I = \{x_1, x_2, \dots, x_m, X_{m+1}, X_{m+2,\dots,} X_n\}$, then $T_1 \; \triangleq \{RS(Y) | Y \in \mathcal{P}(\mathrm{I})\}$.
Proof:
Let $C = \{RS(Y) | Y \; \in \mathcal{P}(\mathrm{I})\}$ Define a function, $f : C \to T_1$, by $f(RS(Y)) = \; [RS(Y)]_{R_1}$. Clearly *f* is well defined and if $f(RS(Y)) = \; f(RS(Z))$ then $[RS(Y)]_{R_1} = [RS(Z)]_{R_1}$

$\Rightarrow RS(Z) \in [RS(Y)]_{R_1}$
$\Rightarrow RS(Y) = RS(Z)\ as\ Y, Z \in$ Ƥ(I).
Hence, f is 1-1.
Clearly, f is onto and hence it is an isomorphism.

Remark: In T_1, we are considering only the non-zero element of T (excluding $RS(\phi)$.

IV. BOOLEAN ALGEBRA INDUCED BY SET OF ANNIHILATORS

In this section, we obtain a Boolean algebra induced by the elements of $\boldsymbol{T_1}$.

Definition 4.1: Let $\mathbf{T_1} = \{[\mathbf{RS(X)}]_{\mathbf{R_1}} | \mathbf{RS(X)} \in \mathbf{T}\}$ define a relation $\sim$ on $\boldsymbol{T_1}$ by $[\mathbf{RS(X)}]_{\mathbf{R_1}} \sim [\mathbf{RS(Y)}]_{\mathbf{R_1}}$ iff for every $\mathbf{RS}(\boldsymbol{Z_1}) \in [\mathbf{RS(X)}]_{\mathbf{R_1}}$, there exists $\mathbf{RS}(\boldsymbol{Z_2}) \in [\mathbf{RS(Y)}]_{\mathbf{R_1}}$ such that $\mathbf{RS}(\boldsymbol{Z_1}), \mathbf{RS}(\boldsymbol{Z_2}) \in \mathbf{R}$.

Theorem 10: $(\boldsymbol{T_1}, \sim)$ is a Boolean Algebra.
Proof:
A straight forward verification shows that $\sim$ is a partially ordered set. Also, $\boldsymbol{GLB}([\mathbf{RS(X)}]_{\mathbf{R_1}}, [\mathbf{RS(Y)}]_{\mathbf{R_1}}) = [\mathbf{RS(X \cap Y)}]_{\mathbf{R_1}}$. Now, for $[\mathbf{RS(X)}]_{\mathbf{R_1}} \in \boldsymbol{T_1}, [\mathbf{RS(E - E_X)}]_{\mathbf{R_1}}$ is the complement of $[\mathbf{RS(X)}]_{\mathbf{R_1}}$. Hence, $(\boldsymbol{T_1}, \sim)$ is a Boolean Algebra.

The Boolean Algebra corresponding to $\boldsymbol{T_1}$ (Figure-1) is given in Figure-2.

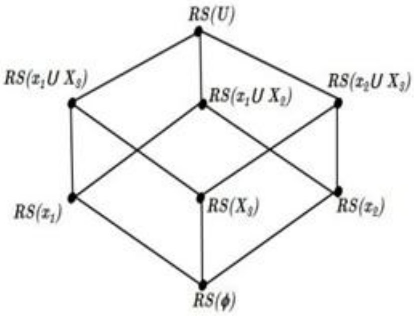

Figure 2 Boolean Algebra

Consider the atoms of the Rough Lattice T, note that $P_1 = \{x_1,\ x_2 \ldots x_m, X_{m+1}, \ldots X_n,\}$ are the atoms of T. Let $J_1 = \{RS(Y) | Y \in$ Ƥ$(P_1)\}$then J_1 is an ideal in T and T_1 is isomorphic to J_1 Hence, we have the following theorem.

Theorem 11: The Boolean algebra induced by the set of annihilators of T is given by $T_1 = \{[RS(X)]_{R_1} RS(X) \in T\}$
is isomorphic to $\mathbf{J_1}$.

V. CONCLUSION

In this paper, we define the annihilators of a Rough Semiring (T, Δ,∇). The Characterization of these annihilators are discussed in detail. Also it is proved that the equivalence classes induced by these annihilators is a Boolean algebra which is isomorphic to the power set. Boolean algebra corresponding to the atoms of T. Our future work in this direction is to explore these annihilators.

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