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New Types of Topologies and Neutrosophic Topologies

(Improved Version)

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Abstract: In this paper we recall the six new types of topologies, and their corresponding topological spaces, that we introduced in the last years (2019-20223), such as: NeutroTopology, AntiTopology, Refined Neutrosophic Topology, Refined Neutrosophic Crisp Topology, SuperHyperTopology, and Neutrosophic SuperHyperTopology.

The n[th]-PowerSets $P^n(H)$ and $P_*^n(H)$, that the SuperHyperTopology and respectively Neutrosophic SuperHyperTopology are based on, better describe our real world, since a system *H* (that may be a set, company, institution, country, region, etc.) is organized in sub-systems, which in their turn are organized each in sub-sub-systems, and so on.

Keywords: Classical Topology; Topological Space; NeutroTopology; AntiTopology; Refined Neutrosophic Topology; Refined Neutrosophic Crisp Topology; SuperHyperTopology; Neutrosophic SuperHyperTopology.

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1. Introduction

We recall the classical definition of Topology, then the procedures of NeutroSophication and respectively AntiSophication of it, that result in adding in two new types of topologies: NeutroTopology and respectively AntiTopology.

Then we define topology on Refined Neutrosophic Set (2013), Refined Neutrosophic Crisp Set [3]. Afterwards, we extend the topology on the framework of SuperHyperAlgebra [6].

The corresponding neutrosophic topological spaces are presented.

This research is an improvement of paper [7].

2. *Classical Topology*

Let $\mathcal{U}$ be a non-empty set, and $P(\mathcal{U})$ the power set of $\mathcal{U}$.

Let $\tau \subseteq P(\mathcal{U})$ be a family of subsets of $\mathcal{U}$.

Then τ is called a Classical Topology on $\mathcal{U}$ if it satisfies the following axioms:

(CT-1) ϕ and $\mathcal{U}$ belong to τ.

(CT-2) The intersection of any finite number of elements in τ is in τ.

(CT-3) The union of any finite or infinite number of elements in τ is in τ.

All three axioms are totally (100%) true (or T = 1, I = 0, F = 0). We simply call them (classical) *Axioms*.

Then ($\mathcal{U}$, τ) is called a *Classical Topological Space* on $\mathcal{U}$.

3. *NeutroSophication of the Topological Axioms*

NeutroSophication of the topological axioms means that the axioms become partially true, partially indeterminate, and partially false. They are called *NeutroAxioms*.

(NCT-1) Either $\{\phi \notin \tau \text{ and } \mathcal{U} \in \tau\}$, or $\{\phi \in \tau \text{ and } \mathcal{U} \notin \tau\}$.

(NCT-2) There exist a finite number of elements in τ whose intersection belong to τ (degree of truth *T*); and a finite number of elements in τ whose intersection is indeterminate (degree of indeterminacy *I*); and a finite number of elements in τ whose intersection does not belong to τ (degree of falsehood *F*); where (*T, I, F*) $\notin \{(1,0,0),(0,0,1)\}$ since (1, 0, 0) represents the above Classical Topology, while (0, 0, 1) the below AntiTopology.

(NCT-3) There exist a finite or infinite number of elements in τ whose union belongs to τ (degree of truth *T*); and a finite or infinite number of elements in τ whose union is indeterminate (degree of indeterminacy *I*); and a finite or infinite number of elements in τ whose union does not belong to τ (degree of falsehood *F*); where of course (*T, I, F*) $\notin \{(1,0,0),(0,0,1)\}$.

4. *AntiSophication of the Topological Axioms*

AntiSophication of the topological axioms means to negate (anti) the axioms, the axioms become totally (100%) false (or T = 0, I = 0, F = 1). They are called *AntiAxioms*.

(ACT-1) $\phi \notin \tau$ and $\mathcal{U} \notin \tau$.

(ACT-2) The intersection of any finite number ($n \geq 2$) of elements in τ is not in τ.

(ACT-3) The union of any finite or infinite number ($n \geq 2$) of elements in τ is not in τ.

5. Neutrosophic Triplets related to Topology

As such, we have a neutrosophic triplet of the form:

<Axiom(1, 0, 0), NeutroAxiom(*T, I, F*), AntiAxiom(0, 0, 1)>,

where (*T, I, F*) $\neq$ (1, 0, 0) and (*T, I, F*) $\neq$ (0, 0, 1).

Correspondingly, one has:

<Topology, NeutroTopology, AntiTopology>.

Therefore, in general:

(Classical) Topology is a topology that has all axioms totally true. We simply call them *Axioms*.

NeutroTopology is a topology that has at least one *NeutroAxiom* and the others are all *classical Axioms* [therefore, no AntiAxiom].

AntiTopology is a topology that has one or more *AntiAxioms*, no matter what the others are (*classical Axioms*, or *NeutroAxioms*).

6. Theorem on the number of Structures/NeutroStructures/AntiStructures

If a Structure has *m* axioms, with $m \geq 1$, then after NeutroSophication and AntiSophication one obtains 3^m types of structures, categorized as follows:

1 *Classical Structure* + $(2^m - 1)$ *NeutroStructures* + $(3^m - 2^m)$ *AntiStructures*.

7. Consequence on the number of Topologies/NeutroTopologies/AntiTopologies

As a particular case of the previous theorem, from a Topology which has $m = 3$ axioms, one makes, after NeutrosSophication and AntiSophication, $3^3 = 27$ types of structures, as follows: 1 classical Topology, $2^3 - 1 = 7$ NeutroTopologies, and $3^3 - 2^2 = 19$ AntiTopologies.

1 *Classical Topology* + 7 *NeutroTopologies* + 19 *AntiTopologies*

are presented below:

There is 1 (one) type of Classical Topology, whose axioms are listed below:

1 *Classical Topology*

$$\begin{pmatrix} CT-1 \\ CT-2 \\ CT-3 \end{pmatrix}$$

8. Definition of NeutroTopology [4, 5]

It is a topology that has at least one topological axiom which is partially true, partially indeterminate, and partially false,

or *(T, I, F)*, where T = True, *I* = Indeterminacy, *F* = False,

and no topological axiom is totally false,

in other words: $(T, I, F) \notin \{(1,0,0),(0,0,1)\}$, where *(1, 0, 0)* represents the classical Topology, while *(0, 0, 1)* represents the below AntiTopology.
Therefore, the NeutroTopology is a topology in between the classical Topology and the AntiTopology.

There are 7 types of different NeutroTopologies, whose axioms, for each type, are listed below:

7 *NeutroTopologies*

$$\begin{pmatrix} NCT-1 \\ CT-2 \\ CT-3 \end{pmatrix}, \begin{pmatrix} CT-1 \\ NCT-2 \\ CT-3 \end{pmatrix}, \begin{pmatrix} CT-1 \\ CT-2 \\ NCT-3 \end{pmatrix},$$

$$\begin{pmatrix} NCT-1 \\ NCT-2 \\ CT-3 \end{pmatrix}, \begin{pmatrix} CT-1 \\ NCT-2 \\ NCT-3 \end{pmatrix}, \begin{pmatrix} NCT-1 \\ CT-2 \\ NCT-3 \end{pmatrix},$$

$$\begin{pmatrix} NCT-1 \\ NCT-2 \\ NCT-3 \end{pmatrix}.$$

9. Definition of AntiTopology [4, 5]

It is a topology that has at least one topological axiom that is 100% false (T, I, F) = (0, 0, 1).
The NeutroTopology and AntiTopology are particular cases of NeutroAlgebra and AntiAlgebra [4] and, in general, they all are particular cases of the NeutroStructure and AntiStructure respectively, since we consider "Structure" in any field of knowledge [5].

There are 19 types of different AntiTopologies, whose axioms, for each type, are listed below:

19 *AntiTopologies*

$$\begin{pmatrix} ACT-1 \\ CT-2 \\ CT-3 \end{pmatrix}, \begin{pmatrix} CT-1 \\ ACT-2 \\ CT-3 \end{pmatrix}, \begin{pmatrix} CT-1 \\ CT-2 \\ ACT-3 \end{pmatrix},$$

$$\begin{pmatrix} ACT-1 \\ ACT-2 \\ CT-3 \end{pmatrix}, \begin{pmatrix} CT-1 \\ ACT-2 \\ ACT-3 \end{pmatrix}, \begin{pmatrix} ACT-1 \\ CT-2 \\ ACT-3 \end{pmatrix},$$

$$\begin{pmatrix} ACT-1 \\ NCT-2 \\ NCT-3 \end{pmatrix}, \begin{pmatrix} NCT-1 \\ ACT-2 \\ NCT-3 \end{pmatrix}, \begin{pmatrix} NCT-1 \\ NCT-2 \\ ACT-3 \end{pmatrix},$$

$$\begin{pmatrix} ACT-1 \\ ACT-2 \\ NCT-3 \end{pmatrix}, \begin{pmatrix} NCT-1 \\ ACT-2 \\ ACT-3 \end{pmatrix}, \begin{pmatrix} ACT-1 \\ NCT-2 \\ ACT-3 \end{pmatrix},$$

$$\begin{pmatrix} ACT-1 \\ NCT-2 \\ CT-3 \end{pmatrix}, \begin{pmatrix} CT-1 \\ ACT-2 \\ NCT-3 \end{pmatrix}, \begin{pmatrix} NCT-1 \\ CT-2 \\ ACT-3 \end{pmatrix},$$

$$\begin{pmatrix} ACT-1 \\ CT-2 \\ NCT-3 \end{pmatrix}, \begin{pmatrix} CT-1 \\ NCT-2 \\ ACT-3 \end{pmatrix}, \begin{pmatrix} NCT-1 \\ ACT-2 \\ CT-3 \end{pmatrix},$$

$$\begin{pmatrix} ACT-1 \\ ACT-2 \\ ACT-3 \end{pmatrix}.$$

10. Refined Neutrosophic Set

Let U be a universe of discourse, and a non-empty subset *R* of it,

$$R = \left\{ \begin{array}{c} x\left(T_1(x), T_2(x), \ldots, T_p(x)\right); \\ \left(I_1(x), I_2(x), \ldots, I_r(x)\right); \\ \left(F_1(x), F_2(x), \ldots, F_s(x)\right); \end{array} \right\}$$

with all $T_j, I_k, F_l \in [0,1]$, $1 \le j \le p, 1 \le k \le r, 1 \le l \le s$, and no restriction on their sums $0 \le T_m + I_m + F_m \le 3$, with $1 \le m \le \max\{p, r, s\}$, where $p, r, s \geq 0$ are fixed integers, and at least one of them is ≥ 2, in order to ensure the refinement (sub-parts) or multiplicity (multi-parts) – depending on the application, of at least one neutrosophic component amongst *T* (truth), *I* (indeterminacy), *F* (falsehood); and of course $x \in \mathcal{U}$.

By notation we consider that index zero means the empty-set, i.e. $T_0 = I_0 = F_0 = \phi$ (or zero), and the same for the missing sub-parts (or multi-parts).

For example, the below (2,3,1)-Refined Neutrosophic Set is identical to a (3,3,3)-Refined Neutrosophic Set: $(T_1, T_2; I_1, I_2, I_3; F_1) \equiv (T_1, T_2, 0; I_1, I_2, I_3; F_1, 0, 0)$,

where the missing components T_3, and F_2, F_3 were replaced each of them by 0 (zero)

R is called a *(p, r, s)-refined neutrosophic set* { or *(p, r, s)-RNT* }.

The neutrosophic set has been extended to the Refined Neutrosophic Set (Logic, and Probability) by Smarandache [1] in 2013, where there are multiple parts of the neutrosophic components, as such T was split into subcomponents $T_1, T_2, \ldots, T_p$, and I into $I_1, I_2, \ldots, I_r$, and F into $F_1, F_2, \ldots, F_s$, with $p + r + s = n \ge 2$ and integers $p, r, s \ge 0$ and at least one of them is ≥ 2 in order to ensure the refinement (or multiplicity) of at least one neutrosophic component amongst T, I, and F.

Even more: the subcomponents T_j, I_k, and/or F_l can be countable or uncountable infinite subsets of [0, 1].

This definition also includes the *Refined Fuzzy Set*, when $r = s = 0$ and $p \geq 2$;

and the definition of the *Refined Intuitionistic Fuzzy Set*, when $r = 0$, and either $p \geq 2$ and $s \geq 1$, or $p \geq 1$ and $s \geq 2$.

All other fuzzy extension sets (Pythagorean Fuzzy Set, Spherical Fuzzy Set, Fermatean Fuzzy Set, q-Rung Orthopair Fuzzy Set, etc.) can be refined/multiplicated in a similar way.

11. Definition of Refined Neutrosophic Topology

Let $\mathcal{U}$ be a universe of discourse, and $\mathcal{P}(\mathcal{U})$ be the family of all (*p, r, s*)-refined neutrosophic subsets of $\mathcal{U}$.

Let $\tau_{RNT} \subseteq \mathcal{P}(\mathcal{U})$ be a family of (*p, r, s*)-refined neutrosophic subsets of $\mathcal{U}$.

Then τ_{RNT} is called a *Refined Neutrosophic Topology* (*RNT*) if it satisfies the axioms:

(RNT-1) ϕ and $\mathcal{U}$ belong to τ_{RNT};

(RNT-2) The intersection of any finite number of elements in τ_{RNT} is in τ_{RNT};

(RNT-3) The union of any finite or infinite number of elements in τ_{RNT} is in τ_{RNT}.

Then $(\mathcal{U}, \tau_{RNT})$ is called a Refined Neutrosophic Topological Space on $\mathcal{U}$.

The *Refined Neutrosophic Topology* is a topology defined on a Refined Neutrosophic Set.

{Similarly, the Refined Fuzzy Topology is defined on a Refined Fuzzy Set, while the Refined Intuitionistic Fuzzy Topology is defined on a Refined Intuitionistic Fuzzy Set, etc.

And, as a generalization, on any type of fuzzy extension set [such as: Pythagorean Fuzzy Set, Spherical Fuzzy Set, Fermatean Fuzzy Set, q-Rung Orthopair Fuzzy Set, etc.] one can define a corresponding fuzzy extension topology.}

12. <u>Neutrosophic Crisp Set</u>

The *Neutrosophic Crisp Set* was defined by Salama and Smarandache in 2014 and 2015.
Let X be a non-empty fixed space. And let *D* be a Neutrosophic Crisp Set [2], where
$D = <A, B, C>$, with *A, B, C* as subsets of *X*.

Depending on the intersections and unions between these three sets *A, B, C* one gets several:
Types of Neutrosophic Crisp Sets [2, 3]
The object having the form $D = <A, B, C>$ is called:

(a) A neutrosophic crisp set of Type 1 (NCS-Type1) if it satisfies:

$A \cap B = B \cap C = C \cap A = \phi$ (empty set).

(b) A neutrosophic crisp set of Type 2 (NCS-Type2) if it satisfies:

$A \cap B = B \cap C = C \cap A = \phi$ and $A \cup B \cup C = X$.

(c) A neutrosophic crisp set of Type 3 (NCS-Type3) if it satisfies:

$A \cap B \cap C = \phi$ and $A \cup B \cup C = X$.

Of course, more types of Neutrosophic Crisp Sets may be defined by modifying the intersections and unions of the subsets *A, B*, and *C*.

13. Refined Neutrosophic Crisp Set

The ***Refined Neutrosophic Crisp Set*** [3] was introduced by Smarandache in 2019, by refining/multiplication of *D* (and denoting it by *RD* = Refined D) by refining/multiplication of its sets *A, B, C* into sub-subsets/multi-sets as follows:

$RD = (A_1, \ldots, A_p; B_1, \ldots, B_r; C_1, \ldots, C_s)$, with $p, r, s \geq 1$ be positive integers and at least one of them be ≥ 2 in order to ensure the refinement/multiplication of at least one component amongs A, B, C, where

$$A = \bigcup_{i=1}^{p} A_i, B = \bigcup_{j=1}^{r} B_j, C = \bigcup_{k=1}^{s} C_k$$

and many types of Refined Neutrosophic Crisp Sets may be defined by modifying the intersections or unions of the subsets/multisets $A_i, B_j, C_k, 1 \leq i \leq p, 1 \leq j \leq r, 1 \leq k \leq s$,

depending on each application.

14. Definition of Refined Neutrosophic Crisp Topology

Let $\mathcal{U}$ be a universe of discourse, and $\mathcal{P}(\mathcal{U})$ be the family of all (*p, r, s*)-refined neutrosophic crisp subsets of $\mathcal{U}$.

Let $\tau_{RNCT} \subseteq \mathcal{P}(\mathcal{U})$ be a family of (*p, r, s*)-refined neutrosophic crisp subsets of $\mathcal{U}$.

Then τ_{RNCT} is called a *Refined Neutrosophic Crisp Topology* (*RNCT*) if it satisfies the axioms:

(RNCT-1) ϕ and $\mathcal{U}$ belong to τ_{RNCT};

(RNCT-2) The intersection of any finite number of elements in τ_{RNCT} is in τ_{RNCT};

(RNCT-3) The union of any finite or infinite number of elements in τ_{RNCT} is in τ_{RNCT}.

Then $(\mathcal{U}, \tau_{RNCT})$ is called a Refined Neutrosophic Crisp Topological Space on $\mathcal{U}$.

Therefore, the *Refined Neutrosophic Crisp Topology* is a topology defined on the Refined Neutrosophic Crisp Set.

15. SuperHyperOperation

We recall our 2016 concepts of SuperHyperOperation, SuperHyperAxiom, SuperHyperAlgebra, and their corresponding Neutrosophic SuperHyperOperation Neutrosophic SuperHyperAxiom and Neutrosophic SuperHyperAlgebra [6].

Let $P_*^n(H)$ be the n[th]-powerset of the set *H* such that none of *P(H)*, $P^2(H)$, …, $P^n(H)$ contain the empty set ϕ.

Also, let $P_n(H)$ be the n[th]-powerset of the set *H* such that at least one of the *P(H)*, $P^2(H)$, …, $P^n(H)$ contain the empty set ϕ. For any subset A, we identify {A} with A.

The SuperHyperOperations are operations whose codomain is either $P_*^n(H)$ and in this case one has classical-type SuperHyperOperations, or $P^n(H)$ and in this case one has Neutrosophic SuperHyperOperations, for integer $n \geq 2$.

16. The n[th]-PowerSet better describe our real world

The n[th]-PowerSets $P^n(H)$ and $P_*^n(H)$, that the SuperHyperTopology and respectively Neutrosophic SuperHyperTopology are based on, better describe our real world, since a system *H* (that may be a set, company, institution, country, region, etc.) is organized in sub-systems, which in their turn are organized each in sub-sub-systems, and so on.

17. SuperHyperAxiom

A classical-type SuperHyperAxiom or more accurately a *(m, n)*-SuperHyperAxiom is an axiom based on classical-type SuperHyperOperations.

Similarly, a Neutrosophic SuperHyperAxiom {or Neutrosphic (m, n)-SuperHyperAxiom} is an axiom based on Neutrosophic SuperHyperOperations.

There are:

- Strong SuperHyperAxioms, when the left-hand side is equal to the right-hand side as in non-hyper axioms,
- and Week SuperHyperAxioms, when the intersection between the left-hand side and the right-hand side is non-empty.

18. SuperHyperAlgebra and SuperHyperStructure

A SuperHyperAlgebra or more accurately *(m-n)*-SuperHyperAlgebra is an algebra dealing with SuperHyperOperations and SuperHyperAxioms.

Again, a Neutrosophic SuperHyperAlgebra {or Neutrosphic (m, n)-SuperHyperAlgebra} is an algebra dealing with Neutrosophic SuperHyperOperations and Neutrosophic SuperHyperOperations.

In general, we have SuperHyperStructures {or *(m-n)*-SuperHyperStructures}, and corresponding Neutrosophic SuperHyperStructures.

For example, there are SuperHyperGrupoid, SuperHyperSemigroup, SuperHyperGroup, SuperHyperRing, SuperHyperVectorSpace, etc.

19. Distinction between SuperHyperAlgebra vs. Neutrosophic SuperHyperAlgebra

i. If none of the power sets $P^k(H)$, $1 \le k \le n$, do not include the empty set ϕ, then one has a classical-type SuperHyperAlgebra;

ii. If at least one power set, $P^k(H)$, $1 \le k \le n$, includes the empty set ϕ, then one has a Neutrosophic SuperHyperAlgebra.

20. Definition of SuperHyperTopology (SHT) [6]

It is a topology designed on the n[th]-PowerSet of a given non-empty set H, that excludes the empty-set, denoted as $P_*^n(H)$, built as follows:

$P_*(H)$ is the first powerset of the set H, and the index $*$ means without the empty-set (∅);

$P_*^2(H) = P_*(P_*(H))$ is the second powerset of H (or the powerset of the powerset of H), without the empty-sets; and so on,

the n-th powerset of H,

$P_*^n(H) = P_*(P_*^{n-1}(H)) = \underbrace{P_*(P_*(...P_*(H)...))}_{n}$, where P_* is repeated n time ($n \ge 2$), and without the empty-sets.

Let consider τ_{SHT} be a family of subsets of $P_*^n(H)$.

Then τ_{SHT} is called a Neutrosophic SuperHyperTopology on $P_*^n(H)$, if it satisfies the following axioms:

(SHT-1) ϕ and $P_*^n(H)$ belong to τ_{SHT}.

(SHT-2) The intersection of any finite number of elements in τ_{SHT} is in τ_{SHT}.

(SHT-3) The union of any finite or infinite number of elements in τ_{SHT} is in τ_{SHT}.

Then $(P_*^n(H), \tau_{SHT})$ is called a SuperHyperTopological Space on $P_*^n(H)$.

21. Definition of Neutrosophic SuperHyperTopology (NSHT) [6]

It is, similarly, a topology designed on the n-th PowerSet of a given non-empty set H, but includes the empty-sets [that represent indeterminacies] too.

As such, in the above formulas, $P_*(H)$ that excludes the empty-set, is replaced by $P(H)$ that includes the empty-set.

$P(H)$ is the first powerset of the set H, including the empty-set (∅);

$P^2(H) = P(P(H))$ is the second powerset of H (or the powerset of the powerset of H), that includes the empty-sets;

and so on, the n-th powerset of H,

$$P^n(H) = P(P^{n-1}(H)) = \underbrace{P(P(...P(H)...))}_{n}$$

where P is repeated n times ($n \geq 2$), and includes the empty-sets (∅).

Let consider τ_{NSHT} be a family of subsets of $P^n(H)$.

Then τ_{NSHT} is called a Neutrosophic SuperHyperTopology on $P^n(H)$, if it satisfies the following axioms:

(NSHT-1) ϕ and $P^n(H)$ belong to τ_{NSHT}.

(NSHT-2) The intersection of any finite number of elements in τ_{NSHT} is in τ_{NSHT}.

(NSHT-3) The union of any finite or infinite number of elements in τ_{NSHT} is in τ_{NSHT}.

Then $(P^n(H), \tau_{NSHT})$ is called a Neutrosophic SuperHyperTopological Space on $P^n(H)$.

22. Conclusion

These six new types of topologies, and their corresponding topological space, were introduced by Smarandache in 2019-2023, but they have not yet been much studied and applied, except the NeutroTopologies and AntiTopologies which got some attention from researchers.

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