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ON SOFT γ- OPERATIONS IN SOFT TOPOLOGICAL SPACES

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Abstract − In this paper,the notion of soft γ-operation on soft topological spaces is introduced and studied. Also,the concepts of soft γ-open set,soft γ-interior, soft γ-closure, soft γ-regular operation, soft γ-regular space, soft γ^*-regular space are defined and studied.The notion of soft $\gamma - T_i$ spaces are introduced,which generalizes the notion of soft T_i-spaces ($i = 0, 1/2, 1, 2$) and some of their properties are studied.

Keywords − *Soft γ-operation, soft γ-open set,soft γ-interior, soft γ-closure, soft γ-regular operation, soft γ-regular space, soft γ^*-regular space*

1 Introduction

In 1999, Molodtsov [17] introduced the soft set theory and showed how soft set theory is free from the parametrization inadequacy syndrome of fuzzy set theory, rough set theory and game theory. Based on the work of Molodtsov [17], Maji et al [14], [15] initiated the theoretical study of soft set theory which includes several basic definitions and basic operations of soft sets.Further, Shabir and Naz [19] introduced soft topological spaces which are defined over an initial universe with a fixed set of parameters and studied the basic notions such as soft open sets, soft closed sets, soft closure,soft separation axioms. Hussain and Ahmad [10] and Cagman et al [6] have continued the study of properties of soft topological spaces. Further, Benchalli et al [4] studied

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the properties of soft regular spaces and soft normal spaces. The study of soft sets and related aspects was also undertaken in [2], [3], [9], [16], [18], [20],[23]. Recently, many researchers have introduced various weaker forms of soft open sets and soft closed sets in soft topological spaces and studied their properties in [1], [5], [7, 8], [11], [12], [13], [21], [22]. In this paper,the notion of soft γ-operations on soft topological spaces is introduced and studied.The concepts of soft γ-open set,soft γ-interior, soft γ-closure, soft γ-regular operation, soft γ-regular space, soft γ^*-regular space are defined and studied. The notions of soft $\gamma - T_i$ spaces are introduced,which generalizes the notion of soft T_i-spaces $(i = 0, 1/2, 1, 2)$ and some of their properties are studied.

2 Preliminary

The following definitions and results are required.

Definition 2.1. [17] Let U be an initial universe and E be a set of parameters. Let $P(U)$ denote the power set of U and A be a non-empty subset of E . A pair (F, A) is called a soft set over U , where F is a mapping given by $F : A \to P(U)$.
In other words, a soft set over U is a parameterized family of subsets of the universe U. For $e \in A, F(e)$ may be considered as the set of e-approximate elements of the soft set (F, A) . Clearly, a soft set need not be a set.

Definition 2.2. [14] For two soft sets (F, A) and (G, B) over a common universe U , we say that (F, A) is a soft subset of (G, B) if (i)$A \subset B$ and (ii) for all $e \in A, F(e)$ and $G(e)$ are identical approximations.

Definition 2.3. [19] Let τ be the collection of soft sets over X. Then τ is said to be a soft topology on X if
(1) $\emptyset, \widetilde{X}$ belongs to τ.
(2) The union of any number of soft sets in τ belongs to τ.
(3) The intersection of any two soft sets in τ belongs to τ.
The triplet (X, τ, E) is called a soft topological space.

Here the members of τ are called soft open sets in X and the relative complements of soft open sets are called as soft closed sets.

Theorem 2.4. [19] Arbitrary union of soft open sets is a soft open set and finite intersection of soft closed sets is a soft closed set.

Definition 2.5. [19] Let (X, τ, E) be a soft space over X and (F, E) be a soft set over X. Then,the soft closure of (F, E) denoted by $\overline{(F, E)}$ is the intersection of all soft closed super sets of (F, E).Clearly, $\overline{(F, E)}$ is the smallest soft closed set over X contains (F, E).

The soft neighbourhood, soft relative topology, soft T_0- space, soft T_1- space and soft T_2- space are defined by Shabir and Naz in [19].

Definition 2.6. [23] The soft interior of (G, E) is the soft set defined as $(G, E)^o = \text{int}(G, E) = \bigcup\{(S, E) : (S, E) \text{ is soft open and } (S, E) \subseteq (G, E)\}$. Here $(G, E)^o$ is largest soft open set contained in (G, E).

Throughout the study, $Cl(A, E)$ and $Int(A, E)$ means soft closure and soft interior of a soft set (A, E) respectively, in the soft topological space (X, τ, E).

Definition 2.7. [19] The difference (H, E) of two soft sets (F, E) and (G, E) over X, denoted by $(F, E) \setminus (G, E)$, is defined as $H(e) = F(e) - G(e)$, for all $e \in E$.

Definition 2.8. Let (A, E) and (B, E) be two soft sets. Then, $(A, E) \setminus (B, E) = (A, E) \cap (B, E)'$

Definition 2.9. [19] Let $x \in X$.Then (x, E) is the soft set over x for which $x(e) = \{x\}$, for all $e \in E$. Clearly, $x \in (x, E)$.

Definition 2.10. [19] Let X be an initial universe set, E be the set of parameters and $\tau = \{\phi, X\}$. Then, τ is called the soft indiscrete topology on X and (X, τ, E) is called a soft indiscrete space over X.

3 Soft γ-operations

Definition 3.1. Let (X, τ, E) be a soft topological space. An operation γ on the soft topology τ is a mapping from τ into the power set $P(X)$ of X such that $(V, E) \subset (V, E)^\gamma$, for each $(V, E) \in \tau$, where $(V, E)^\gamma = \gamma(V, E)$. It is denoted by $\gamma : \tau \to P(X)$.

Definition 3.2. A subset (A, E) of a soft topological space (X, τ, E) is called a soft γ-open set of (X, τ, E), if for each $x \in (A, E)$ there exists a soft open set (U, E) such that $x \in (U, E) \subset (U, E)^\gamma \subset (A, E)$. τ_γ will denote the set of all soft γ-open sets. Clearly, we have $\tau_\gamma \subset \tau$.
A subset (B, E) of (X, τ, E) is called soft γ-closed if $(B, E)'$ is soft γ-open in (X, τ, E).

Definition 3.3. A point $x \in X$ is called a soft γ-closure point of (A, E), if $(U, E)^\gamma \cap (A, E) \neq \phi$ for each soft open neighborhood (nbd) (U, E) of x. The set of soft γ-closure points is called the soft γ-closure of (A, E) and is denoted by $Cl_\gamma(A, E)$. For the family τ_γ, we define a soft set $\tau_\gamma - Cl(A, E)$ as,
$\tau_\gamma - Cl(A, E) = \cap\{(F, E)/(F, E) \supset (A, E) and (F, E)' \in \tau\}$

Definition 3.4. Let (A, E) be a soft set. A point $x \in (A, E)$ is said to be a soft γ-interior point of (A, E) if and only if there exist a soft open nbd (N, E) of x such that $(N, E)^\gamma \subseteq (A, E)$.That is $(N, E)^\gamma \cap (A, E)' = \phi$. We denote the set of all such points by $Int_\gamma(A, E)$.
Thus, $Int_\gamma(A, E) = \{x \in (A, E)/x \in (N, E) \in \tau, (N, E)^\gamma \subseteq (A, E)\} \subseteq (A, E)$.

Definition 3.5. An operation γ on τ is said to be soft open if for every soft nbd (U, E) of each of $x \in X$, there exists a soft γ-open set (B, E) such that $x \in (B, E) \subseteq (U, E)^\gamma$.

Definition 3.6. An operation γ on τ is said to be soft regular if for any soft nbds (U, E) and (V, E) of $x \in X$, there exists soft open nbd (W, E) of x such that $(W, E)^\gamma \subseteq (U, E)^\gamma \cap (V, E)^\gamma$.

Definition 3.7. A soft topological space (X, τ, E) is called soft γ-regular if for each soft open nbd (U, E) of x in X, there exists a soft open nbd (V, E) of x such that $(V, E)^\gamma \subseteq (U, E)$.

Proposition 3.8. Let $\gamma : \tau \to P(X)$ be an operation on a soft topological space (X, τ, E). Then, (X, τ, E) is a soft γ-regular space iff $\tau = \tau_\gamma$ holds.

Proof. Suppose that $\gamma : \tau \to P(X)$ be an operation on a soft topological space (X, τ, E) and (X, τ, E) is a soft γ-regular space. We have $\tau_\gamma \subset \tau$. Thus, it is sufficient to prove that $\tau \subset \tau_\gamma$. Let $(A, E) \in \tau$. Then for any $x \in (A, E)$ there exist a soft nbd (U, E) of x such that $x \in (U, E) \subset (A, E)$. Then, by definition 3.7, there exists a soft open nbd (W, E) of x such that $(W, E)^\gamma \subseteq (U, E)$. Thus, for each $x \in (A, E)$, we have $x \in (W, E) \subset (W, E)^\gamma \subset (A, E)$. Then, (A, E) is soft γ-open. Thus, $(A, E) \in \tau_\gamma$. Hence, $\tau = \tau_\gamma$. Conversely, for each $x \in X$ and for each soft nbd (V, E) of x, since $(V, E) \in \tau = \tau_\gamma$, there exists soft open nbd (W, E) of x such that $(W, E)^\gamma \subset (V, E)$. This implies (X, τ, E) is soft γ-regular.

Example 3.9. Let $X = \{a, b, c\}, E = \{e_1, e_2\}$ and $\tau = \{\phi, X, (A, E), (B, E), (C, E)\}$ be a soft topology on X.
Here $(A, E) = \{(e_1, \{a\}), (e_2, \{a\})\}, (B, E) = \{(e_1, \{b\}), (e_2, \{b\})\}, (C, E) = \{(e_1, \{a, b\}), (e_2, \{a, b\})\}$.
Let $\gamma : \tau \to P(X)$ be an operation defined by $\gamma(V, E) = Cl(V, E)$ and let $\delta : \tau \to P(X)$ be an operation defined by $\delta(V, E) = Int(Cl(V, E))$. Then, we have $\tau_\gamma = \{\phi, X\}$ and $\tau_\delta = \tau$. Then we see that, γ is soft regular but not soft open on (X, τ, E) and δ is soft regular and soft open on (X, τ, E).

Example 3.10. Let $X = \{a, b, c\}, E = \{e_1, e_2\}$ and
$\tau = \{\phi, X, (A, E), (B, E), (C, E), (D, E)\}$ be a soft topology on X.
where,$(A, E) = \{(e_1, \{a\}), (e_2, \{a\})\}, (B, E) = \{(e_1, \{b\}), (e_2, \{b\})\}$
$(C, E) = \{(e_1, \{a, b\}), (e_2, \{a, b\})\}, (D, E) = \{(e_1, \{a, c\}), (e_2, \{a, c\})\}$.
For $b \in X$ we define an operation $\gamma : \tau \to P(X)$ by
$$\gamma(F, E) = (F, E)^\gamma = \begin{cases} (F, E) & \text{if } b \in (F, E) \\ Cl(F, E) & \text{if } b \notin (F, E) \end{cases}$$
Then, the operation γ is not soft γ-regular on τ. Because, if (A, E) and (C, E) are soft open nbds of point a then $(A, E)^\gamma \cap (C, E)^\gamma = Cl(A, E) \cap (C, E) = \{(e_1, \{a\}), (e_2, \{a\})\}$. And there is no soft open nbd (W, E) of a such that $(W, E)^\gamma \subset (A, E)^\gamma \cap (C, E)^\gamma$. Therefore, γ is not a soft regular operation. But we can easily verify that γ is soft open operation.

Proposition 3.11. Let $\gamma : \tau \to P(X)$ be a soft regular operation on τ. Then,
(i) if (A, E) and (B, E) are soft γ-open sets then $(A, E) \cap (B, E)$ is soft γ-open.
(ii) τ_γ is a soft topology on X.

Proof (i). Let (A, E) and (B, E) be two soft γ-open sets. By definition, for each $x \in (A, E), (B, E)$, there exist soft open nbds $(U, E), (V, E)$ such that $x \in (U, E) \subset (U, E)^\gamma \subset (A, E)$ and $x \in (V, E) \subset (V, E)^\gamma \subset (B, E)$. Now, (U, E) and (V, E) are soft nbds of x, since γ is soft regular , there exists soft open nbd (W, E) of x such that $(W, E)^\gamma \subset (U, E)^\gamma \cap (V, E)^\gamma \subset (A, E) \cap (B, E)$. Therefore, $x \in (W, E) \subset (W, E)^\gamma \subset (A, E) \cap (B, E)$. Thus, $(A, E) \cap (B, E)$ is a soft γ-open set.
(ii). Proof follows from proposition 3.8.

Remark 3.12. If γ is not soft regular, then proposition 3.11 is not true in general by the space (X, τ, E) and the operation γ as in example 3.10. Here we get $\tau_\gamma = \{\phi, X, (F, E), (G, E), (H, E)\}$, where

$(F, E) = \{(e_1, \{b\}), (e_2, \{b\})\}$,
$(G, E) = \{(e_1, \{a, b\}), (e_2, \{a, b\})\}$,
$(H, E) = \{(e_1, \{a, c\}), (e_2, \{a, c\})\}$.

Proposition 3.13. For a point $x \in X, x \in \tau_\gamma - Cl(A,E)$ if and only if $(V,E) \cap (A,E) \neq \phi$ for any $(V,E) \in \tau_\gamma$ such that $x \in (V,E)$.

Proof. Let $(F_0,E) = \{(x,E)/(V,E) \cap (A,E) \neq \phi, (V,E) \in \tau_\gamma, x \in (V,E)\}$. Let $x \in \tau_\gamma - Cl(A,E)$.It can be seen that $(F_0,E)'$ is a soft γ-open set and $(A,E) \subset \tau_\gamma - Cl(A,E) \subset (F_0,E)$, that is $(A,E) \subset (F_0,E)$. Thus, $\tau_\gamma - Cl(A,E) \subset (F_0,E)$. Conversely, let (F,E) be a soft set such that $(A,E) \subset (F,E)$ and $(F,E)' \in \tau_\gamma$. If $x \notin (F,E)$ then $x \in (F,E)'$ and $(A,E) \cap (F,E)' = \phi$. Then, $x \notin (F_0,E)$ implies $(F_0,E) \subset (F,E)$ and $(F_0,E) \subset \tau_\gamma - Cl(A,E)$ by definition.Hence, the proof.

Remark 3.14. It can be easily shown that for any soft set (A,E) of (X,τ,E),
$(A,E) \subset Cl(A,E) \subset Cl_\gamma(A,E) \subset \tau_\gamma - Cl(A,E)$.

Theorem 3.15. Let $\gamma : \tau \to P(X)$ be an operation on τ and (A,E) be a soft subset of X.Then, the following are true:
(i) The subset $Cl_\gamma(A,E)$ is soft closed in (X,τ,E).
(ii) If (X,τ,E) is soft γ-regular then $Cl_\gamma(A,E) = Cl(A,E)$ holds.
(iii) If γ is soft open then $Cl_\gamma(A,E) = \tau_\gamma - Cl(A,E)$ and $Cl_\gamma(Cl_\gamma(A,E)) = Cl_\gamma(A,E)$ hold, and $Cl_\gamma(A,E)$ is soft γ-closed.

Proof (i). Proof follows from the definition of soft γ-closure.
(ii). By remark 3.14, it is sufficient to prove that $Cl_\gamma(A,E) \subset Cl(A,E)$. Let $x \in Cl_\gamma(A,E)$ and (U,E) be any soft open nbd of x. By definition of soft γ-regularity, there exists a soft open nbd (V,E) of x such that $(V,E)^\gamma \subset (U,E)$. Since, $x \in Cl_\gamma(A,E)$, we have $(V,E)^\gamma \cap (A,E) \neq \phi$. This implies $(U,E) \cap (A,E) \neq \phi$. Thus, $x \in Cl(A,E)$. Therefore, $Cl_\gamma(A,E) \subset (A,E)$. Hence, $Cl_\gamma(A,E) = Cl(A,E)$.
(iii). Suppose that $x \notin Cl_\gamma(A,E)$. Then there exists a soft open set (U,E) such that $x \in (U,E)$ and $(U,E)^\gamma \cap (A,E) = \phi$. Since,$\gamma$ is soft open, for (U,E) and $x \in (U,E)$, there exists a soft γ-open set (S,E) such that $x \in (S,E) \subset (U,E)^\gamma$. Then $(S,E) \cap (A,E) = \phi$. From proposition 3.13, it shows that $x \notin \tau_\gamma - Cl(A,E)$ and hence $Cl_\gamma(A,E) \supset \tau_\gamma - Cl(A,E)$. By remark 3.14, we have $Cl_\gamma(A,E) \subset \tau_\gamma - Cl(A,E)$. Thus, $Cl_\gamma(A,E) = \tau_\gamma - Cl(A,E)$. Then we obtain, $Cl_\gamma(Cl_\gamma(A,E)) = \tau_\gamma - Cl(\tau_\gamma - Cl(A,E)) = \tau_\gamma - Cl(A,E) = Cl_\gamma(A,E)$.

Theorem 3.16. For a subset (A,E) of X, the following statements are equivalent.
(i) (A,E) is soft γ-open in (X,τ,E).
(ii)$Cl_\gamma((A,E)') = (A,E)'$
(iii)$\tau_\gamma - Cl(A,E)' = (A,E)'$ holds.
(iv) $(A,E)'$ is soft γ-closed.

Proof (i)⇒(ii). Suppose (A,E) is soft γ-open. Let $x \notin (A,E)'.Then x \in (A,E)$, and there exists a soft open nbd (U,E) of x such that $(U,E)^\gamma \subset (A,E)$, which implies $(U,E)^\gamma \cap (A,E)' = \phi$, then $x \notin Cl_\gamma(A,E)'$.Thus, $Cl_\gamma(A,E)' \subset (A,E)'$. We have $(A,E)' \subset Cl_\gamma(A,E)'$ is always true. Thus, statement (ii) holds.

(ii)⇒(iii). We prove that ,$\tau_\gamma - Cl(A,E)' \subset (A,E)'$. Let $x \notin (A,E)'$.Then,$x \notin Cl_\gamma(A,E)'$.Thus, there exists a soft open nbd (U,E) of x such that $(U,E)^\gamma \cap (A,E)' = \phi$. This implies $(U,E)^\gamma \subset (A,E)$.Then, (A,E) is soft γ-open. Thus, we have $(A,E) \cap (A,E)' = \phi$ and hence $x \notin \tau_\gamma - Cl(A,E)'$. Thus,$\tau_\gamma - Cl(A,E)' \subset (A,E)'$ and from remark 3.14, we have $(A,E)' \subset \tau_\gamma - Cl(A,E)'$. Therefore, statement (iii) holds.

(iii)⇒(iv). We prove that $((A, E)')' = (A, E) \in \tau_\gamma$. Let $x \notin (A, E)'$ then $x \notin \tau_\gamma - Cl(A, E)'$.Then, by proposition 3.13, there exists a soft γ-open set (U, E) such that $x \in (U, E)$ and $(U, E) \cap (A, E)' = \phi$. Since, $x \in (U, E) \in \tau_\gamma$, there exists a soft nbd (V, E) of x such that $(V, E)^\gamma \subset (U, E)$.Then, we have $x \in (V, E) \subset (V, E)^\gamma \subset (U, E) \subset (A, E)$. Thus, (A, E) is soft γ-open. That is $(A, E) \in \tau_\gamma$.Therefore, statement (iv) holds.

(iv)⇒(i). The proof is straight forward from the definition.

Proposition 3.17. If γ is soft regular then $Cl_\gamma((A, E) \cup (B, E)) = Cl_\gamma(A, E) \cup Cl_\gamma(B, E)$.

Proof. Proof is straight forward.

Theorem 3.18. (A, E) is soft γ-open if and only if $(A, E) = Int_\gamma(A, E)$.

Proof. Proof follows from the definitions of soft γ-open set and soft $Int_\gamma(A, E)$.

4 Soft $\gamma - T_i$ Spaces (i=0,1/2,1,2)

Let $\gamma : \tau \to P(X)$ be an operation on a soft topology τ.

Definition 4.1. A space (X, τ, E) is called a soft $\gamma - T_0$-space if for each distinct points $x, y \in X$ there exist a soft open set (U, E) such that either $x \in (U, E)$ and $y \notin (U, E)^\gamma$ or $y \in (U, E)$ and $x \notin (U, E)^\gamma$.

Definition 4.2. A space (X, τ, E) is called a soft $\gamma - T_1$-space if for each distinct points $x, y \in X$ there exists soft open sets $(U, E), (V, E)$ containing x and y respectively such that $y \notin (U, E)^\gamma$ and $x \notin (V, E)^\gamma$.

Definition 4.3. A space (X, τ, E) is called a soft $\gamma - T_2$-space if for each distinct points $x, y \in X$ there exists soft open sets $(U, E), (V, E)$ such that $x \in (U, E), y \in (v, E)$ and $(U, E)^\gamma \cap (V, E)^\gamma = \phi$.

To define soft $\gamma - T_{1/2}$- space we introduce the notion of soft γ-g-closed sets.

Definition 4.4. A subset (A, E) of (X, τ, E) is called soft γ-g-closed if $Cl_\gamma(A, E) \subset (U, E)$, whenever $(A, E) \subset (U, E)$ and (U, E) is soft γ-open in (X, τ, E).

Remark 4.5. Every soft γ-closed set is soft γ-g-closed set.

Proposition 4.6. Let $\gamma : \tau \to P(X)$ be an operation and (A, E) be a soft set in (X, τ, E). Then,the following results are hold good:
(i) If $\tau_\gamma - Cl((x, E)) \cap (A, E) \neq \phi$ holds for every $x \in Cl_\gamma(A, E)$ then (A, E) is soft γ-g-closed in (X, τ, E).
(ii) If γ is a soft regular operation, then the converse of (i) is true.

Proof (i). Let (U, E) be any soft γ-open set such that $(A, E) \subset (U, E)$. Let $x \in Cl_\gamma(A, E)$. By assumption, there exists a point x such that $x \in \tau_\gamma - Cl(x, E)$ and $x \in (A, E) \subset (U, E)$. It follows from the proposition 3.13 that $(U, E) \cap (x, E) \neq \phi$ and hence $x \in (U, E)$. Therefore $Cl_\gamma(A, E) \subset (U, E)$, whenever $(A, E) \subset (U, E)$ and (U, E) is soft γ-open. Hence,by definition (A, E) is soft γ-g-closed in (X, τ, E).
(ii). Let (A, E) be a soft γ-g-closed set in (X, τ, E). Suppose that there exist a point

$x \in Cl_\gamma(A,E)$ such that $(\tau_\gamma - Cl(x,E)) \cap (A,E) = \phi$. Since, γ is soft regular operation, then τ_γ is a soft topology on X by proposition 3.11. Then, $\tau_\gamma - Cl(x,E)$ is soft τ_γ-closed and the soft complement $(\tau_\gamma - Cl(x,E))'$ is soft τ_γ-open,by theorem 3.16. Since $(A,E) \subset (\tau_\gamma - Cl(x,E))'$ and (A,E) is soft γ-g-closed, we have $Cl_\gamma(A,E) \subset (\tau_\gamma - Cl(x,E))'$. Thus, $x \notin Cl_\gamma(A,E)$.This is a contradiction. Hence, if γ is a regular operation then the converse of statement (i) is true.

Theorem 4.7. Let $(A,E),(B,E)$ be soft sets of (X,τ,E). Then we have the following;
(i) $Int_\gamma(Int_\gamma(A,E)) = Int_\gamma(A,E)$
(ii) $Int_\gamma((A,E) \cup (B,E)) \supseteq Int_\gamma(A,E) \cup Int_\gamma(B,E)$
(iii) $Int_\gamma((A,E) \cap (B,E)) = Int_\gamma(A,E) \cap Int_\gamma(B,E)$, if γ is soft regular operation.

Proof. Statements (i) and (ii) follows from the definition of soft γ interior.
(iii). Note that if $(A,E) \subseteq (B,E)$ then $Int_\gamma(A,E) \subseteq Int_\gamma(B,E)$ follows from the definition. Thus, $Int_\gamma((A,E) \cap (B,E)) \subseteq Int_\gamma(A,E) \cap Int_\gamma(B,E)$. Now , let $x \in Int_\gamma(A,E) \cap Int_\gamma(B,E)$. Then, $x \in Int_\gamma(A,E), x \in Int_\gamma(B,E)$. This implies, there exists soft open nbds (U,E) and (V,E) of x such that ,$(U,E)^\gamma \subseteq (A,E)$ and $(V,E)^\gamma \subseteq (B,E)$.This implies $(U,E)^\gamma \cap (V,E)^\gamma \subseteq (A.E) \cap (B,E)$. Since γ is regular, therefore there exists a soft open nbd (W,E) of x such that $(W,E)^\gamma \subseteq (U,E)^\gamma \cap (V,E)^\gamma$. Thus, $(W,E)^\gamma \subseteq (A,E) \cap (B,E)$. Thus, $x \in Int_\gamma((A,E) \cap (B,E))$. Thus, we get $Int_\gamma((A,E) \cap (B,E)) \subseteq Int_\gamma(A,E) \cap Int_\gamma(B,E)$. Hence, the result.

Remark 4.8. The following example shows that, the equality does not hold if γ is not soft regular operation.

Example 4.9. Consider the example 3.10. Here, γ is not soft regular. Let $(A,E) = \{(e_1,\{a,b\}),(e_2,\{a,b\})\}$,
$(B,E) = \{(e_1,\{a,c\}),(e_2,\{a,c\})\}$.Here, $Int_\gamma((A,E) \cap (B,E)) \subset Int_\gamma(A,E) \cap Int_\gamma(B,E)$, but $Int_\gamma(A,E) \cap Int_\gamma(B,E) \nsubseteq Int_\gamma((A,E) \cap (B,E))$.

Theorem 4.10. The following results are true, in any soft topological space.
(a) $Int_\gamma(A,E)' = (Cl_\gamma(A,E))'$
(b)$Cl_\gamma(A,E)' = (Int_\gamma(A,E))'$
(c)$Int_\gamma(A,E) = (Cl_\gamma(A,E)')'$

Proof(a). Let $x \in Int_\gamma(A,E)'$.Then, there exists soft open nbd (U,E) of x such that $(U,E)^\gamma \subseteq (A,E)'$. This implies $(U,E)^\gamma \cap (A,E) = \phi$. This gives $x \notin Cl_\gamma(A,E)$. That is $x \in (Cl_\gamma(A,E))'$. Thus, $Int_\gamma(A,E)' \subset (Cl_\gamma(A,E))'$.Similarly we can easily prove the converse by reversing these steps. Hence, the result.
(b). Let $x \notin Cl_\gamma(A,E)'$. Then, there exists soft open nbd (U,E) of x such that $(U,E)^\gamma \cap (A,E)' = \phi$, which implies $(U,E)^\gamma \subset (A,E)$. Thus, $x \in Int_\gamma(A,E)$, implies $x \notin (Int_\gamma(A,E))'$. Thus, $(Int_\gamma(A,E))' \subset Cl_\gamma(A,E)'$. Similarly we can easily prove the converse by reversing these steps.
(c). Let $x \in (Cl_\gamma(A,E)')'$ then $x \notin Cl_\gamma(A,E)'$. Thus, there exists soft open nbd (U,E) of x such that $(U,E)^\gamma \subset (A,E)$. Thus, $x \in Int_\gamma(A,E)$. Hence, $(Cl_\gamma(A,E)')' \subset Int_\gamma(A,E)$. Similarly the converse can be proved by reversing these steps.

Definition 4.11. The soft γ- exterior of (A,E) is defined as the soft γ-interior of $(A,E)'$. That is $ext_\gamma(A,E) = Int_\gamma(A,E)'$.

Definition 4.12. The soft γ-boundary of (A, E), denoted by $bd_\gamma(A, E)$, is defined as the set of all points which do not belong to the soft γ-interior or soft γ-exterior of (A, E).

Theorem 4.13. In any soft topological spaces (X, τ, E) the following are equivalent:
(a) $(bd_\gamma(A, E))' = Int_\gamma(A, E) \cup Int_\gamma(A, E)'$
(b) $Cl_\gamma(A, E) = Int_\gamma(A, E) \cup bd_\gamma(A, E)$
(c) $bd_\gamma(A, E) = Cl_\gamma(A, E) \cap Cl_\gamma(A, E)' = Cl_\gamma(A, E) - Int_\gamma(A, E)$

Proof (a)$\Rightarrow$ (b). We have, $(ext_\gamma(A, E))' = Int_\gamma(A, E) \cup bd_\gamma(A, E)$.Which implies, $(Int_\gamma(A, E)')' = Int_\gamma(A, E) \cup bd_\gamma(A, E)$, from definition 4.11.Thus, $((Cl_\gamma(A, E))')' = Int_\gamma(A, E) \cup bd_\gamma(A, E)$, from theorem 4.10. This implies $Cl_\gamma(A, E) = Int_\gamma(A, E) \cup bd_\gamma(A, E)$. Thus,(b) holds.

(b)$\Rightarrow$(c). We have $(bd_\gamma(A, E))' = Int_\gamma(A, E) \cup ext_\gamma(A, E) = (Cl_\gamma(A, E)')' \cup (Cl\gamma(A, E))' = (Cl_\gamma(A, E) \cap Cl_\gamma(A, E)')'$. Thus, $bd_\gamma(A, E) = Cl_\gamma(A, E) \cap Cl_\gamma(A, E)' = Cl_\gamma(A, E) \cap (Int_\gamma(A, E))'$, from theorem 4.10. Hence, $bd_\gamma(A, E) = Cl_\gamma(A, E) - Int_\gamma(A, E)$. Thus, (c) holds.

(c)$\Rightarrow$(a). Consider, $Int_\gamma(A, E) \cup Int_\gamma(A, E)'$
$= ((Int_\gamma(A, E))')' \cup ((Int_\gamma(A, E)')')'$
$= [(Int_\gamma(A, E))' \cap (Int_\gamma(A, E)')']'$
$= (Cl_\gamma(A, E)' \cap Cl_\gamma(A, E))'$, from theorem 4.10
$=(bd_\gamma(A, E))'$. Thus, (a) holds.

Remark 4.14. From theorem 4.13(c), we have $bd_\gamma(A, E) = bd_\gamma(A, E)'$

Proposition 4.15. For a soft set (A, E) of X, we have the following:
(a) (A, E) is soft γ-open if and only if $(A, E) \cap bd_\gamma(A, E) = \phi$
(b) (A, E) is soft γ-closed if and only if $bd_\gamma(A, E) \subseteq (A, E)$.

Proof (a). Let (A, E) be soft γ-open set. Then, $(A, E)'$ is soft γ-closed. Therefore,by theorem 3.16, $Cl_\gamma(A, E)' = (A, E)'$. Now, $(A, E) \cap bd_\gamma(A, E) = (A, E) \cap [Cl_\gamma(A, E) \cap Cl_\gamma(A, E)'] = (A, E) \cap Cl_\gamma(A, E) \cap (A, E)' = \phi$. Conversely, let $(A, E) \cap bd_\gamma(A, E) = \phi$. Then, $(A, E) \cap Cl_\gamma(A, E) \cap Cl_\gamma(A, E)' = \phi$ or $(A, E) \cap Cl_\gamma(A, E)' = \phi$. This implies $Cl_\gamma(A, E)' \subseteq (A, E)'$ and $(A, E)' \subseteq Cl_\gamma(A, E)'$ is always true. Thus, $(A, E)'$ is soft γ-closed and hence (A, E) is soft γ-open.
(b). Let (A, E) be a soft γ-closed set. Then, $Cl_\gamma(A, E) = (A, E)$. Now, $bd_\gamma(A, E) = Cl_\gamma(A, E) \cap Cl_\gamma(A, E)' \subseteq Cl_\gamma(A, E) = (A, E)$. That is, $bd_\gamma(A, E) \subseteq (A, E)$. Conversely, let $bd_\gamma(A, E) \subseteq (A, E)$.Then, $bd_\gamma(A, E) \cap (A, E)' = \phi$.Since from remark 4.14, $bd_\gamma(A, E) = bd_\gamma(A, E)'$. We have $bd_\gamma(A, E)' \cap (A, E)' = \phi$. By (a), $(A, E)'$ is soft γ-open set and hence (A, E) is soft γ-closed.

Theorem 4.16. The following hold in any soft topological space (X, τ, E).
(a) $bd_\gamma(A, E) \cap Int_\gamma(A, E) = \phi$
(b) $Int_\gamma(A, E) = (A, E) - bd_\gamma(A, E)$

Proof (a). Consider $bd_\gamma(A, E) \cap Int_\gamma(A, E)$
$= Cl_\gamma(A, E) \cap Cl_\gamma(A, E)' \cap Int_\gamma(A, E)$
$= Cl_\gamma(A, E) \cap (Int_\gamma(A, E))' \cap Int_\gamma(A, E)$, from theorem 4.10(b).
$= \phi$

(b). Consider $(A,E) - bd_\gamma(A,E)$
$= (A,E) - [Cl_\gamma(A,E) \cap Cl_\gamma(A,E)']$
$= (A,E) \cap [(Cl_\gamma(A,E) \cap Cl_\gamma(A,E)')']$
$= (A,E) \cap [(Cl_\gamma(A,E))' \cup (Cl_\gamma(A,E)')']$
$= (A,E) \cap [(Cl_\gamma(A,E))' \cup (Int_\gamma(A,E))]$, from theorem 4.10(c).
$= [(A,E) \cap (Cl_\gamma(A,E))'] \cup [(A,E) \cap Int_\gamma(A,E)]$
$= Int_\gamma(A,E)$

Theorem 4.17. For any two soft sets $(A,E),(B,E)$ of X, if γ is soft regular operation, then we have the following:
(a) $ext_\gamma((A,E) \cup (B,E)) = ext_\gamma(A,E) \cap ext_\gamma(B,E)$
(b) $bd_\gamma((A,E) \cup (B,E)) = [bd_\gamma(A,E) \cap Cl_\gamma(B,E)'] \cup [bd_\gamma(B,E) \cap Cl_\gamma(A,E)']$
(c)$bd_\gamma((A,E) \cap (B,E)) = [bd_\gamma(A,E) \cap Cl_\gamma(B,E)] \cup [bd_\gamma(B,E) \cap Cl_\gamma(A,E)]$

Proof (a). Consider $ext_\gamma[(A,E) \cup (B,E)]$
$= Int_\gamma[(A,E) \cup (B,E)]'$
$= Int_\gamma[(A,E)' \cap (B,E)']$
$= Int_\gamma(A,E)' \cap Int_\gamma(B,E)'$, since γ is soft regular.
$= ext_\gamma(A,E) \cap ext_\gamma(B,E)$
(b). Consider, $bd_\gamma((A,E) \cup (B,E))$
$= Cl_\gamma((A,E) \cup (B,E)) \cap Cl_\gamma((A,E) \cup (B,E))'$, from theorem 4.13(c)
$= (Cl_\gamma(A,E) \cup Cl_\gamma(B,E)) \cap ((Cl_\gamma(A,E)' \cap (B,E)')$
$= (Cl_\gamma(A,E) \cup Cl_\gamma(B,E)) \cap ((Cl_\gamma(A,E)' \cap Cl_\gamma(B,E)')$
$= [Cl_\gamma(A,E) \cap Cl_\gamma(A,E)' \cap Cl_\gamma(B,E)'] \cup [Cl_\gamma(B,E) \cap Cl_\gamma(A,E)' \cap Cl_\gamma(B,E)'] = [bd_\gamma(A,E) \cap Cl_\gamma(B,E)'] \cup [bd_\gamma(B,E) \cap Cl_\gamma(A,E)']$
(c). Consider, $bd_\gamma((A,E) \cap (B,E))$
$= Cl_\gamma((A,E) \cap (B,E)) \cap Cl_\gamma((A,E) \cap (B,E))'$
$= [Cl_\gamma(A,E) \cap Cl_\gamma(B,E)] \cap [Cl_\gamma((A,E)' \cup (B,E)')]$
$= [Cl_\gamma(A,E) \cap Cl_\gamma(B,E)] \cap [Cl_\gamma(A,E)' \cup Cl_\gamma(B,E)']$
$= [Cl_\gamma(A,E) \cap Cl_\gamma(B,E) \cap Cl_\gamma(A,E)'] \cup [Cl_\gamma(A,E) \cap Cl_\gamma(B,E) \cap Cl_\gamma(B,E)']$
$= [bd_\gamma(A,E) \cap Cl_\gamma(B,E)] \cup [Cl_\gamma(A,E) \cap bd_\gamma(B,E)]$

Theorem 4.18. For any soft sets $(A,E),(B,E)$ in soft topological space (X,τ,E) the following hold:
(a) $Cl_\gamma[(A,E) - (B,E)] \supseteq Cl_\gamma(A,E) - Cl_\gamma(B,E)$
(b) $Int_\gamma[(A,E) - (B,E)] \subseteq Int_\gamma(A,E) - Int_\gamma(B,E)$
(c)If (A,E) is soft γ-open, then $(A,E) \cap Cl_\gamma(B,E) \subseteq Cl_\gamma(B,E) \subseteq Cl_\gamma((A,E) \cap (B,E))$

Proof (a). Let $x \in Cl_\gamma(A,E) - Cl_\gamma(B,E)$. Then, $x \in Cl_\gamma(A,E)$ and $x \notin Cl_\gamma(B,E)$.Then, there exists soft open nbd (U,E) of x such that $(U,E)^\gamma \cap (A,E) \neq \phi$ and $(U,E)^\gamma \cap (B,E) = \phi$. This implies $(U,E)^\gamma \cap ((A,E) - (B,E)) \neq \phi$. That is $x \in Cl_\gamma((A,E) - (B,E))$. Thus it proves (a).

(b). Let $x \notin Int_\gamma(A,E) - Int_\gamma(B,E)$. Then, $x \notin Int_\gamma(A,E), x \in Int_\gamma(B,E)$. Thus, there exists a soft open nbd (U,E) of x such that $(U,E)^\gamma \cap (A,E)' \neq \phi$ and $(U,E)^\gamma \cap (B,E)' = \phi$. Thus, $(U,E)^\gamma \cap ((A,E) - (B,E)) = \phi$. Therefore, $x \notin Int_\gamma((A,E) - (B,E))$. Hence, $Int_\gamma[(A,E) - (B,E)] \subseteq Int_\gamma(A,E) - Int_\gamma(B,E)$.

(c). Since (A,E) is soft γ-open, then $(A,E) = Int_\gamma(A,E)$.
Now, $(A,E) \cap Cl_\gamma(B,E)$

$= Cl_\gamma(B,E) \cap Int_\gamma(A,E)$
$= Cl_\gamma(B,E) - (Int_\gamma(A,E))'$
$= Cl_\gamma(B,E) - Cl_\gamma(A,E)'$, from theorem 4.10(b).
$\subseteq Cl_\gamma[(B,E) - (A,E)']$, from theorem 4.18(a).
$= Cl_\gamma[(B,E) \cap (A,E)] = Cl_\gamma[(A,E) \cap (B,E)]$
Therefore, $(A,E) \cap Cl_\gamma(B,E) \subseteq Cl_\gamma((A,E) \cap (b,E))$.

Definition 4.19. An operation $\gamma : \tau \to P(X)$ is said to be strictly soft regular, if for any soft open nbds $(U,E),(V,E)$ of x there exists soft open nbd (W,E) of x such that $(U,E)^\gamma \cap (V,E)^\gamma = (W,E)^\gamma$.

Definition 4.20. An operation $\gamma : \tau \to P(X)$ is said to be soft γ-open if $(V,E)^\gamma$ is soft γ-open for each $(V,E) \in \tau$.

Example 4.21. Let $X = \{a,b,c\}, E = \{e_1,e_2\}, \tau = \{\phi, X, (A,E),(B,E),(C,E)\}$. where
$(A,E) = \{(e_1,\{a\}),(e_2,\{a\})\}$,
$(B,E) = \{(e_1,\{b\}),(e_2,\{b\})\}$,
$(C,E) = \{(e_1,\{a,b\}),(e_2,\{a,b\})\}$.
Let us define an operation $\gamma : \tau \to P(X)$ by $\gamma(A,E) = IntCl(A,E)$. Then, soft γ-open sets are only $\phi, X, (A,E),(B,E),(C,E)$. We can easily verify that γ is strictly soft regular and soft γ-open on (X,τ,E).

Example 4.22. Consider (X,τ,E) be same as in above example 4.21. Let us define an operation γ by $\gamma(A,E) = Cl(A,E)$. Then, the soft γ-open sets are only ϕ, X. We can verify that γ is strictly soft regular but not soft γ-open on (X,τ,E).

Theorem 4.23. If (X,τ,E) is a soft $\gamma - T_2$ space then for any two distinct points $a,b \in X$, there are soft γ-closed sets (F,E) and (G,E) such that $a \in (F,E), b \notin (F,E)$ and $a \notin (G,E), b \in (G,E)$ and $\widetilde{X} = (F,E) \cup (G,E)$, where γ is soft γ operation.

Proof. Since (X,τ,E) is soft $\gamma - T_2$ space then for any $a,b \in X$ there exist soft open sets $(U,E),(V,E)$ such that $a \in (U,E), b \in (V,E)$ and $(U,E)^\gamma \cap (V,E)^\gamma = \phi$. Therefore, $(U,E)^\gamma \subseteq ((V,E)^\gamma)'$ and $(V,E)^\gamma \subseteq ((U,E)^\gamma)'$. Hence, $a \in ((V,E)^\gamma)'$ and $b \in ((U,E)^\gamma)'$. Let $((V,E)^\gamma)' = (F,E)$ and $((U,E)^\gamma)' = (G,E)$. This gives, $a \in (F,E), b \notin (F,E)$ and $a \notin (G,E), b \in (G,E)$. Also, $(F,E) \cup (G,E) = ((V,E)^\gamma)' \cup ((U,E)^\gamma)' = [(V,E)^\gamma \cap (U,E)^\gamma]' = (\phi)' = \widetilde{X}$.

Theorem 4.24. If (X,τ,E) is a soft $\gamma - T_2$ space, then for every point x of X, $(x,E) = \cap(C,E)_x$, where $(C,E)_x$ is a soft γ-closed set containing soft open set (U,E) which contains x, where γ is soft γ-open operation.

Proof. Since (X,τ,E) is a soft $\gamma - T_2$ space, then for any $x,y \in X$ with $x \neq y$, there exist soft open sets (U,E) and (V,E) such that $x \in (U,E), y \in (V,E)$ and $(U,E)^\gamma \cap (V,E)^\gamma = \phi$. Thus,$(U,E)^\gamma \subseteq ((V,E)^\gamma)'$. Since $((V,E)^\gamma)'$ is a soft γ-closed and $(U,E)^\gamma \subseteq ((V,E)^\gamma)' = (C,E)_x$ is a soft γ-closed nbd of x and $y \notin ((V,E)^\gamma)' = (C,E)_x$. Thus, x is the only point which is in every soft γ-closed nbd of x. i.e. $(x,E) = \cap(C,E)_x$.

Definition 4.25. A soft topological space (X,τ,E) is said to be soft γ^*-regular space if for any soft γ-closed set (A,E) and $x \notin (A,E)$, there exist disjoint soft γ-open sets $(U,E),(V,E)$ such that $x \in (U,E), (A,E) \subseteq (V,E)$.

Example 4.26. The soft indiscrete space is a soft γ^*-regular space, for if any soft γ-closed set (A,E) and any point $x \notin (A,E)$ there are soft γ-open sets $(U,E),(V,E)$ such that $x \in (U,E),(A,E) \subseteq (V,E)$ and $(U,E) \cap (V,E) = \phi$.

Theorem 4.27. If (X,τ,E) is soft γ^*-regular space then for any soft γ-open set (U,E) in (X,τ,E) and $x \in (U,E)$, there is a soft γ-open set (V,E) containing x such that $x \in Cl_\gamma(V,E) \subseteq (U,E)$.

Proof. Let (X,τ,E) be soft γ^*-regular space and (U,E) be a soft γ-open set and $x \in (U,E)$. Then, $(U,E)'$ is a soft γ-closed set such that $x \notin (U,E)'$. By the definition of soft γ^*-regularity, there are soft γ-open sets $(V,E),(W,E)$ such that $x \in (V,E),(U,E)' \subseteq (W,E)$ and $(V,E)\cap(W,E) = \phi$. Clearly, $(W,E)' \subseteq (U,E)$ and $(W,E)'$ is a soft γ-closed set. Now, $(V,E) \subseteq (W,E)' \subseteq (U,E)$. This gives, $Cl_\gamma(V,E) \subseteq (W,E)' \subseteq (U,E)$. Thus, $x \in (V,E)$ and $Cl_\gamma(V,E) \subseteq (U,E)$.

Definition 4.28. Let (X,τ,E) is soft topological space and (U,E) be a soft subset. Then, the class of soft γ-open sets in(A,E) is defined in a natural way as:
$\tau_{\gamma_{(A,E)}} = \{(A,E) \cap (O,E) : (O,E) \in \tau_\gamma\}$
where τ_γ is the set of soft γ-open sets of X. That is (G,E) is soft γ-open in (A,E) iff $(G,E) = (A,E) \cap (O,E)$, where (O,E) is a soft γ-open in (X,τ,E).

Theorem 4.29. Every soft subspace of soft γ^*-regular space is soft γ^*-regular space.

Proof. Let (Y,τ,E) be a soft subspace of soft γ^*-regular space (X,τ,E). Suppose (A,E) is a soft γ-closed set in (Y,τ,E) and $y \in Y$ such that $y \notin (A,E)$. Then, $(A,E) = (B,E)\cap\widetilde{Y}$, where (B,E) is soft γ-closed in (X,τ,E). Then, $y \notin (B,E)$. Since, (X,τ,E) is soft γ^*-regular space, there exist disjoint soft γ-open sets $(U,E),(V,E)$ in (X,τ,E) such that $y \in (U,E),(B,E) \subseteq (V,E)$. Then, $(U,E) \cap \widetilde{Y}$ and $(V,E) \cap \widetilde{Y}$ are disjoint soft γ-open sets in (Y,τ,E) such that $y \in (U,E) \cap \widetilde{Y}$ and $(A,E) \subseteq (V,E) \cap \widetilde{Y}$. Thus, (Y,τ,E) is a soft γ^*-regular space.

Theorem 4.30. A soft topological space (X,τ,E) is soft γ^*-regular if and only if for each $x \in X$ and a soft γ-closed set (A,E) such that $x \notin (A,E)$, there exist soft γ-open sets $(U,E),(V,E)$ in (X,τ,E) such that $x \in (U,E),(A,E) \subseteq (V,E)$ and $Cl_\gamma(U,E) \cap Cl_\gamma(V,E) = \phi$.

Proof. For each $x \in X$ and a soft γ-closed set (A,E) such that $x \notin (A,E)$, that is $x \in (A,E)'$ and $(A,E)'$ is soft γ-open set, by theorem 4.27, there exist a soft γ-open set (W,E) such that $x \in (W,E)$ and $Cl_\gamma(W,E) \subseteq (A,E)'$. Again by theorem 4.27, there exists a soft γ-open set (U,E) containing x such that $Cl_\gamma(U,E) \subseteq (W,E)$. Let $(V,E) = (Cl_\gamma(W,E))'$. Then, $Cl_\gamma(U,E) \subseteq (W,E) \subseteq Cl_\gamma(W,E) \subseteq (A,E)'$. This implies $(A,E) \subseteq (Cl_\gamma(W,E))' = (V,E)$. Also, $Cl_\gamma(U,E) \cap Cl_\gamma(V,E) = Cl_\gamma(U,E) \cap Cl_\gamma(Cl_\gamma(W,E))' \subseteq (W,E)\cap Cl_\gamma(Cl_\gamma(W,E))' \subseteq Cl_\gamma[(W,E)\cap(Cl_\gamma(W,E))']$, (from theorem 4.18(c))$= Cl_\gamma(\phi) = \phi$. The converse is straight forward from the definition. Hence, this completes the proof.

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