Annals of **F**uzzy **M**athematics and **I**nformatics
Volume 6, No. 2, (September 2013), pp. 425–431
ISSN: 2093–9310 (print version)
ISSN: 2287–6235 (electronic version)
http://www.afmi.or.kr

An introduction to open and closed sets on fuzzy soft topological spaces

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Received 2 January 2013; Revised 30 January 2013; Accepted 19 February 2013

Abstract. The aim of this paper is to construct a relation between the closure of a fuzzy soft set and its fuzzy soft limit points on a fuzzy soft topological spaces.

2010 AMS Classification: 54A40, 06D72

Keywords: Fuzzy soft point, Fuzzy soft interior point, Quasi-coincident, Q-neighborhood, Fuzzy soft limit point, Fuzzy soft closure.

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1. Introduction

After having initiated the notion of fuzzy set first by Zadeh[11] in 1965, much research has been carried out in the areas of general theories as well as application. In 1968, Chang[4] introduced the theory of fuzzy topological spaces and then in 1973, Wong[10] developed this spaces by covering properties. Then after a long time, D. Molodtsov initiated a concept namely, soft set theory to solve complicated problems in engineering, physics, computer science, medical science etc. To improve this concept, many researchers applied this notion on group theory[2], ring theory[1], topological spaces[7] and also on decision making problem[6].

In the present times, researchers have combined these two above concepts to generalize the spaces and to solve more complicated problems. In 2001, Maji and et. al. first combined these two sets and called it fuzzy soft set. Then many researchers defined group[3], ring[5], topology[8] on fuzzy soft set. In our paper[9], we also studied fuzzy soft topological spaces in another suitable form.

In this paper, we have defined open, closed fuzzy soft sets and established a relation between the closure of a fuzzy soft set and its fuzzy soft limit points. But here we have apprehend that it may not possible to construct a limit point of a fuzzy soft set by usual neighborhood properties. To define fuzzy soft limit point of a fuzzy soft set, at first we recall some definitions and theorem on fuzzy soft set from our paper[9]. Then we define a few new definitions such as Quasi-coincident, Q-neighborhood etc. and establish some important propositions and theorems on fuzzy soft topological spaces.

2. Preliminaries

This section contains some basic definitions and theorem which will be needed in the sequel.

Definition 2.1 ([9])**.** Let $A \subseteq E$. Then the mapping $F_A : E \to I^U$, defined by $F_A(e) = \mu^e_{F_A}$(a fuzzy subset of U), is called fuzzy soft set over (U, E), where $\mu^e_{F_A} = \overline{0}$ if $e \in E \setminus A$ and $\mu^e_{F_A} \neq \overline{0}$ if $e \in A$.
The set of all fuzzy soft set over (U, E) is denoted by $FS(U, E)$.

Definition 2.2 ([9])**.** The fuzzy soft set $F_\phi \in FS(U, E)$ is called null fuzzy soft set and it is denoted by Φ. Here $F_\phi(e) = \overline{0}$ for every $e \in E$.

Definition 2.3 ([9])**.** Let $F_E \in FS(U, E)$ and $F_E(e) = \overline{1}$ for all $e \in E$. Then F_E is called absolute fuzzy soft set. It is denoted by $\widetilde{E}$.

Definition 2.4 ([9])**.** Let $F_A,\, G_B \in FS(U, E)$. If $F_A(e) \subseteq G_B(e)$ for all $e \in E$, i.e., if $\mu^e_{F_A} \subseteq \mu^e_{G_B}$ for all $e \in E$, i.e., if $\mu^e_{F_A}(x) \leq \mu^e_{G_B}(x)$ for all $x \in U$ and for all $e \in E$, then F_A is said to be fuzzy soft subset of G_B, denoted by $F_A \sqsubseteq G_B$.

Definition 2.5 ([9])**.** Let $F_A,\, G_B \in FS(U, E)$. Then the union of F_A and G_B is also a fuzzy soft set H_C, defined by $H_C(e) = \mu^e_{H_C} = \mu^e_{F_A} \cup \mu^e_{G_B}$ for all $e \in E$, where $C = A \cup B$. Here we write $H_C = F_A \sqcup G_B$.

Following the arbitrary union of fuzzy subsets and the union of two fuzzy soft sets, the definition of arbitrary union of fuzzy soft sets can be described in the similarly fashion.

Definition 2.6 ([9])**.** Let $F_A,\, G_B \in FS(U, E)$. Then the intersection of F_A and G_B is also a fuzzy soft set H_C, defined by $H_C(e) = \mu^e_{H_C} = \mu^e_{F_A} \cap \mu^e_{G_B}$ for all $e \in E$, where $C = A \cap B$. Here we write $H_C = F_A \sqcap G_B$.

Definition 2.7 ([9])**.** A fuzzy soft topology $\mathcal{T}$ on (U, E) is a family of fuzzy soft sets over (U, E) satisfying the following properties

1. $\Phi, \widetilde{E} \in \mathcal{T}$.
2. If $F_A,\, G_B \in \mathcal{T}$ then $F_A \sqcap G_B \in \mathcal{T}$.
3. If $F^\alpha_{A_\alpha} \in \mathcal{T}$ for all $\alpha \in \Lambda$, an index set, then $\sqcup_{\alpha\in\Lambda} F^\alpha_{A_\alpha} \in \mathcal{T}$.

Definition 2.8 ([9])**.** If $\mathcal{T}$ is a fuzzy soft topology on (U, E), the triple $(U, E, \mathcal{T})$ is said to be a fuzzy soft topological space. Also each member of $\mathcal{T}$ is called a fuzzy soft open set in $(U, E, \mathcal{T})$.

Definition 2.9 ([9])**.** A subfamily β of $\mathcal{T}$ is called a fuzzy soft open base or simply a base of fuzzy soft topological space $(U, E, \mathcal{T})$ if the following conditions hold:

1. $\Phi \in \beta$.
2. $\sqcup\beta = \widetilde{E}$ i.e. for each $e \in E$ and $x \in U$, there exists $F_A \in \beta$ such that $\mu^e_{F_A}(x) = 1$.

3. If F_A, $G_B \in \beta$ then for each $e \in E$ and $x \in U$, there exists $H_C \in \beta$ such that $H_C \sqsubseteq F_A \sqcap G_B$ and $\mu^e_{H_C}(x) = \min\{\mu^e_{F_A}(x), \mu^e_{G_B}(x)\}$, where $C \subseteq A \cap B$.

Theorem 2.10 ([9]). *Let β be a fuzzy soft base for a fuzzy soft topology $\mathcal{T}_\beta$ on (U, E). Then $F_A \in \mathcal{T}_\beta$ if and only if $F_A = \sqcup_{\alpha\in\Lambda} B^\alpha_{A_\alpha}$, where $B^\alpha_{A_\alpha} \in \beta$ for each $\alpha \in \Lambda$, Λ an index set.*

3. Fuzzy soft point and its neighborhood structure

Definition 3.1. A fuzzy soft point F_e over (U, E) is a special fuzzy soft set, defined by

$$F_e(a) = \mu_{F_e} \text{ if } a = e, \text{ where } \mu_{F_e} \neq \overline{0}$$
$$= \overline{0} \text{ if } a \neq e$$

Definition 3.2. Let F_A be a fuzzy soft set over (U, E) and G_e be a fuzzy soft point over (U, E). Then we say that $G_e \in F_A$ if and only if $\mu_{G_e} \subseteq \mu^e_{F_A} = F_A(e)$ i.e., $\mu_{G_e}(x) \leq \mu^e_{F_A}(x)$ for all $x \in U$.

Definition 3.3. A fuzzy soft set F_A is said to be a neighborhood of a fuzzy soft point G_e if there exists $H_B \in \mathcal{T}$ such that $G_e \in H_B \sqsubseteq F_A$. Then clearly, every open fuzzy soft set is a neighborhood of each of its points.

Theorem 3.4. *Let $F_A \in FS(U, E)$. Then $F_A \in \mathcal{T}$ if and only if F_A is a neighborhood of each of its fuzzy soft points.*

Proof. If $F_A \in \mathcal{T}$, then obviously F_A is a neighborhood of each of its fuzzy soft points.

Conversely, let F_A is a neighborhood of each of its fuzzy soft points. Then for any $F^\alpha_e \in F_A, \alpha \in \Lambda$, there exists $G^\alpha_{A^\alpha_e} \in \mathcal{T}$ such that $F^\alpha_e \in G^\alpha_{A^\alpha_e} \sqsubseteq F_A$. So that

$$\sqcup F^\alpha_e \sqsubseteq \sqcup G^\alpha_{A^\alpha_e} \sqsubseteq F_A, \tag{3.1}$$

where union is taken over the set of all $\alpha \in \Lambda$ and all $e \in E$. We now show that $\sqcup F^\alpha_e = F_A$. Since each $F^\alpha_e(a) \subseteq F_A(a)$, where $e \in E$ and $\alpha \in \Lambda$, there exists $\alpha \in \Lambda$ such that $F^\alpha_e(a) = F_A(a)$. Therefore $\sqcup F^\alpha_e(a) = F_A(a)$, where union is taken over the set of all $\alpha \in \Lambda$ and all $e \in E$. It implies that

$$\sqcup F^\alpha_e = F_A. \tag{3.2}$$

From (3.1) and (3.2) we get $F_A = \sqcup G^\alpha_{A^\alpha_e}$. Again since each $G^\alpha_{A^\alpha_e} \in \mathcal{T}$, $\sqcup G^\alpha_{A^\alpha_e} \in \mathcal{T}$. Hence $F_A \in \mathcal{T}$. □

Definition 3.5. The collection of all neighborhoods of a point F_e over (U, E) is called the neighborhood system at F_e and it is denoted by η_{F_e}.

Theorem 3.6. *The neighborhood system η_{F_e} at any point F_e over (U, E) satisfy the following properties*

(i) $\eta_{F_e} \neq \phi$,
(ii) $G_A \in \eta_{F_e} \Rightarrow F_e \in G_A$.
(iii) G_A, $H_B \in \eta_{F_e} \Rightarrow G_A \sqcap H_B \in \eta_{F_e}$
(iv) $G_A \in \eta_{F_e}$ *and* $G_A \sqsubseteq H_B \Rightarrow H_B \in \eta_{F_e}$.

Proof. (i) Since $\widetilde{E} \in \mathcal{T}$ and $F_e \in \widetilde{E}$, $\widetilde{E} \in \eta_{F_e}$.

(ii) Obvious.

(iii) Since G_A and $H_B \in \eta_{F_e}$, there exist V_{A_1} and W_{B_1} in $\mathcal{T}$ such that $F_e \in V_{A_1} \sqsubseteq G_A$ and $F_e \in W_{B_1} \sqsubseteq H_B$. Thus $\mu_{F_e}(x) \leq \mu^e_{V_{A_1}}(x)$ and $\mu_{F_e}(x) \leq \mu^e_{W_{B_1}}(x)$ for all $x \in U$. Therefore $\mu_{F_e}(x) \leq \min\{\mu^e_{V_{A_1}}(x), \mu^e_{W_{B_1}}(x)\}$ for all $x \in U$. So, $\mu_{F_e} \subseteq \mu^e_{V_{A_1}} \cap \mu^e_{W_{B_1}}$. That is, $F_e \in V_{A_1} \sqcap W_{B_1} \sqsubseteq G_A \sqcap H_B$. Again since $V_{A_1} \sqcap W_{B_1} \in \mathcal{T}$, $G_A \sqcap H_B \in \eta_{F_e}$.

(iv) Obvious. □

Definition 3.7. The union of all fuzzy soft open subsets of F_A over (U, E) is called the interior of F_A and is denoted by $intF_A$.

Example 3.8. Let $E = \{e_1,\ e_2,\ e_3\}$, $U = \{a,\ b,\ c\}$ and $A,\ B,\ C$ be the subsets of E, where $A = \{e_1,\ e_2\}$, $B = \{e_2,\ e_3\}$ and $C = \{e_1,\ e_3\}$ and also let $\mathcal{T}= \{\phi,\ \widetilde{E},\ F_A,\ G_B,\ H_{e_2},\ I_E,\ J_B,\ K_{e_2}\}$ be a fuzzy soft topology over (U, E) where $F_A,\ G_B,\ H_{e_2},\ I_E,\ J_B,\ K_{e_2}$ are fuzzy soft set over (U, E), defined as follows

$\mu^{e_1}_{F_A} = \{.5,\ .75,\ .4\}$, $\mu^{e_2}_{F_A} = \{.3,\ .8,\ .7\}$,
$\mu^{e_2}_{G_B} = \{.4,\ .6,\ .3\}$, $\mu^{e_3}_{G_B} = \{.2,\ .4,\ .45\}$,
$\mu_{H_{e_2}} = \{.3,\ .6,\ .3\}$,
$\mu^{e_1}_{I_E} = \{.5,\ .75,\ .4\}$, $\mu^{e_2}_{I_E} = \{.4,\ .8,\ .7\}$, $\mu^{e_3}_{I_E} = \{.2,\ .4,\ .45\}$,
$\mu^{e_2}_{J_B} = \{.4,\ .8,\ .7\}$, $\mu^{e_3}_{J_B} = \{.2,\ .4,\ .45\}$,
$\mu_{K_{e_2}} = \{.3,\ .8,\ .7\}$.

Now let us consider a fuzzy soft set L_E as follows

$\mu^{e_1}_{L_E} = \{.7,\ .8,\ .5\}$, $\mu^{e_2}_{L_E} = \{.4,\ .9,\ .7\}$, $\mu^{e_3}_{L_E} = \{.2,\ .3,\ .1\}$.

Therefore $intL_E = F_A \sqcup H_{e_2} \sqcup K_{e_2} = F_A$.

Proposition 3.9. $int(F_A \sqcap G_B) = intF_A \sqcap intG_B$

Proof. Since $F_A \sqcap G_B \sqsubseteq F_A$, $int(F_A \sqcap G_B) \sqsubseteq intF_A$.Similarly, $int(F_A \sqcap G_B) \sqsubseteq intG_B$. Therefore $int(F_A \sqcap G_B) \sqsubseteq intF_A \sqcap intG_B$. Let $H_C \in \mathcal{T}$ such that $H_C \sqsubseteq intF_A \sqcap intG_B$. Then $H_C \sqsubseteq intF_A$ and $H_C \sqsubseteq intG_B$. That is $H_C(e) \subseteq F_A(e)$ and $H_C(e) \subseteq G_B(e)$ for all $e \in E$. So, $H_C(e) \subseteq F_A(e) \cap G_B(e) = (F_A \sqcap G_B)(e)$ for all $e \in E$. Thus $H_C \sqsubseteq F_A \sqcap G_B$. So $H_C = intH_C \sqsubseteq int(F_A \sqcap G_B)$. This implies that $intF_A \sqcap intG_B \sqsubseteq int(F_A \sqcap G_B)$. This completes the proof. □

Definition 3.10. Let $F_A \in FS(U, E)$ be a fuzzy soft set. Then the complement of F_A, denoted by F^c_A, is defined by

$$F^c_A(e) = \bar{1} - \mu^e_{F_A} \text{ for } e \in A,$$
$$= \bar{1}, \text{ otherwise.}$$

Definition 3.11. A fuzzy soft set $F_A \in FS(U, E)$ is called a fuzzy soft closed set if F^c_A is a fuzzy soft open set in $FS(U, E)$.

Definition 3.12. Let $F_A \in FS(U, E)$ be a fuzzy soft set. Then the intersection of all closed sets, each containing F_A, is called the closure of F_A and is denoted by $\overline{F_A}$.

Example 3.13. Let us consider the example 3.8 and a fuzzy soft set L_{e_2}, where $\mu_{L_{e_2}} = \{.5,\ .2,\ .6\}$. Then $L_{e_2} \sqsubseteq G^c_B,\ H^c_{e_2}$. Therefore $\overline{L_{e_2}} = G^c_B \sqcap H^c_{e_2} = G^c_B$.

4. Q-neighborhood structure and accumulation point

Definition 4.1. A fuzzy soft point G_e is said to be a quasi-coincident with F_A, denoted by G_eqF_A if and only if $\mu_{G_e}(x)+ \mu^e_{F_A}(x) > 1$ for some $x \in U$.

Definition 4.2. A fuzzy soft set H_A is said to be a quasi-coincident with F_B, denoted by H_AqF_B if and only if $\mu^e_{H_A}(x)+ \mu^e_{F_B}(x) > 1$ for some $x \in U$ and $e \in A \cap B$.

Definition 4.3. A fuzzy soft set F_A is called a Q-neighborhood of G_e if and only if there exists $H_B \in \mathcal{T}$ such that G_eqH_B and $H_B \sqsubseteq F_A$.

Proposition 4.4. *$H_B \sqsubseteq F_A$ if and only if H_B and F^c_A are not quasi-coincident. In particular, $G_e \in H_B$ if and only if G_e is not a quasi-coincident with H^c_B.*

Proof. This follows from the fact:
$H_B \sqsubseteq F_A \Leftrightarrow \mu^e_{H_B}(x) \leq \mu^e_{F_A}(x)$ for all $x \in U$ and $e \in E$
$\Leftrightarrow \mu^e_{H_B}(x)+\mu^e_{F^c_A}(x) = \mu^e_{H_B}(x) + 1 - \mu^e_{F_A}(x) \leq 1$ for all $x \in U$ and $e \in E$. □

Proposition 4.5. *Let $\mathfrak{U}_{G_e}$ be a family of Q-neighborhood of a fuzzy soft point G_e in a fuzzy soft topological space $\mathcal{T}$.*

(i) *If $F_A \in \mathfrak{U}_{G_e}$, then G_e is quasi-coincident with F_A.*
(ii) *If $F_A \in \mathfrak{U}_{G_e}$ and $F_A \sqsubseteq H_B$, then $H_B \in \mathfrak{U}_{G_e}$.*
(iii) *If $F_A \in \mathfrak{U}_{G_e}$, then there exists $H_B \in \mathfrak{U}_{G_e}$ such that $H_B \sqsubseteq F_B$ and $H_B \in \mathfrak{U}_{I_d}$ for every fuzzy soft point I_d which is quasi-coincident with H_B.*

Proof. (i) suppose $F_A \in \mathfrak{U}_{G_e}$. Then there exists $I_C \in \mathcal{T}$ such that G_eqI_C and $I_C \sqsubseteq F_A$. That is, $\mu_{G_e}(x_0)+\mu^e_{I_C}(x_0) > 1$ for some $x_0 \in U$.
Again $\mu^e_{I_C}(x) \leq \mu^e_{F_A}(x)$ for all $x \in U$.
Therefore $\mu_{G_e}(x_0)+\mu^e_{F_A}(x_0) \geq \mu_{G_e}(x_0)+ \mu^e_{I_C}(x_0) > 1$. Hence G_e is quasi-coincident with F_A.

(ii) obvious.

(iii) Suppose $F_A \in \mathfrak{U}_{G_e}$. Then there exists $H_B \in \mathcal{T}$ such that G_eqH_B and $H_B \sqsubseteq F_A$. That is, there exists $H_B \in \mathfrak{U}_{G_e}$ such that G_eqH_B and $H_B \sqsubseteq F_A$. Let I_d be any fuzzy soft point which is quasi-coincident with H_B. Therefore $H_B \in \mathfrak{U}_{I_d}$. □

Proposition 4.6. *Let $\{F^j_{A_j}\}_{j\in\Lambda}$ be a family of fuzzy soft sets over (U, E). Then a fuzzy soft point G_e is quasi-coincident with $\sqcup F^j_{A_j}$ if and only if $G_eqF^j_{A_j}$ for some $j \in \Lambda$.*

Proof. Obvious. □

Theorem 4.7. *A subfamily β of a fuzzy soft topology $\mathcal{T}$ over (U, E) is a base for $\mathcal{T}$ if and only if for each fuzzy soft point G_e and for each Q-neighborhood F_A of G_e, there exists a member $H_B \in \beta$ such that G_eqH_B and $H_B \sqsubseteq F_A$.*

Proof. First we suppose that β is a base for $\mathcal{T}$. Let G_e be a fuzzy soft point and F_A be a Q-neighborhood of G_e. Then there exists $I_C \in \mathcal{T}$ such that G_eqI_C and $I_C \sqsubseteq F_A$. Since $I_C \in \mathcal{T}$ and β is a base for $\mathcal{T}$, by theorem 2.10, I_C can be expressed as $\sqcup_{j\in J} H_{B_j}$ where $H_{B_j} \in \beta$ for all $j \in J$. Therefore G_e is a quasi-coincident with $\sqcup_{j\in J} H_{B_j}$. So there exists some H_{B_j} such that $G_eqH_{B_j}$ and $H_{B_j} \sqsubseteq F_A$. This proves

the necessary part of the theorem. We shall now prove the sufficient part of the theorem.
If possible, let β is not a base for $\mathcal{T}$. Then there exists $F_A \in \mathcal{T}$ such that $G = \sqcup\{H_B \in \beta\colon H_B \sqsubseteq F_A\} \neq F_A$.
Therefore there exists $e \in E$ such that $\mu^e_G(x) < \mu^e_{F_A}(x)$ for some $x \in U$. Thus $\mu^e_{F_A}(x) + 1 - \mu^e_G(x) > 1$. That is $I_e q F_A$ where $\mu_{I_e}(x) = 1 - \mu^e_G(x)$. So by the given condition there exists $H_B \in \beta$ such that $I_e q H_B$ and $H_B \sqsubseteq F_A$. Since $H_B \in G$, it follows that $\mu^e_{H_B}(x) \leq \mu^e_G(x)$. That is, $\mu^e_{H_B}(x) + \mu_{I_e}(x) \leq 1$, which contradicts the fact that $I_e q H_B$. This completes the proof. □

Theorem 4.8. *A fuzzy soft point $G_e \in \overline{F_A}$ if and only if each Q-neighborhood of G_e is a quasi-coincident with F_A.*

Proof. $G_e \in \overline{F_A}$ if and only if for every closed set H_B containing F_A, $G_e \in H_B$ i.e., $\mu^e_{H_B}(x) \geq \mu_{G_e}(x)$ for all $x \in U$.
That is, $G_e \in \overline{F_A}$ if and only if $1 - \mu^e_{H_B}(x) \leq 1 - \mu_{G_e}(x)$ for all $x \in U$ and for all closed set $H_B \sqsupseteq F_A$.
Therefore $G_e \in \overline{F_A}$ if and only if for any fuzzy soft open set $I_C \sqsubseteq F^c_A$, we have $\mu^e_{I_C}(x) \leq 1 - \mu_{G_e}(x)$ for all $x \in U$.
In other words, for every fuzzy soft open set I_C satisfying $\mu^e_{I_C}(x) > 1 - \mu_{G_e}(x)$ for some $x \in U$, I_C is not contained in F^c_A. Again I_C is not contained in F^c_A if and only if I_C is a quasi-coincident with F_A. We have thus proved that $G_e \in \overline{F_A}$ if and only if every open Q-neighborhood I_C of G_e is quasi-coincident with F_A, which is evidently equivalent to what we want to prove. □

Definition 4.9. A fuzzy soft point G_e is called an adherence point of a fuzzy soft set F_A if and only if every Q-neighborhood of G_e is a quasi-coincident with F_A.

Proposition 4.10. *Every fuzzy soft point of F_A is an adherence point of F_A.*

Definition 4.11. A fuzzy soft point G_e is called an accumulation point of a fuzzy soft set F_A if G_e is an adherence point of F_A and every Q-neighborhood of G_e and F_A are quasi-coincident at some fuzzy soft point different from e, whenever $G_e \in F_A$. The union of all accumulation points of F_A is called the derived set of F_A, denoted by F^d_A.

Theorem 4.12. $\overline{F_A} = F_A \sqcup F^d_A$

Proof. Let $\Omega = \{G_e : \; G_e$ is an adherent point of $F_A\}$. Then by theorem 4.8, $\overline{F_A} = \sqcup\Omega$. Now $G_e \in \Omega$ if and only if either $G_e \in F_A$ or $G_e \in F^d_A$. Hence $\overline{F_A} = \sqcup\Omega = F_A \sqcup F^d_A$. □

Corollary 4.13. *A fuzzy soft set $F_A \in FS(U,E)$ is closed in a fuzzy soft topological space $(U, E, \mathcal{T})$ if and only if F_A contains all its accumulation points.*

5. Conclusions

Many research works have been done in fuzzy soft topological spaces. The concepts of closed set and accumulation point have been defined there but no relation between the closed set and its accumulation points is established there. In this paper, we have defined the accumulation point with the help of Q-neighborhood structure and have been able to construct a relation between the closed set and its accumulation points. One can try to establish separation axioms on fuzzy soft topological spaces with the help of Q-neighborhood structure.

Acknowledgements. The authors are grateful to the referees for their valuable comments and suggestions.

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