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Semicompactness degree in L-topological spaces

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Abstract. In this paper, we introduce the notion of the degree to which an L-fuzzy set is semicompact in an L-topological space by means of the implication operator of L. An L-fuzzy set G is semicompact if and only if its semicompactness degree $\mathrm{scom}(G) = \top$. Some properties of semicompactness degree are investigated.

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1. Introduction

The notion of semicompactness [2] was introduced in L-topological spaces by Kudri in [4]. However Kudri's semicompactness relies on the structure of L and L is required to be completely distributive. Subsequently Shi introduced a new definition of semicompactness in L-topological spaces by means of semiopen L-sets and their inequality (see [5]). This definition does not rely on the structure of basis lattice L and no distributivity in L is required.

For the above notions of semicompactness, an L-fuzzy set is either semicompact or not. Considering fuzziness degree of semicompactness, we shall introduce the concept of the fuzzy semicompactness degree of an L-fuzzy set in L-topological spaces by means of the implication operator of L.

2. Preliminaries

Throughout this paper, $(L, \bigvee, \bigwedge, ')$ is a complete De Morgan frame [3]. The smallest element and the largest element in L are denoted by $\perp$ and $\top$, respectively.

In a complete De Morgan frame L, there exists a binary operation $\mapsto$. Explicitly the implication is given by

$$a \mapsto b = \bigvee \{c \in L \mid a \wedge c \leq b\}.$$

It is easy to check the following properties of $\mapsto$.

(1) $(a \mapsto b) \geq c \Leftrightarrow a \wedge c \leq b$;
(2) $a \mapsto b = \top \Leftrightarrow a \leq b$;
(3) $a \mapsto (\bigwedge_i b_i) = \bigwedge_i (a \mapsto b_i)$;
(4) $(\bigvee_i a_i) \mapsto b = \bigwedge_i (a_i \mapsto b)$;
(5) $(a \mapsto c) \wedge (c \mapsto b) \leq a \mapsto b$;
(6) $a \leq b \Rightarrow c \mapsto a \leq c \mapsto b$.
(7) $a \leq b \Rightarrow b \mapsto c \leq a \mapsto c$.
(8) $(a \mapsto b) \wedge (c \mapsto d) \leq a \wedge c \mapsto b \wedge d$.

For a nonempty set X, L^X denotes the set of all L-fuzzy sets on X. $\underline{a}$ denotes the constant L-fuzzy sets on X taking the value a.

An L-topological space is a pair (X, τ), where τ is a subfamily of L^X which contains $\underline{\perp}$, $\underline{\top}$ and is closed for any suprema and finite infima. Each member of τ is called an open L-set and its quasi-complement is called a closed L-set.

For a subfamily $\Phi \subseteq L^X$, $2^{(\Phi)}$ denotes the set of all finite subfamilies of Φ. $2^{[\Phi]}$ denotes the set of all countable subfamilies of Φ.

Definition 2.1 ([1])**.** An L-set G in an L-space (X, τ) is called semiopen if there exists $A \in \mathcal{T}$ such that $A \leq G \leq cl(A)$. G is called semiclosed if G' is semiopen.

Definition 2.2. Let (X, τ_1) and (Y, τ_2) be two L-spaces. A map $f : (X, \tau_1) \to (Y, \tau_2)$ is said to be

(1) semicontinuous [1] if $f_L^{\leftarrow}(G)$ is semiopen in (X, τ_1) for every open L-set G in (Y, τ_2).
(2) irresolute [8] if $f_L^{\leftarrow}(G)$ is semiopen in (X, τ_1) for every semiopen L-set G in (Y, τ_2).
(3) strong irresolute [5] if $f_L^{\leftarrow}(G)$ is open in (X, τ_1) for every semiopen L-set G in (Y, τ_2).

Definition 2.3 ([7])**.** An L-fuzzy inclusion on X is a mapping $\widetilde{\subset} : L^X \times L^X \to L$ defined by the equality $\widetilde{\subset}(A, B) = \bigwedge_{x \in X} (A'(x) \vee B(x))$.

In the sequel, we shall write $[A \widetilde{\subset} B]$ instead of $\widetilde{\subset}(A, B)$. It is evident that for ordinary subsets A and B of a set X, if $A \subseteq B$, then $[A \widetilde{\subset} B] = 1$, and $[A \widetilde{\subset} B] = 0$ otherwise. Moreover we have the following properties:

(1) $[A \widetilde{\subset} B] \wedge [A \widetilde{\subset} C] = [A \widetilde{\subset} B \wedge C]$;
(2) $[A \vee B \widetilde{\subset} C] = [A \widetilde{\subset} C] \wedge [B \widetilde{\subset} C]$.

Lemma 2.4 ([6, 7])**.** *Let $f : X \to Y$ be a set map and $f_L^{\rightarrow} : L^X \to L^Y$ be the extension of f (see [3]). Then for any $\mathcal{P} \subseteq L^Y$, we have that*

$$\bigwedge_{y \in Y} \left(f_L^{\rightarrow}(G)'(y) \vee \bigvee_{B \in \mathcal{P}} B(y) \right) = \bigwedge_{x \in X} \left(G'(x) \vee \bigvee_{B \in \mathcal{P}} f_L^{\leftarrow}(B)(x) \right),$$

i.e.,

$$\left[f_L^{\rightarrow}(G) \widetilde{\subset} \bigvee \mathcal{P} \right] = \left[G \widetilde{\subset} f_L^{\leftarrow} \left(\bigvee \mathcal{P} \right) \right].$$

Definition 2.5 ([5])**.** Let (X,τ) be an L-topological space. An L-set $G\in L^X$ is called (countably) semicompact if for every (countable) family $\mathcal{U}$ of semiopen L-sets, it follows that

$$\bigwedge_{x\in X}\left(G'(x)\vee\bigvee_{A\in\mathcal{U}}A(x)\right)\le\bigvee_{\mathcal{V}\in 2^{(\mathcal{U})}}\bigwedge_{x\in X}\left(G'(x)\vee\bigvee_{A\in\mathcal{V}}A(x)\right),$$

i.e.,

$$\left[G\widetilde{\subset}\bigvee\mathcal{U}\right]\le\bigvee_{\mathcal{V}\in 2^{(\mathcal{U})}}\left[G\widetilde{\subset}\bigvee\mathcal{V}\right].$$

Definition 2.6 ([5])**.** Let (X,τ) be an L-topological space. An L-set $G\in L^X$ is said to have the semi-Lindelöf property or be a semi-Lindelöf L-set if for every family $\mathcal{U}$ of semiopen L-sets, it follows that

$$\bigwedge_{x\in X}\left(G'(x)\vee\bigvee_{A\in\mathcal{U}}A(x)\right)\le\bigvee_{\mathcal{V}\in 2^{[\mathcal{U}]}}\bigwedge_{x\in X}\left(G'(x)\vee\bigvee_{A\in\mathcal{V}}A(x)\right).$$

Definition 2.7 ([7])**.** Let (X,τ) be an L-topological space and $G\in L^X$. The compactness degree $\mathrm{com}(G)$ of G is defined as

$$\begin{aligned}\mathrm{com}(G)&=\bigwedge_{\mathcal{U}\in 2^{\tau}}\left(\bigwedge_{x\in X}\left(G'\vee\bigvee_{A\in\mathcal{U}}A\right)(x)\mapsto\bigvee_{\mathcal{V}\in 2^{(\mathcal{U})}}\bigwedge_{x\in X}\left(G'\vee\bigvee_{A\in\mathcal{V}}A\right)(x)\right)\\&=\bigwedge_{\mathcal{U}\in 2^{\tau}}\left(\left[G\widetilde{\subset}\bigvee\mathcal{U}\right]\mapsto\bigvee_{\mathcal{V}\in 2^{(\mathcal{U})}}\left[G\widetilde{\subset}\bigvee\mathcal{V}\right]\right).\end{aligned}$$

Definition 2.8 ([7])**.** Let (X,τ) be an L-topological space and $G\in L^X$. The countable compactness degree $\mathrm{ccom}(G)$ of G is defined as

$$\begin{aligned}\mathrm{ccom}(G)&=\bigwedge_{\mathcal{U}\in 2^{[\tau]}}\left(\bigwedge_{x\in X}\left(G'\vee\bigvee_{A\in\mathcal{U}}A\right)(x)\mapsto\bigvee_{\mathcal{V}\in 2^{(\mathcal{U})}}\bigwedge_{x\in X}\left(G'\vee\bigvee_{A\in\mathcal{V}}A\right)(x)\right)\\&=\bigwedge_{\mathcal{U}\in 2^{[\tau]}}\left(\left[G\widetilde{\subset}\bigvee\mathcal{U}\right]\mapsto\bigvee_{\mathcal{V}\in 2^{(\mathcal{U})}}\left[G\widetilde{\subset}\bigvee\mathcal{V}\right]\right).\end{aligned}$$

Definition 2.9 ([7])**.** Let (X,τ) be an L-topological space and $G\in L^X$. The degree $\mathrm{Lp}(G)$ to which G has the Lindelöf property is defined as

$$\begin{aligned}\mathrm{Lp}(G)&=\bigwedge_{\mathcal{U}\in 2^{\tau}}\left(\bigwedge_{x\in X}\left(G'\vee\bigvee_{A\in\mathcal{U}}A\right)(x)\mapsto\bigvee_{\mathcal{V}\in 2^{[\mathcal{U}]}}\bigwedge_{x\in X}\left(G'\vee\bigvee_{A\in\mathcal{V}}A\right)(x)\right)\\&=\bigwedge_{\mathcal{U}\in 2^{\tau}}\left(\left[G\widetilde{\subset}\bigvee\mathcal{U}\right]\mapsto\bigvee_{\mathcal{V}\in 2^{[\mathcal{U}]}}\left[G\widetilde{\subset}\bigvee\mathcal{V}\right]\right).\end{aligned}$$

3. The semicompactness degree of L-sets

Let τ_s denote the set of all semiopen L-sets in τ. Based on Definitions 2.5 and 2.6, we can naturally introduce the notion of semicompactness degree as follows:

Definition 3.1. Let (X,τ) be an L-topological space and $G \in L^X$. The semicompactness degree $\mathrm{scom}(G)$ of G is defined as

$$\begin{aligned}\mathrm{scom}(G) &= \bigwedge_{\mathcal{U}\in 2^{\tau_s}} \left(\bigwedge_{x\in X} \left(G' \vee \bigvee_{A\in\mathcal{U}} A \right)(x) \mapsto \bigvee_{\mathcal{V}\in 2^{(\mathcal{U})}} \bigwedge_{x\in X} \left(G' \vee \bigvee_{A\in\mathcal{V}} A \right)(x) \right) \\ &= \bigwedge_{\mathcal{U}\in 2^{\tau_s}} \left(\left[G \widetilde{\subset} \bigvee \mathcal{U} \right] \mapsto \bigvee_{\mathcal{V}\in 2^{(\mathcal{U})}} \left[G \widetilde{\subset} \bigvee \mathcal{V} \right] \right).\end{aligned}$$

Obviously G is semicompact if and only if $\mathrm{scom}(G) = \top$.

Since an open L-set is semiopen, we easily obtain the the following result.

Theorem 3.2. *Let (X,τ) be an L-topological space and $G \in L^X$. Then* $\mathrm{scom}(G) \le \mathrm{com}(G)$.

The next lemma is obvious.

Lemma 3.3. *Let (X,τ) be an L-topological space and $G \in L^X$. Then* $\mathrm{scom}(G) \ge a$ *if and only if for any $\mathcal{U} \in 2^{\tau_s}$,*

$$\left[G \widetilde{\subset} \bigvee \mathcal{U} \right] \wedge a \le \bigvee_{\mathcal{V}\in 2^{(\mathcal{U})}} \left[G \widetilde{\subset} \bigvee \mathcal{V} \right].$$

By Lemma 3.3 we can easily obtain the following characterization of the semicompactness degree.

Theorem 3.4. *Let (X,τ) be an L-topological space and $G \in L^X$. Then*

$$\mathrm{scom}(G) = \bigvee \left\{ a \in L : \left[G \widetilde{\subset} \bigvee \mathcal{U} \right] \wedge a \le \bigvee_{\mathcal{V}\in 2^{(\mathcal{U})}} \left[G \widetilde{\subset} \bigvee \mathcal{V} \right] \ \textit{ for any } \ \mathcal{U} \in 2^{\tau_s} \right\}.$$

Now we consider some properties of semicompactness degree.

Theorem 3.5. *For any $G, H \in L^X$,* $\mathrm{scom}(G \vee H) \ge \mathrm{scom}(G) \wedge \mathrm{scom}(H)$.

Proof. By Theorem 3.4 we have

$$\begin{aligned}
&\mathrm{scom}(G \vee H)\\
&= \bigvee \left\{ a \in L : \left[G \vee H \widetilde{\subset} \bigvee \mathcal{U}\right] \wedge a \leq \bigvee_{\mathcal{V} \in 2^{(\mathcal{U})}} \left[G \vee H \widetilde{\subset} \bigvee \mathcal{V}\right], \forall \mathcal{U} \in 2^{(\tau_s)} \right\}\\
&= \bigvee \Big\{ a \in L : \left[G \widetilde{\subset} \bigvee \mathcal{U}\right] \wedge \left[H \widetilde{\subset} \bigvee \mathcal{U}\right] \wedge a\\
&\qquad\qquad \leq \bigvee_{\mathcal{V} \in 2^{(\mathcal{U})}} \left[G \widetilde{\subset} \bigvee \mathcal{V}\right] \wedge \left[H \widetilde{\subset} \bigvee \mathcal{V}\right], \forall \mathcal{U} \in 2^{(\tau_s)} \Big\}\\
&\geq \bigvee \left\{ a \in L : \left[G \widetilde{\subset} \bigvee \mathcal{U}\right] \wedge a \leq \bigvee_{\mathcal{V} \in 2^{(\mathcal{U})}} \left[G \widetilde{\subset} \bigvee \mathcal{V}\right] \right\} \wedge\\
&\qquad\qquad \bigvee \left\{ a \in L : \left[H \widetilde{\subset} \bigvee \mathcal{U}\right] \wedge a \leq \bigvee_{\mathcal{V} \in 2^{(\mathcal{U})}} \left[H \widetilde{\subset} \bigvee \mathcal{V}\right], \forall \mathcal{U} \in 2^{(\tau_s)} \right\}\\
&= \mathrm{scom}(G) \wedge \mathrm{scom}(H).
\end{aligned}$$

This completes the proof. □

Theorem 3.6. *For any $G \in L^X$ and any semiclosed L-set H,* $\mathrm{scom}(G \wedge H) \geq \mathrm{scom}(G)$.

Proof. By Theorem 3.4 we have

$$\begin{aligned}
&\mathrm{scom}(G \wedge H)\\
&= \bigvee \left\{ a \in L : \left[G \wedge H \widetilde{\subset} \bigvee \mathcal{U}\right] \wedge a \leq \bigvee_{\mathcal{V} \in 2^{(\mathcal{U})}} \left[G \wedge H \widetilde{\subset} \bigvee \mathcal{V}\right], \forall \mathcal{U} \in 2^{(\tau_s)} \right\}\\
&= \bigvee \left\{ a \in L : \left[G \widetilde{\subset} H' \vee \bigvee \mathcal{U}\right] \wedge a \leq \bigvee_{\mathcal{V} \in 2^{(\mathcal{U})}} \left[G \widetilde{\subset} H' \vee \bigvee \mathcal{V}\right], \forall \mathcal{U} \in 2^{(\tau_s)} \right\}\\
&\geq \mathrm{scom}(G).
\end{aligned}$$

This completes the proof. □

Theorem 3.7. *Let $f : X \to Y$ be a set map, τ_1 be an L-topology on X, τ_2 be an L-topology on Y, and $f : (X, \tau_1) \to (Y, \tau_2)$ be irresolute. Then* $\mathrm{scom}\left(f_L^{\to}(G)\right) \geq \mathrm{scom}(G)$.

Proof. Let $(\tau_1)_s$ and $(\tau_2)_s$ denote respectively the sets of all semiopen L-sets in τ_1 and τ_2. By means of Lemma 2.4, we can obtain the following inequality.

$$\begin{aligned}
&\operatorname{scom}(f_L^{\rightarrow}(G))\\
&= \bigwedge_{\mathcal{U}\in 2^{((\tau_2)_s)}} \left\{ \bigwedge_{y\in Y} \left(f_L^{\rightarrow}(G)'(y) \vee \bigvee_{A\in\mathcal{U}} A(y) \right) \mapsto \bigvee_{\mathcal{V}\in 2^{(\mathcal{U})}} \bigwedge_{y\in Y} \left(f_L^{\rightarrow}(G)'(y) \vee \bigvee_{A\in\mathcal{V}} A(y) \right) \right\}\\
&= \bigwedge_{\mathcal{U}\in 2^{((\tau_2)_s)}} \left\{ \bigwedge_{x\in X} \left(G'(x) \vee \bigvee_{A\in\mathcal{U}} f_L^{\leftarrow}(A)(x) \right) \mapsto \bigvee_{\mathcal{V}\in 2^{(\mathcal{U})}} \bigwedge_{x\in X} \left(G'(x) \vee \bigvee_{A\in\mathcal{V}} f_L^{\leftarrow}(A)(x) \right) \right\}\\
&\geq \operatorname{scom}(G).
\end{aligned}$$

This completes the proof. □

Analogously we can prove the following two results.

Theorem 3.8. *Let $f : X \to Y$ be a set map, τ_1 be an L-topology on X, τ_2 be an L-topology on Y, and $f : (X, \tau_1) \to (Y, \tau_2)$ be semicontinuous. Then* $\operatorname{com}(f_L^{\rightarrow}(G)) \geq \operatorname{scom}(G)$.

Theorem 3.9. *Let $f : X \to Y$ be a set map, τ_1 be an L-topology on X, τ_2 be an L-topology on Y, and $f : (X, \tau_1) \to (Y, \tau_2)$ be strong irresolute. Then* $\operatorname{scom}(f_L^{\rightarrow}(G)) \geq \operatorname{com}(G)$.

4. The countable semicompactness degree of L-sets

Analogous to the last section, we can naturally introduce the notion of countable semicompactness degree and the degree to which an L-set has the semi-Lindelöf property as follows:

Definition 4.1. Let (X, τ) be an L-topological space and $G \in L^X$. The countable semicompactness degree $\operatorname{sccom}(G)$ of G is defined as

$$\begin{aligned}
\operatorname{sccom}(G) &= \bigwedge_{\mathcal{U}\in 2^{[\tau_s]}} \left(\bigwedge_{x\in X} \left(G' \vee \bigvee_{A\in\mathcal{U}} A \right)(x) \mapsto \bigvee_{\mathcal{V}\in 2^{(\mathcal{U})}} \bigwedge_{x\in X} \left(G' \vee \bigvee_{A\in\mathcal{V}} A \right)(x) \right)\\
&= \bigwedge_{\mathcal{U}\in 2^{[\tau_s]}} \left(\left[G \tilde{\subset} \bigvee \mathcal{U} \right] \mapsto \bigvee_{\mathcal{V}\in 2^{(\mathcal{U})}} \left[G \tilde{\subset} \bigvee \mathcal{V} \right] \right).
\end{aligned}$$

Definition 4.2. Let (X, τ) be an L-topological space and $G \in L^X$. The degree $\operatorname{slp}(G)$ to which G has semi-Lindelöf property is defined as

$$\begin{aligned}
\operatorname{slp}(G) &= \bigwedge_{\mathcal{U}\in 2^{\tau_s}} \left(\bigwedge_{x\in X} \left(G' \vee \bigvee_{A\in\mathcal{U}} A \right)(x) \mapsto \bigvee_{\mathcal{V}\in 2^{[\mathcal{U}]}} \bigwedge_{x\in X} \left(G' \vee \bigvee_{A\in\mathcal{V}} A \right)(x) \right)\\
&= \bigwedge_{\mathcal{U}\in 2^{\tau_s}} \left(\left[G \tilde{\subset} \bigvee \mathcal{U} \right] \mapsto \bigvee_{\mathcal{V}\in 2^{[\mathcal{U}]}} \left[G \tilde{\subset} \bigvee \mathcal{V} \right] \right).
\end{aligned}$$

Obviously G is countably semicompact if and only if $\operatorname{sccom}(G) = \top$, and G has the semi-Lindelöf property if and only if $\operatorname{slp}(G) = \top$.

Analogous to Theorem 3.2 we easily obtain the the following result.

Theorem 4.3. *Let (X, τ) be an L-topological space and $G \in L^X$. Then* $\mathrm{sccom}(G) \leq \mathrm{ccom}(G)$, $\mathrm{slp}(G) \leq \mathrm{Lp}(G)$.

The next theorem is obvious.

Theorem 4.4. *Let (X, τ) be an L-topological space and $G \in L^X$. Then* $\mathrm{scom}(G) = \mathrm{sccom}(G) \wedge \mathrm{slp}(G)$.

Analogous to the last section we can easily obtain the following some results.

Theorem 4.5. *Let (X, τ) be an L-topological space and $G \in L^X$. Then*

$$\mathrm{sccom}(G) = \bigvee \left\{ a \in L : \left[G \tilde{\subset} \bigvee \mathcal{U} \right] \wedge a \leq \bigvee_{\mathcal{V} \in 2^{(\mathcal{U})}} \left[G \tilde{\subset} \bigvee \mathcal{V} \right] \quad \textit{for any} \;\; \mathcal{U} \in 2^{[\tau_s]} \right\}.$$

and

$$\mathrm{slp}(G) = \bigvee \left\{ a \in L : \left[G \tilde{\subset} \bigvee \mathcal{U} \right] \wedge a \leq \bigvee_{\mathcal{V} \in 2^{[\mathcal{U}]}} \left[G \tilde{\subset} \bigvee \mathcal{V} \right] \quad \textit{for any} \;\; \mathcal{U} \in 2^{\tau_s} \right\}.$$

Theorem 4.6. *For any $G, H \in L^X$, we have*

$$\mathrm{sccom}(G \vee H) \geq \mathrm{sccom}(G) \wedge \mathrm{sccom}(H) \quad \textit{and} \quad \mathrm{slp}(G \vee H) \geq \mathrm{slp}(G) \wedge \mathrm{slp}(H).$$

Theorem 4.7. *For any $G \in L^X$ and any semiclosed L-set H, we have*

$$\mathrm{sccom}(G \wedge H) \geq \mathrm{sccom}(G) \quad \textit{and} \quad \mathrm{slp}(G \wedge H) \geq \mathrm{slp}(G).$$

Theorem 4.8. *Let $f : X \to Y$ be a set map, τ_1 be an L-topology on X, τ_2 be an L-topology on Y, and $f : (X, \tau_1) \to (Y, \tau_2)$ be irresolute. Then* $\mathrm{sccom}\left(f_L^{\rightarrow}(G)\right) \geq \mathrm{sccom}(G)$ *and* $\mathrm{slp}\left(f_L^{\rightarrow}(G)\right) \geq \mathrm{slp}(G)$.

Theorem 4.9. *Let $f : X \to Y$ be a set map, τ_1 be an L-topology on X, τ_2 be an L-topology on Y, and $f : (X, \tau_1) \to (Y, \tau_2)$ be semicontinuous. Then* $\mathrm{ccom}\left(f_L^{\rightarrow}(G)\right) \geq \mathrm{sccom}(G)$ *and* $\mathrm{Lp}\left(f_L^{\rightarrow}(G)\right) \geq \mathrm{slp}(G)$.

Theorem 4.10. *Let $f : X \to Y$ be a set map, τ_1 be an L-topology on X, τ_2 be an L-topology on Y, and $f : (X, \tau_1) \to (Y, \tau_2)$ be strong irresolute. Then* $\mathrm{sccom}\left(f_L^{\rightarrow}(G)\right) \geq \mathrm{ccom}(G)$ *and* $\mathrm{slp}\left(f_L^{\rightarrow}(G)\right) \geq \mathrm{Lp}(G)$.

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