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Intuitionistic fuzzy semi-generalized closed mappings

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Abstract

In this paper we study the concepts of intuitionistic fuzzy semi-generalized closed mappings and intuitionistic fuzzy semi-generalized open mappings in intuitionistic fuzzy topological space. We also study various properties and relations between the other existing intuitionistic fuzzy open and closed mappings.

Keywords: Intuitionistic fuzzy topology, Intuitionistic fuzzy semi-generalized closed set, open set, Intuitionistic fuzzy semi-generalized closed mapping, open mapping, Intuitionistic fuzzy semi-T1/2 space.

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1 Introduction

Fuzzy set (FS), proposed by Zadeh [12] in 1965, as a framework to encounter uncertainty, vagueness and partial truth represents a degree of membership for each member of the universe of discourse to a subset of it. Later, fuzzy topology was introduced by Chang [2] in 1967. After this, there have been several generalizations of notions of fuzzy sets and fuzzy topology. By adding the degree of non-membership to FS, Atanassov proposed intuitionistic fuzzy set (IFS) in 1983 [1] which looks more accurately to uncertainty quantification and provides the opportunity to precisely model the problem based on the existing knowledge and observations. In the last few years various concepts in fuzzy were extended to intuitionistic fuzzy sets. In 1997, Coker [3] introduced the concept of intuitionistic fuzzy topological space. After this many concepts in fuzzy topological spaces are being extended to intuitionistic fuzzy topological spaces. Intuitionistic fuzzy open mappings were discussed in [7]. In this paper, we study the concepts of intuitionistic fuzzy semi-generalized closed mappings and intuitionistic fuzzy semi-generalized open mappings as an extension of our work done in the papers [8] and [9]. We studied some of the basic properties and also some characterizations and preservation theorems with the help of intuitionistic fuzzy semi $T_{1/2}$ space.

2 Preliminaries

Definition 2.1. [1] *An* intuitionistic *fuzzy set* (*IFS*) *A in X is an object having the form* $A=\{\langle x, \mu_A(x), \gamma_A(x)\rangle / x \in X\}$ *where the functions* $\mu_A : X \to [0,1]$ *and* $\gamma_A: X \to [0,1]$ *define the degree of the membership and the degree of non- membership of the element* $x \in X$ *to the set A* *respectively*, the functions μ_A *and* γ_A should satisfy the condition $0 \le \mu_A(x) + \gamma_A(x) \le 1$ *for each* $x \in X$.

Definition 2.2. [1] *Let A and B be IFS's of the forms* $A = \{\langle x, \mu_A(x), \gamma_A(x) \rangle / x \in X\}$ *and* $B = \{\langle x, \mu_B(x), \gamma_B(x) \rangle / x \in X\}$**.** *Then*

(*a*) $A \subseteq B$ *if* $\mu_A(x) \le \mu_B(x)$ *and* $\gamma_A(x) \ge \gamma_B(x)$ *for all* $x \in X$.
(*b*) $A = B$ *if* $A \subseteq B$ *and* $B \subseteq A$.
(*c*) $\bar{A} = \{\langle x, \gamma_A(x), \mu_A(x) \rangle / x \in X\}$.
(*d*) $A \cap B = \{\langle x, \mu_A(x) \wedge \mu_B(x), \gamma_A(x) \vee \gamma_B(x)\rangle / x \in X\}$.
(*e*) $A \cup B = \{\langle x, \mu_A(x) \vee \mu_B(x), \gamma_A(x) \wedge \gamma_B(x)\rangle / x \in X\}$.
(*f*) $0_\sim = \{\langle x, 0, 1\rangle : x \in X\}$ *and* $1_\sim = \{\langle x, 1, 0\rangle : x \in X\}$.
(*g*) $\bar{1}_\sim = 0_\sim$ *and* $\bar{0}_\sim = 1_\sim$.

Definition 2.3. [3] *An intuitionistic fuzzy topology* (*IFT*) *on a nonempty X is a family* τ *of IFSs in X satisfying the following axioms:*
(*i*) $0_\sim, 1_\sim \in \tau$,
(*ii*) $G_1 \cap G_2 \in \tau$ *for any* $G_1, G_2 \in \tau$, *and*
(*iii*) $\cup G_i \in \tau$, *for any arbitrary family* $\{G_i \mid i \in J\} \subseteq \tau$.

In this case the pair (X,τ) is called an intuitionistic fuzzy topological space (IFTS) and any IFS in τ is known as an intuitionistic fuzzy open set (IFOS) in X . The complement $\bar{A}$ of an IFOS A in IFTS (X,τ) is called an intuitionistic fuzzy closed set (IFCS) in X.

Definition 2.4. [3] *Let* (X,τ) *be an IFTS and* $A = \langle x, \mu_A, \gamma_A\rangle$ *be an IFS in X. Then the intuitionistic fuzzy interior and intuitionistic fuzzy closure of A are defined by*

$$int(A) = \cup\{G \mid G \text{ is an IFOS in } X \text{ and } G \subseteq A\},$$
$$cl(A) = \cap\{K \mid K \text{ is an IFCS in } X \text{ and } A \subseteq K\}.$$

Note that, for any IFS A in (X,τ), *we have* $cl(\overline{A}) = \overline{\text{int}(A)}$ *and* $\text{int}(\overline{A}) = \overline{cl(A)}$

Definition 2.5. [**5**] *An IFS* $A = \{\langle x, \mu_A(x), \gamma_A(x) \rangle / x \in X\}$ *in an IFTS* (X,τ) *is called*

(i) *an intuitionistic fuzzy semi open set* (*IFSOS*) *if* $A \subseteq cl(\text{int}(A))$.
(ii) *an intuitionistic fuzzy α-open set* (*IFαOS*) *if* $A \subseteq \text{int}(cl(\text{int}(A)))$.
(iii) *an intuitionistic fuzzy pre-open set* (*IFαOS*) *if* $A \subseteq \text{int}(cl(A))$.
(iv) *an intuitionistic fuzzy regular open set* (*IFROS*) *if* $\text{int}(cl(A)) = A$.

Definition 2.6.[11] *An IFS* $A = \{\langle x, \mu_A(x), \gamma_A(x) \rangle / x \in X\}$ *in an IFTS* (X,τ) *is called an intuitionistic fuzzy semi-pre open set* (*IFSPOS*) *if there exists* $B \in IFPO(X)$, *such that* $B \subseteq A \subseteq cl(B)$.

An IFS A is called intuitionistic fuzzy semi-closed set , intuitionistic fuzzy α-closed set , intuitionistic fuzzy pre-closed set , intuitionistic fuzzy regular closed set, intuitionistic fuzzy semi-pre-closed set, (IFCS , IFαCS, IFPCS, IFRCS and IFSPCS respectively), if the complement of $\bar{A}$ is an IFSOS, IFαOS, IFPOS, IFROS and IFSPOS respectively.

The family of all intuitionistic fuzzy semi-open (respectively intuitionistic fuzzy α-open , intuitionistic fuzzy pre-open , intuitionistic fuzzy regular-open and intuitionistic fuzzy semi-preopen) sets of an IFTS (X,τ) is denoted by IFSO(X) (respectively IFαO(X) , IFPO(X) , IFRO(X) and IFSPO(X)).

Definition 2.6. [8] *An IFS A of an IFTS* (X,τ) *is called an intuitionistic fuzzy semi-generalized closed set* (*IFSGCS*) *if* $scl(A) \subseteq U$, *whenever* $A \subseteq U$ *and U is an IFSOS.*

The complement of an IFSGCS is called an intuitionistic fuzzy semi-generalized open set (IFSGOS).The family of all IFSGCS (respectively IFSGOS) sets of an IFS (X,τ) is denoted by IFSGC(X) (respectively IFSGO(X)).

Definition 2.7. [**5**] *Let (X,τ) be an IFTS and $A = \langle x, \mu_A, \gamma_A \rangle$ be an IFS in X. Then the intuitionistic fuzzy semi-interior and intuitionistic fuzzy semi-closure of A are defined by*

$$sint(A) = \cup \{G \mid G \text{ is an IFSOS in } X \text{ and } G \subseteq A\},$$
$$scl(A) = \cap \{K \mid K \text{ is an IFSCS in } X \text{ and } A \subseteq K\}.$$

Definition 2.8. [**9**] *Let (X,τ) be an IFTS and $A = \langle x, \mu_A, \gamma_A \rangle$ be an IFS in X. Then the intuitionistic fuzzy semi-interior and intuitionistic fuzzy semi-closure of A are defined by*

$$sgint(A) = \cup \{G \mid G \text{ is an IFSOS in } X \text{ and } G \subseteq A\},$$
$$sgcl(A) = \cap \{K \mid K \text{ is an IFSCS in } X \text{ and } A \subseteq K\}.$$

Definition 2.9. [**5**] *A mapping $f: (X,\tau) \to (Y,\kappa)$ from an IFTS (X,τ) into an IFTS (Y,κ) is said to be an intuitionistic fuzzy continuous mapping if $f^{-1}(A)$ is an IFCS in X, for every IFCS A in Y.*

Definition 2.10. [**9**] *A mapping $f: (X,\tau) \to (Y,\kappa)$ from an IFTS (X,τ) into an IFTS (Y,κ) is said to be an intuitionistic fuzzy semi-generalized continuous (intuitionistic fuzzy sg-continuous) mapping if $f^{-1}(A)$ is an IFSGCS in X, for every IFCS A in Y.*

Definition 2.11. [**9**] *A mapping $f: (X,\tau) \to (Y,\kappa)$ from an IFTS (X,τ) into an IFTS (Y,κ) is said to be an intuitionistic fuzzy semi-generalized irresolute (intuitionistic fuzzy sg-irresolute) mapping if $f^{-1}(A)$ is an IFSGCS in X, for every IFSGCS A in Y.*

Definition 2.12. [7] *A mapping $f: (X,\tau) \to (Y,\kappa)$ from an IFTS (X,τ) into an IFTS (Y,κ) is said to be an intuitionistic fuzzy open mapping if f(A) is an IFOS in Y, for every IFOS A in X.*

Definition 2.13. [6] *A mapping $f: (X,\tau) \to (Y,\kappa)$ from an IFTS (X,τ) into an IFTS (Y,κ) is said to be*

(i) *an intuitionistic fuzzy semi-open mapping if f(A) is an IFSOS in Y, for every IFSOS A in X.*

(ii) *an intuitionistic fuzzy pre-open mapping if f(A) is an IFPOS in Y, for every IFPOS A in X.*

(iii) *an intuitionistic fuzzy α- open mapping if if f(A) is an IFαOS in Y, for every IFαOS A in X.*

Definition 2.14. [**10**] *A mapping $f: (X,\tau) \to (Y,\kappa)$ from an IFTS (X,τ) into an IFTS (Y,κ) is said to be an intuitionistic fuzzy pre regular closed if the image of every intuitionistic fuzzy regular closed set of X is intuitionistic fuzzy regular closed in Y.*

Definition 2.15. [**4**] *An intuitionistic fuzzy point (IFP), written as $p_{(\alpha,\beta)}$, is defined to be an IFS of X given by*

$$p(\alpha,\beta) = \begin{cases} (\alpha,\beta), x = p \\ (0,1), otherwise \end{cases}$$

Definition 2.16. [7] *Let $x_{(\alpha,\beta)}$ be an IFP of an IFTS (X,τ). An IFS A of X is called an intuitionistic fuzzy neighborhood (IFN) of $x_{(\alpha,\beta)}$ if there is an IFOS B in X such that $x_{(\alpha,\beta)} \in B \subseteq A$.*

Definition 2.17. [**8**] *An IFTS (X,τ) is said to be an intuitionistic fuzzy $T^*_{1/2}$ space if every intuitionistic fuzzy sg-closed set in X is intuitionistic fuzzy semi-closed in X.*

Definition 2.18. [**8**] *An IFTS(X,τ) is said to be an intuitionistic fuzzy semi-$T_{1/2}$ space if every intuitionistic fuzzy sg-closed set in X is intuitionistic fuzzy closed set in X.*

3 Intuitionistic fuzzy Semi-generalized open mapping

Definition 3.1. *A mapping f:X→Y is said to be an intuitionistic fuzzy semi-generalized open (intuitionistic fuzzy sg-open) mapping if f(B) is an IFSGOS in Y, for every IFOS B in X.*

Definition 3.2. *A mapping f:X→Y is said to be an intuitionistic fuzzy semi-generalized closed (intuitionistic fuzzy sg-closed) mapping if f(B) is an IFSGCS in Y, for every IFCS B in X.*

Example 3.3. Let $X = \{a, b\}$ and $Y = \{u, v\}$. Let $A = \langle x, (0.5, 0.6), (0.1, 0.3)\rangle$ and $B = \langle y, (0.4, 0.3), (0.6, 0.7)\rangle$. Then $\tau = \{0_\sim, 1_\sim, A\}$ and $\sigma = \{0_\sim, 1_\sim, B\}$ are IFT on X and Y respectively. Define a mapping $f : (X, \tau) \to (Y, \sigma)$ by $f(a) = u$ and $f(b) = v$.

$IFSOS(Y) = \left\{0_\sim, 1_\sim, G_{u,v}^{(l_1,m),(l_2,m_2)}, l_1, m_1 \in [0.4,0.6], l_2, m_2 \in [0.3,0.7],\ l_i + m_i \leq 1, i = 1,2\right\}$.

$IFSCS(Y) = \left\{0_\sim, 1_\sim, H_{u,v}^{(a_1,b_1),(a_2,b_2)};\ a_1, b_1 \in [0.4,0.6], a_2, b_2 \in [0.3,0.7], a_i + b_i \leq 1, i = 1,2\right\}$.

Now sint($f(A)$) = $\langle y, (0.5, 0.6), (0.4, 0.3)\rangle$. Since $U \subseteq$ sint($f(A)$) whenever $U \subseteq f(A)$, U is an IFSCS. Hence $f(A)$ is an IFSGOS in Y. Therefore f is an intuitionistic fuzzy sg- open mapping.

Theorem 3.4. *Every intuitionistic fuzzy open (respectively intuitionistic fuzzy closed) mapping is an intuitionistic fuzzy sg-open (respectively intuitionistic fuzzy sg-closed) mapping but not conversely.*

Proof. Obvious. ■

Example 3.5. Let $X = \{a, b\}$, $Y = \{u, v\}$. Let $A = \langle x, (0.4, 0.5), (0.4, 0.3)\rangle$ and $B = \langle y, (0.3, 0.1), (0.5, 0.7)\rangle$. Then $\tau = \{0_\sim, 1_\sim, A\}$ and □ = $\{0_\sim, 1_\sim, B\}$ are IFT on X and Y respectively. Define a mapping $f : (X, \tau) \to (Y,$ □$)$ by $f(a) = u$ and $f(b) = v$.

$IFSOS(Y) = \left\{0_\sim, 1_\sim, G_{u,v}^{(l_1,m),(l_2,m_2)}, l_1, m_1 \in [0.3,0.5],\ l_2, m_2 \in [0.1,0.7], l_i + m_i \leq 1, i = 1,2\right\}$.

Then $f(A) = \langle y, (0.4,0.5), (0.4,0.3)\rangle$, *sint*($f(A)$) = $f(A)$. Therefore, $f(A)$ is an IFSGOS in Y. Hence f is an intuitionistic fuzzy sg-open mapping. Since $f(A) \notin \sigma$□, f is not an intuitionistic fuzzy open mapping.

Theorem 3.6. *Every intuitionistic fuzzy α-open mapping is an intuitionistic fuzzy sg-open mapping but not conversely.*

Proof. Obvious. ■

Example 3.7. Let $X = \{a, b\}$, $Y = \{u, v\}$. Let $A = \langle x, (0.3, 0.4), (0.1, 0.1)\rangle$ and $B = \langle y, (0.2, 0.4), (0.6, 0.6)\rangle$. Then $\tau = \{0\sim, 1\sim, A\}$ and □ = $\{0\sim, 1\sim, B\}$ are IFT on X and Y respectively. Define a mapping f : (X, τ) → (Y, □) by f(a) = u and f(b) = v.

$$\mathrm{IFSOS}(Y) = \left\{0_\sim, 1_\sim, G_{u,v}^{(l_1,\ m),(l_2,m_2)}, l_1, m_1 \in [0.2,0.6], l_2, m_2 \in [0.4,0.6], l_i + m_i \leq 1, i = 1,2\right\}$$

Then $f(A) = \langle y, (0.3, 0.4), (0.1, 0.1)\rangle$, $\mathrm{sint}(f(A)) = \langle y, (0.3, 0.4), (0.2, 0.4)\rangle$. Thus f(A) is an IFSGOS in Y. Therefore f is an intuitionistic fuzzy sg-open mapping. Now int(f(A)) = $0_\sim \cup B = B$, cl(int(f(A))) = cl(B) = $\overline{B}$ and int(cl(int(f(A)))) = int($\overline{B}$) = B. Therefore f(A) $\nsubseteq$ int(cl(int(f(A)))) which implies f(A) is not an IFαOS in Y. Hence f is not an intuitionistic fuzzy α-open mapping.

Theorem 3.8. *Every intuitionistic fuzzy semiopen mapping is an intuitionistic fuzzy sg-open mapping but not conversely.*

Proof. Since every IFSOS is an IFSGOS, the proof follows immediately. ■

Example 3.9. Let $X = \{a, b\}$, $Y = \{u, v\}$. Let $A = \langle x, (0.5, 0.4), (0.1, 0.1)\rangle$ and $B = \langle y, (0.4, 0.4), (0.6, 0.5)\rangle$. Then $\tau = \{0_\sim, 1_\sim, A\}$ and □ = $\{0_\sim, 1_\sim, B\}$ are IFT on X and Y respectively. Define a mapping $f : (X, \tau) \to (Y,$ □$)$ by $f(a) = u$ and $f(b) = v$.

$\mathrm{IFSOS}(Y) = \left\{0_\sim, 1_\sim, G_{u,v}^{(l_1,\ m),(l_2,m_2)}, l_1, m_1 \in [0.4,0.6], l_2, m_2 \in [0.4,0.5], l_i + m_i \leq 1,\ i = 1,2\right\}$.

Then $f(A) = \langle y, (0.5,\ 0.4), (0.1,\ 0.1)\rangle$. $sint(f(A)) = \langle y, (0.5,\ 0.4), (0.4, 0.4)\rangle$. Therefore, $f(A)$ is an IFSGOS in Y. Hence f is an intuitionistic fuzzy sg-open mapping. Since $f(A) \notin \mathrm{IFSOS}(Y)$, $f(A)$ is not an IFSOS in Y, which implies f is not an intuitionistic fuzzy semiopen mapping.

Theorem 3.10. *Every intuitionistic fuzzy pre-regular open mapping is an intuitionistic fuzzy sg-open mapping but not conversely.*

Proof. Since every IFROS is an IFSGOS, the proof follows immediately. ■

Example 3.11. Let $X = \{a,\ b\}$, $Y = \{u,\ v\}$. Let $A = \langle x, (0.4,\ 0.4), (0.5,\ 0.6)\rangle$ and $B = \langle y, (0.3,\ 0.1), (0.5,\ 0.7)\rangle$. Then $\tau = \{0_\sim, 1_\sim, A\}$ and $\sigma = \{0_\sim, 1_\sim, B\}$ are IFT on X and Y respectively. Define a mapping $f : (X, \tau) \rightarrow (Y, \sigma)$ by $f(a) = u$ and $f(b) = v$.

$IFSOS(Y) = \left\{0_\sim, 1_\sim, G_{u,v}^{(l_1,m),(l_2,m_2)},\ l_1, m_1 \in [0.3,0.5],\ l_2, m_2 \in [0.1,0.7], l_i + m_i \leq 1,\ i = 1,2\right\}$.

Then $f(A) = \langle y, (0.4,\ 0.4), (0.5,\ 0.6)\rangle$. We have $\mathrm{sint}(f(A)) = f(A)$. Therefore $f(A)$ is an IFSOS and hence it is an IFSGOS in Y. Hence, f is an intuitionistic fuzzy sg- open mapping. Clearly A is an IFROS in X and since $\mathrm{cl}(f(A)) = \bar{B}$, $\mathrm{int}\left(\mathrm{cl}(f(A))\right) = B \neq f(A)$ we have $f(A)$ is not an IFROS in Y. Hence f is not an intuitionistic fuzzy pre-regular open mapping.

We have the following implications in which reverse implications are not valid, where "IF" means "intuitionistic fuzzy" and "OM" means open mapping.

$$\begin{tikzcd}
 & & \text{IFSOM} \arrow[dr] & \\
\text{IFOM} \arrow[r] & \text{IF}\alpha\text{OM} \arrow[ur] \arrow[dr] & & \textbf{IFSGOM} \\
 & & \text{IFPROM} \arrow[ur] &
\end{tikzcd}$$

Theorem 3.12. *Let $f : (X, \tau) \rightarrow (Y, \sigma)$ be a mapping, where (Y, σ) is an intuitionistic fuzzy semi $T_{1/2}$ space. Then the following are equivalent:*

(i) *f is an intuitionistic fuzzy sg-closed mapping.*
(ii) *$scl(f(A)) \subseteq f(cl(A))$ for each IFS A of X.*

Proof. (i) ⇒ (ii): Let A be an IFS in X. Then $\mathrm{cl}(A)$ is an IFCS in X. By assumption, $f(\mathrm{cl}(A))$ is an IFSGCS in Y. Since (Y, σ) is an intuitionistic fuzzy semi $T_{1/2}$ space, $f(\mathrm{cl}(A))$ is an IFSCS in Y. Therefore $\mathrm{scl}(f(\mathrm{cl}(A))) = f(\mathrm{cl}(A))$. Now $\mathrm{scl}(f(A)) \subseteq \mathrm{scl}(f(\mathrm{cl}(A))) = f(\mathrm{cl}(A))$. Hence $\mathrm{scl}(f(A)) \subseteq f(\mathrm{cl}(A))$ for each IFS A of X.

(ii) ⇒ (i): Let A be an IFCS in X. Then $\mathrm{cl}(A) = A$. By assumption, $\mathrm{scl}(f(A)) \subseteq f(\mathrm{cl}(A)) = f(A)$. But $f(A) \subseteq \mathrm{scl}(f(A))$. Therefore $\mathrm{scl}(f(A)) = f(A)$. This implies $f(A)$ is an IFSCS in Y. Since every IFSCS is an IFSGCS, $f(A)$ is an IFSGCS in Y. Hence f is an intuitionistic fuzzy sg-closed mapping. ■

Theorem 3.13. *A mapping $f : X \rightarrow Y$ is an intuitionistic fuzzy sg-closed mapping if and only if for each IFS S of Y and for each IFOS U containing $f^{-1}(S)$, there is an IFSGOS V of Y such that $S \subseteq V$ and $f^{-1}(V) \subseteq U$.*

Proof. Necessity: Suppose that f is an intuitionistic fuzzy sg-closed mapping. Let $S \subseteq Y$ and U be an IFOS of X such that $f^{-1}(S) \subseteq U$. Then $V = \overline{\left(f(\bar{U})\right)}$ is an IFSGOS of Y containing S such that $f^{-1}(V) \subseteq U$.

Sufficiency: Let S be an IFCS of X. Then $f^{-1}\left(\overline{\left(f(S)\right)}\right) \subseteq \bar{S}$ and $\bar{S}$ is an IFOS. By assumption, there exists an IFSGOS V of Y such that $\overline{\left(f(S)\right)} \subseteq V$ and $f^{-1}(V) \subseteq \bar{S}$ and so $S \subseteq \overline{\left(f^{-1}(V)\right)}$. Hence

$\bar{V} \subseteq f(S) \subseteq f\left(\left(\overline{f^{-1}(V)}\right)\right) \subseteq \bar{V}$ implies $f(S) = \bar{V}$. Since $\bar{V}$ is an IFSGCS, $f(S)$ is an IFSGCS in Y and therefore f is an intuitionistic fuzzy sg-closed mapping. ■

Theorem 3.14. *If $f : X \rightarrow Y$ be an intuitionistic fuzzy sg-closed mapping, then sgcl($f(A)$) $\subseteq f(cl(A))$ for each IFS A of X.*

Proof. Assume that f is an intuitionistic fuzzy sg-closed mapping and $A \subseteq X$. Then cl(A) is an IFCS in X. Thus f(cl(A)) is an IFSGCS in Y. We have $f(A) \subseteq f$(sgcl(A)) $\subseteq f$(cl(A)). Since f(cl(A)) is an IFSGCS, sgcl(f(cl(A))) = f(cl(A)). Since $f(A) \subseteq f$(cl(A)), we have sgcl($f(A)$) $\subseteq$ sgcl(f(cl(A)) = f(cl(A)). That is sgcl((A)) $\subseteq f$(cl(A)). ■

Proposition 3.15. *If f: $(X,\tau) \rightarrow (Y,\sigma)$ and g: $(Y,\sigma) \rightarrow (Z, \eta)$ are intuitionistic fuzzy sg-closed mappings and (Y, σ) is an intuitionistic fuzzy $T^*_{1/2}$ space, then their composition $g \circ f : (X, \tau) \rightarrow (Z, \eta)$ is an intuitionistic fuzzy sg-closed mapping.*

Proof. Let A be an IFCS in X. Since f is an intuitionistic fuzzy sg-closed mapping, $f(A)$ is an IFSGCS in Y. Since (Y, σ) is an intuitionistic fuzzy $\mathrm{T}^*_{1/2}$ space, $f(A)$ is an IFCS in Y. By assumption g($f(A)$) is an IFSGCS in Z. Hence $(\mathrm{g} \circ f)(A)$ = g($f(A)$) is an IFSGCS in Z. Therefore $\mathrm{g} \circ f$ is an intuitionistic fuzzy sg-closed mapping. ■

Proposition 3.16. *If f: $(X, \tau) \rightarrow (Y, \sigma)$ is an intuitionistic fuzzy sg-closed mapping, $g : (Y, \sigma) \rightarrow (Z, \eta)$ is an intuitionistic fuzzy semiclosed mapping and (Y, σ) is an intuitionistic fuzzy $T^*_{1/2}$ space, then their composition $g \circ f : (X, \tau) \rightarrow (Z, \eta)$ is an intuitionistic fuzzy semiclosed mapping.*

Proof. Let A be an IFCS in X. Since f is an intuitionistic fuzzy sg-closed mapping, $f(A)$ is an IFSGCS in Y. Since Y is an intuitionistic fuzzy $\mathrm{T}^*_{1/2}$ space, $f(A)$ is an IFCS in Y. By assumption, g($f(A)$) is an IFSCS in Z. Hence, $(\mathrm{g} \circ f)(A)$ = g($f(A)$) is an IFSCS in Z. Therefore $\mathrm{g}\circ f$ is an intuitionistic fuzzy semiclosed mapping. ■

Proposition 3.17. *If $f : X \rightarrow Y$ is an intuitionistic fuzzy closed mapping and $g : Y \rightarrow Z$ is an intuitionistic fuzzy sg-closed mapping, then $g \circ f : X \rightarrow Z$ is an intuitionistic fuzzy sg-closed mapping.*

Proof. Let A be an IFCS in X. Since f is an intuitionistic fuzzy closed mapping, $f(A)$ is an IFCS in Y. By assumption g($f(A)$) is an IFSGCS in Z. Therefore $(\mathrm{g} \circ f)(A)$ = g($f(A)$) is an IFSGCS in Z. Hence, $\mathrm{g} \circ f$ is an intuitionistic fuzzy sg-closed mapping. ■

Proposition 3.18. *If $f : (X, \tau) \rightarrow (Y, \sigma)$ is an intuitionistic fuzzy g-closed mapping and $g : (Y, \sigma) \rightarrow (Z, \eta)$ is an intuitionistic fuzzy semiclosed mapping and (Y, σ) is an intuitionistic fuzzy $T_{1/2}$ space, then $g \circ f : (X, \tau) \rightarrow (Z, \eta)$ is an intuitionistic fuzzy sg-closed mapping.*

Proof. Let A be an IFCS in X. Since f is an intuitionistic fuzzy g-closed mapping, $f(A)$ is an IFGCS in Y. Since (Y, σ) is an intuitionistic fuzzy $\mathrm{T}_{1/2}$ space, $f(A)$ is an IFCS in Y. By the hypothesis g($f(A)$) is an IFSCS in Z. By Theorem 2.2.5, g($f(A)$) is an IFSGCS in Z. Therefore, $(\mathrm{g} \circ f)(A)$ = g($f(A)$) is an IFSGCS in Z. Hence, $\mathrm{g} \circ f$ is an intuitionistic fuzzy sg-closed mapping. ■

Remark 3.19. If $f : X \rightarrow Y$ is an intuitionistic fuzzy sg-closed mapping and $\mathrm{g} : Y \rightarrow \mathrm{Z}$ is an intuitionistic fuzzy closed mapping, then their composition $\mathrm{g} \circ f: X \rightarrow \mathrm{Z}$ needs not be an intuitionistic fuzzy sg-closed mapping as seen from the following example.

Example 3.20. Let $X = \{\mathrm{a}, \mathrm{b}\}$, $Y = \{\mathrm{c}, \mathrm{d}\}$, $\mathrm{Z} = \{u, v\}$. Let $A = \langle \mathrm{x}, (0.3, 0.4), (0.7, 0.6)\rangle$, $B = \langle \mathrm{y}, (0.3, 0.1), (0.5, 0.7)\rangle$ and $\mathrm{C} = \langle \mathrm{z}, (0.7, 0.6), (0.3, 0.4)\rangle$.Then $\tau = \{0_\sim, 1_\sim, A\}$, □ $= \{0_\sim, 1_\sim, B\}$ and $\eta = \{0_\sim, 1_\sim, \mathrm{C}\}$ and are IFT on X,Y and Z respectively. Define a mapping $f : (X, \tau) \rightarrow (Y,$ □$)$ by $f(a)$ = c and $f(b)$ = d and g : $(Y,$ □$) \rightarrow (\mathrm{Z}, \eta)$ by g(c) = u and g(d) = v. Then $\mathrm{g} \circ f : (X, \tau) \rightarrow (\mathrm{Z}, \eta)$ is defined by $(\mathrm{g} \circ f)(\mathrm{a}) = u$ and $(\mathrm{g} \circ f)(\mathrm{b}) = v$. Then $(\mathrm{g} \circ f)(f(\bar{A})) = \langle \mathrm{z}, (0.7, 0.6), (0.3, 0.4)\rangle$. $\mathrm{scl}((\mathrm{g} \circ f)(f(\bar{A}))) = 1_\sim$. Since $(\mathrm{g} \circ f)(f(\bar{A})) \subseteq \mathrm{C}$ and $\mathrm{scl}(\mathrm{g} \circ f)f(\bar{A}) \nsubseteq$

C. Therefore, $(g \circ f)(f(\bar{A}))$ is not an IFSGCS in Z. Hence, $g \circ f$ is not an intuitionistic fuzzy sg-closed mapping.

Theorem 3.21. *Let $f : X \to Y$ and $g : Y \to Z$ be two mappings such that $g \circ f : X \to Z$ is an intuitionistic fuzzy sg-closed mapping. Then the following statements are true.*

(i) *If f is an intuitionistic fuzzy continuous and surjective mapping, then g is an intuitionistic fuzzy sg-closed mapping.*

(ii) *If g is an intuitionistic fuzzy sg-irresolute and injective mapping, then f is an intuitionistic fuzzy sg-closed mapping.*

Proof. (i) Let B be an IFCS in Y. Since f is an intuitionistic fuzzy continuous mapping, $f^{-1}(B)$ is an IFCS in X. Also since $g \circ f$ is an intuitionistic fuzzy sg-closed mapping, $(g \circ f)(f^{-1}(B))$ is an IFSGCS in Z. Further f is surjective implies $g(f(f^{-1}(B))) = g(B)$ is an IFSGCS in Z. Therefore, g is intuitionistic fuzzy sg-closed mapping.

(ii) Let B be an IFCS in X. Since $g \circ f$ is an intuitionistic fuzzy sg-closed mapping, $(g \circ f)(B)$ is an IFSGCS in Z. Since g is an intuitionistic fuzzy sg-irresolute and injective mapping, $g^{-1}((g \circ f)(B)) = g^{-1}(g(f(B))) = f(B)$ is an IFSGCS in Y. Hence, f is an intuitionistic fuzzy sg-closed mapping. ■

Proposition 3.22. *Let $f : X \to Y$ be a bijective mapping. Then the following statements are equivalent:*

(i) *$f^{-1} : Y \to X$ is an intuitionistic fuzzy sg-continuous mapping.*

(ii) *f is an intuitionistic fuzzy sg-open mapping.*

(iii) *f is an intuitionistic fuzzy sg-closed mapping.*

Proof. (i) ⇒ (ii): Let B be an IFOS of X. By assumption, $(f^{-1})^{-1}(B) = f(B)$ is an IFSGOS in Y and so f is an intuitionistic fuzzy sg-open mapping.

(ii) ⇒ (iii): Let B be an IFCS of X. Then $\bar{B}$ is an IFOS in X. Since f is an intuitionistic fuzzy sg-open mapping, $f(\bar{B})$ is an IFSGOS in Y. Since $f(\bar{B}) = \overline{f(B)}$, $f(B)$ is an IFSGCS in Y. Hence, f is an intuitionistic fuzzy sg-closed mapping.

(iii) ⇒ (i): Let B be an IFCS in X. By assumption $f(B)$ is an IFSGCS in Y. But $f(B) = (f^{-1})^{-1}(B)$ Therefore $(f^{-1})^{-1}(B)$ is an IFSGCS in Y. Hence f^{-1} is an intuitionistic fuzzy sg-continuous mapping. ■

Definition 3.23. *Let $p_{(\alpha,\beta)}$ be an IFP of an IFTS (X, τ) and A be an IFS of X. Then A is called an intuitionistic fuzzy semi-neighborhood of $p_{(\alpha,\beta)}$, if there exists an IFSOS B in X such that $p_{(\alpha,\beta)} \in B \subseteq A$.*

Theorem 3.24. *Let $f : (X, \tau) \to (Y, \sigma)$ be a mapping and (X, τ), (Y, σ) are intuitionistic fuzzy semi $T_{1/2}$ spaces. Then the following statements are equivalent:*

(i) *f is an intuitionistic fuzzy sg-open mapping.*

(ii) *$f(int(A)) \subseteq sint(f(A))$, for any IFS A of X.*

(iii) *For each $p_{(\alpha,\beta)}$ of X and for each IFN B of $p_{(\alpha,\beta)}$ in X, there exists an intuitionistic fuzzy semi-neighborhood A of $f(p_{(\alpha,\beta)})$ in Y such that $A \subseteq f(B)$.*

Proof. (i) ⇒ (ii): Assume that f is an intuitionistic fuzzy sg-open mapping. Let $A \subseteq X$. Since $\text{int}(A)$ is an IFOS in X, $f(\text{int}(A))$ is an IFSGOS in Y and by the hypothesis $f(\text{int}(A))$ is an IFSOS in Y. Hence $f(\text{int}A) \subseteq f(A)$ and we have $f(\text{int}A) \subseteq \text{sint}(f(A))$.

(ii) ⇒ (iii): Assume that (ii) holds. Let $p_{(\alpha,\beta)} \in X$ and B be an arbitrary neighborhood of $p_{(\alpha,\beta)}$ in X. Then there exists an IFOS C such that $p_{(\alpha,\beta)} \in C \subseteq B$. By assumption $f(C) = f(\text{int}(C)) \subseteq \text{sint}(f(C))$.

This implies f(C) = sint(f(C)). Therefore f(C) is an IFSOS in Y. Further $f(p_{(\alpha,\beta)}) \in f(C) \subseteq f(B)$ and so (iii) holds, by taking $A = f(C)$.

(iii) ⇒ (i): Suppose that (iii) holds. Let B be an IFOS in X, $p_{(\alpha,\beta)} \in B$ and $f(p_{(\alpha,\beta)}) = q_{(\alpha,\beta)}$. Then for each $p_{(\alpha,\beta)} \in B$, $q_{(\alpha,\beta)} \in f(B)$, by assumption, there exists an intuitionistic fuzzy semi-neighborhood $A_{q_{(\alpha,\beta)}}$ of $q_{(\alpha,\beta)}$ in Y such that $A_{q_{(\alpha,\beta)}} \subseteq f(B)$. Since $A_{q_{(\alpha,\beta)}}$ is an intuitionistic fuzzy semi-neighborhood of $q_{(\alpha,\beta)}$, there exists an IFSOS $C_{q_{(\alpha,\beta)}}$ in Y such that $q_{(\alpha,\beta)} \in C_{q_{(\alpha,\beta)}} \subseteq A_{q_{(\alpha,\beta)}}$. Therefore $f(B) = \cup \left\{C_{q_{(\alpha,\beta)}} : q_{(\alpha,\beta)} \in f(B)\right\}$. Since any union of IFSOS is an IFSOS, $f(B)$ is an IFSOS in Y and hence $f(B)$ is an IFSGOS in Y. Then f is an intuitionistic fuzzy sg-open mapping. ■

Theorem 3.25. *A mapping $f : X \to Y$ is an intuitionistic fuzzy sg - open mapping if and only if for each IFS B of Y and for each IFCS S containing $f^{-1}(B)$, there is an IFSGCS A of Y such that $B \subseteq A$ and $f^{-1}(A) \subseteq S$.*

Proof. Similar to Theorem 5.2.13. ■

Theorem 3.26. *Let $f : (X, \tau) \to (Y, \sigma)$ be a bijective mapping. If (Y, σ) is an intuitionistic fuzzy semi $T_{1/2}$ space, then the following are equivalent:*

(i) *f is an intuitionistic fuzzy sg-closed mapping.*
(ii) *$scl(f(A)) \subseteq f(cl(A))$ for each IFS A of X.*
(iii) *$f^{-1}(scl(B)) \subseteq cl(f^{-1}(B))$ for every IFS B of Y.*

Proof. (i) ⇔ (ii): The proof follows from Theorem 5.2.12.

(ii) ⇒ (iii): Let B be an IFS in Y. Then $f^{-1}(B)$ is an IFS of X. Since f is onto, scl(B) = scl($f(f^{-1}(B))$). By assumption scl($f(f^{-1}(B))$) ⊆ f(cl($f^{-1}(B)$)). So scl(B) ⊆ f(cl($f^{-1}(B)$)). Now f^{-1}(scl(B)) ⊆ f^{-1}f(cl($f^{-1}(B)$)). Since f is one-one, f^{-1}(scl(B)) ⊆ cl($f^{-1}(B)$).

(iii) ⇒ (ii): Let A be any IFS of X. Then $f(A)$ is an IFS of Y. Since f is one-one, by (iii) f^{-1}(scl($f(A)$)) ⊆ cl(f^{-1}f((A))) = cl(A). So $f(f^{-1}$(scl($f(A)$))) ⊆ f(cl(A)). Since f is onto, scl($f(A)$) ⊆ f(cl(A)). ■

Theorem 3.27. *Let $f : X \to Y$ be an intuitionistic fuzzy sg-closed mapping. Then for every IFS A of X, $f(cl(A))$ is an IFSGCS of Y.*

Proof. Let A be any IFS in X. Then cl(A) is an IFCS in X. By assumption, we have f(cl(A)) is an IFSGCS in Y. ■

Theorem 3.28. *Let $f : (X, \tau) \to (Y, \sigma)$ be an intuitionistic fuzzy sg-closed mapping, where (Y, σ) is an intuitionistic fuzzy semi $T_{1/2}$ space. Then f is an intuitionistic fuzzy pre-regular closed mapping if every IFSCS is an IFRCS in Y.*

Proof. Let A be an IFRCS in X. Since every IFRCS is an IFCS, A is an IFCS in X. By assumption $f(A)$ is an IFSGCS in Y. Since (Y, σ) is an intuitionistic fuzzy semi $T_{1/2}$ space, $f(A)$ is an IFSCS in Y and by the hypothesis IFRCS in Y. This implies that f is an intuitionistic fuzzy pre-regular closed mapping. ■

Theorem 3.29. *Let $f:(X, \tau) \to (Y, \sigma)$ be an intuitionistic fuzzy sg-closed mapping, where (Y, σ) is an intuitionistic fuzzy semi $T_{1/2}$ space. Then f is an intuitionistic fuzzy closed mapping, if every IFSCS is an IFCS in Y.*

Proof. Let A be an IFCS in X. By the hypothesis, $f(A)$ is an IFSGCS in Y. Since (Y,σ) is an intuitionistic fuzzy semi-$T_{1/2}$ space, $f(A)$ is an IFSCS in Y. By assumption, $f(A)$ is an IFCS in Y. Hence f is an intuitionistic fuzzy closed mapping. ■

Theorem 3.30. *Let A be an IFSGCS in X and $f : X \to Y$ be both surjective intuitionistic fuzzy irresolute and intuitionistic fuzzy sg-closed mapping. Then $f(A)$ is an IFSGCS in Y.*

Proof. Let $f(A) \subseteq U$, where U is an IFSOS in Y. By the hypothesis $f^{-1}(U)$ is an IFSOS in X. Since A is an IFSGCS, $\mathrm{scl}(A) \subseteq f^{-1}(U)$ in X. This implies $f(\mathrm{scl}(A)) \subseteq f(f^{-1}(U)) = U$. Since f is an intuitionistic fuzzy sg-closed mapping and $\mathrm{cl}(A)$ is an IFCS in X, $f(\mathrm{cl}(A))$ is an IFSGCS in Y. By definition of IFSGCS, $\mathrm{scl}(f(\mathrm{cl}(A))) \subseteq U$. Now $\mathrm{scl}(f(A)) \subseteq \mathrm{scl}(f(\mathrm{cl}(A))) \subseteq U$. Hence, $f(A)$ is an IFSGCS in Y. ■

Theorem 3.31. *A mapping $f : (X, \tau) \to (Y, \sigma)$ is an intuitionistic fuzzy sg-open mapping if and only if $int(f^{-1}(B)) \subseteq f^{-1}(sint(B))$ for every $B \subseteq Y$, where (Y, σ) is an intuitionistic fuzzy semi $T_{1/2}$ space.*

Proof. Necessity: Let $B \subseteq Y$. Then $f^{-1}(B) \subseteq X$ and $\mathrm{int}(f^{-1}(B))$ is an IFOS in X. Since f is an intuitionistic fuzzy sg-open mapping, $f(\mathrm{int}(f^{-1}(B)))$ is an IFSGOS in Y. Since (Y, σ) is an intuitionistic fuzzy semi $T_{1/2}$ space, $f(\mathrm{int}(f^{-1}(B)))$ is an IFSOS in Y. Therefore, $f(\mathrm{int}(f^{-1}(B))) = \mathrm{sint}(f(\mathrm{int}(f^{-1}(B)))) \subseteq \mathrm{sint}(B)$. Hence, $\mathrm{int}(f^{-1}(B)) \subseteq f^{-1}(\mathrm{sint}(B))$.

Sufficiency: Let A be an IFOS in X. Therefore $\mathrm{int}(A) = A$. Then $f(A) \subseteq Y$. By the hypothesis $\mathrm{int}(f^{-1}(f(A))) \subseteq f^{-1}(\mathrm{sint}(f(A)))$, $\mathrm{int}(A) \subseteq \mathrm{int}(f^{-1}(f(A))) \subseteq f^{-1}(\mathrm{sint}(f(A)))$. Therefore, $A \subseteq f^{-1}(\mathrm{sint}(f(A)))$. This implies $f(A) \subseteq \mathrm{sint}(f(A)) \subseteq f(A)$. Hence $\mathrm{sint}(f(A)) = f(A)$, which implies $f(A)$ is an IFSOS in Y. Since every IFSOS is an IFSGOS, $f(A)$ is an IFSGOS in Y. Thus, f is an intuitionistic fuzzy sg-open mapping. ■

Theorem 3.32. *Let $f : (X, \tau) \to (Y, \sigma)$ be a surjective mapping, where (Y, σ) is an intuitionistic fuzzy semi $T_{1/2}$ space. Then the following statements are equivalent:*

(i) *f is an intuitionistic fuzzy sg-open mapping.*

(ii) *$f(int(A)) \subseteq sint(f(A))$ for each IFS A of X.*

(iii) *$int(f^{-1}(B)) \subseteq f^{-1}(sint(B))$ for each IFS B of Y.*

Proof. (i) ⇒ (ii): Let f be an intuitionistic fuzzy sg-open mapping and A be any IFS of X. Clearly $\mathrm{int}(A)$ is an IFOS in X. By assumption $f(\mathrm{int}(A))$ is an IFSGOS in Y. Since (Y, σ) is an intuitionistic fuzzy semi $T_{1/2}$ space, $f(\mathrm{int}(A))$ is an IFSOS in Y. Now $f(\mathrm{int}(A)) = \mathrm{sint}(f(\mathrm{int}(A))) \subseteq \mathrm{sint}(f(A))$.

(ii) ⇒ (iii): Let B be any IFS of Y. Then $f^{-1}(B)$ is an IFS in X. By (ii), $f(\mathrm{int}(f^{-1}(B))) \subseteq \mathrm{sint}(f(f^{-1}(B))) = \mathrm{sint}(B)$. Now $\mathrm{int}(f^{-1}(B)) \subseteq f^{-1}(f(\mathrm{int}(f^{-1}(B)))) \subseteq f^{-1}(\mathrm{sint}(B))$.

(iii) ⇒ (i): Follows from the Theorem 5.2.31. ■

Theorem 3.33. *A mapping $f : X \to Y$ is an intuitionistic fuzzy sg-open mapping if $f(sint(A)) \subseteq sint(f(A))$ for every IFOS A in X.*

Proof. Let A be an IFOS in X. Then $\mathrm{int}(A) = A$. By the hypothesis, $f(A) = f(\mathrm{int}(A)) \subseteq f(\mathrm{sint}(A)) \subseteq \mathrm{sint}(f(A))$. But $\mathrm{sint}(f(A)) \subseteq f(A)$. Hence $\mathrm{sint}(f(A)) = f(A)$, which implies that $f(A)$ is an IFSOS in Y. Since every IFSOS is an IFSGOS, $f(A)$ is an IFSGOS in Y. Hence, f is an intuitionistic fuzzy sg-open mapping. ■

Theorem 3.34. *Let $f : (X, \tau) \to (Y, \sigma)$ be an bijective mapping, where (Y, σ) is an intuitionistic fuzzy semi $T_{1/2}$ space. Then f is an intuitionistic fuzzy sg-open mapping if and only if for any IFP $p_{(\alpha, \beta)} \in Y$ and for any IFN B of $f^{-1}(p_{(\alpha, \beta)})$, there is an intuitionistic fuzzy semi-neighborhood A of $p_{(\alpha, \beta)}$ such that $p_{(\alpha, \beta)} \in A$ and $f^{-1}(A) \subseteq B$.*

Proof. Necessity: Let $p_{(\alpha, \beta)} \in Y$ and let B be an IFN of $f^{-1}(p_{(\alpha, \beta)})$. Then there exists an IFOS C in X such that $f^{-1}(p_{(\alpha, \beta)}) \in C \subseteq B$. Since f is an intuitionistic fuzzy sg-open mapping, $f(C)$ is an IFSGOS in Y and $p_{(\alpha, \beta)} \subseteq f(f^{-1}(p_{(\alpha, \beta)})) \in f(C) \subseteq f(B)$. Since (Y, σ) is an intuitionistic fuzzy semi $T_{1/2}$ space, $f(C)$

is an IFSOS in Y and taking $A = f(C)$. Then A is an intuitionistic fuzzy semi-neighborhood of $p_{(\alpha\,,\,\beta)}$ and $p_{(\alpha\,,\,\beta)} \in A \subseteq f(B)$. Thus $p_{(\alpha\,,\,\beta)} \in A$ and $f^{-1}(A) \subseteq f^{-1}(f(B)) = B$. Thus $f^{-1}(A) \subseteq B$.

Sufficiency: Let $B \subseteq X$ be an IFOS. If $f(B) = 0_{\sim}$, then it is obvious. Suppose that $p_{(\alpha\,,\,\beta)} \in f(B)$. This implies $f^{-1}(p_{(\alpha\,,\,\beta)}) \in B$. Then B is an IFN of $f^{-1}(p_{(\alpha\,,\,\beta)})$. By the hypothesis there is an intuitionistic fuzzy semi-neighborhood A of $p_{(\alpha\,,\,\beta)}$ such that $p_{(\alpha\,,\,\beta)} \in A$ and $f^{-1}(A) \subseteq B$. Therefore there is an IFSOS C in Y such that $p_{(\alpha\,,\,\beta)} \in C \subseteq A = f(f^{-1}(A)) \subseteq f(B)$. Hence $f(B) = \cup \left\{p_{(\alpha,\beta)}/p_{(\alpha,\beta)} \in C\right\} \subseteq \cup \left\{p_{(\alpha,\beta)}/p_{(\alpha,\beta)} \subseteq C\right\} \subseteq f(B)$. Thus, $f(B) = \cup \left\{p_{(\alpha,\beta)}/p_{(\alpha,\beta)} \in C\right\}$. Since each C is an IFSOS, $f(B)$ is also an IFSOS and hence $f(B)$ is an IFSGOS in Y. Therefore, f is an intuitionistic fuzzy sg-open mapping. ■

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