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Intuitionistic Fuzzy Almost Generalized β Closed Mappings

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ABSTRACT:
In this paper we introduce intuitionistic fuzzy almost generalized β closed mappings and intuitionistic fuzzy almost generalized β open mappings. We investigate some of their properties. Also we provide the relation between intuitionistic fuzzy almost generalized β closed mappings and other intuitionistic fuzzy closed mappings.

Key words and phrases : Intuitionistic fuzzy topology, intuitionistic fuzzy generalized β $T_{1/2}$ space, intuitionistic fuzzy almost generalized β closed mappings.

1. Introduction

The notion of intuitionistic fuzzy sets is introduced by Atanassov [1]. Using this notion, Coker [2] introduced the notion of intuitionistic fuzzy topological spaces. D. Jayanthi [4] introduced the notion of intuitionistic fuzzy generalized β closed mappings and intuitionistic fuzzy generalized β open mappings. In this paper we introduce intuitionistic fuzzy almost generalized β closed mappings. We investigate some of its properties. Also we provide the relation between an intuitionistic fuzzy almost generalized β closed mapping and other intuitionistic fuzzy closed mappings.

2. Preliminaries

Definition 2.1: [1] An intuitionistic fuzzy set (IFS) A in X is an object having the form

$$A = \{\langle x, \mu_A(x), \nu_A(x)\rangle / x \in X\}$$

where the functions $\mu_A: X \to [0,1]$ and $\nu_A: X \to [0,1]$ denote the degree of membership (namely $\mu_A(x)$) and the degree of non -membership (namely $\nu_A(x)$) of each element $x \in X$ to the set A, respectively, and $0 \leq \mu_A(x) + \nu_A(x) \leq 1$ for each $x \in X$.

Definition 2.2: [1] Let A and B be IFSs of the form $A = \{\langle x, \mu_A(x), \nu_A(x)\rangle / x \in X\}$ and $B = \{\langle x, \mu_B(x), \nu_B(x)\rangle / x \in X\}$.
Then

(a) $A \subseteq B$ if and only if $\mu_A(x) \leq \mu_B(x)$ and $\nu_A(x) \geq \nu_B(x)$ for all $x \in X$
(b) $A = B$ if and only if $A \subseteq B$ and $B \subseteq A$
(c) $A^c = \{\langle x, \nu_A(x), \mu_A(x)\rangle / x \in X\}$
(d) $A \cap B = \{\langle x, \mu_A(x) \wedge \mu_B(x), \nu_A(x) \vee \nu_B(x)\rangle / x \in X\}$
(e) $A \cup B = \{\langle x, \mu_A(x) \vee \mu_B(x), \nu_A(x) \wedge \nu_B(x)\rangle / x \in X\}$

For the sake of simplicity, we shall use the notation $A = \langle x, \mu_A, \nu_A\rangle$ instead of $A = \{\langle x, \mu_A(x), \nu_A(x)\rangle / x \in X\}$.

The intuitionistic fuzzy sets $0_\sim = \{\langle x, 0, 1\rangle / x \in X\}$ and $1_\sim = \{\langle x, 1, 0\rangle / x \in X\}$ are respectively the empty set and the whole set of X.

Definition 2.3: [2] Let $\alpha, \beta \in [0, 1]$ with $\alpha + \beta \leq 1$. An intuitionistic fuzzy point (IFP), written as $p_{(\alpha, \beta)}$, is defined to be an IFS of X given by

$$p_{(\alpha, \beta)}(x) = \begin{cases} (\alpha, \beta) & \text{if } x = p, \\ (0, 1) & \text{otherwise.} \end{cases}$$

Definition 2.4: [2] An intuitionistic fuzzy topology (IFT) on 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 $G_1, G_2 \in \tau$

(iii) $\cup G_i \in \tau$ for any family $\{ G_i / i \in J \} \subseteq \tau$.

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 A^c of an IFOS A in IFTS (X, τ) is called an intuitionistic fuzzy closed set (IFCS) in X.

Definition 2.5:[2] Let (X, τ) be an IFTS and $A = \langle x, \mu_A, \nu_A\rangle$ be an IFS in X. Then the intuitionistic fuzzy interior and intuitionistic fuzzy closure are defined by

$\text{int}(A) = \cup \{ G / G$ is an IFOS in X and $G \subseteq A \}$

$\text{cl}(A) = \cap \{ K / K$ is an IFCS in X and $A \subseteq K \}$

Definition 2.6:[3] An IFS $A = \langle x, \mu_A, \nu_A\rangle$ in an IFTS (X, τ) is said to be an

(i) *intuitionistic fuzzy regular closed set* (IFRCS) if $\text{cl}(\text{int}(A)) = A$

(ii) *intuitionistic fuzzy semi closed set* (IFSCS) if $\text{int}(\text{cl}(A)) \subseteq A$

(iii) *intuitionistic fuzzy pre closed set* (IFPCS) if $\text{cl}(\text{int}(A)) \subseteq A$

(iv) *intuitionistic fuzzy α closed set* (IFαCS) if $\text{cl}(\text{int}(\text{cl}(A)) \subseteq A$

(v) *intuitionistic fuzzy β closed set* (IFβCS) if $\text{int}(\text{cl}(\text{int}(A))) \subseteq A$

The respective complements of the above IFCSs are called their respective IFOSs.

Definition 2.7:[2] Let A be an IFS in an IFTS (X, τ). Then the β interior and the β closure of A are defined by

$\beta\text{int}(A) = \cup \{G / G$ is an IFβOS in X and $G \subseteq A\}$.

$\beta\text{cl}(A) = \cap \{K / K$ is an IFβCS in X and $A \subseteq K\}$.

Definition 2.8:[5] An IFS A in an IFTS (X, τ) is said to be an intuitionistic fuzzy generalized β closed set (IFGβCS) if $\beta\text{cl}(A) \subseteq U$ whenever $A \subseteq U$ and U is an IFOS in (X, τ).The complement A^c, is called an intuitionistic fuzzy generalized β open set (IFGβOS) in X.

Definition 2.9:[3] Let $p_{(\alpha, \beta)}$ be an IFP of (X, τ). An IFS A of X is called an intuitionistic fuzzy neighborhood (IFN) of $p_{(\alpha, \beta)}$ if there exists an IFOS B in X such that $p_{(\alpha, \beta)} \in B \subseteq A$.

Definition 2.10:[5] If every IFGβCS in (X, τ) is an IFβCS in (X, τ), then the space can be called as an intuitionistic fuzzy β $T_{1/2}$ space (IF$\beta T_{1/2}$ space).

Definition 2.11:[3] A map $f: X \rightarrow Y$ is called an intuitionistic fuzzy closed mapping (IFCM) if $f(A)$ is an IFCS in Y for each IFCS A in X.

Definition 2.12:[3] A map $f: X \rightarrow Y$ is called an
(i) intuitionistic fuzzy semi open mapping (IFSOM) if $f(A)$ is an IFSOS in Y for each IFOS A in X.
(ii) intuitionistic fuzzy α open mapping (IFαOM) if $f(A)$ is an IFαOS in Y for each IFOS A in X.
(iii) intuitionistic fuzzy preopen mapping (IFPOM) if $f(A)$ is an IFPOS in Y for each IFOS A in X.
(iv) intuitionistic fuzzy β open mapping (IFβOM) if $f(A)$ is an IFβOS in Y for each IFOS A in X.

Definition 2.13: [3] The intuitionistic fuzzy semi closure and the intuitionistic fuzzy α closure of an IFS A in an IFTS (X, τ) are defined by
$scl(A) = \cap \{ K / K$ is an IFSCS in X and $A \subseteq K \}$.
$\alpha cl(A) = \cap \{ K / K$ is an IFαCS in X and $A \subseteq K \}$.

Definition 2.14:[5] Let $p_{(\alpha, \beta)}$ be an IFP in (X, τ). An IFS A of X is called an intuitionistic fuzzy β neighborhood (IFβN) of $p_{(\alpha, \beta)}$ if there is an IFβOS B in X such that $p_{(\alpha, \beta)} \in B \subseteq A$.

Definition 2.15: [4]A mapping $f : X \rightarrow Y$ is said to be an intuitionistic fuzzy generalized β closed mapping (IFGβCM) if $f(A)$ is an IFGβCS in Y for every IFCS A in X.

Definition 2.16: [4]A mapping $f : X \rightarrow Y$ is said to be an intuitionistic fuzzy M-generalized β closed mapping (IFMGβCM) if $f(A)$ is an IFGβCS in Y for every IFGβCS A in X.

Definition 2.17: [5] An IFS A is said to be an intuitionistic fuzzy dense (IFD) in another IFS B in an IFTS (X, τ), if $cl(A) = B$.

Definition 2.18: [6] A mapping $f : X \rightarrow Y$ is said to be an intuitionistic fuzzy generalized β continuous mapping (IFGβcts.M) if $f^{-1}(A)$ is an IFGβCS in X for every IFCS A in Y.

3. Intuitionistic fuzzy almost generalized β closed mappings and intuitionistic fuzzy almost generalized β open mappigs.

In this section we introduce intuitionistic fuzzy almost generalized β closed mappings and intuitionistic fuzzy almost generalized β open mappings. We study some of their properties

Definition 3.1: A map f: X $\rightarrow$ Y is called an intuitionistic fuzzy almost generalized β closed mapping (IFaGβCM) if f(A) is an IFGβCS in Y for each IFRCS A in X.

Example 3.2: Let X = {a, b}, Y = {u, v} and $G_1 = \langle x, (0.5, 0.4), (0.5, 0.6)\rangle$, $G_2 = \langle y, (0.2, 0.3), (0.8, 0.7)\rangle$. Then $\tau = \{0_\sim, G_1, 1_\sim\}$ and $\sigma = \{0_\sim, G_2, 1_\sim\}$ are IFTs on X and Y respectively. Define a mapping f : (X, τ) $\rightarrow$ (Y, σ) by f(a) = u and f(b) = v. Then f is an IFaGβCM.

The relation between various types of intuitionistic fuzzy closedness is given in the following diagram.

$$\begin{tikzcd}
 & \mathrm{IF\alpha CM} \arrow[dl] \arrow[rr] & & \mathrm{IFG\beta CM} \arrow[d] & \\
\mathrm{IFCM} \arrow[rr] \arrow[dr] & & \mathrm{IFPCM} \arrow[r] & \mathrm{IFaG\beta CM} & \mathrm{IFMG\beta CM} \arrow[l] \arrow[ul] \\
 & \mathrm{IFSCM} \arrow[urr] & & &
\end{tikzcd}$$

The reverse implications are not true in general in the above diagram. This can be seen from the following examples.

Example 3.3: In Example 3.2, f is an IFaGβCM but not an IFCM, since $G_1^c = \langle x, (0.5, 0.6), (0.5, 0.4)\rangle$ is an IFCS in X but $f(G_1^c) = \langle y, (0.5, 0.6), (0.5, 0.4)\rangle$ is not an IFCS in Y .

Example 3.4: Let X = {a, b}, Y = {u, v} and $G_1 = \langle x, (0.5, 0.4), (0.5, 0.6)\rangle$, $G_2 = \langle y, (0.5, 0.4), (0.2, 0.3)\rangle$. Then $\tau = \{0_\sim, G_1, 1_\sim\}$ and $\sigma = \{0_\sim, G_2, 1_\sim\}$ are IFTs on X and Y respectively. Define a mapping f : X $\rightarrow$ Y by f(a) = u and f(b) = v. Then f is an IFaGβCM but not an IFSCM, since $G_1^c = \langle x, (0.5, 0.6), (0.5, 0.4)\rangle$ is an IFCS in X but $f(G_1^c) = \langle y, (0.5, 0.6), (0.5, 0.4)\rangle$ is not an IFSCS in Y, since $int(cl(f(G_1^c))) = 1_\sim \not\subseteq f(G_1^c)$.

Example 3.5: In Example 3.4 f is an IFaGβCM but not an IFαCM, since $G_1^c = \langle x, (0.5, 0.6), (0.5, 0.4)\rangle$ is an IFCS in X but $f(G_1^c) = \langle y, (0.5, 0.6), (0.5, 0.4)\rangle$ is not an IFαCS in Y, since $cl(int(cl(f(G_1^c)))) = 1_\sim \not\subseteq f(G_1^c)$.

Example 3.6: In Example 3.2 f is an IFaGβCM but not an IFPCM, since $G_1^c = \langle x, (0.5, 0.6), (0.5, 0.4)\rangle$ is an IFCS in X but $f(G_1^c) = \langle y, (0.5, 0.6), (0.5, 0.4)\rangle$ is not an IFPCS in Y, since $cl(int(f(G_1^c))) = G_2^c \not\subseteq f(G_1^c)$.

Example 3.7: Let X = {a, b}, Y = {u, v} and $G_1 = \langle x, (0.2, 0.2), (0.4, 0.4)\rangle$, $G_2 = \langle x, (0.2, 0), (0.5, 0.4)\rangle$, $G_3 = \langle y, (0.5, 0.6), (0.2, 0)\rangle$ and $G_4 = \langle x, (0.4, 0.1), (0.2, 0.1)\rangle$,. Then $\tau = \{0_\sim, G_1, G_2, 1_\sim\}$ and $\sigma = \{0_\sim, G_3, G_4, 1_\sim\}$ are IFTs on X and Y respectively. Define a mapping f: (X, τ) $\rightarrow$ (Y, σ) by f(a) = u and f(b) = v. Then f is an IFaGβM but not an IFGβCM, since $G_2^c = \langle x, (0.5, 0.4), (0.2, 0)\rangle$ is an IFCS in X but $f(G_2^c) = \langle y, (0.5, 0.4), (0.2, 0)\rangle$ is not an IFGβCS in Y, since $f(G_2^c) \subseteq G_3$ but $\beta cl(f(G_2^c)) = 1_{\sim} \not\subset G_3$.

Example 3.8: In Example 3.7 f is an IFaGβCM but not an IFMGβCM, since $A = \langle x, (0.4, 0.2), (0.2, 0)\rangle$ is an IFGβCS in X but $f(A) = \langle y, (0.4, 0.2), (0.2, 0)\rangle$ is not an IFGβCS in Y, since $f(A) \subseteq G_3$ but $\beta cl(f(A)) = 1_{\sim} \not\subset G_3$.

Definition 3.9: A map $f: X \to Y$ is called an intuitionistic fuzzy almost generalized β open mapping (IFaGβOM) if f(A) is an IFGβOS in Y for each IFROS A in X.
An IFaGβOM is an IFaGβCM if it is a bijective mpping.

Theorem 3.10: Let $p_{(\alpha, \beta)}$ be an IFP in X. A bijective mapping $f: X \to Y$ is an IFaGβCM if for every IFOS A in X with $f^{-1}(p_{(\alpha, \beta)}) \in A$, there exists an IFOS B in Y with $p_{(\alpha, \beta)} \in B$ such that f (A) is IFD in B.
Proof: Let A be an IFROS in X. Then A is an IFOS in X. Let $f^{-1}(p_{(\alpha, \beta)}) \in A$, then there exists an IFOS B in Y such that $p_{(\alpha, \beta)} \in B$ and cl(f (A)) = B. Since B is an IFOS, cl(f(A)) = B is also an IFOS in Y. Therefore int(cl(f(A))) = cl(f (A)). Now $f(A) \subseteq cl(f(A)) = int(cl(f(A))) \subseteq cl(int(cl(f(A))))$. This implies f(A) is an IFβOS in Y and hence an IFGβOS in Y. Thus f is an IFaGβCM.

Theorem 3.11: Let $f: X \to Y$ be a bijective mapping where Y is an IFβ$T_{1/2}$ space. Then the following are equivalent

- (i) f is an IFaGβCM.
- (ii) $\beta cl(f(A)) \subseteq f(cl(A))$ for every IFβOS A in X
- (iii) $\beta cl(f(A)) \subseteq f(cl(A))$ for every IFSOS A in X
- (iv) $f(A) \subseteq \beta int(f(int(cl(A))))$ for every IFPOS A in X.

Proof: (i) ⇒ (ii) Let A be an IFβOS in X. Then cl(A) is an IFRCS in X. By hypothesis f(A) is an IFGβCS in Y and hence is an IFβCS in Y, since Y is an IFβ$T_{1/2}$ space. This implies $\beta cl(f(cl(A))) = f(cl(A))$. Now $\beta cl(f(A)) \subseteq \beta cl(f(cl(A))) = f(cl(A))$. Thus $\beta cl(f(A)) \subseteq f(cl(A))$.
(ii) ⇒ (iii) Since every IFSOS is an IFβOS, the proof directly follows.
(iii) ⇒ (i) Let A be an IFRCS in X. Then A = cl(int(A)). Therefore A is an IFSOS in X. By hypothesis, $\beta cl(f(A)) \subseteq f(cl(A)) = f(A) \subseteq \beta cl(f(A))$. Hence f(A) is an IFβCS and hence is an IFGβCS in Y. Thus f is an IFaGβCM.
(i) ⇒ (iv) Let A be an IFPOS in X. Then $A \subseteq int(cl(A))$. Since int(cl(A)) is an IFROS in X, by hypothesis, f(int(cl(A))) is an IFGβOS in Y. Since Y is an IFβ$T_{1/2}$ space, f(int(cl(A))) is an IFβOS in Y. Therefore $f(A) \subseteq f(int(cl(A))) \subseteq \beta int(f(int(cl(A))))$.
(iv) ⇒ (i) Let A be an IFROS in X. Then A is an IFPOS in X. By hypothesis, $f(A) \subseteq \beta int(f(int(cl(A)))) = \beta int(f(A)) \subseteq f(A)$. This implies f(A) is an IFβOS in Y and hence is an IFGβOS in Y. Therefore f is an IFaGβCM.

Theorem 3.12: Let $f: X \to Y$ be a map. Then f is an IFaGβCM if for each IFP $p_{(\alpha, \beta)} \in Y$ and for each IFβOS B in X such that $f^{-1}(p_{(\alpha, \beta)}) \in B$, βcl(f(B)) is an IFβN of $p_{(\alpha, \beta)} \in Y$.
Proof: Let $p_{(\alpha, \beta)} \in Y$ and let A be an IFROS in X. Then A is an IFβOS in X. By hypothesis $f^{-1}(p_{(\alpha, \beta)}) \in A$, that is $p_{(\alpha, \beta)} \in f(A)$ in Y and βcl((f(A)) is an IFβN of $p_{(\alpha, \beta)}$

in Y. Therefore there exists an IFβOS B in Y such that $p_{(\alpha,\beta)} \in B \subseteq \beta cl(f(A))$. We have $p_{(\alpha,\beta)} \in f(A) \subseteq \beta cl(f(A))$. Now $B = \cup \{ p_{(\alpha,\beta)} / p_{(\alpha,\beta)} \in B\} = f(A)$. Therefore f(A) is an IFβOS in Y and hence an IFGβOS in Y. Thus f is an IFaGβOM. By Theorem f is an IFaGβCM.

Theorem 3.13: Let f: X → Y be a mapping where Y is an IFβ$T_{1/2}$ space. Then the following are equivalent.

(i) f is an IFaGβOM

(ii) for each IFP $p_{(\alpha,\beta)}$ in Y and each IFROS B in X such that $f^{-1}(p_{(\alpha,\beta)}) \in B$, cl(f(cl(B))) is an IFβN of $p_{(\alpha,\beta)}$ in Y.

Proof: (i) ⇒ (ii) Let $p_{(\alpha,\beta)} \in Y$ and let B be an IFROS in X such that $f^{-1}(p_{(\alpha,\beta)}) \in B$. That is $p_{(\alpha,\beta)} \in f(B)$. By hypothesis, f(B) is an IFGβOS in Y. Since Y is an IFβ$T_{1/2}$ space, f(B) is an IFβOS in Y. Now $p_{(\alpha,\beta)} \in f(B) \subseteq f(cl(B)) \subseteq cl(f(cl(B)))$. Hence cl(f(cl(B))) is an IFβN of $p_{(\alpha,\beta)}$ in Y.

(ii) ⇒ (i) Let B be an IFOS in X. Then $f^{-1}(p_{(\alpha,\beta)}) \in B$. This implies $p_{(\alpha,\beta)} \in f(B)$. By hypothesis, cl(f(cl(B))) is an IFβN of $p_{(\alpha,\beta)}$. Therefore there exists an IFβOS A in Y such that $p_{(\alpha,\beta)} \in A \subseteq cl(f(cl(B)))$. Now $A = \cup \{ p_{(\alpha,\beta)} / p_{(\alpha,\beta)} \in A\} = f(B)$. Therefore f(B) is an IFβOS and hence an IFGβOS in Y. Thus f is an IFaGβOM.

Theorem 3.14: The following are equivalent for a mapping f: X → Y where y is an IFβ$T_{1/2}$ space.

(i) f is an IFaGβCM

(ii) $\beta cl(f(A)) \subseteq f(\alpha cl(A))$ for every IFβOS A in X

(iii) $\beta cl(f(A)) \subseteq f(\alpha cl(A))$ for every IFSOS A in X

(iv) $f(A) \subseteq \beta int(f(scl(A)))$ for every IFPOS A in X.

Proof: (i) ⇒ (ii) Let A be an IFβOS in X. Then cl(A) is an IFRCS in X. By hypothesis f(A) is an IFGβCS in Y and hence is an IFβCS in Y, since Y is an IFβ$T_{1/2}$ space. This implies $\beta cl(f(cl(A))) = f(cl(A))$. Now $\beta cl(f(A)) \subseteq \beta cl(f(cl(A))) = f(cl(A))$. Since cl(A) is an IFRCS, $cl(int(cl(A))) = cl(A)$. Therefore $\beta cl(f(A)) \subseteq f(cl(A)) = f(cl(int(cl(A)))) \subseteq f(A \cup cl(int(cl(A)))) \subseteq f(\alpha cl(A))$. Hence $\beta cl(f(A)) \subseteq f(\alpha cl(A))$.

(ii) ⇒ (iii) Let A be an IFSOS in X. Since every IFSOS is an IFβOS, the proof is obvious.

(iii) ⇒ (i) Let A be an IFRCS in X. Then A = cl(int(A)). Therefore A is an IFSOS in X. By hypothesis, $\beta cl(f(A)) \subseteq f(\alpha cl(A)) \subseteq f(cl(A)) = f(A) \subseteq \beta cl(f(A))$. That is $\beta cl(f(A)) = f(A)$. Hence f(A) is an IFβCS and hence is an IFGβCS in Y. Thus f is an IFaGβCM.

(i) ⇒ (iv) Let A be an IFPOS in X. Then $A \subseteq int(cl(A))$. Since int(cl(A)) is an IFROS in X, by hypothesis, f(int(cl(A))) is an IFGβOS in Y. Since Y is an IFβ$T_{1/2}$ space, f(int(cl(A))) is an IFβOS in Y. Therefore $f(A) \subseteq f(int(cl(A))) \subseteq \beta int(f(int(cl(A)))) = \beta int(f(A \cup int(cl(A)))) = \beta int(f(scl(A)))$. That is $f(A) \subseteq \beta int(f(scl(A)))$.

(iv) ⇒ (i) Let A be an IFROS in X. Then A is an IFPOS in X. By hypothesis, $f(A) \subseteq \beta int(f(scl(A)))$. This implies $f(A) \subseteq \beta int(f(A \cup int(cl(A)))) \subseteq \beta int(f(A \cup A)) = \beta int(f(A)) \subseteq f(A)$. Therefore f(A) is an IFβOS in Y and hence an IFGβOS in Y. Thus f is an IFaGβCM.

Next we provide the characterization theorem for an IFaGβOM.

Theorem 3.15: Let f: X $\rightarrow$ Y be a bijective mapping. Then the following are equivalent.

(i) f is an IFaGβOM
(ii) f is an IFaGβCM
(iii) f^{-1} is an IFaGβCts.M.

Proof: (i) $\Leftrightarrow$ (ii) is obvious.
(ii) $\Rightarrow$ (iii) Let A $\subseteq$ X be an IFRCS. Then by hypothesis, f(A) is an IFGβCS in Y. That is $(f^{-1})^{-1}(A)$ is an IFGβCS in Y. This implies f^{-1} is an IFaGβCts.M.
(iii) $\Rightarrow$ (ii) Let A $\subseteq$ X be an IFRCS. Then by hypothesis $(f^{-1})^{-1}(A)$ is an IFGβCS in Y. That is f(A) is an IFGβCS in Y. Hence f is an IFaGβCM.

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