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► **To cite this version:**

Majid Mirmiran. Insertion of a Contra-Baire-1 (Baire-.5) Function. Communications in Mathematics, 2019, Volume 27 (2019), Issue 2 (2), pp.89 - 101. 10.2478/cm-2019-0009 . hal-03664970

HAL Id: hal-03664970

<https://hal.science/hal-03664970>

Submitted on 11 May 2022

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Insertion of a Contra-Baire-1 (Baire-.5) Function

Majid Mirmiran

Abstract. Necessary and sufficient conditions in terms of lower cut sets are given for the insertion of a Baire-.5 function between two comparable real-valued functions on the topological spaces that F_σ -kernel of sets are F_σ -sets.

1 Introduction

A generalized class of closed sets was considered by Maki in 1986 [17]. He investigated the sets that can be represented as union of closed sets and called them V -sets. Complements of V -sets, i.e., sets that are intersection of open sets are called Λ -sets [17].

Recall that a real-valued function f defined on a topological space X is called A -continuous [20] if the preimage of every open subset of \mathbb{R} belongs to A , where A is a collection of subsets of X . Most of the definitions of function used throughout this paper are consequences of the definition of A -continuity. However, for unknown concepts the reader may refer to [4], [10]. In the recent literature many topologists had focused their research in the direction of investigating different types of generalized continuity.

J. Dontchev in [5] introduced a new class of mappings called contra-continuity. A good number of researchers have also initiated different types of contra-continuous like mappings in the papers [1], [3], [7], [8], [9], [11], [12], [19].

Results of Katětov [13], [14] concerning binary relations and the concept of an indefinite lower cut set for a real-valued function, which is due to Brooks [2], are used in order to give a necessary and sufficient condition for the insertion of a Baire-.5 function between two comparable real-valued functions on the topological spaces that F_σ -kernel of sets are F_σ -sets.

2010 MSC: 26A15, 54C30.

Key words: Insertion, strong binary relation, Baire-.5 function, kernel of sets, lower cut set.

This work was supported by University of Isfahan and Centre of Excellence for Mathematics (University of Isfahan).

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A real-valued function f defined on a topological space X is called *contra-Baire-.5* (*Baire-.5*) if the preimage of every open subset of \mathbb{R} is a G_δ -set in X [21].

If g and f are real-valued functions defined on a space X , we write $g \leq f$ (resp. $g < f$) in case $g(x) \leq f(x)$ (resp. $g(x) < f(x)$) for all x in X .

The following definitions are modifications of conditions considered in [15].

A property P defined relative to a real-valued function on a topological space is a *B-.5-property* provided that any constant function has property P and provided that the sum of a function with property P and any Baire-.5 function also has property P . If P_1 and P_2 are *B-.5-properties*, the following terminology is used:

- (i) A space X has the *weak B-.5-insertion property* for (P_1, P_2) if and only if for any functions g and f on X such that $g \leq f$, g has property P_1 and f has property P_2 , then there exists a Baire-.5 function h such that $g \leq h \leq f$.
- (ii) A space X has the *B-.5-insertion property* for (P_1, P_2) if and only if for any functions g and f on X such that $g < f$, g has property P_1 and f has property P_2 , then there exists a Baire-.5 function h such that $g < h < f$.

In this paper, for a topological space that F_σ -kernel of sets are F_σ -sets, is given a sufficient condition for the weak *B-.5-insertion property*. Also for a space with the weak *B-.5-insertion property*, we give a necessary and sufficient condition for the space to have the *B-.5-insertion property*. Several insertion theorems are obtained as corollaries of these results.

2 The Main Result

Before giving a sufficient condition for insertability of a Baire-.5 function, the necessary definitions and terminology are stated.

Definition 1. Let A be a subset of a topological space (X, τ) . We define the subsets A^Λ and A^V as follows:

$$A^\Lambda = \bigcap \{O : O \supseteq A, O \in (X, \tau)\}$$

and

$$A^V = \bigcup \{F : F \subseteq A, F^c \in (X, \tau)\}.$$

In [6], [16], [18], A^Λ is called the *kernel* of A .

Definition 2. We define the subsets $G_\delta(A)$ and $F_\sigma(A)$ as follows:

$$G_\delta(A) = \bigcup \{O : O \subseteq A, O \text{ is } G_\delta\text{-set}\}$$

and

$$F_\sigma(A) = \bigcap \{F : F \supseteq A, F \text{ is } F_\sigma\text{-set}\}.$$

$F_\sigma(A)$ is called the *F_σ -kernel* of A .

The following first two definitions are modifications of conditions considered in [13], [14].

Definition 3. If ρ is a binary relation in a set S then $\bar{\rho}$ is defined as follows: $x \bar{\rho} y$ if and only if $y \rho v$ implies $x \rho v$ and $u \rho x$ implies $u \rho y$ for any u and v in S .

Definition 4. A binary relation ρ in the power set $P(X)$ of a topological space X is called a *strong binary relation* in $P(X)$ in case ρ satisfies each of the following conditions:

1. If $A_i \rho B_j$ for any $i \in \{1, \dots, m\}$ and for any $j \in \{1, \dots, n\}$, then there exists a set C in $P(X)$ such that $A_i \rho C$ and $C \rho B_j$ for any $i \in \{1, \dots, m\}$ and any $j \in \{1, \dots, n\}$.
2. If $A \subseteq B$, then $A \bar{\rho} B$.
3. If $A \rho B$, then $F_\sigma(A) \subseteq B$ and $A \subseteq G_\delta(B)$.

The concept of a lower indefinite cut set for a real-valued function was defined by Brooks [2] as follows:

Definition 5. If f is a real-valued function defined on a space X and if

$$\{x \in X : f(x) < \ell\} \subseteq A(f, \ell) \subseteq \{x \in X : f(x) \leq \ell\}$$

for a real number ℓ , then $A(f, \ell)$ is a *lower indefinite cut set* in the domain of f at the level ℓ .

We now give the following main results:

Theorem 1. Let g and f be real-valued functions on the topological space X , that F_σ -kernel of sets in X are F_σ -sets, with $g \leq f$. If there exists a strong binary relation ρ on the power set of X and if there exist lower indefinite cut sets $A(f, t)$ and $A(g, t)$ in the domain of f and g at the level t for each rational number t such that if $t_1 < t_2$ then $A(f, t_1) \rho A(g, t_2)$, then there exists a Baire-.5 function h defined on X such that $g \leq h \leq f$.

Proof. Let g and f be real-valued functions defined on the X such that $g \leq f$. By hypothesis there exists a strong binary relation ρ on the power set of X and there exist lower indefinite cut sets $A(f, t)$ and $A(g, t)$ in the domain of f and g at the level t for each rational number t such that if $t_1 < t_2$ then $A(f, t_1) \rho A(g, t_2)$.

Define functions F and G mapping the rational numbers \mathbb{Q} into the power set of X by $F(t) = A(f, t)$ and $G(t) = A(g, t)$. If t_1 and t_2 are any elements of \mathbb{Q} with $t_1 < t_2$, then $F(t_1) \bar{\rho} F(t_2), G(t_1) \bar{\rho} G(t_2)$, and $F(t_1) \rho G(t_2)$. By Lemmas 1 and 2 of [14] it follows that there exists a function H mapping \mathbb{Q} into the power set of X such that if t_1 and t_2 are any rational numbers with $t_1 < t_2$, then $F(t_1) \rho H(t_2), H(t_1) \rho H(t_2)$ and $H(t_1) \rho G(t_2)$.

For any x in X , let

$$h(x) = \inf\{t \in \mathbb{Q} : x \in H(t)\}.$$

We first verify that $g \leq h \leq f$: If x is in $H(t)$ then x is in $G(t')$ for any $t' > t$; since x in $G(t') = A(g, t')$ implies that $g(x) \leq t'$, it follows that $g(x) \leq t$. Hence

$g \leq h$. If x is not in $H(t)$, then x is not in $F(t')$ for any $t' < t$; since x is not in $F(t') = A(f, t')$ implies that $f(x) > t'$, it follows that $f(x) \geq t$. Hence $h \leq f$.

Also, for any rational numbers t_1 and t_2 with $t_1 < t_2$, we have

$$h^{-1}(t_1, t_2) = G_\delta(H(t_2)) \setminus F_\sigma(H(t_1)).$$

Hence $h^{-1}(t_1, t_2)$ is a G_δ -set in X , i.e., h is a Baire-.5 function on X . \square

The above proof used the technique of Theorem 1 of [13].

Theorem 2. *Let P_1 and P_2 be B -.5-property and X be a space that satisfies the weak B -.5-insertion property for (P_1, P_2) . Also assume that g and f are functions on X such that $g < f$, g has property P_1 and f has property P_2 . The space X has the B -.5-insertion property for (P_1, P_2) if and only if there exist lower cut sets $A(f - g, 3^{-n+1})$ and there exists a decreasing sequence $\{D_n\}$ of subsets of X with empty intersection and such that for each n , $X \setminus D_n$ and $A(f - g, 3^{-n+1})$ are completely separated by Baire-.5 functions.*

Proof. Assume that X has the weak B -.5-insertion property for (P_1, P_2) . Let g and f be functions such that $g < f$, g has property P_1 and f has property P_2 . By hypothesis there exist lower cut sets $A(f - g, 3^{-n+1})$ and there exists a sequence (D_n) such that $\bigcap_{n=1}^{\infty} D_n = \emptyset$ and such that for each n , $X \setminus D_n$ and $A(f - g, 3^{-n+1})$ are completely separated by Baire-.5 functions. Let k_n be a Baire-.5 function such that $k_n = 0$ on $A(f - g, 3^{-n+1})$ and $k_n = 1$ on $X \setminus D_n$. Let a function k on X be defined by

$$k(x) = 1/2 \sum_{n=1}^{\infty} 3^{-n} k_n(x).$$

By the Cauchy condition and the B -.5-properties, the function k is a Baire-.5 function. Since $\bigcap_{n=1}^{\infty} D_n = \emptyset$ and since $k_n = 1$ on $X \setminus D_n$, it follows that $0 < k$. Also $2k < f - g$: In order to see this, observe first that if x is in $A(f - g, 3^{-n+1})$, then $k(x) \leq 1/4(3^{-n})$. If x is any point in X , then $x \notin A(f - g, 1)$ or for some n ,

$$x \in A(f - g, 3^{-n+1}) - A(f - g, 3^{-n});$$

in the former case $2k(x) < 1$, and in the latter $2k(x) \leq 1/2(3^{-n}) < f(x) - g(x)$. Thus if $f_1 = f - k$ and if $g_1 = g + k$, then $g < g_1 < f_1 < f$. Since P_1 and P_2 are B -.5-properties, then g_1 has property P_1 and f_1 has property P_2 . Since X has the weak B -.5-insertion property for (P_1, P_2) , then there exists a Baire-.5 function such that $g_1 \leq h \leq f_1$. Thus $g < h < f$, it follows that X satisfies the B -.5-insertion property for (P_1, P_2) . (The technique of this proof is by Katětov [13].)

Conversely, let g and f be functions on X such that g has property P_1 , f has property P_2 and $g < f$. By hypothesis, there exists a Baire-.5 function such that $g < h < f$. We follow an idea contained in Lane [15]. Since the constant function 0 has property P_1 , since $f - h$ has property P_2 , and since X has the B -.5-insertion property for (P_1, P_2) , then there exists a Baire-.5 function k such that $0 < k < f - h$. Let $A(f - g, 3^{-n+1})$ be any lower cut set for $f - g$ and let

$$D_n = \{x \in X : k(x) < 3^{-n+2}\}.$$

Since $k > 0$ it follows that $\bigcap_{n=1}^{\infty} D_n = \emptyset$. Since

$$A(f - g, 3^{-n+1}) \subseteq \{x \in X : (f - g)(x) \leq 3^{-n+1}\} \subseteq \{x \in X : k(x) \leq 3^{-n+1}\}$$

and since

$$\{x \in X : k(x) \leq 3^{-n+1}\}$$

and

$$\{x \in X : k(x) \geq 3^{-n+2}\} = X \setminus D_n$$

are completely separated by Baire-.5 function $\sup\{3^{-n+1}, \inf\{k, 3^{-n+2}\}\}$, it follows that for each n , $A(f - g, 3^{-n+1})$ and $X \setminus D_n$ are completely separated by Baire-.5 functions. \square

3 Applications

Definition 6. A real-valued function f defined on a space X is called *contra-upper semi-Baire-.5* (resp. *contra-lower semi-Baire-.5*) if $f^{-1}(-\infty, t)$ (resp. $f^{-1}(t, +\infty)$) is a G_δ -set for any real number t .

The abbreviations usc, lsc, cusB-.5 and clsB-.5 are used for upper semicontinuous, lower semicontinuous, contra-upper semi-Baire-.5, and contra-lower semi-Baire-.5, respectively.

Remark 1. [13], [14]. A space X has the weak c -insertion property for (usc, lsc) if and only if X is normal.

Before stating the consequences of Theorem 1, and Theorem 2 we suppose that X is a topological space that F_σ -kernel of sets are F_σ -sets.

Corollary 1. For each pair of disjoint F_σ -sets F_1, F_2 , there are two G_δ -sets G_1 and G_2 such that $F_1 \subseteq G_1$, $F_2 \subseteq G_2$ and $G_1 \cap G_2 = \emptyset$ if and only if X has the weak B-.5-insertion property for (cusB-.5, clsB-.5).

Proof. Let g and f be real-valued functions defined on the X , such that f is lsc B_1 , g is usc B_1 , and $g \leq f$. If a binary relation ρ is defined by $A \rho B$ in case $F_\sigma(A) \subseteq G_\delta(B)$, then by hypothesis ρ is a strong binary relation in the power set of X . If t_1 and t_2 are any elements of \mathbb{Q} with $t_1 < t_2$, then

$$A(f, t_1) \subseteq \{x \in X : f(x) \leq t_1\} \subseteq \{x \in X : g(x) < t_2\} \subseteq A(g, t_2);$$

since $\{x \in X : f(x) \leq t_1\}$ is a F_σ -set and since $\{x \in X : g(x) < t_2\}$ is a G_δ -set, it follows that

$$F_\sigma(A(f, t_1)) \subseteq G_\delta(A(g, t_2)).$$

Hence $t_1 < t_2$ implies that $A(f, t_1) \rho A(g, t_2)$. The proof follows from Theorem 1.

On the other hand, let F_1 and F_2 are disjoint F_σ -sets. Set $f = \chi_{F_1^c}$ and $g = \chi_{F_2}$, then f is clsB-.5, g is cusB-.5, and $g \leq f$. Thus there exists Baire-.5 function h such that $g \leq h \leq f$. Set

$$G_1 = \left\{x \in X : h(x) < \frac{1}{2}\right\}$$

and

$$G_2 = \left\{ x \in X : h(x) > \frac{1}{2} \right\},$$

then G_1 and G_2 are disjoint G_δ -sets such that $F_1 \subseteq G_1$ and $F_2 \subseteq G_2$. \square

Remark 2. [22] A space X has the weak c -insertion property for (lsc, usc) if and only if X is extremally disconnected.

Corollary 2. For every G of G_δ -set, $F_\sigma(G)$ is a G_δ -set if and only if X has the weak B -5-insertion property for (clsB-.5, cusB-.5).

Before giving the proof of this corollary, the necessary lemma is stated.

Lemma 1. The following conditions on the space X are equivalent:

- (i) For every G of G_δ -set we have $F_\sigma(G)$ is a G_δ -set.
- (ii) For each pair of disjoint G_δ -sets as G_1 and G_2 we have $F_\sigma(G_1) \cap F_\sigma(G_2) = \emptyset$.

The proof of Lemma 1 is a direct consequence of the definition F_σ -kernel of sets.

We now give the proof of Corollary 2.

Proof of Corollary 2. Let g and f be real-valued functions defined on the X , such that f is clsB-.5, g is cusB-.5, and $f \leq g$. If a binary relation ρ is defined by $A \rho B$ in case

$$F_\sigma(A) \subseteq G \subseteq F_\sigma(G) \subseteq G_\delta(B)$$

for some G_δ -set g in X , then by hypothesis and Lemma 1 ρ is a strong binary relation in the power set of X . If t_1 and t_2 are any elements of \mathbb{Q} with $t_1 < t_2$, then

$$A(g, t_1) = \{x \in X : g(x) < t_1\} \subseteq \{x \in X : f(x) \leq t_2\} = A(f, t_2);$$

since $\{x \in X : g(x) < t_1\}$ is a G_δ -set and since $\{x \in X : f(x) \leq t_2\}$ is a F_σ -set, by hypothesis it follows that $A(g, t_1) \rho A(f, t_2)$. The proof follows from Theorem 1.

On the other hand, Let G_1 and G_2 are disjoint G_δ -sets. Set $f = \chi_{G_2}$ and $g = \chi_{G_1^c}$, then f is clsB-.5, g is cusB-.5, and $f \leq g$.

Thus there exists Baire-.5 function h such that $f \leq h \leq g$. Set

$$F_1 = \left\{ x \in X : h(x) \leq \frac{1}{3} \right\}$$

and

$$F_2 = \left\{ x \in X : h(x) \geq \frac{2}{3} \right\}$$

then F_1 and F_2 are disjoint F_σ -sets such that $G_1 \subseteq F_1$ and $G_2 \subseteq F_2$. Hence

$$F_\sigma(F_1) \cap F_\sigma(F_2) = \emptyset. \quad \square$$

Before stating the consequences of Theorem 2, we state and prove the necessary lemmas.

Lemma 2. *The following conditions on the space X are equivalent:*

- (i) *Every two disjoint F_σ -sets of X can be separated by G_δ -sets of X .*
- (ii) *If F is a F_σ -set of X which is contained in a G_δ -set G , then there exists a G_δ -set H such that $F \subseteq H \subseteq F_\sigma(H) \subseteq G$.*

Proof. (i) \Rightarrow (ii) Suppose that $F \subseteq G$, where F and G are F_σ -set and G_δ -set of X , respectively. Hence, G^c is a F_σ -set and $F \cap G^c = \emptyset$.

By (i) there exists two disjoint G_δ -sets G_1, G_2 such that $F \subseteq G_1$ and $G^c \subseteq G_2$. But

$$G^c \subseteq G_2 \Rightarrow G_2^c \subseteq G,$$

and

$$G_1 \cap G_2 = \emptyset \Rightarrow G_1 \subseteq G_2^c$$

hence

$$F \subseteq G_1 \subseteq G_2^c \subseteq G$$

and since G_2^c is a F_σ -set containing G_1 we conclude that $F_\sigma(G_1) \subseteq G_2^c$, i.e.,

$$F \subseteq G_1 \subseteq F_\sigma(G_1) \subseteq G.$$

By setting $H = G_1$, condition (ii) holds.

(ii) \Rightarrow (i) Suppose that F_1, F_2 are two disjoint F_σ -sets of X .

This implies that $F_1 \subseteq F_2^c$ and F_2^c is a G_δ -set. Hence by (ii) there exists a G_δ -set H such that $F_1 \subseteq H \subseteq F_\sigma(H) \subseteq F_2^c$.

But

$$H \subseteq F_\sigma(H) \Rightarrow H \cap (F_\sigma(H))^c = \emptyset$$

and

$$F_\sigma(H) \subseteq F_2^c \Rightarrow F_2 \subseteq (F_\sigma(H))^c.$$

Furthermore, $(F_\sigma(H))^c$ is a G_δ -set of X . Hence $F_1 \subseteq H$, $F_2 \subseteq (F_\sigma(H))^c$ and $H \cap (F_\sigma(H))^c = \emptyset$. This means that condition (i) holds. \square

Lemma 3. *Suppose that X is the topological space such that we can separate every two disjoint F_σ -sets by G_δ -sets. If F_1 and F_2 are two disjoint F_σ -sets of X , then there exists a Baire-.5 function $h: X \rightarrow [0, 1]$ such that*

$$h(F_1) = \{0\} \quad \text{and} \quad h(F_2) = \{1\}.$$

Proof. Suppose F_1 and F_2 are two disjoint F_σ -sets of X . Since $F_1 \cap F_2 = \emptyset$, hence $F_1 \subseteq F_2^c$. In particular, since F_2^c is a G_δ -set of X containing F_1 , by Lemma 2, there exists a G_δ -set $H_{1/2}$ such that,

$$F_1 \subseteq H_{1/2} \subseteq F_\sigma(H_{1/2}) \subseteq F_2^c.$$

Note that $H_{1/2}$ is a G_δ -set and contains F_1 , and F_2^c is a G_δ -set and contains $F_\sigma(H_{1/2})$. Hence, by Lemma 2, there exists G_δ -sets $H_{1/4}$ and $H_{3/4}$ such that,

$$F_1 \subseteq H_{1/4} \subseteq F_\sigma(H_{1/4}) \subseteq H_{1/2} \subseteq F_\sigma(H_{1/2}) \subseteq H_{3/4} \subseteq F_\sigma(H_{3/4}) \subseteq F_2^c.$$

By continuing this method for every $t \in D$, where $D \subseteq [0, 1]$ is the set of rational numbers that their denominators are exponents of 2, we obtain G_δ -sets H_t with the property that if $t_1, t_2 \in D$ and $t_1 < t_2$, then $H_{t_1} \subseteq H_{t_2}$. We define the function h on X by

$$h(x) = \inf\{t : x \in H_t\}$$

for $x \notin F_2$ and $h(x) = 1$ for $x \in F_2$.

Note that for every $x \in X, 0 \leq h(x) \leq 1$, i.e., h maps X into $[0, 1]$. Also, we note that for any $t \in D, F_1 \subseteq H_t$; hence $h(F_1) = \{0\}$. Furthermore, by definition, $h(F_2) = \{1\}$. It remains only to prove that h is a Baire-.5 function on X . For every $\alpha \in \mathbb{R}$, we have if $\alpha \leq 0$ then $\{x \in X : h(x) < \alpha\} = \emptyset$ and if $0 < \alpha$ then

$$\{x \in X : h(x) < \alpha\} = \bigcup\{H_t : t < \alpha\},$$

hence, they are G_δ -sets of X . Similarly, if $\alpha < 0$ then

$$\{x \in X : h(x) > \alpha\} = X$$

and if $0 \leq \alpha$ then

$$\{x \in X : h(x) > \alpha\} = \bigcup\{(F_\sigma(H_t))^c : t > \alpha\}$$

hence, every of them is a G_δ -set. Consequently h is a Baire-.5 function. \square

Lemma 4. Suppose that X is the topological space such that every two disjoint F_σ -sets can be separated by G_δ -sets. The following conditions are equivalent:

- (i) Every countable covering of G_δ -sets of X has a refinement consisting of G_δ -sets such that, for every $x \in X$, there exists a G_δ -set containing x such that it intersects only finitely many members of the refinement.
- (ii) Corresponding to every decreasing sequence $\{F_n\}$ of F_σ -sets with empty intersection there exists a decreasing sequence $\{G_n\}$ of G_δ -sets such that, $\bigcap_{n=1}^{\infty} G_n = \emptyset$ and for every $n \in \mathbb{N}, F_n \subseteq G_n$.

Proof. (i) \Rightarrow (ii). suppose that $\{F_n\}$ be a decreasing sequence of F_σ -sets with empty intersection. Then $\{F_n^c : n \in \mathbb{N}\}$ is a countable covering of G_δ -sets. By hypothesis (i) and Lemma 2, this covering has a refinement $\{V_n : n \in \mathbb{N}\}$ such that every V_n is a G_δ -set and $F_\sigma(V_n) \subseteq F_n^c$. By setting $F_n = (F_\sigma(V_n))^c$, we obtain a decreasing sequence of G_δ -sets with the required properties.

(ii) \Rightarrow (i). Now if $\{H_n : n \in \mathbb{N}\}$ is a countable covering of G_δ -sets, we set for $n \in \mathbb{N}, F_n = (\bigcup_{i=1}^n H_i)^c$. Then $\{F_n\}$ is a decreasing sequence of F_σ -sets with empty intersection. By (ii) there exists a decreasing sequence $\{G_n\}$ consisting of G_δ -sets such that, $\bigcap_{n=1}^{\infty} G_n = \emptyset$ and for every $n \in \mathbb{N}, F_n \subseteq G_n$. Now we define the subsets W_n of X in the following manner:

W_1 is a G_δ -set of X such that $G_1^c \subseteq W_1$ and $F_\sigma(W_1) \cap F_1 = \emptyset$.

W_2 is a G_δ -set of X such that $F_\sigma(W_1) \cup G_2^c \subseteq W_2$ and $F_\sigma(W_2) \cap F_2 = \emptyset$, and so on. (By Lemma 2, W_n exists).

Then since $\{G_n^c : n \in \mathbb{N}\}$ is a covering for X , hence $\{W_n : n \in \mathbb{N}\}$ is a covering for X consisting of G_δ -sets. Moreover, we have

(i) $F_\sigma(W_n) \subseteq W_{n+1}$

(ii) $G_n^c \subseteq W_n$

(iii) $W_n \subseteq \bigcup_{i=1}^n H_i$.

Now suppose that $S_1 = W_1$ and for $n \geq 2$, we set $S_n = W_{n+1} \setminus F_\sigma(W_{n-1})$.

Then since $F_\sigma(W_{n-1}) \subseteq W_n$ and $S_n \supseteq W_{n+1} \setminus W_n$, it follows that $\{S_n : n \in \mathbb{N}\}$ consists of G_δ -sets and covers X . Furthermore, $S_i \cap S_j \neq \emptyset$ if and only if $|i - j| \leq 1$. Finally, consider the following sets:

$$\begin{array}{ccccccc} S_1 \cap H_1, & S_1 \cap H_2 & & & & & \\ S_2 \cap H_1, & S_2 \cap H_2, & S_2 \cap H_3 & & & & \\ S_3 \cap H_1, & S_3 \cap H_2, & S_3 \cap H_3, & S_3 \cap H_4 & & & \end{array}$$

and continue ad infinitum. These sets are G_δ -sets, cover X and refine $\{H_n : n \in \mathbb{N}\}$. In addition, $S_i \cap H_j$ can intersect at most the sets in its row, immediately above, or immediately below row.

Hence if $x \in X$ and $x \in S_n \cap H_m$, then $S_n \cap H_m$ is a G_δ -set containing x that intersects at most finitely many of sets $S_i \cap H_j$. Consequently,

$$\{S_i \cap H_j : i \in \mathbb{N}, j = 1, \dots, i + 1\}$$

refines $\{H_n : n \in \mathbb{N}\}$ such that its elements are G_δ -sets, and for every point in X we can find a G_δ -set containing the point that intersects only finitely many elements of that refinement. □

Remark 3. [13], [14] A space X has the c -insertion property for (usc, lsc) if and only if X is normal and countably paracompact.

Corollary 3. X has the B -.5-insertion property for (cusB-.5, clsB-.5) if and only if every two disjoint F_σ -sets of X can be separated by G_δ -sets, and in addition, every countable covering of G_δ -sets has a refinement that consists of G_δ -sets such that, for every point of X we can find a G_δ -set containing that point such that, it intersects only a finite number of refining members.

Proof. Suppose that F_1 and F_2 are disjoint F_σ -sets. Since $F_1 \cap F_2 = \emptyset$, it follows that $F_2 \subseteq F_1^c$. We set $f(x) = 2$ for $x \in F_1^c$, $f(x) = \frac{1}{2}$ for $x \notin F_1^c$, and $g = \chi_{F_2}$.

Since F_2 is a F_σ -set, and F_1^c is a G_δ -set, therefore g is cusB-.5, f is clsB-.5 and furthermore $g < f$. Hence by hypothesis there exists a Baire-.5 function h such that, $g < h < f$. Now by setting

$$G_1 = \{x \in X : h(x) < 1\}$$

and

$$G_2 = \{x \in X : h(x) > 1\}.$$

We can say that G_1 and G_2 are disjoint G_δ -sets that contain F_1 and F_2 , respectively. Now suppose that $\{F_n\}$ is a decreasing sequence of F_σ -sets with empty intersection. Set $F_0 = X$ and define for every $x \in F_n \setminus F_{n+1}$,

$$f(x) = \frac{1}{n+1}.$$

Since

$$\bigcap_{n=0}^{\infty} F_n = \emptyset$$

and for every $x \in X$, there exists $n \in \mathbb{N}$, such that, $x \in F_n \setminus F_{n+1}$, f is well defined. Furthermore, for every $r \in \mathbb{R}$, if $r \leq 0$ then

$$\{x \in X : f(x) > r\} = X$$

is a G_δ -set and if $r > 0$ then by Archimedean property of \mathbb{R} , we can find $i \in \mathbb{N}$ such that

$$\frac{1}{i+1} \leq r.$$

Now suppose that k is the least natural number such that $\frac{1}{k+1} \leq r$. Hence $\frac{1}{k} > r$ and consequently,

$$\{x \in X : f(x) > r\} = X \setminus F_k$$

is a G_δ -set. Therefore, f is clsB-.5. By setting $g = 0$, we have g is cusB-.5 and $g < f$. Hence by hypothesis there exists a Baire-.5 function h on X such that, $g < h < f$.

By setting

$$G_n = \left\{x \in X : h(x) < \frac{1}{n+1}\right\},$$

we have G_n is a G_δ -set. But for every $x \in F_n$, we have

$$f(x) \leq \frac{1}{n+1}$$

and since $g < h < f$ therefore

$$0 < h(x) < \frac{1}{n+1},$$

i.e., $x \in G_n$ therefore $F_n \subseteq G_n$ and since $h > 0$ it follows that

$$\bigcap_{n=1}^{\infty} G_n = \emptyset.$$

Hence by Lemma 4, the conditions holds.

On the other hand, since every two disjoint F_σ -sets can be separated by G_δ -sets, therefore by Corollary 1, X has the weak B -.5-insertion property for

(cusB-.5, clsB-.5). Now suppose that f and g are real-valued functions on X with $g < f$, such that, g is cusB-.5 and f is clsB-.5. For every $n \in \mathbb{N}$, set

$$A(f - g, 3^{-n+1}) = \{x \in X : (f - g)(x) \leq 3^{-n+1}\}.$$

Since g is cusB-.5, and f is clsB-.5, therefore $f - g$ is clsB-.5. Hence $A(f - g, 3^{-n+1})$ is a F_σ -set of X . Consequently, $\{A(f - g, 3^{-n+1})\}$ is a decreasing sequence of F_σ -sets and furthermore since $0 < f - g$, it follows that

$$\bigcap_{n=1}^{\infty} A(f - g, 3^{-n+1}) = \emptyset.$$

Now by Lemma 4, there exists a decreasing sequence $\{D_n\}$ of G_δ -sets such that

$$A(f - g, 3^{-n+1}) \subseteq D_n$$

and

$$\bigcap_{n=1}^{\infty} D_n = \emptyset.$$

But by Lemma 3, $A(f - g, 3^{-n+1})$ and $X \setminus D_n$ of F_σ -sets can be completely separated by Baire-.5 functions. Hence by Theorem 2, there exists a Baire-.5 function h defined on X such that, $g < h < f$, i.e., X has the B -.5-insertion property for (cusB-.5, clsB-.5). \square

Remark 4. [15] A space X has the c -insertion property for (lsc, usc) iff X is extremally disconnected and if for any decreasing sequence $\{G_n\}$ of open subsets of X with empty intersection there exists a decreasing sequence $\{F_n\}$ of closed subsets of X with empty intersection such that $G_n \subseteq F_n$ for each n .

Corollary 4. For every G of G_δ -set, $F_\sigma(G)$ is a G_δ -set and in addition for every decreasing sequence $\{G_n\}$ of G_δ -sets with empty intersection, there exists a decreasing sequence $\{F_n\}$ of F_σ -sets with empty intersection such that for every $n \in \mathbb{N}$, $G_n \subseteq F_n$ if and only if X has the B -.5-insertion property for (clsB-.5, cusB-.5).

Proof. Since for every G of G_δ -set, $F_\sigma(G)$ is a G_δ -set, therefore by Corollary 2, X has the weak B -.5-insertion property for (clsB-.5, cusB-.5). Now suppose that f and g are real-valued functions defined on X with $g < f$, g is clsB-.5, and f is cusB-.5. Set

$$A(f - g, 3^{-n+1}) = \{x \in X : (f - g)(x) < 3^{-n+1}\}.$$

Then since $f - g$ is cusB-.5, hence $\{A(f - g, 3^{-n+1})\}$ is a decreasing sequence of G_δ -sets with empty intersection. By hypothesis, there exists a decreasing sequence $\{D_n\}$ of F_σ -sets with empty intersection such that, for every $n \in \mathbb{N}$, $A(f - g, 3^{-n+1}) \subseteq D_n$. Hence $X \setminus D_n$ and $A(f - g, 3^{-n+1})$ are two disjoint G_δ -sets and therefore by Lemma 1, we have

$$F_\sigma(A(f - g, 3^{-n+1})) \cap F_\sigma((X \setminus D_n)) = \emptyset$$

and therefore by Lemma 3, $X \setminus D_n$ and $A(f-g, 3^{-n+1})$ are completely separable by Baire-.5 functions. Therefore by Theorem 2, there exists a Baire-.5 function h on X such that, $g < h < f$, i.e., X has the B -.5-insertion property for (clsB-.5, cusB-.5).

On the other hand, suppose that G_1 and G_2 be two disjoint G_δ -sets. Since $G_1 \cap G_2 = \emptyset$. We have $G_2 \subseteq G_1^c$. We set $f(x) = 2$ for $x \in G_1^c$, $f(x) = \frac{1}{2}$ for $x \notin G_1^c$ and $g = \chi_{G_2}$.

Then since G_2 is a G_δ -set and G_1^c is a F_σ -set, we conclude that g is clsB-.5 and f is cusB-.5 and furthermore $g < f$. By hypothesis, there exists a Baire-.5 function h on X such that, $g < h < f$. Now we set

$$F_1 = \left\{ x \in X : h(x) \leq \frac{3}{4} \right\}$$

and

$$F_2 = \{x \in X : h(x) \geq 1\}.$$

Then F_1 and F_2 are two disjoint F_σ -sets contain G_1 and G_2 , respectively. Hence $F_\sigma(G_1) \subseteq F_1$ and $F_\sigma(G_2) \subseteq F_2$ and consequently $F_\sigma(G_1) \cap F_\sigma(G_2) = \emptyset$. By Lemma 1, for every G of G_δ -set, the set $F_\sigma(G)$ is a G_δ -set.

Now suppose that $\{G_n\}$ is a decreasing sequence of G_δ -sets with empty intersection.

We set $G_0 = X$ and $f(x) = \frac{1}{n+1}$ for $x \in G_n \setminus G_{n+1}$. Since $\bigcap_{n=0}^{\infty} G_n = \emptyset$ and for every $n \in \mathbb{N}$ there exists $x \in G_n \setminus G_{n+1}$, f is well-defined. Furthermore, for every $r \in \mathbb{R}$, if $r \leq 0$ then

$$\{x \in X : f(x) < r\} = \emptyset$$

is a G_δ -set and if $r > 0$ then by Archimedean property of \mathbb{R} , there exists $i \in \mathbb{N}$ such that $\frac{1}{i+1} \leq r$. Suppose that k is the least natural number with this property. Hence $\frac{1}{k} > r$. Now if $\frac{1}{k+1} < r$ then

$$\{x \in X : f(x) < r\} = G_k$$

is a G_δ -set and if $\frac{1}{k+1} = r$ then

$$\{x \in X : f(x) < r\} = G_{k+1}$$

is a G_δ -set. Hence f is a cusB-.5 on X . By setting $g = 0$, we have conclude that g is clsB-.5 on X and in addition $g < f$. By hypothesis there exists a Baire-.5 function h on X such that, $g < h < f$.

Set

$$F_n = \left\{ x \in X : h(x) \leq \frac{1}{n+1} \right\}.$$

This set is a F_σ -set. But for every $x \in G_n$, we have $f(x) \leq \frac{1}{n+1}$ and since $g < h < f$ thus $h(x) < \frac{1}{n+1}$, this means that $x \in F_n$ and consequently $G_n \subseteq F_n$.

By definition of F_n , $\{F_n\}$ is a decreasing sequence of F_σ -sets and since $h > 0$, $\bigcap_{n=1}^{\infty} F_n = \emptyset$. Thus the conditions holds. \square

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Received: 15 May 2018

Accepted for publication: 7 July 2019

Communicated by: Karl Dilcher