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Research paper

On gg-Separation Axioms in Topological Spaces

Govardhana Reddy H G[1]*, Basavaraj M. Ittanagi[2]

[1]Department of Mathematics, Alliance College of Engineering and Design, Alliance University, Bangalore-562106, India
[2]Department of Mathematics, Siddaganga Institute of Technology, Tumakuru-572103, India
**Corresponding author E-mail: govardhana.reddy@alliance.edu.in*

Abstract

Study and investigate a class of separation axiom namely gg-T_k space (k=0, 1, 2), gg-regular and gg-normal space. Meanwhile, some of their properties are obtained.

Keywords: *gg-T_k spaces (K=0, 1, 2), gg-regular space and gg-normal space.*

1. Introduction

From the literature survey on separation axiom, we observed that there has been significant work on T_0 space, T_1 space, T_2 space, regular space and normal space. In 1980, R. C. Jain [5] introduced a new class of separation axioms namely δT_i space (i=0, 1, 2). Since then different types of separation axioms are investigated. Using g-closed sets of Levine [6], T. Noiri and Papa [7] and Sheik John [8] contributed their work in the field of separation axiom. Recently, Basavaraj M. Ittanagi [1], studied basic properties of gg-closed sets, gg-continuous functions and gg-closed maps in topological spaces. In present paper, gg-T_0, gg-T_1 and gg-T_2 spaces are studied. The relation with existing separation axioms is discussed.

2. Prerequisites

In study, (X, T_1), (Y, T_2) (or X, Y) denote topological spaces. Let g:X→Y (or simply g) always denote map. For B⊆X, int(B), cl(B), X-B or B^c represent interior, closure and complement of B respectively. The basic definitions required for this research work are listed below.

Definition 2.1 Let B ⊆ X. Then B is said to be
i) g-closed [5] if cl(B) ⊆ W whenever B ⊆ W and W is open.
ii) gg-closed [1] if gcl(B) ⊆ W whenever B ⊆ W and W is regular semiopen. Also, ggC(X) (resp. ggO(X)) always denote family of gg-closed (resp. gg-open) sets in X.
iii) δT_0 space [4] if for every explicit points p, q of X, q ∉ M, p ∈ M, or p ∉ M, q ∈ M, where M is a δ -open set of X.
iv) δT_1-space [4] if for every explicit points p, q of X, q ∉ M, p ∈ M and p ∉ N, q ∈ N where M and N are two δ-open sets of X.
v) δT_2 -space [4] if for every explicit points p, q of X, q ∉ H_1, p ∈ H_1 and p∉ H_2, q∈ H_2 where H_1, H_2 are two δ -open sets with $H_1 \neq H_2$.

Definition 2.2 A map g is known as gg-continuous [2](gg-irresolute[2]) if $f^{-1}(F)$ ∈ggC(X), ∀ closed(gg-closed)set F in Y.

3. gg-T_0, gg-T_1 and gg-T_2 Spaces

Definition 3.1 Let X be

i) gg-T_0 if for every explicit points p, q of X, q ∉ M, p ∈ M or p∉ M, q∈ M where M is an open set of X.

ii) gg-T_1 space if for every explicit points p, q of X, q ∉ M, p ∈ M and p ∉ N, q∈ N where N, M ∈ ggO(X) .

iii) gg-T_2 space (gg-Housdorff space) if for every explicit points p, q of X, q∉ H_1, p ∈ H_1 and p ∉ H_2, q ∈ H_2 where H_2, H_1 ∈ ggO(X) ∋ $H_2 \neq H_1$.

Theorem 3.2
i) If X is T_0, then X is gg-T_0
ii) If X is T_1, then X is gg-T_0 and gg-T_1
iii) If X is T_2, then X is gg-T_2
iv) If X is gg-T_1, then X is gg-T_0
v) If X is gg-T_2, then X is gg-T_1

Proof. i) Given, X is T_0 space. For distinct points of every pair p, q of X ∃ open set U where q ∉ U, p∈ U, or p∉ U, q ∈ U, Then U ∈ ggO(X) with q ∉ U, p ∈ U or p ∉ U, q ∈ U. Therefore X is gg-T_0 space.
Similarly we can prove ii), iii), iv) and v).

Example 3.3 Let X={n, m, l, k} and T_1={φ, { l, k}, { n, m}, X} be a topology on X. Then ggC(X)=P(X)=ggO(X).
Here (X, T_1) is a
(i) gg-T_0 space but not a T_0 space. For explicit points k, l of X, no open set M exist ∋ k∈ M, l∉ M or l∈ M, k∉ M.
(ii) gg-T_0 space but not a T_1 space. For explicit points k, l of X, no two open sets M and N exist ∋ k∈ M, l∉ M and l∈ N, k∉N.
(iii) gg-T_1 space but not a T_1 space. For explicit points k, l of X, no two open sets M and N exist ∋ k∈ M, l∉ M and l∈ N, k∉N.

(iv) gg-T_2 space but not a T_2 space. For explicit points k, l of X, no two distinct open sets H_1 and H_2 exist ∋ k∈ H_1, l∉ H_1 and l∈ H_2, k∉ H_2.

Theorem 3.4

1) If X is δT_0, then it is gg-T_0
2) If X is δT_1, then it is gg-T_1
3) If X is δT_2 , then it is gg-T_2.

Proof. Based on fact, every δ- open set is in ggO(X).

Remark 3.5 Converse of this theorem is untrue.

Example 3.6 Let T_1={φ, X, {l}, {m, n}} be a topology on X={n, m, l}. Then
ggO(X)=P(X)
δ-O(X)= { φ, X, {l}, {m, n}}
Here (X, T_1) is a
(1) gg-T_0 but not a δT_0 space. For explicit points m, n of X, no δ open set exist with n ∉ M, m ∈ M or m∉ M, n ∈ M
(2) gg-T_1 space but not a δT_1 space. For explicit points m, n of X, no two δ open sets M and N exist with n ∉ M, m ∈ M and m ∉ N, n ∈ N.
(3) gg-T_2 space but not a δT_2 space. For explicit points m, n of X, no two distinct δ-open sets H_1 and H_2 exist with m ∈ H_1, n ∉ H_1 and n ∈ H_2, m ∉ H_2.

Theorem 3.7 Let X is gg-T_0 iff ggcl{x_1}≠ ggcl{x_2}, ∀ $x_1 \neq x_2$ of X.

Proof. Given that X is gg-T_0. Let x_2, x_1 ∈ X and x_2≠ x_1, then ∃ V∈ ggO(X), x_2 ∉ V and x_1 ∈ V implies x_1 ∉ V^c, x2 ∈ V^c. But ggcl{x_2} is the smallest gg-closed containing x_2. Therefore ggcl({y}) ⊆ V^c. Hence x ∉ ggcl{x_2}. Thus ggcl{x_1} ≠ ggcl{x_2}.
Conversely, suppose ggcl{x_1}≠ ggcl{x_2}, ∀ $x_1 \neq x_2$ of X. Let x_3 ∈ X with x_3∈ ggcl({x_1}) but x_3 ∉ ggcl({x_2}). If x ∈ ggcl({y}) then ggcl({x_1}) ⊆ ggcl({x_2}). Hence x_3 ∈ ggcl({x_2}). This contradicts our assumption. Thus x_1 ∉ ggcl({x_2}) implies x_1 ∈ $(\text{ggcl}(\{x_2\}))^c$ implies $(\text{ggcl}(\{x_2\}))^c$ is gg-open containing x_1 and not x_2. Therefore X is gg-T_0.

Theorem 3.8 If g is bijective, strongly gg-open and X is gg-T_0, then Y is gg-T_0 space.

Proof Take y_2 and y_1 of Y with $y_2 \neq y_1$. By hypothesis y_1= g(x_1) and y_2= g(x_2) where x_2 and x_1 are explicit points of X. By hypothesis, M∈ ggO(X) with x_1 ∈ M and x_2 ∉ M. Therefore g(x_1) ∈ g(M) and g(x_2) ∉ g(M). As X is strongly gg-open, g(M) ∈ ggO(Y). Therefore g(M) is gg-open set in Y with y_1 ∈ g(M) and y_2 ∉ g(M). Thus Y is a gg-T_0 space.

Theorem 3.9 If g is gg-irresolute, injective, Y is gg-T_0 then X is gg-T_0.

Proof. Take explicit points x_2 and x_1 of X. As g is injective implies g(x_1)≠ g(x_2). As Y is gg-T_0, exists U ∈ ggO(Y) such that g(x_1) ∈ U, g(x_2) ∉ U or exists a V∈ ggO(Y) such that g(x_1) ∉ V, g(x_2)∈ V with g(x_2)≠ g(x_1). Sine g is gg-irresolute then g^{-1}(U) ∈ ggO(X) ∋ x_2 ∉ g^{-1}(U), x_1 ∈ g^{-1}(U) or g^{-1}(V)∈ ggO(X) ∋ x_1 ∉ g^{-1}(V), x_2 ∈ g^{-1}(V). Hence X is gg-T_0.

Theorem 3.10 Let X is gg-T_1 iff x_2 ∈ X singleton {x_2}∈ ggC(X).

Proof Let X is gg-T_1, x_1 ∈ X. Then x_2 ∈ X-{x_1} ⇒ x_1≠ x_2∈ X. But X is gg-T_1 space implies their exist G_1, G_2 ∈ ggO(X) ∋ x_1 ∉ G_1, x_2 ∈ G_2 ⊆ (X-{x_1}). Also x_2 ∈ G_2 ⊆ (X-{x_1}) implies (X-{x_1})∈ggO(X). Thus {x_1} is gg-closed.

Conversely, Let x_1≠ x_2∈ X then {x_1} and {x_2} are gg-closed sets and $\{x_1\}^c$ is gg-open. Clearly x_1 ∉ $\{x_1\}^c$ and x_2 ∈ $\{x_1\}^c$. Similarly $\{x_2\}^c$ is gg-open, x_2 ∉ $\{x_2\}^c$ and x_1 ∈ $\{x_2\}^c$. Hence X is gg-T_1 space.

Theorem 3.11 The following results holds

i) If g is gg-continuous, injective, Y is T_1 space, imply X is gg-T_1.
ii) If g is gg-continuous, injective, Y is T_2 space, imply X is gg-T_2 space.
iii) If g is gg-irresolute, injective, Y is gg-T_2 space, imply X is gg-T_2 space.

Proof. i) Consider two points x_1, x_2 of X with x_2≠ x_1, then g(x_1)= y_1 and g(x_2)= y_2. Also, g(x_1) ≠ g(x_2). Since (Y, σ) is T_1 then y_1 ∈ M, y_2 ∉ M and y_1 ∉ N, y_2 ∈ N. Then x_1 ∈ g^{-1}(M), x_1 ∉ g^{-1}(N) and x_2 ∈ g^{-1} (N), x_2 ∉ g^{-1} (M). By the definition of gg-continuity, g^{-1}(M) and g^{-1}(N) ∈ ggO(X). For x_1, x_2 ∈ X with x_1 ≠ x_2, x_1 ∈ g^{-1}(M), x_1∉ g^{-1}(N) and x_2 ∉ g^{-1}(M), x_2 ∈ g^{-1}(N). Therefore (X, T_1) is gg-T_1 space.
Similarly we can prove ii) and iii)

Theorem 3.12 The statements given below are equivalent.
1) X is gg-T_2
2) If x_1 ∈ X, then x_2 ≠ x_1, ∃ W containing x_1 ∋ x_2 ∉ ggcl(W).

Proof. (1) ⟹ (2)
Take x_1 ∈ X and x_2 ∈ X with x_1 ≠ x_2, ∃ disjoint sets W, V∈ ggO(X) ∋ x_1 ∈ W and x_2 ∈ V. Then x_1 ∈ W⊆ V^c and V^c ∈ ggC(X) and x_2 ∉ V^c. Thus x_2 ∉ ggcl(W).

(2) ⟹ (1)
Let x_1, x_2 ∈ X with x_1≠ x_2. By (ii), ∃ gg-open W containing x_1 ∋ x_2 ∉ ggcl(W) implies x_2 ∈ (X-(ggcl(W))). (X-(ggcl(W))) ∈ ggO(X) and x_1 ∉ (X-(ggcl(W))). Also W∩ (X-ggcl(W))=φ. Thus X is gg-T_2.

4. gg-Regular Space

Definition 4.1 Let X is known as gg-regular if ∀ F∈ ggC(X) and x∉ F, ∃ disjoint open sets G and H ∋ F⊆ G, x∈ H.
We have the following relationship between gg-regularity and regularity.

Theorem 4.2 Every gg-regular space is regular.

Proof. Given that X is gg-regular. Take F∈ ggC(X) and x ∉ F. As X is gg-regular, ∃ a pair of disjoint open sets U and V ∋ F ⊆ U and x ∈ V. Hence X is a regular.

Remark 4.3 Every regular space is not a gg-regular space.

Example 4.4 Let T_1={φ, {k}, {m, l}, X} be topology on X={m, l, k}. Here (X, T_1) is regular but not a gg-regular space. For the gg-closed set {l} with m ∉ {l}, no two disjoint open sets U, H exist ∋ {l} ⊆ U, m ∈ H.

Theorem 4.5 Every regular with ggTc space is gg-regular.

Proof. Given that X is regular, ggTc . Let F ∈ ggC(X) and x ∈ X ∋ x ∉ F. Now X is ggTc space, F is closed, x ∉ F. As X is regular, ∃ pair of disjoint open sets M and N ∋ F⊆ M and x ∈ N. Therefore X is gg regular.

Theorem 4.6 If X is gg-regular then it is g-regular space.

Proof. Based on the fact, every g-closed belongs to ggC(X).

Theorem 4.7 If X is gg-regular, then it is w regular space.

Proof. Based on fact, each w closed belongs to ggC(X).

Theorem 4.8 The statements given below are equivalent.
1) X is gg-regular
2) ∀ x∈ X and each gg-open nbhd U ∃ an open nbhd N of X ∋ cl(N) ⊆ U.

Proof.
(1) ⟹ (2)
Let U be gg-neighbourhood of x, ∃ a G ∈ ggO(X) ∋ x ∈ G ⊆ U. Now G^c ∈ ggC(X) and x ∉ G^c. From (1), ∃ P, Q ∋ G^c ⊆ P, x ∈ Q, P∩ Q=φ. So Q ⊆ M^c. Now cl(Q) ⊆ cl(p^c)= G^c and G^c ⊆ P. This implies (P^c ⊆ G ⊆ U. Therefore cl(Q) ⊆ U.
(2) ⟹ (1)
Let gg-closed F in X and x ∉ F or x ∈ F^c and X is gg-open and so F^c is a gg-nbhd of x. By hypothesis, ∃ an open nbhd N ∋ x ∈ N, cl(N) ⊆ F^c. This implies F ⊆ {X-cl(N)} and N∩{(X-cl(N))} = φ. Thus X is gg-regular.

Theorem 4.9 Let X is gg-regular iff for every G ∈ ggC(X) and point p ∈ (X-G) then x ∈ U, G ⊆ N and cl(N) ∩ cl(U)= φ where N and U are open sets.

Proof. Given that X is gg-regular. Let G ∈ ggC(X) and x ∉ G. Then p ∈ M and G ⊆ N and M∩ N=φ where M and N are open sets. This implies M∩cl(N)=φ. Since (X, T_1) is gg-regular, p ∈ P and cl(N)⊆ Q, P∩N=φ where P, Q are open. Also cl(P)∩ Q= φ. Let U =M∩P then p ∈ U, G ⊆ N and cl(N) ∩ cl(U) = φ where N, U are open in X.
Conversely, suppose ∀ G ∈ ggC(X) and p ∈ (X-G), we have p ∈ U, G ⊆ N and cl(N)∩cl(U)= φ where N and U are open sets. This implies p ∈ U, G ⊆ N and U∩N= φ. Therefore (X, T_1) is gg-regular.

Theorem 4.10 A subspace Y of gg-regular (X, T_1) is gg-regular.

Proof. Obvious.

Theorem 4.11 Let g is bijective, gg-irresolute and open map from gg-regular X in to Y, then Y is gg-regular.

Proof Take y ∈ Y and F ∈ ggC(X) with y ∉ F. As g is gg-irresolute then g^{-1}(F) ∈ ggC(X). Let y=g(x) then g^{-1}(y)=x and x ∉ g^{-1}(F). Again X is gg-regular, ∃ open sets P and Q ∋ x ∈ P and g^{-1}(F) ⊆ Q, P∩ Q=φ. Given g is open and bijective implies y ∈ g(P), F ⊆ g(Q) and g(Q∩P)=g(φ)= φ. Thus Y is gg-regular.

Theorem 4.12 Let g be bijective, gg-closed map from X into gg-regular Y. If X is ggTc , then it is gg-regular

Proof. Consider x ∈ X, F ∈ ggC(X) with x ∉ F. Then F is closed. Also g is gg-closed implies g(F) ∈ ggC(Y) with g(x) ∉ g(F) in Y. As Y is gg-regular, ∃ P, Q ∋ p ∈ R and g(x) ∈ P and g(F) ⊆ Q. Therefore x ∈ g^{-1}(P) and F ⊆ g^{-1}(Q). Hence X is gg-regular space.

5. gg-Normal Space

Definition 5.1 Let X is known as gg-normal if for each pair D, C ∈ ggC(X), ∃ disjoint open sets P, Q in X ∋ C ⊆ P and D ⊆ Q.

Theorem 5.2 Every gg-normal is normal

Proof. Given that X is a gg-normal. Consider closed D, C which are disjoint in X. Then D, C ∈ ggC(X). Since X is gg-normal, ∃ a pair G, H ∋ C ⊆ G, D ⊆ H. Hence X is normal.

Example 5.3 Let T_1={φ, {l}, {k}, {l, k}, {k, m}, X} be a topology on X={m, k, l}. Here X is normal and not gg-normal. For the disjoint gg-closed sets {m} and {k, l} does not exist disjoint open sets P and Q.

Theorem 5.4 If Y is normal, ggTc space, then Y is gg-normal.

Proof. Given Y is normal. Let a pair of disjoint sets C, D ∈ ggC(Y). Since ggTc space, then C and D are closed. As Y is normal, ∃ a pair of disjoint open sets P, Q in Y ∋, C ⊆ P and D ⊆ Q. Hence Y is gg-normal.

Theorem 5.5 Every gg-normal is g-normal.

Proof. Given X is gg-normal. Let pair of disjoint sets C, D ∈ ggC(Y). Then ∃ a pair of disjoint P, Q ∋ C ⊆ P and D ⊆ Q. Hence X is g-normal.

Remark 5.6 Every g-normal is not a gg-normal

Example 5.7 Let T_1={φ, {l}, {k}, {k, l}, {k, m}, X} be a topology on X={m, l, k}. Here (X, T_1) is g normal and not a gg-normal space. For the disjoint gg-closed sets {m} and {k, l} does not exist P, Q.

Theorem 5.8 Every gg-normal is w-normal.

Proof. Similar as Theorem 5.5

Remark 5.9 In general, converse is untrue

Example 5.10 Let T_1={φ, {l}, {k}, {k, l}, {m, k}, X} be a topology on X={m, l, k}. Here (X, T_1) is w normal and not a gg-normal space. For the disjoint gg-closed sets {m} and {k, l} does not exist P, Q.

Theorem 5.11 If Y is gg-closed subspace of gg-normal X, then Y is is gg-normal.

Proof. Let X be gg-normal and Y is gg-closed subspace. Let a pair of disjoint sets C, D ∈ ggC(Y). Then ∃ G, H ∈ X ∋ C ⊆ G and D ⊆ H. Then G∩Y and H∩Y are open in Y. Also we have C ⊆ G and D ⊆ H implies C∩Y ⊆ Y∩G and Y∩D ⊆ Y∩H and (G∩Y) ∩ (Y∩H)= Y∩(G∩H)=φ. Hence Y is gg-normal.

Theorem 5.12 Statements given below are equivalent in (X, T_1).
1) X is gg-normal
2) For each C ∈ ggC(X) and each M ∈ ggO(X) with C ⊆ M then C ⊆ N ⊆ cl(N) ⊆ M where N is an open set.
3) For any disjoint sets C, D ∈ ggC(X), ∃ an open set N ∋ C ⊆ N and cl(N)∩D= φ
4) For each disjoint sets C, D ∈ ggC(X), ∃ open sets M, N ∋ C ⊆ M, D ⊆ N, cl(M)∩cl(N)= φ.

Proof. (1)⟹(2)
Take C ∈ ggC(X), M ∈ ggO(X) ∋ C ⊆ M. This implies C and (X-M) are two disjoint sets of ggC(X). By the definition of gg-normal, C ⊆ N and (X-M) ⊆ O where N and O are disjoint open sets. Thuss N ⊆ (X-O) and O∩N=φ. This implies N ⊆ (X-O) and cl(N) ⊆ (X-O)⊆ M and so cl(N) ⊆ M. Therefore C ⊆ N ⊆ cl(N)⊆ M.
(2)⟹(3)
Let a pair of disjoint sets D, C ∈ ggC(X), C ⊆ (X-D) where C and (X-D) are gg-closed and gg-open sets in X respectively. By (2) there exist an open set N with C ⊆ N ⊆ cl(N) ⊆ (X-D). But cl(N) ⊆ (X-D) implies D ∩ cl(N)=φ. Therefore C ⊆ N and cl(N) ⊆ D=φ.
(3)⟹(4)

Consider two disjoint gg-closed sets C and D in X. Then from (3), ∃ an open set M ∋ C ⊆ M and cl(M)∩D=φ. But cl(M) is closed and hence gg-closed set in X. Now cl(M), D belongs to ggC(X). By (3), we have D ⊆ N and cl(M)∩cl(N)= φ where N is open set exist in X.

(4)⟹(1)

Consider two disjoint gg-closed C, D in X. By hypothesis ∃ open sets N, M with C ⊆ M, D ⊆ N, cl(M)∩cl(N)= φ. This implies that C ⊆ M, D ⊆ N. Therefore X is gg-normal.

Theorem 5.13 A map g is bijective open, gg-irresolute from gg-normal X on to Y, then Y is gg-normal.

Proof. Take A, B in ggC(X), which are disjoint. As g is gg-irresolute then $g^{-1}(A)$ and $g^{-1}(B)$ are in ggC(X). As X is gg-normal $g^{-1}(A)$ ⊆ M and $g^{-1}(B)$ ⊆ N where M and N are open sets exist in X. Further, as g is bijective and open, g(M) and g(N) are open with A ⊆ g(M), B ⊆ g(N). Therefore Y is gg-normal.

Theorem 5.14 The statements given below are equivalent in X

(1) X is g-normal

(2) For each disjoint closed sets C, D, ∃ disjoint sets M, N ∈ ggO(X) ∋ C ⊆ M, D ⊆ N.

Proof. (i) ⟹ (ii)

Suppose X is g-normal. Let disjoint closed C, D of X. As (X, T_1) is g-normal then ∃ disjoint g-open sets M, N ∋ C ⊆ M, D ⊆ N.. Then M, N ∈ ggO(X) with C ⊆ M, D ⊆ N and M∩N= φ.

(ii) ⟹ (i)

Consider two disjoint gg-closed sets C, D ∈ ggC(X). By hypothesis C ⊆ M, D ⊆ N and N∩M= φ where N, M are disjoint sets in ggO(X). We know that C ⊆ gint(M), D ⊆ gint(N) and gint(M)∩ gint(N) = φ. Therefore (X, T_1) is g-normal.

6. Conclusion

A new class of separation axioms called gg-separation axioms are introduced and studied in (X, T). The relations between gg-separation axioms with existing separation axioms are discussed. The useful results on gg-regular and gg-normal spaces are also presented.

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