

A Decomposition of m -Continuity

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Abstract

By using an m -space (X, m_X) , we define the notions of gm -closed sets and m -lc-sets and obtain a decomposition of m -continuity. Then, the decomposition provides a kind of decomposition of weak forms of continuity.

Keywords: m -structure, m -space, gm -closed, g -closed, m -lc set, locally closed set, decompositions of weak forms of continuity.

Introduction

It is known that the notion of decomposition of continuity is important in General Topology. Therefore, many authors [12], [16], [18], [19], [37], [30], [35] and others studied on this subject in General Topology.

In 1970, Levine [21] introduced the notion of generalized closed (g -closed) sets in topological spaces. Among many modifications of g closed sets, the notions of αg -closed [22] (resp. gs -closed [6], gp -closed [28], γg -closed [14], gsp -closed [9]) sets are investigated by using α -open (resp. semi-open, preopen, b -open, semi-preopen) sets.

The present authors [31], [32] introduced and investigated the notions of m -structures, m -spaces and m -continuity. In [27], Noiri introduced the notion of generalized m -closed (gm -closed) sets and tried to construct the unified theory of the notions containing αg -closed sets, gs -closed sets, gp -closed sets, γg -closed sets and gsp -closed sets.

In this paper, we introduce the notion of m -lc sets as a modification of locally closed sets. By using the notions of gm -closed sets and m -lc sets, we obtain a decomposition of m -continuity. Then, the decomposition provides a decomposition of weak forms of continuity (semi-continuity, precontinuity, β -continuity etc).

Preliminaries

Let (X, τ) be a topological space and A a subset of X . The closure of A and the interior of A are denoted by $Cl(A)$ and $Int(A)$, respectively.

Definition 2.1. A subset A of a topological space (X, τ) is said to be *semi-open* [20] (resp. *preopen* [24], *α -open* [26], *b -open* [4], *β -open* [1] or *semi-preopen* [3]) if $A \subset \text{Cl}(\text{Int}A)$ (resp. $A \subset \text{Int}(\text{Cl}(A))$, $A \subset \text{Int}(\text{Cl}(\text{Int}(A)))$, $A \subset \text{Cl}(\text{Int}(A)) \cup \text{Int}(\text{Cl}(A))$, $A \subset \text{Cl}(\text{Int}(\text{Cl}(A)))$).

The family of all semi-open (resp. preopen, α -open, b -open, β -open) sets in (X, τ) is denoted by $\text{SO}(X)$ (resp. $\text{PO}(X)$, $\alpha(X)$, $\text{BO}(X)$, $\beta(X)$).

Definition 2.2. The complement of a semi-open (resp. preopen, α -open, β -open, semi-preopen, b -open) set is said to be *semi-closed* [8] (resp. *preclosed* [13], *α -closed* [25], *β -closed* [1], *semi-preclosed* [3], *b -closed* [4]).

Definition 2.3. The intersection of all semi-closed (resp. preclosed, α -closed, β -closed, semi-preclosed, b -closed) sets of X containing A is called the *semi-closure* [8] (resp. *preclosure* [13], *α -closure* [25], *β -closure* [2], *semi-preclosure* [3], *b -closure* [4]) of A and is denoted by $\text{sCl}(A)$ (resp. $\text{pCl}(A)$, $\alpha\text{Cl}(A)$, $\beta\text{Cl}(A)$, $\text{spCl}(A)$, $\text{bCl}(A)$).

Definition 2.4. The union of all semi-open (resp. preopen, α -open, β -open, semi-preopen, b -open) sets of X contained in A is called the *semi-interior* (resp. *preinterior*, *α -interior*, *β -interior*, *semi-preinterior*, *b -interior*) of A and is denoted by $\text{sInt}(A)$ (resp. $\text{pInt}(A)$, $\alpha\text{Int}(A)$, $\beta\text{Int}(A)$, $\text{spInt}(A)$, $\text{bInt}(A)$).

Definition 2.5. Let (X, τ) be a topological space. A subset A of X is said to be

- (1) *g -closed* [21] if $\text{Cl}(A) \subset U$ whenever $A \subset U$ and $U \in \tau$,
- (2) *αg -closed* [22] if $\alpha\text{Cl}(A) \subset U$ whenever $A \subset U$ and $U \in \tau$,
- (3) *gs -closed* [6] if $\text{sCl}(A) \subset U$ whenever $A \subset U$ and $U \in \tau$,
- (4) *gp -closed* [28] if $\text{pCl}(A) \subset U$ whenever $A \subset U$ and $U \in \tau$,
- (5) *gb -closed* (or *γg -closed* [14]) if $\text{bCl}(A) \subset U$ whenever $A \subset U$ and $U \in \tau$,
- (6) *gsp -closed* (or *$g\beta$ -closed*) [9] if $\text{spCl}(A) \subset U$ whenever $A \subset U$ and $U \in \tau$.

Definition 2.6. Let (X, τ) be a topological space. A subset A is called a *locally closed* set (briefly *LC-set*) [7], [15] (resp. *B -set* [36], *A_7 -set* [37], *η -set* [30], *BC -set* [19], *C -set* [18]) if $A = U \cap F$, where U is open and F is closed (resp. semi-closed, preclosed, α -closed, b -closed, semi-preclosed).

Throughout the present paper, (X, τ) and (Y, σ) always denote topological spaces and $f : (X, \tau) \rightarrow (Y, \sigma)$ presents a function.

Definition 2.7. A function $f : (X, \tau) \rightarrow (Y, \sigma)$ is said to be *semi-continuous* [20] (resp. *precontinuous* [24], *α -continuous* [25], *b -continuous* [4], *β -continuous* [1]) if $f^{-1}(V)$ is a semi-open (resp. preopen, α -open, b -open, β -open) set in (X, τ) for each open set V of (Y, σ) .

Definition 2.8. A function $f : (X, \tau) \rightarrow (Y, \sigma)$ is said to be *g -continuous* [5] (resp. *gs -continuous* [11], *gp -continuous* [28], *αg -continuous* [22], *γg -continuous* [14], *gsp -continuous* [9]) if $f^{-1}(F)$ is *g -closed* (resp. *gs -closed*, *gp -closed*, *αg -closed*, *γg -closed*, *gsp -closed*) in (X, τ) for every closed set F of (Y, σ) .

m -Continuity

Definition 3.1. A subfamily m_X of the power set $\mathcal{P}(X)$ of a nonempty set X is called a *minimal structure* (briefly *m -structure*) [31], [32] on X if $\emptyset \in m_X$ and $X \in m_X$.

By (X, m_X) , we denote a nonempty set X with a minimal structure m_X on X and call it an *m -space*. Each member of m_X is said to be *m_X -open* and the complement of a m_X -open set is said to be *m_X -closed*.

Remark 3.1. Let (X, τ) be a topological space. Then the families τ , $\text{SO}(X)$, $\text{PO}(X)$, $\alpha(X)$, $\text{BO}(X)$ and $\beta(X)$ are all m -structures on X .

Definition 3.2. Let X be a nonempty set and m_X an m -structure on X . For a subset A of X , the m_X -closure of A and the m_X -interior of A are defined in [23] as follows:

- (1) $m_X\text{-Cl}(A) = \cap\{F : A \subset F, X - F \in m_X\}$,
- (2) $m_X\text{-Int}(A) = \cup\{U : U \subset A, U \in m_X\}$.

Remark 3.2. Let (X, τ) be a topological space and A be a subset of X . If $m_X = \tau$ (resp. $\text{SO}(X)$, $\text{PO}(X)$, $\alpha(X)$, $\beta(X)$, $\text{BO}(X)$), then we have

- (1) $m_X\text{-Cl}(A) = \text{Cl}(A)$ (resp. $s\text{Cl}(A)$, $p\text{Cl}(A)$, $\alpha\text{Cl}(A)$, $\beta\text{Cl}(A)$, $b\text{Cl}(A)$),
- (2) $m_X\text{-Int}(A) = \text{Int}(A)$ (resp. $s\text{Int}(A)$, $p\text{Int}(A)$, $\alpha\text{Int}(A)$, $\beta\text{Int}(A)$, $b\text{Int}(A)$).

Lemma 3.1 (Maki et al. [23]). Let (X, m_X) be an m -space. For subsets A and B of X , the following properties hold:

- (1) $m_X\text{-Cl}(X - A) = X - m_X\text{-Int}(A)$ and $m_X\text{-Int}(X - A) = X - m_X\text{-Cl}(A)$,
- (2) If $(X - A) \in m_X$, then $m_X\text{-Cl}(A) = A$ and if $A \in m_X$, then $m_X\text{-Int}(A) = A$,
- (3) $m_X\text{-Cl}(\emptyset) = \emptyset$, $m_X\text{-Cl}(X) = X$, $m_X\text{-Int}(\emptyset) = \emptyset$ and $m_X\text{-Int}(X) = X$,
- (4) If $A \subset B$, then $m_X\text{-Cl}(A) \subset m_X\text{-Cl}(B)$ and $m_X\text{-Int}(A) \subset m_X\text{-Int}(B)$,
- (5) $A \subset m_X\text{-Cl}(A)$ and $m_X\text{-Int}(A) \subset A$,
- (6) $m_X\text{-Cl}(m_X\text{-Cl}(A)) = m_X\text{-Cl}(A)$ and $m_X\text{-Int}(m_X\text{-Int}(A)) = m_X\text{-Int}(A)$.

Definition 3.3. A minimal structure m_X on a nonempty set X is said to have *property \mathcal{B}* [23] if the union of any family of subsets belonging to m_X belongs to m_X .

Remark 3.3. Let (X, τ) be a topological space and $m_X = \text{SO}(X)$ (resp. $\text{PO}(X)$, $\alpha(X)$, $\beta(X)$, $\text{BO}(X)$), then m_X satisfies property \mathcal{B} .

Lemma 3.2 (Popa and Noiri [33]). Let (X, m_X) be an m -space and m_X satisfies property \mathcal{B} . Then for a subset A of X , the following properties hold:

- (1) $A \in m_X$ if and only if $m_X\text{-Int}(A) = A$,
- (2) A is m_X -closed if and only if $m_X\text{-Cl}(A) = A$,
- (3) $m_X\text{-Int}(A) \in m_X$ and $m_X\text{-Cl}(A)$ is m_X -closed.

Definition 3.4. Let (X, τ) be a topological space and m_X an m -structure on X . A subset A is said to be *generalized m -closed* (briefly *gm-closed*) [27] if $m_X\text{-Cl} A \subset U$ whenever $A \subset U$ and $U \in \tau$. The complement of a *gm-closed* set is said to be *gm-open*.

Remark 3.4. Let (X, τ) be a topological space and A a subset of X . If $m_X = \tau$ (resp. $\text{SO}(X)$, $\text{PO}(X)$, $\alpha(X)$, $\text{BO}(X)$, $\beta(X)$) and A is *gm-closed*, then A is *g-closed* (resp. *gs-closed*, *gp-closed*, *ag-closed*, *γg-closed*, *gsp-closed*).

Definition 3.5. Let (X, τ) be a topological space and m_X an m -structure on X . A subset A is called an *m -lc set* if $A = U \cap F$, where $U \in \tau$ and F is m_X -closed.

Remark 3.5. Let (X, τ) be a topological space and A a subset of X . If $m_X = \tau$ (resp. $\text{SO}(X)$, $\text{PO}(X)$, $\alpha(X)$, $\text{BO}(X)$, $\beta(X)$) and A is an *m -lc set*, then A is an *LC set* (resp. a *B-set*, an *A_7 -set*, an *η -set*, a *BC-set*, a *C-set*).

Definition 3.6. Let $f : X \rightarrow Y$ be a function, where X is a nonempty set with a minimal structure m_X and Y is a topological space. The function $f : X \rightarrow Y$ is said to be *m -continuous* [32] if for

each $x \in X$ and each open set V of Y containing $f(x)$, there exists a subset $U \in m_X$ containing x such that $f(U) \subset V$.

Lemma 3.3 (Popa and Noiri [32]). For a function $f : X \rightarrow Y$, where X is a nonempty set with a minimal structure m_X and Y is a topological space, the following properties are equivalent:

- (1) f is m -continuous;
- (2) $f^{-1}(V) = m_X\text{-Int}(f^{-1}(V))$ for every open set V of Y ;
- (3) $m_X\text{-Cl}(f^{-1}(F)) = f^{-1}(F)$ for every closed set F of Y .

Corollary 3.1. (Popa and Noiri [32]) Let X be a nonempty set with a minimal structure m_X satisfying property \mathcal{B} and Y a topological space. For a function $f : X \rightarrow Y$, the following are equivalent:

- (1) f is m -continuous;
- (2) $f^{-1}(V)$ is m_X -open in (X, m_X) for every open set V of Y ;
- (3) $f^{-1}(F)$ is m_X -closed in (X, m_X) for every closed set F of Y .

Remark 3.6. Let (X, τ) be a topological space and m_X an m -structure on X . If $f : (X, \tau) \rightarrow (Y, \sigma)$ is m -continuous and $m_X = \tau$ (resp. $\text{SO}(X)$, $\text{PO}(X)$, $\alpha(X)$, $\text{BO}(X)$, $\beta(X)$), then f is continuous (resp. semi-continuous, precontinuous, α -continuous, b -continuous, β -continuous).

Decompositions of m -continuity

Theorem 4.1. Let (X, τ) be a topological space and m_X a minimal structure on X having property \mathcal{B} . Then a subset A of X is m_X -closed if and only if it is gm -closed and an m -lc set.

Proof. Necessity: Suppose that A is m_X -closed in X . Let $A \subset U$ and $U \in \tau$. Since A is m_X -closed, by Lemma 3.2 $A = m_X\text{-Cl}(A)$ and hence $m_X\text{-Cl}(A) \subset U$. Therefore, A is gm -closed. Since $A = X \cap A$, A is an m -lc set.

Sufficiency: Suppose that A is gm -closed and an m -lc set. Since A is an m -lc set, $A = U \cap F$, where $U \in \tau$ and F is m_X -closed in X . Therefore, we have $A \subset U$ and $A \subset F$. By the hypothesis, we obtain $m_X\text{-Cl}(A) \subset U$ and $m_X\text{-Cl}(A) \subset F$ and hence $m_X\text{-Cl}(A) \subset U \cap F = A$. Thus, $m_X\text{-Cl}(A) = A$ and by Lemma 3.2 A is m_X -closed.

Corollary 4.1. Let A be a subset of a topological space (X, τ) . Then, the following properties hold:

- (1) A is closed if and only if A is g -closed and an LC -set.
- (2) A is semi-closed if and only if A is gs -closed and a B -set.
- (3) A is pre-closed if and only if A is gp -closed and an A_7 -set.
- (4) A is α -closed if and only if A is αg -closed and an η -set.
- (5) A is b -closed if and only if A is γg -closed and a BC -set.
- (6) A is β -closed if and only if A is gsp -closed and a C -set.

Definition 4.1. Let (X, τ) be a topological space and m_X a minimal structure on X . A function $f : (X, \tau) \rightarrow (Y, \sigma)$ is said to be

- (1) gm -continuous if $f^{-1}(F)$ is gm -closed in (X, τ) for each closed set F of (Y, σ) ,
- (2) contra m -lc-continuous if $f^{-1}(F)$ is an m -lc set of (X, τ) for each closed set F of (Y, σ) .

Remark 4.1. Let (X, τ) be a topological space and m_X an m -structure on X .

(2) δ - β -open [17](resp. θ - β -open [29]) if $A \subset \text{Cl}(\text{Int}(\text{Cl}_\delta(A)))$ (resp. $A \subset \text{Cl}(\text{Int}(\text{Cl}_\theta(A)))$).

By $\delta\text{PO}(X)$ (resp. $\delta\beta(X)$, $\theta\text{PO}(X)$, $\theta\beta(X)$), we denote the collection of all δ -preopen (resp. δ - β -open, θ -preopen, θ - β -open) sets of a topological space (X, τ) . These four collections are m -structures with property \mathcal{B} .

Definition 5.2. The complement of a δ -preopen (resp. θ -preopen, δ - β -open, θ - β -open) set is said to be δ -preclosed (resp. θ -preclosed, δ - β -closed, θ - β -closed).

Definition 5.3. Let (X, τ) be a topological space and A a subset of X . The intersection of all δ -preclosed (resp. θ -preclosed, δ - β -closed, θ - β -closed) sets of X containing A is called the δ -preclosure (resp. θ -preclosure, δ - β -closure, θ - β -closure) of A and is denoted by $\text{pCl}_\delta(A)$ (resp. $\text{pCl}_\theta(A)$, $\text{spCl}_\delta(A)$, $\text{spCl}_\theta(A)$).

For subsets of a topological space (X, τ) , we can define many new variations of g -closed sets. For example, in case $m_X = \delta\text{PO}(X)$, $\delta\beta(X)$, $\theta\text{PO}(X)$, $\theta\beta(X)$, we can define new types of g -closed sets as follows:

Definition 5.4. A subset A of a topological space (X, τ) is said to be $g\delta p$ -closed [19] (resp. $g\theta p$ -closed, $g\delta\beta$ -closed, $g\theta\beta$ -closed) if $\text{Cl}(A) \subset U$ whenever $A \subset U$ and U is δ -preopen (resp. θ -preopen, δ - β -open, θ - β -open) in (X, τ) .

Definition 5.5. A subset A of a topological space (X, τ) is called a δp -lc set or ξ -set [19] (resp. θp -lc set, $\delta\beta$ -lc set, $\theta\beta$ -lc set) if $A = U \cap F$, where U is open in (X, τ) and F is δp -closed (resp. θp -closed, δ - β -closed, θ - β -closed) in (X, τ) .

Corollary 5.1. For a subset A of a topological space (X, τ) , the following properties hold:

- (1) A is δ -preclosed if and only if A is $g\delta p$ -closed and a δp -lc set (Theorem 4 of [19]).
- (2) A is θ -preclosed if and only if A is $g\theta p$ -closed and a θp -lc set.
- (3) A is δ - β -closed if and only if A is $g\delta\beta$ -closed and a $\delta\beta$ -lc set.
- (4) A is θ - β -closed if and only if A is $g\theta\beta$ -closed and a $\theta\beta$ -lc set.

Proof. Let $m_X = \delta\text{PO}(X)$, $\theta\text{PO}(X)$, $\delta\beta(X)$ and $\theta\beta(X)$. Then this is an immediate consequence of Theorem 4.1.

By defining functions similarly to Definition 4.1, we obtain the following decompositions of weak forms of continuity:

Corollary 5.2. For a function $f : (X, \tau) \rightarrow (Y, \sigma)$, the following properties hold:

- (1) f is δ -precontinuous if and only if f is $g\delta p$ -continuous and δp -lc-continuous.
- (2) f is θ -precontinuous if and only if f is $g\theta p$ -continuous and θp -lc-continuous.
- (3) f is δ - β -continuous if and only if f is $g\delta\beta$ -continuous and $\delta\beta$ -lc-continuous.
- (4) f is θ - β -continuous if and only if f is $g\theta\beta$ -continuous and $\theta\beta$ -lc-continuous.

Proof. This is an immediate consequence of Theorem 4.2.

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O descompunere a m -continuității

Rezumat

Folosind un m -spațiu (X, m_X) , definim noțiunile de mulțimi gm -închise și de m -lc-mulțimi și obținem o descompunere a m -continuității. Această descompunere permite apoi obținerea unor descompuneri ale formelor slabe de continuitate.