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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$A \subset \mathrm{Cl}(\mathrm{Int}A))$ (resp. $A \subset \mathrm{Int}(\mathrm{Cl}(A))$, $A \subset \mathrm{Int}(\mathrm{Cl}(\mathrm{Int}(A)))$, $A \subset \mathrm{Cl}(\mathrm{Int}(A)) \cup \mathrm{Int}(\mathrm{Cl}(A))$, $A \subset \mathrm{Cl}(\mathrm{Int}(\mathrm{Cl}(A))))$.

The family of all semi-open (resp. preopen, α-open, b-open, β-open) sets in (X, τ) is denoted by SO(X) (resp. PO(X), $\alpha(X)$, 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 sCl(A) (resp. pCl(A), αCl(A), $_\beta$Cl(A), spCl(A), 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 sInt(A) (resp. pInt(A), αInt(A), $_\beta$Int(A), spInt(A), 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 Cl(A) $\subset U$ whenever $A \subset U$ and $U \in \tau$,

(2) *αg-closed* [22] if αCl(A) $\subset U$ whenever $A \subset U$ and $U \in \tau$,

(3) *gs-closed* [6] if sCl(A) $\subset U$ whenever $A \subset U$ and $U \in \tau$,

(4) *gp-closed* [28] if pCl(A) $\subset U$ whenever $A \subset U$ and $U \in \tau$,

(5) *gb-closed* (or γg-closed [14]) if bCl(A) $\subset U$ whenever $A \subset U$ and $U \in \tau$,

(6) *gsp-closed* (or *gβ-closed*) [9] if 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 $f : (X, \tau) \to (Y, \sigma)$ presents a function.

Definition 2.7. A function $f : (X, \tau) \to (Y, \sigma)$ 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 $f : (X, \tau) \to (Y, \sigma)$ 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-openset is said to be *m_X-closed*.

Remark 3.1. Let (X, τ) be a topological space. Then the families τ, SO(X), PO(X), $\alpha(X)$, 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-Cl(A) = $\cap\{F : A \subset F, X - F \in m_X\}$,

(2) m_X-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. SO(X), PO(X), $\alpha(X)$, $\beta(X)$, BO(X)), then we have

(1) m_X-Cl(A) = Cl(A) (resp. sCl(A), pCl(A), αCl(A, ${}_\beta$Cl(A), bCl(A)),

(2) m_X-Int(A) = Int(A) (resp. sInt(A), pInt(A), αInt(A), ${}_\beta$Int(A), bInt(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-$\mathrm{Cl}(X - A) = X - m_X$-$\mathrm{Int}(A)$ and m_X-$\mathrm{Int}(X - A) = X - m_X$-$\mathrm{Cl}(A)$,

(2) If $(X - A) \in m_X$, then m_X-$\mathrm{Cl}(A) = A$ and if $A \in m_X$, then m_X-$\mathrm{Int}(A) = A$,

(3) m_X-$\mathrm{Cl}(\emptyset) = \emptyset, m_X$-$\mathrm{Cl}(X) = X$, m_X-$\mathrm{Int}(\emptyset) = \emptyset$ and m_X-$\mathrm{Int}(X) = X$,

(4) If $A \subset B$, then m_X-$\mathrm{Cl}(A) \subset m_X$-$\mathrm{Cl}(B)$ and m_X-$\mathrm{Int}(A) \subset m_X$-$\mathrm{Int}(B)$,

(5) $A \subset m_X$-$\mathrm{Cl}(A)$ and m_X-$\mathrm{Int}(A) \subset A$,

(6) m_X-$\mathrm{Cl}(m_X$-$\mathrm{Cl}(A)) = m_X$-$\mathrm{Cl}(A)$ and m_X-$\mathrm{Int}(m_X$-$\mathrm{Int}(A)) = m_X$-$\mathrm{Int}(A)$.

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 = SO(X) (resp. PO(X), $\alpha(X)$, $\beta(X)$, 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-$\mathrm{Int}(A) = A$,

(2) A is m_X-closed if and only if m_X-$\mathrm{Cl}(A) = A$,

(3) m_X-$\mathrm{Int}(A) \in m_X$ and m_X-$\mathrm{Cl}(A)$ 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-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. SO(X), PO(X), $\alpha(X)$, BO(X), $\beta(X)$) and A is gm-closed, then A is g-closed (resp. gs-closed, gp-closed, αg-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. SO(X), PO(X), $\alpha(X)$, 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 $f : X \to Y$ be a function, where X is a nonempty set with a minimal structure m_X and Y is a topological space. The function $f : X \to Y$ 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 $f : X \to Y$, 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 $f : X \to Y$, 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 $f : (X, \tau) \to (Y, \sigma)$ is m-continuous and $m_X = \tau$ (resp. SO(X), PO(X), $\alpha(X)$, 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 $A = m_X$-Cl(A) and hence m_X-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-Cl(A) $\subset U$ and m_X-Cl(A) $\subset F$ and hence m_X-Cl(A) $\subset U \cap F = A$. Thus, m_X-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 $f : (X, \tau) \to (Y, \sigma)$ 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.

(1) If $m_X = \tau$ (resp. SO(X), PO(X), $\alpha(X)$, BO(X), $\beta(X)$) and $f : (X, \tau) \to (Y, \sigma)$ is gm-continuous, then we obtain Definition 2.8.

(2) If $m_X = \tau$ (resp. SO(X), PO(X), $\alpha(X)$, BO(X), $\beta(X)$) and $f : (X, \tau) \to (Y, \sigma)$ is contra m-lc-continuous, then f is said to be *contra LC-continuous* (resp. *contra B-continuous*, *contra* A_7*-continuous*, *contra* η*-continuous*, *contra BC-continuous*, *contra C-continuous*).

Theorem 4.2. Let (X, τ) be a topological space and m_X a minimal structure on X having property $\mathcal{B}$. Then a function $f : (X, \tau) \to (Y, \sigma)$ is m-continuous if and only if f is gm-continuous and contra m-lc-continuous.

Proof. This is an immediate consequence of Theorm 4.1 and Corollary 3.1.

Corollary 4.2. For a function $f : (X, \tau) \to (Y, \sigma)$, the following properties hold:

(1) f is continuous if and only if f is g-continuous and contra LC-continuous.

(2) f is semi-continuous if and only if f is gs-continuous and contra B-continuous.

(3) f is precontinuous if and only if f is gp-continuous and contra A_7-continuous. (4) f is α-continuous if and only if f is αg-continuous and contra η-continuous. (5) f is γg-continuous if and only if f is γg-continuous and contra BC-continuous. (6) f is β-continuous if and only if f is gsp-continuous and contra C-continuous.

Definition 4.2. A function $f : (X, \tau) \to (Y, \sigma)$ is said to be *contra-continuous* [10] if $f^{-1}(F)$ is open in (X, τ) for each closed set F of (Y, σ).

Theorem 4.3. Let (X, τ) be a topological space and m_X a minimal structure on X having property $\mathcal{B}$. Then, a contra continuous function $f : (X, \tau) \to (Y, \sigma)$ is m-continuous if and only if f is gm-continuous.

Proof. Suppose that f is contra continuous and gm-continuous. Let F be any closed set of (Y, σ). Since f is contra-continuous, $f^{-1}(F)$ is open in (X, τ) and hence an m-lc-set of (X, τ). Since f is gm-continuous, $f^{-1}(F)$ is gm-closed and hence, by Theorem 4.1, $f^1(F)$ is m-closed. Therefore, f is m-continuous. The converse is obvious.

Corollary 4.3. Let $f : (X, \tau) \to (Y, \sigma)$ be a contra-continuous function. Then the following properties hold:

(1) f is continuous if and only if f is g-continuous.

(2) f is semi-continuous if and only if f is gs-continuous.

(3) f is pre-continuous if and only if gp-continuous.

(4) f is α-continuous if and only if f is αg-continuous.

(5) f is b-continuous if and only if f is γg-continuous. (6) f is β-continuous if and only f is gsp-continuous.

New forms of decomposition of m-continuity

First, we recall the θ-closure and the δ-closure of a subset in a topological space. Let (X, τ) be a topological space and A a subset of X. A point $x \in X$ is called a θ-cluster (resp. δ-cluster) point of A if Cl(V) $\cap A \neq \emptyset$ (resp. Int(Cl(V)) $\cap A \neq \emptyset$) for every open set V containing x. The set of all θ-cluster (resp. δ-cluster) points of A is called the *θ-closure* (resp. *δ-closure*) of A and is denoted by Cl$_\theta(A)$ (resp. Cl$_\delta(A)$)[38].

Definition 5.1. A subset A of a topological space (X, τ) is said to be (1) *δ-preopen* [34] (resp. *θ-preopen* [29]) if $A \subset \mathrm{Int}(\mathrm{Cl}_\delta(A))$ (resp. $A \subset \mathrm{Int}(\mathrm{Cl}_\theta(A))$),

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

By δPO(X) (resp. $\delta\beta(X)$, θPO(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-preclose (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 pCl$_\delta(A)$ (resp. pCl$_\theta(A)$, spCl$_\delta(A)$, 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 $m_X = \ delta$PO(X), $\delta\beta(X)$, θPO(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*, *$g\delta sp$-closed*, *$g\theta sp$-closed*) if 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 gδp-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 $g\delta sp$-closed and a $\delta\beta$-lc set.

(4) A is θ-β-closed if and only if A is $g\theta sp$-closed and a $\theta\beta$-lc set.

Proof. Let m_X = δPO(X)), θPO(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 $f : (X, \tau) \to (Y, \sigma)$, the following properties hold:

(1) f is δ-precontinuous if and only if f is $g\delta p$-continuous and δplc-continuous.

(2) f is θ-precontinuous if and only if f is $g\theta p$-continuous and θplc-continuous.

(3) f is δ-β-continuous if and only if f is $g\delta sp$-continuous and $\delta\beta$-lc-continuous.

(4) f is θ-β-continuous if and only if f is $g\theta sp$-continuous and $\theta\beta$-lc-continuous.

Proof. This is an immediate consequence of Theorem 4.2.

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O descompunere a m-continuităţii

Rezumat

Folosind un m-spaţiu (X, m_X), definim noţiunile de mulţimi gm-închise si de m-lc-mulţimi şi obţinem o descompunere a m-continuităţii. Această descompunere permite apoi obţinerea unor descompuneri ale formelor slabe de continuitate.