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About Pre-Lindelöf Mappings

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ABSTRACT: A space can be regarded as a special case of a mapping by identifying the given space with its mapping to a point. This viewpoint leads to the idea of extending to mappings the notions and results established for spaces, which makes it possible to generalize certain results. In this paper, pre-Lindelöf mappings are introduced and studied. In particular, it is shown that if the mapping is pre-Lindelöf, then pre-Lindelöf property converse both to direction of image and to one of preimage.

Keywords: Uniform space, uniformly continuous mapping, pre-Lindelöf space, pre-Lindelöf mapping, uniform cover, topological group, homomorphism.

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1. Introduction

Throughout this paper all uniform spaces are assumed to be Hausdorff and mappings are uniformly continuous.

For systems α and β of a set X, we have: $\alpha \wedge \beta = \{A \bigcap B : A \in \alpha, B \in \beta\}$. $\alpha(x) = \bigcup St(\alpha, x)$, $St(\alpha, x) = \{A \in \alpha : A \ni x\}$, $x \in X$, $\alpha(H) = \bigcup St(\alpha, H)$, $St(\alpha, H) = \{A \in \alpha : A \bigcap H \neq \varnothing\}$, $H \subset X$. For systems α and β of the set X, the symbol $\alpha \succ \beta$ means that the system α is a refinement of the system β, i.e. for any $A \in \alpha$ there exists $B \in \beta$ such that $A \subset B$ and, the symbol $\alpha * \succ \beta$ means that the system α is a strongly star refinement of the system β, i.e. for any $A \in \alpha$ there exists $B \in \beta$ such that $\alpha(A) \subset B$.

A uniformity on a nonempty set X is a family U of covers of X which satisfies the following conditions:

$U1$. If $\alpha \in U$ and if β is a cover of X such that $\alpha \succ \beta$, then $\beta \in U$.

$U2$. If $\alpha_1, \alpha_2 \in U$, then there exists $\alpha \in U$ such that $\alpha \succ \alpha_1$ and $\alpha \succ \alpha_2$.

$U3$. If $\alpha \in U$, then there exists $\beta \in U$ such that $\beta * \succ \alpha$.

$U4$. For any two distinct points $x, y \in X$ there is an $\alpha \in U$ such that no member of α contains both x and y, [1], [3].

The covers from U are called uniform covers, and the pair (X, U) a uniform space. If conditions $U1$-$U3$ are met, then U is called preuniformity [1], [3].

The topology on X generated by U, denoted $\tau_U = \{O \subset X : \forall x \in O \exists \alpha \in U : \alpha(x) \subset O\}$.

A uniform space (X, U) is called precompact if it has a base consisting of finite covers [1], [3]; a uniform space (X, U) is called pre-Lindelöf if it has a base consisting of countable covers [1], [3].

A mapping $f : (X, U) \to (Y, V)$ of uniform space (X, U) onto uniform space (Y, V) is called a uniformly continuous, if for any $\beta \in U$ there exists $\alpha \in U$ such that $f\alpha \succ \beta$ [1]; a preuniformity $U_f \subset U$, is called a base of a uniformly continuous mapping f, if for each uniform cover $\alpha \in U$ there exist $\beta \in V$ and $\gamma \in U_f$ such that $f^{-1}\beta \wedge \gamma \succ \alpha$ [1]; a uniformly continuous mapping $f : (X, U) \to (Y, V)$ of uniform space (X, U) onto uniform space (Y, V) is called a perfect, if it is closed and f^{-1} is compact for any $y \in Y$ [1]; a uniformly continuous mapping $f : (X, U) \to (Y, V)$ of uniform space (X, U) onto a uniform space (Y, V) is called a precompact, if for each $\alpha \in U$ there exists a uniform cover $\beta \in V$ and finite uniform cover $\gamma \in U$, such that $f^{-1}\beta \wedge \gamma \succ \alpha$ [1]; a uniformly continuous mapping $f : (X, U) \to (Y, V)$ of uniform space (X, U) onto a uniform space (Y, V) is called a uniformly perfect, if it is both precompact and perfect [1].

If U and V are two uniformities on a set X and $U \subset V$, then we say that the uniformity V is finer than the uniformity and U.

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2. About Pre-Lindelöf Mappings

Let $f : (X, U) \to (Y, V)$ be a uniformly continuous mapping of a uniform space (X, U) to a uniform space (Y, V).

Definition 2.1 *A uniformly continuous mapping f is called a pre-Lindelöf mapping if for any uniform cover $\alpha \in U$ there exists a uniform cover $\beta \in V$ and a countable uniform cover $\gamma \in U$ such that $f^{-1}\beta \wedge \gamma \succ \alpha$. In other words, the mapping $f : (X, U) \to (Y, V)$ has a base U_f consisting of countable covers.*

Any precompact mapping is pre-Lindelöf.

Proposition 2.1 *If a uniformly continuous mapping $f : (X, U) \to (Y, V)$ of a uniform space (X, U) to a uniform space (Y, V) and a uniformly continuous mapping $g : (Y, V) \to (Z, W)$ of a uniform space (Y, V) to a uniform space (Z, W) are both pre-Lindelöf mappings, then their composition $g \circ f : (X, U) \to (Z, W)$ is also a pre-Lindelöf mapping.*

Proof: Let $f : (X, U) \to (Y, V)$ and $g : (Y, V) \to (Z, W)$ be a pre-Lindelöf uniformly continuous mappings and $\alpha \in U$ be an arbitrary uniform cover. Then there exists a countable uniform cover $\gamma \in U$ and uniform cover $\beta \in V$ such that $f^{-1}\beta \wedge \gamma \succ \alpha$. Then there exists a countable uniform cover $\eta \in V$ and uniform cover $\mu \in W$ such that $g^{-1}\mu \wedge \eta \succ \beta$. Hence, $f^{-1}(g^{-1}\mu \wedge \eta) \wedge \gamma \succ f^{-1}\beta \wedge \gamma$, where $f^{-1}\eta \wedge \gamma$ is a countable uniform cover. Therefore, $g \circ f : (X, U) \to (Z, W)$ is a pre-Lindelöf mapping. □

Corollary 2.1 *If a uniformly continuous mapping $f : (X, U) \to (Y, V)$ of a uniform space (X, U) to a uniform space (Y, V) and a uniformly continuous mapping $g : (Y, V) \to (Z, W)$ of a uniform space (Y, V) to a uniform space (Z, W) are both precompact mappings, then their composition $g \circ f : (X, U) \to (Z, W)$ is also a precompact mapping.*

It is easily proved the following proposition.

Proposition 2.2 *Let $f : (X, U) \to (Y, V)$ and $g : (Y, V) \to (Z, W)$ be a uniformly continuous mappings. If composition $g \circ f : (X, U) \to (Z, W)$ is pre-Lindelöf, then $f : (X, U) \to (Y, V)$ is pre-Lindelöf.*

Corollary 2.2 *Let $f : (X, U) \to (Y, V)$ and $g : (Y, V) \to (Z, W)$ be a uniformly continuous mappings. If composition $g \circ f : (X, U) \to (Z, W)$ is precompact, then $f : (X, U) \to (Y, V)$ is precompact.*

Proposition 2.3 *Any uniformly continuous mapping $f : (X, U) \to (Y, V)$ of a pre-Lindelöf uniform space (X, U) onto a uniform space (Y, V) is a pre-Lindelöf mapping.*

Proof: Let $f : (X, U) \to (Y, V)$ be a uniformly continuous mapping of a pre-Lindelöf uniform space (X, U) onto a uniform space (Y, V). Take an arbitrary uniform cover $\alpha \in U$. Then, by the pre-Lindelöfness of the space (X, U), there exists a countable uniform cover $\gamma \in U$ such that $\gamma \succ \alpha$. Due to the uniformly continuity of the mapping $f : (X, U) \to (Y, V)$, the preimage $f^{-1}\beta$ of the uniform cover $\beta \in V$ is also a uniform cover. It is easy to see that $f^{-1}\beta \wedge \gamma \succ \alpha$. Hence, f is pre-Lindelöf. □

Corollary 2.3 *Any uniformly continuous mapping $f : (X, U) \to (Y, V)$ of a precompact uniform space (X, U) onto a uniform space (Y, V) is a precompact mapping.*

Theorem 2.1 *Let $f : (X, U) \to (Y, V)$ be a pre-Lindelöf mapping of a uniform space (X, U) onto a uniform space (Y, V). Then pre-Lindelöfness converse both to direction of image and to one of preimage.*

Proof: Let $\beta \in V$ be an arbitrary uniform cover. Then $f^{-1}\beta \in U$. Put $\alpha = f^{-1}\beta$. By virtue of the pre-Lindelöf property of the space (X, U), the uniform cover α contains a countable subcover α_0. It follows that $f\alpha_0 = \{fA_1 = B_1, ..., fA_n = B_n\}$. Then $f\alpha_0 = \beta_0 = \{B_1, ..., B_n\}$ is a countable subcover of β . Consequently, (X, U) is pre-Lindelöf.

Now, let us prove the preservation of this property in the direction of the preimage. Let (Y, V) and f be pre-Lindelöf. Let $\alpha \in U$ be an arbitrary uniform cover. Then there exists a uniform cover $\gamma \in U$ and a countable uniform cover $\beta \in V$ such that $f^{-1}\beta \wedge \gamma \succ \alpha$. Since the uniform cover $\beta \in V$ contains a countable subcover β_0, it follows that the countable uniform cover $f^{-1}\beta_0 \wedge \gamma$. will be refined into the uniform cover $\alpha \in U$. Thus, the uniform space (X, U) is pre-Lindelöf. $\square$

Corollary 2.4 *Let $f : (X, U) \to (Y, V)$ be a precompact mapping of a uniform space (X, U) onto a uniform space (Y, V). Then precompactness converse both to direction of image and to one of preimage.*

Proposition 2.4 *If f is a pre-Lindelöf mapping and $Y = \{y\}$, then (X, U) is pre-Lindelöf.*

Proof: Let $\alpha \in U$ be an arbitrary uniform cover. Then there exists a countable uniform cover $\gamma \in U$ and a uniform cover $\beta \in V$ such that $f^{-1}\beta \wedge \gamma \succ \alpha$. Clearly, $f^{-1}\beta \wedge \gamma = \gamma$. Therefore, the uniform space (X, U) is pre-Lindelöf. $\square$

Corollary 2.5 *If f is a precompact mapping and $Y = \{y\}$, then (X, U) is precompact.*

Proposition 2.5 *Let (X, U) be an arbitrary uniform space and (Y, V) be a pre-Lindelöf space. Then the projection $\pi : (X, U) \times (Y, V) \to (X, U)$ is a pre-Lindelöf mapping.*

Proof: Let $\alpha \in X \times Y$ be an arbitrary uniform cover. Define $\pi_Y : (X, U) \times (Y, V) \to (Y, V)$. Then there exists $\beta \in U$ and $\lambda \in V$ such that $\pi_X^{-1}\beta \succ \alpha$ and $\pi_Y^{-1}\lambda \succ \alpha$. Since the uniform space (Y, V) is pre-Lindelöf, it is easy to see that the cover $\pi_Y^{-1}\lambda \in U \times V$ is countable. Thus, $\pi : (X, U) \times (Y, V) \to (X, U)$ is a pre-Lindelöf mapping $\square$

Corollary 2.6 *Let (X, U) be an arbitrary uniform space and (Y, V) be a precompact space. Then the projection $\pi : (X, U) \times (Y, V) \to (X, U)$ is a precompact mapping.*

Proposition 2.6 *If $f : (X, U) \to (Y, V)$ is a pre-Lindelöf mapping, then for any uniform subspace (M, U_M) of the uniform space (X, U) and any uniform subspace (N, V_N) of the uniform space (Y, V), the restrictions $f|_M : (M, U_M) \to (fM, V_{fM})$ and $f_N : (f^{-1}N, U_{f^{-1}N}) \to (N, V_N)$ are pre-Lindelöf.*

Proof: Let $\alpha_M \in U_M$ be an arbitrary uniform cover. Then there exists a uniform cover $\alpha \in U$ such that $\alpha \wedge \{M\} = \alpha_M$. Since the mapping $f : (X, U) \to (Y, V)$ is pre-Lindelöf, there exists a uniform cover $\beta \in V$ and a countable uniform cover $\gamma \in U$ such that $f^{-1}\beta \wedge \gamma \succ \alpha$. It is easy to see that $f^{-1}|_M\beta_M \wedge \gamma_M \succ \alpha_M$, where $\beta_M = \beta \wedge \{M\}$, $\gamma_M = \gamma \wedge \{M\}$. The pre-Lindelöfness of the mapping $f_N : (f^{-1}N, U_{f^{-1}N}) \to (N, V_N)$ is proved analogously. $\square$

Corollary 2.7 *If $f : (X, U) \to (Y, V)$ is a precompact mapping, then for any uniform subspace (M, U_M) of the uniform space (X, U) and any uniform subspace (N, V_N) of the uniform space (Y, V), the restrictions $f|_M : (M, U_M) \to (fM, V_{fM})$ and $f_N : (f^{-1}N, U_{f^{-1}N}) \to (N, V_N)$ are precompact.*

Theorem 2.2 *The Cartesian product $f = \prod\limits_{a \in M} f_a$, where $f_a : (X_a, U_a) \to (Y_a, V_a)$, $a \in M$ is pre-Lindelöf if and only if all mappings f_a are pre-Lindelöf.*

Proof: Necessity. Let the Cartesian product $f = \prod\limits_{a \in M} f_a$, where $f_a : (X_a, U_a) \to (Y_a, V_a)$, $a \in M$, be pre-Lindelöf. Then, from Proposition 2.6. follows that all mappings $f_a : (X_a, U_a) \to (Y_a, V_a)$ are pre-Lindelöf.

Sufficiency. Let all mappings $f_a : (X_a, U_a) \to (Y_a, V_a)$ be pre-Lindelöf. We show that the product $f = \prod\limits_{a \in M} f_a$ of pre-Lindelöf mappings is pre-Lindelöf. Let U_{f_a} be a pre-Lindelöf base of the mapping

U_{f_a}. Then the uniformity $U_f = \prod\limits_{a\in M} U_{f_a}$ is pre-Lindelöf. We proof that $U_f = \prod\limits_{a\in M} U_{f_a}$ is a base for the mapping $f = \prod\limits_{a\in M} f_a$. Let $\alpha \in \prod\limits_{a\in M} U_a$. It is clear that the covers $\bigwedge\limits_{i=1}^{n} \pi_{a_i}^{-1}\alpha_{a_i}$, $\alpha_{a_i} \in U_{a_i}$, $i = 1, 2, ..., n$ form a base for the uniformity $\prod\limits_{a\in M} U_a$. Therefore, we assume that $\alpha = \bigwedge\limits_{i=1}^{n} \pi_{a_i}^{-1}\alpha_{a_i}$. Since U_{f_a} is a pre-Lindelöf base for the mapping $f_a : (X_a, U_a) \to (Y_a, V_a)$, there exists a uniform cover γ_{a_i} from $U_{f_{a_i}}$ and a countable uniform cover β_{a_i} from V_{a_i} such that $f_{a_i}^{-1}\beta_{a_i} \wedge \gamma_{a_i} \succ \alpha_{a_i}$, $i = 1, 2, ..., n$.Let $\gamma = \bigwedge\limits_{i=1}^{n} \pi_{a_i}^{-1}\gamma_{a_i}$, $\beta = \bigwedge\limits_{i=1}^{n} P_{a_i}^{-1}\beta_{a_i}$, $\pi_{a_i} : \prod\limits_{a\in M} X_a \to X_{a_i}$, $P_{a_i} : \prod\limits_{a\in M} Y_a \to Y_{a_i}$. By the definition of uniformity, $\gamma \in \prod\limits_{a\in M} U_{f_a}$ and $\beta \in \prod\limits_{a\in M} V_a$. Consequently, $f^{-1}\beta \wedge \gamma \succ \alpha$. Thus, the product $f = \prod\limits_{a\in M} f_a$ is pre-Lindelöf.

□

Corollary 2.8 *The Cartesian product* $f = \prod\limits_{a\in M} f_a$, *where* $f_a : (X_a, U_a) \to (Y_a, V_a)$, $a \in M$ *is precompact if and only if all mappings* f_a *are precompact.*

Proposition 2.7 *Let* $\{f_a\}_{a\in M}$ *be a system of uniformly continuous mappings* $f_a : (X, U) \to (Y_a, V_a)$. *If there exists* $a_0 \in M$ *such that* $f_{a_0} : (X, U) \to (Y_{a_0}, V_{a_0})$ *is pre-Lindelöf, then the diagonal product* $f = \Delta \{f_a : a \in M\}$ *is pre-Lindelöf.*

Proof: Let $f_{a_0} : (X, U) \to (Y_{a_0}, V_{a_0})$ be pre-Lindelöf and let $\pi_{a_0} : \prod\limits_{a\in M} (Y_a, V_a) \to (Y_{a_0}, V_{a_0})$ be the projection. Then $f_{a_0} = \pi_{a_0} \circ f$, where $f = \underset{a\in M}{\Delta} f_a$ is the diagonal product. Consequently, by Proposition 2, the mapping f is pre-Lindelöf. □

Corollary 2.9 *Let* $\{f_a\}_{a\in M}$ *be a system of uniformly continuous mappings* $f_a : (X, U) \to (Y_a, V_a)$. *If there exists* $a_0 \in M$ *such that* $f_{a_0} : (X, U) \to (Y_{a_0}, V_{a_0})$ *is precompact, then the diagonal product* $f = \Delta \{f_a : a \in M\}$ *is precompact.*

Theorem 2.3 *For a uniformly continuous mapping the following conditions are equivalent:*

1. $f : (X, U) \to (Y, V)$ *is pre-Lindelöf;*
2. *The completion* $\hat{f} : (\hat{X}, \hat{U}) \to (Y, V)$ *is pre-Lindelöf.*

Proof: 1) ⇒ 2). Let $f : (X, U) \to (Y, V)$ be a pre-Lindelöf mapping and $\hat{\alpha} \in \hat{U}$ be an arbitrary uniform cover. Let $\alpha = \hat{\alpha} \wedge \{X\}$. By virtue of the pre-Lindelöf property of the mapping $f : (X, U) \to (Y, V)$, there exists a uniform cover $\gamma \in U$ and a countable uniform cover $\beta \in V$, such that $f^{-1}\beta \wedge \gamma \succ \alpha$. Then there exists a countable uniform cover $\hat{\gamma} \in \hat{U}$, such that $\gamma = \hat{\gamma} \wedge \{X\}$. It is easy to see that $\hat{f}^{-1}\beta \wedge \hat{\gamma} \succ \hat{\alpha}$.

2) ⇒ 1) This follows easily from Proposition 2.5. □

Corollary 2.10 *For a uniformly continuous mapping the following conditions are equivalent:*

1. $f : (X, U) \to (Y, V)$ *is precompact;*
2. *The completion* $\hat{f} : (\hat{X}, \hat{U}) \to (Y, V)$ *is uniformly perfect.*

Let G and H be topological groups, and let U_T and V_T be their two-sided uniformities, respectively. Suppose that $(G, \cdot, U)$ and $(H, \cdot, V)$ are arbitrary uniform groups.

A uniformly continuous homomorphism $f : (G, \cdot, U) \to (H, \cdot, V)$ of a uniform group $(G, \cdot, U)$ onto a uniform group $(H, \cdot, V)$ is called a pre-Lindelöf homomorphism if the uniformly continuous mapping $f : (G, U) \to (H, V)$ of the uniform space (G, U) onto the uniform space (H, V) is pre-Lindelöf.

We note some properties of pre-Lindelöf homomorphisms of uniform groups:

1. The product of any family of pre-Lindelöf homomorphisms of uniform groups is pre-Lindelöf.
2. The restriction of a pre-Lindelöf homomorphism to any uniform subgroup is a pre-Lindelöf homomorphism.
3. The composition of two pre-Lindelöf homomorphisms of uniform groups is also a pre-Lindelöf homomorphism.
4. The completion of a pre-Lindelöf homomorphism of a uniform group is pre-Lindelöf.
5. The preimage of a pre-Lindelöf uniform group under a pre-Lindelöf homomorphism is pre-Lindelöf.

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