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NORMALITY AND THE WEAK *cb* PROPERTY

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It is demonstrated that the Alexandroff duplicate of a Dowker space is again a Dowker space which is not weak *cb*, while the existence of weak *cb* Dowker spaces is made manifest.

A nonmetrizable, first countable compact space was created by Alexandroff in [1] and the construction has been subsequently generalized and employed ([2], [3], [7], [8]). The present note concentrates on some properties of the Alexandroff duplicate $A(X)$ which, in particular, show that a (collectionwise) normal space need not have the weak *cb* property, thus resolving the open question in [11, p. 240].

1. Preliminaries. No separation axioms are implicitly assumed for the topological space X . The Hewitt–Nachbin realcompactification of a Tychonoff space X is denoted by νX . We will write $A_n \searrow \emptyset$ to indicate that (A_n) is a decreasing sequence of subsets of X such that $\bigcap_n A_n = \emptyset$. \mathbf{N} denotes the natural numbers. A set A is regular closed if $A = \text{cl}_X \text{int}_X A$, and ∂A denotes the boundary of A .

PROPOSITION 1.1. ([10], [11]) *A space X is *cb* (weak *cb*) if and only if for each sequence $A_n \searrow \emptyset$ of closed (regular closed) subsets of X , there exists a sequence of zero sets (Z_n) with $A_n \subseteq Z_n$ and $\bigcap_n Z_n = \emptyset$.*

cb-spaces originated in [5] and were studied by Mack in [10]. Every normal, countably paracompact space is *cb* and every *cb*-space is countably paracompact. Weak *cb*-spaces were defined in [11]. They form a natural generalization of *cb*-spaces and include the Tychonoff pseudocompact spaces and all extremally disconnected spaces. Interest in weak *cb*-spaces is centered in the theorem ([11]) that for a Tychonoff space X , the Dedekind completion of $C(X)$ is isomorphic to $C(Y)$, for some space Y , if and only if νX is weak *cb*. It should be noted that if X is Tychonoff and weak *cb*, then any space T with $X \subseteq T \subseteq \nu X$ is weak *cb*. The converse fails in general (see [4]) but the following result is evident and will be needed below.

PROPOSITION 1.2. *Let X be Tychonoff and consider the statements:*

(a) *For any sequence $A_n \searrow \emptyset$ of regular closed sets in X we have $\bigcap_n \text{cl}_{\nu X} A_n = \emptyset$.*

(b) For any decreasing sequence (A_n) of regular closed sets in X we have $\bigcap_n \text{cl}_{\nu X} A_n = \text{cl}_{\nu X} \bigcap_n A_n$.

(c) If νX is weak cb, then any space T , with $X \subseteq T \subseteq \nu X$ is weak cb. Then (a) if and only if (b); and (a) or (b) implies (c).

Proof. We merely recall that if X is dense in T and A is a regular closed subset of X then $\text{cl}_T A = B$ is the unique regular closed subset of T with $A = B \cap X$.

According to a result of Ishikawa [6], a space X is countably paracompact if and only if for each sequence $A_n \searrow \emptyset$ of closed subsets of X , there exists a sequence (G_n) of open sets such that $A_n \subseteq G_n$ and $\bigcap_n \text{cl}_X G_n = \emptyset$. The following observation will be useful below and may have independent interest.

PROPOSITION 1.3. *The following statements are equivalent:*

(a) X is countable paracompact.

(b) For each sequence $F_n \searrow \emptyset$ of closed nowhere dense subsets of X , there exists a sequence (G_n) of open sets such that $F_n \subseteq G_n$ and $\bigcap_n \text{cl}_X G_n = \emptyset$.

(c) Each countable increasing cover ([10]) by dense open sets has a countable closed refinement whose interiors cover X .

Proof. It is enough to show (b) implies (a). Let $A_n \searrow \emptyset$ be an arbitrary sequence of closed sets and define a sequence of open sets (G_n) with $A_n \subseteq G_n$ and $\bigcap_n \text{cl}_X G_n = \emptyset$ in the following manner:

(i) If $\text{int}_X A_m = \emptyset$ for some $m \geq 1$, there exist open sets G_k with $A_k \subseteq G_k$, $k \geq m$ and $\bigcap_k \text{cl}_X G_k = \emptyset$; put $G_n = X$ for $1 \leq n < m$.

Now assume that $\text{int}_X A_n \neq \emptyset$ for all n .

(ii) If a subsequence (A_{n_k}) exists with $A_{n_{k+1}} \subseteq \text{int}_X A_{n_k}$, let $G_{n_{k+1}} = \text{int}_X A_{n_k}$ and $G_n = X$ otherwise.

(iii) If there exists $m \geq 1$ such that $F_k = \partial A_k \cap \partial A_{k+1} \neq \emptyset$ for $k \geq m$ then $F_k \searrow \emptyset$ is a sequence of closed nowhere dense sets and there exists a sequence of open sets (U_k) with $F_k \subseteq U_k$ and $\bigcap_k \text{cl}_X U_k = \emptyset$. Define $G_{k+1} = \text{int}_X A_k \cup U_k$ for $k \geq m$ and $G_n = X$ for $1 \leq n \leq m$.

In order to exploit the use of nowhere dense closed subsets, we venture to make the following:

DEFINITION 1.4. X is an nd -space if for each sequence $F_n \searrow \emptyset$ of closed nowhere dense sets, there exists a sequence of zero sets (Z_n) with $F_n \subseteq Z_n$ and $\bigcap_n Z_n = \emptyset$.

Every cb -space is an nd -space. Since every zero set Z is a regular G_δ -set (a countable intersection of closed sets whose interiors contain Z),

we may adapt the proof of Proposition 1.3 to conclude that every *nd*-space is countably paracompact. A space is *cb* if and only if it is both a weak *cb* and an *nd*-space. The example on p. 240 of [11] is countably paracompact but not an *nd*-space. It is conjectured that an *nd*-space need not be *cb*, although an example at the present time is not forthcoming.

2. Properties of $A(X)$. Recall the construction in [7]. Given an arbitrary topological space X , consider the set $A(X) = X \cup X'$, where X' is a disjoint copy of X . For any $x \in X$, let x' denote the corresponding point of X' and if $S \subseteq X$ define $S' = \{x' \mid x \in S\}$. A topology is introduced to $A(X)$ by defining a base $\{B(z) \mid z \in A(X)\}$ as follows:

$$B(x') = \{\{x'\}\} \quad \text{and} \quad B(x) = \{V \cup (V' \setminus \{x'\}) \mid V \in \mathcal{V}(x)\},$$

where $\mathcal{V}(x)$ is a neighbourhood base of x in X . The resulting space, also denoted by $A(X)$, generalizes the original construction in [1] and is called the Alexandroff duplicate of X . It is clear that X is a closed, C -embedded subspace of $A(X)$.

Many properties of X are shared with $A(X)$. It has been noticed that $A(X)$ is compact ([2]), α -compact (for any infinite cardinal α), realcompact and Tychonoff ([7]), if X has the corresponding property. We will now expand this list of properties.

Observe that a space is normal if and only if each pair of disjoint closed nowhere dense sets can be separated by disjoint open neighbourhoods.

PROPOSITION 2.1. *X is normal if and only if $A(X)$ is normal.*

Proof. Let A and B be disjoint closed nowhere dense subsets of $A(X)$. Then A and B are closed and disjoint in X and can be separated by disjoint open sets U and V in X . The sets $U \cup U'$ and $V \cup V'$ are open disjoint neighbourhoods of A and B in $A(X)$.

PROPOSITION 2.2. *X is countably paracompact if and only if $A(X)$ is countably paracompact.*

Proof. For the necessity, let $F_n \searrow \emptyset$ be a sequence of closed nowhere dense subsets of $A(X)$. Then $F_n \subseteq X$ and there exists a sequence (V_n) of open subsets of X with $F_n \subseteq U_n$ and $\bigcap_n \text{cl}_X U_n = \emptyset$. Define $G_n = U_n \cup U'_n$ and note that $\text{cl}_{A(X)} G_n = \text{cl}_X U_n \cup U'_n$, so that $F_n \subseteq G_n$ and $\bigcap_n \text{cl}_{A(X)} G_n = \emptyset$.

PROPOSITION 2.3. *If $A(X)$ is weak *cb* then both X and $A(X)$ are *cb*.*

Proof. To show that X is cb , take a sequence $A_n \searrow \emptyset$ of closed sets in X . Then $B_n = A_n \cup A'_n$ is regular closed in $A(X)$ and $B_n \searrow \emptyset$. There exist zero sets W_n in $A(X)$ with $B_n \subseteq W_n$ and $\bigcap_n W_n = \emptyset$. Then $Z_n = W_n \cap X$ is a zero set in X and $A_n \subseteq Z_n$ with $\bigcap_n Z_n = \emptyset$. If X is cb then both X and $A(X)$ are countably paracompact, hence $A(X)$ is cb .

One may show that $A(X)$ is countably compact if and only if X is. Furthermore, if X contains a C -embedded copy of \mathbf{N} , so does $A(X)$ so that $A(X)$ is pseudocompact implies that X is also. However, if X is pseudocompact (Tychonoff) but not countable compact then $A(X)$ is not weak cb , in particular, not pseudocompact.

3. Dowker spaces. A Dowker space is a normal Hausdorff space which is not countably paracompact. Such spaces exist within Zermelo–Fraenkel set theory; the axiom of choice implies the existence of a zero-dimensional P -space which is Dowker [12] and more recently the continuum hypothesis implies existence of a first countable, hereditarily separable Dowker space [9].

The open question in [11, p. 240] may be phrased as follows: Must every Dowker space have the weak cb property? It follows from Propositions 2.1 and 2.2 that $A(X)$ is a Dowker space if and only if X is such. Since no Dowker space can be even an nd -space, 2.3 implies that for any Dowker space X , the space $A(X)$ answers the above question negatively. It may be of interest however that the (collectionwise normal) Dowker space of M. E. Rudin [12] is weak cb , as is now shown.

The reader is referred to [12] for details. With the same notation as in [12], define

$$F = \{f: \mathbf{N} \rightarrow \omega_\omega \mid f(n) \leq \omega_n \text{ for all } n \in \mathbf{N}\}.$$

$$X = \{f \in F \mid \omega_1 \leq cf(f(n)) \leq \omega_k \text{ for all } n \in \mathbf{N} \text{ and some } k \in \mathbf{N}\},$$

$$X' = \{f \in F \mid \omega_1 \leq cf(f(n)) \text{ for all } n \in \mathbf{N}\}.$$

F carries a topology generated by the basic open-and-closed sets

$$(f, g] = \{h \in F \mid f(n) < h(n) \leq g(n) \text{ for all } n \in \mathbf{N}\}.$$

Then $X \subseteq X' \subseteq F$ are subspaces and $\nu X = X'$ is paracompact, and hence a weak cb -space.

To show that X is weak cb , let $A_n \searrow \emptyset$ be a sequence of regular closed subsets of X and suppose $g \in \bigcap_n \text{cl}_{\nu X} A_n$. We will define an increasing sequence $\{f_\alpha \in X \mid \alpha < \omega_1\}$ as follows:

(1) Choose any $f_0 \in \text{int}_X A_1$ with $f_0 \leq g$.

(2) Assume $f_\beta \in X$ is defined for all $\beta < \alpha$, and

(a) if $\alpha = \beta + 1$, let $i \in \mathbf{N}$ be the smallest integer with $f_\beta \notin \text{int}_X A_i$ and choose $f_\alpha \in (\text{int}_X A_i) \cap (f_\beta, g]$.

(b) if α is a limit ordinal, let $h_\alpha(n) = \sup\{f_\beta(n) \mid \beta < \alpha\}$ and choose $f_\alpha \in (\text{int}_X A_1) \cap (h_\alpha, g]$.

Now define $f(n) = \sup\{f_\alpha(n) \mid \alpha < \omega_1\}$. Then $f \leq g$ and $cf(f(n)) = \omega_1$ for all $n \in \mathbb{N}$ implies that $f \in X$. However, $f \in A_k$ for all $k \in \mathbb{N}$: let $h < f$ and for each $n \in \mathbb{N}$ there is $f_{\alpha_n} \in \{f_\alpha \mid \alpha < \omega_1\}$ with $h(n) < f_{\alpha_n}(n)$. Let $\beta = \sup\{\alpha_n \mid n \in \mathbb{N}\}$ and then $f_{\beta+k} \in (\text{int}_X A_k) \cap (h, f]$, that is $f \in \text{cl}_X \text{int}_X A_k = A_k$.

We have a contradiction and so $A_n \searrow \emptyset$ implies $\bigcap_n \text{cl}_{vX} A_n = \emptyset$. Finally, apply Proposition 1.2 to infer that X is weak cb .

4. Remarks. Since the Dowker space X in [12] is weak cb , it follows from [4] that $E(vX) = vE(X)$, where $E(X)$ denotes the absolute of X (see for example [4, p. 652]). Thus, $vE(X)$ is paracompact. However, it has been shown by E. K. van Douwen that $E(X)$ is not normal. It would seem natural therefore to pose the following questions. (1) Is there a normal space X with normal absolute $E(X)$; (2) Is there an extremally disconnected Dowker space; and ultimately (3) Is there a Dowker space X with Dowker absolute $E(X)$.

Added in proof. Regarding questions (2) and (3) above, M. Wage has proved that the set-theoretic hypothesis Φ implies the existence of a separable extremally disconnected Dowker space.

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