

A short note on hit–and–miss hyperspaces

RENÉ BARTSCH AND HARRY POPPE

Dedicated to Professor S. Naimpally on the occasion of his 70th birthday.

ABSTRACT. Based on some set-theoretical observations, compactness results are given for general hit-and-miss hyperspaces. Compactness here is sometimes viewed splitting into “ κ -Lindelöfness” and “ κ -compactness” for cardinals κ . To focus only hit-and-miss structures, could look quite old-fashioned, but some importance, at least for the techniques, is given by a recent result, [8], of Som Naimpally, to who this article is hearty dedicated.

2000 AMS Classification: 54B20, 54D30, 54F99.

Keywords: hit-and-miss topology, compactness, relative completeness, relative compact unions, upper Vietoris topology.

1. INTRODUCTION.

Let (X, τ) be a topological space. By $\mathfrak{P}(X)$, $\mathfrak{P}_0(X)$, $Cl(X)$ and $K(X)$ respectively we denote the power set, the power set without the empty set \emptyset , the family of all closed subsets and the set of all compact subsets of X . For $B \in \mathfrak{P}(X)$ and $\mathfrak{A} \subseteq \mathfrak{P}(X)$ we define $B^{-\mathfrak{A}} := \{A \in \mathfrak{A} \mid A \cap B \neq \emptyset\}$ (hit-set) and $B^{+\mathfrak{A}} := \{A \in \mathfrak{A} \mid A \cap B = \emptyset\}$ (miss-set). Specializing $\mathfrak{A} := Cl(X)$, we get the usual symbols B^-, B^+ . By $\tau_{\mathfrak{A}}$ we denote the topology for \mathfrak{A} , generated by the subbase of all $G^{-\mathfrak{A}}, G \in \tau$. Now consider $\emptyset \neq \alpha \subseteq \mathfrak{P}(X)$; by $\tau_{\alpha, \mathfrak{A}}$ we denote the topology for \mathfrak{A} which is generated from the subbase of all $B^{+\mathfrak{A}}, B \in \alpha$ and $G^{-\mathfrak{A}}, G \in \tau$. Of course, for every possible α we have $\tau_{\mathfrak{A}} \subseteq \tau_{\alpha, \mathfrak{A}}$; for $\alpha = Cl(X)$ we get the Vietoris topology and for $\alpha = K(X)$ we get the Fell topology for \mathfrak{A} . If $\alpha = \Delta \subseteq Cl(X)$, $\tau_{\alpha, \mathfrak{A}}$ is called Δ -topology by Beer and Tamaki [2], and was first introduced by Poppe [10].

By $\mathfrak{F}(X)$ and $\mathfrak{F}_0(X)$ we denote the set of all filters and ultrafilters, respectively, on a set X (a filter is not allowed to contain the empty set \emptyset); the symbol $\mathfrak{F}(\varphi)$ (resp. $\mathfrak{F}_0(\varphi)$) means the set of all filters (resp. ultrafilters) which contain a given filter φ ; \dot{x} is the filter generated by a singleton $\{x\}, x \in X$. The symbol q_τ denotes the convergence structure induced by a topology τ , i.e. $q_\tau := \{(\varphi, x) \in \mathfrak{F}(X) \times X \mid \varphi \supseteq \dot{x} \cap \tau\}$, so q_τ is a relation between filters and points of a set X .

If X is a set, τ, \mathfrak{A} are subsets of $\mathfrak{P}(X)$, then we call \mathfrak{A} *weakly complementary w.r.t.* τ , iff for every subset $\sigma \subseteq \tau$ there exist a subset $\mathfrak{B} \subseteq \mathfrak{A}$, s.t. $\bigcup_{B \in \mathfrak{B}} B = X \setminus \bigcup_{S \in \sigma} S$.

Lemma 1.1. *Let X be a set, $\tau, \mathfrak{A} \subseteq \mathfrak{P}(X)$ and $K \subseteq X$. Then holds*

$$\bigcup_{i \in I} G_i \supseteq K \implies \bigcup_{i \in I} G_i^{-\mathfrak{A}} \supseteq K^{-\mathfrak{A}}$$

for every collection $G_i, i \in I, G_i \in \tau$.

If \mathfrak{A} is weakly complementary w.r.t. τ , then for every collection $G_i, i \in I, G_i \in \tau$ the implication

$$\bigcup_{i \in I} G_i \supseteq K \iff \bigcup_{i \in I} G_i^{-\mathfrak{A}} \supseteq K^{-\mathfrak{A}}$$

holds, too.

Proof. Let $\bigcup_{i \in I} G_i \supseteq K$. $A \in K^{-\mathfrak{A}} \Rightarrow A \cap K \neq \emptyset \Rightarrow \emptyset \neq A \cap \bigcup_{i \in I} G_i \Rightarrow \exists i_0 \in I : A \cap G_{i_0} \neq \emptyset \Rightarrow A \in G_{i_0}^{-\mathfrak{A}} \Rightarrow A \in \bigcup_{i \in I} G_i^{-\mathfrak{A}}$.

Conversely, let \mathfrak{A} be weakly complementary w.r.t. τ and $\bigcup_{i \in I} G_i^{-\mathfrak{A}} \supseteq K^{-\mathfrak{A}}$. Assume $\bigcup_{i \in I} G_i \not\supseteq K$. Then $X \setminus \bigcup_{i \in I} G_i \supseteq K \setminus \bigcup_{i \in I} G_i \neq \emptyset$ holds, so there is an $A \in \mathfrak{A}, A \subseteq X \setminus \bigcup_{i \in I} G_i$ with $A \cap K \setminus \bigcup_{i \in I} G_i \neq \emptyset$. Thus $A \in K^{-\mathfrak{A}}$, implying $A \in \bigcup_{i \in I} G_i^{-\mathfrak{A}}$. This yields $\exists i_0 \in I : A \cap G_{i_0} \neq \emptyset$ in contradiction to the construction of A . \square

Corollary 1.2. *Let X be a set, $\tau, \mathfrak{A} \subseteq \mathfrak{P}(X)$ and $K \subseteq X$. Then holds*

$$(1.1) \quad \bigcup_{i \in I} G_i \supseteq K \iff \bigcup_{i \in I} G_i^{-\mathfrak{A}} \supseteq K^{-\mathfrak{A}}$$

for every collection $G_i, i \in I, G_i \in \tau$ if and only if \mathfrak{A} is weakly complementary w.r.t. τ .

Proof. We only have to show, that \mathfrak{A} is weakly complementary w.r.t. τ , if (1.1) holds. Assume, \mathfrak{A} is not weakly complementary w.r.t. τ . Then there must be a collection $\{G_i | i \in I\} \subseteq \tau$, such that $\bigcup \{A | A \in \mathfrak{P}(X \setminus \bigcup_{i \in I} G_i) \cap \mathfrak{A}\} \not\supseteq X \setminus \bigcup_{i \in I} G_i$. Now, we chose $K := (X \setminus \bigcup_{i \in I} G_i) \setminus \bigcup \{A | A \in \mathfrak{P}(X \setminus \bigcup_{i \in I} G_i) \cap \mathfrak{A}\} \neq \emptyset$. Then no element of \mathfrak{A} , which meets K , can be contained in $X \setminus \bigcup_{i \in I} G_i$, i.e. every element of $K^{-\mathfrak{A}}$ meets $\bigcup_{i \in I} G_i$, too. So, it must meet a $G_{i_0}, i_0 \in I$ and consequently it is contained in $\bigcup_{i \in I} G_i^{-\mathfrak{A}}$. But, by construction, the collection $\{G_i | i \in I\}$ doesn't cover K , so (1.1) would fail. \square

Obviously, if for every collection $\{G_i | i \in I\} \subseteq \tau$ the complement $X \setminus \bigcup_{i \in I} G_i$ itself belongs to \mathfrak{A} , or if all singletons $\{x\}, x \in X$ are elements of \mathfrak{A} , then \mathfrak{A} is weakly complementary w.r.t. τ . So, if τ is a topology on X , $Cl(X)$ and $K(X)$ are weakly complementary w.r.t. τ .

Corollary 1.3. *Let (X, τ) be a topological space, $K \subseteq X$ and $\forall i \in I : G_i \in \tau$. Then holds*

$$\bigcup_{i \in I} G_i \supseteq K \iff \bigcup_{i \in I} G_i^- \supseteq K^-$$

We have yet another easy, but useful set-theoretical lemma:

Lemma 1.4. *Let X be a set, $\mathfrak{A} \subseteq \mathfrak{P}(X)$ and $\varphi \in \mathfrak{F}(X)$. Assume, \mathfrak{A} is closed under finite unions of its elements. Then holds*

$$\varphi \cap \mathfrak{A} \neq \emptyset \iff \forall \psi \in \mathfrak{F}_0(\varphi) : \psi \cap \mathfrak{A} \neq \emptyset,$$

i.e. a filter contains an \mathfrak{A} -set, iff each refining ultrafilter contains an \mathfrak{A} -set.

Proof. Suppose $\forall \psi \in \mathfrak{F}_0(\varphi) : \exists A_\psi \in \mathfrak{A} : A_\psi \in \psi$. Now, assume $\varphi \cap \mathfrak{A} = \emptyset$. From this automatically follows $X \notin \mathfrak{A}$.

Consider $\mathfrak{B} := \{X \setminus A \mid A \in \mathfrak{A}\}$. Because of the closedness of \mathfrak{A} under finite unions, \mathfrak{B} is closed under finite intersection of its elements, and $\emptyset \notin \mathfrak{B}$, because $X \notin \mathfrak{A}$. For any $F \in \varphi, B \in \mathfrak{B}$ we have $F \cap B \neq \emptyset$, because $F \cap B = \emptyset$ would imply $F \subseteq X \setminus B \in \mathfrak{A}$ and therefore $\varphi \cap \mathfrak{A} \neq \emptyset$. So, $\varphi \cup \mathfrak{B}$ is a subbase of a filter and consequently, there exists an ultrafilter ψ , containing $\varphi \cup \mathfrak{B}$, therefore containing φ and the complement of every \mathfrak{A} -set - in contradiction to $\forall \psi \in \mathfrak{F}_0(\varphi) : \psi \cap \mathfrak{A} \neq \emptyset$. The other direction of the statement of the lemma is obvious. \square

Definition 1.5. Let κ be a cardinal. Then a topological space (X, τ) is called κ -compact, iff every open cover of X with cardinality at most κ admits a finite subcover.

(X, τ) is called κ -Lindelöf, iff every open cover of X admits a subcover of cardinality at most κ .

A filter is called κ -generated, iff it has a base of cardinality at most κ . A filter φ is called κ -completable, iff every subset $\mathfrak{B} \subseteq \varphi$ with $\text{card}(\mathfrak{B})$ at most κ fulfills $\bigcap_{B \in \mathfrak{B}} B \neq \emptyset$. It is called κ -complete, iff $\bigcap_{B \in \mathfrak{B}} B \in \varphi$ holds under this condition.

Proposition 1.6. A topological space (X, τ) is κ -compact, if and only if every κ -generated filter on X has a convergent refining ultrafilter.

Proof. Let (X, τ) be κ -compact and φ a filter on X with a base \mathfrak{B} of cardinality at most κ . Assume, all refining ultrafilters of φ would fail to converge in X . Then for each element $x \in X$, all refining ultrafilters of φ contain the complement of an open neighbourhood of x . But the set of complements of open neighbourhoods of a point x is closed w.r.t. finite unions, thus by Lemma 1.4, φ contains the complement of an open neighbourhood of x . So, for each $x \in X$ there must exist $O_x \in \tau \cap \dot{x}$ and $B_x \in \mathfrak{B}$, s.t. $B_x \subseteq X \setminus O_x$, implying $\overline{B_x} \subseteq X \setminus O_x$ and thus $X \setminus \overline{B_x} \supseteq O_x$. Now, for each $B \in \mathfrak{B}$ we define $O_B := X \setminus \overline{B}$ and find, that $\{O_B \mid B \in \mathfrak{B}\}$ is an open cover of X , because of the preceding facts. So, there must exist a finite subcover $O_{B_1} \cup \dots \cup O_{B_n} = X$, implying $\bigcup_{i=1}^n (X \setminus \overline{B_i}) = X$, just meaning $\bigcap_{i=1}^n \overline{B_i} = \emptyset$, which is impossible, because all B_i belong to the filter φ . So, the assumption must be false; there must exist convergent refining ultrafilters of φ .

Otherwise, let all κ -generated filters on X have a convergent refining ultrafilter. Assume, there would exist an open cover $\mathfrak{C} := \{O_i \in \tau \mid i \in I\}, \bigcup_{i \in I} O_i = X, \text{card}(I) \leq \kappa$ such that all finite subcollections fail to cover X (implying κ to be infinite). But the set of all finite subcollections of the infinite collection \mathfrak{C} of cardinality at most κ has cardinality at most κ , too. So, $\mathfrak{B} := \{X \setminus \bigcup_{k=1}^n O_{i_k} \mid n \in \mathbb{N}, i_k \in I\}$ is a filterbasis of cardinality at most κ , thus there must exist an ultrafilter $\varphi \supseteq \mathfrak{B}$, which converges in X - leading to the usual contradiction, because every $x \in X$ is contained in an open $O_x \in \mathfrak{C}$ and $X \setminus O_x$ belongs to $\mathfrak{B} \subseteq \varphi$. \square

Analogously we get a characterization of κ -Lindelöf-spaces.

Proposition 1.7. If (X, τ) is κ -Lindelöf, then every κ -completable filter on X has a convergent refining ultrafilter.

If κ is an infinite cardinal and every κ -complete filter on a topological space (X, τ) has a convergent refining ultrafilter, then (X, τ) is κ -Lindelöf.

Of course, every κ -complete filter is κ -completable, so we may say, that a topological space (X, τ) is κ -Lindelöf, if and only if each κ -complete filter on X has a convergent refinement.

2. COMPACTNESS PROPERTIES FOR HYPERSPACES.

Lemma 2.1. *Let κ be a cardinal, (X, τ) a topological space and let $\mathfrak{A} \subseteq \mathfrak{P}(X)$ be weakly complementary w.r.t. τ . If $\mathfrak{A}_0 := \mathfrak{A} \setminus \{\emptyset\}$ is κ -Lindelöf (resp. κ -compact) in τ_{l, \mathfrak{A}_0} , then (X, τ) is κ -Lindelöf (resp. κ -compact).*

Proof. If \mathfrak{A} is weakly complementary w.r.t. τ , then \mathfrak{A}_0 is, too. So, Corollary 1.2 is applicable. Let $\{G_i | i \in I\}$ be an open cover (resp. an open cover with cardinality at most κ) of X . By Corollary 1.2, then $\{G_i^{-\mathfrak{A}_0} | i \in I\}$ is an open cover of $X^{-\mathfrak{A}_0} = \mathfrak{A}_0$ (resp. of card. at most κ), so there exists a subset $J \subseteq I$ of cardinality at most κ (resp. a finite subset J), s.t. $\bigcup_{j \in J} G_j^{-\mathfrak{A}_0} \supseteq \mathfrak{A}_0 = X^{-\mathfrak{A}_0}$, implying $\bigcup_{j \in J} G_j \supseteq X$ by Corollary 1.2. \square

Of course, the assumed topology τ_{l, \mathfrak{A}_0} is not really hit-and-miss, because the miss-sets are missed. But every proper hit-and-miss topology would be stronger and therefore it would enforce the desired properties for (X, τ) as well.

Lemma 2.2. *Let (X, τ) be a κ -compact (resp. κ -Lindelöf) topological space and assume $Cl(X) \subseteq \mathfrak{A} \subseteq \mathfrak{P}(X)$. Then $\mathfrak{A}_0 := \mathfrak{A} \setminus \{\emptyset\}$ is κ -compact (resp. κ -Lindelöf) in τ_{l, \mathfrak{A}_0} .*

Proof. Let $\hat{\varphi}$ be a κ -generated (resp. κ -complete) filter on \mathfrak{A}_0 . Then, for an arbitrary $h \in \mathcal{A} := \{g \in X^{\mathfrak{P}_0(X)} | \forall M \in \mathfrak{P}_0(X) : g(M) \in M\}$ the image $h(\hat{\varphi})$ is a κ -generated (resp. κ -complete) filter on X and consequently it has a τ -convergent refining ultrafilter ψ_h . Furthermore, there must exist an ultrafilter $\hat{\psi} \supseteq \hat{\varphi}$, s.t. $h(\hat{\psi}) = \psi_h$. So, the set

$$A := \{a \in X | \exists f \in \mathcal{A} : (f(\hat{\psi}), a) \in q_\tau\}$$

is not empty and consequently the closure \bar{A} belongs to \mathfrak{A}_0 . Now, for any $O \in \tau$ with $\bar{A} \in O^{-\mathfrak{A}_0}$ ($\Leftrightarrow \bar{A} \cap O \neq \emptyset$) we get $A \cap O \neq \emptyset$ (because of the closure-properties). Now, the assumption $O^{-\mathfrak{A}_0} \notin \hat{\psi}$ would imply $O^{+\mathfrak{A}_0} \in \hat{\psi}$, yielding $\forall f \in \mathcal{A} : X \setminus O \in f(\hat{\psi})$, thus $\forall f \in \mathcal{A} : \forall b \in A \cap O : (f(\hat{\psi}), b) \notin q_\tau$ - in contradiction to the construction of A . Thus, $O \in \tau, \bar{A} \in O^{-\mathfrak{A}_0}$ always imply $O^{-\mathfrak{A}_0} \in \hat{\psi}$ and consequently $\hat{\psi}$ τ_{l, \mathfrak{A}_0} -converges to \bar{A} . \square

Definition 2.3. Let (X, τ) be a topological space. A subset $A \subseteq X$ is called *weakly relatively complete* in X , iff

$$\forall \varphi \in \mathfrak{F}(A) \cap q_\tau^{-1}(X) : \mathfrak{F}(\varphi) \cap q_\tau^{-1}(A) \neq \emptyset,$$

i.e. every filter φ on A , which converges in X , has a refinement, converging in A .

Proposition 2.4. *Let (X, τ) be a topological space and $A \subseteq X$. Then holds:*

- (a) *A is weakly relatively complete in X , iff $\mathfrak{F}_0(A) \cap q_\tau^{-1}(X) = \mathfrak{F}_0(A) \cap q_\tau^{-1}(A)$, i.e. every ultrafilter on A , which converges in X , converges in A .*
- (b) *If A is closed in X , then A is weakly relatively complete in X .*
- (c) *If A is compact, then A is weakly relatively complete in X .*

- (d) If (X, τ) is compact and A is weakly relatively complete in X , then A is compact.
- (e) If (X, τ) is Hausdorff, then every weakly relatively complete subset $A \subseteq X$ is closed in (X, τ) .
- (f) A is compact iff A is weakly relatively complete and relatively compact.
- (g) If (X, τ) is κ -compact and A is weakly relatively complete in (X, τ) , then A is κ -compact.
- (h) If (X, τ) is κ -Lindelöf and A is weakly relatively complete in (X, τ) , then A is κ -Lindelöf.
- (i) Weak relative completeness is transitive, i.e. for all $A \subseteq B \subseteq X$ with B weakly relatively complete in (X, τ) and A weakly relatively complete in $(B, \tau|_B)$, the subset A is weakly relatively complete in (X, τ) .

There is also a useful description by coverings for weak relative completeness.

Lemma 2.5. *Let (X, τ) be a topological space and $A \subseteq X$. Then the following are equivalent:*

- (1) A is weakly relatively complete in X .
- (2) For every open cover \mathfrak{A} of A and every element x of X , there is an open neighbourhood $U_{x, \mathfrak{A}}$ of x , s.t. $U_{x, \mathfrak{A}} \cap A$ is covered by finitely many members of \mathfrak{A} .
- (3) For every open cover \mathfrak{A} of A there exists an open cover $\mathfrak{A}' \supseteq \mathfrak{A}$ of X , such that the intersection of every member of \mathfrak{A}' with A can be covered by finitely many members of \mathfrak{A} , i.e. $\forall O \in \mathfrak{A}' : \exists n \in \mathbb{N}, P_1, \dots, P_n \in \mathfrak{A} : \bigcup_{i=1}^n P_i \supseteq O \cap A$ holds.

Proof. (1) \Rightarrow (2): Let $\mathfrak{A} \subseteq \tau$ with $\bigcup_{P \in \mathfrak{A}} P \supseteq A$ be given. For every $x \in A$ we can chose a single member of \mathfrak{A} as open neighbourhood, whose intersection with A is covered by itself. So, assume

$$(2.2) \quad \exists x \in X \setminus A : \forall U_x \in \underline{U}(x) \cap \tau : \forall n \in \mathbb{N}, P_1, \dots, P_n \in \mathfrak{A} : U_x \cap A \not\subseteq \bigcup_{i=1}^n P_i$$

Then $\mathfrak{B} := \{(U \cap A) \setminus \bigcup_{i=1}^n P_i \mid U \in \underline{U}(x) \cap \tau, n \in \mathbb{N}, P_i \in \mathfrak{A}\}$ would be closed under finite intersections and thus there would exist an ultrafilter φ on A with $\varphi \supseteq \mathfrak{B}$. By construction $\varphi \rightarrow x$ must hold for this ultrafilter, and now by the weak relative completeness of A it follows $\exists a \in A : \underline{U}(a) \subseteq \varphi$. But \mathfrak{A} is an open cover of A , so there is an open set $P \in \mathfrak{A}$ with $a \in P$, implying $P \in \varphi$ – in contradiction to the construction of φ . Thus (2.2) is false and we have

$$\forall x \in X \setminus A : \exists U_x \in \underline{U}(x) \cap \tau : \exists n \in \mathbb{N}, P_1, \dots, P_n \in \mathfrak{A} : U_x \cap A \subseteq \bigcup_{i=1}^n P_i$$

(2) \Rightarrow (3): Note, that (3) is fulfilled with $\mathfrak{A}' := \{U_x \mid x \in X \setminus A\} \cup \mathfrak{A}$.

(3) \Rightarrow (1): For a given ultrafilter φ on A with $\varphi \rightarrow x \in X$ assume $\varphi \not\subseteq q_\tau^{-1}(A)$. Then $\forall a \in A : \exists U_a \in \underline{U}(a) \cap \tau : U_a^c = X \setminus U_a \in \varphi$. With these neighbourhoods define $\mathfrak{A} := \{U_a \mid a \in A\}$, which is an open cover of A . By (2) there is an open cover $\mathfrak{A}' \supseteq \mathfrak{A}$ of X such that $\forall O \in \mathfrak{A}' : \exists n \in \mathbb{N}, P_1, \dots, P_n \in \mathfrak{A} : \bigcup_{i=1}^n P_i \supseteq O \cap A$ holds. Now, $\varphi \rightarrow x$ implies $\exists O \in \mathfrak{A}' : O \in \varphi$ (especially $A \cap O \neq \emptyset$ follows), and then we have $\exists n \in \mathbb{N}, P_1, \dots, P_n \in \mathfrak{A} : O \cap A \subseteq \bigcup_{i=1}^n P_i$, implying $\exists j \in \{1, \dots, n\} : P_j \in \varphi$

– in contradiction to the construction of \mathfrak{A} . So, the assumption $\varphi \notin q_\tau^{-1}(A)$ must be false, showing, that every ultrafilter on A , which converges in X , converges in A . \square

Theorem 2.6. *Let (X, τ) be a topological space, and let $\alpha \subseteq \mathfrak{P}(X)$ consist of weakly relatively complete subsets of X . Then holds for any \mathfrak{A} with $Cl(X) \subseteq \mathfrak{A} \subseteq \mathfrak{P}(X)$: $(\mathfrak{A}_0, \tau_\alpha)$ is compact $\iff (X, \tau)$ is compact.*

Proof. According to Lemma 2.1 we need only to show that $(\mathfrak{A}_0, \tau_\alpha)$ is compact, if (X, τ) is compact. So, assuming (X, τ) to be compact, by Proposition 2.4 every weakly relatively complete subset of X is compact, and we have $\alpha \subseteq K(X)$. Now we will use Alexander's Lemma: let \underline{U} be a cover of \mathfrak{A}_0 , consisting of subbase elements $K_i^{+\mathfrak{a}_0}, G_j^{-\mathfrak{a}_0}$ with K_i compact and G_j open.

$A := X \setminus (\bigcup\{G|G^{-\mathfrak{a}_0} \in \underline{U}\})$ is closed.

By construction, $A \notin G^{-\mathfrak{a}_0}$ for any $G^{-\mathfrak{a}_0} \in \underline{U}$, so for $A \neq \emptyset$ there must exist some $K_0^{+\mathfrak{a}_0} \in \underline{U}$ with $A \in K_0^{+\mathfrak{a}_0}$, yielding that $K_0 \subseteq \bigcup\{G|G^{-\mathfrak{a}_0} \in \underline{U}\}$; K_0 compact $\implies \exists G_1, \dots, G_n \in \underline{U}$ with $K_0 \subseteq \bigcup_{k=1}^n G_k$, but then $\{K_0^{+\mathfrak{a}_0}\} \cup \{G_1^{-\mathfrak{a}_0}, \dots, G_n^{-\mathfrak{a}_0}\}$ is a cover of \mathfrak{A}_0 .

If $A = \emptyset$, then $\bigcup\{G_i|G_i^{-\mathfrak{a}_0} \in \underline{U}\} = X$, so from the compactness of X the existence of some $G_1^{-\mathfrak{a}_0}, \dots, G_n^{-\mathfrak{a}_0} \in \underline{U}$ with $X = \bigcup_{k=1}^n G_k$ follows. By Lemma 1.1 then $\bigcup_{k=1}^n G_k^{-\mathfrak{a}_0} = \mathfrak{A}_0$ holds. \square

Many known theorems of compactness w.r.t. the Fell- or the Vietoris-topology follow immediately from the above result.

Lemma 2.7. *Let (X, τ) be a topological space, $\mathfrak{A} \subseteq \mathfrak{P}_0(X)$ with $Cl(X) \subseteq \mathfrak{A}$ and $\alpha \subseteq Cl(X)$. If $R \subseteq X$ is relatively compact in X , then $\mathfrak{P}_0(R) \cap \mathfrak{A}$ is relatively compact in $(\mathfrak{A}, \tau_\alpha)$.*

Proof. Let $\mathfrak{B} := \{O_i^{-\mathfrak{a}} | i \in I, O_i \in \tau\} \cup \{C_j^{+\mathfrak{a}} | j \in J, C_j \in \alpha\}$ be an open cover of \mathfrak{A} by subbase elements of τ_α . Let $O := \bigcup_{i \in I} O_i$.

If $O = X$, then there exists finitely many $i_1, \dots, i_n \in I$ with $\bigcup_{k=1}^n O_{i_k} \supseteq R$, because R is relatively compact, and thus $\bigcup_{k=1}^n O_{i_k}^{-\mathfrak{a}} \supseteq R^{-\mathfrak{a}} \supseteq \mathfrak{P}_0(R) \cap \mathfrak{A}$, by Lemma 1.1.

If $O \neq X$, then $X \setminus O$ is nonempty and closed, but not covered by the $O_i^{-\mathfrak{a}}$ from \mathfrak{B} . Thus, there must exist a $j_0 \in J$ with $X \setminus O \in C_{j_0}^{+\mathfrak{a}}$, implying $C_{j_0} \subseteq O$. Now, we have $\mathfrak{P}_0(R) \cap \mathfrak{A} = (\mathfrak{P}_0(R) \cap C_{j_0}^{+\mathfrak{a}}) \cup (\mathfrak{P}_0(R) \cap C_{j_0}^{-\mathfrak{a}})$, and, of course, $\mathfrak{P}_0(R) \cap C_{j_0}^{+\mathfrak{a}}$ is covered just by $C_{j_0}^{+\mathfrak{a}} \in \mathfrak{B}$. So, we have to find a finite subcover for $(\mathfrak{P}_0(R) \cap C_{j_0}^{-\mathfrak{a}})$, if this is not empty. Observe, that $R \cap C_{j_0}$ is relatively compact in X , because it is a subset of R . Furthermore, $\{O_i | i \in I\} \cup \{X \setminus C_{j_0}\}$ is an open cover of X . Thus we find again finitely many $i_1, \dots, i_n \in I$, s.t. $\bigcup_{k=1}^n O_{i_k} \supseteq R \cap C_{j_0}$ (because $X \setminus C_{j_0}$ can be removed from any cover of $R \cap C_{j_0}$ without losing the covering property). Therefore $\bigcup_{k=1}^n O_{i_k}^{-\mathfrak{a}} \supseteq (R \cap C_{j_0})^{-\mathfrak{a}}$, by Lemma 1.1. But $\mathfrak{P}_0(R) \cap C_{j_0}^{-\mathfrak{a}} \subseteq (R \cap C_{j_0})^{-\mathfrak{a}}$ holds, because any subset of R , which hits C_{j_0} , automatically hits $R \cap C_{j_0}$. \square

3. COMPACT UNIONS.

As an interesting application of a simple set-theoretical property, concerning the $+$ -operator, we want to take a brief look at the naturally arising question, whether a union of compact sets itself is compact. Michael showed in [6] that a union of

closed sets is compact, if the unifying family is compact w.r.t. the Vietoris-topology. Now, the Vietoris-topology is induced by the upper-Vietoris τ_V^+ (miss sets: $A^{+\mathfrak{X}}$ with $A^c \in \tau$) and τ_l , but τ_l is not sufficient to enforce compactness of a union of compact sets, as the following example shows: Let $X := \mathbb{R}$, endowed with euclidian topology, $\mathfrak{M} := \{[-m, m] \mid m \in \mathbb{N}\}$. Then $\bigcup_{M \in \mathfrak{M}} M = \mathbb{R}$, is obviously not compact. But every cover of \mathfrak{M} with elements of the defining subbase for τ_l must especially cover the element $\{0\} = [0, 0]$ of \mathfrak{M} , so it must contain a set O^- with $0 \in O$. Now, every element of \mathfrak{M} contains the point 0, thus $\mathfrak{M} \subseteq O^-$ follows. So, \mathfrak{M} is compact in τ_l by Alexander's subbase Lemma.

And unifying compact sets, τ_l is not necessary, too, as we will see.

Proposition 3.1. *Let X be a set, $\mathfrak{X} \subseteq \mathfrak{P}(X)$ and $\mathfrak{M} \subseteq \mathfrak{X}$. Then holds*

$$\bigcup_{i \in I} C_i^{+\mathfrak{X}} \supseteq \mathfrak{M} \implies \bigcup_{i \in I} C_i^c \supseteq \bigcup_{M \in \mathfrak{M}} M$$

for every collection $C_i, i \in I$.

Proof. For every $M \in \mathfrak{M}$ there must exist an $i_M \in I$ with $M \in C_{i_M}^{+\mathfrak{X}}$, because of $\bigcup_{i \in I} C_i^{+\mathfrak{X}} \supseteq \mathfrak{M}$. Thus $M \subseteq C_{i_M}^c \subseteq \bigcup_{i \in I} C_i^c$. \square

In [5] it was shown

Lemma 3.2. *Let (X, τ) be a topological space and $\mathfrak{M} \subseteq K(X)$ compact w.r.t. the upper-Vietoris topology. Then*

$$K := \bigcup_{M \in \mathfrak{M}} M$$

is compact w.r.t. τ .

Applying our simple set-theoretical statement, we get a similar result for unions of relatively compact subsets.

Lemma 3.3. *Let (X, τ) be a topological space, let \mathfrak{X} be the family of all relatively compact subsets of X and let $\mathfrak{M} \subseteq \mathfrak{X}$ be relatively compact in \mathfrak{X} w.r.t. the upper Vietoris topology. Then*

$$R := \bigcup_{M \in \mathfrak{M}} M$$

is relatively compact in (X, τ) .

Proof. Let $\bigcup_{i \in I} O_i \supseteq X$ with $O_i \in \tau, i \in I$ an open cover of X . Because of the relative compactness of all $P \in \mathfrak{X}$, there is a finite subcover O_{i_1}, \dots, O_{i_n} for every $P \in \mathfrak{X}$, i.e. $O_P := \bigcup_{k=1}^n O_{i_k} \supseteq P$. Of course, $O_P \in \tau$ and so $(O_P)^c$ is closed w.r.t. τ . Furthermore, $P \cap O_P^c = \emptyset$, implying $P \in (O_P^c)^{+\mathfrak{X}}$. Thus we have $\mathfrak{X} \subseteq \bigcup_{P \in \mathfrak{X}} (O_P^c)^{+\mathfrak{X}}$, where the $(O_P^c)^{+\mathfrak{X}}$ are open w.r.t. the upper-Vietoris topology. Because of the relative compactness of \mathfrak{X} w.r.t. the upper-Vietoris topology, there must exist finitely many $P_1, \dots, P_n \in \mathfrak{X}$ with $\mathfrak{M} \subseteq \bigcup_{j=1}^n (O_{P_j}^c)^{+\mathfrak{X}}$. Now, from Proposition 3.1 we get $R = \bigcup_{M \in \mathfrak{M}} M \subseteq \bigcup_{j=1}^n O_{P_j}$, where every O_{P_j} is a finite union of members of the original cover $\{O_i \mid i \in I\}$ by construction. \square

Corollary 3.4. *Let (X, τ) be a topological space and let $\mathfrak{M} \subseteq \mathfrak{P}_0(X)$ consist of relatively compact subsets of X . If \mathfrak{M} is compact w.r.t. the upper-Vietoris topology, then*

$$R := \bigcup_{M \in \mathfrak{M}} M$$

is relatively compact in (X, τ) .

Proof. \mathfrak{M} is compact and therefore relatively compact in every set, which contains \mathfrak{M} , especially in the family of all relatively compact subsets of X . So, Lemma 3.3 applies. \square

REFERENCES

- [1] Bartsch, R., Dencker, P., Poppe, H., *Ascoli-Arzelà-Theory based on continuous convergence in an (almost) non-Hausdorff setting*, in "Categorical Topology"; Dordrecht (1996).
- [2] Beer, G., Tamaki, R., *On hit-and-miss hyperspace topologies*, Commentat. Math. Univ. Carol. **34** (1993), No.4, 717-728.
- [3] Beer, G., Tamaki, R., *The infimal value functional and the uniformization of hit-and-miss hyperspace topologies*, Proc. Am. Math. Soc. **122**, No.2 (1994), 601-612.
- [4] Comfort, W.W., Negrepointis, S., *The Theory of Ultrafilters*, Berlin (1974).
- [5] Klein, E., Thompson, A.C., *Theory of correspondences. Including applications to mathematical economics*. Canadian Mathematical Society Series of Monographs and Advanced Texts (1984).
- [6] Michael, E., *Topologies on spaces of subsets*, Trans. Amer. Math. Soc. **71** (1951), 152-182.
- [7] Naimpally, S., *Hyperspaces and Function Spaces*, Q & A in General Topology **9** (1991), 33-60.
- [8] Naimpally, S., *All Hypertopologies are Hit-and-Miss*, Appl. Gen. Topol. **3**, No.1 (2001), 45-53.
- [9] Poppe, H., *Eine Bemerkung über Trennungssaxiome in Räumen von abgeschlossenen Teilmengen topologischer Räume*, Arch.Math. **16** (1965), 197-199.
- [10] Poppe, H., *Einige Bemerkungen über den Raum der abgeschlossenen Mengen*, Fund.Math. **59** (1966), 159-169.
- [11] Poppe, H., *Compactness in General Function Spaces*, Berlin (1974).

RECEIVED NOVEMBER 2001

REVISED SEPTEMBER 2002

RENÉ BARTSCH

Dept. of Computer Science, Rostock University, Albert-Einstein-Straße 21, 18059 Rostock, Germany

E-mail address: rene.bartsch@informatik.uni-rostock.de

HARRY POPPE

Dept. of Mathematics, Rostock University, Universitätsplatz 1, 18055 Rostock, Germany

E-mail address: harry.poppe@mathematik.uni-rostock.de