

Todorcevic orderings as examples of ccc forcings without adding random reals

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TODORCEVIC ORDERINGS AS EXAMPLES OF CCC FORCINGS WITHOUT ADDING RANDOM REALS

TERUYUKI YORIOKA

ABSTRACT. In [13], Todorcevic introduced a ccc forcing which is Borel definable in a separable metric space. In [2], Balcar, Pazák and Thümmel applied it to more general topological spaces and called such forcings *Todorcevic orderings*. In [2], they analyze Todorcevic orderings quite deeply. A significant remark is that Thümmel solved the problem of Horn and Tarski by use of Todorcevic ordering [11].

This paper supplements the analysis of Todorcevic orderings due to Balcar, Pazák and Thümmel in [2]. More precisely, it is proved that Todorcevic orderings add no random reals whenever they have the countable chain condition.

1. INTRODUCTION

In [13], Todorcevic introduced a Borel definable ccc forcing which consistently does not have property K. He defined it on a separable metric space. By generalizing it and applying it to other topological spaces, Thümmel discovered a forcing notion which has the σ -finite chain condition but does not have the σ -bounded chain condition, and so he solved the problem of Horn and Tarski [11]. (For Horn-Tarski's problem, see [5, 14].) Right after Thümmel's result, Todorcevic introduced a Borel definable solution of the problem of Horn and Tarski [15].

In [2], Balcar, Pazák and Thümmel applied Todorcevic's Borel definable ccc forcing in [13] to more general topological spaces. They called such forcings *Todorcevic orderings*. In [2], they analyzed Todorcevic orderings from several view points. One of them is about the countable chain condition. They introduced a sufficient condition for topological spaces (which is called *condition 1*, see below) for which Todorcevic orderings have the countable chain condition. Moreover, they introduced a necessary and sufficient condition for topological spaces for which Todorcevic orderings have the countable chain condition under the Proper Forcing Axiom (in fact, Todorcevic's dichotomy for ω_1 -generated ideals suffices). They also found the space for which Todorcevic ordering does not have the countable chain condition.

In [9], Solovay introduced notion of random reals in terms of forcing theory. The phrase "adding a random real" is equivalent to the phrase "having a regular subalgebra which supports a measure in terms of Boolean algebras". In this paper, we will show that Todorcevic orderings add no random reals whenever they have the countable chain condition (ccc). Todorcevic [13] and Balcar-Pazák-Thümmel [2] provided two sufficient conditions for topological spaces with the cccness of

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Todorćevic orderings. These conditions cover a wide class of topological spaces. So many Todorćevic orderings add no random reals.

In fact, it is proved that ccc Todorćevic orderings satisfy the ${}^\omega 2$ -hyper-properness. The hyper-properness was introduced by Dow-Steprāns [4]. In [4], the hyper-properness is formulated for the Baire space ${}^\omega \omega$. The ${}^\omega 2$ -hyper-properness is Dow-Steprāns' hyper-properness about the Cantor space ${}^\omega 2$ instead of ${}^\omega \omega$. The ${}^\omega 2$ -hyper-properness is stronger than the property "adding no random reals".

In §2, we argue the definition of Todorćevic orderings, their basic observations, two sufficient conditions for topological spaces with the cccness of Todorćevic orderings, Dow-Steprāns' hyper-properness, the theorem in this paper, and its remarks. In §3, it is proved that Todorćevic orderings with the countable chain condition are ${}^\omega 2$ -hyper-proper.

2. PRELIMINARIES

2.1. Todorćevic orderings. As said in [2], when a topological space is applied to Todorćevic ordering, it is natural to require it to be sequential and have the unique limit property⁽¹⁾. A topological space X is called sequential if for any $Z \subseteq X$, Z is closed in X iff for any $A \subseteq Z$ and $x \in X$ to which A converges, x belongs to Z . A topological space X has the unique limit property if any converging subset of X converges to the unique point. For example, Hausdorff spaces have the unique limit property. For a subset F of a topological space, let F^d denote the first Cantor-Bendixson derivative of F , that is, the set of all accumulation points of F .

Definition 2.1 (Todorćevic [13], see also [2, 11]). *For a topological space X , $\mathbb{T}(X)$ is the set of all subsets of X which are unions of finitely many converging sequences including their limit points, and for each p and q in $\mathbb{T}(X)$, $q \leq_{\mathbb{T}(X)} p$ iff $q \supseteq p$ and $q^d \cap p = p^d$.⁽²⁾*

For $p, q \in \mathbb{T}(X)$, the statement $q \leq_{\mathbb{T}(X)} p$ means that q is an extension of p (as the subset relation) and the isolated points in p are still isolated in q . $\mathbb{T}(X)$ is called *Todorćevic ordering for the space X* in [2, 11].

In [15], Todorćevic introduced the Borel definable version of Todorćevic orderings, which consists of all countable compact subsets whose first Cantor-Bendixson derivative is finite. In [2], Balcar-Pazák-Thümmel introduced a separable version of Todorćevic orderings, which consists of all functions f from members p of $\mathbb{T}(X)$ into $\{0, 1\}$ such that $f^{-1}(1)$ is a finite set including p^d as a subset, ordered by the function-extension. In this paper, we adopt the definition of Todorćevic orderings in Definition 2.1. However, all of the proofs in this paper can be applied for the other definitions without any change.

We note that $\mathbb{T}(X)$ is closed under finite unions, i.e. for every $p, q \in \mathbb{T}(X)$, $p \cup q$ is a condition of $\mathbb{T}(X)$ too. But then, $p \cup q$ may not be an extension of p or q . We also note that each condition of $\mathbb{T}(X)$ is a countable closed subset of X .

⁽¹⁾It is used to show that Todorćevic ordering for a space X has the ccc whenever X satisfies condition 1. For condition 1, see below.

⁽²⁾This definition is slightly different from the original one, in [13], which consists of all finite sets σ of convergent sequences in X including their limit points such that for any $A, B \in \sigma$,

$$\lim(A) \notin (B \setminus \{\lim(B)\}),$$

ordered by the reverse inclusion. But essentially, both are same. In fact, both are forcing-equivalent.

In [13], Todorćevic proved that Todorćevic ordering for the reals has the countable chain condition [13, Claim 3]. His proof can be extended to spaces which satisfy that any of its finite powers is hereditarily separable. Namely, for a space X , if each of finite powers of X is hereditarily separable, then Todorćevic ordering for X has the countable chain condition.

In [2], Balcar-Pazák-Thümmel analyzed for what spaces Todorćevic orderings have the countable chain conditions. They gave the property, called *condition 1*, for topological spaces X which is a sufficient condition to introduce Todorćevic orderings to have the countable chain condition:

Condition 1: For any $x \in X$ and $Y \in [X]^{\aleph_1}$, there exists $Y' \in [Y]^{\aleph_1}$ such that any countable subset of Y' does not converge to the point x .

They pointed out that condition 1 is a weak property for topological spaces. Topological spaces with condition 1 includes first countable spaces (hence metric spaces), linear ordered spaces, and hereditarily Lindelöf T_1 -spaces. It seems that condition 1 may not be related to the hereditary separability. A nonseparable metric space has condition 1 but is not hereditarily separable. If a hereditarily separable space does not have condition 1, it has to be an S -space. (For S -spaces, see e.g. [12].)

In [11], Thümmel discovered a counterexample of the problem of Horn and Tarski in [5] whether every poset with the σ -finite chain condition also has the σ -bounded chain condition. More precisely, he proved that Todorćevic ordering for the ordered topological space $\left(\bigcup_{\alpha \in \omega_1} \omega^{\alpha+1}, <_{\text{lex}}\right)^{(3)}$ has the σ -finite chain condition but does not have the σ -bounded chain condition. At first, the author proved that his Todorćevic ordering adds no random reals.

Since a Boolean algebra which supports a measure has the σ -bounded chain condition (see e.g. [1, §4], [14, §1]), it follows from Thümmel's result that the Boolean completion of his Todorćevic ordering does not support a measure. We recall that the phrase “adding a random real” means the phrase “having a regular subalgebra which supports a measure in terms of Boolean algebras”. So it follows from the author's result that a Boolean completion of Thümmel's Todorćevic ordering has no regular subalgebras which support a measure.

2.2. The ω_2 -hyper-properness. In [4, Definition 3.8], Dow and Steprāns introduced the property for forcing notions like the following definition, called the hyper-properness. This is a useful property to show some preservation theorems of the iterated forcings. In fact, the hyper-properness is preserved by countable support iterations. The original definition is formulated for the Baire space ω^ω . But in this paper, we consider it on the Cantor space 2^ω . Two of them are slightly different, so in this paper, we call the following *the ω_2 -hyper properness*.

Definition 2.2 (Dow-Steprāns). *A forcing notion \mathbb{P} is called ω_2 -hyper-proper if for any regular cardinal $\kappa > 2^{|\mathbb{P}|}$, countable elementary submodel N of $H(\kappa)$ which contains \mathbb{P} as a member, $p \in \mathbb{P} \cap N$, and countable family \mathcal{A} of open subsets of 2^ω ,*

⁽³⁾ ω^* stands for the set of natural numbers with the reverse order, and $<_{\text{lex}}$ stands for the lexicographic order. We note that the space $\left(\bigcup_{\alpha \in \omega_1} \omega^{\alpha+1}, <_{\text{lex}}\right)$ satisfies the condition 1.

if ${}^\omega 2 \cap N \subseteq \bigcap \mathcal{A}$, then there is an extension q of p in \mathbb{P} such that q is (N, \mathbb{P}) -generic and

$$q \Vdash_{\mathbb{P}} " {}^\omega 2 \cap N[\dot{G}] \subseteq \bigcap \mathcal{A} ".$$

Since the countable set can be covered by a G_δ Lebesgue measure zero set, the ${}^\omega 2$ -hyper proper forcings add no random reals.

In §3, the following theorem is proved.

Theorem 2.3. *For a topological space X , if $\mathbb{T}(X)$ has the countable chain condition, then $\mathbb{T}(X)$ is ${}^\omega 2$ -hyper-proper, and hence adds no random reals.*

2.3. Remarks on the theorem. In the first draft of the paper, the author proved that for a topological space X , if X satisfies one of the following cases, then $\mathbb{T}(X)$ adds no random reals.

- Any of finite powers of X is hereditarily separable.
- X satisfies condition 1.

Proofs in two cases are in a similar fashion, which has been appeared in [19, Theorem 5.4] and [22]. The only difference in two cases is a proof of **Claim** in §3. The referee let the author know about Dow-Steprāns' hyper-properness and gave a proof of **Claim** in the case that Todorćević orderings have the ccc.

There are several non-ccc forcings which add no random reals, e.g. forcings with the Laver property. But one does not know so many such ccc-examples. A σ -centered forcing was the only well known ccc forcing without adding random reals which is proved in ZFC (due to Judah and Repický [6, Lemma 6], see also [3, Theorem 6.5.30])⁽⁴⁾. As consistent examples, Suslin tree is such a typical example (because this is a ccc forcing without adding new reals), and it is consistent that there exists a ccc perfect poset (due to Velickovic [16, §4]). Talagrand found a weakly distributive ccc σ -complete Boolean algebra which does not carry a measure [10] (which answers Maharam's problem); however, it is not known whether the completion of Talagrand's algebra has a regular subalgebra which carries a measure, that is, which adds a random real.

In [19, Theorem 5.4], the author found a subclass of ccc forcings (which was implicitly introduced by Larson and Todorćević [7]) whose members add no random reals ([19, Theorem 5.3], [21]). This subclass is somewhat wide, for example, it includes a specializing an Aronszajn tree and an interpolating a destructible gap [17, 18, 19, 20, 21]. The theorem in this paper gives a new class of ccc forcings without adding random reals. This is the main motivation of this research.

3. PROOF OF THE THEOREM

Suppose that X is a topological space such that $\mathbb{T}(X)$ has the countable chain condition. We will show that $\mathbb{T}(X)$ is ${}^\omega 2$ -hyper-proper.

Let κ and λ be large enough regular cardinals such that

$$\left(2^{|X|}\right)^+ < \lambda < (2^\lambda)^+ < \kappa,$$

N a countable elementary submodel of $H(\kappa)$ which contains all of finitely many objects we need in the proof (in the current case, N contains X , $\mathcal{P}(X)$ and $H(\lambda)$)

⁽⁴⁾Osuga and Kamo develop Judah-Repický's result to σ -linked forcings of a strong form in some sense [8].

as members), $p \in \mathbb{T}(X) \cap N$, $\langle U_n; n \in \omega \rangle$ a sequence of open subsets of ${}^\omega 2$ such that

$${}^\omega 2 \cap N \subseteq \bigcap_{n \in \omega} U_n,$$

and \dot{x} a $\mathbb{T}(X)$ -name for a real in ${}^\omega 2$. We will show that

$$p \Vdash_{\mathbb{T}(X)} \text{“}\dot{x} \in \bigcap_{n \in \omega} U_n\text{”}.$$

This is what we want.

Suppose that

$$p \not\Vdash_{\mathbb{T}(X)} \text{“}\dot{x} \in \bigcap_{n \in \omega} U_n\text{”},$$

and take an extension q of p in $\mathbb{T}(X)$ and $m \in \omega$ such that

$$q \Vdash_{\mathbb{T}(X)} \text{“}\dot{x} \notin U_m\text{”}.$$

For each $k \in \omega$, define

$S_k := \left\{ v \in {}^k 2; \text{ there exists a countable elementary submodel } M \text{ of } H(\lambda) \text{ which contains the set } \{X, \mathcal{P}(X), \dot{x}, q^d \cap N\} \text{ as a member such that for every } r \in \mathbb{T}(X), \text{ if } r \text{ satisfies the statement} \right.$

(*) r^d includes $q^d \cap N$ as a subset, the size of r^d is equal to the size of q^d , and $(r^d \setminus (q^d \cap N)) \cap M = \emptyset$,

then $r \not\Vdash_{\mathbb{T}(X)} \text{“}\dot{x} \restriction k \neq v\text{”} \left. \right\}$.

We note that the sequence $\langle S_k; k \in \omega \rangle$ belongs to the model N and for each $k \in \omega$, it holds that

$$\{v \restriction k; v \in S_{k+1}\} \subseteq S_k,$$

that is, $\bigcup_{k \in \omega} S_k$ forms a subtree of $2^{<\omega}$ (with respect to the subset relation).

The following is the key point of the proof.

Claim. *For every $k \in \omega$, S_k is not empty.*

We will show this later, and at first we finish the proof assuming **Claim**.

By our assumption and the elementarity of the model N , we can find $u \in {}^\omega 2 \cap N$ such that for every $k \in \omega$, $u \restriction k \in S_k$. Since ${}^\omega 2 \cap N$ is covered by the intersection of the open sets U_n , we can take $l \in \omega$ such that

$$[u \restriction l] := \{y \in {}^\omega 2; u \restriction l \subseteq y\} \subseteq U_m.$$

Since $u \restriction l \in S_l$ in the model N , there exists a countable elementary submodel $M \in N$ of $H(\lambda)$ which witnesses the statement $u \restriction l \in S_l$. Then since q satisfies the statement (*) above for this M in the definition of S_l , it follows that

$$q \not\Vdash_{\mathbb{T}(X)} \text{“}\dot{x} \restriction l \neq u \restriction l\text{”}.$$

Therefore there exists $q' \leq_{\mathbb{T}(X)} q$ such that

$$q' \Vdash_{\mathbb{T}(X)} \text{“}\dot{x} \restriction l = u \restriction l\text{”}.$$

But then

$$q' \Vdash_{\mathbb{T}(X)} \text{“}\dot{x} \in [\dot{x} \restriction l] = [u \restriction l] \subseteq U_m\text{”},$$

which is a contradiction.

Proof of Claim (Due to the referee). Let $k \in \omega$. We show that S_k is not empty.

Assume not, and let $\{v_j; j < 2^k\}$ be an enumeration of the set ${}^k 2$. Then by our assumption, there exists a sequence $\langle r_\xi^j; j < 2^k, \xi \in \omega_1 \rangle$ of conditions of $\mathbb{T}(X)$ such that

- for each $j < 2^k$ and $\xi \in \omega_1$,

$$r_\xi^j \Vdash_{\mathbb{T}(X)} "\dot{x} \restriction k \neq v_j"$$

and

- the set $\left\{ \left(r_\xi^j \right)^d; j < 2^k, \xi \in \omega_1 \right\}$ forms a Δ -system with root $q^d \cap N$.

Then the set $I := \left\{ \bigcup_{j < 2^k} r_\xi^j; \xi \in \omega_1 \right\}$ is an uncountable set of conditions of $\mathbb{T}(X)$.

(Here we don't say that $\bigcup_{j < 2^k} r_\xi^j$ is a common extension of the set $\{r_\xi^j; j < 2^k\}$ in

$\mathbb{T}(X)$. But each $\bigcup_{j < 2^k} r_\xi^j$ is a condition of $\mathbb{T}(X)$.) Since $\mathbb{T}(X)$ is ccc, there exists

$s \in \mathbb{T}(X)$ which forces that $I \cap \dot{G}$ is uncountable (here \dot{G} is the canonical $\mathbb{T}(X)$ -name for a generic filter). Then we can find $s' \leq_{\mathbb{T}(X)} s$ and $\{\xi_i; i < 2^k\} \in [\omega_1]^{2^k}$

such that s' forces that $\left\{ \bigcup_{j < 2^k} r_{\xi_i}^j; i < 2^k \right\} \subseteq \dot{G}$. Then the set $\left\{ \bigcup_{j < 2^k} r_{\xi_i}^j; i < 2^k \right\}$ has a common extension in $\mathbb{T}(X)$.

Therefore the set $\{r_{\xi_i}^i; i < 2^k\}$ has a common extension in $\mathbb{T}(X)$, actually, the set $\bigcup_{i < 2^k} r_{\xi_i}^i$ is its common extension. Then it follows that

$$\bigcup_{i < 2^k} r_{\xi_i}^i \Vdash_{\mathbb{T}(X)} "\dot{x} \restriction k \notin {}^k 2",$$

which is a contradiction.

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DEPARTMENT OF MATHEMATICS, SHIZUOKA UNIVERSITY, OHYA 836, SHIZUOKA, 422-8529, JAPAN.
E-mail address: styorio@ipc.shizuoka.ac.jp