Combinatorial properties of Hechler forcing

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Abstract


Using a notion of rank for Hechler forcing we show: (1) assuming \(\omega_1^\ast = \omega_1\), there is no real in \(V[d]\) which is eventually different from the reals in \(L[d]\), where \(d\) is Hechler over \(V\); (2) adding one Hechler real makes the invariants on the left-hand side of Cichoń's diagram equal \(\omega_1\), and those on the right-hand side equal \(2^\omega\) and produces a maximal almost disjoint family of subsets of \(\omega\) of size \(\omega_1\); (3) there is no perfect set of random reals over \(V\) in \(V[r][d]\), where \(r\) is random over \(V\) and \(d\) Hechler over \(V[r]\), thus answering a question of the first and second authors.

Introduction

In this work we use a notion of rank first introduced by Baumgartner and Dordal in [4, Section 2] and later developed independently by the third author in [8, Section 4] to show that adding a Hechler real has strong combinatorial consequences. Recall that the Hechler partial order \(\mathbb{D}\) is defined as follows:

\[(s, f) \in \mathbb{D} \iff s \in \omega^{<\omega} \land f \in \omega^\omega \land s \subseteq f \land f \text{ strictly increasing},\]

\[(s, f) \preceq (t, g) \iff s \supseteq t \land \forall n \in \omega \ (f(n) \geq g(n)).\]

We note here that our definition differs from the usual one in that it generically adds a strictly increasing function from \(\omega\) to \(\omega\). This is, however, a minor point

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making the definition of the rank in Section 1 easier. We indicate at the end of Section 1 how it can be changed to get the corresponding results in Sections 2 and 4 for classical Hechler forcing.

The theorems of Section 2 are all consequences of one technical result which is expounded in 2.1. We shall sketch how some changes in the latter’s argument prove that adding one Hechler real produces a maximal almost disjoint family of subsets of \( \omega \) of size \( \omega_1 \) (Theorem 2.2). Recall that \( A, B \subset \omega \) are said to be almost disjoint (a.d. for short) iff \( |A \cap B| < \omega \); \( \mathcal{A} \subset [\omega]^\omega \) is an a.d. family iff the members of \( \mathcal{A} \) are pairwise a.d.; and \( \mathcal{A} \) is a m.a.d. family (maximal almost disjoint family) iff it is a.d. and maximal with this property.—We shall then show that assuming \( \omega_1^V = \omega_1^L \), there is no real in \( V[d] \) which is eventually different from the reals in \( L[d] \), where \( d \) is Hechler over \( V \) (Theorem 2.4). Here, we say that given models \( M \subseteq N \) of ZFC, a real \( f \in \omega^\omega \cap N \) is eventually different from the reals in \( M \) iff \( \forall g \in \omega^\omega \cap M \forall n (g(n) \neq f(n)) \), where \( \forall n \) abbreviates for all but finitely many \( n \). (Similarly, \( \exists^* n \) will stand for there are infinitely many \( n \).)—Next we will prove that adding one Hechler real makes the invariants on the left-hand side of Cichoń’s diagram equal \( \omega_1 \) and those on the right-hand side equal \( 2^\omega \) (Theorem 2.5). These invariants (which describe combinatorial properties of measure and category on the real line, and of the eventually dominating order on \( \omega^\omega \)) will be defined, and the shape of Cichoń’s diagram explained, in the discussion preceding the result in Section 2. Theorem 2.5 should be seen as a continuation of research started by Cichoń and Pawlikowski in [6] and [14]. They investigated the effect of adding a Cohen or a random real on the invariants in Cichoń’s diagram.—We close Section 2 with an application concerning absoluteness in the projective hierarchy (Theorem 2.6); namely we show that \( \Sigma^1_4 - \mathcal{B} \)-absoluteness (which means that \( V \) and \( V[d] \), where \( d \) is Hechler over \( V \), satisfy the same \( \Sigma^1_4 \)-sentences with parameters in \( V \)) implies that \( \omega_1^V > \omega_1^{[r]} \) for any real \( r \); in particular \( \omega_1^V \) is inaccessible in \( L \). So, for projective statements, Hechler forcing is much stronger than Cohen or random forcing for \( \Sigma^1_4 \)-Cohen-absoluteness (\( \Sigma^1_4 \)-random-absoluteness) is true in any model gotten by adding \( \omega_1 \) Cohen (random) reals [10, Section 2].

In Section 3 we leave Hechler forcing for a while to deal with perfect sets of random reals instead, and to continue a discussion initiated in [2] and [5]. Recall that given two models \( M \subseteq N \) of ZFC, we say that \( g \in \omega^\omega \cap N \) is a dominating real over \( M \) iff \( \forall f \in \omega^\omega \cap M \forall n (g(n) > f(n)) \); and \( r \in 2^\omega \cap N \) is random over \( M \) iff \( r \) avoids all Borel null sets coded in \( M \) iff \( r \) is the real determined by some filter which is \( \mathcal{B} \)-generic over \( M \) (where \( \mathcal{B} \) is the algebra of Borel sets of \( 2^\omega \) modulo the null sets (random algebra)—see [9, Section 42] for details).—A tree \( T \subseteq 2^{<\omega} \) is perfect iff \( \forall t \in T \exists s \subseteq t (s^{<\omega}(0) \in T \land s^{<\omega}(1) \in T) \). For a perfect tree \( T \) we let \( [T] := \{ f \in 2^\omega; \forall n (f \upharpoonright n \in T) \} \) denote the set of its branches. Then \( [T] \) is a perfect set (in the topology of \( 2^\omega \)). Conversely, given a perfect set \( S \subseteq 2^\omega \) there is a perfect tree \( T \subseteq 2^{<\omega} \) such that \( [T] = S \). This allows us to confuse perfect sets and perfect trees in the sequel; in particular, we shall use the symbol \( T \) for both the
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1. Prelude—a notion of rank for Hechler forcing

1.1. Main Definition (Shelah, see [8, Section 4]—cf. also [4, Section 2]). Given \( t \in \omega^{<\omega} \) strictly increasing and \( A \subseteq \omega^{<\omega} \), we define by induction when the rank \( \text{rk}(t, A) \) is \( \alpha \).

(a) \( \text{rk}(t, A) = 0 \) iff \( t \in A \).
(b) \( \text{rk}(t, A) = \alpha \) iff for no \( \beta < \alpha \) we have \( \text{rk}(t, A) = \beta \), but there are \( m \in \omega \) and \( \langle f_k; k \in \omega \rangle \) such that for all \( i \in \omega \), \( f(i) \geq k \), and \( \text{rk}(t, A, m) < \alpha \).

Clearly, the rank is either \( <\omega_1 \) or undefined (in which case we say \( \text{rk} = \infty \)). We repeat the proof of the following result for it is the main tool for Sections 2 and 4.

1.2. Main Lemma (Baumgartner–Dordal [4, Section 4] and Shelah [8, Section 4]). Let \( I \subseteq \mathcal{D} \) be dense. Set \( A := \{ t; \exists f \in \omega^\omega \text{ such that } (t, f) \in I \} \). Then \( \text{rk}(t^*, A) < \omega_1 \) for any \( t^* \in \omega^{<\omega} \).

Proof. Suppose \( \text{rk}(t^*, A) = \infty \) for some \( t^* \in \omega^{<\omega} \). Let \( S := \{ s \in \omega^{<\omega} \text{ strictly increasing}; t^* \subseteq s \} \) and for all \( s^* \) with \( t^* \subseteq s^* \) and with \( \forall i \in \text{dom}(s^*) \setminus \text{dom}(t^*) \), \( s^*(i) \neq s(i) \), we have \( \text{rk}(s^*, A) = \infty \). \( S \subseteq \omega^{<\omega} \) is a tree with stem \( t^* \).
Suppose $S$ has an infinite branch $(s_i; i \in \omega)$ (i.e., $s_0 = t^*$, $\text{lh}(s_i) = \text{lh}(t^*) + i$, and $s_i \subseteq s_{i+1}$). Let $g$ be the function defined by this branch: $g = \bigcup_{i \in \omega} s_i$. Then $(t^*, g) \in D$. Choose $(t, f) \equiv (t^*, g)$ such that $(t, f) \in I$. Then $t \in A$, i.e., $\text{rk}(t, A) = 0$; but also $t \in S$, i.e., $\text{rk}(t, A) = \infty$, a contradiction.

So suppose $S$ has no infinite branches, and let $s^*$ be a maximal point in $S$. Then we have a sequence $(t_k; k \in \omega)$ such that $\text{lh}(t_k) = \text{lh}(s^*) + 1$, $t_k(\text{lh}(s^*)) \geq k$, $t^* \subseteq t_k$, $\forall i \in \text{dom}(s^*) \setminus \text{dom}(t_k) (t_k(i) \geq s^*(i))$, and $\text{rk}(t_k, A) < \infty$. Now we can find a subset $B \subseteq \omega$ and $\text{lh}(t^*) = m = \text{lh}(s^*)$ and $t \in \omega^m$ such that $\forall k \in B (t_k \upharpoonright m = t)$ and $k < t$, $k, l \in B$, implies $t_k(\text{lh}(i)) < t_l(\text{lh}(i))$. Hence the sequence $(t_k; k \in B)$ witnesses $\text{rk}(t, A) < \infty$. On the other hand $t \in S$; i.e., $\text{rk}(t, A) = \infty$, again a contradiction. □

Usually Hechler forcing $D'$ is defined as follows:

$(s, f) \in D' \iff s \in \omega^{<\omega} \land f \in \omega^\omega \land s \subseteq f$,

$(s, f) \equiv (t, g) \iff s \supseteq t \land \forall n \in \omega (f(n) \geq g(n))$.

We sketch how to introduce a rank on $D'$ having the same consequences as the one on $D$ defined above. Let $\Omega = \{t; \text{dom}(t) \subseteq \omega \land |t| < \omega \land \text{rng}(t) \subseteq \omega\}$. Given $t \in \Omega$ and $A \subseteq \omega^{<\omega}$ we define by induction when the rank $\text{rk}(t, A)$ is $\alpha$.

(a) $\text{rk}(t, A) = 0$ iff $t \in A$.

(b) $\text{rk}(t, A) = \alpha$ iff for no $\beta < \alpha$ we have $\text{rk}(t, A) = \beta$, but there are $M \in [\omega]^{<\omega}$ and $(t_k; k \in \omega)$ such that $\text{dom}(t) \subseteq M$ and $\forall k \in \omega: t \subseteq t_k$, $t_k \in \omega^M$, $\text{rk}(t_k, A) < \alpha$ and $\forall i \in M \setminus \text{dom}(t) \forall k_1, k_2 (t_k_1(i) \neq t_k_2(i))$.

We leave it to the reader to verify that the result corresponding to 1.2 is true for this rank on $D'$, and that the theorems of Sections 2 and 4 can be proved for $D'$ in the same way as they are proved for $D$.

2. Application I—the effect of adding one Hechler real on the invariants in Cichon's diagram

Before being able to state the main result of this section (the consequences of which will be (1) and (2) in the abstract) we have to set up some notation.

Let $A \subseteq [\omega]^\omega$ be an a.d. family. We will produce a set of $D$-names $\{\tau_A; A \in A\}$ for functions in $\omega^\omega$ as follows. For each $A \in A$ fix $f_A: A \to \omega$ onto with $\forall n \exists m \in A (f_A(m) = n)$. Now, if $r \in \omega^\omega$ is a real having the property that $\{n \in \omega; r(n) \in A\}$ is infinite, let $g_r: \omega \to \omega$ be an enumeration of this set (i.e., $g_r(0) :=$ the least $n$ such that $r(n) \in A$; $g_r(1) :=$ the least $n > g_r(0)$ such that $r(n) \in A$; etc.). In this case we let $\tau_A(r): \omega \to \omega$ be defined as follows:

$$\tau_A(r)(n) := f_A(r(g_r(n))).$$

As $A$ is infinite, we have $\|\tau_A\|_{\text{rng}(\bar{A}) \cap A} = \omega^\omega$, where $\bar{A}$ is the name for the Hechler real; in particular $\tau_A(\bar{A}) \in \text{rng}(\bar{A}) \cap A$. Thus we
can think of \( \langle \tau_A(d); A \in \mathcal{A} \rangle \) as a sequence of names in Hechler forcing for objects in \( \omega^\omega \).

2.1. Main Theorem. Whenever \( \mathcal{A} \subseteq [\omega]^\omega \) is an a.d. family in the ground model \( V \), \( d \) is Hechler over \( V \), and \( f \in \omega^\omega \) is any real in \( V[d] \), then \( \{ A \in \mathcal{A}; \forall n \, (f(n) \neq \tau_A(d)(n)) \} \) is at most countable (in \( V[d] \)).

Remark. Slight changes in the proof show that, in fact, \( \{ \tau_A; A \in \mathcal{A} \} \) is a Luzin set in \( V[d] \) for uncountable \( \mathcal{A} \). (Recall that an uncountable set of reals is called Luzin iff for all meager sets \( M \), \( M \cap S \) is at most countable.)

Proof. The proof uses the Main Lemma 1.2 as principal tool. Let \( \dot{f} \) be a \( D \)-name for a real (for an element of \( \omega^\omega \)). Let \( I_n \) be the set of conditions deciding \( \dot{f} \upharpoonright (n + 1) \) (\( n \in \omega \)). All \( I_n \) are dense. Let \( D_n := \{ t; \exists f \in \omega^\omega \) such that \( t, f \in I_n \) \) (cf. the Main Lemma). We want to define when a set \( A \in \mathcal{A} \) is \( n \)-bad.

For each \( t \in \omega^{<}\omega \setminus D_n \) strictly increasing we can find (according to the Main Lemma for \( 0 \)) an \( m \in \omega \) and \( t, k \in \omega^\omega \) such that for all \( k \in \omega : t_k \) is strictly increasing, \( t \subseteq t_k \), \( t_k \in \omega^\omega \), \( t_k(\text{lh}(t)) \geq k \), and \( \text{rk}(t_k, D_n) < \text{rk}(t, D_n) \). Let \( m_1 := m - \text{lh}(t) \). We define by induction on \( i < m_1 \) when \( A \in \mathcal{A} \) is \( t-i-n \)-bad. Along the way we also construct sets \( B_i \) (\( i < m_1 \)).

1. \( i = 0 \). Let \( B_0 = \omega \). If there is \( A \in \mathcal{A} \) such that \( A \cap \{ t_k(\text{lh}(t)); k \in B_0 \} \) is infinite, choose such an \( A_0 \) and let \( A_0 \) be \( t-0-n \)-bad. Now let \( B_1 = \{ k \in \omega; t_k(\text{lh}(t)) \in A_0 \} \). If there is no such \( A \), let \( B_1 = B_0 = \omega \).

2. \( i \rightarrow i + 1 \) (\( i + 1 < m_1 \)). We assume that \( B_{i+1} \) is defined and infinite. If there is \( A \in \mathcal{A} \) such that \( A \cap \{ t_k(\text{lh}(t)); k \in B_{i+1} \} \) is infinite, choose such an \( A_{i+1} \) and let \( A_{i+1} \) be \( t-(i+1)-n \)-bad. Now let \( B_{i+2} = \{ k \in B_{i+1}; t_k(\text{lh}(t) + i + 1) \in A_{i+1} \} \). If there is no such \( A \), let \( B_{i+2} = B_{i+1} \).

In the end, we set \( B_i := B_{m_1} \). We say that \( A \in \mathcal{A} \) is \( n \)-bad iff it is \( t-i-n \)-bad for some strictly increasing \( t \in \omega^{<}\omega \setminus D_n \) and \( i < m_1 \). Finally \( A \in \mathcal{A} \) is bad iff it is \( n \)-bad for some \( n \in \omega \). Let \( A_j = \{ A \in \mathcal{A}; A \text{ bad} \} \). Since for \( n \in \omega \), \( t \in \omega^{<}\omega \) and \( i < m_1 \) at most one \( A \in \mathcal{A} \) is \( t-i-n \)-bad, \( A_j \) is countable.

Claim. If \( A \in \mathcal{A} \setminus \mathcal{A}_j \), then \( \forall D \exists n \, (\hat{f}(n) = \tau_A(d)(n)) \).

Remark. Clearly this Claim finishes the proof of the Main Theorem.

Proof. Suppose not, and choose \( (s, g) \in D, k \in \omega, \) and \( A \in \mathcal{A} \setminus \mathcal{A}_j \) such that

\[
(s, g) \upharpoonright D \forall n \geq k \, (\hat{f}(n) \neq \tau_A(d)(n)).
\]

Let \( l \geq k \) be such that \( |\text{rng}(s) \cap A| \leq l \); i.e., \( s \) does not decide the value of \( \tau_A(d)(l) \). By increasing \( s \), if necessary, we can assume that \(|\text{rng}(s) \cap A| = l \). Let \( Y := \{ t \in \omega^{<}\omega; t \text{ strictly increasing, } s \subseteq t, \forall i \in \text{dom}(s) \setminus \text{dom}(s) \, ((i) \geq g(i)), \text{ and } |\text{rng}(t) \cap A| = l \} \). Choose \( t \in Y \) such that \( \text{rk}(t, D_t) \) is minimal.

Subclaim. \( \text{rk}(t, D_t) = 0 \).
Proof. Suppose not. Then choose by the Main Lemma 1.2 \( m \in \omega \) and \( \langle t_k; k \in \omega \rangle \) (i.e., all \( t_k \) are strictly increasing, \( t \subseteq t_k \), \( t_k \in \omega^\omega \), \( t_k(l(t)) \succ k \), and \( \text{rk}(t_k, D_i) < \text{rk}(t, D_i) \)). In fact, we require that \( m \) and \( \langle t_k; k \in \omega \rangle \) are the same as the ones chosen for \( l, t \) in the definition of \( l \)-badness. Let \( m = m - \text{lh}(t) \) as above, and look at \( B_\gamma \). By construction (as \( A \) is not \( t \)-i \( l \)-bad for any \( i < m_1 \)) and almost disjointness, \( A \cap \{ t_k(l(h(t)) + i); k \in B_{t+1} \} \) is finite for all \( i < m_1 \). So there is \( k \in B_\gamma \) such that \( \text{rng}(t_k) \cap A = \text{rng}(t) \cap A \), i.e., \( |\text{rng}(t_k) \cap A| = l \), and \( t_k(i) \geq g(i) \) for all \( i \in \text{dom}(t_k) \setminus \text{dom}(s) \). Hence \( t_k \in Y \) and \( \text{rk}(t_k, D_i) < \text{rk}(t, D_i) \), contradicting the minimality of \( \text{rk}(t, D_i) \). This proves the Subclaim. \( \square \)

Continuation of the Proof of the Claim. As \( \text{rk}(t, D_i) = 0 \) we have an \( h \in \omega^\omega \) such that \( (t, h) \in I \). Then \( (t, \text{max}(h, g)) \leq (s, g) \), and this condition decides the value of \( f \) at \( i \) without deciding the value of \( \tau_A(\vec{a}) \) at \( l \). Suppose that \( (t, \text{max}(h, g)) \not\models \vec{A} \), \( "f(l) = j" \). Now choose \( i \geq \text{max}(h, g)(l(t)) \) such that \( i \in A \) and \( f_A(i) = j \) (this exists by the choice of the function \( f_A \)). Then

\[
(t \ominus (i), \text{max}(h, g)) \not\models \vec{A} \), \( f(l) = j \).
\]

This final contradiction ends the proof of the Claim and of the Main Theorem. \( \square \)

We will sketch how a modification of this argument gives the following result.

2.2. Theorem. After adding one Hechler real \( d \) to \( V \), there is a maximal almost disjoint family of subsets of \( \omega \) of size \( \omega \), in \( V[d] \).

Sketch of Proof. We start with an observation which will relate Luzin sets and maximal almost disjoint families.

Observation. Let \( \langle N_\alpha; \omega \leq \alpha < \omega_1 \rangle \), \( \langle h_\alpha; \omega \leq \alpha < \omega_1 \rangle \) and \( \langle r_\alpha; \omega \leq \alpha < \omega_1 \rangle \) be sequences such that \( N_\alpha \prec H(\kappa) \) is countable and \( N_\alpha \prec N_\beta \) for \( \alpha < \beta \), \( h_\alpha \in \omega^\omega \cap N_\alpha \) is one-to-one and onto, \( r_\alpha \in \omega^\omega \) is Cohen over \( N_\alpha \) and \( \langle r_\alpha; \alpha < \beta \rangle \in N_\beta \). Define recursively sets \( C_\alpha \) for \( \alpha < \omega_1 \). \( \langle C_\alpha; n \in \omega \rangle \) is a partition of \( \omega \) into countable pieces lying in \( N_\alpha \). For \( \alpha \geq \omega \), \( C_\alpha := \{ r_\alpha(n); n \in \omega \land \forall m < n \ (r_\alpha(n) \notin C_{h_\alpha(m)}) \}. Then \{ C_\alpha; \alpha \in \omega_1 \} \) is an a.d. family.

Proof. The construction gives almost-disjointness. So it suffices to show that each \( C_\alpha \) is infinite. But this follows from the fact that each \( r_\alpha \) is Cohen over \( N_\alpha \) and that the union of finitely many \( C_\beta \)'s (for \( \beta < \alpha \)) is countinfinite. \( \square \)

Now let \( \mathcal{A} = \langle A_\alpha; \alpha < \omega_1 \rangle \in V \) be an a.d. family. As \( \langle \tau_{A_\alpha}(d); \alpha < \omega_1 \rangle \) is Luzin in \( V[d] \) (see the remark following the statement of Theorem 2.1) we can find a strictly increasing function \( \phi: \omega_1 \setminus \omega \to \omega_1 \) and sequences \( \langle N_\alpha; \omega \leq \alpha < \omega_1 \rangle \), \( \langle h_\alpha; \omega \leq \alpha < \omega_1 \rangle \) such that for \( r_\alpha := \tau_{A_\phi(n)}(d) \) the requirements of the above observation are satisfied. By ccc-ness of \( \mathbb{D} \), we may assume that \( \phi \in V \); and
hence, that $\phi = \text{id}$, thinning $\mathcal{A}$ out if necessary. We want to show that the resulting family $\langle C_\alpha; \alpha < \omega_1 \rangle$ is a m.a.d. family.

For suppose not. Then there is a $\mathbb{D}$-name $\check{C}$ such that

$$\mathbb{D} \models \forall \alpha < \omega_1 (|\check{C}_\alpha \cap \check{C}| < \omega).$$

Let $\check{f}$ be the $\mathbb{D}$-name for the strictly increasing enumeration of $\check{C}$. As in the proof of Theorem 2.1 we let $I_n$ be the set of conditions deciding $\check{f} \restriction (n + 1)$, $D_n := \{ t; \exists f \in \omega^\omega ((t, f) \in I_n) \}$, and we define when a set $A \in \mathcal{A}$ is $n$-bad (so that at most countably many sets will be $n$-bad).

Furthermore, for each $\alpha < \omega_1$ we let $\sigma_\alpha$ be the $\mathbb{D}$-name for a natural number such that

$$\mathbb{D} \models \check{C}_\alpha \cap \check{C} \subseteq \sigma_\alpha.$$

We let $I'_\alpha$ be the set of conditions deciding $\sigma_\alpha$, $D'_\alpha := \{ t; \exists f' \in \omega^\omega ((t, f') \in I'_\alpha) \}$; analogously to the proof of Theorem 2.1 we define when a set $A \in \mathcal{A}$ is $\alpha$-bad (so that at most countably many sets will be $\alpha$-bad).

Next choose $\alpha < \omega_1$ such that

1. if $A_\beta$ is $n$-bad for some $n$, then $\beta < \alpha$;
2. if $\beta < \alpha$ and $A_\gamma$ is $\beta$-bad, then $\gamma < \alpha$.

Claim. $\mathbb{D} \models |\check{C}_\alpha \cap \check{C}| = \omega$.

Proof. Suppose not, and choose $(s, g) \in \mathbb{D}$ and $k \in \omega$ such that

$$(s, g) \nvdash \check{C}_\alpha \cap \check{C} \subseteq k.$$

Let $l \geq k$ be such that $|\text{rng}(s) \cap A_\alpha| = l$; without loss of generality $|\text{rng}(s) \cap A_\alpha| = l$. Let $Y := \{ t \in \omega^\omega; t$ strictly increasing, $s \subseteq t, \forall i \in \text{dom}(t) \backslash \text{dom}(s) \ (t(i) \equiv g(i)) \}$, and $|\text{rng}(t) \cap A_\alpha| = l$. By the argument of the Subclaim in the proof of 2.1 there is a $t \in Y$ such that $\forall m < l \ (rk(t, D_{h(m)}') = 0)$. Hence there is an $h \in \omega^\omega$ such that $(t, h) \in \bigcap_{m < l} I_{h(m)}$. Without loss of generality $h \equiv g$. Then $(t, h) \leq (s, g)$, and this condition decides the values of $\sigma_{h(m)}(m < l)$; suppose that $(t, h) \nvdash \forall m < l \ (\sigma_{h(m)}(m < l))$. Choose $l'$ larger than the maximum of the $s_m(m < l)$ and $k$. Again using the argument of the Subclaim (proof of 2.1) find $t' \supseteq t$ such that $\forall i \in \text{dom}(t') \backslash \text{dom}(i) \ (t'(i) > h(i))$, $|\text{rng}(t') \cap A_\alpha| = l$, and $rk(t', D_{l'}) = 0$. Thus there exists an $h' \in \omega^\omega$ such that

$$(t', h') \nvdash \check{f}(l') = j$$

for some $j$.

Without loss of generality $h' \geq h$. Then $(t', h') \leq (t, h)$. As $\nvdash \check{f}$ is strictly increasing', $j \geq h' \geq h$; by construction we have in particular that $(t', h') \nvdash \forall m < l \ (j \not\in \check{C}_{h(m)})$. Choose $i \geq h'(lh(t'))$ such that $i \in A_\alpha$ and $f_{A_\alpha}(i) = j$. Then

$$(t''(i), h') \nvdash \check{f}(l') = j = f_{A_\alpha}(i) = \tau_{A_\alpha}(\check{d})(l) = \check{r}_\alpha(l) \in \check{C}_\alpha.$$

This final contradiction proves the Claim, and Theorem 2.2 as well. □
In our proof we constructed a m.a.d. family of size $\omega_1$ from a Luzin set in $V[d]$. We do not know whether this can be done in ZFC.

2.3. **Question** (Fleissner, see [13, 4.7.]). Does the existence of a Luzin set imply the existence of a m.a.d. family of size $\omega_1$?

**Remark.** It is consistent that there is a m.a.d. family of size $\omega_1$, but no Luzin set. This is known to be true in the model obtained by adding at least $\omega_2$ random reals to a model ZFC + CH.

We next turn to consequences of Theorem 2.1.

2.4. **Theorem.** Let $V \subseteq W$ be universes of set theory, $\omega^V = \omega^W$. Then no real in $W[d]$ is eventually different from the reals in $V[d]$, where $d$ is Hechler over $W$.

**Remark.** Remember that Hechler forcing has an absolute definition. So $d$ will be Hechler over $V$ as well.

**Proof.** Let $\mathcal{A} \subseteq [\omega]^{\omega_1}$ be an almost disjoint family in $V$ of size $\omega_1$. Assume that the functions $f_A$ for $A \in \mathcal{A}$ (defined at the beginning of this section) are also in $V$. Then each real in $W[d]$ can only be eventually different from countably many of the reals in $\{\tau_A(d); A \in \mathcal{A}\} \in V[d]$, by the Main Theorem. \qed

To be able to explain our next corollary to the Main Theorem, we need to introduce a few cardinals. Given a $\sigma$-ideal $\mathcal{F} \subseteq P(\omega)$, we let

- $\text{add}(\mathcal{F}) :=$ the least $\kappa$ such that $\exists \mathcal{F} \in [\mathcal{F}]^\kappa (\bigcup \mathcal{F} \notin \mathcal{F})$;
- $\text{cov}(\mathcal{F}) :=$ the least $\kappa$ such that $\exists \mathcal{F} \in [\mathcal{F}]^\kappa (\bigcup \mathcal{F} = 2^{\omega})$;
- $\text{unif}(\mathcal{F}) :=$ the least $\kappa$ such that $[2^{\omega}]^\kappa \setminus \mathcal{F} \neq \emptyset$;
- $\text{cof}(\mathcal{F}) :=$ the least $\kappa$ such that $\exists \mathcal{F} \in [\mathcal{F}]^\kappa \forall A \in \mathcal{F} \exists B \in \mathcal{F} (A \subseteq B)$.

We also define

- $b :=$ the least $\kappa$ such that $\exists \mathcal{F} \in [\omega^{\omega}]^\kappa \forall f \in \omega^{\omega} \exists g \in \mathcal{F} \exists n (g(n) > f(n))$;
- $d :=$ the least $\kappa$ such that $\exists \mathcal{F} \in [\omega^{\omega}]^\kappa \forall f \in \omega^{\omega} \exists g \in \mathcal{F} \forall n (g(n) > f(n))$.

If $\mathcal{M}$ is the ideal of meager sets, and $\mathcal{N}$ is the ideal of null sets, then we can arrange these cardinals in the following Diagram 1 (called Cichon’s diagram). (Here, the invariants grow larger, as one moves up and to the right in Diagram 1.) The dotted line says that $\text{add}(\mathcal{M}) = \min\{b, \text{cov}(\mathcal{M})\}$ and $\text{cof}(\mathcal{M}) = \max\{d, \text{unif}(\mathcal{M})\}$. For the results which determine the shape of this diagram, we refer the reader to [7]. A survey on independence proofs showing that no other relations can be proved between these cardinals can be found in [3]. We shall need the following characterizations of the cardinals $\text{unif}(\mathcal{M})$ and $\text{cov}(\mathcal{M})$, which
are due to Bartoszyński [1]:

\[ \text{unif}(\mathcal{M}) = \text{the least } \kappa \text{ such that } \exists \mathcal{F} \in [\omega^\omega]^\kappa \forall g \in \omega^\omega \exists f \in \mathcal{F} \exists n (f(n) = g(n)); \]

\[ \text{cov}(\mathcal{M}) = \text{the least } \kappa \text{ such that } \exists \mathcal{F} \in [\omega^\omega]^\kappa \forall g \in \omega^\omega \exists f \in \mathcal{F} \forall n (f(n) \neq g(n)). \]

We are ready to give our next result, which says essentially that after adding one Hechler real, the invariants on the left-hand side of Diagram 1 all equal \( \omega_1 \), whereas those on the right-hand side are all equal to \( 2^\omega \).

2.5. Theorem. After adding one Hechler real \( d \) to \( V \), \( \text{unif}(\mathcal{M}) = \omega_1 \) and \( \text{cov}(\mathcal{M}) = 2^\omega \) in \( V[d] \).

**Proof.**

(i) Let \( \mathcal{A} \subseteq [\omega]^\omega \) be an a.d. family of size \( \omega_1 \) in \( V \). Then by the main theorem no real is eventually different from \( \{ r_A(d); A \in \mathcal{A} \} \), giving \( \text{unif}(\mathcal{M}) = \omega_1 \) (by Bartoszyński's characterization).

(ii) Let \( \mathcal{A} \subseteq [\omega]^\omega \) be an a.d. family of size \( 2^\omega \) in \( V \) (such a family exists, see e.g. [12, Chapter II, Theorem 1.3]). Suppose \( \kappa = \text{cov}(\mathcal{A}) < 2^\omega \), and let \( \{ g_\alpha; \alpha < \kappa \} \) be a family of functions such that \( \forall g \in V[d] \cap \omega^\omega \exists \alpha < \kappa \forall \omega n (g(n) \neq g_\alpha(n)) \), using Bartoszyński's characterization. As \( |\mathcal{A}| = 2^\omega \), there is \( \mathcal{A}' \subseteq \mathcal{A}, |\mathcal{A}'| \geq \omega_1 \), and \( \alpha < \kappa \) such that \( \forall A \in \mathcal{A}' \forall \omega n (\tau_A(A)(n) \neq g_\alpha(n)) \). This contradicts the Main Theorem. \( \square \)

**Remark.** Instead of Bartoszyński's characterization we could have used the fact that \( \{ r_A(d); A \in \mathcal{A} \} \) is a Luzin set (see the remark after 2.1). We leave it to the reader to verify that the existence of a Luzin set implies \( \text{unif}(\mathcal{M}) = \omega_1 \); and that the existence of a Luzin set of size \( 2^\omega \) implies \( \text{cov}(\mathcal{M}) = 2^\omega \).

We close with an application concerning absoluteness in the projective hierarchy. We first recall a notion due to the second author [10, Section 2]. Given a universe of set theory \( V \) and a forcing notion \( \mathbb{P} \) in \( V \) we say that \( V \) is \( \Sigma^0_n \)-\mathbb{P}-absolute if for every \( \Sigma^0_n \)-sentence \( \phi \) with parameters in \( V \) we have \( V \models \phi \) iff \( V^\mathbb{P} \models \phi \). So this is equivalent to saying that \( V^\mathbb{P} <_{\Sigma^0_n} V^\mathbb{P} \). Note that Schoenfield's absoluteness Lemma [9, Theorem 98] says that \( V \) is always \( \Sigma^1_2 \)-\mathbb{P}-absolute. Furthermore, \( \Sigma^1_2 \)-\mathbb{P}-Absoluteness is equivalent to all \( \Sigma^1_2 \)-sets have the property of Baire [10, Section 2]. This is a consequence of Solovay's classical characterization
of the latter statement which says that it is equivalent to: for all reals \( a \), the set of reals Cohen over \( L[a] \) is comeager.

### 2.6. Theorem

\( \Sigma^1_3 \)-\( \mathbb{D} \)-absoluteness implies that \( \omega_1 > \omega^1_1 \) for any real \( r \).

**Proof.** Suppose there is an \( a \in \mathbb{R} \) such that \( \omega^1_1[a] = \omega^V_1 \). By \( \Sigma^1_3 \)-\( \mathbb{D} \)-absoluteness we have that all \( \Sigma^1_3 \)-sets have the property of Baire (see above); i.e., \( \forall b \in \mathbb{R} \) (Co(L[b]) is comeager) (Co(M) denotes the set of reals Cohen over some model \( M \) of ZFC). Note that \( x \in \text{Co}(L[b]) \) is equivalent to

\[ \forall c (c \notin L[b] \cap BC \vee \hat{c} \text{ is not meager} \vee x \notin \hat{c}) \]

where \( BC \) is the set of Borel codes which is \( \Pi^1_1 \) [9, Lemma 42.1], and for \( c \in BC \), \( \hat{c} \) is the set coded by \( c \). As \( L[b] \) is \( \Sigma^1_3 \) [9, Lemma 41.1], Co(L[b]) is a \( \Pi^1_2 \)-set. Hence \( \forall b \in \mathbb{R} \) (Co(L[b]) is comeager) which is equivalent to

\[ \forall b \exists c (c \in BC \land \hat{c} \text{ is meager} \land \forall x (x \in \hat{c} \lor x \in \text{Co}(L[b]))) \]

is a \( \Pi^1_2 \)-sentence. So it is true in \( V^\mathbb{D} \) by \( \Sigma^1_3 \)-\( \mathbb{D} \)-absoluteness; in particular Co(L[a][d]) is comeager in \( V[d] \) which implies that there is a dominating real in \( V[d] \) over \( L[a][d] \), contradicting Theorem 2.4.

### 2.7. Question

Are there results similar to Theorems 2.4, 2.5, and 2.6, for Amoeba forcing or Amoeba-meager forcing?

We conjecture that the answer is yes because both the Amoeba algebra and the Amoeba-meager algebra contain \( \mathbb{D} \) as a complete subalgebra (see [15, Section 6]; a definition of the algebras can also be found there). But there doesn't seem to be a way to introduce a rank on these algebras (as in Section 1).

### 3. Interlude—perfect sets of random reals

#### 3.1. Theorem

Let \( V \subseteq W \) be models of ZFC. Suppose there is a perfect set of random reals in \( W \) over \( V \). Then either

1. there is a dominating real in \( W \) over \( V \); or
2. \( \mu(2^\omega \cap V) = 0 \) in \( W \).

**Proof.** Suppose not, and let \( T \in W \) be a perfect set of random reals. Define \( f \in \omega^\omega \cap W \) as follows:

\[ f(i) = \min\{k; \forall \sigma \in T \cap 2^i (|T \cap 2^k| > 4^i)\}. \]

Let \( g \in \omega^\omega \cap V \) be such that \( \exists^\omega \sigma (g(i) \geq f(i)) \). Let \( U \) be the family of all \( u \in \Pi_{i<\omega} P(2^{<i}) \) such that \( u(i) \leq g(i) \) and \( |u(i)|/2^{g(i)} - 2^{-i} \). \( U \) can be thought of as
a measure space (namely, for \( u \in 2^{g(i)} \) with \(|u|/2^{g(i)} = 2^{-i}\) let
\[
\mu_i(u) = 1 / \left(2^{g(i)}\right);
\]
and let \( \mu \) be the product measure of the \( \mu_i \).

Let \( N \subset \langle H(\kappa)^W, \ldots \rangle \) be countable with \( g, T \in N \). As \( \mu(2^\omega \cap V) \neq 0 \) in \( W \), we cannot have that \( 2^\omega \cap V \subseteq \bigcup \{ B; \mu(B) = 0, B \in N, B \text{ Borel} \} \); i.e., there are reals in \( V \) which are random over \( N \). Let \( u^* \in U \) be such a real. Using \( u^* \) we can define a measure zero set \( B \) in \( V \) as follows:
\[
B = \{ h \in 2^\omega; \exists i (h \upharpoonright g(i) \in u^*(i)) \}.
\]
Let (for \( k \in \omega \)) \( B_k = \{ h \in 2^\omega; \forall i \geq k (h \upharpoonright g(i) \notin u^*(i)) \} \). Clearly \( 2^\omega \setminus B = \bigcup_{k \in \omega} B_k \); and the \( B_k \) form an increasing chain of perfect sets of positive measure.

As all reals in \( T \) are random over \( V \) we must have \( T \subseteq \bigcup_{k \in \omega} B_k \). This gives us \( \sigma \in T \) and \( k \in \omega \) such that \( T_0 \subseteq B_k \) (otherwise choose \( \sigma_0 \in T \) such that \( \sigma_0 \notin B_0 \), \( \sigma_1 \in T_{\sigma_0} \) such that \( \sigma_1 \notin B_1 \), etc. This way we construct a branch in \( T \) which does not lie in \( \bigcup_{k \in \omega} B_k \), a contradiction).

By construction, we know that for infinitely many \( i \), we have \( |T_o \cap 2^{g(i)}| > 4^i \) and \( u^*(i) \cap (T_o \cap 2^{g(i)}) = \emptyset \). For each such \( i \) and \( u \subseteq 2^{g(i)} \) with \(|u|/2^{g(i)} = 2^{-i}\), the probability that \( u \cap (T_o \cap 2^{g(i)}) = \emptyset \) (in the sense of the measure \( \mu_i \) defined above) is
\[
\leq \left(\frac{2^{g(i)} - 4^i}{2^{g(i)}}\right)^{2^{g(i)-i}} \leq (e^{-4^i/2^{g(i)}})^{2^{g(i)-i}} = e^{-2^i}.
\]
So the probability that this happens infinitely often is zero. But \( u^* \) is random over \( N \), a contradiction. \( \Box \)

**Corollary** (Cichoń [2, Section 2]). If \( r \) is random over \( V \), then there is no perfect set of random reals in \( V[r] \) over \( V \). \( \Box \)

**Remark.** Theorem 3.1 is best possible in the following sense.

(1) It is consistent that there are \( V \subseteq W \) and a perfect tree \( T \) of random reals in \( W \) over \( V \) and \( \mu^*(2^\omega \cap V) > 0 \) in \( W \) (\( \mu^* \) denotes outer measure). To see this add a Laver real \( l \) to \( V \) and then a random real \( r \) to \( V[l] \); set \( W = V[l][r] \). By [2, Theorem 2.7] there is a perfect tree of random reals in \( W \) over \( V \); and by [11, Section 1] \( \mu^*(2^\omega \cap V) > 0 \) in \( V[l] \) and hence in \( W \).

(2) It is consistent that there are \( V \subseteq W \) and a perfect tree \( T \) of random reals in \( W \) over \( V \) and no dominating real in \( W \) over \( V \) (see [5, Theorem 1]).

Before being able to state some consequences of this result, we need to introduce two further cardinals.

\[
\text{wcov}(\mathcal{N}) := \text{the least } \kappa \text{ such that } \exists \mathcal{F} \in [\mathcal{N}]^\kappa \quad (2^\omega \setminus \bigcup \mathcal{F} \text{ does not contain a perfect set});
\]
\[
\text{wunif}(\mathcal{N}) := \text{the least } \kappa \text{ such that there is a family } \mathcal{F} \in [[2^{<\omega}]^{<\omega}]^\kappa \text{ of perfect sets with } \forall N \in \mathcal{N} \exists T \in \mathcal{F} (N \cap T = \emptyset).
\]
We can arrange these cardinals and some of those of the preceding section in the following Diagram 2. (Here the invariants get larger as one moves up in Diagram 2.) The dotted line says that $\text{wcov}(\mathcal{N}) \geq \min\{\text{cov}(\mathcal{N}), b\}$ (and dually, $\text{wunif}(\mathcal{N}) \leq \max\{\text{unif}(\mathcal{N}), d\}$) (see [2, Section 2] or [5, 1.9]). Using the above result we get

3.2. Theorem. (i) $\text{wcov}(\mathcal{N}) \leq \max\{b, \text{unif}(\mathcal{N})\}$.

(ii) $\text{wunif}(\mathcal{N}) \leq \min\{d, \text{cov}(\mathcal{N})\}$.—In fact, given $V \subseteq W$ models of ZFC such that in $W$ there is a real which is random over a real which is unbounded over $V$, there exists a null set $N \in W$ such that for all perfect sets $T \in V$, $T \cap N \neq \emptyset$.

Proof. (i) follows immediately from Theorem 3.1; and the first sentence of (ii) follows from the last sentence of (ii). The latter is proved by an argument which closely follows the lines of the proof of Theorem 3.1, and is therefore left to the reader. □

The most interesting question concerning the relationship of the cardinals in the above diagram is the following (Question 3' of [5]).

3.3. Question. Is it consistent that $\text{wcov}(\mathcal{N}) > d$? Dually, is it consistent that $\text{wunif}(\mathcal{N}) > b$?

4. Application II—adding a Hechler real over a random real does not produce a perfect set of random reals

4.1. Theorem. Let $V \subseteq W$ be models of ZFC such that

(1) there is no dominating real in $W$ over $V$;
(2) $2^{\omega} \cap V$ is non-measurable in $W$.

Then there is no perfect set of random reals in $W[d]$, where $d$ is Hechler over $W$. 
Remark. This result clearly contains Theorem 3.1 as a special case; still we
decided to bring the latter as a separate result because it has consequences for the
cardinals involved (see above, Theorem 3.2). Also, the proof of Theorem 4.1 can
be seen as a combination of the argument for 3.1 and the techniques developed in
Section 1.

4.2. Corollary. There is no perfect set of random reals in \( V[r][d] \), where \( r \) is
random over \( V \), and \( d \) is Hechler over \( W = V[r] \). \( \square \)

Proof of Theorem 4.1. We work in \( W \). Let \( \hat{T} \) be a \( \mathbb{D} \)-name for a perfect tree. We
want to show that \( T = \hat{T}[G] \) (\( G \) \( \mathbb{D} \)-generic over \( W \)) contains reals which are not
random over \( V \). We say that \( A \subseteq \omega^{<\omega} \) is large iff \( \forall(s, f) \in \mathbb{D} \exists s' \in A \) with
\((s', f) \leq (s, f) \). (By \((s', f) \) we mean here and in the sequel the condition \((s', f') \)
where \( f' \upharpoonright \text{dom}(s') = s' \) and \( f'(n) = f(n) \) for \( n > \text{dom}(s') \)).

Claim. The following set \( A \) is large: \( s \in A \iff \) for some \( k < \omega \) and \( \langle t_i, f_i, f'_i; \)
\( i \in \omega \rangle \) we have \( s \subseteq t_i \), \( t_i \in \omega^k \), \( t_i(\text{lh}(s)) \geq i \), \( f_i \neq f'_i \in \omega^2 \), \( f_i \upharpoonright i = f'_i \upharpoonright i \), and
\( \forall f \in \omega^\omega \) (with \( t_i \subseteq f \)) \( \forall m \in \omega \forall i \in \{1, 2\} \langle (t_i, f) \not\models f'_i \upharpoonright m \).

Proof. Let \( sp \hat{T} \) be the \( \mathbb{D} \)-name for the subset of \( \omega \) which describes the levels at
which there is a splitting node in \( \hat{T} \). By thinning out \( T \) (in the generic extension) if
necessary, we may assume that

\[ \upharpoonright_{\omega_0} \text{the } j \text{-th member of } sp \hat{T} \text{ (denoted by } \tau_j \text{) is } >_{\hat{d}}(j), \]

where \( \hat{d} \) is (as always) the \( \mathbb{D} \)-name for the Hechler real. Let \((s^*, f^*) \in \mathbb{D},
\text{lh}(s^*) = f^* \). So \((s^*, f^*) \) forces no bound on \( \tau_j \)--even no \((s^*, f') \) does \((*)\). We
assume there is no \( s \in A \) with \((s^*, f^*) \leq (s^*, f^*) \) and reach a contradiction.

Let \( I \) be the dense set of conditions forcing a value to \( \tau_j \), and let
\( B = \{s \in \omega^{<\omega}; \exists f \in \omega^\omega ((s, f) \in I) \}. \) By the Main Lemma 1.2 we have \( \text{rk}(s^*, B) < \omega_1 \). We prove by induction on the ordinal \( \beta < \omega_1 \)

\[ \text{(**) if } s \in \omega^{<\omega} \text{ is such that } (s, f^*) \equiv (s^*, f^*) \text{ and } \text{rk}(s, B) = \beta, \text{ then} \]
\[ \exists m < \omega \forall f \in \omega^\omega \text{ (with } s \subseteq f \langle (s, f) \not\models \tau_j \neq m \rangle. \]

If we succeed for \( s = s^* \) then we get a contradiction to \((*)\).

\( \beta = 0. \) So \( s \in B \). Thus for some \( f' \supseteq f^* \), \((s, f') \) forces a value to \( \tau_j \):
\( (s, f') \models \tau_j = m \), for some \( m \in \omega \), giving \((**)\).

\( \beta > 0. \) By the definition of rank there are \( k \in \omega \), \( t_i \in \omega^k \) \( (l \in \omega) \) such that
\( s \subseteq t_i \), \( t_i(\text{lh}(s)) \geq i \), and \( \text{rk}(t_i, B) = \beta_i < \beta \). (We consider only \( l \) with \( l \geq \text{max}(\text{rng}(f^* \upharpoonright \{k\})) \). By induction hypothesis there are \( m_i \in \omega \) such that \( \forall f \in \omega^\omega \) (with \( t_i \subseteq f \) \( (t_i, f) \not\models \tau_j \neq m_i \)). We consider two subcases.

Case 1. For some \( m \) we have infinitely many \( l \) such that \( m_l = m \). Then we can
use this \( m \) for \( s \) and get \((**)\).

Case 2. \( \langle m_i; l \in \omega \rangle \) converges to \( \infty \). Replacing it by a subsequence, if
necessary, we may assume that it is strictly increasing. We show that \( \langle t_i; l \in \omega \rangle \)
witnesses \( s \in A \), contradicting our initial assumption.
For each \( l \) let \( T_l = \{ \rho \in 2^{<\omega} ; \text{ for no } \tau \in \omega^\omega \text{ does } (t_l, f) \vdash \rho \notin \bar{T} \} \). Clearly \( T_1 \subseteq 2^{<\omega} \), \( \langle \rangle \in T_1 \), and \( T_1 \) is closed under initial segments. Also we have that \( \rho \in T_l \) implies either \( \rho^{-}(0) \in T_l \) or \( \rho^{-}(1) \in T_l \) (otherwise we can find \( f_0, f_1 \in \omega^\omega \) such that \( (t_l, f_0) \models \rho^{-}(0) \notin \bar{T} \) and \( (t_l, f_1) \models \rho^{-}(1) \notin \bar{T} \); let \( f = \max\{f_0, f_1\} \); choose \( p \leq \langle t_l, f \rangle \) such that \( p \vdash \rho \in \bar{T} \) (by assumption on \( \rho \)); but then there exists \( q \leq p \) such that either \( q \vdash \rho^{-}(0) \in \bar{T} \) or \( q \vdash \rho^{-}(1) \in \bar{T} \), a contradiction).

Finally, \( T_1 \) has a splitting node at level \( m_1 \); i.e., for some \( \rho = \rho_{m_1} \in 2^{<\omega} \), \( \rho^{-}(0) \in T_1 \) and \( \rho^{-}(1) \in T_1 \) (if not, for each \( \rho \in 2^{<\omega} \) \( \exists f_0, f_1 \in \omega^\omega \) such that \( (t_l, f_0) \models \rho^{-}(0) \notin \bar{T} \) or \( (t_l, f_1) \models \rho^{-}(1) \notin \bar{T} \); let \( f = \max\{f_0, f_1\} \). We know that \( (t_l, f) \not\models m_1 \neq \tau_j \); so there is \( p \leq \langle t_l, f \rangle \) such that \( p \vdash \rho \in \bar{T} \); i.e., \( \rho \vdash m_1 = \tau_j \); we now get a contradiction as before).

Hence we can find \( f_1, f_2 \in \bar{T} \) such that \( f_1 \upharpoonright (m_1 + 1) = \rho_{m_1}^{-}(0) \) and \( f_2 \upharpoonright (m_1 + 1) = \rho_{m_1}^{-}(1) \). Thus \( \langle t_l ; l \in \omega \rangle, \langle f_1, f_2 ; l \in \omega \rangle \) witness \( s \in A \). This final contradiction proves the Claim. \( \Box \)

Continuation of the Proof of Theorem 4.1. We assume that \( \models \bar{T} = \{ \tau_{j_1} ; j \in \omega \} \); i.e., \( \tau_j[G] (j \in \omega) \) will enumerate the tree \( T = \bar{T}[G] \) in the generic extension. We also let \( \bar{T}_j \) be the name for the tree \( T_{\tau_j[G]} \); i.e., \( \models_{\omega} \bar{T}_j = \{ \nu \in \bar{T} ; \nu \subseteq \tau_j \text{ or } \tau_j \subseteq \nu \} \). For each \( j \in \omega \) there is—according to the Claim for \( \bar{T}_j \) instead of \( \bar{T} \)—a large set \( A_j \subseteq \omega^{<\omega} \); and for \( s \in A_j \) there is a sequence \( \langle t_{j, l}^{i}, f_{j, l}^{i} , f_{j, l}^{i-j} ; l \in \omega \rangle \) that witnesses \( s \in A_j \). For every \( j \in \omega \), \( s \in A_j \) and \( m \in \omega \) we define \( S_{j, i, m} = \{ f_{j, l}^{i} \upharpoonright k ; k \in \omega, i \in \{1, 2\}, m \leq l \in \omega \} \). By construction the function \( f_{j, i, m} \) defined by \( f_{j, i, m}(k) = |S_{j, i, m} \cap 2^{k}| \) converges to \( \omega \). Assume (1) we can choose \( g \in \omega^\omega \cap M \) such that \( \forall j, s, m \exists i (|S_{j, i, m} \cap 2^{g(i)}| > 4') \).

Now let \( U \) be as in the proof of Theorem 3.1; and choose \( u^* \in U \) as there (i.e., \( u^* \) is random over a countable model \( N \) containing \( g \) and all \( S_{j, i, m} \) using assumption (2)). We also define \( B_k (k \in \omega) \) as in the proof of Theorem 3.1.

We assume that \( \models \bar{T} \) is a perfect set of reals random over \( V^\omega \); in particular \( \models \bar{T} \subseteq \bigcup_{k \in \omega} B_k \). So there are \( (s^*, f^*) \in D, j \in \omega \) and \( k \in \omega \) such that \( (s^*, f^*) \models \bar{T}_j \subseteq B_k \) (cf. the corresponding argument in the proof of Theorem 3.1). Without loss of generality \( s^* \in A_j \) (otherwise increase the condition using the Claim). Let \( m > \max(\text{rng}(f^* \upharpoonright k_{j, s^*})) \) where \( k_{j, s^*} \) is such that for all \( l \in \omega \), \( t_l^{i, j} \in \omega^{k_{j, s^*}} \). Then \( \forall l \geq m \quad (t_l^{i, j} , f^*) \) is an extension of \( (s^*, f^*) \). So we must have \( S_{j, i, s^*, m} \subseteq B_k \) (because for any element of the former set we have extension of \( (s^*, f^*) \) forcing this element into \( \bar{T}_j \)).

The rest of the proof is again as in the proof of Theorem 3.1. For infinitely many \( i \) we have \( |S_{j, i, s^*, m} \cap 2^{g(i)}| > 4' \); for each such \( i \), the probability that \( u^*(i) \cap (S_{j, i, s^*, m} \cap 2^{g(i)}) = \emptyset \) is \( e^{-2} \); the probability that this happens infinitely often is zero, contradicting the fact that \( u^* \) is random over \( N \). \( \Box \)

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Combinatorial properties of Hechler forcing

References