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\title{LARGE CONTINUUM, ORACLES
SH895}
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\begin{document}
\maketitle

\section*{Abstract.}
Our main theorem is about iterated forcing for making the continuum larger than $\aleph_2$. We present a generalization of [Sh:669] which dealt with oracles for random, (also for other cases and generalities), by replacing $\aleph_1, \aleph_2$ by $\lambda, \lambda^+$ (starting with $\lambda = \aleph^\lambda > \aleph_1$). Well, we demand absolute c.c.c. So we get, e.g. the continuum is $\lambda^+$ but we can get $\text{cov(meagre)} = \lambda$ and we give some applications. As in “non-Cohen oracles”, [Sh:669], it is a “partial” countable support iteration but it is c.c.c.

\section{Introduction}
Starting, e.g. with $V \models \text{G.C.H.}$ and $\lambda = \aleph^\lambda > \aleph_1$, we construct a forcing notion $P$ of cardinality $\lambda^+$, by a partial CS iteration but the result is a c.c.c. forcing.

The general iteration theorems (treated in §1) seem generally suitable for constructing universes with $\text{MA}_{<\lambda} + 2^{\aleph_0} = \lambda^+$, and taking more care, we should be able to get universes without $\text{MA}_{<\lambda}$, see 0.4 below.

Our method is to imitate [Sh:669]; concerning the differences, some are inessential: using games not using diamonds in the framework itself, (inessential means that we could have in [Sh:669] imitate the choice here and vice versa).

An essential difference is that we deal here with large continuum - $\lambda^+$; we concentrate on the case where we shall (in $V^P$) have $\text{MA}_{<\lambda}$ but e.g. $\text{non(null)} = \lambda$ and $b = \lambda^+$ (or $b = \lambda$).

It seems to us that generally:

\textit{Thesis 0.1.} The iteration theorem here is enough to get results parallel to known results with $2^{\aleph_0} = \aleph_2$ replacing $\aleph_1, \aleph_2$ by $\lambda, \lambda^+$.

To test this thesis we have asked Bartoszyński to suggest test problems for this method and he suggests:

\textit{Problem 0.2.} Prove the consistency of each of the

\begin{enumerate}
\item[(A)] $\aleph_1 < \lambda < 2^{\aleph_0}$ and the $\lambda$-Borel conjecture, i.e. $A \subseteq \omega^2$ is of strong measure zero iff $|A| < \lambda$
\item[(B)] $\aleph_1 < \text{non(null)} < 2^{\aleph_0}$, see 5.1
\end{enumerate}

\end{document}
(C) $\aleph_1 < b = \lambda < 2^{\aleph_0}$ the dual $\lambda$-Borel conjecture (i.e. $A \subseteq \omega_2$ is strongly meagre iff $|A| < \lambda$)

(D) $\aleph_1 < b = \lambda < 2^{\aleph_0}+$ the dual $2^{\aleph_0}$-Borel conjecture

(E) combine (A) and (C) and/or combine (A) and (D).

Parallely Steprans suggests:

\textbf{Problem 0.3.} 1) Is there a set $A \subseteq \omega_2$ of cardinality $\aleph_2$ of $p$-Hausdorff measure $> 0$, but for every set of size $\aleph_2$ is null (for the Lebesgue measure)?

2) The (basic product) I think $b = d \lor d = 2^{\aleph_0}$ gives an answer, what about $\text{cov(meagre)} = \lambda < 2^{\aleph_0}$?

We shall deal with the iteration in §1, give an application to a problem from [Sh:885] in §2 (and §3, §4).

Lastly, in §5 we deal with Bartoszyński’s test problem (B), in fact, we get quite general such results.

It is natural to ask

\textbf{Discussion 0.4.} 1) In §1, we may wonder if we can give a “reasonable” sufficient condition for $b = \aleph_1$ or $b = \kappa < \lambda$? The answer is yes. It is natural to assume that we have in $V$ a $<_{\text{cf}\omega}$-increasing sequence $f = \langle f_\alpha : \alpha < \kappa \rangle$ of functions from $\omega^2$ with no $<_{\text{cf}\omega}$-upper bound and we would like to preserve this property of $f$, i.e. in §1 we

(a) restrict ourselves to $p \in K^1_\lambda$ such that $\Vdash_p \bar{f}$ as above”.

More formally redefine $K^1_\lambda$ such that

(b) replace “$P$ is absolute c.c.c.” by “$P$ is c.c.c., preserve $\bar{f}$ as above and if $Q$ satisfies those two conditions then also the product $P \times Q$ satisfies those two conditions”.

This has similar closure properties, that is, the proofs do not really change.

2) More generally consider $K$, a property of forcing notions such that:

(a) $P \in K \Rightarrow P$ is c.c.c.

(b) $K$ is closed under $\prec$-increasing continuous unions

(c) $K$ is closed under composition

(d) we replace in §1 “$p \in K^1_\lambda$” by “$p \in K$ has cardinality $< \lambda$”

(e) we replace in §1, “$P$ is absolutely c.c.c.” by “$P \in K$ and $R \in K \Rightarrow P \times R \in K$”.

3) What about using $\mathcal{P}(n)$-amalgamation of forcing notions? (See [Sh:705] in model theoretic version.) If we fix $n$ this seems a natural way to get non-equality for many $n$-tuples of cardinal invariants; hopefully we shall return to this sometime.

4) What about forcing by the set of approximations $K$? See 1.15.

5) You may wonder why here “absolute c.c.c.” play a major role but is not used in [Sh:669]. The answer is that the “absolute c.c.c.” is demanded on forcing notions of cardinality $< \lambda$ which in [Sh:669] means countable.
Definition 0.5. 1) We say a forcing notion $P$ is absolutely c.c.c. when for every c.c.c. forcing notion $Q$ we have $\Vdash_Q "P$ is c.c.c." 
2) We say $P_2$ is absolutely c.c.c. over $P_1$ when ($P_1 \subsetneq P_2$ and) $P_2/P_1$ is absolutely c.c.c.
3) Let $P_1 \subseteq ic P_2$ mean that $P_1 \subseteq P_2$ (as quasi orders) and if $p, q \in P_1$ are incompatible in $P_1$ then they are incompatible in $P_2$ (the inverse follows by $P_1 \subseteq P_2$).

The following tries to describe the iteration theorem, this may be more useful to the reader after having a first reading of §1.

We treat $\lambda$ as the vertical direction and $\lambda^+$ as the horizontal direction, the meaning will be clarified in §2; our forcing is the increasing union of $\langle P_\alpha[k_\varepsilon] : \varepsilon < \lambda^+ \rangle$ where $k_\varepsilon \in K_2$ (so $k_\varepsilon$ gives an iteration $\langle P_\alpha[k_\varepsilon] : \alpha < \lambda \rangle$, i.e. a $\subseteq$-increasing continuous sequence of c.c.c. forcing notions) and for each such $k_\varepsilon$ each iterand $P_{p_\varepsilon}[k_\varepsilon]$ is of cardinality $< \lambda$ and for each $\varepsilon < \lambda^+$ the forcing notion $P^{k_\varepsilon}$ is the union of the increasing continuous sequence $\langle P_{p_\varepsilon}[k_\varepsilon] : \alpha < \lambda \rangle$. So we can say that $P^{k_\varepsilon}$ is the limit of an FS iteration of length $\lambda$, each iterand of cardinality $< \lambda$ and for $\zeta \in (\varepsilon, \lambda^+)$, $k_\zeta$ gives a “fatter” iteration, which for “most” $\delta \in S(\subseteq \lambda)$, is a reasonable extension.

Question 0.6. Can we get something interesting for the continuum $> \lambda^+$ and/or get $\text{cov}(\text{meagre}) < \lambda$? This certainly involves some losses! We intend to try elsewhere.

Definition 0.7. 1) For a set $x$ let $\text{otrcl}(x)$, the transitive closure over the ordinals of $x$, be the minimal set $y$ such that $x \subseteq y \land (\forall t \in y)(t \not\in \text{Ord} \rightarrow t \subseteq y)$.
2) For a set $u$ of ordinals let $\mathcal{H}_{<\kappa}(u)$ be the set of $x$ such that $\text{otrcl}(x) \cap \text{Ord}$ is a subset of $u$ of cardinality $< \kappa$.

Remark 0.8. 0) We use $\mathcal{H}_{<\kappa}(u)$ (in Definition 1.2) just for bookkeeping convenience.
1) It is natural to have $\text{Ord}$, the class of ordinals, a class of urelements.
2) If $\omega_1 \subseteq u$ for $\mathcal{H}_{<\kappa_1}(u)$ it makes no difference, but if $\omega_1 \not\subseteq u$ and $\beta = \min(\omega_1 \setminus u)$ then $\beta$ is a countable subset of $u$ but $\not\in \mathcal{H}_{<\kappa_1}(u)$. Also we use $\mathcal{H}_{<\omega_0}(u)$ where $\omega \subseteq u$, so there are no problems.
§ 1. The Iteration Theorem

If we use the construction for $\lambda = \aleph_1$, the version we get is closer to, but not the same as [Sh:669]; in this case it may be more convenient to have the forcing locally Cohen.

We now list “atomic” forcings used below coming from three sources:

(a) the forcing given by the winning strategies $s_\beta$ (see below), i.e. the quotient $\mathbb{P}_q_i/\mathbb{P}_{p_i}$, see Definition 1.11

(b) forcing notions intended to generate $\text{MA}_\lambda$

[see 1.24; we are given $k_1 \in K_2^\lambda$; an approximation of size $\lambda$, see Definition 1.15, and a $\mathbb{P}_{k_i}$-name $Q$ of a c.c.c. forcing and sequence $\langle \mathbb{S}_i : i < i(*) \rangle$ of $< \lambda$ dense subsets of $Q$. We would like to find $k_2 \in K_2$ satisfying $k_1 \leq K_2^\lambda k_2$ such that $\Vdash_{k_2} \text{there is a directed } G \subseteq Q \text{ not disjoint to any } \mathbb{S}_i(i < i(*))$. We do not use composition, only $\mathbb{P}_{p_1[k_2]} = \mathbb{P}_{p_1[k_1]} \ast Q$ for some $\alpha \in E_{k_1} \cap E_{k_2}$]

(c) given $k_1 \in K_2^\lambda$, and $Q$ which is a $\mathbb{P}_{k_1}$-name of a suitable c.c.c. forcing notion of cardinality $\lambda$ can we find $k_2$ such that $k_1 \leq K_2^\lambda k_2$ and in $V$ we have $\Vdash_{p_{1[k_2]}} \text{there is a subset of } Q \text{ generic over } V[G, \mathbb{P}[k_2] \cap \mathbb{P}_{k_1}]$.

Let us describe the roles of some of the definitions. We shall construct (in the main case) a forcing notion of cardinality $\lambda^+$ by approximations $k \in K_2^\lambda$ of size ($= \text{cardinality}$) $\lambda$, see Definition 1.15, which are constructed by an increasing sequence of approximations $p \in K_1$ of cardinality $< \lambda$, see Definition 1.2.

Now $p \in K_1$ is essentially a forcing notion of cardinality $< \lambda$, i.e. $\mathbb{P}_p = (P_p, \leq_p)$, and we add the set $u = u_p$ to help the bookkeeping, so (in the main case) $u_p \in [\lambda^+]^{< \lambda}$. For the bookkeeping we let $P_p \subseteq \mathcal{H} < K_1(u_p)$, see 0.7(2).

More specifically $k$ (from Definition 1.15) is mainly a $\leq$-increasing continuous sequence $p = \langle p_\alpha : \alpha \in E_k \rangle = \langle p_\alpha[k] : \alpha \in E_k \rangle$, where $E_k$ is a club of $\lambda$. Hence $k$ represents the forcing notion $\mathbb{P}_k = \bigcup (\langle P_{p_\alpha}, \leq_{p_\alpha} \rangle : \alpha < \lambda)$; the union of a $\leq$-increasing continuous sequence of forcing notions $\mathbb{P}_{p_\alpha} = \mathbb{P}[p_\alpha] = (P_{p_\alpha}, \leq_{p_\alpha})$, so we can look at $\mathbb{P}_k$ as a FS-iteration. But then we would like to construct an “immediate successor” $k^+$ of $k$, so in particular $\mathbb{P}_k \leq \mathbb{P}_{k^+}$, e.g. taking care of (b) above so $\mathbb{Q}$ is a $\mathbb{P}_k$-name and even a $\mathbb{P}_{\text{min}(E_k)}$-name of a c.c.c. forcing notion. Toward this we choose $p_{\alpha}[k^+] = p_\alpha[k^+]$ by induction on $\alpha \in E_k$. So it makes sense to demand $p_\alpha \leq_k p_{\alpha}[k^+]$, which naturally implies that $u[p_\alpha] \subseteq u[p_{\alpha}[k^+]]$, $\mathbb{P}_{p_\alpha} \leq \mathbb{P}_{p_{\alpha}[k^+]}$. So as $p_{\alpha}[k^+]$ for $\alpha \in E_k$ is $\leq_{K_1}$-increasing continuous, the main case is when $\beta = \text{min}(E_k \setminus (\alpha + 1))$, can we choose $p_{\alpha}[k^+]$?

Let us try to draw the picture:

$$\begin{array}{c}
\mathbb{P}_{p_{\alpha}[k]} \\
\uparrow
\end{array} \quad \overset{?}{\longrightarrow} \quad \overset{?}{\longrightarrow} \\
\mathbb{P}_{p_{\alpha}[k]} \quad \leftarrow \longrightarrow \quad \mathbb{P}_{p_{\alpha}[k^+]}
$$

So we have three forcing notions, $\mathbb{P}_{p_{\alpha}[k]}, \mathbb{P}_{p_{\alpha}[k]}, \mathbb{P}_{p_{\alpha}[k^+]},$ where the second and third are $\leq$-extensions of the first. The main problem is the c.c.c. As in the main case we like to have $\text{MA}_{\lambda,<\lambda}$, there is no restriction on $\mathbb{P}_{p_{\alpha}[k^+]} / \mathbb{P}_{p_{\alpha}[k]}$, so it is natural to demand $\mathbb{P}_{p_{\alpha}[k^+]} / \mathbb{P}_{p_{\alpha}[k]}$ is absolutely c.c.c. for $\alpha < \beta$ from $E_k$ (recall $p_{\alpha}[k]$ is demanded to be $<_{K_1}$-increasing with $\alpha$).
How do we amalgamate? There are two natural ways which say that "we leave $\mathbb{P}_{p_0}/\mathbb{P}_{p_0}$ as it is".

First way: We decide that $\mathbb{P}_{p_0}/\mathbb{P}_{p_0}$ is $\mathbb{P}_{p_0}/\mathbb{P}_{p_0} \times (\mathbb{P}_{p_0}/\mathbb{P}_{p_0})$. This is the "do nothing" case, the lazy man strategy, which in glorified fashion we may say: do nothing when in doubt. Note that $\mathbb{P}_{p_0}/\mathbb{P}_{p_0}$ and $\mathbb{P}_{p_0}/\mathbb{P}_{p_0}$ are $\mathbb{P}_{p_0}/\mathbb{P}_{p_0}$-names of forcing notions.

Second way: $\mathbb{P}_{p_0}/\mathbb{P}_{p_0}$ is defined in some way, e.g. is a random real forcing in the universe $V[\mathbb{P}_{p_0}]$ and we decide that $\mathbb{P}_{p_0}/\mathbb{P}_{p_0}$ is defined in the same way: the random real forcing in the universe $V[\mathbb{P}_{p_0}]$; this is expressed by the strategy $s_\lambda$.

[That is: retain the same definition of the forcing in the $\alpha$-th place, so in some sense we again do nothing novel.]

Context 1.1. Let $\lambda = \text{cf}(\lambda) > K_1$ or just $1 = \text{cf}(\lambda) \geq K_1$.

Below, $\leq_{K_1}$ is used in defining $k \in K_2$ as consisting also of $\leq_{K_1}$-increasing continuous sequence $(p_\alpha : \alpha \in E \subseteq \lambda)$ (so increasing vertically).

Definition 1.2. 1) Let $K_1$ be the class of $p$ such that:

(a) $p = (u, P, \leq) = (u, P, \leq_p) = (u, P, \mathbb{P})$
(b) $\omega \subseteq u \subseteq \text{Ord}$ and $\lambda > K_1 \Rightarrow \omega_1 \subseteq u$,
(c) $P$ is a set $\subseteq \mathcal{P}_{<K_1}(u)$,
(d) $\leq$ is a quasi-order on $P$,

satisfying

(e) the pair $(P, \leq)$ which we denote also by $P = \mathbb{P}_p$ is a c.c.c. forcing notion.

1) We may write $u[p], P[p], \mathbb{P}[p]$.
2) $\leq_{K_1}$ is the following two-place relation on $K_1 : p \leq_{K_1} q$ iff $u_p \subseteq u_q$ and $P_p \subseteq P_q$ and $P_q \cap \mathcal{P}_{<K_1}(u_p) = \mathbb{P}_p$; moreover, just for transparency $q \leq_{[\mathbb{P}_q]} p \in \mathbb{P}_p \Rightarrow q \in \mathbb{P}_p$.
3) $\leq_{K_1}$ is the following two-place relation on $K_1 : p \leq_{K_1} q$ iff $p \leq_{K_1} q$ and $P_q/P_p$ is absolutely c.c.c., see Definition 0.5(1).
4) $K_1$ is the family of $p \in K_1$ such that $u_p \subseteq \lambda^+$ and $|u_p| < \lambda$.
5) We say $p$ is the exact limit or the union of $(p_\alpha : \alpha \in v, v \subseteq \text{Ord})$, in symbols $p = \cup\{p_\alpha : \alpha \in v\}$ when $u_p = \cup\{u_{p_\alpha} : \alpha \in v\}, \mathbb{P}_p = \cup\{\mathbb{P}_{p_\alpha} : \alpha \in v\}$ and $\alpha \in v$ implies $p_\alpha \leq_{K_1} p$; hence $p \in K_1$.
6) We say $p$ is just a limit of $(p_\alpha : \alpha \in v)$ when $u_p = \cup\{u_{p_\alpha} : \alpha \in v\}, \mathbb{P}_p = \cup\{\mathbb{P}_{p_\alpha} : \alpha \in v\}$ and $\alpha \in v \Rightarrow p_\alpha \leq_{K_1} p$.
7) We say $p = (p_\alpha : \alpha < \alpha^*)$ is $\leq_{K_1}$-increasing continuous [strictly $\leq_{K_1}$-increasing continuous] when it is $\leq_{K_1}$-increasing and for every limit $\alpha < \alpha^*, p_\alpha$ is a limit of $p \upharpoonright \alpha$ [is the exact limit of $p \upharpoonright \alpha$], respectively.

Observation 1.3. 1) $\leq_{K_1}$ is a partial order on $K_1$.
2) $\leq_{K_1} \subseteq \leq_{K_1}$ is a partial order on $K_1$.
3) If $p = (p_\alpha : \alpha < \delta)$ is a $\leq_{K_1}$-increasing sequence and $\cup\{\mathbb{P}_{p_\alpha} : \alpha < \delta\}$ satisfies the c.c.c. and $\delta < \lambda$ then some $p \in K_1$ is the union $\cup\{p_\alpha : \alpha < \delta\}$ of $p$, i.e. $u_p \in K_1$ and $\alpha < \delta \Rightarrow p_\alpha \leq_{K_1} p$; this determines $p$ uniquely and $p$ is the exact limit of $p$.

1If $\lambda = K_1$, we may change the definitions of $k \in K_2$, instead $(\mathbb{P}_p[k] : \alpha < \lambda)$ is $\leq$-increasing, we carry with us large enough family of dense subsets, e.g. coming from some countable $N$.}
4) If \( p = (p_\alpha : \alpha < \delta) \) is \( \leq K_1 \)-increasing and \( cf(\delta) = \aleph_1 \) implies \( \{ \alpha < \delta : p_\alpha \text{ the exact limit of } p \upharpoonright \alpha \text{ or just } \bigcup_{\beta < \alpha} P_\beta \triangleleft p_\alpha \} \) is a stationary subset of \( \delta \) then \( \bigcup p \in K_1 \) is a \( \leq K_1 \)-upper bound of \( p \) and is the exact limit of \( p \).

5) If in part (4), \( p \) is also \( \leq K_1 \)-increasing then \( \alpha < \delta \Rightarrow p_\alpha \leq K_1 p \).

**Proof.** Should be clear, e.g. in part (5) recall that c.c.c. forcing preserve stationarity of subsets of \( \delta \). \( \square_{1.3} \)

*Definition 1.4.* 1) Let \( \leq K_1 \) be the following two-place relation on the family of pairs \( \{(p, q) : p \leq K_1 q\} \). We let \((p_1, q_1) \leq K_1 (p_2, q_2)\) iff

\[
\begin{align*}
(a) & \quad p_1 \leq p_2
\end{align*}
\]

\[
\begin{align*}
(b) & \quad q_1 \leq q_2
\end{align*}
\]

\[
\begin{align*}
(c) & \quad \models_{P_2} \left( G_{\{p_2\}} \cap P_{p_1} \right) \triangleleft P_{q_2}/G_{\{p_2\}}
\end{align*}
\]

\[
\begin{align*}
(d) & \quad u_{p_2} \cap u_{q_1} = u_{p_1}
\end{align*}
\]

2) Let \( \leq K_1 \) be the following two-place relation on the family \( \{(p, q) : p \leq K_1 q\} \) of pairs. We let \((p_1, q_1) \leq K_1 (p_2, q_2)\) iff clauses (a),(b),(d) from part (1) above and

\[
\begin{align*}
(c)' & \quad \text{if } p_1 \in P_{p_1}, q_1 \in P_{q_1}, \text{ and } \models_{P_2} \left( q_1 \in P_{p_2}/G_{\{p_2\}} \right) \text{ then } p_1 \models_{P_2} \left( q_1 \in P_{q_2}/G_{\{p_2\}} \right).
\end{align*}
\]

3) Assume \( p_\ell \in K_1 \) for \( \ell = 0, 1, 2 \) and \( p_0 \leq K_1 p_1 \) and \( p_0 \leq K_1 p_2 \) and \( u_{p_1} \cap u_{p_2} = u_{p_0} \). We define the amalgamation \( p = p_3 = p_1 \times p_0, p_2 \) or \( p_3 = p_1 \times p_2/p_0 \) as the triple \((u_p, P_p, p)\) as follows:

\[
\begin{align*}
(a) & \quad u_p = u_{p_1} \cup u_{p_2}
\end{align*}
\]

\[
\begin{align*}
(b) & \quad P_p = P_{p_1} \cup P_{p_2} \cup \{(p_1, p_2) : p_1 \in P_{p_1} \setminus P_{p_0}, p_2 \in P_{p_2} \setminus P_{p_0} \text{ and for some } p \in P_{p_0} \text{ we have } p \models_{P_{p_0}} \left( p_1 \models_{P_{p_1}} \right) \\ & \quad \text{for } \ell = 1, 2 \}
\end{align*}
\]

\[
\begin{align*}
(c) & \quad \text{is defined naturally as } \leq_{p_1} \cup \leq_{p_2} \cup \{(p_1, q_2) : p_1 \in P_{p_1}, p_1, q_2 \in P_{p_2} \text{ and } \models_{P_{p_2}} \left( q_2 \leq_{p_2} q_1 \right) \text{ for } \ell = 1, 2 \}
\end{align*}
\]

**Remark 1.5.** Why not use \( u \) instead \( \mathcal{H}_{\leq K_1}(u) \)? Not a real difference but, e.g. there may not be enough elements in a union of two.

*Observation 1.6.* 1) \( \leq K_1 \), \( \leq K_1 \) are partial orders on their domains.

2) \( (p_1, q_1) \leq K_1 (p_2, q_1) \) implies \( (p_1, q_1) \leq K_1 (p_2, q_2) \).

For the “successor case vertically and horizontally” we shall use

*Claim 1.7.* Assume that \( p_1 \leq K_1 p_2 \) and \( p_1 \leq K_1 q_1 \) and \( u_{p_2} \cap u_{q_1} = u_{p_1} \) then \( q_2 \in K_1 \) and \( (p_1, q_1) \leq K_1 (p_2, q_2) \) when we define \( q_2 = q_1 \times p_2 \) as in 1.4(3).

**Proof.** Straight.

The following claim will be applied to a pair of vertically increasing continuous sequences, one standing horizontally to the right of the other.

\[ \text{If in clause (b) of 1.4(3) we would like to avoid } p_\ell \models_{P_{p_1} \setminus P_{p_0}} \text{ we may replace } (p_1, p_2) \text{ by } (p_1, p_2, u_{p_1}, u_{p_2}) \text{ when } p_1 \neq p_1 \wedge p_0 \neq p_2 \text{ equivalently } p_0 \neq p_1 \wedge p_0 \neq p_2. \]
Claim 1.8. Assume $\varepsilon(*) < \lambda$ and

\begin{itemize}
  \item[(a)] $(p^\ell_\varepsilon : \varepsilon \leq \varepsilon(*))$ is strictly $< K_1^+,\text{-increasing continuous for } \ell = 1, 2$
  \item[(b)] $(p^1_\varepsilon, p^2_\varepsilon) \leq_{K_1} (p^1_{\varepsilon+1}, p^2_{\varepsilon+1})$ for $\varepsilon < \varepsilon(*)$.
\end{itemize}

Then

\begin{itemize}
  \item[(a)] $p^1_{\varepsilon(*)} \leq_{K_1} p^2_{\varepsilon(*)}$
  \item[(b)] for $\varepsilon < \zeta \leq \varepsilon(*)$ we have

\[ (p^1_\varepsilon, p^2_\varepsilon) \leq_{K_1} (p^1_{\varepsilon}, p^2_{\varepsilon}). \]

\end{itemize}

Proof. Easy. □_{1.8}

For the "successor case horizontally, limit case vertically when the relevant game, i.e. the relevant winning strategy is not active" we shall use

Claim 1.9. Assume $\varepsilon(*) < \lambda$ is a limit ordinal and

\begin{itemize}
  \item[(a)] $(p_\varepsilon : \varepsilon \leq \varepsilon(*))$ and $(q_\varepsilon : \varepsilon < \varepsilon(*))$ are strictly $< K_1^+,\text{-increasing$
  \item[(b)] $p_\varepsilon \leq_{K_1} q_\varepsilon$ for $\varepsilon < \varepsilon(*)$
  \item[(c)] if $\varepsilon < \zeta < \varepsilon(*)$ then $(p_\varepsilon, q_\varepsilon) \leq_{K_1} (p_{\varepsilon}, q_{\varepsilon}).$
\end{itemize}

Then we can choose $q_{\varepsilon(*)}$ such that

\begin{itemize}
  \item[(a)] $p_{\varepsilon(*)} \leq_{K_1} q_{\varepsilon(*)}$
  \item[(b)] $(p_\varepsilon, q_\varepsilon) \leq_{K_1} (p_{\varepsilon(*)}, q_{\varepsilon(*)})$ for every $\varepsilon < \varepsilon(*)$
  \item[(γ)] $(q_\varepsilon : \varepsilon \leq \varepsilon(*))$ is strictly $< K_1^+,\text{-increasing continuous.}$
\end{itemize}

Remark 1.10. We can replace $\leq_{K_1}$ by $\leq_{K_1}^*$ in (c) and (β) of 1.9 and (b), (γ) of 1.8.

Proof. But 1.8 should be clear. □_{1.9}

The game defined below is the non-FS ingredient; (in the main application below, $\gamma = \lambda$), it is for the horizontal direction; it lasts $\gamma \leq \lambda$ steps but will be used in $\leq_{K_1^+}$-increasing subsequences of $(k_i : i < \lambda^+)$. 

Definition 1.11. For $\delta < \lambda$ and $\gamma \leq \lambda$ let $\partial_{\delta, \gamma}$ be the following game between the player INC (incomplete) and COM (complete).

A play last $\gamma$ moves. In the $\beta$-th move a pair $(p_\beta, q_\beta)$ is chosen such that $p_\beta \leq_{K_1} q_\beta$ and $\beta(1) < \beta \Rightarrow (p_{\beta(1)}, p_\beta) \leq_{K_1} (q_{\beta(1)}, q_\beta)$ and $u_{p_\beta} \cap \lambda = \delta$ and $u_{q_\beta} \cap \lambda = u_{q_\beta} \cap \lambda \geq \delta + 1$.

In the $\beta$-th move first INC chooses $(p_\beta, u_\beta)$ such that $p_\beta$ satisfies the requirements and $u_\beta$ satisfies the requirements on $u_{q_\beta}$ (i.e. $\cup \{u_{q_\alpha} : \alpha < \beta\} \cup u_{p_\beta} \subseteq \beta \in [\lambda^+]^{< \lambda}$ and $u_\beta \cap \lambda = u_{q_\beta} \cap \lambda$ and say $u_\beta \setminus u_{p_\beta} \cup \{u_\beta : \gamma < \beta\}$ has cardinality $\geq |\delta|$ (if $\lambda$ is weakly inaccessible we may be interested in asking more).

Second, COM chooses $q_\beta$ as required such that $u_\beta \subseteq u_{q_\beta}$.

A player who has no legal moves loses the play, and arriving to the $\gamma$-th move, COM wins.

\[^3\text{we could ask for equality usually}\]
Remark 1.12. It is not problematic for COM to have a winning strategy. But having "interesting" winning strategies is the crux of the matter. More specifically, any application of this section is by choosing such strategies.

Such examples are the

(a) lazy man strategy: preserve $P_{q_0} = P_{q_0} \times_{P_{p_0}} P_{p_0}$ recalling Claim 1.7
(b) it is never too late to become lazy, i.e. arriving to $(P_{\beta(\alpha), q_{\beta(\alpha)}})$ the COM player may decide that $\beta \geq \beta(*) \Rightarrow P_{q_0} = P_{\beta(*)} \times_{P_{\beta(*)}} P_{p_0}$
(c) definable forcing strategy, i.e. preserve $^*_{P_{q_0}} / P_{p_0}$ is a definable c.c.c. forcing (in $V_{P[p, \alpha]}$).

Definition 1.13. We say $f$ is $\lambda$-appropriate if

(a) $f \in ^\lambda (\lambda + 1)$
(b) $\alpha < \lambda \land f(\alpha) < \lambda \Rightarrow (\exists \beta)[f(\alpha) = \beta + 1]$
(c) if $\varepsilon < \lambda^+$, $\langle u_\alpha : \alpha < \lambda \rangle$ is an increasing continuous sequence of subsets of $\varepsilon$ of cardinality $< \lambda$ with union $\varepsilon$ then $\{\delta < \lambda : \text{otp}(u_\delta) < f(\delta)\}$ is a stationary subset of $\lambda$.

Convention 1.14. Below $f$ is $\lambda$-appropriate function.

We arrive to defining the set of approximations of size $\lambda$ (in the main application $f_\ast$ is constantly $\lambda$); we shall later connect it to the oracle version (also see the introduction).

Definition 1.15. For $f_\ast$ a $\lambda$-appropriate function let $K_{f_\ast}^2$ be the family of $k$ such that:

(a) $k = \langle E, p, S, s, g, f \rangle$
(b) $E$ is a club of $\lambda$
(c) $p = \langle p_\alpha : \alpha \in E \rangle$
(d) $p_\alpha \in K_\lambda^1$
(e) $p_\alpha \leq K_1, p_\beta$ for $\alpha < \beta$ from $E$
(f) if $\delta \in \text{acc}(E)$ then $p_\delta = \cup\{p_\alpha : \alpha \in E \cap \delta\}$
(g) $S \subseteq \lambda$ is a stationary set of limit ordinals
(h) if $\delta \in S \cap E$ (hence a limit ordinal) then $\delta + 1 \in E$
(i) $s = \langle s_\delta : \delta \in E \cap S \rangle$
(j) $s_\delta$ is a winning strategy for the player COM in $\mathcal{O}_{\delta, f_\ast(\delta)}$, see 1.16(1)
(k) $g = \langle g_\delta : \delta \in S \cap E \rangle$
(l) $g_\delta$ is an initial segment of a play of $\mathcal{O}_{\delta, f_\ast(\delta)}$ in which the COM player uses the strategy $s_\delta$
   • if its length is $< f_\ast(\delta)$ then $g_\delta$ has a last move
   • $(p_\delta, p_{\delta + 1})$ is the pair chosen in the last move, call it $\text{mv}(g_\delta)$
   • let $S_0 = \{\delta \in S \cap E : g_\delta \text{ has length } < f_\ast(\delta)\}$ and $S_1 = S \cap E \setminus S_0$
(m) if $\alpha < \beta$ are from $E$ then $p_\alpha \leq K_1, p_\beta$, so in particular $P_{\beta}/P_{\alpha}$ is absolutely c.c.c. that is if $P \sub P'$ and $P'$ is c.c.c. then $P' \ast_{P_{\alpha}} P_{\beta}$ is c.c.c.; this strengthens clause (e)
\( (n) \ f \in \lambda \alpha \)
\( (o) \) if \( \delta \in S \cap E \) then \( f(\delta) + 1 \) is the length of \( g_\delta \)
\( (p) \) for every \( \delta \in E, \) if \( f_\alpha(\delta) < \lambda \) then \( f(\delta) \leq \operatorname{otp}(u_{p_\alpha}). \)

Remark 1.16. 1) Concerning clause \((j),\) recall (using the notation of Definition 1.11) that during a play the player INC chooses \( p_\varepsilon \) and \( \text{COM} \) chooses \( q_\varepsilon, \varepsilon \leq f(\delta) \) and recalling clause \((o)\) we see that \((p_{f(\delta)}, q_{f(\delta)})\) there stands for \((p_\delta, p_{\delta + 1})\) here. You may wonder from where does the \((p_\varepsilon, q_\varepsilon)\) for \( \varepsilon < f(\delta) \) comes from; the answer is that you should think of \( k \) as a stage in an increasing sequence of approximations of length \( f(\delta) \) and \((p_\varepsilon, q_\varepsilon)\) comes from the \( \delta \)-place in the \( \varepsilon \)-approximation. This is cheating a bit - the sequence of approximations has length \( < \lambda^+, \) but as on a club of \( \lambda \) this reflects to length \( < \lambda, \) all is O.K.

2) Below we define the partial order \( \leq_{K_\varepsilon} \) (or \( \leq_{K_\varepsilon}^1 \)) on the set \( K_\varepsilon^2, \) recall our goal is to choose an \( \leq_{K_\varepsilon} \)-increasing sequence \( \langle k_\varepsilon : \varepsilon < \lambda^+ \rangle \) and our final forcing will be \( \cup \{ p_{k_\varepsilon} : \varepsilon < \lambda^+ \} \).

3) Why clause \((d)\) in Definition 1.17(2) below? It is used in the proof of the limit existence claim 1.23. This is because the club \( E_k \) may decrease (when increasing \( k \)).

4) If we omit the restriction \( u \in [\lambda^+]^{\leq \lambda} \) and allow \( f : \lambda \to \delta^* + 1, \) replace the club \( E \) by an end segment, we can deal with sequences of length \( \delta^* < \lambda^+ \).

In the direct order in 1.17(3) we have \( \alpha(\varepsilon) = 0. \) Using e.g. a stationary non-reflecting \( S \subseteq S_\varepsilon^\alpha \) we can often allow \( \alpha(\varepsilon) \neq 0. \)

5) Is the “\( S_\varepsilon \) a winning strategy” in addition for telling us what to do, crucial? The point is preservation of c.c.c. in limit of cofinality \( \aleph_1. \)

6) If we use \( f_k \in \lambda(\lambda + 1) \) constantly \( \lambda, \) we do not need \( f_k \) so we can omit clauses \((n),(o),(p)\) of 1.15 and \((c),\) and part of \((o)\) in 1.17(2).

6A) Alternatively we can omit clause \((o)\) in 1.15 but demand “\( \prod_{\alpha < \lambda} f(\alpha)/\mathcal{D} \) is \( \lambda^+ \)-directed”, fixing a normal filter \( \mathcal{D} \) on \( \lambda \) (and demand \( S_k \in \mathcal{D}^+ \)).

7) The “omitting type” argument here comes from using the strategies. We may add in clause 1.15(n) that for some \( \gamma < \lambda^+ \) and sequence \( \vec{u} = \langle u_\alpha : \alpha < \lambda, f(\alpha) \leq \operatorname{otp}(u_\alpha) \rangle \) contains a club of \( \lambda. \)

Definition 1.17. 1) In Definition 1.15, let \( E = E_k, \bar{p} = \bar{p}_k, p_\alpha = p_\alpha^k, \) \( p_\alpha = p_\alpha^k = p_\alpha^k \in \mathbb{P}_k, S = S_k \) for \( \ell = 0, 1, \) etc. and we let \( \mathbb{P}_k = \mathcal{U} \{ p_\alpha^k : \alpha \in E_k \} \) and \( u_k = u[k] = \cup \{ u_{p_\alpha^k} : \alpha \in E_k \}. \)

2) We define a two-place relation \( \leq_{K_\varepsilon} \) on \( K_\varepsilon^2, \) \( k_1 \leq_{K_\varepsilon} k_2 \) if (both are from \( K_\varepsilon^2 \) and for some \( \alpha(\varepsilon) < \lambda \) (and \( \alpha(k_1, k_2) \) is the first such \( \alpha(\varepsilon) \in E_{k_2} \)) we have:

\( (a) \) \( E_{k_2 \setminus k_1} \) is bounded in \( \lambda, \) moreover \( \subseteq \alpha(\varepsilon) \)

\( (b) \) for \( \alpha \in E_{k_2 \setminus \alpha(\varepsilon)} \) we have \( p_{k_1} \subseteq p_{k_1}^2 \)
(c) if $\alpha \in E_{k_2}\setminus \alpha(\ast)$ then $f_{k_1}(\alpha) \leq f_{k_2}(\alpha)
(d) if \gamma_0 < \gamma_1 \leq \gamma_2 < \lambda, \gamma_0 \in E_{k_2}\setminus \alpha(\ast) \cup S_{k_1}, \gamma_1 = \min(E_{k_2}\setminus (\gamma_0 + 1)) and \gamma_2 = \min(E_{k_2}\setminus (\gamma_0 + 1)), then $(p^{k_0}, p^{k_0}) \leq (p^{k_1}, p^{k_2}), see Definition 1.17(2) really follows from clause (h) below
(e) if $\delta \in S_{k_1} \cap E_{k_2}\setminus \alpha(\ast)$ then $\delta \in S_{k_2} \cap E_{k_2}\setminus \alpha(\ast)$; but note that if $f_{k_1}(\delta) \geq f(\delta)$ we put $\delta$ into $S_{k_2}$ just for notational convenience as “the game is over”
(f) if $\delta \in S_{k_1} \cap E_{k_2}\setminus \alpha(\ast)$ then $s^{k_2}_\delta = s^{k_1}_\delta$ and $g^{k_1}_\delta$ is an initial segment of $g^{k_2}_\delta$

3) We define a two-place relation $\leq^{\text{dir}}_{K_j}$ on $K_j^2$ as follows: $k_1 \leq^{\text{dir}}_{K_j} k_2$ iff

(a) $k_1 \subseteq K_j^2 k_2$
(b) $E_{k_1} \subseteq E_{k_2}$; no real harm here if we add $k_1 \neq k_2 \Rightarrow E_{k_2} \subseteq \text{acc}(E_{k_1})$
(c) $\alpha(k_1, k_2) = \text{Min}(E_{k_2})$

4) We write $K_j^2 \leq_{K_j^2} \leq^{\text{dir}}_{K_j^2}$ or just $K_1^2, K_2^2, \leq^{\text{dir}}_{K_j^2}$ for $K_j^2, K_j^2, \leq^{\text{dir}}_{K_j^2}$ when $f$ is constantly $\lambda$.

Remark 1.18. 1) In [Sh:669] we may increase $S$ as well as here but we may replace clause (e) of Definition 1.17(2) by

$$(e') if \delta \in S_{k_1} \cap E_{k_2}\setminus \alpha(\ast) then f_{k_1}(\delta) < f(\delta) \land \delta \in S_{k_2} \cap E_{k_2}\setminus \alpha(\ast).$$

If we do this, is it a great loss? No! This can still be done here by choosing $s_\delta$ such that as long as $\text{INC}$ chooses $u_\delta$ of certain form (e.g. $u_\delta \setminus \nu P^3 = \{\delta\}$) the player COM chooses $q_\delta = p^3$. We can allow in Definition 1.17(2) to extend $S$ but a priori start with $\langle S_\varepsilon : \varepsilon < \lambda^+ \rangle$ such that $S_\varepsilon \subseteq \lambda$ and $S_\varepsilon \subseteq \lambda^+$ is bounded in $\lambda$ when $\varepsilon < \zeta < \lambda$ and demand $S_\kappa = S_\varepsilon$.

2) We can weaken clause (e) of 1.17(2) to

$$(e'') if \delta \in S_{k_1} \cap E_{k_2}\setminus \alpha(\ast) then f_{k_1}(\delta) < f(\delta) then \delta \in S_{k_2}.$$ But then we have to change accordingly, e.g. 1.17(c),(f), 1.20(c).

3) We can define $k_1 \leq K_j^2 k_2$ demanding $(S_{k_1}, S_{k_1}) = (S_{k_2}, S_{k_2})$ but replace everywhere “$\delta \in S_k \cap E_k$” by “$\delta \in S_k \cap E_k \land f_k(\delta) \leq f(\delta)$” so omit clause (e) of 1.17.

Revision: 2011-10-05

Observation 1.19. 1) $K_j^2 \leq K_j^2$ is a partial order on $K_j^2$.
2) $\leq^{\text{dir}}_{K_j^2} \leq^{\text{dir}}_{K_j^2}$ is a partial order on $K_j^2$.
3) if $k_1 \leq K_j^2 k_2$ then $P_{k_1} \prec P_{k_2}$.
4) If $(k_\varepsilon : \varepsilon < \lambda^+)$ is $<_{K_j^2}$-increasing and $P = \cup\{P_{k_\varepsilon} : \varepsilon < \lambda^+\}$ then

(a) $P$ is a c.c.c. forcing notion of cardinality $\leq \lambda^+$
(b) $P_{k_\varepsilon} \prec P$ for $\varepsilon < \lambda^+$. 
Definition 1.20. 1) Assume $k = \langle k_\varepsilon : \varepsilon < \varepsilon(*) \rangle$ is $\leq K^*\varepsilon$-increasing with $\varepsilon(*)$ a limit ordinal $< \lambda$. We say $k$ is a limit of $\bar{k}$ when $\varepsilon < \varepsilon(*) \Rightarrow k_\varepsilon \leq K^*\varepsilon \bar{k} \in K^*_\varepsilon$ and for some $\alpha(*)$

(a) $\alpha(*) = \cup \{\alpha(k_\varepsilon, k_\xi) : \varepsilon < \xi < \varepsilon(*)\}$
(b) $E_\varepsilon \setminus \alpha(*) \subseteq \cap \{E_\varepsilon \setminus \alpha(*) : \varepsilon < \varepsilon(*)\}$
(c) $S_\varepsilon = (\cup \{S_{k_\varepsilon} : \varepsilon < \varepsilon(*)\}) \cap (\cap \{E_\varepsilon : \varepsilon < \varepsilon(*)\}) \alpha(*)$
(d) if $\delta \in S_\varepsilon$ then $g^k_\delta$ is an initial segment of $g^k_\delta$ for every $\varepsilon < \varepsilon(*)$
(e) $f_\varepsilon(\delta) = \cup \{f_\varepsilon(\delta) : \varepsilon < \varepsilon(*)\} + 1$ for $\delta \in S_\varepsilon$.

2) Assume $k = \langle k_\varepsilon : \varepsilon < \lambda \rangle$ is $\leq K^*\varepsilon$-increasing continuous, see part (3) below (no viscous circle). We say $k$ is a limit of $\bar{k}$ when $\varepsilon < \lambda \Rightarrow k_\varepsilon \leq K^*\varepsilon \bar{k} \in K^*_\varepsilon$ and for some $\alpha$

(a) $\alpha = \langle \alpha_\varepsilon : \varepsilon < \lambda \rangle$ is increasing continuous, $\lambda > \alpha_\varepsilon \in \cap \{E_\varepsilon : \xi < 1 + \varepsilon\} \setminus \cup \{\alpha(k_\varepsilon, k_\xi) : \xi < \varepsilon < 1 + \varepsilon\}$
(b) $E_\varepsilon = \{\alpha_\xi : \varepsilon < \lambda\} \cup \{\alpha_\varepsilon + 1 : \varepsilon < \lambda \text{ and } \varepsilon \in S\}$ and $p^k_\alpha = p^k_{\alpha_\varepsilon}, p^k_{\alpha_\varepsilon+1} = p^k_{\alpha_\varepsilon+1}$
(c) $S_\varepsilon = \{\alpha_\varepsilon : \alpha_\varepsilon \in S_{k_\varepsilon} \text{ for every } \xi < \varepsilon \text{ large enough}\}$
(d) if $\delta = \alpha_\varepsilon \in S_{k_\varepsilon}$ then $g^k_\delta = g^k_\delta$
(e) if $\alpha < \delta$ and $\xi = \min\{\varepsilon : \alpha \leq \varepsilon_\varepsilon\} \text{ then } f_\varepsilon(\alpha) = f_\varepsilon(\alpha)$.

3) We say that $\langle k_\varepsilon : \varepsilon < \varepsilon(*) \rangle$ is $\leq K^*\varepsilon$-increasing continuous when:

(a) $k_\varepsilon \leq K^*\varepsilon k_\xi$ for $\varepsilon < \xi < \varepsilon(*)$
(b) $k_\varepsilon$ is a limit of $\langle k_\varepsilon : \varepsilon < \varepsilon(*) \rangle$ for some increasing continuous sequence $\langle \xi(\varepsilon) : \varepsilon < \varepsilon(*) \rangle$ of ordinals with limit $\varepsilon$, for every limit $\varepsilon < \varepsilon(*)$, by part (1) or part (3).

Definition 1.21. 1) In part (1) of 1.20, we say “a direct limit” when in addition

(a) the sequences are $\leq K^*\varepsilon$-increasing
(b) in clause (b) we have equality

(γ) $p^k_{\min(E_\varepsilon)}$ is the exact union of $\{p^k_{\min(E_\varepsilon)} : \varepsilon < \varepsilon(*)\}$
(d) if $\gamma \in E_\varepsilon, \xi < \varepsilon(*)$, $\gamma \notin S^0_{k_\xi}$ and $\langle \gamma_\varepsilon : \varepsilon \in [\xi, \varepsilon(*)] \rangle$ is defined by $\gamma_\varepsilon = \min(E_\varepsilon, \{\gamma_\varepsilon : \varepsilon \in [\xi, \varepsilon(*)] \})$ when $\xi < \varepsilon \leq \varepsilon(*)$, so $\langle \gamma_\varepsilon : \varepsilon \in [\xi, \varepsilon(*)] \rangle$ is an $\leq$-increasing continuous sequence of ordinals, then $p^k_{\gamma_\varepsilon} = p_{\gamma_\varepsilon} = \cup \{p^k_{\gamma_\varepsilon} : \varepsilon \in [\xi, \varepsilon(*)] \}$ with the obvious meaning.

2) In part (2) of Definition 1.20 we say a “direct limit” when in addition

(a) the sequence is $\leq K^*\varepsilon$
(b) $\alpha_\varepsilon$ is minimal under the restrictions.

3) We say that $k = \langle k_\varepsilon : \varepsilon < \varepsilon(*) \rangle$ is $\leq K^*\varepsilon$-increasing continuous or directly increasing continuous when:
\[ \ell \]

Definition 1.11 (and clause (k) may happen when we try to choose \( \alpha \) if \( \gamma \) /\( \gamma \).

But what if the play is over? Recall that in Definition 1.13, \( \epsilon < \epsilon(\ast) \) is a limit ordinal then \( k_\epsilon \) is a (really the) direct limit of \( \tilde{k} \upharpoonright C \) for some club of \( \epsilon \).

Claim 1.22. If \( k_1 \leq K_1 \) \( k_2 \) then for some \( k_\ast \) we have

\[ \begin{align*}
(a) & \quad k_\epsilon \leq \text{dir}_K k_\ast \quad \text{for } \epsilon \leq \zeta < \epsilon(\ast) \\
(b) & \quad \text{if } \epsilon < \epsilon(\ast) \text{ is a limit ordinal then } k_\epsilon \text{ is a (really the) direct limit of } \tilde{k} \upharpoonright C \text{ for some club of } \epsilon.
\end{align*} \]

Claim 1.23. The limit existence claim 1) If \( \epsilon(\ast) < \lambda \) is a limit ordinal and \( \tilde{k} = \langle k_\epsilon : \epsilon < \epsilon(\ast) \rangle \) is a directly increasing continuous then \( k \) has a direct limit.

2) Similarly for \( \epsilon(\ast) = \lambda \), i.e. if \( \langle k_\epsilon : \epsilon < \lambda \rangle \) is directly increasing continuous then there is \( k \) such that:

\[ \begin{align*}
(a) & \quad \epsilon < \lambda \Rightarrow k_\epsilon \leq k \\
(b) & \quad \text{for each } \epsilon < \lambda, \text{ if } k[\epsilon] \text{ is like } k \text{ omitting } E_k \cap \epsilon \text{ then } k_\epsilon \leq \text{min}_E(k[\epsilon]).
\end{align*} \]

Proof. It is enough to prove the direct version.

1) We define \( k = k_{(\epsilon)} \) as in the definition, we have no freedom left.

The main points concern the c.c.c. and the absolute c.c.c., \( \leq_{K_1} \leq K_1 \) demands.

We prove the relevant demands by induction on \( \beta \in E_{k_{(\epsilon)}} \).

Case 1: \( \beta = \text{min}(E_{k_{(\epsilon)}}) \).

First note that \( \langle p_{\text{min}(E_{k_{(\epsilon)}})}^\epsilon : \epsilon \leq \epsilon(\ast) \rangle \) is increasing continuous (in \( K_1 \)) moreover \( \langle p_{\text{min}(E_{k_{(\epsilon)}})}^\epsilon : \epsilon \leq \epsilon(\ast) \rangle \) is increasing continuous, see clause (\( \gamma \)) of Definition 1.21(1).

As each \( p_{\text{min}(E_{k_{(\epsilon)}})} \) is c.c.c. if \( \epsilon < \epsilon(\ast) \), we know that this holds for \( \epsilon = \epsilon(\ast) \), too.

Case 2: \( \beta = \delta + 1, \delta \in S^1_k \cap E_k \).

Since \( S^1_k \) is a winning strategy in the game \( D_{\delta, f(\delta)} \) we have \( p_{\delta}^k_{(\epsilon)} \leq_{K_1} p_{\delta}^k_{(\epsilon)} \).

But what if the play is over? Recall that in Definition 1.13, \( f(\delta) = \lambda \) or \( f(\delta) \) is successor and \( \langle f_k(\delta) : \epsilon < \epsilon(\ast) \rangle \) is (strictly) increasing, so this never happens; it may happen when we try to choose \( k \) such that \( k < K_{\ast} \) \( k \), see 1.24.

We also have to show: if \( \alpha < \beta \in E_k \) then \( p_{\beta}^k / p_{\beta}^k \) is absolutely c.c.c. First, if \( \alpha = \delta \) this holds by Definition 1.2(3) of \( \leq_{K_1} \) and the demand \( p_{\beta}^k \leq_{K_1} q_{\beta}^k \) in Definition 1.11 (and clause (\( f \)) of Definition 1.15). Second, if \( \alpha < \delta \), it is enough to show that \( p_{\beta}^k_{(\epsilon)} / p_{\beta}^k_{(\epsilon)} \) and \( p_{\beta}^k_{(\epsilon)} / p_{\beta}^k_{(\epsilon)} \) are absolutely c.c.c., but the first holds by the previous sentence, the second by the induction hypothesis. In particular, when \( \epsilon < \epsilon(\ast) \Rightarrow p_{\beta}^k \leq p_{\beta}^k \).

Case 3: For some \( \gamma, \gamma = \max(E_k \cap \beta), \gamma \notin S^1_k \).

As \( \gamma \notin S^1_k \) there is \( \xi < \epsilon(\ast) \) such that \( \gamma \notin S^1_k \) let \( \gamma_\epsilon = \gamma \) and for \( \epsilon \in (\xi, \epsilon(\ast)] \) we define \( \gamma_{\epsilon} = \text{min}(E_k \setminus (\beta + 1)) \).

Now as \( k \) is directly increasing continuous we have

\[ \begin{align*}
\oplus (a) & \quad \langle \gamma_{\epsilon} : \epsilon \in [\xi, \epsilon(\ast)] \rangle \text{ is increasing continuous}
\end{align*} \]
(b) $\gamma_\xi = \gamma$
(c) $\gamma_\xi(\ast) = \beta$
(d) $(\mathbf{p}_{\gamma_\xi}^k : \xi \in [\xi, \varepsilon(\ast))$ is increasing continuous.

So by claim 1.9 we are done, the main point is that clause (d) there holds by clause (d) of the definition of $\leq_{K_f}^\ast$ in 1.17(2).

Case 4: $\beta = \operatorname{sup}(E_k \cap \beta)$.

It follows by the induction hypothesis and 1.3(3) as $(\mathbf{p}_\gamma^k : \gamma \in E_k \cap \beta)$ is $\leq_{K_f}^\ast$ increasing continuous with union $\mathbf{p}_\gamma^k$; of course we use clause (h) of Definition 1.17, so Definition 1.4(2), (5) applies.

2) Similarly.

The following is an atomic step toward having MA$_{<\lambda}$.

Claim 1.24. Assume

(a) $k_1 \in K_f^2$
(b) $\alpha(\ast) \in E_{k_1}$
(c) $Q$ is a $\mathbb{P}^k_{\alpha(\ast)}$-name of a c.c.c. forcing (hence $\Vdash_{k_1}$ “$Q$ is a c.c.c. forcing”)

(d) $u_* \subseteq \lambda^+$ is disjoint to $u[k_1] = \bigcup\{u_{\alpha_*}[k_1] : \alpha \in E_k\}$ and of cardinality $< \lambda$

Then we can find $k_2$ such that

(a) $k_1 \leq_{K_f}^\ast k_2 \in K_f^2$
(b) $E_{k_2} = E_{k_1} \setminus \alpha(\ast)$
(c) $u_{k_2}^\alpha = u_{k_1}^\alpha \cup u_*$ for $\alpha \in E_{k_2} \cap S_{k_1}^1$
(d) $\mathbb{P}_{\alpha(\ast)}[k_2]$ is isomorphic to $\mathbb{P}_{\alpha(\ast)}[k_1] * Q$ over $\mathbb{P}_{\alpha(\ast)}[k_1]$
(e) $S_{k_1} = S_{k_1} \setminus \alpha(\ast)$ and $S_{k_2} = S_{k_1} \setminus S_{k_2}$
(f) $f_{k_2} = f_{k_1} + 1$

Proof. We choose $\mathbb{P}_{\alpha(\ast)}^k$ by induction on $\alpha \in E_{k_1} \setminus \alpha(\ast)$, keeping all relevant demands in particular $u_{\alpha_*}[k_2] \cap u[k_1] = u_{\alpha_*}[k_1]$.

Case 1: $\alpha = \alpha(\ast)$.

As only the isomorphism type of $Q$ is important, without loss of generality $\Vdash_{\mathbb{P}_{\alpha(\ast)}^k}$ “every member of $Q$ belongs to $u_*$”.

So we can interpret the set of elements of $\mathbb{P}_{\alpha(\ast)}[k_1] * Q$ such that it is $\subseteq \mathcal{H}_{<\lambda}(u_{\alpha_*}[k_1] \cup u_*)$.

Now $\mathbb{P}_{\alpha(\ast)}[k_1] \leq \mathbb{P}_{\alpha(\ast)}[k_2]$ by the classical claims on composition of forcing notions.

Case 2: $\alpha = \delta + 1, \delta \in S_{k_1} \cap E_{k_1} \setminus \alpha(\ast)$.

The case split to two subcases.
Subcase 2A: The play $g^k_\delta$ is not over, i.e. $f(\delta)$ is larger than the length of the play so far.

In this case do as in case 2 in the proof of 1.23, just use $s_\delta$.

Subcase 2B: The play $g^k_\delta$ is over.

In this case let $p^{k_2}_{\delta+1} = p^{k_1}_{\delta+1} \ast_{P_{\delta}} p^{k_2}_{\delta}$, in fact, $p^{k_2}_{\delta+1} = p^{k_1}_{\delta+1} \ast_{P_{\delta}} p^{k_2}_{\delta}$ (and choose $u_{p^{k_1}_{\delta+1}}$ appropriately). Now possible and $(p^{k_1}_{\delta}, p^{k_2}_{\delta}) < K_{1} (p^{k_1}_{\delta+1}, p^{k_2}_{\delta+1})$ by 1.7.

Case 3: For some $\gamma, \gamma = \max(E_k \cap \beta) \geq \alpha(*)$ and $\gamma \notin S_k$.

Act as in Subcase 2B of the proof of 1.23

Case 4: $\beta = \sup(E_k \cap \beta)$.

As in Case 4 in the proof of 1.23.
\[ \text{§ 2. } \mathfrak{p} = \mathfrak{t} \text{ does not decide the existence of a peculiar cut} \]

We deal here with a problem raised in [Sh:885], toward this we quote from there. Recall (Definition [Sh:885, 1.10]).

**Definition 2.1.** Let \( \kappa_1, \kappa_2 \) be infinite regular cardinals. A \( (\kappa_1, \kappa_2) \)-peculiar cut in \( \omega \) is a pair \((f_i : i < \kappa_1), (f^\alpha : \alpha < \kappa_2)\) of sequences of functions in \( \omega \) such that:

\begin{align*}
(\alpha) & \quad (\forall i < \kappa_1)(f_i <_{J^\omega} f_i), \\
(\beta) & \quad (\forall \alpha < \beta < \kappa_2)(f^\alpha <_{J^\omega} f^\beta), \\
(\gamma) & \quad (\forall i < \kappa_1)(\forall \alpha < \kappa_2)(f^\alpha <_{J^\omega} f_i), \\
(\delta) & \quad \text{if } f : \omega \rightarrow \omega \text{ is such that } (\forall i < \kappa_1)(f \leq_{J^\omega} f_i), \text{ then } f \leq_{J^\omega} f^\alpha \text{ for some } \alpha < \kappa_2, \\
(\varepsilon) & \quad \text{if } f : \omega \rightarrow \omega \text{ is such that } (\forall \alpha < \kappa_2)(f^\alpha \leq_{J^\omega} f), \text{ then } f_i \leq_{J^\omega} f \text{ for some } i < \kappa_1.
\end{align*}

The motivation of looking at \( (\kappa_1, \kappa_2) \)-peculiar cuts is understanding the case \( \mathfrak{p} > \mathfrak{t} \), (see [Sh:885]). Also \( \mathfrak{p} = \aleph_1 \Rightarrow \mathfrak{t} = \mathfrak{p} \) by the classical theorem of Rothberger and MA\( \aleph_1 \). Recall from [Sh:885] that

**Claim 2.2.**

1) If \( \mathfrak{p} < \mathfrak{t} \) then there is a \( (\kappa_1, \kappa_2) \)-peculiar type for some (regular) \( \kappa_1, \kappa_2 \) satisfying \( \kappa_1 < \kappa_2 = \mathfrak{p} \).

2) There is a \( (\kappa_2, \kappa_1) \)-peculiar type if there is a \( (\kappa_1, \kappa_2) \)-peculiar cut.

**Proof.** 1) A) See [Sh:885, 1.12]. 2) Trivial. \( \square \)

**Observation 2.3.** If \( (\eta^\text{up}, \eta^\text{dn}) \) is a peculiar \( (\kappa_{\text{up}}, \kappa_{\text{dn}}) \)-cut and if \( A \subseteq \omega \) is infinite, \( \eta \in \omega^\text{\text{-}\omega} \) then:

\begin{align*}
(a) & \quad \eta <_{J^\eta} \eta^\text{up}_\alpha \text{ for every } \alpha < \kappa_{\text{up}} \text{ if } \eta <_{J^\eta} \eta^\text{dn}_\beta \text{ for every large enough } \beta < \kappa_{\text{dn}}, \\
(b) & \quad \neg(\eta^\text{up}_\alpha <_{J^\eta} \eta^\text{dn}_\beta) \text{ for every } \alpha < \kappa_{\text{up}} \text{ if } \neg(\eta^\text{up}_\alpha <_{J^\eta} \eta^\text{dn}_\beta) \text{ for every large enough } \beta < \kappa_{\text{dn}}.
\end{align*}

**Proof.** Clause (a): The implication \( \Leftarrow \) is trivial as \( \beta < \kappa_{\text{dn}} \wedge \alpha < \kappa_{\text{up}} \Rightarrow \eta^\text{dn}_\beta <_{J^\eta} \eta^\text{up}_\alpha \). So assume the leftside.

We define \( \eta^\prime \in \omega^\text{\text{-}\omega} \) by: \( \eta^\prime(n) = \eta(n) \) if \( n \in A \) and \( 0 \) if \( n \in \omega \setminus A \). Clearly \( \eta^\prime <_{J^\eta} \eta^\text{up}_\alpha \text{ for every } \alpha < \kappa_{\text{up}} \) hence by clause (\( \delta \)) of 2.1 we have \( \eta^\prime <_{J^\eta} \eta^\text{dn}_\beta \) for some \( \gamma < \kappa_{\text{dn}} \) hence \( \eta = \eta^\prime \upharpoonright A \leq_{J^\eta} \eta^\text{dn}_{\beta+1} <_{J^\eta} \eta^\text{dn}_\beta \) for every \( \beta \in (\gamma, \kappa_{\text{dn}}) \).

Clause (b): Again the direction \( \Leftarrow \) is obvious. For the other direction define \( \eta^\prime \in \omega^\text{\text{-}\omega} \) by \( \eta^\prime(n) = \eta(n) \) if \( n \in A \) and is \( \eta^\text{up}_0(n) \) if \( n \in \omega \setminus A \). So clearly \( \alpha < \kappa_{\text{up}} \Rightarrow \neg(\eta^\text{up}_\alpha <_{J^\eta} \eta^\prime) \) hence \( \neg(\eta^\text{up}_\alpha <_{J^\eta} \eta^\prime) \) hence by clause (\( \varepsilon \)) of 2.1 for some \( \beta < \kappa_{\text{dn}} \) we have \( \neg(\eta^\text{dn}_\beta <_{J^\eta} \eta^\prime) \).

As \( \eta^\prime <_{J^\eta} \eta^\text{up}_0 \), necessarily \( \neg(\eta^\text{dn}_\beta <_{J^\eta} \eta^\prime) \) but \( \gamma \in (\beta, \kappa_{\text{dn}}) \Rightarrow \eta^\text{dn}_\beta <_{J^\eta} \eta^\text{dn}_\gamma \) hence \( \gamma \in (\beta, \kappa_{\text{dn}}) \Rightarrow \neg(\eta^\text{dn}_\beta <_{J^\eta} \eta^\prime) \Rightarrow \neg(\eta^\text{dn}_\beta <_{J^\eta} \eta^\prime) \) as required.

We need the following from [Sh:885, 2.1]:

\[ \square \]
Claim 2.4. Assume that $\kappa_1 \leq \kappa_2$ are infinite regular cardinals, and there exists a $(\kappa_1, \kappa_2)$-peculiar cut in $\omega^\omega$.

Then for some $\sigma$-centered forcing notion $Q$ of cardinality $\kappa_1$ and a sequence $\langle F_\alpha : \alpha < \kappa_2 \rangle$ of open dense subsets of $Q$, there is no directed $G \subseteq Q$ such that $(\forall \alpha < \kappa_2)(G \cap I_\alpha \neq \emptyset)$. Hence $\mathsf{MA}_{\kappa_2}$ fails.

Theorem 2.5. Assume $\lambda = \text{cf}(\lambda) = \lambda^\kappa > \aleph_2, \lambda > \kappa = \text{cf}(\kappa) \geq \aleph_1$ and $2^\lambda = \lambda^+$ and $(\forall \mu < \lambda)(\mu^{< \kappa} < \lambda)$.

For some forcing $\mathbb{P}^*$ of cardinality $\lambda^+$ not adding new members to $\lambda^\kappa$ and $\mathbb{P}$-name $\dot{Q}^*$ of a $\sigma$-c.c. forcing we have $\Vdash_{\mathbb{P}^*} \bigwedge_{\alpha < \omega} \dot{Q}^*_{\alpha} = \dot{Q}^*$ and for no regular $\kappa < \lambda$ there is a pair $(\dot{\eta}^\mu, \dot{\eta}^\beta)$ which is a peculiar $(\kappa, \lambda)$-cut

Remark 2.6. 1) The proof of 2.5 is done in §4 and broken into a series of Definitions and Claims, in particular we specify some of the free choices in the general iteration theorem.

2) In 4.1(1), is $\text{cf}(\delta) > \aleph_0$ necessary?

3) What if $\lambda = \aleph_2$? The problem is 3.2(2). To eliminate this we may, instead quoting 3.2(2), start by forcing $\dot{\eta} = \langle \eta_\alpha : \alpha < \omega_1 \rangle$ in $\mathbb{P}_{\aleph_0}$ and change some points.

Complementary to 2.5 is

Observation 2.7. Assume $\lambda = \text{cf}(\lambda) > \aleph_1$ and $\mu = \text{cf}(\mu) = \mu^{< \lambda} > \lambda$ then for some c.c.c. forcing notion $\mathbb{P}$ of cardinality $\mu$ we have:

$\Vdash_{\mathbb{P}} \bigwedge_{\alpha < \omega} \dot{Q}^*_\alpha = \dot{Q}$ and for no regular $\kappa < \lambda$ there is a peculiar $(\kappa, \lambda)$-cut so $\lambda = \omega^\omega$.

Proof. We choose $\dot{Q} = \langle \mathbb{P}_\alpha, \dot{Q}_\beta : \alpha < \mu, \beta < \mu \rangle$ such that:

1. $\dot{Q}$ is an FS-iteration
2. $\dot{Q}_0$ is a $\sigma$-centered forcing notion of cardinality $< \lambda$
3. if $\alpha < \mu$, $\dot{Q}$ is a $\mathbb{P}_\alpha$-name of a $\sigma$-centered forcing notion of cardinality $< \lambda$ then for some $\beta \in [\alpha, \mu)$ we have $\dot{Q}_\beta = \dot{Q}$
4. $\dot{Q}_0$ is adding $\lambda$ Coheons, $\langle \tau_\varepsilon : \varepsilon < \lambda \rangle$ say $\tau_\varepsilon \in \omega^\omega$.

Clearly in $\mathbb{V}^{\mathbb{P}_\alpha}$ we have $\dot{Q}^*_0 = \dot{Q}$, also every $\sigma$-centered forcing notion of cardinality $< \mu$, is from $\mathbb{V}^{\mathbb{P}^\alpha}$ for some $\alpha < \mu$, so as $\mu$ is regular we have

1. MA for $\sigma$-centered forcing notions of cardinality $< \lambda$ and $< \mu$ dense sets.

Hence by 2.4 there is no peculiar $(\kappa_1, \kappa_2)$-cut when $\aleph_1 \leq \kappa_1 < \kappa_2 = \lambda$ (even $\kappa_1 < \kappa_2 < \mu, \kappa_1 < \lambda < \mu$).

Lastly,

1. for $\alpha < \mu$, in $\mathbb{V}^{\mathbb{P}_{\alpha}^\varepsilon}$ for every $\eta \in \omega^\omega$ for every $\varepsilon < \lambda$ large enough we have $\tau_\varepsilon \notin \mathbb{V}^{\mathbb{P}_\alpha} \eta$.

[Why? We prove this by induction on $\alpha < \mu$. For $\alpha = 0$ this holds by $\exists (d)$. For $\alpha$ limit of uncountable cofinality recall $\langle \omega^\omega \rangle^{\mathbb{P}_{\alpha}} = \bigcup \langle \omega^\omega \rangle^{\mathbb{P}_{\beta}} : \beta < \alpha \rangle$. For $\alpha$ limit of cofinality $\aleph_0$ use $\langle \dot{Q} \rangle$ is a FS-iteration$. Lastly, for $\alpha = \beta + 1$ use the “of cardinality $< \lambda$” of clause (c) of $\exists (d)$]
§ 3. SOME SPECIFIC FORCING

Definition 3.1. Let $\bar{\eta} := \langle \eta_\alpha : \alpha < \alpha^+ \rangle$ be a sequence of members of $\omega^\omega$ which is $<_{\text{p.d.}}$-increasing or just $\leq_{\text{p.d.}}$-directed. We define the set $\mathcal{F}_\eta$ and the forcing notion $\mathbb{Q} = \mathbb{Q}_\eta$ and a generic real $\nu$ for $\mathbb{Q} = \mathbb{Q}_\eta$ as follows:

(a) $\mathcal{F}_\eta = \{ \nu \in \omega'(\omega + 1) : \alpha < \ell g(\bar{\eta}) \text{ then } \eta_\alpha <_{\text{p.d.}} \nu \}$, here $\bar{\eta}$ is not necessarily $<_{\text{p.d.}}$-increasing.

(b) $\mathbb{Q}$ has the set of elements consisting of all triples $p = (\rho, \alpha, \eta) = (\rho^P, \alpha^P, g^P)$ (and $\alpha(p) = \alpha^P$) such that

(a) $\rho \in \omega^\omega$, 
(b) $\alpha < \ell g(\bar{\eta})$, 
(g) $g \in \mathcal{F}_\eta$, and 
(d) if $n \in [\ell g(\rho), \omega)$ then $\eta_\alpha(n) \leq g(n)$;

(c) $\leq_\mathbb{Q}$ is defined by: $p \leq_\mathbb{Q} q$ iff (both are elements of $\mathbb{Q}$ and)

(a) $\rho^P \leq \rho^P$, 
(b) $\alpha^P \leq \alpha^P$ and $\eta_{\alpha^P} \leq_{\text{p.d.}} \eta_{\alpha^q}$

(γ) $g^P \leq \eta^P$,

(d) if $n \in [\ell g(\rho^P), \omega)$ then $\eta_{\alpha^P}(n) \leq \eta_{\alpha^q}(n)$,

(e) if $n \in (\ell g(\rho^P), \ell g(\rho^P))$ then $\eta_{\alpha^P}(n) \leq \rho^P(n) \leq g^P(n)$.

(d) For $\mathbb{F} \subseteq \mathcal{F}_\eta$ which is downward directed (by $<_{\text{p.d.}}$) we define $\mathbb{Q}_{\mathbb{F}, \bar{\eta}}$ as

$\mathbb{Q}_{\mathbb{F}, \bar{\eta}} = \mathbb{Q}_\eta \upharpoonright \{ p \in \mathbb{Q}_\eta : g^P \in \mathbb{F} \}$

(e) $\nu = \nu_\mathbb{Q} = \nu_{\mathbb{Q}_{\mathbb{F}, \bar{\eta}}} = \bigcup\{ \rho^P : p \in G_{\mathbb{Q}_{\mathbb{F}, \bar{\eta}}} \}$.

Claim 3.2. 1) If $\nu \in \omega'(\omega)$ then $\mathcal{F}_\eta$ is downward directed, in fact if $g_1, g_2 \in \mathcal{F}_\eta$ then $g = \min\{g_1, g_2\} \in \mathcal{F}_\eta$, i.e., $g(n) = \min\{g_1(n), g_2(n)\}$ for $n < \omega$. Also “$f \in \mathcal{F}_\eta$” is absolute.

2) If $\eta_i \in \omega'(\omega)$ is $<_{\text{p.d.}}$-increasing and $\text{cl}(\delta) > \aleph_1$ then $\mathbb{Q}_\eta$ is c.c.c.

3) Moreover any set of $\aleph_1$ members of $\mathbb{Q}_\eta$ is included in the union of countably many directed subsets of $\mathbb{Q}_\eta$.

4) Assume $\langle \mathbb{P}_\varepsilon : \varepsilon \leq \zeta \rangle$ is a $<\varepsilon$-increasing sequence of c.c.c. forcing notions, $\bar{\eta} := \langle \eta_\alpha : \alpha < \delta \rangle$ is a $\mathbb{P}_\varepsilon$-name of a $<_{\text{p.d.}}$-increasing sequence of members of $\omega^\omega$ and $\text{cl}(\delta) > \aleph_1$. For $\varepsilon \leq \zeta$ let $\mathbb{Q}_\varepsilon$ be the $\mathbb{P}_\varepsilon$-name of the forcing notion $\mathbb{Q}_\eta$ as defined in $V^{\mathbb{P}_\varepsilon}$. Then $\text{cl}(\varepsilon) > \aleph_1$ and $\mathbb{Q}_{\mathbb{F}, \bar{\eta}} \subseteq \mathbb{Q}_{\mathbb{P}_\varepsilon, \bar{\eta}}$ is c.c.c.

5) Let $\bar{\eta} \in \delta(\omega^\omega)$ be as in part (2).

(a) If $\mathbb{F} \subseteq \mathcal{F}_\eta$ is downward directed (by $<_{\text{p.d.}}$) then $\mathbb{Q}_{\mathbb{F}, \bar{\eta}}$ is absolutely c.c.c.
(b) If $\mathbb{F}_1 \subseteq \mathbb{F}_2 \subseteq \mathcal{F}_\eta$ are downward directed then $\mathbb{Q}_{\mathbb{F}_1, \bar{\eta}} \subseteq_{\text{c.c.}} \mathbb{Q}_{\mathbb{F}_2, \bar{\eta}}$.

6) 

(a) $\models_{\mathbb{Q}_\eta}$ “$\nu \in \omega^\omega$ and $V[G] = V[\nu]$”

(b) $p \in \mathbb{Q}_\eta$ “$\rho^P \triangleleft_\nu$ and $n \in [\ell g(\rho), \omega)$ \Rightarrow $\eta_{\alpha^P}(n) \leq \nu(n) \leq g^P(n)$”

4the central case is $\bar{\eta}$ is $\aleph_2$-directed by $<_{\text{p.d.}}$

5so if $\bar{\eta}$ is $<_{\text{p.d.}}$-increasing this can be omitted and is equivalent to $\alpha^P \leq \alpha^\eta$
Proof. 1) Trivial.

2) Assume \( p_e \in \mathbb{Q}_\eta \) for \( e < \omega_1 \). So \( \{ \alpha(p_e) : e < \omega_1 \} \) is a set of \( \leq \aleph_1 \) ordinals \( < \delta \).

But \( \text{cf}(\delta) > \aleph_1 \) hence there is \( \alpha(*) < \delta \) such that \( e < \omega_1 \Rightarrow \alpha(p_e) < \alpha(*) \). For each \( e \) let \( n_e = \text{Min}(n) : \text{for every } k \in [n, \omega) \text{ we have } \eta_{\alpha(p_e)}(k) \leq \eta_{\alpha(*)}(k) \leq g^p(k) \). It is well defined because \( \eta_{\alpha(p_e)} < \eta_{\alpha(*)} < \eta_{\alpha(*)}^g g^p \) recalling \( \alpha(p_e) < \alpha(*) \) and \( g^p \in \mathbb{Q}_\eta \).

So clearly for some \( x = (\rho^*, n^*, \eta^*, \nu^*) \) the following set is uncountable

\[ \mathcal{U} = \mathcal{U}_x = \{ e < \omega_1 : \rho^p = \rho^* \text{ and } n_e = n^* \text{ and } \eta_{\alpha(p_e)}|n^* = \eta^* \text{ and } g^p|n^* = \nu^* \}. \]

Let

\[ \mathbb{Q}' = \mathbb{Q}'_x = \{ p \in \mathbb{Q}_\eta : \ell g(p^\rho) \geq \ell g(\rho^*) \text{ and } n_e = n^* \text{ and } \eta_{\alpha(p_e)}|n^* = \eta^* \text{ and } g^p|n^* = \nu^* \}. \]

Clearly

\[ \begin{align*}
\mathcal{U} & \subseteq \mathcal{U}' \\
\mathbb{Q}' & \subseteq \mathbb{Q}_\eta \text{ is directed.}
\end{align*} \]

So we are done.

3) The proof of part (2) proves this as the set \( \mathbb{X} = \{ (\rho^*, n^*, \eta^*, \nu^*) : n^* < \omega, \{ \rho^*, \eta^*, \nu^* \} \subseteq \omega^\omega \} \) is countable and \( \omega_1 = \bigcup \{ \mathcal{U}_x : x \in \mathbb{X} \} \).

4, 5) First we can check clause (b) of part (5) by the definitions of \( \mathbb{Q}_{\eta, \mathcal{F}}, \mathbb{Q}_{\eta} \). Second, concerning “\( \mathbb{Q}_{\eta, \mathcal{F}} \) is absolutely c.c.c.” (i.e. clause (a) of part (5)) note that if \( \mathbb{P} \) is c.c.c., \( G \subseteq \mathbb{P} \) is generic over \( \mathbb{V} \) then \( \mathbb{V}_G = \mathbb{V}_{\mathbb{Q}_{\eta, \mathcal{F}}} \) and \( \mathbb{V}_{\mathbb{Q}_{\eta, \mathcal{F}}} \) is ic c.c.c. by clause (b) and the last one is c.c.c. (as \( \mathbb{V}[\mathbb{G}] \models \text{“cf}(\ell g(\eta)) > \aleph_1” \)). Hence \( \mathbb{Q}_{\eta, \mathcal{F}} \) is c.c.c. even in \( \mathbb{V}[\mathbb{G}] \) as required. Turning to part (4), letting \( \mathcal{F}_e = (\mathcal{F}_\eta)|\mathcal{V}[\mathbb{P}_e] \), clearly \( \mathbb{Q}_e = \mathbb{Q}_{\eta, \mathcal{F}_e} \) for \( e_1 < e_2 < \zeta \). Now about the c.c.c., as \( \mathbb{P}_e \) is c.c.c., it preserves “\( \text{cf}(\delta) > \aleph_1 \)” so the proof of part (1) works.

6) Easy, too.

\[ \square_{1.2} \]

**Definition 3.3.** Assume \( \mathbb{A} = (A_\alpha : \alpha < \alpha^*) \) is a \( \subseteq^* \)-decreasing sequence of members of \( [\omega]^\aleph_0 \). We define the forcing notion \( \mathbb{Q}_{\mathbb{A}} \) and the generic real \( w \) by:

\( \begin{align*}
(A) & \quad p \in \mathbb{Q}_{\mathbb{A}} \text{ iff } (a) \quad p = (w, n, A_\alpha) = (w_p, n_p, A_\alpha(p)), \\
(b) & \quad w \subseteq \omega \text{ is finite}, \\
(c) & \quad \alpha < \alpha^* \text{ and } n < \omega, \\
(B) & \quad p \leq_{\mathbb{Q}_{\mathbb{A}}} q \text{ iff } (a) \quad w_p \subseteq w_q \subseteq w_p \cup (A_\alpha(p) \setminus n_p), \\
(b) & \quad n_p \leq n_q, \\
(c) & \quad A_\alpha(p) \cap n_p \geq A_\alpha(q) \cap n_q, \\
(C) & \quad w = \bigcup \{ w_p : p \in G_{\mathbb{Q}_{\mathbb{A}}} \},
\end{align*} \)
Claim 3.4. Let $A$ be as in Definition 3.3.
1) $Q_A$ is a c.c.c. and even a $\sigma$-centered forcing notion.
2) $\Vdash_{Q_A} \forall \alpha \in [\omega]^{\aleph_0} \exists \gamma \in \mathcal{A}_\alpha$ for each $\alpha < \alpha^*$ and $V[G] = V[w]$.
3) Moreover, for every $p \in Q_A$ we have $\Vdash \diamondsuit$ if $w_p \subseteq w \subseteq (A_{\alpha(p)} \setminus n_p) \cup w_p$.

Proof. Easy. □

Claim 3.5. Assume $\eta \in \delta(\omega)$ is $\leq \nu_{\omega}$-increasing.
1) If $\mathcal{F} \subseteq \mathcal{F}_0$ is downward cofinal in $(\mathcal{F}_0, \delta^{\aleph_0})$, i.e. $(\forall \nu \in \mathcal{F}_0)(\exists \rho \in \mathcal{F})(\rho < \nu \land \gamma)$ and $\mathcal{U} \subseteq \delta$ is unbounded then $Q_{\eta} \cap \mathcal{U} = \{p \in Q_{\eta} : \alpha^p \in \mathcal{U} \land \eta^p \in \mathcal{F}\}$ is (not only $\subseteq Q_{\eta}$ but also is) a dense subset of $Q_{\eta}$.
2) If cf($\delta$) > $\aleph_0$ and $\mathcal{R}$ is Cohen forcing then $\Vdash_{\mathcal{R}} \forall \omega \subseteq Q$ is dense in $Q_{\mathcal{V}[G][\mathcal{R}]}$.

Remark 3.6. 1) We can replace “$\eta_\alpha \leq \nu_{\omega}$” by “$p$ belongs to the $F_\sigma$-set $B_\alpha$”, where $B_\alpha$ denotes a Borel set from the ground model, i.e. its definition.
2) Used in 4.4.

Proof. 1) Check.
2) See next claim. □

Claim 3.7. Let $\eta = \langle \eta : \gamma < \delta \rangle$ is $\leq \nu_{\omega}$-increasing in $\omega$.
1) If $\mathcal{P}$ is a forcing notion of cardinality $< \text{cf}(\delta)$ then $\Vdash_{\mathcal{P}} \forall \gamma < \nu_{\omega}$ $\mathcal{P}$ is dense in $Q_{\mathcal{V}[G][\mathcal{P}]}$.
2) A sufficient condition for the conclusion of part (1) is:

\[ \bigoplus_{\mathcal{P}}^{\mathcal{V}[G][\mathcal{P}]} \forall X \in [\mathcal{P}]^{\text{cf}(\delta)} \text{ there is } Y \in [\mathcal{P}]^{<\text{cf}(\delta)} \text{ such that } (\forall p \in X)(\exists q \in Y)(p \leq q). \]

2A) We can weaken the condition to: if $X \in [\mathcal{P}]^{<\text{cf}(\delta)}$ then for some $q \in \mathcal{P}$, $\text{cf}(\delta) \leq |\{p \in X : p \leq q\}|$.
3) If $\langle A_\alpha : \alpha < \delta^* \rangle$ is a decreasing sequence of infinite subsets of $\omega$ and $\text{cf}(\delta^*) \neq \text{cf}(\delta)$ then $\bigoplus_{\mathcal{P}}^{\mathcal{V}[G][\mathcal{P}]}$ holds.

Proof. 1) By part (2).
2) Let $\mathcal{U} \subseteq \delta$ be unbounded of order type $\text{cf}(\delta)$. Assume $p \in \mathcal{P}$ and $\nu$ satisfies $p \Vdash \forall \gamma < \nu_{\omega} \forall \mathcal{V}[G][\mathcal{P}]$. So for every $\gamma \in \mathcal{U}$ we have $p \Vdash \exists \mathcal{V}[G][\mathcal{P}]$ hence there is a pair $(p_\gamma, n_\gamma)$ such that:

\[ (\ast) \begin{align*} (a) & \; p \leq p_\gamma, \\ (b) & \; n_\gamma < \omega, \\ (c) & \; p_\gamma \Vdash \forall \nu \exists n (n < n_\gamma \Rightarrow \eta_\gamma(n) < \nu(n)). \end{align*} \]

We apply the assumption to the set $X = \{p_\gamma : \gamma \in \mathcal{U}\}$ and get $Y \in [\mathcal{P}]^{<\text{cf}(\delta)}$ as there. So for every $\gamma \in \mathcal{U}$ there is $q_\gamma$ such that $p_\gamma \leq p q_\gamma \in Y$. As $|\mathcal{U}| = |Y| + \aleph_0 < \text{cf}(\delta) = |\mathcal{V}|$ there is a pair $(q_\gamma, n_\gamma) \in Y \setminus \omega$ such that $\mathcal{U} \subseteq \delta$ is unbounded where $\mathcal{U}^* := \{\gamma \in \mathcal{U} : q_\gamma = q_\gamma \land n_\gamma = n_\gamma\}$. Lastly, define $\nu_\gamma = \omega_1$ by $n_\gamma$ is 0 if $n < n_\gamma$ is $\mathcal{U} \cap \eta_\gamma(n) + 1 : \alpha \in \mathcal{U}^*$ when $n \geq n_\gamma$.

Clearly

\[ \begin{align*} (\ast) & \begin{align*} (a) & \; \nu_\gamma \leq \omega_1, \\ (b) & \; \gamma \in \mathcal{U}^* \Rightarrow \eta_\gamma \cap [n_\gamma, \omega) < \nu_\gamma \cap [n_\gamma, \omega), \\ (c) & \; \gamma < \delta \text{ then } \eta_\gamma \leq \nu_\gamma. \end{align*} \end{align*} \]
(d) \( \nu_* \in \mathcal{F}_q^Y \)
(e) \( p \leq q_* \)
(f) \( q_* \parallel P \) "\( \nu_* \leq \nu' \)."

So we are done.

2A) Similarly.

3) If \( \text{cf}(\delta^*) < \text{cf}(\delta) \) let \( \mathcal{U} \subseteq \delta^* \) be unbounded of order type \( \text{cf}(\delta^*) \) and \( Q'_A = \{ p \in Q_A : \alpha^p \in \mathcal{U} \} \), it is dense in \( Q_A \) and has cardinality \( \leq \aleph_0 + \text{cf}(\delta^*) < \text{cf}(\delta) \), so we are done.

If \( \text{cf}(\delta^*) > \text{cf}(\delta) \) and \( X \in [\mathcal{P}]^{\text{cf}(\delta)} \), let \( \alpha(\ast) = \sup \{ \alpha^p : p \in X \} \) and \( Y = \{ p \in Q_A : \alpha^p = \alpha(\ast) \} \).

The rest should be clear. □3.7
§ 4. Proof of Theorem 2.5

Choice 4.1. 1) $S \subseteq \{ \delta < \lambda : \text{cf}(\delta) > \aleph_0 \}$ stationary.
2) $\bar{\eta}$ is as in 4.2 below, so possibly using a preliminary forcing of cardinality $\aleph_2$ we have such $\bar{\eta}$.

Definition/Claim 4.2. 1) Assume $\kappa = \text{cf}(\kappa) \in [\aleph_2, \lambda]$ and $\bar{\eta} = \langle \eta_\alpha : \alpha < \kappa \rangle$ is an $\langle \text{cf}(\alpha) \rangle$-increasing sequence in $\omega$ and $\delta \in \lambda \setminus \omega_1$ a limit ordinal and $\gamma < \lambda$. Then the following $s = s_{\delta, \gamma}$ is a winning strategy of $\text{COM}$ in the game $\bar{\delta}, \gamma$; $\text{COM}$ just preserves:

$\otimes \ (a)$ if for every $\zeta < \varepsilon$ we have $(\alpha) + (\beta)$ then we have $(\ast)$ where
\begin{align*}
(\alpha) & \quad \mathbb{P}_{\eta_\zeta} = \mathbb{P}_{\eta_\zeta} \ast \mathbb{Q}_\eta \text{ where } \mathbb{Q}_\eta \text{ is from 3.1 and in } \mathbb{V}^{[p, \varepsilon]} \text{, i.e. is a } \mathbb{P}_{\eta_\zeta} \text{-name} \\
(\beta) & \quad \mathbb{P}_{\eta_\zeta} \ast \mathbb{Q}_\eta \ast \mathbb{P}_{\eta_\zeta} \\
(\ast) & \quad \mathbb{P}_{\eta_\zeta} = \mathbb{P}_{\eta_\zeta} \ast \mathbb{Q}_\eta, \text{ so we have to interpret } \mathbb{P}_{\eta_\zeta} \text{ such that its set of elements is } \subseteq \mathcal{H}_{\eta_\zeta}(\eta_\zeta) \text{ which is easy, i.e. it is } \mathbb{P}_{\eta_\zeta} \cup \{(p, r) : p \in \mathbb{P}_{\eta_\zeta} \text{ and } \tau \text{ is a canonical } \mathbb{P}_{\eta_\zeta} \text{-name of a member of } \mathbb{Q}_\eta \text{ (i.e. use } \aleph_0 \text{ maximal antichains, etc.)}\}
\end{align*}

(b) if in (a) clause $(\alpha)$ holds but $(\beta)$ fail then
\begin{align*}
(\alpha) & \quad \text{the set of elements of } \mathbb{P}_{\eta_\zeta} \text{ is } \mathbb{P}_{\eta_\zeta} \cup \{(p, r) : \text{for some } \zeta < \varepsilon \text{ and } (p', r) \in \mathbb{P}_{\eta_\zeta} \text{ we have } \mathbb{P}_{\eta_\zeta} \models \langle p' \leq p \rangle \\
(\beta) & \quad \text{the order is defined naturally}
\end{align*}

(c) if in (a), clause $(\alpha)$ fail, let $\zeta$ be minimal such that it fails, then
\begin{align*}
(\alpha) & \quad \text{the set of elements of } \mathbb{P}_{\eta_\zeta} \text{ is } \mathbb{P}_{\eta_\zeta} \cup \{(p, r) : \text{for some } \xi < \zeta \text{ and } p' \in \mathbb{P}_{\eta_\zeta} \text{ and } \mathbb{P}_{\eta_\zeta} \models \langle p' \leq p \rangle \\
(\beta) & \quad \text{the order is natural}
\end{align*}

Remark 4.3. In 4.2 we can combine clauses (b) and (c).

Proof. By 3.2 this is easy, see in particular 3.2(4).

Technically it is more convenient to use the (essentially equivalent) variant.

Definition/Claim 4.4. 1) We replace $\mathbb{P}_{\eta_\zeta} = \mathbb{P}_{\eta_\zeta} \ast \mathbb{Q}_\eta$ by $\mathbb{P}_{\eta_\zeta} = \mathbb{P}_{\eta_\zeta} \ast \mathbb{Q}_\eta, \mathcal{F}_\zeta$ where
$$\mathcal{F}_\zeta = \{ \nu : \text{ for some } \varepsilon \leq \zeta, \nu \in \mathcal{F}_\eta^{[p, \varepsilon]} \text{ but for no } \xi < \varepsilon \text{ and } \nu_1 \in \mathcal{F}_\eta^{[p, \varepsilon]} \text{ do we have } \nu_1 \leq_{\eta_\zeta} \nu \}.$$  

2) No change by 3.5(1).

Remark 4.5. In 4.2 we can use $\bar{\eta} = \langle \eta_\alpha : \alpha < \kappa \rangle$ say a $\mathbb{P}_{\eta_\alpha}$-name, but then for the game $\bar{\delta}, \delta$ we better assume $\delta \in E_{\eta_0}$ and $\bar{\eta}$ is a $\mathbb{P}_{[p_\delta]}$-name.

Definition/Claim 4.6. 1) Let $k_* \in K_2^\lambda$ and $\nu_\alpha (\alpha < \lambda)$ be chosen as follows:

$\text{(a)} \quad E_{k_*} = \lambda \text{ and } u[p_{k_*}^\alpha] = \omega_1 + \alpha \text{ hence } u[k_*] = \lambda$  

$\text{(b)} \quad p_{k_*}^\alpha \text{ is } \prec \text{-increasing continuous}$  

$\text{(c)} \quad p_{k_*}^{\alpha + 1} = p_{k_*}^\alpha \ast \mathbb{Q}_\eta \text{ and } \nu_\delta \text{ is the generic (for this copy) of } \mathbb{Q}_\eta \text{ where } \bar{\eta} \text{ is from 4.2}$

$\text{(d)} \quad S_{k_*} = S \text{ (a stationary subset of } \lambda), \delta \in S \Rightarrow \text{cf}(\delta) > \aleph_0$
(e) for each $\delta \in S_k, s^k_\delta = s^k_{\delta, \lambda}$ is from 4.2 or better 4.4

(f) $g^k_\delta$ is $\langle (p^k_\delta, p^k_{\delta + 1}) \rangle$, $\text{mv}(g^k_\delta) = 0$, only one move was done.

2) If $k_1 \leq K_2$ then $\vdash_{P_{k_1}}$ “the pair $(\langle \nu_\alpha : \alpha < \lambda \rangle, \langle \eta_i : i < \kappa \rangle)$ is a $(\lambda, \kappa)$-peculiar cut”.

{pt.28}

**Definition 4.7.** Let $P^*$ be the following forcing notion:

(A) the members are $k$ such that

(a) $k_1 \leq_k k \in K^2_\lambda$

(b) $u[k] = \cup \{u[p^k_\alpha] : \alpha \in E_k\}$ is an ordinal $< \lambda^+$ (but of course $\geq \lambda$)

(c) $S_k = S_k^*$ and $s^k_\delta = s^k_{\delta, \lambda}$ for $\delta \in S_k$

(B) the order: $\leq_{K^2_\lambda}$

{pt.35}

**Definition 4.8.** We define the $P^*$-name $Q^*$ as

$$\cup\{P^k_\lambda : k \in G_{P^*}\} = \cup\{P_p[p^k_\alpha] : \alpha \in E_k \text{ and } k \in G_{P^*}\}.$$  

{pt.42}

**Claim 4.9.** 1) $P^*$ has cardinality $\lambda^+$.

2) $P^*$ is strategically $(\lambda + 1)$-complete hence add no new member to $\lambda^* V$.

3) $\Vdash P^*$ “$Q^*$ is c.c.c. of cardinality $\leq \lambda^+$”.

4) $P^* * Q^*$ is a forcing notion of cardinality $\lambda^+$ neither collapsing any cardinal nor changing cofinalities.

5) If $k \in P^*$ then $k \Vdash_{P^*}$ “$P_k \in Q^*$” hence $\Vdash_{P^*}$ “$P_k \in Q^*$”.

**Proof.** 1) Trivial.

2) By claim 1.23.

3) $G_{P^*}$ is $(< \lambda^+)$-directed.

4), 5) Should be clear.  

{pt.45}

**Claim 4.10.** If $k \in P^*$ and $G \subseteq P_k$ is generic over $V$ then

(a) $\langle \nu_\alpha[G \cap P_k] : \alpha < \lambda \rangle$ is $<_{j^*_\mu}$-decreasing and $i < \kappa \Rightarrow \eta_i < j^*_\mu \nu_\alpha[G \cap P_k]$, (this concerns $P_k$ only)

(b) if $\rho \in \langle \omega_\mu \rangle^{\lambda^*}$ and $i < \kappa \Rightarrow \eta_i < j^*_\mu \rho$ then for every $\alpha < \lambda$ large enough we have $\nu_\alpha[G] < j^*_\mu \rho$

(c) if $\rho \in \langle \omega_\mu \rangle^{\lambda^*}$ and $i < \kappa \Rightarrow \eta_i < j^*_\mu \rho$ then for every $\alpha < \lambda$ large enough we have $\nu_\alpha[G] \not< j^*_\mu \rho$.

**Proof.** Should be clear.  

{pt.49}

**Claim 4.11.** 1) If $k \in P^*$ and $Q$ is a $P_k$-name of a c.c.c. forcing of cardinality $< \lambda$ and $\alpha \in E_k$ and $Q$ is a $P[p^k_\alpha]$-name then for some $k_1$ we have:

(a) $k \leq_{K_2} k_1 \in P^*$

(b) $\Vdash_{P_k}$ “there is a subset of $Q$ generic over $V[G_{P_{k_1}} \cap P[p^k_\alpha]]$”.

2) In (1) if $\Vdash_{P[p^k_\alpha] * Q}$ “there is $\rho \in \omega^2$ not in $V[G_{P_{k_1}}]$ then $\Vdash_{P_{k_1}}$ “there is $\rho \in \omega^2$ not in $V[G_{P_{k_1}}]$”.

**Proof.** 1) By 1.24.

2) By part (1) and clause (\eta) of 1.24.
Proof. Proof of Theorem 2.5\ We force by $\mathbb{P}^* \ast \mathbb{Q}^*$ where $\mathbb{P}^*$ is defined in 4.7 and the $\mathbb{P}^*$-name $\mathbb{Q}^*$ is defined in 4.8. By Claim 4.9(4) we know that no cardinal is collapsed and no cofinality is changed. We know that $\Vdash_{\mathbb{P}^* \ast \mathbb{Q}^*} 2^{\aleph_0} \leq \lambda^+$ because $|\mathbb{P}^*| = \lambda^+$ and $\Vdash_{\mathbb{P}^*} \mathbb{Q}^*$ has cardinality $\leq \lambda^+$, so $\mathbb{P}^* \ast \mathbb{Q}^*$ has cardinality $\lambda^+$, see 4.9(3),(4).

Also $\Vdash_{\mathbb{P}^* \ast \mathbb{Q}^*} 2^{\aleph_0} \geq \lambda^+$ as by 4.9(2) it suffices to prove: for every $k_1 \in \mathbb{P}^*$ there is $k_2 \in \mathbb{P}^*$ such that $k_1 \leq k_2$ and forcing by $\mathbb{P}_{k_2}/\mathbb{P}_{k_1}$ adds a real, which holds by 4.11(2).

Lastly, we have to prove that $(\langle \eta_i : i < \kappa \rangle, \langle \nu_\alpha : \alpha < \lambda \rangle)$ is a peculiar cut. In Definition 2.1 clauses $(\alpha), (\beta), (\gamma)$ holds by the choice of $k_*$. As for clauses $(\delta), (\varepsilon)$ to check this it suffices to prove that for every $f \in \omega$ they hold, so it is suffice to check it in any sub-universe to which $(\bar{\eta}, \bar{\nu})$, $f$ belong. Hence by 4.9(1) it suffices to check it in $\mathbb{V}^{\mathbb{P}_k}$ for any $k \in \mathbb{P}^*$. But this holds by 4.6(2). $\square_{2.5}$
§ 5. QuIte General Applications

{bt.7} Theorem 5.1. Assume \( \lambda = \text{cf}(\lambda) = \lambda^{<\lambda} > \aleph_2 \) and \( 2^\lambda = \lambda^+ \) and \( (\forall \mu < \lambda)(\mu^{\aleph_0} < \lambda) \). Then for some forcing \( \mathbb{P}^* \) of cardinality \( \lambda^+ \) not adding new members to \( \lambda^+ \) and \( \mathbb{P}^* \)-name \( \dot{\mathbb{Q}}^* \) of a c.c.c. forcing it is forced, i.e. \( \Vdash_{\mathbb{P}^*\dot{\mathbb{Q}}^*} \) that \( 2^{\aleph_0} = \lambda^+ \) and

(a) \( p = \lambda \) and \( \text{MA}_{<\lambda} \)

(b) for every regular \( \kappa \in (\aleph_1, \lambda) \) there is a \( (\kappa, \lambda) \)-peculiar cut \( (\langle \eta_i^\kappa : i < \kappa \rangle, \langle \nu_i^\kappa : \alpha < \lambda \rangle) \) hence \( p = t = \lambda \)

(c) if \( \mathbb{Q} \) is a (definition of a) Suslin c.c.c. forcing notion defined by \( \dot{\varphi} \) possibly with a real parameter from \( \mathbb{V} \), then we can find a sequence \( \langle \nu_{3,q,a} : \alpha < \lambda \rangle \) which is positive for \( (\mathbb{Q}, \dot{\eta}) \), see [Sh:630], e.g. non(null) = \( \lambda \)

(d) in particular \( b = d = \lambda \).

{bt.9} Remark 5.2. 0) In clause (c) we can let \( \mathbb{Q} \) be a c.c.c nep forcing (see [Sh:630]), with \( \mathcal{B}, \mathcal{C} \) of cardinality \( \leq \lambda \) and \( \dot{\eta} \) is a \( \dot{\mathbb{Q}} \)-name of a real (i.e. member of \( \mathbb{V}^\mathbb{Q} [\mathbb{P}_{k_1}] \)).

1) Concerning 5.1 as remarked earlier in 1.18(1), if we like to deal with Suslin forcing defined with a real parameter from \( \mathbb{V}^{P^{\mathbb{Q}}+} \) and similarly for \( \mathcal{B}, \mathcal{C} \) we in a sense have to change/create new strategies. We could start with \( \langle \dot{\alpha}_n : \alpha < \lambda^+ \rangle \) such that \( S_\alpha \subseteq \lambda, \alpha < \beta \Rightarrow |S_\alpha \setminus S_\beta| < \lambda \) and \( S_{\alpha+1} \setminus S_\alpha \) is a stationary subset of \( \lambda \). But we can code this in the strategies, do nothing till you know the definition of the forcing.

2) We may like to strengthen 5.1 by demanding

(c) for some \( \mathbb{Q} \) as in clause (c) of 5.1, \( \text{MA}_\mathbb{Q} \) holds or even for a dense set of \( k_1 \in \mathbb{P}^* \), see below, there is \( k_2 \in \mathbb{P}^* \) such that \( k_1 \leq k_2 \) and \( \mathbb{P}_{k_2}/\mathbb{P}_{k_1} \) is \( \mathbb{Q}^{\mathbb{V}^\mathbb{P}_{k_1}} \).

For this we have to restrict the family of \( \mathbb{Q} \)'s in clause (c) such that those two families are orthogonal, i.e. commute. Note, however, that for Suslin c.c.c forcing this is rare, see [Sh:630].

3) This solves the second Bartoszynski test problem, i.e. (B) of Problem 0.2.

4) So \( (\varphi, \mathbb{Q}, \nu, \dot{\eta}) \) in clause (c) of 5.1 satisfies

(a) \( \nu \in \omega^2 \)

(b) \( \varphi = (\varphi_0, \varphi_1, \varphi_2), \Sigma_1 \) formulas with the real parameter \( \nu \)

(c) \( \mathbb{Q} \) is the forcing notion defined by:

| set of elements \( \{ \rho \in \omega^2 : \varphi[\rho] \} \) |
| quasi order \( \leq_{\mathbb{Q}} \{ (\rho_1, \rho_2) : \rho_1, \rho_2 \in \omega^2 \) and \( \varphi_1(\rho_1, \rho_2) \} |
| incompatibility in \( \mathbb{Q} \) is defined by \( \varphi_3 \) |

(d) \( \dot{\eta} \) is a \( \mathbb{Q} \)-name of a real, i.e. \( \langle p_{n,k} : k \leq \omega \rangle \) a (absolute) maximal antichain of \( \mathbb{Q}, t_k = \langle t_{n,k} : k < \omega \rangle, t_{k,n} \) a truth value.

Proof. The proof is like the proof of 2.5 so essentially broken to a series of definitions and Claims. \( \square \)

Claim 5.3. Claim/Choice: Without loss of generality there is a sequence \( (S_\alpha : \alpha < \lambda^+) \) such that:

(a) \( S_\alpha \subseteq S^\mathbb{Q}_\alpha \) is stationary
(b) if $\alpha < \beta$ then $S_\alpha \setminus S_\beta$ is bounded (in $\lambda$)
(c) $\Diamond_{S_{\alpha+1}\setminus S_\alpha}$ and $\Diamond_{S_\alpha \setminus \{S_{\alpha} : \alpha < \lambda^+\}}$.

Proof. E.g. by a preliminary forcing. \hfill {bt.28}

**Definition 5.4.** Let $\mathbb{P}^*$ be the following forcing notion:

(A) The members are $k$ such that

(a) $k \in K^\lambda_1$
(b) $u[k] = \bigcup\{u[p^k_\alpha] : \alpha \in E_k\}$ is an ordinal $< \lambda^+$ (but of course $\geq \lambda$)
(c) $S_k \in \{S_\alpha : \alpha < \lambda^+\}$.

(B) The order: $\leq_{K^\lambda_1}$.

**Definition 5.5.** We define the $\mathbb{P}^*$-name $\dot{Q}$ as

$$\bigcup\{\mathbb{P}^k_\lambda : k \in G_{\mathbb{P}^*}\} = \bigcup\{\mathbb{P}[p^k_\alpha] : \alpha \in E_k \text{ and } k \in G_{\mathbb{P}^*}\}.$$ \hfill {bt.35}

**Claim 5.6. As in 4.9:**
1) $\mathbb{P}^*$ has cardinality $\lambda^+$.
2) $\mathbb{P}^*$ is strategically $(\lambda + 1)$-complete hence add no new member to $\lambda^V$.
3) $\Vdash_{\mathbb{P}^*}$ “$\dot{Q}$” is c.c.c. of cardinality $\leq \lambda^+$.
4) $\mathbb{P}^* * \dot{Q}$ is a forcing notion of cardinality $\lambda^+$ neither collapsing any cardinal nor changing cofinalities.
5) If $k \in \mathbb{P}^*$ then $k \Vdash_{\mathbb{P}^*}$ “$\mathbb{P}_k \in \dot{Q}$” hence $\Vdash_{\mathbb{P}^*}$ “$\mathbb{P}_k \in \dot{Q}$”.

Proof. 1) Trivial.
2) By claim 1.23.
3) $G_{\mathbb{P}^*}$ is $(< \lambda^+)$-directed.
4),5) Should be clear. \hfill {bt.42}

**Claim 5.7. Assume**

(A) (a) $k \in \mathbb{P}^*$
(b) $S_k = S_\alpha, \alpha < \lambda^+$
(c) $\nu$ is a $\mathbb{P}^k_\lambda$-name of a member of $\omega^2, \varepsilon < \kappa$
(d) $\dot{Q}$ is a $\mathbb{P}_k$-name of a c.c.c. Suslin forcing and $\eta$ a $\dot{Q}$-name both definable from $\nu$.

Then there is $k_2$ such that

(B) (a) $k_1 \leq k_2$
(b) $S_{k_2} = S_{\alpha+1}$
(c) if $\varepsilon \in S_{\alpha+1} \setminus S_\alpha$ then $\mathbb{P}^k_{\varepsilon+1} = \mathbb{P}^k_{\varepsilon} * \dot{Q}$ and $\eta_\varepsilon$ is the copy of $\eta$
(d) if $\varepsilon \in S_{\alpha+1} \setminus S_\varepsilon$ then the strategy $\text{st}_\varepsilon$ is as in 4.2, using $\dot{Q}$ instead of $\dot{Q}_0$.

Proof. Straight. \hfill {bt.45}

**Claim 5.8. Like 4.11:**
1) If $k \in \mathbb{P}^*$ and $\dot{Q}$ is a $\mathbb{P}_k$-name of a c.c.c. forcing of cardinality $< \lambda$ and $\alpha \in E_k$ and $\dot{Q}$ is a $\mathbb{P}[p^k_\alpha]$-name then for some $k_1$ we have:
(a) $k \preceq K_2$, $k_1 \in P^*$
(b) $\Vdash_{P_k}$ “there is a subset of $\mathcal{Q}$ generic over $V[G_{P_k} \cap P[\check{p}_k]]$.

2) In (1) if $\Vdash_{P_k \ast Q}$ “there is $\rho \in {}^\omega 2$ not in $V[G_{P_k}]$” then $\Vdash_{P_k}$ “there is $\rho \in {}^\omega 2$ not in $V[G_{P_k}]$”.

Proof. 1) By 1.24.

2) By part (1) and clause (η) of 1.24. □_{4.11}

Claim 5.9. Assume $\kappa \in [\aleph_2, \lambda]$ is regular, $k \in \Pi^*$ and $S_k = S_\alpha$ and $\Vdash_{P_k}$ “$(\check{\eta}_n : \varepsilon < \kappa)$ is increasing. Then we can find $k_1$ such that $k \leq k_1 \in \Pi^*$ and $\gamma(*) < \lambda, P_{k_1}$-name = $\langle \check{v}_i : i \in S_{\alpha+1} \setminus S_\alpha \setminus \gamma(*) \rangle$ such that

$(*)_1$ $\Vdash_{P_k}$ “$(\check{\eta}_n : \varepsilon < \kappa), \langle \check{v}_i : i \in S_{\alpha+1} \setminus S_\alpha \setminus \gamma(*) \rangle$ is a $(\kappa, \lambda)$-peculiar uct

$(*)_2$ moreover if $k_1 \leq k_2 \in \Pi^*$ this still holds.

Proof. As in the proof of 2.5. □

Proof of Theorem 5.1

We force by $\Pi^* \ast \check{Q}^*$ where $\Pi^*$ is defined in 5.4 and the $\Pi^*$-name $\check{Q}$ is defined in 5.5. By Claim 5.6(4) we know that no cardinal is collapsed and no cofinality is changed. We know that $\Vdash_{P \ast Q}$ “$2^{\aleph_0} \leq \lambda^+$” because $\Pi^*| = \lambda^+$ and $\Vdash_{P^*} “\check{Q}$ has cardinality $\leq \lambda^+”, so $\Pi^* \ast \check{Q}^*$ has cardinality $\lambda^+$, see 5.6(3),(4).

Also $\Vdash_{P \ast Q} “2^{\aleph_0} \geq \lambda^+$ as by 4.9(2) it suffices to prove: for every $k_1 \in \Pi^*$ there is $k_2 \in \Pi^*$ such that $k_1 \leq K_2, k_2$ and forcing by $P_{k_1}/P_{k_2}$ add a real, which holds by 5.8(2). Similarly $\Vdash_{P \ast Q} “\text{MA}_{\lambda<\lambda}$ for $< \lambda$ dense subsets” by 5.8(1) hence $p \geq \lambda$ follows; as $p \leq \lambda$ by clause (b) we have proved clause (a) of 5.1.

Clause (b) of 5.1 is proved as in the proof of 2.5, that is by 5.9.

As for clause (c) we are given $k_0$ and $Q, \nu, \check{\eta}$ such that $\nu$ is a $(\Pi^* \ast \check{Q}^*)$-name of a real and $\check{Q}$ is a Suslin c.c.c. forcing definable (say by $\varphi_0$) from the real $\nu$ and $\eta$ a $(\Pi^* \ast \check{Q}^*)$-name of $Q$-name for $Q$ of a real defined by $k_0$ maximal antichain of $Q$, absolutely of course.

As $\Vdash_{P^*} “\check{Q}$ satisfies the c.c.c.$”, for some $k_1 \in \Pi^*$ above $k_0$ and $P_{k_1}$-name $\nu'$ of a member of $\lambda \geq 2$ and $\eta'$ is a $P_{k_1}$-name in $Q, \nu'$ we have $k_1 \Vdash_{P^*} “\nu = \nu' \land \eta = \eta'”$.

As $P_{k_1}$ satisfies the c.c.c. for some $\varepsilon < \lambda$, $(k_1, \varepsilon, \eta', \check{\eta})$ satisfies the assumptions on $(k, \varepsilon, \check{\eta'})$ as in 5.7 so there is $k_2$ and $(\check{\eta}_a : a \in S_{\alpha+1} \setminus S_\alpha)$ as there. So $k_0 \leq k_1 \leq k_2$ and

$(*)$ if $k_2 \leq k_3$ then for a club of $\zeta < \lambda, \nu'$ is a $\Pi^*_{k_3}$-name and $\check{\eta}_c$ is $(Q, \varphi, \check{\nu}'', \eta')$-generic over $V[P[\check{k}_3]]$.

This is clearly enough, so clause (a) of 5.1 holds. For clause (d) of 5.1, first Random real forcing is a Suslin c.c.c. forcing so non(null) $\leq \lambda$ follows from clause (c) and non(null) $\geq \lambda$ follows from clause (a).

Lastly, $b \geq \lambda$ by $\text{MA}_{\lambda<\lambda}$ and we know $\check{\sigma} \geq b$. As dominating real forcing = Hechler forcing is a c.c.c. Suslin forcing so by clause (c) we have $\check{\sigma} \leq \lambda$, together $\check{\sigma} = \check{b} = \lambda$, i.e. clause (d) holds. □_{5.1}
§ 6. Private Appendix

Moved Oct. 2009 from after 3.4, p.26:

What is the special property of $Q_A$ which we shall use to differentiate it from some undesirable c.c.c. forcing, e.g. the case $\{A_\alpha : \alpha < \alpha^+\}$ is downward $\subseteq^*$-directed? (see more in [Sh:885], they are of cardinality $> \kappa$).

Debts (09.11.01)

1) Should we give more details in §13?
2) In Discussion 0.4(q) getting $b < \lambda$, should we give more details.
3) Return to the problems of Tomeka and of Juris.
4) Consider revising §1 to: if $\chi = \chi^\lambda > \lambda^+$ instead of $\lambda^+$, so $E_k$ is always $\lambda$, $\mathbb{P}[\mathcal{P}_\alpha(k)]$ is of cardinality $< \lambda \leq \chi$.
5) Each game $\delta, \gamma$ has actually only countable many moves. Moreover, we may have by $\Diamond \mathfrak{p} = \langle \mathfrak{p}_\alpha : \alpha < \gamma \rangle$ which is $\leq_{K^*_\lambda}$-increasing $u = \cup\{u[\mathfrak{p}_\alpha] : \alpha < \gamma\}$ and $N \prec \mathcal{H}_{\mathfrak{N}_0}(u)$, countable and the game will be really active only for $\alpha \in N \cap \gamma$; so during a play $\mathfrak{q}_\alpha$ for $\alpha < \gamma$ are chosen.

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