

# GENERALIZING RANDOM REAL FORCING FOR INACCESSIBLE CARDINALS

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ABSTRACT. The two parallel concepts of “small” sets of the real line are meagre sets and null sets. Those are equivalent to Cohen forcing and Random Real forcing for  ${}^{\mathbb{N}}\mathbb{N}$ ; in spite of this similarity, the Cohen forcing and Random Real forcing have very different shapes. One of these differences is in the fact that the Cohen forcing has an easy natural generalization for  ${}^{\lambda}2$  for regular  $\lambda > \aleph_0$ , corresponding to an extension for the meagre sets, while the Random Real forcing didn't seem to have a natural generalization, as Lebesgue measure doesn't have a generalization for space  $2^\lambda$  while  $\lambda > \aleph_0$ . In the work [1], Shelah found a forcing resembling the properties of Random Real forcing for  $2^\lambda$  while  $\lambda$  is a weakly compact cardinal. Here we describe, with additional assumptions, such a forcing for  $2^\lambda$  while  $\lambda$  is an Inaccessible Cardinal; this forcing is strategically  $< \lambda$ -complete and satisfies the  $\lambda^+$ -c.c hence preserves cardinals and cofinalities, however unlike Cohen forcing, does not add an undominated real.

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## INTRODUCTION

There are two classical ways of defining what is a small set of the real line  ${}^\omega 2$ ; the topological definition of a small set is a meagre set, which is a countable union of nowhere stationary sets. The second definition uses measure and defines a set to be small if it is a null set, which means that it has Lebesgue measure zero.

Both the collection of meagre sets and the collection of null sets are ideals in the set  ${}^\omega 2$ ; the forcing modulo the ideal of meagre sets is the Cohen Forcing while the forcing modulo the ideal of null sets is Random Real forcing [4].

Looking at  $\lambda$ - reals for  $\lambda > \aleph_0$ , so elements of the set:

${}^\lambda 2 = \{\eta : \eta \text{ is a sequence of } 0\text{'s and } 1\text{'s of length } \lambda\}$ , there is a natural extension to a Cohen Forcing; that would be a forcing modulo sets that are  $\lambda$ - meagre [2]. Unlike this case, Lebesgue measure has no natural extension in  ${}^\lambda 2$  for regular cardinals  $\lambda > \aleph_0$ , thus there is no generalization of Random Real forcing for those cardinals.

An important and useful property of Random Real forcing is not adding a function that is undominated; recall that Cohen Forcing adds  $f : \lambda \rightarrow \lambda$  not smaller (meaning, modulo finite set) than any real in the ground model (where  $\lambda$ -reals here are functions  $\lambda \rightarrow \lambda$ , i.e. members of  ${}^\lambda \lambda$ ). However Random Real forcing has the property that every “new” real ( $\in {}^\omega \omega$ ) is bounded by a real in the ground model. One of the uses of this property is for cardinal invariants; the bounding number  $\mathfrak{b}$  [3] does not change after forcing with Random Real forcing.

In the paper [1], Shelah described a generalization of the null ideal (meaning, the ideal of Lebesgue measure zero sets) for a weakly compact cardinal  $\lambda$ ; that was done by constructing a forcing that has the properties of Random Real forcing in  $2^\lambda$  for a weakly compact  $\lambda$ ; this result is surprising since there is no clear similarity in the definition of the forcing in [1] and Random Real forcing.

By “having the properties of Random Real forcing” we mean a forcing for which: (1) the  $\lambda^+$ - chain condition holds and (2) the forcing is strategically  $< \lambda$ - complete; by those conditions it follows that the forcing preserves cardinals and cofinalities when  $\lambda = \lambda^{< \lambda}$ . Moreover, any new real added in the forcing shall be bounded by a real in the ground model, that will be condition (3): the forcing is  $\lambda$ - bounding. An additional important property is symmetry, but it fails by [1].

The purpose of this work is to find a forcing as in [1] for Mahlo, and even any inaccessible cardinal (therefore may be smaller than the first weakly compact cardinal). In section 2 we shall describe a construction for which the properties of Random Real forcing [27] hold for any inaccessible and in particular Mahlo cardinal; those are cardinals whose existence is a weaker condition than the existence of a weakly compact cardinal [5]. However compare to [1] we need some parameter  $X \subseteq \lambda$  so the definition is not “pure” as in [1].

We shall assume the existence of a stationary set that reflects only in inaccessibles and has a diamond sequence. Note that this demand can be gotten by an easy forcing [6] and if  $V = L$  this is equivalent to not being weakly compact. For a Mahlo cardinal there is a stationary set of inaccessible cardinals below it so in particular this set reflects only in inaccessibles and then we still need to assume the existence of diamond sequence for it. In [1], the main use of the weak compactness was by reflecting a maximal antichain of conditions to a maximal antichain in a

corresponding forcing for a smaller cardinal; the purpose of the diamond sequence here will be to overcome this inability.

Furthermore, for convenience we shall assume that the conditions of the desired forcing are trees that are pruned only in levels of the stationary set (we demand the stationary set only to contain limit ordinals). However it is possible to allow pruning in successor levels; e.g. as long as the pruned set is only of a bounded set, when we use a tree with splitting to  $\theta_\epsilon = cf(\theta_\epsilon) \in [|\epsilon|^+, \lambda)$ .

Notation:

- (1) we use  $\alpha, \beta, \gamma, \delta, \epsilon$  to denote ordinals,
- (2) we use  $\lambda, \mu, \kappa$  to denote cardinals,
- (3)  ${}^B A$  denote the set of functions from  $B$  to  $A$ .

We may like to make our forcing  $< \lambda$ -complete (rather than strategically  $< \lambda$ -complete); this is not clear.

This work is a part of what was promised in [1], the ideas of the construction were stated in Rutgers in 2011.

We intend to deal later with accessible  $\lambda = \lambda^{<\lambda} > \aleph_0$ , (under reasonable condition); also we can use  $|\epsilon|^+$ -complete  $D_\epsilon$  filter on  $\theta_\epsilon$  (or  $D_\eta$  on  $suc_{\mathcal{T}}(\eta)$  when  $lg(\eta) = \epsilon$ , as in [1], or Remark 17 below).

We also continue [1] in [1100; second author publication list] and in work in preparation with T. Baumhauer and M. Goldstern.

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## 1. PRELIMINARIES

In the paper [1] Shelah showed a method of finding, for a weakly compact cardinal  $\lambda$ , a forcing that generalizes the properties of a Random Real forcing for  $\aleph_0$ . In section 2 we add the assumption of a diamond principle and then see a similar forcing that generalizes the same properties for inaccessible cardinals, with the assumption that there exists a stationary set that reflects only in inaccessibles; so in particular for Mahlo cardinals it follows. Here we show some general definitions that will be used throughout this paper.

**Definition 1.** A forcing resembling Random Real forcing for a regular cardinal  $\lambda = \lambda^{<\lambda}$  will be a forcing for which the following conditions hold:

- (1) The forcing is not trivial and the  $\lambda^+$ -chain condition holds.
- (2) The forcing is  $<\lambda$ -strategically complete.
- (3) The forcing is  $\lambda$ -bounding.
- (4) The forcing does not add  $\lambda$ -Cohen reals (follows from 3).

This definition reflects the properties of Random Real forcing in the case of  $\lambda = \aleph_0$ .

*Remark 2.* At this point we shall ignore another desired property, symmetry. This property states that for all  $\eta_1, \eta_2$  and a model  $M$ :  $\eta_1$  is generic over  $M$  and  $\eta_2$  is generic over  $M[\eta_1]$  if and only if  $\eta_2$  is generic over  $M$  and  $\eta_1$  is generic over  $M[\eta_2]$ . By [1] it fails.

Now we can define the terms used for definition 1:

**Definition 3.** Let  $\alpha$  be an ordinal.

- (1) For a forcing notion  $\mathbb{P}$  and condition  $p \in \mathbb{P}$ , we define a game  $\mathcal{D}_\alpha(p, \mathbb{P})$  as follows. A play of the game has  $\alpha$  moves and for  $\beta < \alpha$  first the player COM chooses a condition  $p_\beta \in \mathbb{P}$  such that:
  - (a)  $p \leq p_\beta$ .
    - (i) For all  $\gamma < \beta$  it holds that  $q_\gamma \leq p_\beta$ .

Next, the player INC plays and chooses  $q_\beta \in \mathbb{P}$  such that  $p_\beta \leq q_\beta$ .  
The player COM wins the game if she survived; i.e. had a legal move for all  $\beta < \alpha$ .
- (b) A forcing  $\mathbb{P}$  is said to be strategically complete in  $\alpha$  (or  $\alpha$ -strategically complete) if for all  $p \in \mathbb{P}$  it holds that in the game  $\mathcal{D}_\alpha(p, \mathbb{P})$  between players COM and INC, player COM has a winning strategy.

**Definition 4.** A forcing  $\mathbb{P}$  is  $<\lambda$ -strategically complete if it is  $\alpha$ -strategically complete for all  $\alpha < \lambda$ .

**Definition 5.** For a cardinal  $\lambda$ , a forcing  $\mathbb{P}$  will be called  $\lambda$ -bounding when the following holds:  $\Vdash_{\mathbb{P}} (\forall f : \lambda \rightarrow \lambda)(\exists g \in {}^\lambda \lambda^V : (\forall \alpha < \lambda)(f(\alpha) \leq g(\alpha)))$ .

**Definition 6.** A set of ordinals  $S$  will be called tenuous (or “nowhere stationary” as in [1]) if for each ordinal  $\delta$  of uncountable cofinality, the set  $S \upharpoonright \delta$  is not a stationary set in  $\delta$ .

**Definition 7.** Let  $\lambda$  be a cardinal and  $S \subseteq \lambda$  a stationary set of  $\lambda$ . Then  $S$  is said to be non-reflecting when for each ordinal  $\delta < \lambda$  of cofinality  $> \aleph_0$  the set  $S \upharpoonright \delta$  is not stationary in  $\delta$ .

*Remark 8.* Let  $\lambda$  be a cardinal and let  $S_*$  be a non-reflecting stationary subset of  $\lambda$ . Then the set  $S \subseteq S_*$  is tenuous if and only if  $S$  is not stationary.

*Claim 9.* Let  $\lambda$  be a cardinal and  $S_*$  be a non-reflecting stationary subset of  $\lambda$ .

- (a) If  $\bar{S} = \langle S_i : i < i(*) \rangle$  is such that for all  $i < i(*)$ ,  $S_i \subseteq \lambda$  is a non-stationary with  $i(*) < cf(\lambda)$ ; then  $S = \bigcup_{i < i(*)} S_i$  is not stationary.
- (b) If  $\bar{S} = \langle S_i : i < i(*) \rangle$  is such that for all  $i < i(*)$ ,  $S_i \subseteq S_*$  is a tenuous set with  $i(*) < cf(\lambda)$ ; then  $S = \bigcup_{i < i(*)} S_i$  is tenuous.

*Proof.* We see:

- (a) For each  $i < i(*)$ , there is a club  $E_i$  such that  $S_i \cap E_i = \emptyset$  (as  $S_i$  is not stationary); so let  $E = \bigcap_{i < i(*)} E_i$ .  $E$  is a club in  $\lambda$ , as the intersection of  $i(*) < cf(\lambda)$  clubs. In addition,  $S \cap E = \emptyset$ , thus  $S$  is not stationary.
- (b) From clause 1a,  $S$  is not stationary. In addition for each  $\alpha < \lambda$ ,  $S_* \cap \alpha$  is non-stationary and so does  $S \cap \alpha$ , as a subset of it.

□

2. NEW  $\lambda$ -REAL FOR INACCESSIBLE CARDINAL  $\lambda$ 

To find a forcing resembling Random Real forcing for Mahlo Cardinal, we need to add an additional assumption to those of the weakly compact cardinal case in [1]; the new assumption will be a diamond sequence indexed on a stationary set of inaccessible cardinals (a stationary set of inaccessibles exists for a Mahlo Cardinal). For the more general case of any Inaccessible Cardinal, there is still a need to assume the existence of a diamond sequence; however here it will be indexed on a stationary set that only reflects in inaccessible cardinals. Those two cases are unified here, dealing with an Inaccessible Cardinal with a stationary set that only reflects in inaccessible cardinals; a Mahlo Cardinal will be a special case of this.

## 2.1. Useful Definitions.

**Definition 10.** A good structure  $\tau$  contains:

- (1) An inaccessible cardinal  $\lambda = \lambda_\tau$ .
- (2) A stationary set  $S_* = S_*^\tau \subseteq \lambda$  of strong limit cardinals, such that if  $S_* \cap \delta$  is stationary in  $\delta$  then  $\delta$  is inaccessible.
- (3) An increasing sequence of cardinals  $\bar{\theta} = \bar{\theta}_\tau = \langle \theta_\epsilon : \epsilon < \lambda \rangle$  such that for all  $\epsilon < \lambda$ :  $2 \leq \theta_\epsilon < \lambda$  and if  $\epsilon \in S_*$  then for all  $\zeta < \epsilon$ ,  $\theta_\zeta < \epsilon$ .
- (4) We assume the diamond principle for  $S_*$  and let  $\bar{X} = \bar{X}_\tau$  be a sequence witnessing it, i.e.  $\bar{X} = \langle X_\delta : \delta \in S_* \rangle$ ;  $X_\delta \subseteq \mathcal{H}(\lambda)$ .

*Remark 11.* Observe:

- (1) For  $\lambda$  Mahlo there is a stationary set  $S_* \subseteq \lambda$  that only contains inaccessible cardinals, thus in particular its reflection will only be in inaccessible cardinals.
- (2) For  $\lambda$  inaccessible that isn't Mahlo, a non-reflecting stationary set can be added by forcing that uses initial segments as in [6].
- (3) It is possible to assume that  $S_*$  is a set of just limit ordinals (maybe not strong limit) and the only difference will be that for all  $\delta \in S_*$  the forcing  $\mathbb{Q}_\delta$  (will be defined later) will have the  $|\mathbf{T}_{<\delta}|^+$ -chain condition rather than the  $\delta^+$ -chain condition as we have here; however the forcing  $\mathbb{Q}_\lambda$  will still have the  $\lambda^+$ -chain condition.

*Remark 12.* When  $S_*$  is non-reflecting, the proofs are simpler.

Next, the forcing will be defined in several steps; those will be tree forcings for each  $\delta \in S_* \cup \{\lambda\}$ . First, we shall define the "biggest" forcing  $\mathbb{Q}_\delta^0$ ; later we will define two additional forcing  $\mathbb{Q}_\delta \subseteq \mathbb{Q}'_\delta \subseteq \mathbb{Q}_\delta^0$ . For each of those forcing the forcing relation will be of inverse inclusion.

**Definition 13.** Given a good structure  $\tau$ , we shall define for each  $\alpha \leq \lambda$  the collection of vertices of level  $\alpha$ :  $\mathbf{T}_\alpha = \prod_{\epsilon < \alpha} \theta_\epsilon$ ; for  $\alpha \leq \lambda$  we will define the complete tree up to  $\alpha$  to be the union of those sets:  $\mathbf{T}_{<\alpha} = \bigcup \{\mathbf{T}_\beta : \beta < \alpha\}$ .

*Remark 14.* We assume we have a good structure  $\tau$  until the end of section 2.

**Convention.** We let:

- (1) For all  $\delta_1 < \delta \leq \lambda$  and  $\nu \in \mathbf{T}_\delta$  let  $\nu \upharpoonright \delta_1$  the restriction of  $\nu$  to  $\delta_1$ .
- (2) For each  $\delta \in S_* \cup \{\lambda\}$  and a set  $u \subseteq \mathbf{T}_{<\delta}$  we write  $\text{lim}_\delta(u) = \{\nu \in \mathbf{T}_\delta : \forall \alpha < \delta, \nu \upharpoonright \alpha \in u\}$ .

- (3) For all  $\delta \leq \lambda$  and a set  $u \subseteq \mathbf{T}_{<\delta}$ , for  $\delta_1 < \delta$  we shall write  $u \upharpoonright \delta_1 = u \cap \mathbf{T}_{<\delta_1}$ .
- (4) Assume  $\alpha < \delta$  and  $u \subseteq \mathbf{T}_{<\alpha}$  is a tree: non-empty set closed under taking initial segments. Let  $\eta \in u$  be some node; we write  $u^{[\eta]} = \{\nu \in u : \eta \trianglelefteq \nu \vee \nu \triangleleft \eta\}$ .

**Definition 15.** We can now define the forcing  $\mathbb{Q}_\delta^0$  for each  $\delta \in S_* \cup \{\lambda\}$ .

- (1) A condition in the forcing will be a tree  $p \subseteq \mathbf{T}_{<\delta}$ , such that:
  - (a) There is a trunk  $tr(p)$ ; this is the unique element  $\eta \in p$  with the following properties:
    - (i) For all  $\nu \in p$  it holds that  $\nu \trianglelefteq \eta$  or  $\eta \trianglelefteq \nu$ .
    - (ii) For every  $\eta'$  with the property 1(a)i, we have that  $\eta' \trianglelefteq \eta$ .
  - (b) For each  $\eta \in p$  there is a  $\nu \in \lim_\delta(p)$  with  $\eta \triangleleft \nu$ .
  - (c) For  $tr(p) \trianglelefteq \eta \in p$ ;  $\{j \in \theta_{\lg(\eta)} : \eta \frown \langle j \rangle \in p\} = \theta_{\lg(\eta)}$ .
  - (d) The set  $S_p = \{\delta_1 \in (\lg(tr(p)), \delta) : \lim_{\delta_1}(p \upharpoonright \delta_1) \not\subseteq p\}$  is tenuous, we call this set the witness set.
- (2) For all  $p, q \in \mathbb{Q}_\delta^0$  we say that  $p \leq q$  if and only if  $p \supseteq q$ .

*Remark 16.* We can think of a tree  $p \in \mathbb{Q}_\delta^0$  for  $\delta \in S_* \cup \{\lambda\}$  as a complete tree from the level  $\lg(tr(p))$  that we are pruning: in successor levels we are not allowed to prune. On limit levels we are allowed to prune the tree only if the level is an ordinal in  $S_p$ , so in most limit levels we take all the limits while in stages in  $S_p$  we are allowed to cut as much as we want as long as 1b holds; so there will be a continuation to each node in each level higher than its length.

*Remark 17.* An alternative definition can be such that in successor levels there might be prunings, as long as those are not too big, that is,  $\{j \in \theta_{\lg(\eta)} : \eta \frown \langle j \rangle \notin p\}$  is bounded in  $\theta_{\lg(\eta)}$  (when  $cf(\theta_{\lg(\eta)}) > \lg(\eta)$ ) or even belong to  $D_\eta$ , a  $|\lg(\eta)|^+$ -complete filter on  $\theta_{\lg(\eta)}$ . Not a serious difference.

*Claim 18.* For all  $\delta \in S_* \cup \{\lambda\}$ , the forcing  $\mathbb{Q}_\delta^0$  has the following properties:

- (1) The whole tree  $\mathbf{T}_{<\delta} \in \mathbb{Q}_\delta^0$  and is weaker than any other condition in the forcing  $\mathbb{Q}_\delta^0$ .
- (2) If  $p \in \mathbb{Q}_\delta^0$  and  $\eta \in p$ , then  $p^{[\eta]} \in \mathbb{Q}_\delta^0$  and  $p \leq_{\mathbb{Q}_\delta^0} p^{[\eta]}$ .
- (3) Let  $\epsilon < \delta$ ; then the set  $\{(\mathbf{T}_{<\delta})^{[\eta]} : \eta \in \mathbf{T}_\epsilon\}$  is a maximal antichain of the forcing  $\mathbb{Q}_\delta^0$ .
- (4) Let  $p \in \mathbb{Q}_\delta^0$  and  $\epsilon < \delta$ , then  $\{p^{[\eta]} : \eta \in p \cap \mathbf{T}_\epsilon\}$  is a maximal antichain above  $p$  (if  $\epsilon \leq \lg(tr(p))$ ,  $p = p^{[\eta]}$  and this set is a singleton).

*Proof.* Let  $\delta \in S_* \cup \{\lambda\}$ :

- (1) Trivial.
- (2) Trivial.
- (3) Let  $\epsilon < \delta$ ; the set is an antichain since for any  $\eta \neq \nu \in \mathbf{T}_\epsilon$ , clearly  $(\mathbf{T}_{<\delta})^{[\eta]}$  and  $(\mathbf{T}_{<\delta})^{[\nu]}$  are not compatible. Let  $p \in \mathbb{Q}_\delta^0$  and let  $\eta \in p \cap \mathbf{T}_\epsilon$  be a node. There exists such a node recalling clauses 1a and 1b of definition 15, then  $p^{[\eta]} \in \mathbb{Q}_\delta^0$  by previous clause;  $p \leq_{\mathbb{Q}_\delta^0} p^{[\eta]}$  and clearly  $(\mathbf{T}_{<\delta})^{[\eta]} \leq_{\mathbb{Q}_\delta^0} p^{[\eta]}$ ; thus  $\{(\mathbf{T}_{<\delta})^{[\eta]} : \eta \in \mathbf{T}_\epsilon\}$  is a maximal antichain in  $\mathbb{Q}_\delta^0$ .
- (4) Similar.

□

Next, define a structure that will fulfill the roll of using the diamond principle; the structure will be a collection of objects that contain elements that are antichains with additional properties. In the weakly compact case [1] there was an important roll for the maximal antichains; in the proof of the  $\lambda$ - bounding of the forcing there was a maximal antichain that reflected to an antichain in the forcing corresponding to a smaller cardinal.

In the inaccessible case which we are dealing with here, we will have to use diamond to gain a similar property. Each element is an antichain in the forcing  $\mathbb{Q}_\delta^0$ .

**Definition 19.** For any ordinal  $\delta \in S_* \cup \{\lambda\}$ ,  $\Xi_\delta$  will be the collection of objects  $\bar{q}$ , for which the following conditions hold:

- (1)  $\bar{q} = \langle q_\eta : \eta \in \Lambda \rangle$ ,
- (2)  $\Lambda \subseteq \mathbf{T}_{<\delta}$ ,
- (3) for each  $\eta \in \Lambda$  it holds that  $q_\eta \in \mathbb{Q}_\delta^0$  and  $\eta = tr(q_\eta)$ ,
- (4) for each  $\eta, \nu \in \Lambda$ ,  $\eta \neq \nu$ :  $\eta = tr(q_\eta) \notin q_\nu \vee \nu = tr(q_\nu) \notin q_\eta$ ,
- (5) the union of all the conditions from the set will be an element in the forcing:  
 $r_{\bar{q}}^* = \{\rho \in \mathbf{T}_{<\delta} : (\exists \eta \in \Lambda)(\rho \in q_\eta)\} \in \mathbb{Q}_\delta^0$ .

**Definition 20.** For all  $\delta \in S_* \cup \{\lambda\}$  and  $\bar{q} \in \Xi_\delta$ , we define the coder  $X_{\bar{q}}$ :  $X_{\bar{q}} = \{(\eta, \nu) : (\eta \in \Lambda) \wedge (\nu \in q_\eta)\} \subseteq \mathcal{H}(\delta)$ .

**Definition 21.** Let  $\delta \in S_*$ ; we call  $\delta$  weakly successful when there exists  $\bar{q} \in \Xi_\delta$  with  $X_{\bar{q}} = X_\delta$ , recalling  $X_\delta$  is from the good structure  $\mathfrak{r}$  defined in clause 4 of 10.

*Claim 22.* For a weakly successful  $\delta \in S_*$ , the  $\bar{q}$  of definition 21 is unique.

*Proof.* Observe that the coder  $X_{\bar{q}}$  has all the information on  $\bar{q}$ , therefore such a  $\bar{q}$  must be unique.  $\square$

- Definition 23.**
- (1) For a weakly successful  $\delta \in S_*$ :
    - look at the unique sequence  $\bar{q} = \langle q_\eta : \eta \in \Lambda \rangle$  for which  $X_{\bar{q}} = X_\delta$  and write  $\Lambda_\delta^* = \Lambda$ ; for all  $\eta \in \Lambda_\delta^*$  let  $q_{\delta, \eta}^* = q_\eta$  and lastly  $\bar{q}_\delta^* = \langle q_{\delta, \eta}^* : \eta \in \Lambda_\delta^* \rangle$ ,
    - let  $r_\delta^* = r_{\bar{q}_\delta^*}^* = \{\rho \in \mathbf{T}_{<\delta} : (\exists \nu \in \Lambda_\delta^*)(\rho \in q_{\delta, \nu}^*)\}$ ,
    - finally, for each  $\eta \in \Lambda_\delta^*$  and  $\nu \in \mathbf{T}_{<\delta}$  with:  $\eta \trianglelefteq \nu \in q_{\delta, \eta}^*$ , let  $q_{\delta, \nu}^* = (q_{\delta, \eta}^*)^{[\nu]}$ .
  - (2) For  $\delta \in S_*$  which is not weakly successful, let  $r_\delta^* = \mathbf{T}_{<\delta}$  and for all  $\eta \in r_\delta^*$ :  
 $q_{\delta, \eta}^* = (r_\delta^*)^{[\eta]}$ .

Now we can use the  $\bar{X}$ , being a diamond sequence:

*Claim 24.* For every  $\bar{q} = \langle q_\eta : \eta \in \Lambda \rangle \in \Xi_\lambda$  there is a stationary set of weakly successful  $\delta \in S_*$  for which  $\bar{q}_\delta^* = \langle q_\eta \cap \mathbf{T}_{<\delta} : \eta \in \Lambda \cap \mathbf{T}_{<\delta} \rangle$ .

*Proof.* Recall that  $\bar{X}$  is a diamond sequence, therefore for the set  $X_{\bar{q}}$ , there is a stationary set of  $\delta \in S_*$  for which  $X_\delta = X_{\bar{q}} \cap \mathcal{H}(\delta) = X_{\bar{q}} \cap (\mathbf{T}_{<\delta} \times \mathbf{T}_{<\delta})$ , from the definition of the coder, and as  $X_\delta$  is the coder of  $\bar{q}_\delta^*$  the conclusion follows:  $\bar{q}_\delta^* = \langle q_\eta \cap \mathbf{T}_{<\delta} : \eta \in \Lambda \cap \mathbf{T}_{<\delta} \rangle$ , where  $\bar{q}_\delta^* \in \Xi_\delta$  witness that  $\delta$  is weakly successful.  $\square$

## 2.2. Defining the Main Forcing.

*Remark 25.* Below the main forcing will be defined, however prior to the definition we would like to state the properties that this forcing is expected to have; this remark is meant to describe the general structure of the forcings  $\mathbb{Q}'_\delta$  and  $\mathbb{Q}_\delta$  for each  $\delta \in S_* \cup \{\lambda\}$ .

- (1) We would like those forcing to be subforcings of  $\mathbb{Q}_\delta^0$  (but not necessarily complete subforcings), where  $\mathbb{Q}_\delta \subseteq \mathbb{Q}'_\delta \subseteq \mathbb{Q}_\delta^0$ .
- (2) For a condition  $p \in \mathbb{Q}_\delta$  and a node  $\eta \in p$ , we have  $p^{[\eta]} \in \mathbb{Q}_\delta$ ; the same holds for  $\mathbb{Q}'_\delta$ .
- (3) The complete tree  $\mathbf{T}_{<\delta}$  belongs to  $\mathbb{Q}_\delta$ ; so in particular it belongs to  $\mathbb{Q}'_\delta$ .

*Remark 26.* We are now ready to finally define the desired forcings, the following is the main definition of the forcing. Pedantically, the induction in definition 27 should be carried together with the proof of Claim 29.

**Definition 27.** The definition is inductive on  $\delta$ ; we will define the subforcings of  $\mathbb{Q}_\delta^0$ :  $\mathbb{Q}_\delta$  and  $\mathbb{Q}'_\delta$  for all  $\delta \in S_* \cup \{\lambda\}$ , in addition we will define the term successful for ordinals  $\delta \in S_*$  and for each  $\eta \in \mathbf{T}_{<\delta}$  and a tenuous  $S \subseteq S_* \cap \delta$  we will define  $p_{\eta,\delta,S}^* \in \mathbb{Q}_\delta^0$ , so we have to verify this, see claim 29 below.

- (1)  $\forall p \in \mathbb{Q}_\delta^0, p \in \mathbb{Q}'_\delta$  iff  $\forall \delta_1 \in \delta \cap S_*, \text{lg}(tr(p)) < \delta_1 \Rightarrow p \upharpoonright \delta_1 \in \mathbb{Q}_{\delta_1}$ ,  
So the forcing  $\mathbb{Q}'_\delta$  is derived from the forcings  $\mathbb{Q}_{\delta_1}$  for  $\delta_1 \in \delta \cap S_*$ .
- (2)  $\forall p \in \mathbb{Q}_\delta^0, p \in \mathbb{Q}_\delta$  iff  $p = p_{\eta,\delta,S}^*$  for some  $\eta, S$  satisfying  $\eta \in \mathbf{T}_{<\delta}, S \subseteq S_* \cap \delta$  is tenuous; such  $p_{\eta,\delta,S}^*$  is defined below in clause 4,
- (3) We call  $\delta < \lambda$  successful when it is weakly successful and in addition:  
 $r_\delta^*, q_{\delta,\eta}^* \in \mathbb{Q}'_\delta$  for all  $\eta \in \Lambda_\delta^*$ .  
Explanation: The successful ordinals represent the levels in which there will be a special pruning, determined by the diamond condition, so there is a “control” on the conditions defined uniquely, and in relation to  $r_{\delta_1}^*$  of the corresponding levels  $\delta_1$ .
- (4) We assume that the forcing  $\mathbb{Q}_{\delta'}$  is defined for all  $\delta' \in S_* \cap \delta$ ; the condition  $p_{\eta',\delta',S'}^*$  is defined for all  $\eta' \in \mathbf{T}_{<\delta'}$  and tenuous  $S' \subseteq S_* \cap \delta'$ ; we shall define  $p_{\eta,\delta,S}^* \in \mathbb{Q}_\delta^0$  for  $\eta, S$  as above in the following way:
  - (a) If  $\text{sup}(S) \leq \text{lg}(\eta)$  then  $p_{\eta,\delta,S}^* = \mathbf{T}_{<\delta}^{[\eta]}$ .
  - (b) If  $\text{sup}(S) > \text{lg}(\eta)$  and  $S$  has no maximal element, then for each  $\nu \in \mathbf{T}_{<\delta}$  it holds that  $\nu \in p_{\eta,\delta,S}^*$  if and only if one of the following conditions holds:
    - (i)  $\nu \trianglelefteq \eta$ ,
    - (ii)  $\eta \triangleleft \nu$  and there exists  $\text{lg}(\nu) < \delta_1 \in S$  such that  $\nu \in p_{\eta,\delta_1,S \cap \delta_1}^*$ ,
    - (iii)  $\eta \triangleleft \nu, \text{lg}(\nu) \geq \text{sup}(S)$  and for all  $\delta_1 \in S \setminus (\text{lg}(\eta) + 1)$  and  $\zeta < \delta_1$  it holds that  $\nu \upharpoonright \zeta \in p_{\eta,\delta_1,S \cap \delta_1}^*$ .
  - (c) If  $\text{sup}(S) > \text{lg}(\eta)$  and  $S$  has a last element  $\delta_1 < \delta$ , such that  $\delta_1$  is not successful, then for each  $\nu \in \mathbf{T}_{<\delta}$  it holds that  $\nu \in p_{\eta,\delta,S}^*$  if and only if one of the followings holds:
    - (i)  $\text{lg}(\nu) < \delta_1 \wedge \nu \in p_{\eta,\delta_1,S \cap \delta_1}^*$ ,
    - (ii)  $\text{lg}(\nu) \geq \delta_1 \wedge \nu \upharpoonright \delta_1 \in \lim_{\delta_1} (p_{\eta,\delta_1,S \cap \delta_1}^*)$ .
  - (d) If  $\text{sup}(S) > \text{lg}(\eta)$  and  $S$  has a last element  $\delta_1 < \delta$ , such that  $\delta_1$  is successful, then for each  $\nu \in \mathbf{T}_{<\delta}$  it holds that  $\nu \in p_{\eta,\delta,S}^*$  if and only if one of the following hold:
    - (i)  $\text{lg}(\nu) < \delta_1 \wedge \nu \in p_{\eta,\delta_1,S \cap \delta_1}^*$ ,
    - (ii)  $\text{lg}(\nu) > \delta_1 \wedge \nu \upharpoonright \delta_1 \in p_{\eta,\delta,S}^* \cap \mathbf{T}_{\delta_1}$  according to the definition of  $p_{\eta,\delta,S}^* \cap \mathbf{T}_{\delta_1}$  in the following clause,
    - (iii) On the level of the last element of  $S$ , the process is more interesting; for  $\text{lg}(\nu) = \delta_1$ :

- (A) If  $\nu \notin \lim_{\delta_1}(r_{\delta_1}^*)$  then  $\nu \in \lim_{\delta_1}(p_{\eta, \delta_1, S \cap \delta_1}^*)$ ,  
 (B) If  $\nu \in \lim_{\delta_1}(r_{\delta_1}^*)$  then  $\nu \in (\bigcup \{ \lim_{\delta_1}(q_{\delta_1, \eta'}^*) : \eta' \in \Lambda_{\delta_1}^* \}) \cap \lim_{\delta_1}(p_{\eta, \delta_1, S \cap \delta_1}^*)$ .

Explanation:

0. Why do we arrive to this definition? In [1], we start with  $p = (\mathbf{T}_\lambda)^{[\eta]}$ , as in the  $\lambda$ -Cohen forcing, but add the following pruning: for each condition we have for a tenuous subset  $S \subseteq S_*$  consisting of inaccessible cardinals, for each  $\partial$  we have a set  $\Lambda_\partial$  of  $\partial$  maximal anti-chains of  $\mathbb{Q}_\partial$ . The pruning is: for each  $\partial \in S$  we omit the  $\eta$  of level  $\partial$  avoiding at least one of those maximal antichains (and all proper initial segments of which are in the condition). How is this to be useful in proving the  ${}^\lambda\lambda$ ? In [1] it is done by having reflection of the property of being a maximal antichain; this naturally require reflecting "a set of conditions is a maximal antichain in the forcing". Naturally each maximal antichain in  $\Lambda_\partial$  comes from starting with a maximal antichain in the whole forcing representing a name of an ordinal  $< \lambda$ , and demanding that a condition from the maximal antichain with trunk of length  $< \partial$  will be in the generic sets; i.e. our condition forces this. How can we do this without the weak compactness assumption? by the diamond on  $S_*$ , we guess a "poor man maximal antichain", those are the  $\bar{q}_\delta^*$ -s. They look like an approximation to a maximal antichain inside  $r_\delta^*$ , but usually are far from being a maximal antichain. So we intend to make them maximal antichain above  $r_\delta^*$  by "decree"; or you may say by definition. This of course change the proof in several ways.

- (1) For the level  $\delta \in S_* \cup \{\lambda\}$ , the idea is that the main forcing  $\mathbb{Q}_\delta$ , is a full tree that is only being pruned in levels that are in the matching tenuous set, the idea is to have enough "thickness" to acheive the required completeness and more. In addition, the conditions are unique relative to the tenuous set and the trunk and by their definition closely related to the diamond sequence, intuitively, that is needed for the forcing to be bounding.  
 (2) Note that we gave a definition of  $p_{\eta, \delta, S}^*$  in 27(4), it will defined subset of  $\mathbf{T}_{< \delta}$ , but it really a member of  $\mathbb{Q}_\delta^0$  as is proved in claim 29.

**Definition 28.** For  $\delta \in S_* \cup \{\lambda\}$ , define  $\eta_\delta$  to be a  $\mathbb{Q}_\delta$ -name:  $\eta = \bigcup \{ tr(p) : p \in \mathcal{G}_{\mathbb{Q}_\delta} \}$  where  $\mathcal{G}_{\mathbb{Q}_\delta}$  is a canonical  $\mathbb{Q}_\delta$ - name for the generic filter. If  $\delta$  is clear from the context, we may write  $\eta$  instead  $\eta_\delta$ .

*Claim 29.* For all  $\delta \in S_* \cup \{\lambda\}$ ,  $\eta \in \mathbf{T}_{< \delta}$  and tenuous  $S \subseteq S_* \cap \delta$ ; if  $p = p_{\eta, \delta, S}^*$  then:

- (1) If  $\delta_0 \in S_* \cap \delta$  is such that  $\eta \in \mathbf{T}_{< \delta_0}$  then  $p_{\eta, \delta, S}^* \upharpoonright \delta_0 = p_{\eta, \delta_0, S \cap \delta_0}^*$ .
- (2)  $\eta$  is the trunk of  $p_{\eta, \delta, S}^*$ .
- (3)  $p_{\eta, \delta, S}^* \in \mathbb{Q}_\delta^0$ , moreover  $p_{\eta, \delta, S}^* \in \mathbb{Q}'_\delta$ .
- (4) The tenuous set  $S$  contains the set of pruning levels corresponding to the condition  $p = p_{\eta, \delta, S}^*$ , that is  $S_p \subseteq S$ .
- (5) In addition,  $\mathbb{Q}_\delta \subseteq \mathbb{Q}'_\delta \subseteq \mathbb{Q}_\delta^0$  and  $\mathbb{Q}_\lambda = \mathbb{Q}'_\lambda$ .

*Proof.* We prove all statements of the claim by simultaneous induction on the ordinals  $\delta \in S_* \cup \{\lambda\}$ , assume that the claim it true for  $\mathbb{Q}_{\delta'}$ , so for all conditions  $p_{\eta', \delta', S'}$  where  $\delta' \in \delta \cap S_*$ ,  $\eta' \in \mathbf{T}_{< \delta'}$  and  $S' \subseteq S_* \cap \delta'$ ; we will now prove it for  $p = p_{\eta, \delta, S}^*$  where  $\eta \in \mathbf{T}_{< \delta}$  and  $S \subseteq S_* \cap \delta$ :

- (1) Assume that  $\delta_0 \in S_* \cap \delta$  is such that  $\eta \in \mathbf{T}_{<\delta_0}$ ;
- (a) First, for  $\delta_0 \in S$ , look at the different cases in the definition of  $p_{\eta,\delta,S}^*$ :
- (i) For case 4a,  $p_{\eta,\delta,S}^* \upharpoonright \delta_0 = (\mathbf{T}_{<\delta_0})^{[\eta]} = p_{\eta,\delta_0,S \cap \delta_0}^*$ .
  - (ii) For case 4b, recalling  $\text{lg}(\eta) < \delta_0$ , the initial segments of  $\eta$  are clearly both in  $p_{\eta,\delta,S}^* \upharpoonright \delta_0$  and in  $p_{\eta,\delta_0,S \cap \delta_0}^*$ ; for all  $\eta \leq \nu \in \mathbf{T}_{<\delta_0}$  it holds by clause 4(b)ii of the definition that  $\nu \in p_{\eta,\delta,S}^* \iff \nu \in p_{\eta,\delta_0,S \cap \delta_0}^*$ .
  - (iii) For cases 4c and 4d, for each  $\nu \in \mathbf{T}_{<\delta_0}$  the relevant clauses are 4(c)i of 4c and 4(d)i of 4d. Those clauses trivially imply  $\nu \in p_{\eta,\delta,S}^* \iff \nu \in p_{\eta,\delta_0,S \cap \delta_0}^*$ .
- (b) Next, take any  $\delta_0 \in S_* \cap \delta \setminus S$ :
- (i) For  $\delta_0 < \text{sup}(S)$ , there is  $\delta_0 < \delta' \in S$ , by the induction hypothesis  $p_{\eta,\delta',S \cap \delta'}^* \upharpoonright \delta_0 = p_{\eta,\delta_0,S \cap \delta_0}^*$ . By the clause 1a  $p_{\eta,\delta,S}^* \upharpoonright \delta' = p_{\eta,\delta',S \cap \delta'}^*$  thus  $p_{\eta,\delta,S}^* \upharpoonright \delta_0 = p_{\eta,\delta_0,S \cap \delta_0}^*$  follows.
  - (ii) For  $\delta_0 \geq \text{sup}(S)$ , hence  $\forall \delta' \in S, \delta_0 > \delta'$  (else it is in the case of the previous clause), clearly  $p_{\eta,\delta,S}^* \upharpoonright \delta_0 \subseteq p_{\eta,\delta_0,S \cap \delta_0}^*$ , to prove the other inclusion let  $\nu \in p_{\eta,\delta_0,S \cap \delta_0}^*$ :
    - (A) If for some  $\delta' \in S \cap \delta_0, \text{lg}(\nu) < \delta'$  then by the induction assumption  $\nu \in p_{\eta,\delta',S \cap \delta'}^*$ , which by the previous clause implies  $\nu \in p_{\eta,\delta,S}^*$ .
    - (B) If for all  $\delta' \in S \cap \delta_0, \text{lg}(\nu) \geq \delta'$  and  $\delta_1 = \text{lg}(\nu)$  is the last element of  $S$ : in both relevant cases of the definition (4c, 4d) the level  $\delta_1$  of the condition is determined by the previous levels of  $S$  and by whether or not it is successful, so  $p_{\eta,\delta,S}^* \cap \mathbf{T}_{\delta_1} = p_{\eta,\delta_0,S}^* \cap \mathbf{T}_{\delta_1}$ , in particular  $\nu \in p_{\eta,\delta,S}^*$ .
    - (C) If for all  $\delta' \in S \cap \delta_0$  we have  $\text{lg}(\nu) \geq \delta'$  and  $\text{lg}(\nu) \notin S$ : then the level  $\text{lg}(\nu)$  is determined entirely by the restrictions to previous levels, so we are done.
- (2) For all  $\nu \in p_{\eta,\delta,S}^*$ , first we will show that  $\nu \leq \eta$  or  $\eta \triangleleft \nu$ , the proof splits to cases according to the cases in the definition 27(4):
- (a) For case 4a it is clear.
  - (b) For case 4b it is also clear from the definition.
  - (c) For case 4c:
    - (i) For 4(c)i by the induction hypothesis.
    - (ii) For 4(c)ii also, by the induction hypothesis- each such  $\nu$  has  $\eta \triangleleft \nu$ .
  - (d) For case 4d:
    - (i) For  $\nu$  chosen in clause 4(d)i we have  $\eta \triangleleft \nu$  or  $\nu \leq \eta$  by the induction hypothesis.
    - (ii) For  $\nu$  chosen in clause 4(d)ii it holds that  $\eta \triangleleft \nu$ , again using the induction hypothesis.
    - (iii) For a node  $\nu$  chosen in clause 4(d)iii, since  $\nu \in \lim_{\delta_1} (p_{\eta,\delta_1,S \cap \delta_1}^*)$  and by the induction hypothesis,  $\eta \leq \nu$ .

Second, it remains to prove that  $\eta$  is the maximal node for which each other branch is an extension or an initial segment of it.

In case 4a it is clear; in cases 4b and 4c it follows from the induction hypothesis, the node  $\eta$  is the trunk of the condition  $p_{\eta,\delta_1,S \cap \delta_1}^*$  for each  $\delta_1 \in \delta \cap S_*$  and so it has  $\theta_\epsilon$  extensions to the level of the trunk  $+1$ ; those extensions will be in the new condition  $p_{\eta,\delta,S}^*$  thus  $\eta$  will be a trunk there

as well. For case 4d recall that  $\delta_1$  is a limit cardinal  $> \text{lg}(\eta)$ , we can use the induction hypothesis again observing that before the  $\delta_1$ -th level there are no new prunings that didn't exist in  $p_{\eta, \delta_1, S \cap \delta_1}^*$ , therefore if there were a different trunk containing  $\eta$ , it would have been a trunk of  $p_{\eta, \delta_1, S \cap \delta_1}^*$  as well- a contradiction.

(3) Using induction, first we will show that  $p_{\eta, \delta, S}^* \in \mathbb{Q}_\delta^0$ , checking the clauses in definition 15:

- (a) For clause 1a;  $p_{\eta, \delta, S}^*$  is a tree (follows directly from the induction hypothesis) and it has a trunk  $\eta$  by part 2 of this claim.
- (b) To show clause 1b, let  $\nu \in p_{\eta, \delta, S}^*$ . Assume  $\eta \leq \nu$  (the case of  $\nu \triangleleft \eta$  follows from the case  $\nu = \eta$ ) to show that there is an extension of  $\nu$  to the level  $\delta$ :

- (i) In case 4a of definition 27, let  $\nu \leq \nu' \in \mathbf{T}_\delta$ , then it holds that also  $\eta \leq \nu'$  thus  $\nu' \in \lim_\delta(p_{\eta, \delta, S}^*)$ .

- (ii) In case 4b of definition 27 as  $S$  is tenuous with no last element and  $\text{lg}(\nu) < \text{sup}(S)$  there is a closed unbounded subset  $C$  of  $\text{sup}(S)$  with  $\min(C) > \text{lg}(\nu)$ . Let  $\langle \alpha_i : i < \zeta \rangle$  elements of  $C$  in increasing order \*\*\* that  $\alpha \in C \Rightarrow [\alpha = \text{sup}(C \cap \alpha) \Leftrightarrow \alpha \notin S]$ . We now chose  $\nu_i \in p_{\eta, \alpha_{i+1}, S \cap \alpha_{i+1}}^*$ , then  $\triangleleft$ -increasing,  $\nu \triangleleft \nu_i$ , this is easy and let  $\varrho = \bigcup_{i < \zeta} \nu_i$ . Now if  $\text{lg}(\varrho) = \text{sup}(S) = \delta$  then

$\varrho \in \lim_\delta(p_{\eta, \delta, S}^*)$  and we are done. So assume  $\text{lg}(\varrho) = \text{sup}(S) < \delta$ , clearly  $\varrho \in p_{\eta, \delta, S}^* \cap \mathbf{T}_{\text{lg}(\varrho)}$  hence  $(p_{\eta, \delta, S}^*)^{[\varrho]} = (\mathbf{T}_{< \delta})^{[\varrho]}$  so the derived conclusion is clear.

- (iii) In case 4c of definition 27, so  $\delta_1 = \max(S)$ . First assume that  $\nu \in p_{\eta, \delta, S}^*$  satisfies  $\text{lg}(\nu) < \max(S) = \delta_1$ , then  $\nu \in p_{\eta, \delta_1, S \cap \delta_1}^*$  and by the induction hypothesis, there is some  $\nu' \in \lim_{\delta_1}(p_{\eta, \delta_1, S \cap \delta_1}^*)$  with  $\nu \leq \nu'$ , by the definition it also holds that  $\nu' \in p_{\eta, \delta, S}^*$ . Thus, it is left to prove the claim for any  $\nu \in p_{\eta, \delta, S}^*$  such that  $\text{lg}(\nu) \geq \delta_1$ ; clearly for any extension  $\nu \leq \nu' \in \lim_\delta(p_{\eta, \delta, S}^*)$ ,  $\nu' \upharpoonright \delta_1 \in p_{\eta, \delta, S}^*$  and so  $\nu' \upharpoonright \xi \in p_{\eta, \delta, S}^*$  for all  $\delta_1 \leq \xi < \delta$ .

- (iv) In case 4d of definition 27, so  $\nu \in p_{\eta, \delta, S}^*$ ,  $\delta_1 = \max(S)$  and  $\delta_1$  is successful let  $\beta = \text{lg}(\nu)$ :

- (A) First assume  $\beta < \delta_1$ , by induction hypothesis there is a node  $\nu \leq \nu'$ ,  $\nu' \in \lim_{\delta_1}(p_{\eta, \delta_1, S \cap \delta_1}^*)$ . Now the proof splits to cases:

- Case 1: if  $\nu' \notin \lim_{\delta_1}(r_{\delta_1}^*)$ , then  $\nu' \in p_{\eta, \delta, S}^*$ , hence we have reduced the problem to the case  $\beta = \delta_1$  dealt with below,

- Case 2: if  $\nu' \in \lim_{\delta_1}(r_{\delta_1}^*)$  we still know that  $\eta \in \nu'$  hence  $\eta \in r_{\delta_1}^*$  hence for some  $\varrho \in \Lambda_{\delta_1}^*$  we have  $\eta \in q_{\delta_1, \varrho}^*$  hence there is  $\nu'' \in \lim_{\delta_1}(q_{\delta_1, \eta}^*)$  and we continue as in case 1.

- (B) For  $\beta = \delta_1$ , if  $\nu \in r_{\delta_1}^*$  then for some  $\eta' \in \Lambda_{\delta_1}^*$ ,  $\nu \in q_{\delta_1, \eta'}^*$ , therefore by the induction hypothesis for  $\delta_1$ , there is a node  $\nu' \in \lim_{\delta_1}(q_{\delta_1, \eta'}^*)$  extending  $\nu$  and this node will be in  $p_{\eta, \delta, S}^*$  by clause 4(d)iiiB. Otherwise,  $\nu \notin r_{\delta_1}^*$  and for each  $\nu' \in \mathbf{T}_{\delta_1}$  such that  $\nu \triangleleft \nu'$ ,  $\nu' \notin \lim_{\delta_1}(r_{\delta_1}^*)$ . Since each such  $\nu'$  is in  $\lim_{\delta_1}(p_{\eta, \delta_1, S \cap \delta_1}^*)$  and by clause 4(d)iiiA,  $\nu' \in p_{\eta, \delta, S}^*$ .

(C) Second assume  $\beta \geq \delta_1$ , now every possible extension is being chosen after the level of height  $\delta_1$ , so by the previous clause certainly there is an element in the  $\beta$  level by clause 4(d)ii.

(c) In successor levels all the extensions are taken, as defined in  $\mathbb{Q}_\delta^0$ .

(d) The set  $S$  is tenuous and it holds that  $S_p \subseteq S$  by the next clause, so  $S_p$  (the set of the levels with the prunes) is also tenuous.

Now we can see that  $p_{\eta,\delta,S}^* \in \mathbb{Q}'_\delta$ :

- Let  $\delta'$  be  $\text{lg}(tr(p)) < \delta' \in S_*$ ; observe that in all the cases of the definition it holds that  $p_{\eta,\delta,S}^* \cap \mathbf{T}_{\delta'} = p_{\eta,\delta',S \cap \delta'}^* \in \mathbb{Q}_{\delta'}$  and so we are done.

(4) Looking at the definition, in case 4a trivial; for case 4b we will have that  $S_{p_{\eta,\delta,S}^*} = \bigcap_{\delta' \in S} S_{p_{\eta,\delta',S \cap \delta'}^*}$  so by induction  $S_{p_{\eta,\delta,S}^*} \subseteq S$ ; In case 4c,  $S_{p_{\eta,\delta,S}^*} = S_{p_{\eta,\delta_1,S \cap \delta_1}^*}$  and in case 4d,  $S_{p_{\eta,\delta,S}^*} = S_{p_{\eta,\delta_1,S \cap \delta_1}^*}$  or  $S_{p_{\eta,\delta,S}^*} = S_{p_{\eta,\delta_1,S \cap \delta_1}^*} \cup \{\delta_1\}$ . Using the induction hypothesis and as  $\delta_1 \in S$ , we are done.

(5) Reading the definition 27, clearly  $\mathbb{Q}'_\delta \subseteq \mathbb{Q}_\delta^0$  and  $\mathbb{Q}_\delta \subseteq \mathbb{Q}'_\delta$  follows by clause 3 because  $\mathbb{Q}_\delta = \{p_{\eta,\delta,S}^* : \eta \in \mathbf{T}_{<\delta} \text{ and } S = S_* \cap \delta \text{ is tenuous}\}$ , so clause 5 follows by clause 3. So clause 5 holds indeed. □

Recall the required properties of the forcings discussed in Remark 25 and we shall show that those indeed hold:

*Claim 30.* Let  $\delta \in S_* \cup \{\lambda\}$ ;

- (1) For a condition  $p = p_{\eta,\delta,S}^* \in \mathbb{Q}_\delta$  and a node  $\nu \in p$ , we have  $p \leq_{\mathbb{Q}_\delta} p^{[\nu]} \in \mathbb{Q}_\delta$  and  $tr(p^{[\nu]}) = \max\{tr(p), \nu\}$ , if  $\eta \triangleleft \nu$  then also  $p^{[\nu]} = p_{\nu,\delta,S}^*$  holds, the same is true for  $\mathbb{Q}'_\delta \subseteq \mathbb{Q}_\delta^0$ .
- (2) Let  $p, q \in \mathbb{Q}'_\delta$ , then  $p, q$  are compatible if and only if  $p \cap q \in \mathbb{Q}'_\delta$ .
- (3) Let  $p, q \in \mathbb{Q}_\delta$ , then  $p, q$  are compatible if and only if  $p \cap q \in \mathbb{Q}_\delta$ .
- (4) Let  $p, q \in \mathbb{Q}'_\delta$ , then  $p, q$  are compatible if and only if  $tr(p) \in q \wedge tr(q) \in p$ .
- (5) Let  $p, q \in \mathbb{Q}_\delta$ , then  $p, q$  are compatible if and only if  $tr(p) \in q \wedge tr(q) \in p$ .
- (6) It holds that  $\mathbf{T}_{<\delta} \in \mathbb{Q}_\delta$  and  $\mathbf{T}_{<\delta} \in \mathbb{Q}'_\delta$ , therefore  $\mathbf{T}_{<\delta}$  is the minimal condition of  $\mathbb{Q}_\delta$  and  $\mathbb{Q}'_\delta$ .
- (7) If  $p \in \mathbb{Q}_\delta$  and  $\text{lg}(tr(p)) < \alpha < \delta$  then  $\{p^{[\eta]} : \eta \in p \cap \mathbf{T}_\alpha\}$  is a maximal antichain of  $\mathbb{Q}_\delta$  above  $p$ , the same holds for  $\mathbb{Q}'_\delta$ .

*Proof.* In fact we saw the existence of most of the statements in this claim already. Observe:

- (1) Assume  $p = p_{\eta,\delta,S}^* \in \mathbb{Q}_\delta$  and let  $\nu \in p$ .
  - If  $\nu \leq \eta$  then  $p^{[\nu]} = p \in \mathbb{Q}_\delta$ ; in particular  $tr(p^{[\nu]}) = \eta$ .
  - Else,  $\eta \triangleleft \nu$ . In that case  $p^{[\nu]} = p_{\nu,\delta,S}^*$ , we will show that using induction, looking at the clauses of definition 27(4):
    - (a) If, as in case 4a,  $p = \mathbf{T}_{<\delta}^{[\eta]}$  then  $p^{[\nu]} = \mathbf{T}_\delta^{[\nu]}$  which is in fact  $p_{\nu,\delta,\emptyset}^*$  and thus belongs to  $\mathbb{Q}_\delta$  and  $tr(p^{[\nu]}) = \nu$ .
    - (b) If, as in case 4b, there is a  $\text{lg}(\eta) < \delta' \in S$  with  $\nu \in p_{\eta,\delta',S \cap \delta'}^*$ , then by the induction hypothesis  $p^{[\nu]} \cap \mathbf{T}_{<\delta'} \in \mathbb{Q}_{\delta'}$ . In addition,  $p^{[\nu]} = p_{\nu,\delta,S}^*$  and therefore belongs to  $\mathbb{Q}_\delta$ . If  $\text{lg}(\nu) \geq \text{sup}(S)$  then

for all  $\delta_1 \in S$  and  $\zeta < \delta_1$  it holds that  $\nu \upharpoonright \zeta \in p_{\eta, \delta_1, S \cap \delta_1}^*$ . Then  $p^{[\nu]} = \mathbf{T}_{< \delta}^{[\nu]} = p_{\nu, \delta, S}^*$  and  $tr(p^{[\nu]}) = \nu$ .

(c) If, as in cases 4c and 4d,  $S$  has a last element  $\delta_1 < \delta$ , such that  $lg(\eta) < \delta_1 \in S$ , then if  $\delta_1 \leq lg(\nu)$ ,  $p^{[\nu]} = \mathbf{T}_{< \delta}^{[\nu]} = p_{\nu, \delta, S}^*$ .

(i) In case 4c ( $\delta_1$  is not successful):

(A) If  $lg(\nu) < \delta_1$ , then  $p^{[\nu]}$  contains all the nodes of the shape  $\nu' \in p_{\eta, \delta, S}^*$  such that: (1)  $\nu' \triangleleft \nu$ , (2)  $\nu \trianglelefteq \nu'$  and  $lg(\nu') < \delta_1$  and  $\nu' \in p_{\eta, \delta_1, S \cap \delta_1}^*$  or (3)  $\nu \trianglelefteq \nu'$  and  $lg(\nu') \geq \delta_1$  and  $\nu' \upharpoonright \delta_1 \in \lim_{\delta_1}(p_{\eta, \delta_1, S \cap \delta_1}^*)$ . By induction we have that  $p_{\eta, \delta_1, S \cap \delta_1}^{*[\nu]} = p_{\nu, \delta_1, S \cap \delta_1}^*$  therefore  $p^{[\nu]} = p_{\nu, \delta, S}^* \in \mathbb{Q}_\delta$  and  $tr(p^{[\nu]}) = \nu$ .

(B) If  $lg(\nu) \geq \delta_1$ , then  $p^{[\nu]}$  contains all the nodes of the shape  $\nu' \in p_{\eta, \delta, S}^*$  such that: (1)  $\nu' \triangleleft \nu$  or (2)  $\nu \trianglelefteq \nu'$  (then  $lg(\nu') \geq \delta_1$ ) and  $\nu' \upharpoonright \delta_1 = \nu \upharpoonright \delta_1 \in \lim_{\delta_1}(p_{\eta, \delta_1, S \cap \delta_1}^*)$ , so in fact any  $\nu'$  with  $\nu \trianglelefteq \nu'$  is in that group. Clearly  $p^{[\nu]} = p_{\nu, \delta, S}^* \in \mathbb{Q}_\delta$  and  $tr(p^{[\nu]}) = \nu$ .

(ii) In case 4d ( $\delta_1$  is successful)

(A) If  $lg(\nu) < \delta_1$ , then  $p^{[\nu]}$  contains all the nodes of the shape  $\nu' \in p_{\eta, \delta, S}^*$  such that (1)  $\nu' \triangleleft \nu$ , (2)  $\nu \trianglelefteq \nu'$  and  $lg(\nu') < \delta_1$  and  $\nu' \in p_{\eta, \delta_1, S \cap \delta_1}^*$ , (3)  $\nu \triangleleft \nu'$  and  $lg(\nu') = \delta_1$  and  $(\nu' \in \lim_{\delta_1}(p_{\nu, \delta_1, S \cap \delta_1}^*) \cap \lim_{\delta_1}(r_{\delta_1}^*) \cap (\bigcup_{\eta' \in \Lambda_{\delta_1}^*} \lim_{\delta_1}(q_{\delta_1, \eta'}^*)))$

or  $\nu' \in \lim_{\delta_1}(p_{\nu, \delta_1, S \cap \delta_1}^*) \setminus \lim_{\delta_1}(r_{\delta_1}^*)$  or (4)  $\nu \triangleleft \nu'$ ,  $lg(\nu') > \delta_1$  and  $\nu' \upharpoonright \delta_1 \in p_{\eta, \delta, S}^* \cap \mathbf{T}_{\delta_1}$ . By induction,  $p_{\eta, \delta_1, S \cap \delta_1}^{*[\nu]} = p_{\nu, \delta_1, S \cap \delta_1}^*$  and since  $r_{\delta_1}^*$  and  $\forall \eta' \in \Lambda_{\delta_1}^* : q_{\delta_1, \eta'}^*$  do not depend on the trunk, we see that  $p_{\eta, \delta, S}^{*[\nu]} \upharpoonright \delta_1 = p_{\nu, \delta, S}^* \upharpoonright \delta_1$  and  $p_{\eta, \delta, S}^{*[\nu]} \cap \mathbf{T}_{\delta_1} = p_{\nu, \delta, S}^* \cap \mathbf{T}_{\delta_1}$ , thus the equality follows also for  $\nu \triangleleft \nu'$  such that  $lg(\nu') > \delta_1$  and  $p_{\eta, \delta, S}^{*[\nu]} = p_{\nu, \delta, S}^* \in \mathbb{Q}_\delta$  and  $tr(p^{[\nu]}) = \nu$ .

(B) If  $lg(\nu) \geq \delta_1$  then  $p^{[\nu]}$  contains all the nodes of the shape  $\nu' \in p_{\eta, \delta, S}^*$  such that (1)  $\nu' \trianglelefteq \nu$  or (2)  $\nu \triangleleft \nu'$ ,  $lg(\nu') > \delta_1$  and  $\nu' \upharpoonright \delta_1 \in p_{\eta, \delta, S}^* \cap \mathbf{T}_{\delta_1}$ , which since  $\nu' \upharpoonright \delta_1 = \nu \upharpoonright \delta_1$  implies  $p_{\eta, \delta, S}^{*[\nu]} = p_{\nu, \delta, S}^* \in \mathbb{Q}_\delta$  and  $tr(p^{[\nu]}) = \nu$ .

In particular it holds that  $tr(p^{[\nu]}) = \max\{\eta, \nu\}$ .

We have finished showing that  $\nu \in p \in \mathbb{Q}_\delta \Rightarrow p^{[\nu]} \in \mathbb{Q}_\delta$ . What about  $\mathbb{Q}'_\delta$ ?

Let  $p \in \mathbb{Q}'_\delta$ , then for each  $\delta' \in \delta \cap S_*$  it holds that  $p \upharpoonright \delta' \in \mathbb{Q}_{\delta'}$ . Next, observe that  $q = p^{[\nu]}$  for  $\eta \trianglelefteq \nu \in p$ ; then for all  $lg(\nu) \leq \delta' \in \delta \cap S_*$ ,  $q \upharpoonright \delta' = (p \upharpoonright \delta')^{[\nu]}$ . Observe that  $p \upharpoonright \delta' \in \mathbb{Q}_{\delta'}$  and by the first part of this clause also  $(p \upharpoonright \delta')^{[\nu]} \in \mathbb{Q}_{\delta'}$ . For  $\nu \trianglelefteq \eta$ , it holds that  $p^{[\nu]} = p \in \mathbb{Q}'_\delta$  and in particular  $tr(p^{[\nu]}) = \eta$ ; so indeed  $tr(p^{[\nu]}) = \max\{\eta, \nu\}$ .

By the definition of  $p^{[\nu]}$ ,  $p^{[\nu]} \subseteq p$  and since the order of both forcing  $\mathbb{Q}_\delta$  and  $\mathbb{Q}'_\delta$  is inverse inclusion and by what we just showed if  $p \in \mathbb{Q}_\delta$ , then  $p \leq_{\mathbb{Q}_\delta} p^{[\nu]}$  and if  $p \in \mathbb{Q}'_\delta$  then  $p \leq_{\mathbb{Q}'_\delta} p^{[\nu]}$ .

- (2) This clause and the following are shown by simultaneous induction: considering the forcing  $\mathbb{Q}'_\delta$ , if  $p$  and  $q$  are compatible there exists a condition  $r \in \mathbb{Q}'_\delta$ :  $r \subseteq p, q$ , thus  $tr(p), tr(q) \trianglelefteq tr(r)$ . Let  $\delta_1 \in \delta \cap S_*$ ,  $lg(tr(p)) < \delta_1$ , as  $p \upharpoonright \delta_1, q \upharpoonright \delta_1, r \upharpoonright \delta_1 \in \mathbb{Q}_{\delta_1}$  and  $r \upharpoonright \delta_1 \subseteq p \upharpoonright \delta_1, q \upharpoonright \delta_1$  and the following clause's induction assumption, we conclude that  $p \cap q \upharpoonright \delta_1 \in \mathbb{Q}_{\delta_1}$  and  $p \cap q \in \mathbb{Q}'_\delta$  follows, the other direction is trivial.
- (3) Considering the forcing  $\mathbb{Q}_\delta$ , if  $p$  and  $q$  are compatible there exists a condition  $r \in \mathbb{Q}_\delta$ :  $r \subseteq p, q$ , thus  $tr(p), tr(q) \trianglelefteq tr(r)$ . Assume wlog  $tr(p) \triangleleft tr(q) = \eta$ , then  $p \cap q = p_{\eta, \delta, S}^* \in \mathbb{Q}_\delta$  where  $S = S_p \cup S_q$ , the other direction is trivial.
- (4) This clause and the next one are shown by simultaneous induction on  $\delta$ . Considering the forcing  $\mathbb{Q}'_\delta$ :
- For the first direction, assume  $p$  and  $q$  are compatible; thus there exists a condition  $r \in \mathbb{Q}'_\delta$ :  $r \subseteq p, q$ . In particular,  $tr(p), tr(q) \trianglelefteq tr(r)$  thus  $tr(p), tr(q) \in r \subseteq p \cap q$ .
  - For the other direction, assume  $tr(p) \in q \wedge tr(q) \in p$ , let  $r = p \cap q$  and by previous clause  $r \in \mathbb{Q}'_\delta$ . In particular  $lg(tr(p)), lg(tr(q)) < \delta_1$  and since  $p, q \in \mathbb{Q}'_\delta$  it implies that  $p \upharpoonright \delta_1, q \upharpoonright \delta_1 \in \mathbb{Q}_{\delta_1}$ . We can use the induction hypothesis to conclude that  $(p \upharpoonright \delta_1) \cap (q \upharpoonright \delta_1) = r \upharpoonright \delta_1 \in \mathbb{Q}_{\delta_1}$ ; therefore indeed  $r \in \mathbb{Q}'_\delta$ .
- (5) Considering the forcing  $\mathbb{Q}_\delta$ , assume it holds for  $\mathbb{Q}_{\delta_1}$  with  $\delta_1 < \delta$ :
- For the first direction, assume that  $p$  and  $q$  are compatible; thus there exists  $r \in \mathbb{Q}_\delta$ :  $r \subseteq p, q$ . In particular,  $tr(p), tr(q) \trianglelefteq tr(r)$  thus  $tr(p), tr(q) \in r \subseteq p \cap q$ .
  - For the other direction, assume  $tr(p) \in q \wedge tr(q) \in p$  and remember that for some nodes  $\eta_1, \eta_2 \in \mathbf{T}_{<\delta}$  and tenuous sets  $S_1, S_2 \subseteq S_* \cap \delta$ , the conditions are in fact  $p = p_{\eta_1, \delta, S_1}^*, q = p_{\eta_2, \delta, S_2}^*$ . Recall the assumption and assume by symmetry that  $\eta_1 \triangleleft \eta_2$ . Let  $S = S_1 \cup S_2$  and we will show that  $p_{\eta_2, \delta, S}^* \subseteq p \cap q$ ; this is indeed a condition in the forcing  $\mathbb{Q}_\delta$  looking at definition 27. Let  $\nu \in p_{\eta_2, \delta, S}^*$ ; the possibilities by clause 4 are:
    - If  $S$  has no last element;
      - \* If  $\nu \triangleleft \eta_2$  then  $\nu \in q$ , as  $\eta_2 \in p$  it follows that  $\nu \in p \cap q$ .
      - \* If for some  $\delta_1 \in S$ ,  $\nu \in p_{\eta_2, \delta_1, S \cap \delta_1}^*$  then by the induction assumption,  $p_{\eta_2, \delta_1, S \cap \delta_1}^* \subseteq p \cap q \cap \mathbf{T}_{<\delta_1}$  so  $\nu \in p \cap q$ .
      - \* If  $\forall \delta_1 \in S \forall \zeta < \delta_1 : \nu \upharpoonright \zeta \in p_{\eta_2, \delta_1, S \cap \delta_1}^*$ , by the induction assumption  $\forall \delta_1 \in S \forall \zeta < \delta_1 : \nu \upharpoonright \zeta \in p \cap q$ . If  $p$  or  $q$  had a last element, it was below  $\sup(S)$  and in all the construction possibilities it can be seen that this implies  $\nu \in p$  and  $\nu \in q$ .
    - If  $S$  has a last element  $\delta_1$ , which is not successful;
      - \* If  $\nu \in p_{\eta_2, \delta_1, S \cap \delta_1}^*$ , by the induction assumption  $p_{\eta_2, \delta_1, S \cap \delta_1}^* \subseteq p \cap q \cap \mathbf{T}_{<\delta_1}$  so  $\nu \in p \cap q$ .
      - \* If  $\nu \upharpoonright \delta_1 \in \lim_{\delta_1} (p_{\eta_2, \delta_1, S \cap \delta_1}^*)$ , by the induction assumption  $p_{\eta_2, \delta_1, S \cap \delta_1}^* \subseteq p \cap q \cap \mathbf{T}_{<\delta_1}$ , so  $\nu \upharpoonright \delta_1 \in p \cap q$ . For each one of  $S_1, S_2$ , if it doesn't contain  $\delta_1$  then  $\nu$  belongs to the matching condition ( $p$  or  $q$ ), while if it does contain  $\delta_1$ , as  $\delta_1$  is not successful, the matching condition, say  $p$ , will have that  $\nu \upharpoonright \delta_1 \in \lim_{\delta_1} (p) \Rightarrow \nu \in p$ .
    - If  $S$  has a last element  $\delta_1$ , which is successful;

- \* If  $\nu \in p_{\eta_2, \delta_1, S \cap \delta_1}^*$ , by the induction assumption  $p_{\eta_2, \delta_1, S \cap \delta_1}^* \subseteq p \cap q \cap \mathbf{T}_{< \delta_1}$  so  $\nu \in p \cap q$ .
  - \* If  $\nu \in \lim_{\delta_1}(p_{\eta_2, \delta_1, S \cap \delta_1}^*)$  then by the induction assumption  $\nu \in \lim_{\delta_1}(p \cap q \cap \mathbf{T}_{< \delta_1})$ :
    - In case  $\nu \notin \lim_{\delta_1}(r_{\delta_1}^*)$ , for each one of  $p, q$ , if  $S_1$  or  $S_2$  have  $\delta_1$  as their last element,  $\nu \in p$  or  $\nu \in q$  accordingly. Else the corresponding  $S_1$  or  $S_2$  has all its elements below  $\delta_1$  and so by the possibilities in definition 4,  $\nu \in p \cap q$ .
    - Else  $\nu \in \lim_{\delta_1}(r_{\delta_1}^*)$ , then (\*)  $\nu \in \bigcup \{\lim_{\delta_1}(q_{\delta_1, \eta'}^*) : \eta' \in \Lambda_{\delta_1}^*\}$ , for each one of  $p, q$ , if  $S_1$  or  $S_2$  have  $\delta_1$  as their last element then since  $\nu \in \lim_{\delta_1}(p \cap q)$  and by (\*)  $\nu$  is contained in the corresponding condition. Else the corresponding  $S_1$  or  $S_2$  has all its elements below  $\delta_1$  and so by all the possibilities in definition 4,  $\nu \in p \cap q$ .
  - \* If  $\nu \upharpoonright \delta_1 \in p_{\eta_2, \delta, S}^* \cap \mathbf{T}_{\delta_1}$ , since  $p_{\eta_2, \delta, S}^* \cap \mathbf{T}_{\delta_1} \subseteq p \cap q \cap \mathbf{T}_{\delta_1}$ ,  $\nu \upharpoonright \delta_1 \in p \cap q$  and so  $\nu \in p \cap q$ , for any possibility for the construction of  $p$  and  $q$ .
- (6) It holds that  $\mathbf{T}_{< \delta} = p_{\langle \rangle, \delta, \emptyset}^*$  so trivially it belongs to  $\mathbb{Q}_\delta$ , it then by the first clause of this claim it follows that  $\mathbf{T}_{< \delta} \in \mathbb{Q}'_\delta$  and we are done.
- (7) Let  $\eta, \nu \in p \cap \mathbf{T}_\alpha$  be different, then  $\eta \notin p^{[\nu]}$  and  $\nu \notin p^{[\eta]}$ ; recalling clause 5 it follows that  $p^{[\eta]}, p^{[\nu]}$  are incompatible and so the set  $\{p^{[\eta]} : \eta \in p \cap \mathbf{T}_\alpha\}$  is an antichain in  $\mathbb{Q}_\delta$  above  $p$ . In addition, let  $p \leq_{\mathbb{Q}_\delta} q \in \mathbb{Q}_\delta$  and let  $\eta_0 \in q \cap \mathbf{T}_\alpha \subseteq p \cap \mathbf{T}_\alpha$ ; then  $p^{[\eta_0]}$  is compatible with  $q$ : their common upper bound is  $q^{[\eta_0]}$  and this is in  $\mathbb{Q}_\delta$  by what we just showed. Clearly  $p^{[\eta_0]} \in \{p^{[\eta]} : \eta \in p \cap \mathbf{T}_\alpha\}$  so this set is indeed a maximal antichain. The proof for  $\mathbb{Q}'_\delta$  is identical. □

**Corollary 31.** *Let  $\delta \in S_*$ , if  $\delta$  is successful then the set  $\bar{q}_\delta^* = \langle q_{\delta, \eta}^* : \eta \in \Lambda_\delta^* \rangle$  is an antichain of  $\mathbb{Q}'_\delta$  above  $r_\delta^*$ .*

*Proof.* Recall that if  $\eta \neq \nu \in \Lambda_\delta^*$  then  $\eta \notin q_{\delta, \nu}^* \vee \nu \notin q_{\delta, \eta}^*$  (see definition 19) and recall 30(4). □

### 2.3. Properties of the Forcing.

*Claim 32.* Let  $\delta \in S_*$  be such that  $S_* \cap \delta$  is non-stationary in  $\delta$ , then the forcing  $\mathbb{Q}_\delta$  is strategically complete in  $cf(\delta)$ .

*Remark 33.* Remember that if  $\delta \in S_*$  is not inaccessible then  $S_* \cap \delta$  is not stationary in  $\delta$ , also if  $\alpha < \lambda$  and  $\delta = \min(S_* \setminus (\alpha + 1))$  then  $S_* \cap \delta$  is not stationary.

*Proof.* First, assume that this holds for each  $\delta_0 < \delta$ . Now, there is a club  $E$  of  $\delta$  such that  $E \cap S_* = \emptyset$ . Let  $p \in \mathbb{Q}_\delta$  and  $\alpha = cf(\delta)$ , we shall play the game  $\mathfrak{D}_\alpha(p, \mathbb{Q}_\delta)$ , determining a strategy for COM;

- (1) At the first step player COM will choose a condition  $p_0 \geq p$ .
- (2) In successor step  $i + 1 < \alpha$ : look at the condition  $q_i$  that player INC chose in the  $i$ -th step; let  $\beta_i = \text{lg}(tr(q_i))$ . In addition let  $\gamma_i = \min(E \setminus (\beta_i + 1))$ . Now choose some  $\eta_{i+1} \in q_i \cap \mathbf{T}_{\gamma_i}$ ; player COM will choose  $p_{i+1} = (q_i)^{[\eta_{i+1}]}$ , this is a condition of the forcing  $\mathbb{Q}_\delta$  by claim 30. Observe that  $tr(q_i) \leq \eta_{i+1}$ ,

$q_i \leq_{\mathbb{Q}_\delta} p_{i+1}$  and by the choice player COM made, she forced player INC to have  $\eta_{i+1} \leq tr(q_{i+1})$ .

- (3) In limit step  $i(*) < \alpha$ : player COM will choose  $p_{i(*)} = \bigcap_{i < i(*)} q_i$ , let  $S_{i(*)} =$

$$\bigcup_{i < i(*)} S_{q_i} \setminus \lg(\nu_{i(*)}) \text{ and } \nu_{i(*)} = \bigcup_{i < i(*)} tr(q_i).$$

- (a) The node  $\nu_{i(*)}$  belongs to all the conditions that player INC had chosen in the steps  $i < i(*)$ : observe that  $\delta' = \sup\{\beta_i : i < i(*)\} = \sup\{\gamma_i : i < i(*)\}$  but  $\gamma_i \in E$  hence  $\delta' \in E$ . Since  $E$  is a club disjoint to  $S_i$  there is no pruning in the level  $\delta'$ , in particular  $\nu_{i(*)}$  is not being pruned. Thus  $\nu_{i(*)} \in q_i$  for all  $i < i(*)$ .

- (b) It remains to show that  $p_{i(*)}$  is indeed a condition in the forcing and in fact  $p_{i(*)} = p_{\nu_{i(*)}, \delta, S_{i(*)}}^*$ ; first observe that  $cf(\delta') = cf(i(*))$ , next:

- (i) For each node  $\nu' \in p_{i(*)}$  such that  $\lg(\nu') < \lg(\nu_{i(*)})$  there is  $i < i(*)$  such that  $\lg(\nu') < \lg(tr(q_i))$  and as  $p_{i(*)}$  is the intersection, we get  $\nu' \triangleleft tr(q_i)$  and so  $\nu' \leq \bigcup_{i < i(*)} tr(q_i)$ . Thus  $\bigcup_{i < i(*)} tr(q_i)$  is a node such that there is no splitting before it in  $p_{i(*)}$ . However in each level above this node there are splittings as those splittings exist for each  $q_i$ , and they are “full”, see definition 15(1)(1c) and definition 27. In addition, for each  $i < j < i(*)$  any splitting in the tree  $q_j$  exists in the tree  $q_i$  as well: this is an increasing sequence of conditions and  $q_j \subseteq q_i$ . It follows that  $p_{i(*)}$  is a tree with trunk  $\nu_{i(*)}$  (if we use the filters  $D_\epsilon$  for  $\epsilon < \lambda$ , this is somewhat more delicate, still OK).

- (ii) The set  $S_{i(*)}$  is tenuous: the set  $S_* \cap \delta'$  is non-stationary by the claim assumption, for every  $\delta' \leq \delta$  hence is tenuous and  $S_{i(*)} \subseteq S_* \cap \delta$ , thus  $S_{i(*)}$  is non-stationary in  $\delta$ .

For all  $i < i(*)$ , we shall see that  $p_{\nu_{i(*)}, \delta, S_{i(*)}}^* \subseteq q_i$ ; as  $tr(q_i) \leq \nu_{i(*)}$ , observe that  $q_i^{[\nu_{i(*)}]}$   $\subseteq q_i$  by a previous lemma. Also,  $q_i^{[\nu_{i(*)}]}$  and  $p_{\nu_{i(*)}, \delta, S_{i(*)}}^*$  have the same trunk, with the first having a smaller stationary set:  $S_{q_i} \subseteq S_{i(*)}$ , therefore we indeed get  $p_{\nu_{i(*)}, \delta, S_{i(*)}}^* \subseteq q_i^{[\nu_{i(*)}]}$ , thus  $p_{\nu_{i(*)}, \delta, S_{i(*)}}^* \subseteq q_i$  and  $p_{\nu_{i(*)}, \delta, S_{i(*)}}^* \subseteq p_{i(*)}$ .

We need to also see that  $p_{i(*)} \subseteq p_{\nu_{i(*)}, \delta, S_{i(*)}}^*$ ; assume this doesn't hold. Then, for some  $\nu' \in p_{i(*)}$ ,  $\nu' \notin p_{\nu_{i(*)}, \delta, S_{i(*)}}^*$ ; let  $\delta'$  be the minimal such that  $\nu' \upharpoonright \delta' \notin p_{\nu_{i(*)}, \delta, S_{i(*)}}^*$ ; remembering definition 4, necessarily  $\nu' \upharpoonright \delta' \in \lim_{\delta'}(p_{\nu_{i(*)}, \delta', S_{i(*)} \cap \delta'}^*)$  and  $\nu' \upharpoonright \delta' \in \lim_{\delta'}(r_{\delta'}^*) \setminus (\bigcup\{\lim_{\delta'}(q_{\delta', \eta'}^*) : \eta' \in \Lambda_{\delta'}^*\})$ . As  $\delta' \in S_{i(*)}$ , there exists  $i < i(*)$  such that  $\delta' \in S_{q_i}$ ; since for all  $\delta'' < \delta'$ ,  $\nu' \upharpoonright \delta'' \in p_{\nu_{i(*)}, \delta, S_{i(*)}}^* \subseteq q_i$  so  $\nu' \upharpoonright \delta' \in \lim_{\delta'}(q_i)$  and by the construction of  $q_i$  as  $\nu' \upharpoonright \delta' \in \lim_{\delta'}(r_{\delta'}^*) \setminus (\bigcup\{\lim_{\delta'}(q_{\delta', \eta'}^*) : \eta' \in \Lambda_{\delta'}^*\})$  it follows that  $\nu' \upharpoonright \delta' \notin q_i$ , a contradiction to the assumption  $\nu' \in p_{i(*)} \subseteq q_i$ .

We showed that  $p_{\nu_{i(*)}, \delta, S_{i(*)}}^* = p_{i(*)}$ , in addition for all  $i < i(*)$ ,  $q_i \leq_{\mathbb{Q}_\lambda} p_{i(*)}$  so easily  $p_{i(*)}$  is the smallest supremum of those conditions.  $\square$

**Theorem 34.** *If  $\delta \in S_* \cup \{\lambda\}$  is inaccessible, then the forcing  $\mathbb{Q}_\delta$  is strategically complete in  $\delta$ .*

*Proof.* For  $\delta \in S_* \cup \{\lambda\}$  and  $p \in \mathbb{Q}_\delta$ , we shall play the game  $\mathcal{D}_\delta(p, \mathbb{Q}_\delta)$ . We shall construct inductively the sequence  $\langle p_i, q_i, E_i : i < \delta \rangle$  where  $p_i$  is the  $i$ -th move of player COM,  $q_i$  is the  $i$ -th move of player INC,  $E_i$  is a club in  $\delta$  chosen by COM after INC plays his  $i$ -th move; it shall be disjoint to  $S_{q_i}$ ; assume that for all  $i' < j' < i$ :  $E_{j'} \supseteq E_{i'}$ , this will prove the desired condition.

- (1) At the first step player COM will choose a condition  $p_0 \geq p$ .
- (2) In successor step  $i + 1 < \alpha$ : look at the condition  $q_i$  that player INC chose in the  $i$ -th step;  $E_i$  is a club disjoint to  $S_{q_i}$  s.t.  $E_i \subseteq \bigcap_{j < i} E_j$  (such a club exists since  $\delta$  is inaccessible by our assumption); let  $\beta_i = \text{lg}(tr(q_i))$  and let  $\gamma_i = \min(E_i \setminus (\beta_i + 1))$ . Next, for some node  $\eta_{i+1} \in q_i \cap \mathcal{T}_{\gamma_i}$ ; player COM will choose  $p_{i+1} = (q_i)^{[\eta_{i+1}]}$ , this is a condition of the forcing  $\mathbb{Q}_\delta$  by Claim 30. Observe that  $tr(q_i) \trianglelefteq \eta_{i+1}$ ,  $q_i \leq_{\mathbb{Q}_\delta} p_{i+1}$  and by the choice player COM made, she forced player INC to have  $\eta_{i+1} \trianglelefteq tr(q_{i+1})$ . Finally, after INC will play his  $i + 1$ -th turn, COM will let  $E_{i+1}$  be a club:  $E_{i+1} \subseteq E_i \setminus S_{q_{i+1}}$ ; this is possible as  $E_i$  is a club of  $\delta$ ,  $S_{q_{i+1}}$  is tenuous.

- (3) In limit step  $i(*) < \alpha$ : player COM will choose  $p_{i(*)} = \bigcap_{i < i(*)} q_i$ , let  $S_{i(*)} = \bigcup_{i < i(*)} S_{q_i} \setminus \text{lg}(\nu_{i(*)})$  where  $\nu_{i(*)} = \bigcup_{i < i(*)} tr(q_i)$  and  $E_{i(*)} = \bigcap_{i < i(*)} E_i$ . Observe that  $\text{lg}(\nu_{i(*)}) < \delta$  since  $\delta$  is inaccessible, in addition  $E_{i(*)}$  is a club in  $\delta$  as an intersection of  $i(*) < \delta$  clubs.

- (a) The node  $\nu_{i(*)}$  belongs to all the conditions that player INC had chosen in the steps  $i < i(*)$ : observe that  $\delta' = \sup\{\beta_i : i < i(*)\} = \sup\{\gamma_i : i < i(*)\}$  then  $\delta' \in E_{i(*)}$ . Since  $E_{i(*)}$  is a club that is a decreasing intersection of clubs, note  $i < i(*) \Rightarrow E_i \cap S_{q_i} = \emptyset \Rightarrow E_{i(*)} \cap S_{q_i} = \emptyset$ , there are no prunings in the level  $\delta'$ , in particular  $\nu_{i(*)}$  is not being pruned. Thus  $\nu_{i(*)} \in q_i$  for all  $i < i(*)$ .

- (b) It remains to show that  $p_{i(*)}$  is indeed a condition in the forcing, first observe that  $cf(\delta') = cf(i(*))$ , next:
  - (i) For each node  $\nu' \in p_{i(*)}$  such that  $\text{lg}(\nu') < \delta'$  there is  $i < i(*)$  such that  $\text{lg}(\nu') < \text{lg}(tr(q_i))$  and as  $p_{i(*)}$  is the intersection, we get  $\nu' \triangleleft tr(q_i)$  and so  $\nu' \trianglelefteq \bigcup_{i < i(*)} tr(q_i)$ . We get that  $\bigcup_{i < i(*)} tr(q_i)$  is a node such that there is no splitting before it in  $p_{i(*)}$ . However in each level above it there are splittings as there are such splittings for each  $q_i$ . In addition, for each  $i < j < i(*)$  any splitting in the tree  $q_j$  exists in the tree  $q_i$  as well: this is an increasing sequence of conditions and  $q_j \subseteq q_i$ . It follows that  $p_{i(*)}$  is a tree with trunk  $\nu_{i(*)}$ .

- (ii) The set  $S_{i(*)}$  is tenuous: as a union of  $i(*) < \delta = cf(\delta)$  non-stationary sets,  $S_{i(*)}$  is non-stationary in  $\delta$  by 9(1a). For all  $\epsilon < \delta$ , if  $S_*$  doesn't reflect to  $\epsilon$  then  $S_{i(*)} \upharpoonright \epsilon \subseteq S_*$  is non-stationary in  $\epsilon$  by 9(1a); if  $S_*$  reflects to  $\epsilon$  then  $\epsilon$  is inaccessible and thus  $S_{i(*)} \upharpoonright \epsilon$  is a union of  $i(*)$  sets, non-stationary in  $\epsilon$  so by 9(1a)  $S_{i(*)} \upharpoonright \epsilon$  is non-stationary together  $S_{i(*)}$  is tenuous.

For all  $i < i(*)$ , we shall see that  $p_{\nu_{i(*)}, \delta, S_{i(*)}}^* \subseteq q_i$ ; as  $tr(q_i) \trianglelefteq \nu_{i(*)}$ , observe that  $q_i^{[\nu_{i(*)}]} \subseteq q_i$  by a previous lemma. Also,  $q_i^{[\nu_{i(*)}]}$  and  $p_{\nu_{i(*)}, \delta, S_{i(*)}}^*$  have the same trunk, with the first having a smaller stationary set:  $S_{q_i} \subseteq S_{i(*)}$ ,

therefore we indeed get  $p_{\nu_{i(*)}, \delta, S_{i(*)}}^* \subseteq q_i^{[\nu_{i(*)}]}$ , thus  $p_{\nu_{i(*)}, \delta, S_{i(*)}}^* \subseteq q_i$  and  $p_{\nu_{i(*)}, \delta, S_{i(*)}}^* \subseteq p_{i(*)}$ .

We need to also see that  $p_{i(*)} \subseteq p_{\nu_{i(*)}, \delta, S_{i(*)}}^*$ ; assume this doesn't hold. Then, for some  $\nu' \in p_{i(*)}$ ,  $\nu' \notin p_{\nu_{i(*)}, \delta, S_{i(*)}}^*$ ; let  $\delta'$  be the minimal such that  $\nu' \upharpoonright \delta' \notin p_{\nu_{i(*)}, \delta, S_{i(*)}}^*$ ; remembering definition 4, necessarily  $\nu' \upharpoonright \delta' \in \lim_{\delta'}(p_{\nu_{i(*)}, \delta', S_{i(*)} \cap \delta'}^*)$  and  $\nu' \upharpoonright \delta' \in \lim_{\delta'}(r_{\delta'}^*) \setminus (\bigcup \{\lim_{\delta'}(q_{\delta', \eta'}^*) : \eta' \in \Lambda_{\delta'}^*\})$ . As  $\delta' \in S_{i(*)}$ , there exists  $i < i(*)$  such that  $\delta' \in S_{q_i}$ ; since for all  $\delta'' < \delta'$ ,  $\nu' \upharpoonright \delta'' \in p_{\nu_{i(*)}, \delta, S_{i(*)}}^* \subseteq q_i$  so  $\nu' \upharpoonright \delta' \in \lim_{\delta'}(q_i)$  and by the construction of  $q_i$  as  $\nu' \upharpoonright \delta' \in \lim_{\delta'}(r_{\delta'}^*) \setminus (\bigcup \{\lim_{\delta'}(q_{\delta', \eta'}^*) : \eta' \in \Lambda_{\delta'}^*\})$  it follows that  $\nu' \upharpoonright \delta' \notin q_i$ , a contradiction to the assumption  $\nu' \in p_{i(*)} \subseteq q_i$ .

Finally we have that  $p_{\nu_{i(*)}, \delta, S_{i(*)}}^* = p_{i(*)}$ , in addition for all  $i < i(*)$ ,  $q_i \leq_{\mathbb{Q}_\lambda} p_{i(*)}$  so easily  $p_{i(*)}$  is the smallest supremum of those conditions.

Finally we can see that player COM has a legal move for each  $i < \alpha$  thus the forcing  $\mathbb{Q}_\delta$  is strategically complete in  $\alpha$ .  $\square$

By 32 and 34:

**Corollary 35.** *For all  $\delta \in S_* \cup \{\lambda\}$ , the forcing  $\mathbb{Q}_\delta$  is strategically complete in  $cf(\delta)$ .*

**Theorem 36.** *If  $\delta \in S_* \cup \{\lambda\}$ , then the  $\delta^+$ -chain condition holds for the forcing  $\mathbb{Q}_\delta$ .*

*Proof.* Let  $\mathcal{A} \subseteq \mathbb{Q}_\delta$  be an antichain, then for all  $p, q \in \mathcal{A}$  by Claim 30(5),  $tr(p) \neq tr(q) \in \mathbf{T}_{<\delta}$ ; recalling the definition of the good structure  $\mathfrak{r}$  it holds that for each  $\zeta < \delta$ :  $\theta_\zeta < \delta$  and as  $\delta$  is a strong limit,  $|\bigcup_{\epsilon < \delta^i < \epsilon} \Pi \theta_i| = |\mathbf{T}_{<\delta}| \leq \delta$ ; in particular for any antichain  $\mathcal{A} \subseteq \mathbb{Q}_\delta$ ,  $|\mathcal{A}| \leq \delta$ .  $\square$

**Corollary 37.** *By 35 and 36, the forcing  $\mathbb{Q}_\lambda$  is  $\leq \lambda$ -strategically complete and the  $\lambda^+$ -chain condition holds for it. \*75*

**Theorem 38.** *If  $\lambda$  is an inaccessible cardinal, then the forcing  $\mathbb{Q}_\lambda$  is  $\lambda$ -bounding.*

*Proof.* Let  $p_* \in \mathbb{Q}_\lambda$  and  $\tau$  a  $\mathbb{Q}_\lambda$ -name for a function from  $\lambda$  to  $\lambda$ . We would like to have a condition  $q \geq_{\mathbb{Q}_\lambda} p_*$ ,  $q \in \mathbb{Q}_\lambda$  and a function  $g : \lambda \rightarrow \lambda$  such that  $q \Vdash_{\mathbb{Q}_\lambda} \text{“}\tau \leq g\text{”}$ . In this proof we denote  $\leq$  instead of  $\leq_{\mathbb{Q}_\lambda}$  when comparing forcing conditions.

- We will find a sequence  $\langle p_\epsilon, S_\epsilon, E_\epsilon, \alpha_\epsilon \rangle$  for each  $\epsilon < \lambda$  such that:
  - (1) it holds that  $p_0 = p_*$ ,
  - (2)  $p_\epsilon = p_{\varrho, \lambda, S_\epsilon}^*$  for  $\varrho = tr(p_*)$ ,
  - (3) the sequence  $\langle p_\zeta : \zeta \leq \epsilon \rangle$  is increasing and continuous,
  - (4)  $E_\epsilon$  is a club disjoint to  $S_\epsilon$ ,
  - (5) the sequence  $\langle E_\epsilon : \epsilon < \lambda \rangle$  is decreasing,
  - (6) for  $\epsilon = \zeta + 1 < \lambda$  it holds that  $\alpha_\epsilon \in E_\zeta$  and  $\alpha_\epsilon \in S_* \setminus (S_\zeta \setminus (\alpha_\zeta + 1))$ ,
  - (7) for a limit  $\epsilon < \lambda$ ,  $\alpha_\epsilon \in E_\epsilon$ ,
  - (8) the sequence  $\langle \alpha_\zeta : \zeta \leq \epsilon \rangle$  will be increasing continuous, consisting of ordinals greater than  $\lg(\varrho)$ ,
  - (9) for  $\zeta < \epsilon < \lambda$  it holds that  $S_\zeta \cap (\alpha_\zeta + 1) = S_\epsilon \cap (\alpha_\zeta + 1)$ ,
  - (10) for  $\epsilon = \zeta + 1$ , the ordinal  $\alpha_\epsilon$  represents a level, in which in the corresponding tree the value of the function will be determined, that is:

- (a) for all  $\nu \in p_\epsilon \cap \mathbf{T}_{\alpha_\epsilon}$  it holds that  $p_\epsilon^{[\nu]}$  forces a value for  $\mathcal{T}(\zeta)$ ,
- (b) it holds that  $p_\epsilon \Vdash_{\mathbb{Q}_\lambda}$  “ $\mathcal{T}(\zeta) \in u_\zeta$ ” where  $u_\zeta \subseteq \lambda$  of cardinality  $< \lambda$ .

• Next we see that this construction is possible, by induction:

– For the basis  $\epsilon = 0$ :

We have that  $p_0 = p_*$ ,  $\alpha_0 = \text{lg}(\varrho)$  so 1 holds;  $S_\epsilon$  is the tenuous set corresponding to  $p$  and let  $E_\epsilon$  be a club in  $\lambda$  disjoint to  $S_\epsilon$  (as  $S_\epsilon$  is tenuous).

– For  $\epsilon < \lambda$  limit:

Start with the set  $S_\epsilon$ : let  $S_\epsilon = \bigcup_{\zeta < \epsilon} S_\zeta \subseteq S_*$ . Then it is easy to see that clause 9 holds (by the induction hypothesis); let also  $\alpha_\epsilon = \bigcup_{\zeta < \epsilon} \alpha_\zeta$  and  $E_\epsilon = \bigcap_{\zeta < \epsilon} E_\zeta$ , observe that  $E_\epsilon$  is a club disjoint to  $S_\epsilon$ , so clauses 4 and 5 hold.

Now we will show that the set  $S_\epsilon$  is indeed tenuous: first, the set  $S_\epsilon$  is non-stationary in  $\lambda$  as a union of  $\epsilon < \lambda = cf(\lambda)$  sets that are non-stationary in  $\lambda$  and by Remark 8 when  $S_*$  is non-reflecting,  $S_\epsilon$  is also tenuous, but we have to prove it in general.

Next, let  $\gamma < \lambda$  be an ordinal of uncountable cofinality and look at  $S_\epsilon \upharpoonright \gamma$ :

If there exists  $\zeta < \epsilon$  for which  $\gamma < \alpha_\zeta$  then as  $S_\epsilon \cap (\alpha_\zeta + 1) = S_\zeta \cap (\alpha_\zeta + 1)$  it follows that  $S_\epsilon \cap \gamma = S_\zeta \cap \gamma$  and since  $S_\zeta$  is tenuous this set is non-stationary.

For  $\gamma = \alpha_\epsilon$ , first observe that by the definition of  $E_\epsilon$  as the limit of the clubs  $\langle E_\zeta : \zeta < \epsilon \rangle$  and since the sequence of clubs is decreasing, and by 6 of the induction hypothesis it holds that  $\alpha_\epsilon \in \bigcap_{\zeta < \epsilon} E_\zeta = E_\epsilon$ ,

this was clause 7, and so  $\alpha_\epsilon \notin S_\epsilon$ .

\* When  $\alpha_\epsilon$  is regular (and thus inaccessible): by 8 in the induction hypothesis, the set  $\{\alpha_\zeta : \zeta \text{ is a limit ordinal } < \epsilon\}$  is a club of  $\alpha_\epsilon$ , in addition by clause 7 in the induction hypothesis, for all  $\zeta < \epsilon$  limit:  $\alpha_\zeta \notin S_\zeta$  and by clause 9 in the induction hypothesis, for every  $\zeta < \xi < \epsilon$  it holds that  $\alpha_\zeta \notin S_\xi$  and therefore  $\alpha_\zeta \notin S_\epsilon$  and this club is disjoint to  $S_\epsilon \upharpoonright \alpha_\epsilon$ , so this is not a stationary set.

\* When  $\alpha_\epsilon$  is singular, the set  $S_*$  doesn't reflect to  $\alpha_\epsilon$  by definition, so  $S_* \upharpoonright \alpha_\epsilon$  is a non-stationary set, and in particular  $S_\epsilon \upharpoonright \alpha_\epsilon \subseteq S_* \upharpoonright \alpha_\epsilon$  is not a stationary set by 8.

Lastly for  $\gamma > \alpha_\epsilon$ :

\* If  $cf(\gamma) > \epsilon$  then for all  $\zeta < \epsilon$  it holds that  $S_\zeta \upharpoonright \gamma$  is a non-stationary set from clause 2 of the induction hypothesis, so there is a club of  $\gamma$  disjoint to it, call it  $C_\zeta$ . Letting  $C_\epsilon = \bigcap_{\zeta < \epsilon} C_\zeta$ , this is a club as the intersection of  $\epsilon$  clubs, disjoint to  $S_\epsilon$  by its definition, so  $S_\epsilon \upharpoonright \gamma$  is non-stationary.

\* Otherwise, if  $\gamma > \epsilon \geq cf(\gamma)$  in particular it follows that  $\gamma$  is singular, thus  $S_*$  doesn't reflect to  $\gamma$  and so also  $S_\epsilon \subseteq S_*$  using Claim 8.

Let  $p_\epsilon = p_{\varrho, \lambda, S_\epsilon}^*$  so clauses 2 hold. Moreover, clearly  $p_\epsilon \subseteq \bigcap_{\zeta < \epsilon} p_{\varrho, \lambda, S_\zeta}^*$ ; assume there is some  $\nu' \in \bigcap_{\zeta < \epsilon} p_{\varrho, \lambda, S_\zeta}^* \setminus p_\epsilon$ , as  $\varrho \trianglelefteq \nu'$  there is some minimal  $\delta'$  for which  $\nu' \upharpoonright \delta' \notin p_\epsilon$ ; then  $\nu' \upharpoonright \delta' \in \lim_{\delta'}(p_\epsilon \cap \mathbf{T}_{< \delta'})$  and by definition 4 necessarily  $\nu' \upharpoonright \delta' \in \lim_{\delta'}(r_{\delta'}^*) \setminus (\bigcup \{\lim_{\delta'}(q_{\delta', \eta'}^*) : \eta' \in \Lambda_{\delta'}^*\})$ . Since for some  $\zeta < \epsilon$ ,  $\delta' \in S_\zeta$ , it follows that  $\nu' \upharpoonright \delta' \notin p_{\varrho, \lambda, S_\zeta}^*$  and so  $\nu' \notin p_{\varrho, \lambda, S_\zeta}^*$ , a contradiction. Thus,  $p_\epsilon = \bigcap_{\zeta < \epsilon} p_{\varrho, \lambda, S_\zeta}^*$  and 3 hold.

– For  $\epsilon = \zeta + 1$ :

This is the main case, as here we deal with clause 10 that is responsible for determining the values of the function.

Define the following set:

$$\mathcal{J}_\epsilon = \{r \in \mathbb{Q}_\lambda : r \text{ forces a value on } \tau(\zeta) \wedge p_\zeta \leq_{\mathbb{Q}_\lambda} r \wedge \text{lg}(tr(r)) > \alpha_\zeta\}$$

and observe:

(a) This set is dense above  $p_\zeta$ : for all  $p \in \mathbb{Q}_\lambda$  with  $p_\zeta \leq p$ , we will find a condition  $r$  stronger than  $p$  that forces a value on  $\tau(\zeta)$  and if  $\text{lg}(tr(r)) > \alpha_\zeta$  doesn't hold, we can extend  $r$  to a stronger condition with long enough trunk.

(b) The set is open: for all  $q \in \mathcal{J}_\epsilon$  and  $r \geq q$ ,  $q$  forces a value on  $\tau(\zeta)$  and therefore, so does  $r$ ,  $\text{lg}(tr(r)) \geq \text{lg}(tr(q)) > \alpha_\zeta$  and of course that  $p_\zeta \leq q \leq r$ .

Now define a set  $\Lambda_\epsilon = \{tr(r) : r \in \mathcal{J}_\epsilon\}$  and for every  $\eta \in \Lambda_\epsilon$  choose some  $q_{\epsilon, \eta} \in \{r \in \mathcal{J}_\epsilon : tr(r) = \eta\}$ .

Choose a set  $\Lambda_\epsilon^1 \subseteq \Lambda_\epsilon$  that is maximal under the restriction that for any different  $\eta, \nu \in \Lambda_\epsilon^1$ ,  $\nu \notin q_{\epsilon, \eta} \vee \eta \notin q_{\epsilon, \nu}$ ; let  $\bar{q}_\epsilon = \langle q_{\epsilon, \eta} : \eta \in \Lambda_\epsilon^1 \rangle$ .

\* Observe that the sequence  $\bar{q}_\epsilon = \langle q_{\epsilon, \eta} : \eta \in \Lambda_\epsilon^1 \rangle \in \Xi_\lambda$  because:

- (1)  $\Lambda_\epsilon^1 \subseteq \mathbf{T}_{< \lambda}$ ,
- (2) for all  $\eta \in \Lambda_\epsilon^1$  it holds that  $q_{\epsilon, \eta} \in \mathbb{Q}_\lambda \subseteq \mathbb{Q}_\lambda^0$  and  $tr(q_{\epsilon, \eta}) = \eta$ ,
- (3) if  $\eta, \nu \in \Lambda_\epsilon^1$  are different, then by the definition of  $\Lambda_\epsilon^1$  it holds that  $tr(q_{\epsilon, \nu}) = \nu \notin q_{\epsilon, \eta} \vee tr(q_{\epsilon, \eta}) = \eta \notin q_{\epsilon, \nu}$ ,
- (4) it holds that  $r_{\bar{q}_\epsilon}^* = \{\rho \in \mathbf{T}_{< \lambda} : (\exists \eta \in \Lambda_\epsilon^1)(\rho \in q_{\epsilon, \eta})\} = p_\zeta$ , in particular it belongs to  $\mathbb{Q}_\lambda \subseteq \mathbb{Q}_\lambda^0$ ; observe that for all  $\eta \in \Lambda_\epsilon^1$ , it holds that  $q_{\epsilon, \eta} \subseteq p_\zeta$  and so  $r_{\bar{q}_\epsilon}^* \subseteq p_\zeta$ . Assume via contradiction that  $\nu \in p_\zeta \setminus r_{\bar{q}_\epsilon}^*$  then there is  $p_\zeta^{[\nu]} \leq_{\mathbb{Q}_\lambda} q$  that forces a value for  $\tau(\zeta)$  and its trunk is longer than  $\alpha_\zeta$ , so  $q \in \mathcal{J}_\epsilon$  and  $tr(q) \in \Lambda_\epsilon$ . If  $tr(q) \in \Lambda_\epsilon^1$  we get  $tr(q) \in r_{\bar{q}_\epsilon}^*$ , a contradiction to the assumption; hence there is  $\nu' \in \Lambda_\epsilon^1$  such that  $tr(q) \in q_{\epsilon, \nu'}$  so again we get  $tr(q) \in r_{\bar{q}_\epsilon}^*$  and  $\nu \in r_{\bar{q}_\epsilon}^*$ , a contradiction.

For all  $\eta \in \Lambda_\epsilon^1$  it holds that  $q_{\epsilon, \eta}$  forces a value on  $\tau(\zeta)$ ; call this value  $\gamma_{\epsilon, \eta}$ . In addition let  $C_\eta$  be a club disjoint to  $S_{q_{\epsilon, \eta}}$ .

**First, define an approximation for the club  $E_\epsilon$ .**

$E'_\epsilon = \{\delta \in E_\zeta : \delta > \alpha_\zeta \text{ is a limit ordinal such that } \nu' \in \Lambda_\epsilon^1 \cap \mathbf{T}_{< \delta} \rightarrow \delta \in C_{\nu'} \text{ and } \nu \in p_\zeta \cap \mathbf{T}_{< \delta} \rightarrow \nu \in q_{\epsilon, \eta} \text{ for some } \eta \in \mathbf{T}_{< \delta} \cap \Lambda_\epsilon^1\}$

The set  $E'_\epsilon$  is a club in  $\lambda$ :

- \* Closed- for every increasing sequence of ordinals  $\langle \delta_i : i < \zeta^* \rangle$  such that for all  $i < \zeta^*$ :  $\delta_i \in E'_\epsilon$  and  $\zeta^* < \lambda$ , their limit  $\delta = \lim_{i < \zeta^*} \delta_i$  is of course a limit ordinal. In addition, for all  $\nu' \in \Lambda_\epsilon^1$  with  $\text{lg}(\nu') < \delta$  there is  $j_0 < \zeta^*$  such that for all  $j_0 < j < \zeta^*$  it holds that  $\text{lg}(\nu') < \delta_j$  (as  $\delta$  is defined to be the limit of those), then  $\delta_j \in C_{\nu'}$  and since  $C_{\nu'}$  is a club it follows that  $\delta \in C_{\nu'}$ , as the limit of  $\langle \delta_j : j_0 < j < \zeta^* \rangle$ .
- \* Unbounded- otherwise, the set  $E'_\epsilon$  was bounded by some  $\xi < \lambda$ ; then for every limit  $\xi < \delta \in E_\zeta$ ,  $\delta \notin E'_\epsilon$  so either (1)  $\exists \nu' \in \Lambda_\epsilon^1 \cap \mathbf{T}_{<\delta}$  such that  $\delta \notin C_{\nu'}$  or (2)  $(\exists \nu \in p_\zeta \cap \mathbf{T}_{<\delta})(\forall \eta \in \mathbf{T}_{<\delta} \cap \Lambda'_\epsilon)(\nu \notin q_{\epsilon, \eta})$ . It follows that either (1) holds, so  $\delta \notin \bigcap_{\nu' \in \Lambda_\epsilon^1 \cap \mathbf{T}_{<\delta}} C_{\nu'} \subseteq \bigcap_{\nu' \in \Lambda_\epsilon^1 \cap \mathbf{T}_{<\xi}} C_{\nu'} = C$  or (2) holds, so  $\nu \notin \bigcup \{ \rho \in \mathbf{T}_{<\delta} : (\exists \eta \in \Lambda)(\rho \in q_{\epsilon, \eta}) \} = r_{\bar{q}_\epsilon}^* = p_\zeta$  (last equality by 38)- a contradiction. Thus (2) is impossible and if (1) holds for any  $\xi < \delta \in E_\zeta$  we get  $\{ \delta \in (\xi, \lambda) \cap E_\zeta : \delta \text{ is a limit ordinal} \} \cap C = \emptyset$ , however  $C$  is a club as the intersection of less than  $\lambda$  clubs- a contradiction.

**Define the level.**

We would like to have an ordinal  $\delta$  for which the following properties hold:

- a.  $\delta \in E'_\epsilon \cap S_*$ ,
- b.  $\alpha_\zeta < \delta$  (follows from a.),
- c.  $r_\delta^* = p_\zeta \cap \mathbf{T}_{<\delta}$ ,
- d. It holds that  $\bar{q}_\delta^* = \langle q_{\epsilon, \eta} \cap \mathbf{T}_{<\delta} : \eta \in \Lambda_\epsilon^1 \cap \mathbf{T}_{<\delta} \rangle$ .

An ordinal with those properties exists:

First, by Claim 24 there is a stationary set of  $\delta \in S_*$  such that clause d. holds for and call it  $S^+$ ; as  $E'_\epsilon$  is a club, we get that  $S^+ \cap E'_\epsilon$  is stationary. Observe that for all  $\delta \in S^+ \cap E'_\epsilon$  from clause d. it follows that  $r_\delta^* = \bigcup_{\eta \in \Lambda_\delta^*} q_\eta^* = \bigcup_{\nu \in \Lambda_\epsilon^1 \cap \mathbf{T}_{<\delta}} q_{\epsilon, \nu} \cap \mathbf{T}_{<\delta}$ , in addition by the definition of

$E'_\epsilon$  it holds that  $p_\zeta \cap \mathbf{T}_{<\delta} = \bigcup_{\nu \in \Lambda_\epsilon^1 \cap \mathbf{T}_{<\delta}} q_{\epsilon, \nu} \cap \mathbf{T}_{<\delta}$ , so for all  $\delta \in S^+ \cap E'_\epsilon$

clause c. holds, as this set is not empty (as a stationary set) there is such  $\delta$ , and we are done.

Let  $\alpha_\epsilon = \delta$ . Observe that in particular it follow that  $\Lambda_\epsilon^1 \cap \mathbf{T}_{<\alpha_\epsilon} = \Lambda_{\alpha_\epsilon}^*$ .

We can now let  $E_\epsilon = E'_\epsilon \setminus (\alpha_\epsilon + 1)$ , notice that also  $E_\epsilon$  is a club in  $\lambda$ .

**Define the tenuous set of  $p_\epsilon$ .**

First in the  $\alpha_\epsilon$ -th level we define the set of all the limits formed from the conditions of  $\bar{q}_{\alpha_\epsilon}^*$ :

$$\Lambda_\epsilon^2 = p_\zeta \cap \mathbf{T}_{\alpha_\epsilon} \cap \left( \bigcup \{ \lim(q_{\alpha_\epsilon, \nu}^*) : \nu \in \Lambda_{\alpha_\epsilon}^* \} \right)$$

For  $\eta \in \Lambda_\epsilon^2$ , by the definition above and the definition of the level there is unique  $\nu \in \Lambda_{\alpha_\epsilon}^*$  with  $\eta \in \lim(q_{\alpha_\epsilon, \nu}^*)$ , as  $q_{\epsilon, \nu} \cap \mathbf{T}_{<\alpha_\epsilon} = q_{\alpha_\epsilon, \nu}^*$  and recalling definition 4, the fact that  $\eta \in \lim(q_{\alpha_\epsilon, \nu}^*)$  also implies  $\eta \in q_{\epsilon, \nu}$ ; let  $r_\eta := (q_{\epsilon, \nu})^{[\eta]}$ .

Now, define  $S_\epsilon^1 = \cup \{ S_{r_\eta} \setminus (\alpha_\epsilon + 1) : \eta \in \Lambda_\epsilon^2 \}$ . Observe that for every  $\eta \in \Lambda_\epsilon^2$ ,  $S_{r_\eta} \subseteq S_{q_{\epsilon, \nu}}$  for some  $\nu \in \Lambda_{\alpha_\epsilon}^* \subseteq \mathbf{T}_{<\alpha_\epsilon}$  (follows from

$r_\eta = (q_{\epsilon, \nu})^{[\eta]}$  and 301). Thus  $S_\epsilon^1 \subseteq \cup \{S_{q_{\epsilon, \nu}} : \nu \in \Lambda_{\alpha_\epsilon}^*\}$  and this is a union of  $\leq |\mathbf{T}_{<\alpha_\epsilon}| \leq \alpha_\epsilon$  sets, each one is a tenuous subset of  $S_* \setminus (\alpha_\epsilon + 1)$  and in particular non-stationary in  $\lambda$ . So their union will be the union of  $\leq \alpha_\epsilon < \lambda$  (as  $\lambda$  is inaccessible) non-stationary sets, and as  $\lambda = cf(\lambda)$  and by Claim 9 it follows that  $S_\epsilon^1$  is a non-stationary subset of  $\lambda$ .

Next, let  $\alpha_\epsilon < \delta < \lambda$ :

- \* If  $\delta$  is an inaccessible cardinal in  $S_*$ , we want to show that  $S_\epsilon^1 \upharpoonright \delta$  is non-stationary in  $\delta$ : as  $2^{\alpha_\epsilon} < \delta$  (by inaccessibility of  $\delta$ ) and since for all  $\eta \in \Lambda_\epsilon^2$  the set  $S_{r_\eta}$  is tenuous, in particular  $S_{r_\eta} \upharpoonright \delta$  is non-stationary so  $S_\epsilon^1$  is the union of  $< \delta = cf(\delta)$  non-stationary set and by Claim 9 it is not stationary.
- \* Else, in particular  $S_*$  does not reflect to  $\delta$ , then the set  $S_* \upharpoonright \delta$  is non-stationary in  $\delta$  and so also in  $S_\epsilon^1 \upharpoonright \delta$  by 8.

This shows that  $S_\epsilon^1$  is tenuous and therefore  $S_\epsilon = S_\zeta \cup \{\alpha_\epsilon\} \cup S_\epsilon^1$  that is also tenuous.

Moreover we can see that  $E_\epsilon$  is disjoint to  $S_\zeta \cup \{\alpha_\epsilon\}$  as a subset of  $E_\zeta \setminus (\alpha_\epsilon + 1)$  and by the induction hypothesis; in addition for all  $\delta \in E_\epsilon$ ,  $\delta \in \bigcap_{\nu' \in \Lambda_\epsilon^1 \cap \mathbf{T}_{<\delta}} C_{\nu'}$ . For all  $\eta \in \Lambda_\epsilon^2$  it holds that  $S_{r_\eta} \subseteq S_{q_{\epsilon, \nu}}$  for

some  $\nu \in \Lambda_\epsilon^1 \cap \mathbf{T}_{<\alpha_\epsilon} \subseteq \Lambda_\epsilon^1 \cap \mathbf{T}_{<\delta}$ , so the set  $C_\nu$  is disjoint to  $S_{r_\eta}$  and in particular  $\delta \notin S_{r_\eta}$ . Finally we have that  $S_\epsilon \cap E_\epsilon = \emptyset$ .

**Define the condition.**

The condition will be  $p_\epsilon = p_{\varrho, \lambda, S_\epsilon}^*$  and so  $p_\epsilon \in \mathbb{Q}_\lambda$ ; we want to have  $p_\epsilon \subseteq p_\zeta$  for the condition to be stronger than in the previous level, the difference is created using a larger tenuous set than the one of  $p_\zeta$ .

From the forcing definition it holds that for all  $\rho \in p_\zeta$ ,  $\rho \in p_\epsilon$  if and only if (1)  $\rho \trianglelefteq \varrho$  or (2)  $\varrho \trianglelefteq \rho$  and  $\alpha_\epsilon \leq \lg(\rho) \rightarrow (\forall \eta \in \Lambda_\epsilon^2)(\rho \in r_\eta)$ :

- (1) if  $\rho \in p_\epsilon$  then either (1)  $\rho \trianglelefteq \varrho$  or (2)  $\varrho \trianglelefteq \rho$ , in (2), let  $\eta \in \Lambda_\epsilon^2$  and suppose  $\delta_1$  is minimal such that  $\rho \upharpoonright \delta_1 \notin r_\eta$  so  $\delta_1 \in S_{r_\eta}$ , in which case  $\delta_1$  is successful and  $\rho \upharpoonright \delta_1 \in \lim_{\delta_1}(r_{\delta_1}^*) \setminus (\cup \{\lim_{\delta_1}(q_{\delta_1, \eta'}^*) : \eta' \in \Lambda_{\delta_1}^*\})$ .
  - (a) If  $\delta_1 < \alpha_\epsilon$  there is no requirement besides  $\rho \upharpoonright \delta_1 \in p_\zeta$ ,
  - (b) If  $\delta_1 \geq \alpha_\epsilon$  then  $\delta_1 \in S_\epsilon$  (either  $\delta_1 = \alpha_\epsilon$  or  $\delta_1 \in S_{r_\eta}$ ), thus  $\rho \upharpoonright \delta_1 \notin p_\epsilon \Rightarrow \rho \notin p_\epsilon$ - a contradiction.

It holds then that  $\alpha_\epsilon \leq \lg(\rho) \rightarrow (\forall \eta \in \Lambda_\epsilon^2)(\rho \in r_\eta)$ .

- (2) For the other direction, if  $\rho$  is such that  $\rho \trianglelefteq \varrho$ ,  $\rho \in p_\zeta$  and if  $\varrho \trianglelefteq \rho \upharpoonright \alpha_\epsilon =: \eta$  then  $\eta \in \Lambda_\epsilon^2 \wedge \rho \in r_\eta$ . If  $\rho \notin p_\epsilon$ , for some  $\lg(\varrho) < \delta_1 \in S_\epsilon$ ,  $\rho \upharpoonright \delta_1 \in \lim_{\delta_1}(r_{\delta_1}^*) \setminus (\cup \{\lim_{\delta_1}(q_{\delta_1, \eta'}^*) : \eta' \in \Lambda_{\delta_1}^*\})$ .
  - (a) If  $\delta_1 < \alpha_\epsilon$  then  $\delta_1 \in S_\zeta$  and  $\rho \upharpoonright \delta_1 \notin p_\zeta$ - a contradiction.
  - (b) If  $\delta_1 > \alpha_\epsilon$  then  $\delta_1 \in S_\epsilon^1$  so for some  $\eta' \in \Lambda_\epsilon^2$ ,  $\delta_1 \in S_{r_{\eta'}}$  and  $\rho \upharpoonright \delta_1 \notin r_{\eta'}$ - a contradiction.
  - (c) If  $\delta_1 = \alpha_\epsilon$  we have  $\rho \in r_\eta = (q_{\alpha_\epsilon, \nu}^*)^{[\eta]}$ - a contradiction.

Now observe:

- \* We can easily verify that  $p_\zeta \leq_{\mathbb{Q}_\lambda} p_\epsilon$ .
- \* The set  $\{r_\eta : \eta \in \Lambda_\epsilon^2\}$  is predense above  $p_\epsilon$  in  $\mathbb{Q}_\lambda$ : let  $p_\epsilon \leq q$ , assume there are no forcing conditions in  $\{q \cap r_\eta : \eta \in \Lambda_\epsilon^2\}$ ; recall that  $\rho \in p_\epsilon \Leftrightarrow \rho \in \bigcap \{r_\eta : \eta \in \Lambda_\epsilon^2\}$ , then  $q = q \cap p =$

$\bigcap \{q \cap r_\eta : \eta \in \Lambda_\epsilon^2\}$ - a contradiction, as the right side cannot be a condition.

\* as in fact the pruning had been to get  $p_\epsilon$  exactly by this set.

\* Thus, as for all  $\eta \in \Lambda_\epsilon^2$  it holds that  $r_\eta \Vdash \mathcal{T}(\zeta) = \gamma_{\epsilon, \nu_\eta}$  for some  $\nu_\eta \leq \eta$ , we can write  $u_\zeta = \{\gamma_{\epsilon, \nu_\eta} : \eta \in \Lambda_\epsilon^2\}$  and have  $p_\epsilon \Vdash \mathcal{T}(\zeta) \in u_\zeta$ .

Clause 10 holds and so the construction is possible.

- Let  $S' = \bigcup_{\epsilon < \lambda} S_\epsilon$ , this is non-stationary because  $\bigtriangleup_{\epsilon < \lambda} E_\epsilon \cap S' = \emptyset$  and a tenuous set as for all  $\delta < \lambda$  there is  $\epsilon < \lambda$  with  $S' \cap \delta = S_\epsilon \cap \delta$  (by clause 9).

- Lastly, let  $q = p_{\varrho, \lambda, S'}^*$ , then indeed  $p \leq q$  and we can define  $g : \lambda \rightarrow \lambda$  by: for  $\epsilon < \lambda$  let  $g(\epsilon) = \sup\{u_\epsilon\}$  where  $u_\epsilon$  is from clause (10)(10b) in our induction, so as  $u_\zeta$  is a subset of  $\lambda$  of cardinality  $< \lambda$ , clearly  $g(\epsilon) < \lambda$  indeed. So  $g$  is a function from  $\lambda$  into  $\lambda$  which belongs to  $\mathbf{V}$ . Also by clause (10)(10b) we have  $p_{\epsilon+1} \Vdash \mathcal{T}(\epsilon) \in u_\epsilon$  hence  $p_{\epsilon+1} \Vdash \mathcal{T}(\epsilon) \leq g(\epsilon)$ . But  $q$  is above  $p_{\epsilon+1}$  for every  $\epsilon < \lambda$  hence  $q \Vdash \mathcal{T}(\epsilon) \leq g(\epsilon)$ .

As  $p$  is stronger then our original  $p$  we are done proving the theorem. □

**Corollary 39.** *The forcing  $\mathbb{Q}_\lambda$  resembles Random Real forcing [27].*

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