A.E.C. WITH NOT TOO MANY MODELS
SH893

SAHARON SHELAH

Dedicated to Jouko Väänänen honouring his 60th birthday

Abstract. Consider an a.e.c. (abstract elementary class), that is, a class $K$ of models with a partial order refining $\subseteq$ (submodel) which satisfy the most basic properties of an elementary class. Our test question is trying to show that the function $I(\lambda, K)$, counting the number of models in $K$ of cardinality $\lambda$ up to isomorphism, is “nice”, not chaotic, even without assuming it is sometimes 1, i.e. categorical in some $\lambda$’s. We prove here that for some closed unbounded class $\mathcal{C}$ of cardinals we have (a),(b) or (c) where

(a) for every $\lambda \in \mathcal{C}$ of cofinality $\aleph_0$, $I(\lambda, K) \geq \lambda$
(b) for every $\lambda \in \mathcal{C}$ of cofinality $\aleph_0$ and $M \in K_\lambda$, for every cardinal $\kappa \geq \lambda$ there is $N_\kappa$ of cardinality $\kappa$ extending $M$ (in the sense of our a.e.c.)
(c) it is bounded; that is, $I(\lambda, K) = 0$ for every $\lambda$ large enough (equivalently $\lambda \geq \beth_\delta$ where $\delta_\kappa = (2^{\lambda_\kappa})^+$).

Recall that an important difference of non-elementary classes from the elementary case is the possibility of having models in $K$, even of large cardinality, which are maximal, or just failing clause (b).

Date: April 25, 2014.

2010 Mathematics Subject Classification. Primary: 03C45, 03C48; Secondary: 03C55, 03C75.

Key words and phrases. Model theory, classification theory, a.e.c. (abstract elementary classes), categoricity, number of non-isomorphic models.

The author would like to thank the Israel Science Foundation for partial support of this research (Grant No. 242/03). The author thanks Alice Leonhardt for the beautiful typing. Paper 893 in the author’s list. First Version - 2004/June/20.
§0 Introduction to the subject, pg.3

§1 Introduction to the paper, pg.6
  §(1A) Content, pg.6
  §(1B) Discussion, (label y), pg.7
  §(1C) What is done, pg.8
  §(1D) Recalling Definitions and Notation, (label z), pg.9

[Defining $\mathcal{T}_{\kappa}^{\text{ord}}[t], \mathcal{T}_{\kappa}^{\text{sort.}}$]

§2 More on Templates, pg.13

On $\mathcal{T}_{\mu}^{\text{ord}}[t]$, the ideal ER, being standard; the ideal ER, \cite{?}; isomorphic of vocabularies, 2.7 - 2.9; partial orders on $\mathcal{T}_{\kappa}^{\text{ord}}[t]$, 2.9, 2.12, basic properties of $\leq_3^{\kappa}, \leq_4^{\kappa}$, see 2.14. On $\mathcal{T}_{\kappa}^{\text{sort}}[k_M] \neq \emptyset$, 2.15; amalgamating $\leq_3^{\kappa}, \leq_4^{\kappa}$. Lastly, we define $\text{pit}(\mathcal{T}, I)$, 2.17 and have the relevant partition theorem, 2.18.

§3 Approximations to EM models, (label a), pg.25

We define direct/pre-witnesses, (3.2, 3.3), prove existence, 3.6. Deal with indirect witnesses (used in the main proof (see 3.7, 3.11) and prove the main result.

§4 Concluding Remarks, pg.33
§ 0. Introduction to the subject

We would like to have classification theory for non-elementary classes $K$ and more specifically to generalize stability. Naturally we use the function $I(\lambda, K)$ = number of models up to isomorphism, as a major test problem. Now “non-elementary” has more than one interpretation, we shall start with the infinitary logics $L_{\lambda, \kappa}$.

There are other directions; mostly where compactness in some form holds (e.g. a.e.c. with amalgamation, see about those in [Sh:E53], and on a try to blend with descriptive set theory see [Sh:849]). We had held that for $\kappa > 0$ the above cannot be developed as, e.g. if $V = L$ or just $V \models \text{"0# does not exist"}$, then there is $\psi \in \text{L}_{\aleph_1, \aleph_0}$ such that if $\text{cf}(\mu) = \aleph_0 \land (\forall \alpha < \mu)(|\alpha|^{|\aleph_0} < \mu)$ then $M = \psi, ||M|| = \mu$ iff $M \cong (\text{L}_\mu, \in)$. However, lately [Sh:F1228] gives evidence that for $\theta$ a compact cardinal, we can generalize to $L_{\theta, \theta}$ some theorems of [Shc, Ch:VI] on saturation of ultra-powers and Keisler’s order. This shows that stability theory for $T \subseteq L_{\theta, \theta}$ exists, but it is still not clear how far we can go including $A = [N], N \times M$ and $\cup\{M_u : u \subseteq n\}$ when $\langle M_u : u \subseteq n\rangle$ is a so called stable $\mathcal{P}^\lambda(n)$-system.

Anyhow (for the purposes of this history, and the present paper) we now concentrate on $\text{Mod}_\psi$, $\psi \in \text{L}_{\lambda^+, \aleph_0}$ so $\kappa = \aleph_0$. Here we have both downward LST theorems, even using $\leq \lambda$ finitary Skolem functions. Also we have the upward LST theorem, using EM models.

Naturally all works started with assuming categoricity in some cardinal, except some dealing with the $\aleph_n$’s for $\psi \in \text{L}_{\aleph_1, \aleph_0}$. In this case we may many times deal with $\psi \in \text{L}_{\aleph_1, \aleph_0}(Q)$. Some works appeared in the eighties (see the books [Bal09], also [Sh:h], [Sh:i]).

**Definition 0.1.** Let $I(\lambda, K)$ be the cardinality of $\{M/ \cong : M \in K\}$ of cardinality $\lambda$ where $K$ is a class of $\tau(K)$-models (e.g. $K = K_{\tau}$ where $\tau = (K_{\tau}, \leq_{\tau})$).

First, in ZFC, answering a question of Baldwin, it was proved that $\psi$ cannot be categorical, moreover if $I(\aleph_1, \psi) = 1$ then $I(\aleph_2, \psi) \geq 1$. Also if $I(\aleph_1, \psi) < 2^{\aleph_1}$, then for some countable first order $T$ with an atomic model $K_T = \{M : M$ an atomic model of $T\}$ is $\subseteq \text{Mod}_{\psi}$, but $1 \leq I(\aleph_1, K_T)$. Fix $T$ for awhile, now if $2^{\aleph_n} < \aleph_{n+1}, I(\aleph_n, T) < \mu_{\text{w}}(\aleph_{n+1}, 2^{\aleph_n})$ for every $n$ then $K_T$ is excellent which means it is quite similar to the class of models of an $\aleph_0$-stable countable complete first order theory. For this we consider $\mathbb{S}^m(A, M)$ for $A \subseteq M \in K_T$, only some “nice” $A$. On the other hand for any $n$ for some such $T_n, K_{T_n}$ is categorical in every $\lambda \leq \aleph_n$ but $I(\lambda, T) = 2^\lambda$ for $\lambda$ large enough. However, we do not know:

**Conjecture 0.2.** (Baldwin) If $K_T$ is categorical in $\aleph_1$, then $K_T$ is $\aleph_0$-stable, equivalently is absolutely categorical.

Related is the:

**Conjecture 0.3.** If $K_T$ is categorical in $\aleph_1$ but not $\aleph_0$-stable then $I(2^{\aleph_0}, K_T) = 2_2$.

See work in preparation Baldwin-Laskowski-Shelah ([Sh:F1098]) on such $K_T$’s; it certainly says there is a positive theory for such classes (e.g. pseudo minimal types exist). We recently have changed our mind and now think:

**Conjecture 0.4.** If $K_T$ is categorical in every $\aleph_n$ then $K_T$ is excellent.

This means that the present counter-examples are best possible. As this seems very far we may consider a weaker conjecture.

\footnote{Note that $\mu_{\text{w}}(\lambda^+, 2^\lambda)$ is essentially $2^{\lambda^+}$.}
Conjecture 0.5. Assume $P$ is a c.c.c. forcing notion of cardinality $\lambda$ such that $\Vdash_{P} \text{"MA + } 2^{\aleph_0} = \lambda^+ \text{ and } \lambda = \lambda^{<\lambda} > \beth_\omega\text{"}$. If $K_T$ is categorical in every $\lambda < 2^{\aleph_0}$ then $K_T$ is excellent.

There is more to be said, see [Sh:F1273].

---

In another direction, the investigation of models of cardinality $\aleph_1$ does not point to a canonical choice of logic for which the theorems on $\mathcal{I}(\psi, \aleph_1) = 1$ holds. This had motivated the definition of a.e.c. $\mathfrak{t} = (K_\mathfrak{t}, \leq_\mathfrak{t})$ which has the “bottom” property of elementary class $K = (\text{Mod}_T, \prec)$, $T$ a complete first order theory (i.e. $K_\mathfrak{t}$, a class of $\tau_\mathfrak{t}$-models, $\leq_\mathfrak{t}$ a partial order on it, both closed under isomorphism, union under $\leq_\mathfrak{t}$-directed systems of member of $K_\mathfrak{t}$ belong to $K_\mathfrak{t}$, moreover is a $\leq_\mathfrak{t}$-lub (= union of a directed system of $\leq_\mathfrak{t}$-submodels of $N$ is a $\leq_\mathfrak{t}$-submodel of $N$), existence of a LST number and $M_1 \subseteq M_2 \leq_{\mathfrak{t}} N \leq M_2 \leq_{\mathfrak{t}} N \Rightarrow M_1 \leq_{\mathfrak{t}} M_2$).

Thesis 0.6. 1) The framework of a.e.c. $\mathfrak{t}$ is wider and not too far and better than the family of $(\text{Mod}_\psi, \prec_{\text{sub}(\psi)})$ where $\psi \in \Sigma_{\lambda<\aleph_0}$.

2) The right generalization of types in this context is orbital types.

Why? The “wider” in 0.6(1) is obvious. The “not too far” is by the representation theorem which says that for some vocabulary $\tau_1 \supseteq \tau(\mathfrak{t})$ of cardinality $\leq \lambda$, $\lambda$ the LST-number $+|\tau(\mathfrak{t})|$ and set $\Gamma$ of quantifier free 1-types, $K_\mathfrak{t} = \text{PC}(\emptyset, \Gamma) = \{M|\tau_1 : M \models \tau_1\text{-model omitting every } p(x) \in \Gamma\}$; similarly $\leq_\mathfrak{t}$. We can deduce the upward LST, and so existence of suitable $\Phi \in T^\text{lin}[\mathfrak{t}]$ so we have EM-models. For $\mathfrak{t}$ with $\text{LST}_\mathfrak{t} = \aleph_0$ it is natural to restrict ourselves to the case “$\Gamma$ is countable” above for both $K_\mathfrak{t} \leq_{\mathfrak{t}}$, then we say $\mathfrak{t}$ is $\aleph_0$-presentable. So we may wonder for such $\mathfrak{t}$ if $n < \omega \Rightarrow 2^{\aleph_0} + \mathcal{I}(\aleph_{n+1}, K_\mathfrak{t}) < \mu_{\text{ad}}(\aleph_{n-1}, 2^{\aleph_0})$ implies $\mathfrak{t}$ satisfies the parallel of being excellent? The answer is yes by [Shch], [Sh:i], but the way is long. Also, we may replace $\aleph_0$ by any $\lambda$ provided that $\mathcal{I}(\lambda, K_\mathfrak{t}) = 1 = I(\lambda^+, K_\mathfrak{t})$ and $1 \leq I(\lambda^+, K_\mathfrak{t}) < \mu_{\text{ad}}(\lambda^+, 2^{\lambda^+})$, see more in [Sh:E53].

A central notion there is “$s$ is a good $\lambda$-frame”, $\text{LST}_\mathfrak{t} \leq \lambda$, this is “bare bones superstable”.

This is enough for proving

(*) if $(\mathfrak{t}$ is an a.e.c.$)$, $\text{LST}_\mathfrak{t} \leq \lambda, 2^{\lambda^+} \leq 2^{\lambda^+} + \mathcal{I}(\lambda^+, K_\mathfrak{t}) = 1$ for every $n$ and $K_\mathfrak{t}$ has models of cardinality $\geq \beth_{\text{LST}(\mathfrak{t})}$, then $K_\mathfrak{t}$ is categorical in every $\mu \geq \lambda$.

However

Conjecture 0.7. If $\mathfrak{t}$ is an a.e.c., $K_\mathfrak{t}$ is categorical in some $\lambda$ large enough than $\text{LST}_\mathfrak{t}$, then $K_\mathfrak{t}$ is categorical in every $\mu \geq \lambda$.

Note that [Sh:734] is a step ahead: in the context of 0.7, for many $\mu = \beth_{\mu} \in \text{LST}_\mathfrak{t}$, there is a good $\mu$-frame $\mathfrak{t}_\mu$ such that $\text{LST}_\mathfrak{t} = K_\mathfrak{t}^\mu$. If we have this for $\omega$ successive $\mu$'s we shall be done by [Sh:600], but in [Sh:734] the family of such $\mu$'s is scattered: a beginning is [Sh:842].

A much harder conjecture is:
Conjecture 0.8. 1) The main gap theorem holds for a.e.c. $K_T$ for $\lambda$ large enough.
2) The class $\text{sup} \lim = \{ \lambda : \text{there is a super-limit } M \in K^1_{\lambda} \}$ is “nice”, e.g. contains every large enough $\lambda$ or contains no large enough $\lambda$.

We may wonder

Question 0.9. 1) Maybe there is a natural logic which is the natural framework for categoricity spectrum.
2) Also for the super-limit spectrum.

We expect such logic to be stronger than $L_{\lambda, \aleph_0}$ but weaker than $L_{\lambda, \lambda}$. This may remind us of [Sh:797]. The logic discovered there is $L^{1}_{<\lambda}$ for $\lambda = \beth_\lambda$, it is between $L^{-1}_{<\lambda} = \bigcup \{ L_{\mu^+, \aleph_0} : \mu < \lambda \}$ and $L^0_{<\lambda, \mu} = \bigcup \{ L_{\mu^+, \mu^+} : \mu < \lambda \}$, in a strong way well ordering is not well defined and it can be characterized (as Lindström theorem characterize first order logic) and has interpolation. In addition, for $\lambda$ a compact cardinal $L^{1}_{<\lambda}$-equivalence of $M_1, M_2$ is equivalent to having isomorphism $\omega$-limit ultra-powers by $\lambda$-complete ultrafilters, see [Sh:F1228].

However, probably the characterization in [Sh:797] was by “the maximal logic such that ...”. So maybe we should restrict the logic further such that “EM model can be constructed”.

We conjecture there is a logic characterized by being maximal under this stronger demand, and in it we can say at least something on the function $I(\lambda, \psi)$, and maybe much. This is interesting also from the point of view of soft model theory: we conjecture that there are many such intermediate logics with characterization (and the related interpolation theorem).
§ 1. Introduction to the paper

In this section, we begin by motivating our line of investigation. See notation in §(1D) below (and more self contained introduction in §(1B), §(1C)).

{content}

§ 1(λ). Motivation/Content.

We knew of old (see: [Sh:c, Ch.XIII,4.15]):

{y1}

Theorem 1.1. For a countable complete first order theory $T$, one of the following holds:

(a) $T$ is categorical in every $\lambda > \aleph_0$

(b) $\mathcal{I}(\lambda, T) = \{\lambda\}$ for every cardinal $\lambda \geq 2^{\aleph_0}$

(c) $\mathcal{I}(\aleph_0, T) \geq 1 + |\alpha|$ for every ordinal $\alpha$.

For a.e.c. we have something when

\[ N \leq k \]

and something about $\mathcal{I}(\aleph_1, \text{EM})$ and something about $\mathcal{I}(\aleph_1, \text{EM})$, ([Sh:88r], about when $1 \leq \mathcal{I}(\aleph_1, \text{EM}) < 2^{\aleph_1}$, particularly when $2^{\aleph_0} < 2^{\aleph_1}$ and then on higher cardinals) but nothing for general a.e.c. $\mathfrak{t}$. The current paper is motivated by hopes of finding something like 1.1 for a.e.c.'s. Recall the history.

Our approach here assumes/relies on:

{y1}

Thesis 1.2. Reasonable to concentrate on cardinals from $\mathcal{C}_{fp} = \{\lambda : \lambda = \beth_\lambda\}$, where $fp$ stands for “fixed points”.

Why? If $\mathcal{I} \in \mathcal{C}_{fp}, \lambda > \text{LST}(\mathfrak{t})$ and $M \in K^1_{\lambda}$ then for every $\theta \in \text{LST}(\mathfrak{t}, \lambda)$ and $N \leq M, \|N\| = \theta$ there is $\Phi \in \mathcal{T}_{\lambda, \theta}$ so $|\tau(\Phi)| = \theta$ such that for any linear order $I$, e.g. $I = \lambda$ we have $N \leq \text{EM}_{\text{fp}}$($I, \Phi$). So in $K^1_{\lambda}$ we have models of the form $\text{EM}_{\text{fp}}(I, \Phi), \Phi \in \mathcal{T}_{\lambda, \lambda}$. If $\mathcal{I}(\lambda, \mathfrak{t}) < \lambda$, many of them will be isomorphic. Hence for many $\theta_1 < \theta_2 < \lambda, \theta_1 \geq \text{LST}(\mathfrak{t})$, every $N \leq \mathfrak{t} M$ of cardinality $\theta_2$ can be $\leq \mathfrak{t}$-embedded into some $\text{EM}_{\text{fp}}(\lambda, \Phi), \Phi \in \mathcal{T}_{\mathfrak{t}, \mathfrak{t}}$.

Informally, the point is it allows us to use EM models. The key point is finding a suitable template, set $\Phi$ of quantifier free types, which requires finding enough indiscernible sequences. When $K^1_{\mathfrak{t}}$ is an a.e.c. (as opposed to an elementary or pseudo elementary class) we must go through the Presentation Theorem to find an indiscernible sequence, i.e. we require sufficiently large models omitting the types in $I$.

To further motivate our approach, consider a not so strong conjecture, still enough to exemplify “the function $\lambda \mapsto \mathcal{I}(\lambda, \mathfrak{t})$ cannot be too wild”.

{y4}

Conjecture 1.3. 1) Letting $\mathcal{C}_{fp}^0 = \{\lambda : \lambda = \beth_1 \text{ and } \text{cf}(\lambda) = \aleph_0\}$ and fixing an a.e.c. $\mathfrak{t}$, not both of the following classes are stationary (or restrict yourself to some strongly inaccessible $\mu$ and “stationary” means below it):

(a) $S_1 = \{\lambda \in \mathcal{C}_{fp}^0 : \mathcal{I}(\lambda, \mathfrak{t}) < \lambda\}$

(b) $S_2 = \{\lambda \in \mathcal{C}_{fp}^0 : \mathcal{I}(\lambda, \mathfrak{t}) \geq \lambda\}$.

2) A weaker conjecture (presented in the abstract) is replacing clause (b) by (h)

$S_3 = \{\lambda \in \mathcal{C}_{fp}^0 : \text{for every } M \in K^1_{\lambda} \text{ has } \leq \mathfrak{t}\text{-extensions } N \text{ of any cardinality } > \lambda\}$.

Why “cf$(\lambda) = \aleph_0$”? First, trying to prove $\lambda \in S_3$, we can approximate $N$ by $\Phi \in \mathcal{T}_{\lambda, \lambda}^N$, $\lambda_\Phi < \lambda$ as we can approximate $M$ by $N_n \leq \mathfrak{t} M, \|N_n\| = \lambda_\Phi$ where
\[ \lambda_n < \lambda_{n+1} < \lambda = \sum \{ \lambda_m : m \}. \] Second, for \( \lambda \in C_{fp}^{fp} \) it is enough to show that \( \{ M / \equiv_{\preceq, \lambda} : M \in K^\lambda_\Gamma \} \) is small because it is well known that if \( \text{cf}(\lambda) = \aleph_0 \) and \( M_1, M_2 \) are of cardinality \( \lambda \) and \( L_{\lambda, \lambda} \)-equivalent then they are isomorphic; on such logics see, e.g., [Dyc85].

\textit{Thesis 1.4.} There are, for a.e.c. \( \mathfrak{t} \), meaningful dichotomy theorems for \( I(\lambda, K_\mathfrak{t}) \) when \( K \) is a class of \( \tau(\mathfrak{t}) \)-models, \( K = K_\mathfrak{t} \) and \( \mathfrak{t} = (K_\mathfrak{t}, \leq_\mathfrak{t}) \).

This is a more concrete thesis than “considering a.e.c.’s is a good frame for model theory”\(^{12}\); even more concrete is the “main gap conjecture”. It had been proved that if \( K_\mathfrak{t} \) is the class of models of a complete countable first order theory then it satisfies the “main gap”, i.e. either \( I(\lambda, K) \) is large, even \( = 2^\lambda \) for all uncountable \( \lambda \) or \( I(\aleph_\alpha, K) \) is small, even \( < \beth_{\omega_1}(|\alpha|) \) for all \( \alpha > 0 \); see [Sh:c, Ch.XII], “The book’s main theorem”. In general for a class \( K \) of \( \tau \)-models the “main gap” will say that either \( I(\lambda, K) \) is large (i.e. \( 2^\lambda \) or \( \geq \lambda^+ \)) for every \( \lambda \) large enough or it is small for every \( \lambda \) large enough say \( I(\aleph_\alpha, K) \leq \beth_{\omega_1}(|\alpha|) \) for some \( n = n(K) < \omega \).

We are far away from this, still, until now for the a.e.c. the categoricity case was almost alone, i.e. we start assuming \( I(\lambda, K) = 1 \) in some \( \lambda \), see below, but we try here to look “higher”.

The contribution of the present paper is to show that in the much more general context of a.e.c.’s for some \( \aleph_\theta \)-closed unbounded class \( C \) of cardinals, we have \( \lambda \in C \Rightarrow I(\lambda, K_\mathfrak{t}) \geq \lambda \), a non-structure result, or \( \lambda \in C \wedge M \in K^\lambda_\Gamma \Rightarrow M \) has arbitrary large \( \leq_\Gamma \)-extensions. Note that the latter property is now taken for granted for elementary classes but is a real gain for a.e.c.

As noted in \( \S \), in [Sh:734] and [Sh:600] we obtained results on \( I(\lambda, K) \) for a.e.c.’s assuming categoricity in some \( \lambda \)’s. However, nothing was known for general a.e.c.’s under weaker few models assumption.

On abstract elementary classes, see [Sh:88r], [Bal09] and [Sh:E53]. We will make essential use of the Presentation Theorem, which says that every a.e.c. can be represented as a PC class, say \( PC(T, \Gamma) \), see [Sh:88r, \S 1].

We thank the audience in the lecture in the Hebrew University seminar 2/2005 for their comments on an earlier version of this paper and Maryanthe Malliaris for helping much in improving \( \S 1 \) and some corrections in fall 2011 - winter 2012 and Will Boney for some further corrections (fall 2013).

\textit{Discussion.}\(^\{\text{Discussion}\}\)

We give some further details regarding \( \S (1A) \).

Why? In Thesis 1.2 the result on EM models needed is: [Sh:394, Claim 0.6], [Sh:394, Claim 8.6], the “a.e.c. omitting types theorem” and [Sh:394, Lemma 8.7,p.46].

\textbf{Fact 1.5.} Let \( \mathfrak{t} \) be an a.e.c. If \( \lambda \in C_{fp}, \lambda > \text{LST}_\mathfrak{t} \) and \( M \in K^\lambda_\mathfrak{t} \) then for every \( \theta \in [\text{LST}_\mathfrak{t}, \lambda) \) and \( N \leq_\theta M \) of cardinality \( \theta \) there is \( \Phi \in Y[\mathfrak{t}] \) such that:

\( a \) \( |\tau(\Phi)| = \theta \)

(\( b \) for any linear order \( I \), in particular \( I = \lambda \), without loss of generality \( N \leq_\theta \text{EM}_{(\mathfrak{t}, I)}(I, \Phi) \) where this denotes the reduct of the EM model to the vocabulary of \( \mathfrak{t} \).
Comment:
Let us repeat, the two points when \( \text{cf}(\lambda) = \aleph_0 \) may be as required:

(a) downward depth in \( \S 3 \).
(b) if we like to find large \( N \leq \ell \)-extending \( M \) for a given \( M \in K^\ell_\lambda \), if \( \text{cf}(\lambda) = \aleph_0 \)
we can get it as an \( \omega \)-limit of \( M' \leq \ell M, ||M'|| < \lambda \).

Such considerations further lead us to

\( \{y6\} \)

**Question 1.6.** Let \( \Phi \in \mathcal{Y}_\theta[\ell] \) and \( \kappa \) be a cardinal.

Sort out the functions

(a) \( \lambda \mapsto |\{ \text{EM}_{\ell}(I, \Phi) / \equiv : I \text{ a linear order of cardinality } \lambda \}| \)

(b) \( \lambda \mapsto \check{I}_{\ell}(\lambda, \kappa, \Phi) := |\{ \text{EM}_{\ell}(I, \Phi) / \equiv_{\ell, \omega} : I \text{ a linear order of cardinality } \lambda \}| \).

Recall, by \([Sh:11]\) restricting ourselves to cardinals \( \lambda = \lambda^{<\kappa} \), that the function in clause (b) of 1.6 is “nice”, more specifically: if \( \theta \leq \lambda_1 = \lambda_1^{<\kappa} < \lambda_2 \) then \( \check{I}_{\ell}(\lambda_1, \kappa, \Phi) \geq \min\{\check{I}_{\ell}^{\lambda_1}(\lambda_1, \kappa, \Phi), \check{I}_{\ell}(\lambda_2, \kappa, \Phi)\} \).

What occurs if \( \lambda_1 = \lambda_1^{<\kappa} \)? The case \( \lambda_1 = \beth_\delta, \text{cf}(\delta) = \aleph_0 \) is more approachable than the general case, see 4.2.

Our hope is to get “bare bones superstability”, i.e. good \( \lambda \)-frames inside \( \ell \), (as in \([Sh:600],[Sh:734]\)).

Another point concerning the function \( \check{I}(\lambda, \kappa, \ell) \): for a model \( M \), cardinal \( \theta \) and logic \( L \) we can define the depth of \( M \) for \((L, \theta)\) as \( \min\{\alpha : \text{if } a, b \in \varepsilon M, \varepsilon < \theta \text{ and } a, b \text{ realizes the same formulas of } L_{\infty, \theta} \text{ (or } L_{\infty, \theta}[\ell] \text{)} \text{ of depth } < \alpha \text{ then they realize the same } L_{\infty, \theta}\text{-formulas}\} \); of course, only formulas in \( L_{\infty, \theta}[\ell] \text{-frames} \) are relevant. This is a good way to “slice” the equivalence and it is easier for LST considerations.

\( \{n4\} \)

**What**

\( \S 1(\mathrm{C}) \). **What is Done.**

A phenomena making the investigation of general a.e.c. hard is having \( \leq \ell \)-maximal models of large cardinality. As with amalgamation, we may consider the property

\( (*) \lambda \) if \( M \in K^\ell_\lambda \) then \( M \) is not \( \leq \ell \)-maximal.

In investigations like \([Sh:E46]\) and \([Sh:576]\), which look at \( \bigcup\{ K^\ell_{\lambda, \varepsilon, \ell} : \varepsilon < 4 \} \) this is relevant. But in investigations as in \([Sh:734]\), looking at \( \bigcup\{ K^\ell_{\lambda} : \lambda = \beth_\delta \} \), it is more natural to consider

\( (** \ast) \lambda \) if \( M \in K^\ell_\lambda \) then for any \( \mu > \lambda \) there is \( N \in K^\ell_{\mu} \) which \( \leq \ell \)-extends \( N \).

In \( \S 3 \) we consider a \( \lambda = \beth_\lambda \) of cofinality \( \aleph_0 \) which is more than strong limit and try to prove non-structure from \( \neg(\ast) \lambda^2 \). Given \( N \in K^\ell_\lambda \) we try to build an EM model (that is construct the \( \Phi \)) \( \leq \ell \)-extending \( N \) by an increasing chain of approximations: given \( \lambda_n \rightarrow \lambda, M_n \rightarrow N, M_n \in K^\ell_{\lambda_n} \). The \( n \)-th approximation \( \Phi_n \) to \( \Phi \) has to have “\( \Phi_n \) in a suitable sense is represented in \( N \) say of size \( \lambda_{n+1}^{<\lambda} \)”.

Being stuck should be a reason for non-structure. For simplicity we consider only cardinals \( \mu = \beth_\mu \), the gain without this restriction seems minor.
Concerning the results of §3 it would be nicer to make one more step concerning 3.15, 3.14 and deal also with \( \lambda = \beth_\omega \) instead of \( \lambda = \beth_\omega \), but a more central question is to get the non-structure result for every \( \lambda' > \lambda \). It is natural to try given \( \Phi \in T^\text{def}_\kappa [M] \) and \( M \preceq N \), to define a “depth” for approximation of the existence of a \( \leq_\tau \)-embedding of standard EM \( (I, \Phi) \) into \( N \) (see Definition 2.2(2)), so that depth infinity give existence. But this does not work for us, so Definition 3.2 is a substitute, moreover we need “indirect evidence”, see Definition 3.7.

Our main theorem is

**Theorem 1.7.** For any a.e.c. for some closed unbounded class of cardinals \( C \), if \((\exists \lambda \in C) \text{cf}(\lambda) = \aleph_0 \land I(\lambda, K_\varepsilon) < \lambda \) and \( M \in K_\varepsilon \) of cardinality \( \mu \in C \) of cofinality \( \aleph_0, M \) has a proper \( <_\tau \)-extension, and even ones of arbitrarily large cardinality.

The natural next steps are

**Conjecture 1.8.** 1) In Theorem 3.16, i.e. what is promised in the abstract we can choose \( C \) as an end segment of \( \{ \mu : \mu = \beth_\omega \} \) or just choose \( C \) as \( \{ \mu : \mu = \beth_\omega \} \).
2) For every a.e.c. \( \mathfrak{f} \) for some closed unbounded class \( C \) of cardinals, we have \( M \in K_\varepsilon \land \lambda \in C \land \text{cf}(\lambda) = \aleph_0 \Rightarrow \mathcal{T}_k^\mathfrak{f}[M] \neq \emptyset \lor \lambda \in C \land \text{cf}(\lambda) = \aleph_0 \Rightarrow I(\lambda, K_\varepsilon) \geq 2^\lambda \) or at least \( \geq \lambda^+ \).

We intend to deal with part (1) in a continuation.

---

**§ 1(D). Recalling Definitions and Notation.**

**Notation 1.9.** Let Card be the class of infinite cardinals.

**Definition 1.10.** 1) Let \( \beth_{0,\alpha}(\lambda) = \beth_\alpha(\lambda) := \lambda + \sum \{ 2^{\beth_\beta(\lambda)} : \beta < \alpha \} \). Let \( \beth_{\alpha,\beta}(\lambda) \) be defined by induction on \( \varepsilon > 0 \) and for each \( \varepsilon \) by induction on \( \alpha : \beth_{0,\alpha}(\lambda) = \lambda \), for limit \( \beta \) we let \( \beth_{\gamma,\beta} = \beth_{\sum_{\gamma < \beta} \beth_{\gamma,\gamma}} \) and for \( \varepsilon = \zeta + 1 \) let \( \beth_{\zeta+1,\beta+1}(\lambda) = \beth_{\zeta,\mu} \) where

\[
\mu = (2^{\beth_{\gamma,\gamma}(\lambda)})^+, \text{ lastly for limit } \varepsilon \text{ let } \beth_{\zeta,\alpha} : \alpha \in \text{Ord} \text{ list in increasing order the closed unbounded class } \bigcap_{\zeta \leq \varepsilon} \{ \beth_{\zeta,\alpha} : \alpha \in \text{Ord} \}.
\]

2) Let \( \lambda \gg \kappa \) mean \( (\forall \alpha < \lambda)(|\alpha|^\kappa < \lambda) \).

**Convention 1.11.** 1) \( \mathfrak{f} = (K_\varepsilon, \leq_\varepsilon) \) is an a.e.c., with vocabulary \( \tau_\varepsilon = \tau(\mathfrak{f}) \) and \( \text{LST}(\mathfrak{f}) = \text{LST}_{\leq} \) its L"owenheim-Skolem-Tarski number, see [Sh:88r, §1]. If not said otherwise, we assume \( |\tau_\varepsilon| \leq \text{LST}_{\leq} \).
2) \( K_\varepsilon = K_\varepsilon \) \( \lambda \) = \( \{ M \in K_\varepsilon : \| M \| = \lambda \} \).
3) If \( K = K_\varepsilon \) we may write \( \mathfrak{f} \) instead of \( K \); also we may write \( K \) or \( K_\varepsilon \) omitting \( \mathfrak{f} \) when (as usually here) \( \mathfrak{f} \) is clear from the context.

**Definition 1.12.** For a class \( K \) of \( \tau \)-models:

(a) for a cardinal \( \lambda \), let \( I(\lambda, K) \) be the cardinality of \( \{ M/ \cong : M \in K \text{ has cardinality } \lambda \} \)

(b) for a cardinal \( \lambda \) and a logic \( \mathcal{L} \), let \( I(\lambda, \mathcal{L}, K) = \{ M/ \equiv_{\mathcal{L}(\mathfrak{f})} : M \in K \text{ has cardinality } \lambda \} \).

\(^2\)why not, e.g. \( \mu = \beth_{1,\mu}(\lambda)^+ ? \) not a serious difference as for limit \( \alpha \) we shall get the same value and in 1.14(1) this simplifies the notation.
Definition 1.13. 1) $\Phi$ is a template proper for linear orders when:

(a) for some vocabulary $\tau = \tau_\Phi = \tau(\Phi)$, $\Phi$ is an $\omega$-sequence, with the $n$-th element a complete quantifier free $n$-type in the vocabulary $\tau$.

(b) for every linear order $I$ there is a $\tau$-model $M$ denoted by $EM(I, \Phi)$, generated by $\{a_t : t \in I\}$ such that $s \neq t \Rightarrow a_s \neq a_t$ for $s, t \in I$ and $\langle a_0, \ldots, a_{n-1} \rangle$ realizes the quantifier free $n$-type from clause (a) whenever $n < \omega$ and $t_0 < t_1 \ldots < t_{n-1}$. We call $(M, \{a_t : t \in I\})$ a $\Phi$-EM-pair or EM-pair for $\Phi$; so really $M$ and even $(M, \{a_t : t \in I\})$ are determined only up to isomorphism but abusing notation we may ignore this and use $I_1 \subseteq J_1 \Rightarrow EM(I_1, \Phi) \subseteq EM(I_2, \Phi)$. We call $(a_t : t \in I)$ “the” skeleton of $M$; of course again “the” is an abuse of notation as it is not necessarily unique.

1A) Moreover, assume in (1) also

1) $\Phi$ is a function, giving for any complete quantifier free $n$-type $\tau_\Phi$ realized in some $M \in K$, a quantifier free type $\langle a_0, \ldots, a_{n-1} \rangle$ realizes in $M$ or $EM$-pair for $\Phi$; so really $M$ and even $(M, \{a_t : t \in I\})$ are determined for every finite linear order $I$.

Fact 1.14. 1) Let $k$ be an a.e.c. and $M \in K_k$ be of cardinality $\geq |\mathbb{N}|$.

Then there is a $\Phi$ such that $\Phi$ is proper for linear orders and:

(a) $\tau_\Phi \subseteq \tau(\Phi)$,

(b) $|\tau_\Phi| = LST_\tau + |\tau|$,

(c) $\Phi$ is a function, giving for any complete quantifier free $n$-type $\tau_\Phi$ realized in some $M \in K_k$, a quantifier free type $\langle a_0, \ldots, a_{n-1} \rangle$ realizes in $M$ or $EM$-pair for $\Phi$; so really $M$ and even $(M, \{a_t : t \in I\})$ are determined.

2) $\eta(\Phi)$ is the class of templates $\Phi$ proper for linear orders satisfying clauses

(a) $|\tau_\Phi| \geq |\tau(\Phi)\setminus \tau|$; normally we assume $\kappa \geq |\tau| + LST_\tau$ but using $\ell_M$ we do not assume $\kappa \geq |M|$.

3) For a class $K$ of so called index models, we define “$\Phi$ proper for $K$” similarly when in clause (b) of part (1) we demand $I \in K$, so $K$ is a class of $\kappa$-models, i.e.

(a) $\Phi$ is a function, giving for any complete quantifier free $n$-type in $\tau_K$ realized in some $M \in K_k$, a quantifier free type in $\tau_\Phi$.

(b) $\Phi$ is a function, giving for any complete quantifier free $n$-type in $\tau_K$ realized in some $M \in K_k$, a quantifier free type $\langle a_0, \ldots, a_{n-1} \rangle$ realizes in $M$ or $EM$-pair for $\Phi$; so really $M$ and even $(M, \{a_t : t \in I\})$ are determined.

1A) Moreover, assume in (1) also $|\mathbb{N}| \leq |\mathbb{N}|$, or $\kappa \geq LST_\tau$ so not necessarily assuming $LST_\tau \geq |\tau_\tau|$. $M^+$ is an expansion of $M$ with $\tau(M^+)$ of cardinality $\leq \kappa$ and $b_\alpha \in M$ for $\alpha < \lambda$ are pairwise distinct. Then there is $\Phi$ proper for linear orders such that:

(a) $\tau(M^+) \subseteq \tau_\Phi$ hence $\tau(\Phi) \subseteq \tau_\Phi$

(b) $\tau_\Phi$ has cardinality $\kappa$. 

modified: 2014–04–27
(b), (c) has in part (1)

(d) if $I$ is a finite linear order and $t_0 < I < t_{n-1}$ list its elements and $M_I = EM(I, \Phi)$ with skeleton $(a_t : t \in I)$, then for some ordinals $\alpha_0 < \ldots < \alpha_{n-1} < \lambda$ there is an embedding of $M_I$ into $M^+$ mapping $a_t$ to $b_{\alpha_t}$ for $\ell < n$.

2) If $\text{LST}_I < |\tau_I|$ and there is $M \in K_I$ of cardinality $\geq |LST| + \text{card} \geq 3$ we can combine parts (1A) and (2). Also in both cases having a model of $\text{LST}_I < |\tau_I|$ and $\forall \alpha \leq \text{card} \tau_I$ there is an embedding of $M_I$ into $M^+$ mapping $a_t$ to $b_{\alpha_t}$.

We add

Claim 1.15. For every cardinal $\mu$ and strong limit $\chi \leq \mu$ there is a dense $\kappa$-saturated linear order $I = I_\mu$ of cardinality $\mu$ such that:

(*) if $\theta \leq \mu$, $2^\theta \leq \mu$ then

\[ (*)_{\chi, \theta} \text{ we have } 2^\theta \leq \mu \text{ and } \theta \leq \text{cf}(\theta) \text{ and } (A) \Rightarrow (B) \text{ where:} \]

(A) (a) $I_0 \subseteq I$
(b) $I_0$ has cardinality $\leq \theta$
(c) $I_1$ is a linear order extending $I_0$
(d) $u_n \subseteq u_{n+1} \subseteq \theta = \bigcup_n u_n$
(e) $\bar{I}_\alpha \in \theta(I_1)$ for $\alpha < \theta$ and $\langle \bar{I}_\alpha : \alpha < \theta \rangle$ is an indiscernible sequence in $I_1$ over $I_0$ (for quantifier free formulas)
(f) for every $n, I_{1,n} = I_1 \{(\bar{I}_\alpha, i \in u_n, \alpha < \theta) \cup I_0 \}$ is embeddable into $I$ over $I_0$

(B) there is $\{\bar{I}_\alpha : \alpha < \mu\}$ such that
(a) $\bar{I}_\alpha \in \theta I$
(b) $\{\bar{I}_\alpha : \alpha < \mu\}$ is an indiscernible sequence over $I_0$ into $I$
(for quantifier free formulas)
(c) the quantifier free type of $\bar{I}_0 \ldots \bar{I}_n$ over $I_0$ in $I$ is equal to the quantifier free type of $\bar{I}_0 \ldots \bar{I}_n$ over $I_0$ in $I_1$ for every $n$

(B) $^+$ moreover we can replace $\{\bar{I}_\alpha : \alpha < \mu\}$ by $\{\bar{I}_s : s \in I\}$.

Remark 1.16. 1) We may consider replacing (A)(e) by

\[ (e') \alpha = \{\bar{I}_0, u_n \subseteq u_{n+1} \subseteq \theta = \bigcup_n u_n \text{ and } I_{1,n} = \{\bar{I}_{\alpha', \varepsilon} : \alpha < \theta, \varepsilon \in u_n\} \text{ and} \]

there is $f = (f_\eta : \eta \in \Lambda)$ such that $f_\eta$ embeds $I_{1,\varepsilon(\eta)}$ into $I_1$ over $I_0$ and $\nu < \eta \Rightarrow f_\nu \subseteq f_\eta$ where $\Lambda = \{\eta : \eta \text{ is a decreasing sequence of ordinals } < \alpha\}$.

2) Clauses (A)(d),(e) can be weakened to:

\[ \oplus \text{ if } i, j < \theta \text{ then } I_1 \{(\bar{I}_{\alpha, i} : \alpha = 0, 1 \text{ and } i < \theta) \cup I_0 \} \text{ can be embedded into } I \text{ over } I_0. \]
But the present form fits our application.

Proof. First we give a sufficient condition for $(*_{I,\partial,\theta})$

- the linear order $I$ satisfies $(*)_{I,\partial,\theta}$ when: $\chi > \partial = \text{cf}(\partial) > \theta$ and
  - (a) $I$ is a linear order of cardinality $\mu$
  - (b) if $I_0 \subseteq I, |I_0| \leq \theta$ then the set $I_0^+ = \{ t \in I : t \notin I_0 \}$ and there is no $t' \in I \setminus I_0 \setminus \{ t \}$ realizing the same cut of $I_0$ in $I$ has cardinality $< \partial$, so if $\partial = (2^\theta)^+$ this holds
  - (c) if $a < I b$ then $I$ is embeddable into $(a, b)_I$
  - (d) every linear order of cardinality $\leq \theta$ is embeddable into $I$
  - (e) in $I$ there is a decreasing sequence of length $\mu$ and an increasing sequence of length $\mu$
  - (f) to get $(B)^+$ we need: if $J$ is a linear order of cardinality $\leq \theta$ then we can embed $I \times J$ (ordered lexicographically into $I$).

It is obvious that there is such linear order. It is also each that if $I$ satisfies (a)-(d) then $(*)_{I,\partial,\theta}$. $\Box_{1.15}$
§ 2. More on Templates

Why do we need $T^\forall_\kappa[M, \mathfrak{t}]$? Remember that such $\Phi$’s are witnesses to $M$ having $\leq_\mathfrak{t}$-extensions in every $\mu > \text{LST}_\mathfrak{t} + \|M\|$ so proving existence is a major theme here. First, why do we need below $T^\forall_\kappa$? Because “$T^\forall_\kappa[M, \mathfrak{t}] \neq \emptyset$” is equivalent to $M$ as not $\leq_\mathfrak{t}$-maximal; moreover has $\leq_\mathfrak{t}$-extensions of arbitrarily large cardinality so proving this for every $M \in K^1_\Lambda$ indicates “$\mathfrak{t}$ is nice, at least in $\Lambda$”. Second, why do we need various partial orders on $T^\forall_\kappa[M, \mathfrak{t}]$s?

In a major proof here to build $\Phi \in T^\forall_\kappa[M, \mathfrak{t}]$ we use $\leq_\mathfrak{t}$-increasing $M_n$ with union $M$ and try to choose $\Phi_n \in T^\forall_\kappa[M_n, \mathfrak{t}]$ increasing with $n$. For this we assume $\|M_n\| = \lambda_n, \lambda_n \ll \lambda_{n+1}$ and we use an induction hypothesis that $\Phi_n$ has a say $\lambda_{n+\mathfrak{t}}$-witness in $M$.

Of course, it is nice if $\text{EM}(\lambda_{n+\mathfrak{t}}, \Phi_n)$ is $\leq_\mathfrak{t}$-embeddable into $M$ over $M_n$ but for this we do not have strong enough existence theorem. To fine tune this and having a limit ($\Phi \in T^\forall_\kappa[M, \mathfrak{t}]$) we need some orders.

Definition 2.1. For $\mathfrak{t}$ an a.e.c. and $M \in K_\mathfrak{t}$ let $\mathfrak{t}_M = \mathfrak{t}[M]$ be the following a.e.c.:

(a) vocabulary $\tau_\mathfrak{t} \cup \{c_a : a \in M\}$ where the $c_a$’s are pairwise distinct new individual constants

(b) $N \in K_{\mathfrak{t}_M}$ if $N|\tau_\mathfrak{t} \in K_\mathfrak{t}$ and $a \mapsto c^N_a$ is a $\leq_\mathfrak{t}$-embedding of $M$ into $N|\tau_\mathfrak{t}$;

(c) $N_1 \leq_{\mathfrak{t}_M} N_2$ if

(α) $N_1, N_2$ are $\mathfrak{t}_M$-models from $K_{\mathfrak{t}_M}$

(β) $N_1 \subseteq N_2$

(γ) $(N_1|\tau_\mathfrak{t}) \leq_\mathfrak{t} (N_2|\tau_\mathfrak{t})$.

Definition 2.2. 1) We call $N \in K_{\mathfrak{t}_M}$ standard when $M \leq_\mathfrak{t} N|\tau_\mathfrak{t}$ and $a \in M \Rightarrow c^N_a = a$.

2) If $N^1 \in K_{\mathfrak{t}_M}$ is standard and $N^0 = N^1|\tau_\mathfrak{t}$ then we write $N^1 = N^0_{|M|}$.

3) We call $\Phi \in T^\forall_\kappa[\mathfrak{t}]$ standard when $M = \text{EM}(\emptyset, \Phi)$ implies $N \leq_\mathfrak{t} M|\tau_\mathfrak{t}$ when $N$ is the submodel of $M|\tau_\mathfrak{t}$ with universe $\{c^M : c \in \tau(\Phi) \text{ an individual constant}\}$. We call $\Phi$ fully standard when above $N = M|\tau_\mathfrak{t}$.

4) Let $T^\forall_\kappa[\mathfrak{t}]$ be the class of standard $\Phi \in T^\forall_\kappa[\mathfrak{t}]$.

5) For $M \in K_\mathfrak{t}$ let $T^\forall_\kappa[\mathfrak{t}_M]$ be the class of $\kappa$-standard $\Phi \in T^\forall_\kappa[\mathfrak{t}_M]$ which means:

(a) letting $\kappa_1 = \kappa + \|M\|$, we have $\Phi \in T^\forall_\kappa[\mathfrak{t}]$

(b) $\{c_a : a \in M\} = \{c \in \tau(\Phi) : c \text{ an individual constant}\}$

(c) $N = \text{EM}(\emptyset, \Phi) \Rightarrow |N| = \{c^N : c \in \tau_\mathfrak{t}\}$

(d) $\tau_\Phi := \tau_\mathfrak{t}\{c \in \tau_\Phi \text{ an individual constant}\}$ has cardinality $\leq \kappa$

(e) if $N = \text{EM}(I, \Phi)$ and $N_1$ is a submodel of $N|\tau_\Phi$ then $N_1|\tau_\mathfrak{t} \leq_\mathfrak{t} N|\tau_\mathfrak{t}$.

5A) We may omit $\kappa$ in part (5) when $\kappa = \text{LST}_\mathfrak{t} + |\tau_\mathfrak{t}|$. We may write $T^\forall_\kappa[\mathfrak{t}_M]$ instead of $T^\forall_\kappa[\mathfrak{t}_M]$ for some $\kappa$, useful when $\mathfrak{t}$ is not clear from the context.

---

$^3$Note that we have not said “$\Phi \in T^\forall_\kappa[\mathfrak{t}]$” but by renaming this follows.

$^4$So though such $\Phi$ belongs to $T^\forall_\kappa[\mathfrak{t}]$, being standard for $T^\forall_\kappa[\mathfrak{t}_M]$ is a different demand than being standard for $T^\forall_\kappa[\mathfrak{t}]$ as for the latter possibly $\{c_a : a \in M\} \subsetneq \{c \in \tau_\Phi : c \text{ an individual constant}\}$. 

---

modified: 2014-04-25

revision: 2014-04-27

(893)
Observation 2.3. 1) If $\Phi \in \mathcal{Y}_{\kappa}^{\text{or}}[\mathfrak{t}, M]$ then $\Phi \in \mathcal{Y}_{\kappa+\|M\|}^{\text{or}}[\mathfrak{t}]$ but not necessarily the inverse.
2) If $\Phi \in \mathcal{Y}_{\kappa}^{\text{or}}[\mathfrak{t}, M]$ then $\Phi$ is a fully standard member of $\mathcal{Y}_{\kappa}^{\text{or}}[\mathfrak{t}_M]$.

Claim 2.4. Assume $\mathfrak{t}$ is an a.e.c. and $M \in K_\mathfrak{t}$ and $\mathfrak{t}_1 = \mathfrak{t}_M$ then:

(a) $\mathfrak{t}_1$ is an a.e.c.
(b) $\text{LST}_{\mathfrak{t}_1} = \text{LST}_\mathfrak{t} + \|M\|
(c) applying 1.14 to $\mathfrak{t}_1$, we can add $\Phi \in \mathcal{Y}_{\kappa}^{\text{or}}[\mathfrak{t}_M]$.

Proof. Straightforward. □

Definition 2.5. Assume $J$ is a linear order of cardinality $\lambda$ and $\lambda \to (\mu)_\theta^n$. We define the ideal $\mathcal{I} = \text{ER}_{J,\mu,\theta}$ on the set $[J]^\mu$ by:

- $\mathcal{I} \subseteq [J]^\mu$ belongs to $\mathcal{I}$ if and only if for some $c : [J]^{\leq n} \rightarrow \theta$ there is no $s \in \mathcal{I}$ such that $c[s]^n$ is constant.

Observation 2.6. 1) If $|J| = \lambda$ and $\lambda \to (\mu)_\theta^n$ then $\text{ER}_{J,\mu,\theta}$ is indeed an ideal, i.e. $J \notin \text{ER}_{J,\mu,\theta}$.
2) If $\theta = \theta^{<\kappa}$ then this ideal is $\kappa$-complete.

Definition 2.7. 1) For vocabularies $\tau_1, \tau_2$ we say that $h$ is an isomorphism from $\tau_1$ to $\tau_2$ when $h$ is a one-to-one function from the non-logical symbols of $\tau_1$ (i.e., the predicates and function symbols) onto those of $\tau_2$ such that:

(a) if $P \in \tau_1$ is a predicate then $h(P)$ is a predicate of $\tau_2$ and $\text{arity}_{\tau_1}(P) = \text{arity}_{\tau_2}(h(P))$
(b) if $F \in \tau_1$ is a function symbol then $h(F)$ is a function symbol of $\tau_2$ and $\text{arity}_{\tau_1}(F) = \text{arity}_{\tau_2}(h(F))$.

2) If $h$ is an isomorphism from the vocabulary $\tau_1$ to the vocabulary $\tau_1$ and $M_1$ is a $\tau_1$-model then $M_1^{[h]}$ is the unique $M_2$ such that:

(a) $M_2$ is a $\tau_2$-model
(b) $|M_2| = |M_1|$
(c) $P_{\tau_2}^{M_2} = P_{\tau_1}^{M_1}$ when $P_1 \in \tau_1$ is a predicate and $P_2 = h(P_1)$
(d) $F_{\tau_2}^{M_2} = F_{\tau_1}^{M_1}$ when $F_1 \in \tau_1$ is a function symbol and $F_2 = h(F_1)$.

3) We say $h$ is an isomorphism from $\tau_1$ to $\tau_2$ over $\tau$ when $\tau \subseteq \tau_1 \cap \tau_2$, $h$ is an isomorphism from $\tau_1$ onto $\tau_2$ and $h|\tau$ is the identity.
4) If $\Phi_1 \in \mathcal{Y}_{\kappa}^{\text{or}}$ and $h$ is an isomorphism from the vocabulary $\tau_1 := \tau(\Phi)$ onto the vocabulary $\tau_2$ then $\Phi_2^{[h]}$ is the unique $\Phi_2 \in \mathcal{Y}_{\kappa}^{\text{or}}$ such that: if $I$ is a linear order, $M_1 = \text{EM}(I, \Phi_1)$ with skeleton $\langle a_t : t \in I \rangle$ then $M_1^{[h]}$ is the model $\text{EM}(I, \Phi_2)^{[h]}$ with the same skeleton.

---

\[\text{this includes individual constants}\]
Observation 2.8. 1) In 2.7(2), $M_2 = M_1^{[h]}$ is indeed a $\tau_2$-model. If in addition $h$ is over $\tau$ (i.e. $\tau \subseteq \tau_1 \cap \tau_2$ and $h|\tau = id_{\tau}$) then $M_1|\tau = M_2|\tau$.

2) In 2.7(4), indeed $\Phi_2 \in \Upsilon_\kappa^{or}$.

3) If $h$ is an isomorphism from $\tau_1$ onto $\tau_2$ over $\tau$ so $\tau_1 \subseteq \tau_1 \cap \tau_2$ and $\Phi_1 \in \Upsilon_\kappa^{or}[\mathfrak{t}]$, $\tau_1 = \tau(\Phi_1)$ then $\Phi_2 = \Phi_1^{[h]}$ belongs to $\Upsilon_\kappa^{or}[\mathfrak{t}]$.

4) In part (3) if in addition $M \in K_\kappa$ and $\Phi_1 \in \Upsilon_\kappa^{or}[M, \mathfrak{t}]$ and $a \in M \Rightarrow h(c_a) = c_a$ then $\Phi_2 = \Phi_1^{[h]}$ belongs to $\Upsilon_\kappa^{or}[M, \mathfrak{t}]$.

Proof. Straightforward. \(\square_{2.8}\)

Next we recall the partial orders $\leq^1_{\kappa}$, $\leq^2_{\kappa}$ and define an equivalence relation and some quasi-orders on $\Upsilon_\kappa^{or}[\mathfrak{t}]$.

Definition 2.9. Fixing $\mathfrak{t}$, we define partial orders $\leq^0_{\kappa} = \leq^1_{\kappa}$ and $\leq^2_{\kappa}$ on $\Upsilon_\kappa^{or}[\mathfrak{t}]$ (for $\kappa \geq LST_\mathfrak{t}$):

1) $\Psi_1 \leq^0_{\kappa} \Psi_2$ if $\tau(\Psi_1) \subseteq \tau(\Psi_2)$ and $EM_{\tau(\mathfrak{t})}(I, \Psi_1) \subseteq EM_{\tau(\mathfrak{t})}(I, \Psi_2)$ and $EM(I, \Psi_1) = EM(I, \Psi_2)$ for any linear order $I$ (so, of course, same $a_t$’s, etc.).

2) For $\Phi_1, \Phi_2 \in \Upsilon_\kappa^{or}$, we say $\Phi_2$ is an inessential extension of $\Phi_1$ and write $\Phi_1 \leq^e_{\kappa} \Phi_2$ if $\Phi_1 \leq^0_{\kappa} \Phi_2$ and for every linear order $I$, we have $EM_{\tau(\mathfrak{t})}(I, \Phi_1) = EM_{\tau(\mathfrak{t})}(I, \Phi_2)$.

(note: there may be more function symbols in $\tau(\Phi_2))$

2A) We define the two-place relation $E^a$ on $\Upsilon_\kappa^{or}[\mathfrak{t}]$ as follows: $\Phi_1, E^a\Phi_2$ i.e. $\tau(\Phi_1) = \tau(\Phi_2)$ and for some unary function symbol $F \in \tau(\Phi_1)$ or $F$ is just a (finite) composition$^6$ of such function symbols, if $M = EM(I, \Phi_1)$ with skeleton $\langle a^I_t : t \in I \rangle$ and we let $a^2_t = F^M(a^1_t)$ for $t \in I$ then:

- $F^M(a^2_t) = a^1_t$
- $M$ is $EM(I, \Phi_2)$ with skeleton $\langle a^2_t : t \in I \rangle$.

$"^a$ stands for almost equal.

2B) Above we say $\Phi_2, E^a\Phi_2$ is witnessed by $F$.

2C) We define the two-place relation $E^e_{\kappa}$ on $\Upsilon_\kappa^{or}[\mathfrak{t}]$ by: $\Phi_1, E^e_{\kappa}\Phi_2$ iff for some $\Phi_3$, $\Phi_1 \leq^e_{\kappa} \Phi_3$ and $\Phi_2 \leq^e_{\kappa} \Phi_3$.

2D) We define a two-place relation $E^{ai}_{\kappa}$ on $\Upsilon_\kappa^{or}[\mathfrak{t}]$ by $\Phi_1, E^{ai}_{\kappa}\Phi_2$ iff for some $\Phi_3 \in \Upsilon_\kappa^{ai}[\mathfrak{t}]$ we have $\Phi_1, E^a\Phi_2$ and $\Phi_2, E^a_{\mathfrak{t}} \Phi_3$.

3) Let $\Upsilon_{\kappa}^{lin}$ be the class of $\Psi$ proper for linear order and producing linear orders, that is, such that:

   (a) $\tau(\Psi)$ has cardinality $\leq \kappa$,
   (b) $EM_{\langle I, \Psi \rangle}$ is a linear order which is an extension of $I$ which means $s < I$ $t \Rightarrow EM(I, \Psi) = \langle a_s < a_t \rangle$; in fact we can have $|t | I \Rightarrow a_s = t$.
   
4) $\Phi_1 \leq^0_{\kappa} \Phi_2$ i.e. there is $\Psi$ such that:

$^6$but abusing our notation we may still write $F \in \tau_{\mathfrak{t}}$
(a) \( \Psi \in \mathcal{T}^\text{lin}_{\kappa} \)
(b) \( \Phi_\ell \in \mathcal{T}^\text{or}_{\kappa} \) for \( \ell = 1, 2 \)
(c) \( \Phi'_2 \leq_{\kappa} \Phi_2 \) where \( \Phi'_2 = \Psi \circ \Phi_1 \), i.e.
\[
\text{EM}_{\tau(\Phi_1)}(I, \Phi'_2) = \text{EM}(\text{EM}_{\prec}(I, \Psi), \Phi_1).
\]

(So we allow further expansion by functions definable from earlier ones (composition or even definition by cases), as long as the number is \( \leq \kappa \)).

It is not a real loss to restrict ourselves to standard \( \Phi \) because

\[\text{Claim 2.10.}\]

1) For every \( \Phi_1 \in \mathcal{T}^\text{or}_{\kappa}[t] \) there is a standard \( \Phi_2 \in \mathcal{T}^\text{or}_{\kappa}[t] \) such that \( \Phi_1 \leq_{\kappa} \Phi_2 \); moreover \( M = \text{EM}(\emptyset, \Phi_2) \Rightarrow |M| = \{ c^M : c \in \tau(\Phi_2) \text{ an individual constant} \} \), that is \( \Phi_2 \) is fully standard.

2) Assume \( \Phi_1 \in \mathcal{T}^\text{or}_{\kappa}[t], F \in \tau(\Phi) \) is a unary function symbol such that \( M = \text{EM}(I, \Phi_1) \land t \in I \Rightarrow F^M(F^M(a_1)) = a_t \). Then for a unique \( \Phi_2, \Phi_1 \varepsilon^\Phi_2 \) as witnessed by \( F \) and \( \Phi_1 \in \mathcal{T}^\text{or}_{\kappa}[tM] \Leftrightarrow \Phi_2 \in \mathcal{T}^\text{or}_{\kappa}[tM] \).

3) \( \varepsilon_{\kappa}^\Phi \) is an equivalence relation on \( \mathcal{T}^\text{or}_{\kappa}[t] \) for \( \lambda \in \{ w, \text{ie, ai} \} \) all refining \( \varepsilon_{\kappa}^\lambda \).

\[\text{Proof.}\] Obvious. \hspace{1cm} \blacksquare_{2.10}

\[\text{Observation 2.11.}\]

1) The relation \( \leq_{\kappa} \) is a partial order on \( \mathcal{T}^\text{or}_{\kappa}[t] \).
2) If \( \langle \Phi_\alpha : \alpha < \delta \rangle \) is \( \leq_{\kappa} \)-increasing with \( \delta \) a limit ordinal \( < \kappa^+ \) then \( \bigcup_{\alpha < \delta} \Phi_\alpha \)

naturally defined is a \( \leq_{\kappa} \)- lub. 

3) \( \varepsilon_{\kappa}^\Phi \) is an equivalence relation on \( \mathcal{T}^\text{or}_{\kappa} \).

4) If \( \mathcal{T}^\text{or}_{\kappa}[t] \leq \mathcal{T}^\text{or}_{\kappa}[t] \) then \( \kappa_1 \leq \kappa_2 \). If \( \kappa_1 \leq \kappa_2 \) and \( t \subseteq \{ 1, 2 \} \) and \( \Phi, \Psi \in \mathcal{T}^\text{or}_{\kappa} \) then

\[ \Phi \leq_{\kappa_1} \Psi \Leftrightarrow \Phi \leq_{\kappa_2} \Psi. \]

5) Similarly for \( \mathcal{T}^\text{or}_{\kappa}[tM] \) defined in 2.2(5).

\[\text{Definition 2.12.}\]

1) For \( \kappa \geq \text{LST}_\alpha + |\tau|_\alpha \), we define \( \leq_{\kappa}^\circ = \leq_{\kappa}^\circ \), in full \( \leq_{\kappa}^\circ \), a two-place relation on \( \mathcal{T}^\text{or}_{\kappa}[t] \), recalling Definition 2.2(5) as follows:

Let \( \Phi_1 \leq_{\kappa}^\circ \Phi_2 \) mean that: for every linear order \( I_1 \) there are a linear order \( I_2 \) and \( \varepsilon_{\tau} \)-embedding \( h \) of \( \text{EM}_{\tau(I)}(I_1, \Phi_1) \) into \( \text{EM}_{\tau(I)}(I_2, \Phi_2) \), moreover every individual constant \( c \) of \( \tau(\Phi_1) \) is an individual constant of \( \tau(\Phi_2) \) and \( h(c^\text{EM}(I_1, \Phi_1)) = c^\text{EM}(I_2, \Phi_2) \).

2) We define \( \leq_{\kappa}^\circ = \leq_{\kappa}^\circ : \) a two-place relation on \( \mathcal{T}^\text{or}_{\kappa}[t] \) as follows.

Let \( \Phi_1 \leq_{\kappa}^\circ \Phi_2 \) mean that: for some \( F \) we have:

(a) \( \Phi_1, \Phi_2 \in \mathcal{T}^\text{or}_{\kappa}[t] \)
(b) \( \tau(\Phi_1) \subseteq \tau(\Phi_2) \)
(c) \( F \in \tau(\Phi_2) \) is a unary function symbol or as in 2.9(2A)

\[\text{if} \ I \ \text{is a linear order and} \ M_I = \text{EM}(I, \Phi_2) \ \text{with skeleton} \ \langle a^I_s : s \in I \rangle \ \text{then} \]

\[ \text{there is} \ M_I = \text{EM}(I, \Phi_1) \ \text{with skeleton} \ \langle a^I_s : s \in I \rangle \ \text{such that} \]

\[ a^I_s = F^M_s(a^I_s) \text{ for } s \in I \]
\[ a^I_s = F^M_s(a^I_s) \text{ for } s \in I \]
\[ M_I \subseteq M_2[I^*_s], \ \text{so} \ \tau(\Phi_1) \subseteq \tau(\Phi_2) \]
\[ \langle M_I[I^*_s] \rangle \leq^\circ (M_2[I^*_s]) \]
\[ c^M_1 = c^M_2 \text{ when } c \in \tau(\Phi_1) \text{ is an individual constant.} \]
Remark 2.13. So \( \leq^4 \) is like \( \leq^1 \) but we demand less as \( a_1^4 = a_2^4 \) is weakened by using the function symbol \( F \).

Claim 2.14. 1) \( \leq^3 \) is a partial order on \( \mathcal{Y}^\text{sort}[t] \) as well as \( \leq^4 \); also for \( \Phi_1, \Phi_2 \in \mathcal{Y}^\text{sort}[t] \) and \( \ell = 1, 2, 3 \) we have \( \Phi_1 \leq^2 \Phi_2 \Rightarrow \Phi_1 \leq^1 \Phi_2 \Rightarrow \Phi_1 \leq^3 \Phi_2 \Rightarrow \Phi_1 \leq^4 \Phi_2 \).

2) Assume \( \Phi_1, \Phi_2 \in \mathcal{Y}^\text{sort}[t] \) have the same individual constants. Then \( \Phi_1 \leq^1 \Phi_2 \) iff as in 2.12(1) restricting ourselves to \( I = \mathbb{N}_1(l) \) iff \( \Phi_1, \Phi_2 \in \mathcal{Y}^\text{sort}[t] \) and for some \( F, F' \) witnessing by \( F \) and \( F', \Phi_2 \) witnessed by \( F \) and for some \( \tau', h \) we have \( \tau(\Phi_2) \leq \tau(\Phi_1) \) and \( \Phi(\Phi_1) \leq_{\leq^4} \Phi(\Phi_2) \).

3) If \( \Phi_n \in \mathcal{Y}^\text{sort}[t] \) and \( \Phi_n \leq^4 \Phi_{n+1} \) there is \( \Phi_\omega \in \mathcal{Y}^\text{sort}[t] \) such that \( n < \omega \Rightarrow \Phi_n \leq^3 \Phi_\omega \) and \( \tau(\Phi_\omega) \) is the union of the \( \leq^4 \)-increasing sequence \( \tau(\Phi_\omega) \) of \( \Phi_n \) such that \( n < \omega \).

4) Similarly for \( \leq^3 \).

Proof. 1) Obvious.

2) First clause implies second clause

Holds trivially.

Second clause implies the third clause

Let \( I_1 = (\mathbb{N}, <, \mathbb{N}) \) and \( I_2 = (\mathbb{N}, <, \mathbb{N}) \). Let \( M_1 = EM(I_1, \Phi_1) \) be with skeleton \( \{a_1^1 : t \in I_1\} \) with \( \Phi_1 \leq^1 \Phi_2 \), there is a linear order \( I_2 \) and \( M_2 = EM(I_2, \Phi_2) \) with skeleton \( \{a_2^1 : t \in I_2\} \) and \( \leq^1 \)-embedding \( f \) from \( M_1 \) into \( M_2 \) such that \( c \in \tau(\Phi_1) \Rightarrow c \in \tau(\Phi_2) \). So by renaming without loss of generality \( f(Sk(\emptyset, M_1)) \) is the identity and \( I_2 \) is \( \mathbb{N} \). As \( \|M_2\| > \|M_1\| \geq \kappa > \kappa \geq |\tau(M_2)| \), clearly we can find pairwise distinct \( t_\alpha \in I_2 \) for \( \alpha < \lambda \) such that \( \{a_2^1 : \alpha < \lambda \} \cap \{f(a_1^1) : \alpha < \lambda \} = \emptyset \).

Let \( \tau_1 = \tau(\Phi_1) \) and \( \tau = \tau(\Phi_1) \). Let the pair \( (h, \tau_1) \) be such that: \( h \) is an isomorphism from the vocabulary \( \tau_2 = \tau(\Phi_2) \). Let \( \tau_3 \) and \( \tau \) be \( \tau(\Phi_1) \) such that \( \tau(\Phi_1) \) is an isomorphism from the vocabulary \( \tau = \tau(\Phi_1) \). Let \( M_3 = M_2^{\|\Phi_2\|} \), so \( \tau(M_3) = \tau_3 \). Then \( \Phi_3 \) and \( \Phi_2^{\|\Phi_2\|} \) are isomorphic to \( \tau(\Phi_1) \). Let \( M_3 \) be an \( EM(I_2, \Phi_3) \) model with skeleton \( \{a_2^2 : t \in I_2\} \).

Let \( \tau_1 = \tau_1 \cap \tau_2 \cup \{F, P\} \) with \( F \) a one place function symbol and \( P, P \notin \tau_1 \cap \tau_2 \) and \( P \) one place predicates for \( \ell = 2, 3, 4 \). We define a \( \tau_1 \)-model \( M_4 \):

1. It has universe \( |M_3| \)
2. \( F^{M_4}(a_3^1) = f(a_1^1) \) and \( F^{M_4}(f(a_1^1)) = a_2^2 \)
3. \( P_1^{M_4} = \{a_2^1 : t \in I_2\}, P_2^{M_4} = \{a_2^1 : t \in I_2\} \), \( P_3^{M_4} = \{f(a_2^1) : t \in I_1\} \), \( P_4^{M_4} = \text{Rang}(f) \)
4. \( M_4 \models \tau_3 = M_3 \)
5. \( \tau_1 \) embeds \( M_1 \) into \( M_4 \).

Clearly there is no problem to do this and we apply 1.14(1A) with \( M_4, \langle a_2^1 : \alpha < \lambda \rangle \) here standing for \( M, M^+, \langle a_\alpha : \alpha < \lambda \rangle \) there and get \( \Phi_4 \) standing for \( \Phi \) there. Now by inspection (see Definition 2.12(2)): \( \tau_1 \models \Phi_1 \leq^3 \Phi_4 \).
\[ (*)_2 \Phi_3 \leq^\kappa \Phi_4; \text{ moreover } \Phi_3 \leq^{ie} \Phi_4. \]

\{z22\} We derive \( \Phi_4 \) from \( \Phi_4 \) by 2.10(2) using our \( F \) so \( \Phi_4 \leq^\kappa \Phi_5 \). To show that the third clause of part (2) indeed holds, we just note that \( \Phi'_1, \Phi'_2, h, \tau_3 \), there can stand for \( \Phi_4, \Phi_5, h, \tau_3 \) here, so we are done.

The third clause implies the first clause:

So we are given \( F \) and \( \Phi_1, \Phi_2 \in \Gamma_\kappa \) with \( \Phi_1, \Phi_2 \in \Gamma_\kappa \), \( \tau_\alpha \subseteq \tau(\Phi_2) \subseteq \tau(\Phi_1) \) and an isomorphism \( h \) from \( \tau(\Phi_2) \) onto \( \tau_\alpha \). Let \( \tau \in \tau_\alpha \). Let \( \Phi_2' \) witness \( F, \Phi_2' \) \( \leq^{\kappa} \Phi_2 \) witness \( F, \Phi_2 \) and \( \Phi_2^{[1]} \leq^{\kappa} \Phi_2^{[2]} \).

Let \( \Psi \in \Psi_1 \) witness \( \Phi_2^{[1]} \leq^{\kappa} \Phi_2^{[2]} \); and for uniformity of notation we let \( \Phi_3 := \Phi_2^{[2]} \).

We have to prove \( \Phi_1 \leq^3 \Phi_2 \) so let \( I_1 \) be a linear order.

Let \( M_1 = EM(I_1, \Phi_1) \) be with skeleton \( \langle a_1^\ell : t \in I_1 \rangle \), let \( I_2 = EM(I_1)(\Psi, I_1) \) so with skeleton \( \langle t : t \in I_1 \rangle \).

Let \( M_1 \subseteq M_2 \) be defined by \( M_2 = EM(I_2, \Phi_2) \) with skeleton \( \langle a_2^\ell : t \in I_2 \rangle \) for \( \ell = 1, 2 \) and let \( M_3 = EM(I_1, \Phi'_1) \) be with skeleton \( \langle a_3^\ell : t \in I_1 \rangle \).

By the choice of \( \Psi \) and of \( I_2 \) without loss of generality \( M_2^{[1]} = M_3 | \tau_\alpha \).

Lastly, there is a unique embedding \( f \) of \( M_1 \) into \( M_3 | \tau(\Phi_1) \) mapping \( a_1^\ell \) to \( F^{M_2}(a_2^\ell) \) for \( \ell \in I_1 \). Easily \( f \) is a \( \leq^{\kappa} \)-embedding of \( M_1 | \tau(\Phi_1) \) into \( M_3 | \tau(\Phi_2) \) mapping \( c^{M_1} \) to \( c^{M_2} \) for \( c \in \tau(\Phi_1) \) and \( M_3 | \tau(\Phi_2) \) mapping \( c \in \tau(\Phi_1) \) and \( c \in \tau(\Phi_2) \wedge \)

We leave the fourth clause to the reader.

\{z28\} 3 By parts (2) and (4) or directly using 1.14(1) and the definition of \( \leq^3 \).

4) So assume that \( n < \omega \Rightarrow \Phi_n \leq^3 \Phi_{n+1} \) as witnessed by \( F_n \in \tau(\Phi_{n+1}) \).

For any infinite linear order \( I \) we can choose \( M_n = EM(I_1, \Phi_n) \) with skeleton \( \langle a_n^\ell : t \in I \rangle \).

Without loss of generality \( M_n \subseteq M_{n+1} \). Without loss of generality \( M_n \subseteq M_{n+1} \). Without loss of generality \( M_n \subseteq M_{n+1} \). Without loss of generality \( M_n \subseteq M_{n+1} \). Without loss of generality \( M_n \subseteq M_{n+1} \).

For each \( n \) we define \( M_{\omega,n} = M_{\omega,n+1} \).

Hence letting \( \tau_n = \tau(\Phi_n) \) there is a \( \tau_n \)-model \( M_n \) with universe \( \tau(M_n) \) such that \( M_n | \tau_n = M_{\omega,n} \) for \( n < \omega \). Now define \( \Phi \) by \( \Phi(n) = \tau(\Phi_n) \).

Clearly \( M_\omega = EM(I, \Phi) \) with skeleton \( \langle a_n^\ell : t \in I \rangle \) and \( F_{n-1,\ldots,1} \) witness \( \Phi_n \leq^4 \Phi_{n+1} \).

We leave the fourth clause to the reader.

\{z29\} Claim 2.15. For \( M \in K_\ell \) of cardinality \( \kappa \geq LST_\ell + |\tau_\ell| \) the following conditions are equivalent:

\[ \begin{align*}
(a) & \; \Gamma_{\kappa}^\ell[M] \neq \emptyset \\
(b) & \; \text{for every } \lambda \geq \kappa \text{ there is } N \text{ such that } M \leq^\kappa N \in K_\lambda^\ell \\
(c) & \; \text{for every } \alpha < (2^n)^+ \text{ there is } N \in K_\ell^\kappa \text{ with } \leq_{\alpha} \text{-extend } M \\
(d) & \; \text{there is } \Phi \in \Gamma_{\kappa}^\ell[M] \text{ such that if } N = EM(I, \Phi) \text{ and } N | \tau_M \text{ is standard then } M = (N | \tau_\ell) \{c^{N} \in \subset \phi_\ell \text{ an individual constant}\} \\
(e) & \; \Gamma_{\kappa}^\ell[M] \text{ is non-empty.}
\end{align*} \]

Proof. For (d) note that we can replace an individual constant by a unary function which is interpreted as being a constant function. More generally an \( n \)-place function \( F^N \) by functions \( F_1, F_2 \) where \( \{F_{n,u} : u \in n, h : u \rightarrow M\} \) where

- \( F_1 \) is a \( (n+1) \)-place function

- \( F_2(a) = F^N(a) \)

modified:2014-04-27

revised:2014-04-25
• if $\bar{a} \in {}^n M$ then $F_1(\bar{a}) = a_0$

\[ \square_{2.15} \]

**Claim 2.16.** If (A) then (B) when:

\(\begin{align*}
(A) & \quad M_1 \leq_t M_2 \\
(b) & \quad \Phi_1, \Psi_1 \text{ are from } \mathcal{Y}_\kappa^{\text{sor}}[t_{M_1}] \text{ so are } \kappa\text{-standard} \\
(c) & \quad \Psi_2 \in \mathcal{Y}_\kappa^{\text{sor}}[t_{M_2}] \\
(d) & \quad \Phi_1 \leq_\kappa^4 \Psi_1 \\
(e) & \quad \Psi_1 \leq_\kappa^4 \Psi_2 \\
(f) & \quad \{c_a : a \in M_2\} \cap \tau(\Psi_1) = \{c_a : a \in M_1\}
\end{align*}\)

\(\begin{align*}
(B) & \quad \text{there is } \Phi_2 \text{ such that} \\
(a) & \quad \Phi_2 \in \mathcal{Y}_\kappa^{\text{sor}}[t_{M_2}] \\
(b) & \quad \Phi_1 \leq_\kappa^4 \Phi_2 \\
(c) & \quad \Phi_2 \leq_\kappa^4 \Psi_2.
\end{align*}\)

**Proof.** Straightforward: let $I$ be an infinite linear order, $M_2 = \text{EM}(I, \Psi_2)$ be with skeleton $\langle a_i^2 : t \in I \rangle$. Let the unary function symbol $F$ witness $\Phi_1 \leq_\kappa^4 \Psi_1$ so $F \in \tau(\Psi_1) \subseteq \tau(\Psi_2)$ and let $a_i^2 = F^{M_2}(a_i^2)$. Clearly $\langle a_i^2 : t \in I \rangle$ is indiscernible for quantifier formulas in $M_2$ and generate it hence for some $\Phi_2 \in \mathcal{Y}_\kappa^{\text{sor}}$ we have $M_2 = \text{EM}(I, \Phi_2)$. Clearly $\Phi_2 \in \mathcal{Y}_\kappa^{\text{sor}}[\ell]$ and the model $M_2$ is $\text{EM}(I, \Phi_2)$ with skeleton $\langle a_i^2 : t \in I \rangle$. Also $\Phi_2 \mathcal{E}^\kappa \Phi_2$ hence $\Phi_2 \leq_\kappa^4 \Psi_2$ and $\Phi_1 \leq_\kappa^4 \Phi_2$ as required. \(\square_{2.16}\)

**Definition 2.17.** 1) We say $i = (\mathcal{I}, I) = (\mathfrak{A}, \mathfrak{I})$ is pit (partially idealized tree) when:

\(\begin{align*}
(a) & \quad \mathcal{I} \text{ is a tree with } \leq \omega \text{ levels and} \\
& \quad \text{for transparency it is a set of finite sequences ordered by } a, \text{ closed under initial segments} \\
& \quad \text{let } \text{lev}_\mathcal{I}(\eta, \mathcal{I}) = \text{lev}_\mathcal{F}(\eta) \text{ be the level of } \eta \in \mathcal{I} \text{ in } \mathcal{F}, \text{ that is} \\
& \quad |\{\nu \in \mathcal{I} : \nu \upharpoonright \eta\}| \\
& \quad \text{let } r_\mathcal{F} \text{ be the root} \\
& \quad \text{the } n\text{-level of } \mathcal{I} \text{ is the set } \{\eta : \text{lev}_\mathcal{I}(\eta) = n\} \text{ so we have} \\
& \quad \text{lev}_\mathcal{I}(\eta) = \ell_\mathcal{F}(\eta) \text{ and } r_\mathcal{F} = \emptyset \\
(b) & \quad I = \langle I_\eta : \eta \in \mathcal{I} \rangle \text{ where } \mathcal{I} \subseteq \mathcal{I} \setminus \text{max}(\mathcal{I}), \text{ we may write } \mathcal{A} = \mathcal{I} \\
(c) & \quad I_\eta \text{ is an ideal on } \text{suc}_\mathcal{F}(\eta) := \{\rho : \nu \in \mathcal{I}, \eta \not<_\mathcal{F} \rho \text{ and there is no } \nu \in \mathcal{I} \text{ satisfying } \eta \not<_\mathcal{F} \nu < \mathcal{F} \rho\} \text{ or just an ideal on a set which } \supseteq \text{suc}_\mathcal{F}(\eta) \text{ such that } \text{suc}_\mathcal{F}(\eta) \notin I_\eta; \text{ we may write } I_{\eta, \eta}.
\end{align*}\)
1A) If $I_{t_0} = \{ s : \eta \langle s \rangle \in X \} : X \in I_{t_0}$ for some ideal $I_{t_0}$ on some set then abusing notation we may write $I_{t_0}$ instead of $I_{t_0}$.

2) Let $(\mathcal{F}_1, I_1) \leq (\mathcal{F}_2, I_2)$ when (each is a pit and):

(a) $\mathcal{F}_1 \subseteq \mathcal{F}_2$ which means:

(α) $\eta \in \mathcal{F}_2$ $\Rightarrow$ $\eta_1 \in \mathcal{F}_1 \land \text{lev}(\eta, \mathcal{F}_2) = \text{lev}(\eta, \mathcal{F}_1) \land \text{suc}(\eta, \mathcal{F}_2) \subseteq \text{suc}(\eta, \mathcal{F}_1)$

(β) $\mathcal{F}_1 = \mathcal{F}_2 \mid \mathcal{F}_1$ i.e. $I_1 \{ \eta \in \mathcal{F}_1 : \eta \in \text{Dom}(I_2) \}$

(c) if $\eta \in \mathcal{F}_2 \setminus \mathcal{F}_1$ then $\text{suc}(\eta, \mathcal{F}_2) = \text{suc}(\eta, \mathcal{F}_1)$.

2A) Let $(\mathcal{F}_1, I_1) \leq_{pr} (\mathcal{F}_2, I_2)$ when (each is a pit and)

(a), (b), (c) as above

(d) if $\eta \in \text{Dom}(I_1)$ then $\text{suc}_{\mathcal{F}_1}(\eta) \cup \text{suc}_{\mathcal{F}_2}(\eta) \in I_{1, \eta}$.

3) We say $(\mathcal{F}, I)$ is $\kappa$-complete when every ideal $I_0$ is.

4) For $i = (\mathcal{F}, I)$ we define $D_p_i = D_p_{\mathcal{F}, I} : \mathcal{F} \rightarrow \text{Ord} \cup \{ \infty \}$ by (stipulate $\infty + 1 = \infty$) defining when $D_p_{\mathcal{F}, I}(\eta) \geq \alpha$ by induction on $\alpha$ as follows:

(a) if $\eta \in \text{max}(\mathcal{F})$ then $D_{\mathcal{F}, I}(\eta) = \alpha$ if $\alpha = 0$

(b) if $\eta \in \mathcal{F} \setminus \text{max}(\mathcal{F})$ and $\eta \in \mathcal{F} = \text{Dom}(I) \text{ then } D_{\mathcal{F}, I}(\eta) = \alpha$ if $(\forall \beta < \alpha)(\exists X \subseteq \text{suc}(\eta) \setminus (\forall \nu \in X)(D_p_{\mathcal{F}, I}(\nu) \geq \beta))$

(c) if $\eta \in \mathcal{F} \setminus \text{max}(\mathcal{F}) \setminus \text{Dom}(I)$ then $D_p_{\mathcal{F}, I}(\eta) \geq \alpha$ if $(\forall \nu \in \text{suc}(\eta) \Rightarrow D_p(\nu) \geq \alpha)$.

6) If $i = (\mathcal{F}, I)$ is a pit and $\eta \in \mathcal{F}$ let $\text{proj}(\eta, i) = \text{proj}_i(\eta)$ is the sequence $\nu$ of length $\text{lg}(\eta)$ such that:

- $\ell < \text{lg}(\eta)$ $\land \eta \in \text{Dom}(I) \Rightarrow \nu(\ell) = -1$
- $\ell < \text{lg}(\eta)$ $\land \eta \notin \text{Dom}(I) \Rightarrow \nu(\ell) = \eta(\ell)$.

7) For $i = (\mathcal{F}, I)$ a pit let $\text{proj}(n, i) = \text{proj}_i(n) = \{ \text{proj}_i(\eta) : \eta \in \mathcal{F} \}$ has length $n$ and

$\text{proj}_i = \text{proj}(i) \{ \text{proj}_i(\eta) : \eta \in \mathcal{F} \}$.

8) If $i$ is a pit for $\ell < n$ then

(a) $\prod_{\ell < n} \mathcal{F}_i$ is $(\eta : \eta = \eta \land \ell < \mathbf{n})$ is such that $\ell < \mathbf{n} \Rightarrow \eta_\ell \in \mathcal{F}_i$ and moreover for some $n$ called $\text{lev}(\eta)$ we have $(\forall \ell < \mathbf{n})(\text{lev}_{\mathcal{F}_i}(\eta) = \mathbf{n})$.

{35}

**Theorem 2.18.** There is a pit $i_2$ and $\{ c_\eta : \eta \in \text{proj}(i_1) \}$ such that: $i_1 \leq i_2, D_{p_1}(\text{rt}_{i_1}) \geq \gamma_2$ and $\eta \in \mathcal{F}_2 \Rightarrow c(\eta) = c_{\text{proj}(\eta, i_1)}$ when:

(a) $i_1$ is $(\mathcal{F}_1, I_1)$ is a pit

(b) $i_1$ is $\lambda$-complete pit

(c) $2^{\kappa^+} < \lambda$ where $\theta = \text{proj}_1, \kappa + \theta$ is infinite for transparency

(d) $c$ is a colouring of $\mathcal{F}_1$ by $\leq \kappa$ colours

(e) $\gamma_1 = \gamma_2 = (2^{\kappa^+})^+$ or just

$\gamma_1 \leq D_{p_1}(\text{rt}_{i_1}), \gamma_1$ is a regular cardinal,

---

8If $\kappa$ and $\theta$ are finite, the computations are somewhat different. Note that $\kappa = 0$ is impossible and if $\kappa = 1$ then $i_2 = i_1$ will do so, without loss of generality $\kappa \geq 2$. 
Remark 2.19. 1) This relates on the one hand to the partition theorem of [Sh:f, Ch.XI] continuing Rubin-Shelah [RuSh:117], Shelah [Sh:f, Ch.XI] and on the other hand to Komjath-Shelah [KoSh:796]; the latter is continued in Gruenhut-Shelah [ZhSh:909] but presently this is not used.

2) Now 2.18 is what we use but we can get a somewhat more general result - see 2.21.

3) In 2.18 the case \( \gamma_1 = \gamma_2 > |T| \) is equivalent to \( \gamma_1 = \gamma_2 = \infty \).

Proof. Let \( C = \{ c : \bar{c} = (c_\theta : \theta \in \text{proj}_I), c_{<\theta} = c(\text{rt}(T)) \) and where \( c_\theta \in \text{Rang}(c) \) or just \( (\exists \eta \in T)(c = \text{proj}_I(\eta) \wedge c_\theta = c(\eta)) \). For transparency without loss of generality we assume \( \text{Rang}(c) \cap \text{max}(T) \) and \( \text{Rang}(c \cap \text{max}(T)) \) are disjoint. Clearly \( |C| \leq \kappa^{\text{proj}(I)} = \kappa^\theta < \lambda \).

Fix for a while \( \bar{c} \in C \), first let \( I_0 = \{ \eta \in T : \nu \leq \eta \text{ then } c(\nu) = c_{\text{proj}(\nu,1)} \} \) so a subtree of \( T \), i.e. a downward closed subset noting that \( \text{rt}_T \neq T \).

Second, for \( \eta \in T \), let \( X^1_{c,\eta} \) be \( \text{succ}_{T'}(\eta) \) if \( \eta \in I_0 \cap \text{Dom}(I_1) \) and this set is \( \in I_1 \), and be \( \emptyset \) otherwise. Let \( I_1 = \{ \eta \in T : \nu < \ell(\eta) \text{ and } \ell \in \text{Dom}(I_1) \text{ then } \eta(\ell+1) \in X^1_{\eta} \} \) i.e. \( \text{succ}_{T'}(\eta) := \{ \nu \in \text{succ}_{T'}(\eta) : \nu \in T \} = \emptyset \mod I_1, \eta \), again \( I_0 \) is a subtree of \( T \), moreover \( I_{2,2} = (I_0, I_1, T) \) is a pit.

Third, for \( \eta \in I_0 \cap \text{Dom}(I_1) \), \( \text{Dp}_{i_2,\eta}(\eta) \in \text{Ord} \cup \{ \infty \} \) is well defined and, now for \( \eta \in I_1 \), let \( X^2_{\eta} \) be \( \{ \nu \in \text{succ}_{T'}(\eta) : \text{Dp}_{i_2,\eta}(\nu) \geq \text{Dp}_{i_2,\eta}(\eta) \} = \emptyset \mod I_{1,\eta} \) if \( \eta \in I_0 \cap \text{Dom}(I_1) \), \( \text{Dp}_{i_2,\eta}(\eta) < 0 \) and be \( \emptyset \) otherwise. If for some \( \bar{c} \in C \), \( \text{Dp}_{i_2,\eta}(\text{rt}_{T'}) \geq \gamma_2 \) easily we are done, so toward a contradiction assume this is not the case, so recalling \( \|C\| > |C| \) clearly \( \gamma_* = \text{sup}\{ \text{Dp}_{i_2,\eta}(\text{rt}_{T'}) + 1 : \bar{c} \in C \} < \gamma_2 \). Now for each \( \eta \in \text{Dom}(I_1) \) clearly all \( X^1_{\eta} \) and \( X^2_{\eta} \) are from \( I_1, \eta \) and their number is \( \leq 2|C| < \lambda \) hence \( X_{\eta} := \bigcup \{ X^1_{\eta}, X^2_{\eta} : \bar{c} \in C \} \) belong to \( I_1, \eta \).

Hence \( i_1 \) is an pit and \( i_1 \leq i_3 \) where \( i_3 = (3) := i_1(\{ \eta \in T : \nu < \ell(\eta) \text{ and } \ell \in \text{Dom}(I_1) \text{ then } \eta(\ell+1) \notin X_{\eta} \} \)}; moreover by the definition of \( \text{Dp}_{i_4,\eta} \) and the choice of \( i_3 \), clearly

\[ (\star)_1 \quad (a) \quad i_3 \text{ is a pit; moreover } i_1 \leq i_3 \text{ hence } \eta \in I_3 \Rightarrow \text{Dp}_{i_3}(\eta) = \text{Dp}_{i_4}(\eta). \]

Define \( h \) by

\[ (\star)_2 \quad h \text{ is a function from } I_1 \times C \text{ defined by } \]

\( h(\eta, \bar{c}) = -1 \text{ if } \eta \in I_1 \setminus I_0 \)

\( h(\eta, \bar{c}) = \text{Dp}_{i_2,\eta}(\eta) \text{ if } \eta \in I_0 \text{ and } \text{Dp}_{i_2,\eta}(\eta) < \gamma_* \)

\( \text{Dp}(\eta, \bar{c}) = \gamma_* \text{ if none of the above.} \)

We now choose \( (c_n, h_n, \mathcal{D}_n, \mathcal{F}_n, \mathcal{S}_n) \) by induction on \( n \) such that:

\( \boxplus \quad (a) \quad \mathcal{D}_n \text{ is a subset of } \bigcup \{ \text{proj}_I(m) : m \leq n \} \)

\( (\beta) \quad \text{if } n = k + 1 \text{ then } \mathcal{D}_n = \mathcal{D}_n \cap (\bigcup \{ \text{proj}_I(m) : m \leq k \}) \)

\( (\gamma) \quad \mathcal{I}_n \subseteq \mathcal{D}_n \)

\( (b) \quad h_n \text{ is a function with domain } \mathcal{D}_n \times C \text{ to } \gamma_* + 1 \)

\( (c) \quad c_n \text{ is a function from } \mathcal{D}_n \text{ to } \text{Rang}(c) \)

\( (e) \quad \mathcal{F}_n = \langle \mathcal{D}_n, \gamma : \gamma < \gamma_1 \rangle \)
(d) \( \mathcal{B}_{n, \gamma} \) is a subset of \( \mathcal{I}_n \), downward closed of cardinality \( \leq \theta \\
(\beta) \) if \( \eta \in \mathcal{B}_{n, \gamma} \) then \( \ell g(\eta) \leq n \\
(\gamma) \) if \( \eta \in \mathcal{B}_{n, \gamma} \) then \( \text{Dp}_1(\eta) = \text{Dp}_1(\eta) \geq \gamma \\
(\delta) \) if \( \eta \in \mathcal{B}_{n, \gamma} \) and \( \ell g(\eta) < n \) and \( \eta \notin \text{Dom}(I_1) \) then \( \text{suc}_{\mathcal{I}_n}(\eta) = \text{suc}_{\mathcal{I}_n}(\eta) \subseteq \mathcal{B}_{n, \gamma} \)
(\varepsilon) \) if \( \eta \in \mathcal{B}_{n, \gamma} \) and \( \ell g(\eta) < n \) and \( \eta \in \text{Dom}(I_1) \) then \( \text{suc}_{\mathcal{I}_n}(\eta) \) is a singleton
(\zeta) \) if \( \gamma < \gamma_2 \) then \( \mathcal{B}_n = \{ \text{proj}_{I_1}(\eta) : \eta \in \mathcal{B}_{n, \gamma} \} \)
(\eta) \) if \( \eta \in \mathcal{B}_{n, \gamma} \) and \( \nu = \text{proj}_{I_1}(\eta) \) then:

- \( \cdot_1 \) \( c(\eta) = c_n(\nu) \)
- \( \cdot_2 \) \( h_n(\nu, \bar{c}) = h(\eta, \bar{c}) \) for every \( \bar{c} \in C \)
- \( \cdot_3 \) \( \eta \in \text{Dom}(I_1) \) if \( \nu \in \mathcal{F}_n \)

(\theta) \) follows: the function \( \eta \mapsto \text{proj}_{I_1}(\eta) \) on \( \mathcal{B}_{n, \gamma} \) is one to one.

Why this is possible:

For \( n = 0 \) this is trivial.

For \( n = m + 1 \) for every \( \gamma < \gamma_1 \), choose \( \bar{b}_{n, \gamma} \in \Pi \{ \text{suc}_{\mathcal{I}_n}(\eta) : \eta \in \mathcal{B}_{n, \gamma}, \ell g(\eta) = m, \eta \in \text{Dom}(I_1) \} \) such that if \( \eta \in \text{Dom}(\bar{b}_{n, \gamma}) \) then \( \text{Dp}_1(\eta) \geq \gamma \), possible as \( \eta \in \text{Dom}(\bar{b}_{n, \gamma}) \Rightarrow \text{Dp}_1(\eta) \geq \gamma + 1 \). Let \( \mathcal{B}_{n, \gamma}^* = \mathcal{B}_{m, \gamma+1} \cup \{ \nu : \text{for some } \eta \in \mathcal{B}_{n, \gamma+1} \text{ we have } \ell g(\eta) = m \text{ and we have } \eta \notin \text{Dom}(I_1) \Rightarrow \nu = \bar{b}_{n, \gamma}(\eta) \text{ and } \eta \notin \text{Dom}(I_1) \Rightarrow \nu \in \text{suc}_{\mathcal{I}_n}(\eta) \} \). Let \( \mathcal{I}^* = \{ \text{proj}_{I_1}(\eta) : \eta \in \mathcal{B}_{n, \gamma}^* \} \) and let the function \( c_{n, \gamma}^* : \mathcal{I}_{n, \gamma} \to \text{Rang}(c) \) be defined by \( \eta \in \mathcal{I}_{n, \gamma} \Rightarrow c_{n, \gamma}^*(\text{proj}_{I_1}(\eta)) = c(\eta) \), well defined as in \( \text{id}(\gamma) \) and let \( \mathcal{B}_{n, \gamma} = \{ \text{proj}_{I_1}(\eta) : \eta \in \mathcal{B}_{n, \gamma} \text{ and } \eta \in \text{Dom}(I_1) \} \). Let \( h_{n, \gamma} : \mathcal{I}_{n, \gamma} \to \gamma_1 \) be defined by: if \( \bar{c} \in C, \nu = \text{proj}_{I_1}(\eta) \) and \( \eta \in \mathcal{B}_{n, \gamma} \) then \( \eta \notin \mathcal{I}_{n, \gamma} \Rightarrow h_{n, \gamma}(\nu, \bar{c}) = \gamma, \eta \in \mathcal{I}_{n, \gamma} \Rightarrow h_{n, \gamma}(\nu) = \text{Dp}_{I_2}(\eta) \).

Now \( \mathcal{I}_{n, \gamma} \) is a subset of \( \text{proj}_{I_1} \), a set of cardinality \( \leq \theta \) and \( c_{n, \gamma}^* \) is a function from \( \mathcal{I}_{n, \gamma} \) into \( \text{Rang}(c) \), a set of cardinality \( \leq \kappa \) and \( h_{n, \gamma} \) is a function from \( \mathcal{B}_{n, \gamma} \subseteq \text{proj}_{I_1} \) into \( \gamma_1 \). But \( \gamma_1 \mapsto \gamma_1, \gamma_1 = \kappa < \gamma_1, \gamma_1 \mapsto \gamma_1 \) is a regular cardinal (recalling clause c) of the theorem) and \( (|\gamma_1| + \kappa)^\theta < \text{cf}(\gamma_1) = \gamma_1 \) hence for every \( \gamma < \gamma_1 \) we have \( \{(X_{n, \gamma}, c_{n, \gamma}, h_{n, \gamma}) : \gamma < \gamma_1\} \| \leq 2^\theta \cdot \kappa^\theta \cdot |\gamma_1|^\theta < \text{cf}(\gamma_1) = \gamma_1 \) hence for some \( c_{n, \gamma}, h_{n, \gamma}, \mathcal{B}_{n, \gamma} \) the set \( S_n := \{ \gamma < \gamma_1 : c_{n, \gamma} = c_n \text{ and } h_{n, \gamma} = h_n, \mathcal{B}_{n, \gamma} = \mathcal{B}_n \text{ and } \mathcal{B}_{n, \gamma} = \mathcal{B}_n \} \) is unbounded in \( \gamma_1 \).

Lastly, let \( \mathcal{B}_{n, \gamma} = \mathcal{B}_{n, \gamma}^{\min(S_n, \gamma)} \). Clearly \( c_{n+1, h_{n+1}, \mathcal{B}_{n, \gamma}} : \gamma < \gamma_2 \) are as required; so we can carry the induction.

Why this is enough:

Let \( \mathcal{I} = \cup \{ \mathcal{I}_n : n < \omega \} \subseteq \text{proj}(I_1) \) and \( \mathcal{I} = \cup \{ \mathcal{I}_n : n < \omega \} \) and \( c = \cup \{ c_n : n < \omega \} \) and \( h = \cup \{ h_n : n < \omega \} \) so by \( \text{id}(\gamma) \) clearly there is \( \bar{c} \in C \) such that \( c_\varphi = c(\bar{c}) \) when the latter is defined, so:

- \( \circ \) if \( n < \omega, \gamma < \gamma_1, \eta \in \mathcal{B}_{n, \gamma} \) and \( \nu = \text{proj}_{I_1}(\eta) \in \mathcal{I} \) then:
  - \( a \) \( c(\eta) = c_n(\text{proj}_{I_1}(\eta)) \)
  - \( b \) \( \text{Dp}_{I_2}(\eta) = h(\eta, \bar{c}) = h_n(\nu, \bar{c}) \)
  - \( c \) \( \text{Dp}_{I_1}(\eta) \geq \gamma \)

Also
\[ \odot_2 \mathcal{R} \subseteq \text{proj}_i \] is a set of finite sequences, closed under initial segments with no \( \alpha \)-maximal member.

[Why? Straight, e.g. if \( \nu \in X \) choose \( n = \ell g(\nu) + 2 \) let \( \gamma < \gamma_1 \) and choose \( \eta \in Y_{n, \gamma + 1} \) such that \( \text{proj}_i(\eta) = \nu \), now by clause (c) of \( \odot_1 \) we know that \( \text{Dp}_i(\eta) \geq \gamma + 1 \), hence there is \( \eta_1 \in \text{suc}\mathcal{R}_i(\eta) \) in \( Y_{n, \gamma + 1} \) hence \( \nu_1 = \text{proj}_i(\eta_1) \) is in \( \mathcal{R}(\nu) \), i.e. successor of \( \eta \) in \( \mathcal{R}_{n+1} \) hence in \( \mathcal{R} \).]

\[ \odot_3 \text{if } \nu \in \mathcal{R} \text{ then } h(\nu, \bar{c}) \neq -1. \]

[Why? Let \( n > \ell g(\nu) \), let \( \gamma < \gamma_2 \). Now by \( \mathbb{B}(d)(\zeta) \) there is \( \eta \in \mathcal{R}_{n, \gamma} \) such that \( \text{proj}_i(\eta) = \nu \).

Next by (**)2 we have \( h(\eta, \bar{c}) \) is -1 iff \( \eta \notin \mathcal{R}' \). However, \( \eta \in \mathcal{R}_i \) by the definition of \( \mathcal{R}_i \) and the choice of \( \bar{c} \) and \( \mathbb{B}(d)(\eta) \); moreover \( \eta \in \mathcal{R}'_i \) by the definition of \( \mathcal{R}'_i \) and clause (a).

By the last two sentences \( h(\eta, \bar{c}) \neq -1 \) hence by the choice of \( \eta \), i.e. \( \text{proj}_i(\eta) = \nu \), clause \( \mathbb{B}(d)(\eta) \) tells us \( h(\nu, \bar{c}) = h(\eta, \bar{c}) \) so together \( h(\nu, \bar{c}) \neq -1 \) as promised.]

\[ \odot_4 \text{if } \nu \in \mathcal{R} \text{ then } 0 \leq \text{Dp}_{\mathcal{R}, \mathcal{I}}(\bar{c}) < \gamma_* \text{ hence } h(\langle \rangle, \bar{c}) < \gamma_* . \]

[Why? Similarly using \( \mathbb{B}(d)(\eta) \).]

\[ \odot_5 \text{if } \nu \in \mathcal{R} \text{ and } 0 \leq h(\nu, \bar{c}) < \gamma_* \text{ then for some } \rho \in \text{succ}_\mathcal{R}(\nu) \text{ we have } 0 \leq h(\rho, \bar{c}) < h(\nu, \bar{c}) < \gamma_* . \]

[Why? Similarly using \( \mathbb{B}(d)(\delta) \).]

\[ \odot_6 \text{if } \nu \in \mathcal{R}(\mathcal{L}) \text{ and } 0 \leq h(\nu, \bar{c}) < \gamma_* \text{ then for the unique } \rho \in \text{succ}_\mathcal{R}(\nu) \text{ we have } 0 \leq h(\rho, \bar{c}) < h(\nu, \bar{c}) < \gamma_* . \]

[Why? Similarly using \( \mathbb{B}(d)(\varepsilon) \).]

By \( \odot_4, \odot_5, \odot_6 \) together we get a contradiction. \( \square_2.18 \)

We may prefer the following variant of 2.18.

**Definition 2.20.** 1) For a pit \( i = (\mathcal{I}, \mathcal{I}) \) and partition \( \mathcal{I} = (\mathcal{I}_0, \mathcal{I}_1) \) of \( \mathcal{I} \) (or just \( \mathcal{I} = (\mathcal{I}_0, \mathcal{I}_1) \) such that \( \mathcal{I}_0 \cap \mathcal{I}_1 = \emptyset \) and \( \mathcal{I}_1 \subseteq \mathcal{I}_0 \cup \mathcal{I}_1 \) we define \( \text{Dp}_{\mathcal{I}, \mathcal{R}} : \mathcal{R} \rightarrow \text{Ord} \cup \{ \infty \} \), stipulating \( \infty + 1 = \infty \) by defining when \( \text{Dp}_{\mathcal{I}, \mathcal{R}}(\eta) \geq \alpha \) by induction on the ordinal \( \alpha \) (compare with 2.17(4)):

\[ \text{(a) if } \eta \in \text{max}(\mathcal{I}) \text{ then } \text{Dp}_{\mathcal{I}, \mathcal{R}}(\eta) \geq \alpha \text{ iff } \alpha = 0 \]

\[ \text{(b) if } \eta \notin \mathcal{I}_0 \text{ hence } \eta \notin \mathcal{I}, \eta \notin \text{max}(\mathcal{I}) \text{ then } \text{Dp}_{\mathcal{I}, \mathcal{R}}(\eta) \geq \alpha \text{ iff for every } \beta < \alpha \text{ the set } \{ \nu \in \text{succ}(\eta) : \text{Dp}_{\mathcal{I}, \mathcal{R}}(\nu) \geq \beta \} \text{ belongs to } I'_\eta \]

\[ \text{(c) if } \eta \in \mathcal{I} \setminus \mathcal{I}_0 \text{ max}(\mathcal{I}) \text{ then } \text{Dp}_{\mathcal{I}, \mathcal{R}}(\eta) \geq \alpha \text{ iff for every } \nu \in \text{succ}(\eta) \text{ we have } \text{Dp}_{\mathcal{I}, \mathcal{R}}(\nu) \geq \alpha \]

**Theorem 2.21.** There are a pit \( i_0 \) and \( \bar{c} = \langle \eta_0 : \eta \in \text{proj}(i_0) \rangle \) such that \( i_1 \leq i_2, \text{Dp}_{i_2, \mathcal{I}}(\eta) \geq \gamma_2 \) and \( \eta \in \mathcal{R}_2 \Rightarrow \mathbb{A}(\eta) = \mathbb{C}(\eta) = \mathbb{C}_{\text{proj}(\eta, i_1)} \) when:

\[ \text{(a) (c) as in 2.18 replacing } \text{Dp}_{i_1, \mathcal{I}} \text{ by } \text{Dp}_{i_2, \mathcal{I}} \text{ in } (e)(\alpha) \]

\[ \text{(f) } \mathcal{I} = (\mathcal{I}_0, \mathcal{I}_1) \text{ is a partition of } \mathcal{I}. \]
Proof. Similarly. □
§ 3. APPROXIMATION TO EM MODELS

In the game below the protagonist tries to exemplify in a weak form that the standard EM\(_{(\tau)}(\lambda, \Phi)\) is \(\leq\)-embeddable into \(N\) over \(M\). We may consider games in which the protagonist tries to exemplify a weak form of isomorphism, this is connected to logics which have EM models, continuing [Sh:797], but not for now.

Here we do not try to get the best cardinal bounds; just enough for the result promised in the abstract.

**Definition 3.1.** Assume \(\lambda > \kappa \geq \text{LST}_1 + |\tau_1|\) and \(M \in K^*_\kappa\) and \(M \leq\) \(N\) and \(\gamma\) is an ordinal.

1) We say \(\Phi\) is an \(\langle M, \lambda, \kappa, \gamma\rangle\)-solution when \(\Phi \in T^\omega_\kappa(t_M)\) and in the game \(\overline{\text{O}^{1}}_{N,M,\lambda,\Phi,\gamma}\) the protagonist has a winning strategy.

2) Assume \(\Phi \in \Upsilon_\kappa(t_M)\) recalling Definition 2.1 fixing \(M_\lambda = \text{EM}(\lambda, \Phi)\) and \(M_I = \text{EM}(I, \Phi)\) for \(I \subseteq \lambda\) and without loss of generality every \(M_I\) (equivalently some \(M_I\)) is standard, hence in particular \(M \leq\) \(M[I]_{\tau}(t)\). We define the game \(\overline{\text{O}^{1}}_{N,M,\lambda,\Phi,\gamma}\) a play last \(<\omega\) moves, in the \(n\)-th move \(\lambda_n,J_n,h_n,\gamma_n\) are chosen such that:

\[
\begin{align*}
\exists \eta_n & \quad (a) \quad \lambda_0 = \lambda \\
& \quad (b) \quad \text{if } n = m + 1 \text{ then } \kappa < \lambda_0 < \lambda_m \text{ moreover } \lambda_m \rightarrow (\lambda_n)^\omega_0 \\
& \quad (c) \quad J_0 = \lambda, \text{ and if } n = m + 1 \text{ then } J_n \subseteq J_m \\
& \quad (d) \quad |J_n| = \lambda_n \\
& \quad (e) \quad \bar{h}_n = \langle h_u : u \in [J_n]^\omega \rangle \\
& \quad (f) \quad \text{if } u \in [J_n]^\omega \text{ then } h_u \text{ is a } \leq\tau\text{-embedding of } M_u \text{ into } N \text{ extending } h_v \\
& \quad \quad \text{whenever } v \subseteq u \\
& \quad (g) \quad \gamma_0 = \gamma \text{ and } \gamma_{n+1} \text{ is an ordinal } < \gamma_n.
\end{align*}
\]

In the \(n\)-th move:

(A) if \(n = 0\) the antagonist chooses \(\lambda_0 = \lambda, J_0 = \lambda, \gamma_0 = \gamma\) and the protagonist chooses \(\bar{h}_0\)

(B) if \(n = m + 1\) then

(a) the antagonist chooses an ordinal \(\gamma_n < \gamma_m\) and \(\lambda_n > \kappa\) such that

\[
\lambda_m \rightarrow (\lambda_n)^\omega_2(\kappa)
\]

(b) the protagonist chooses \(\bar{h}_n\) and \(\mathcal{S}_n \in (\text{ER}^\gamma_{\lambda_n,\lambda_m,2(\kappa)})^+, \text{i.e. } \mathcal{S}_n \subseteq [\lambda_m]^\lambda\) and \(\mathcal{S}_n\) is not from this ideal, see Definition 2.5

(c) the antagonist chooses \(J_n \in \mathcal{S}_n \subseteq [J_m]^\lambda\)

(C) the play ends when a player has no legal move and then this player loses.

Another presentation:

**Definition 3.2.** Assume \(M \leq\) \(N\) and \(\text{LST}_1 + |\tau_1| \leq \theta, \|M\| + \theta \leq \kappa < \lambda\) and \(\Phi \in T^\omega_\kappa[M, t]\).

1) Below we omit \(\gamma\) if (a) or (b), where:

(a) \(\gamma = \text{cf}(\lambda), \lambda \text{ strong limit and } \alpha < \text{cf}(\lambda) \Rightarrow |\alpha|^{2^{\omega + |M|}} < \text{cf}(\lambda)\)
(b) not (a) but γ is maximal such that γ = ωγ is infinite and \( \beth_1(\kappa + ||M||) \leq \lambda \) and \( \lambda \) is strong limit of cofinality > \( \beth_2(\kappa) \)
(similarly in all such definitions).

2) We say that \( \mathbf{x} \) is a direct witness for \( (N, M, \lambda, \kappa, \gamma, \Phi) \) when \( \mathbf{x} \) consists of:

(a) \( N, M, \Phi, \lambda, \kappa \) and \( \gamma \)
(b) \( \mathcal{T} \) is a non-empty set of finite sequences closed under initial segments
(c) if \( \eta \in \mathcal{T} \) then:
   (α) \( \eta(2n) \) is a cardinal when \( 2n < \ell g(\eta) \)
   (β) \( \eta(2n + 1) \) is a subset of \( \lambda \) of cardinality \( \eta(2n) \) when \( 2n + 1 < \ell g(\eta) \)
   (γ) \( \eta(2n + 1) \geq \eta(2n + 3) \) when \( 2n + 3 < \ell g(\eta) \)
   (δ) \( \eta(2n) \geq \eta(2n + 2) \), moreover \( \eta(2n) \to (\eta(2n + 2))^{2n+1}_{\beth_2(\kappa)} \) when \( 2n + 2 < \ell g(\eta) \)
(d) \( I_{\eta}, \lambda_{\eta} \) for \( \eta \in \mathcal{T} \) are defined by:
   (α) if \( \ell g(\eta) = 0 \) then \( I_{\eta} = \lambda, \lambda_{\eta} = \lambda \)
   (β) if \( \ell g(\eta) = 2n + 1 \) then \( I_{\eta} = I_{\eta}[2n], \) see (α) or (γ)
   (γ) if \( \ell g(\eta) = 2n + 2 \) then \( I_{\eta} = \eta(2n + 1), \lambda_{\eta} = \eta(2n) = \lambda_{\eta}[2n+1], \) see (α)
   or (β)
(e) if \( \eta \in \mathcal{T} \setminus \text{max}(\mathcal{T}) \) has length \( 2n + 1 \) then: the set \( \mathcal{S}_{\eta} = \{ I_{\nu} : \nu \in \text{suc}(\eta) \} \leq [I_\eta]^{\lambda_\eta} \) is not from the ideal \( \text{ER}^{[\ell g(\eta)/2]}_{I_{\eta}, \lambda_{\eta}, \beth_2(\kappa)} \)
(f) if \( \eta \in \mathcal{T} \) then:
   (α) \( \bar{h}_{\eta} = \langle h_{\eta,u} : u \in [I_\eta]^{[\ell g(\eta)/2]} \rangle \)
   (β) \( h_{\eta,u} \) is a \( \leq \) embedding of \( \text{EM}_{\langle \ell \rangle}(u, \Phi) \) into \( N \) for \( u \in [I_\eta]^{[\ell g(\eta)/2]} \)
   (γ) \( u_1 \subseteq u_2 \subseteq [I_\eta]^{[\ell g(\eta)/2]} \Rightarrow h_{\eta,u_1} \subseteq h_{\eta,u_2} \)
   (δ) if \( u \in [I_\eta]^{[\ell g(\eta)/2]} \) and \( \nu \in \eta \) and \( \ell g(\nu) \geq 2|u| \), then \( h_{\eta,u} = h_{\nu,u} \)
   (ε) if \( \ell g(\eta) = 2n + 2 \) and \( u \in [I_\eta]^{\leq n} \) then \( h_{\eta,u} = h_{\eta}[2n+1,u] \)
   (ζ) there is \( \bar{a} = \bar{a}_x = \langle a_\alpha : \alpha < \lambda \rangle \in \lambda N \) such that \( \alpha \in u \in [I_\eta]^{[\ell g(\eta)/2]} + h_{\eta,u}(\alpha) = a_\alpha \) and \( \bar{a} \) is with no repetitions
{z32} 
(g) \( \text{Dp}_x(\varnothing) \geq \gamma \) where \( \text{Dp}_x(\eta) \) is defined as \( \text{Dp}_{[x]}(\eta) \), see Definition 2.17, where \( i = i(x) = I_x \) is defined by:
   • \( \mathcal{A}_x = \mathcal{T} \)
   • \( \mathcal{A}_x = \{ \eta \in \mathcal{T} : \eta \) is not \( a \)-maximal in \( \mathcal{T} \) and \( \ell g(\eta) \) is odd\}
   • if \( \eta \in \mathcal{A}_x \) and \( \ell g(\eta) \) is odd then \( I_{i,\eta} = \text{ER}^{[\ell g(\eta)]}_{I_{\eta}, \lambda_{\eta}, \beth_2(\kappa)} \) recalling 2.17(1A)
{z32} 
• if \( \eta \in \mathcal{A}_x \) and \( \ell g(\eta) \) is even then \( \mathcal{A}_{i,\eta} = \{ \emptyset \} \).

{a5} 
{a5} 
{a5} 

**Definition 3.3.**

1) We say \( \mathbf{x} \) is a pre-\( t \)-witness of \( (N, M, \lambda, \kappa, \delta) \) when it as in 3.2 omitting \( h \), i.e. clause (f), so \( N, M \) are irrelevant.

2) We say \( \mathbf{x} \) is a semi-\( t \)-witness of \( (N^+, M, \lambda, \kappa, \delta) \) when: it consists of:

(a) \( N^+ \) expands a model from \( K_t, M \leq t (N^+ | \tau(t)), \lambda \geq \kappa \geq (\tau(N^+)) \)

(b) \( \bar{a} = \langle a_\alpha : \alpha < \lambda \rangle \) as in 3.2(2)
Claim 3.4. 1) The definitions 3.1, 3.2 are equivalent.
2) In Definition 3.2, $i_x$ is indeed a pit.
3) If $\Phi_1, \Phi_2, \Phi_3 \in T^{\text{sort}}_{\kappa}[M, \mathfrak{t}]$ for $\ell = 1, 2$ and $\Phi_1$ has a $(N, M, \lambda, \kappa)$-witness then $\Phi_2$ has a $(N, M, \lambda, \kappa)$-witness.

Proof. Straightforward.

Claim 3.5. 1) If $\Phi_1 \in T^{\text{sort}}_{\kappa}[M, \mathfrak{t}]$, $\kappa \geq \tau(\mathfrak{t}) + ||M||$ and $M_\ell = \text{EM}_{\tau(\mathfrak{t})}(\lambda, \Phi_1)$ for $\ell = 1, 2$ and $\lambda$ is strong limit of cofinality $\mu$ where $\mu = (\square_2(\kappa))^+$ or $\mu$ is regular such that $(\forall \alpha < \mu)(|\alpha|^2^\mathfrak{t} < \mu)$ and the protagonist wins in the game $\mathcal{G}_{M_2, M, \lambda, \Phi_1, \mu}$ (equivalently some $x$ is a witness for $(M_2, M, \lambda, \kappa, \Phi_1)$) then $\Phi_1 \leq_3 \Phi_2$, see Definition 2.12.

Proof. Straightforward by 2.18 and the definitions of the ideal ER in 2.5. See details in a similar case in the proof of 3.6(1) below.

Claim 3.6. Assume $M \leq N, \kappa \geq ||M|| + \theta, \theta \geq \text{LST}_\mathfrak{t} + \tau(\mathfrak{t})$ and $\|N\| \geq \lambda$, $\lambda$ strong limit of cofinality $\mu$ and $\mu = (\square_2(\kappa))^+$ or $\mu$ is regular such that $(\forall \alpha < \mu)(|\alpha|^2^\mathfrak{t} < \mu)$.

1) There are $x, \Phi$ such that:
   (a) $\Phi \in T^{\text{sort}}_{\theta}(\mathfrak{t}_M)$
   (b) $x$ is a direct witness of $(N, M, \lambda, \kappa, \Phi)$.

2) If $M_1 = M, \Phi_1 \in T^{\text{sort}}_{\theta}[M_1]$ and $x_1$ a direct witness for $(N, M_1, \lambda, \kappa, \Phi_1)$ and $M_1 \leq_{\mathfrak{t}} M_2 \leq_{\mathfrak{t}} N$ and $\|M_2\| \leq \kappa$ then there are $\Phi_2, x_2$ such that:
   (a) $\Phi_2 \in T^{\text{sort}}_{\theta}[M_2]$
   (b) $\Phi_1 \leq_3 s_\mathfrak{t} \Phi_2$ and $\Phi_1 \leq_3 \Phi_2$
   (c) $x_2$ is a direct witness $(N, M_2, \lambda, \kappa, \Phi_2)$.

3) If in part (1) we change the assumption on $\lambda$ to $\lambda = \square_{\omega, \gamma}(\kappa)$ then there are $\Phi, x$ such that:
   (a) $\Phi \in T^{\text{sort}}_{\kappa}[M, \mathfrak{t}]$
   (b) $x$ is a direct witness of $(N, M, \Phi, \lambda, \kappa, \gamma, \Phi)$.

4) Also part (2) has a version with $(\gamma_1, \gamma_2)$ as in 2.18.

Proof. 1) Let $(a_\alpha : \alpha < \lambda)$ be a sequence of pairwise distinct members of $N$.

Now

\[ (*)_1 \text{ let } \mathcal{J} \text{ be the set of finite sequences } \eta \text{ satisfying clauses (b),(c) of Definition 3.2} \]
\[ (*)_2 \text{ let } \mathcal{I} = \{ I_\eta : \eta \in \mathcal{J} \} \text{ where } \]
\[ \cdot \quad \mathcal{J} = \{ \eta \in \mathcal{J} : \eta \text{ is not } \prec\text{-maximal in } \mathcal{J} \} \]
\[ \cdot \quad \text{if } \eta \in \mathcal{J}, \ell(\eta) = 2n + 1 \text{ then } I_\eta = \text{ER}^{\mathfrak{t}_\mathfrak{t}}_{\eta, \lambda, \gamma}(\square_2(\kappa)) \]
\[ \cdot \quad \text{if } \eta \in \mathcal{J} \text{ and } \ell(\eta) = 2n \text{ then } I_\eta = \{ \emptyset \}, \text{ the trivial ideal} \]
\[ (*)_3 \text{i}_1 = \text{i}(1) = (\mathcal{J}, \mathcal{I}) \text{ is a pit and is } (2^\mathfrak{t})^+\text{-complete and } \text{Dp}_1(\prec) \geq (\square_2(\kappa))^+. \]

[Why? Just read Definition 2.17(3) and the ideal ER is from Definition 2.5 and it is $(2^\mathfrak{t})^+$-complete by 2.6 and as for the depth recall $\mu = (\square_2(\kappa))^+.$]
Let $M^+$ be such that:

(a) $M^+$ is an expansion of $N$

(b) $|\tau(M^+)| \leq \kappa$ and $\tau' := \tau(M^+)\setminus\{c_a : a \in M\}$ has cardinality $\leq \theta$

(c) if $M^+_i | \tau' \subseteq M^+ | \tau'$ then $M^+_i | \tau(\xi) \leq M^+ | \tau(\xi)$

(d) $|I| = \{c(M^+) : c \in \tau(M^+)\}$.

We like to apply Theorem 2.18 but before this we need

\[ \text{Reason}\] We say 3),4) Similarly.

\[ \text{Why such i(2) exists? By the representation theorem, [Sh:88r, §1] except clause (d) which as before is easy.}\]

\[\text{We like to apply Theorem 2.18 but before this we need}\]

\[\text{Next}\]

\[\text{Next}\]

\[\text{Clearly}\]

\[\text{So by 2.18 (with a degenerate projection; so \(\kappa, \theta\) there stands for 2\(\kappa, \aleph_0\) here):}\]

\[\text{The rest should be clear.}\]

\[\text{2) Similar proof, this time in } M^+ \text{ we have individual constants for every member of } M_2 \text{ and we start with the witness } x_1 \text{ so } 2N \text{ which as before is easy.}\]

\[\text{3),4) Similarly.}\]

\[\text{Definition 3.7. We say } x \text{ is an indirect witness for } (N, M, \lambda, \kappa, \gamma, \Phi), \text{ recalling 3.2(1), when for some } \Psi:\]

\[\text{(a) } M, N, \lambda, \kappa, \gamma, \Phi \text{ are as in Definition 3.2}\]
\{z24\} \quad \begin{align*}
(b) & \quad \Psi \in \mathcal{T}^{\text{cor}}_{\kappa}[t_M] \text{ and } \Phi \leq^4 \Psi, \text{ see Definition 2.12} \\
(c) & \quad \Phi \text{ is a direct witness of } (N, M, \lambda, \kappa, \gamma, \Psi).
\end{align*}

Remark 3.8. Why do we need the indirect witnesses? As if we use direct witness only in the proof of 3.14 it is not clear how to get many non-isomorphic models. \{a22\} \quad \{a13\} 

Claim 3.9. If \( I = I_\chi \) is as in 1.15.

If (A) then (B) where:

(A) \quad \begin{align*}
(a) & \quad \text{LST}_\chi + |\tau| \leq \kappa < \chi_1 < \chi_2 < \chi_3 \leq \chi \text{ and for } \ell = \eta, 2, \chi_{\ell+1} \\
(b) & \quad N = \text{EM}_{\tau}\{I, \Phi_1\} \text{ where } \Phi_1 \in \mathcal{T}^{\text{cor}}_{\kappa}[M_1, t], \|M_1\| \leq \chi_1 \\
(c) & \quad M_2 \leq_t N \text{ and } \|M_2\| \leq \chi_1 \\
(d) & \quad \Phi_2 \in \mathcal{T}^{\text{cor}}_{\kappa}[M, t] \\
(e) & \quad \Phi_2 \text{ has a witness for } (N, M_2, \chi_2, \kappa)
\end{align*}

(B) \quad \begin{align*}
(a) & \quad \Phi_2 \text{ has a witness for } (N, M_2, \chi_3, \kappa) \\
(b) & \quad \text{if in addition } M_2 \leq_t M_1 \text{ then } \Phi_2 \leq^3 \Phi_1 \\
(c) & \quad \text{we can } \leq_t \text{-embed } \text{EM}_{\tau}\{I, \Phi_2\} \text{ into } N.
\end{align*}

Proof. As in the proof of 3.6 recalling the choice of \( I \) in 1.15; for (B)(c) we use Clause (B)\textsuperscript{+} of 3.6. \( \square_{3.9} \) \{a9\} 

Remark 3.10. In fact, in 3.9, \( \chi_2 = \Delta_{\eta,1}(\chi_1) \) and \( \chi_3 = \Delta_{\omega,1}(\chi_1) \) suffices so, of course, in (B)(a) we use \( (N, M_1, \chi_3, \kappa, \gamma) \). \{a13\} 

Claim 3.11. If (A) then (B) where:

(A) \quad \begin{align*}
(a) & \quad M_1 \leq_t M_2 \leq_t N \\
(b)(\alpha) & \quad M_\ell \text{ has cardinality } \kappa_\ell \\
(\beta) & \quad \|N\| \geq \lambda \\
(\gamma) & \quad \kappa_\ell \geq \kappa \geq \text{LST}_\chi + |\tau| \\
(c) & \quad \Phi_1 \in \mathcal{T}^{\text{cor}}_{\kappa}[M_1, t] \\
(d) & \quad \lambda \text{ is strong limit and } \text{cf}(\lambda) = (\Delta_2(\kappa_2))^+ \text{ or just } \\
& \quad (\forall \alpha < \text{cf}(\lambda))(|\alpha|^\gamma < \text{cf}(\lambda)) \\
(e) & \quad x_1 \text{ is an indirect witness for } (N, M_1, \lambda, \kappa, \Phi_1)
\end{align*}

(B) \quad \text{there are } \Phi_2, x_2 \text{ such that:}

\begin{align*}
(a) & \quad \Phi_2 \in \mathcal{T}^{\text{cor}}_{\kappa}[t_{M_2}] \\
(b) & \quad \Phi_1 \leq^1_{\kappa_1} \Phi_2 \\
(c) & \quad x_2 \text{ is an indirect witness for } (N, M_2, \lambda, \kappa_2, \Phi_2).
\end{align*}

Proof. By clause (A)(c) of the assumption and the definition of indirect witness in 3.7 there is \( \Psi_1 \) such that:

\begin{align*}
(*_1)(a) & \quad \Psi_1 \in \mathcal{T}^{\text{cor}}_{\kappa_1}[t_{M_1}] \text{ which is standard} \\
(b) & \quad x_1 \text{ is a direct witness of } (N, M_1, \lambda, \kappa_1, \Psi_1) \\
(c) & \quad \Phi_1 \leq^4_{\kappa_1} \Psi_1.
\end{align*}

By claim 3.6(2) there are \( x_2, \Psi_2 \) such that:

\begin{align*}
(*_2)(a) & \quad \Psi_2 \in \mathcal{T}^{\text{cor}}_{\kappa_2}[t_{M_2}]
\end{align*}
\{z30\} Lastly, by 2.16 applied to our $\Phi_1, \Psi_1, \Psi_2$ and get $\Phi_2$ such that
\begin{align*}
\text{(*)}_3 \hspace{1em} & (a) \hspace{1em} \Phi_1 \in T_{n+4}^{\text{cor}}[t_{M_n}] \\
& (b) \hspace{1em} \Phi_1 \leq_1 \Phi_2 \\
& (c) \hspace{1em} \Phi_2 \leq_4 \Psi_2.
\end{align*}

So we have gotten Clause (B) as promised.

\phantomsection
\labellist
\item (\text{3.11})
\end{itemlist}

### Claim 3.12

If \( (A) + (B) \) then \( (C) \) where:

\begin{align*}
\text{(A)} \ & (a) \hspace{1em} \lambda_n \geq \text{LST}_\ell \text{ is strong limit, } \text{cf}(\lambda_n) = (\sum_2 (\text{LST}_\ell + \lambda_n))^+ \text{ if } n = m + 1 \\
& (b) \hspace{1em} \lambda = \sum_\mu \lambda_n \text{ and } \lambda_n < \lambda_{n+1} \\
& (c) \hspace{1em} N \in K^n_\ell \\
& (d) \hspace{1em} M_n \leq \text{LST}_\ell \text{ and } \|M_n\| = \lambda_n \\
& (e) \hspace{1em} N = \bigcup\{M_n : n < \omega\}
\end{align*}

\begin{align*}
\text{(B)} \ & \text{there is no } \Phi \in T_{n+4}^{\text{cor}}[t_N], \text{ see 2.15} \\
\text{(C)} \ & \text{for some } n \text{ and } \Phi \\
& (a) \hspace{1em} \Phi \in T_{n+4}^{\text{cor}}[t_{M_n}] \\
& (b) \hspace{1em} \text{there is an indirect witness}^9 \text{ for } (N, M_n, \lambda_{n+4}, \lambda_n, \Phi_n) \\
& (c) \hspace{1em} \text{there is no indirect witness for } (N, M_n, \lambda_{n+5}, \lambda_n, \Phi_n).
\end{align*}

Remark 3.13. 1) Later we shall weaken \( (A)(a) \).

2) We may use \( T_{n+4}^{\text{cor}}[t_{M_n}] \) where \( \lambda_0 \geq \kappa \geq \text{LST}_\ell + |\tau| \) in 3.11 and in 3.12, also in 3.14.

\textbf{Proof.} We assume \( (A) + \lnot(C) \) and shall prove \( \lnot(B) \), this suffices. We try to choose \((\Phi_n, x_n)\) by induction on \( n \) such that:

\begin{align*}
\otimes \ & (a) \hspace{1em} \Phi_n \in T_{n+4}^{\text{cor}}[t_{M_n}] \\
& (b) \hspace{1em} \{c_a : a \in N\} \cap \tau(\Phi_n) = \{c_a : a \in M_n\} \\
& (c) \hspace{1em} x_n \text{ is an indirect witness for } (N, M_n, \lambda_{n+2}, \lambda_n, \Phi_n) \\
& (d) \hspace{1em} \text{if } n = m + 1 \text{ then } \Phi_m \leq_4 \Phi_n.
\end{align*}

Now
\begin{align*}
\text{(*)}_1 \ & \text{if we succeed to carry the induction then there is } \Phi \in T_{n+4}^{\text{cor}}[t_N].
\end{align*}

[Why? Note that \( \Phi_n \in T_{n+4}^{\text{cor}}[t_{M_n}] \subseteq T_{n+4}^{\text{cor}}[t] \) and as \( \lambda_n \leq \lambda \text{ clearly } \Phi_n \in T_{n+4}^{\text{cor}}[t] \subseteq T_{n+4}^{\text{cor}}[t] \) and so by 2.11(2) there is \( \Phi \in T_{n+4}^{\text{cor}}[t] \) such that \( n < \omega \Rightarrow \Phi_n \leq_4 \Phi \). Easily \( N \leq \text{LST}_\ell - \text{embeddable into every EM}_{\tau}[I, \Phi] \), in fact, \( \Phi \in T_{n+4}^{\text{cor}}[t_N] \), contradiction to clause (B) of the assumption.]

\begin{align*}
\text{(*)}_2 \ & \text{we can choose } (x_n, \Phi_n) \text{ for } n = 0.
\end{align*}

\phantomsection
\labellist
\item (\text{a9})
\end{itemlist}

[Why? By 3.6(1).]

\begin{align*}
\text{(*)}_3 \ & \text{if } n = m + 1 \text{ and we have chosen } (x_m, \Phi_m) \text{ then we can choose } (x_n, \Phi_n).
\end{align*}

\phantomsection
\labellist
\item (\text{9})
\end{itemlist}
Claim 3.14. We have $I(\mu, K) \geq \chi$ when:

\(\mathfrak{L} \vdash \)

\(\begin{array}{l}
(\text{a}) \quad \text{LST}_t + |\tau_t| \leq \kappa \leq \chi_1 < \chi_2 < \chi_3 \leq \min\{\lambda, \mu\} \\
(\text{b}) \quad M \leq_t N \\
(\text{c}) \quad \|M\| \leq \kappa \text{ and } \|N\| \geq \lambda \\
(\text{d}) \quad \Phi \in \mathcal{Y}^{\text{for}}_{\kappa}[\mathcal{I}_M] \\
(\text{e}) \quad \exists \text{ an indirect witness for } (N, M, \chi_2, \chi_1) \\
(\text{f}) \quad \text{there is no indirect witness for } (N, M, \chi_3, \chi_1, \Phi) \\
(\text{g}) \quad \chi_3 \text{ is strong limit of cofinality } \left(\bigcup_2(\chi_2)^+\right) \\
(\text{h}) \quad \chi = |\{\theta : \theta = \mathcal{M}_\vartheta \text{ and } \vartheta \in [\chi_1, \chi_2]\}| \\
\end{array}\)

\(\text{Proof.}\) Let $\gamma_1$ be maximal such that $\mathcal{N}_{\omega, \gamma}(\chi_1) \leq \chi_2$. Let $\Psi \in \mathcal{Y}^{\text{for}}_{\kappa}[\mathcal{I}_M]$ be such that $\Phi \leq_t \Psi$ and $\Psi$ has a direct witness for $(N, M, \chi_2, \chi_1, \Psi)$ and choose such a witness $\chi$.

Let $M_2$ be such that $M \leq_t M_2 \leq_t N$ and $M_2 = \mathcal{N}_{\omega, \gamma}(\chi_1) \leq \chi_2$ and $\chi$ is a direct witness for $(M_2, \mathcal{N}_{\omega, \gamma}(\chi_1), \chi_1, \gamma, \Psi)$.

As $\chi_3$ is strong limit of cofinality $> \bigcup_2(\chi_2)$ there are $\Phi_3 \in \mathcal{Y}^{\text{for}}_{\kappa}[\mathcal{I}_M]$ and $\eta$ which is a direct witness for $(N, M_2, \chi_3, \Phi_3)$ and so $\tau(\Phi_3)\{\nu_a : a \in M_2\}$ has cardinality $\kappa$. For each $\gamma < \gamma_4$ there are $M_3, \gamma, \chi_5$ such that:

\((\ast)_1\)

\(\begin{array}{l}
(\text{a}) \quad M_2, \gamma \leq_t M_2 \\
(\text{b}) \quad \|M_2, \gamma\| \geq \bigcup_\gamma(\chi_1) \text{ but } \bigcup_{\omega, \gamma}(\chi_1) \text{ can get even} \\
(\text{c}) \quad \text{is a direct witness for } (M_2, \gamma, M, \mathcal{N}_{\omega, \gamma}(\chi_1), \chi_1, \gamma, \Psi). \\
\end{array}\)

\((\ast)_2\)

\(\begin{array}{l}
(\text{a}) \quad \exists \gamma, \Phi_3, \gamma \text{ such that} \\
(\text{b}) \quad \mathcal{F}_3, \gamma \in \mathcal{Y}^{\text{for}}_{\kappa}[M_3, \gamma]. \\
\end{array}\)

\(\text{Next we can find } \gamma, \gamma_5, \Phi_3, \gamma \text{ such that} \)

\(\begin{array}{l}
(\ast)_2\) \quad (a) \quad \gamma, \gamma_5 \text{ is a direct witness of } (N, M_2, \gamma_5, \chi_3, M_2, \gamma_5, \Phi_3, \gamma_5) \\
(\text{b}) \quad \Phi_3, \gamma \gamma \in \mathcal{Y}^{\text{for}}_{\kappa}[M_3, \gamma]. \\
\end{array}\)
undeﬁned otherwise. Let θ be deﬁned if i < i(∗) and let Θ = {θi+1 : i + 1 < i(∗)}. Now |Θ| ≥ χ so it suﬃces to prove that ⟨Nθ : θ ∈ Θ⟩ are pairwise non-isomorphic.

So toward contradiction assume

(∗)3 θ1 < θ2 are from Θ and π is an isomorphism from Nθ1 onto Nθ2.

We can ﬁnd M∗ ≤Γ Nθ1 such that |M∗| = θ2 and M ∪ M2,θ1 ∪ π(M2,θ2) ⊆ M∗ and

and we ﬁnd I∗ ≤µ Nθ1 such that M∗ = EMΓ(I∗, Φ3,θ1).

Let I∗ ⊆ I∗ be of cardinality θ1 such that M2,θ1 ∪ π(M) ⊆ Nθ∗ := EMΓ(I∗, Φ3,θ1)

and let Nθ′ := EMΓ(I∗, Φ3,θ1) and Nθ∗ := EMΓ(I∗, Φ3,θ1) for (M2,θ1, Nθ′, θ2, κ, Ψ′) such that Ψ ≤κ Ψ′ and xθ′1, where θ2 = ℶωγ(χ1).

Now clearly Nθ′, Ψ, π(Ψ′), π(xθ′1) satisﬁes the parallel statements in Nθ1. By

3.9(B)(a) and the choice of Iµ there is a witness for (Nθ1, Nθ′, θ3, κ, π(Ψ′)), hence

applying π−1 there is a witness xθ′1 for (Nθ1, Nθ′, θ3, κ, Ψ′).

Hence by 3.9(B)(b), Ψ′ ≤κ Φ, but together Φ ≤κ Ψ ≤κ Φ, hence

Φ ≤κ Φ, θ2, by 2.14(1) so by 2.14(2), the last clause, there is Φ′ ∈ Φ, θ2, Eθ2

such that Φ ≤κ Φ′, θ2. But as Φ, θ2 has a (N, M2,θ2, θ3, θ2) witness by 3.4(3) also

Φ, θ2 has hence Φ has an indirect witness for (N, M, θ3, κ), contradiction. □

Conclusion 3.15. Assume cf(λ) = N0 and λ = ℶ1,λ.

1) If λ > 1, I(K†) then M ∈ K† ⇒ ℶso(tM) = ∅.

2) If µ ≥ λ > 1, I(µ, K†) then M ∈ K† ⇒ ℶso(tM) = ∅.

Moreover, at least one of the following holds:

(a) for some χ1 < µ if χ1 < χ2 = ℶ2,δ ≤ min{λ, µ} then |δ| ≤ I(µ, K†)

(b) for every M ∈ K†.

Theorem 3.16. The result from the abstract holds, that is, for every a.e.c. t for some closed unbounded class C of cardinals we have (a) or (b) where

(a) for every λ ∈ C of cofinality N0, I(λ, K) ≥ λ

(b) for every λ ∈ C of cofinality N0 and M ∈ Kλ, for every cardinal κ ≥ λ

there is Nκ of cardinality κ extending M (in the sense of our a.e.c.).

Proof. Let Θ = {µ : µ = ℶ2,δ and |δ| > I(µ, K†)} for some limit ordinal δ.

Case 1: Θ is an unbounded class of cardinals.

So C = {µ : µ = sup(µ ∩ Θ)} is a closed unbounded class of cardinals. Easily

µ ∈ C ⇒ µ = ℶ1,µ and by 3.15 + 3.15 for every µ ∈ C, clause (b) of 3.16 holds.

Case 2: Θ is a bounded class of cardinals.

So by the deﬁnition of Θ, C = {µ : µ > sup(Θ), µ = ℶ2,µ} as is required. □

Also

Theorem 3.17. For every a.e.c. t one of the following holds:

(a) for some χ we have χ < µ = ℶ2,µ ⇒ I(µ, K†) ≥ µ and χ < µ = ℶ1,ωγ ⇒ I(µ, K†) ≥ |γ|

(b) for some closed unbounded class C of cardinals we have cf(λ) = N0 ∧ λ ∈ C ∧ M ∈ Kλ ⇒ ℶso(tM, t) = ∅.

Proof. Similarly to 3.16, using Fodor lemma for classes of cardinals. □
§ 4. Concluding Remarks

Definition 4.1. 1) For an ordinal $\gamma, \tau$-models $M_1, M_2$ and cardinal $\lambda$ we define a game $\mathcal{O} = \mathcal{O}_{\lambda, \gamma}(M_1, M_2)$. A play lasts less than $\omega$ models is defined as in [Sh:797, 2.1].

Claim 4.2. 1) Assume $\text{cf}(\lambda) = \aleph_0$ and $M_1, M_2$ are $\tau$-models of cardinality $\lambda$. If the isomorphic player wins in $\mathcal{O}_{\lambda, \gamma}(M_1, M_2)$ for every $\gamma$ or just $\gamma < (2^{<\lambda})^+$ then $M_1, M_2$ are isomorphic.

1A) If above $\lambda$ is strong limit then $\text{"}(2^{<\lambda})^+ = \lambda^+\text{"}$.

2) Assume $\lambda$ is strong limit of cofinality $K = K_{\kappa}$ and $|\tau_{\kappa}| + \text{LST}_{\kappa} \leq \lambda$ and $K = \{M \upharpoonright \tau : M \models \psi\}$ for some $\psi \in \text{L}_{\lambda^+, \aleph_0}$.

If $\dot{I}(\lambda, K) \leq \lambda$ then for every $M_1 \in K$ there is $M_2 \in K_{\leq \lambda}$ such that the isomorphic player wins in $\mathcal{O}_{\lambda, \gamma}(M_1, M_2)$ for every $\lambda$.

Conjecture 4.3. For every a.e.c. $\mathfrak{T}$ letting $\kappa = \text{LST}_{\kappa} + |\tau_{\kappa}|$, at least one of the following occurs:

(a) if $\lambda = \beth_1, \kappa > \kappa$ and $\text{cf}(\lambda) = \aleph_0$, then $\Upsilon_{\kappa}^{\text{sort}}[M, \mathfrak{T}] \neq \emptyset$

(b) if $\lambda = \beth_1, \kappa > \kappa$ and $\text{cf}(\lambda) = \aleph_0$, then $\dot{I}(\lambda, K_{\kappa}) = 2^\lambda$. 
§ 5. Private Appendix

{a23}

Claim 5.1. \( \lambda = \beth_1, \gamma \Rightarrow I(K_\gamma) \geq \gamma \) when (a)-(b) of 3.14.

{a22}

Proof. Like the proof of 3.14 up to the choice of \( y, \Phi_\lambda, \gamma \) in (**)₂.

{a22}

Let \( I_{\lambda} \) be as in 1.15 and let \( t_n \in I_{\lambda} \) be pairwise distinct.

Let \( N_1^+ = \text{EM}(I_{\lambda}, \Phi_3) \) hence \( M_2 \leq_{\mathfrak{I}} N_1 = N_1^+ \).

Let \( N_2^+ \) be the expansion of \( N_1^+ \) by \( P_{N_1^+} = \{ a_t : t \in I_{\lambda} \} \), \( P_{N_1^+} = (M_2) \) and \( \sigma N_1^+ (\overline{x}, \overline{a}_{t_0}, \ldots, \overline{a}_{t_{n-1}}) \) for \( \sigma = \sigma (\overline{x}, y_{t-1}) \) a term in \( \tau_{\Phi_3} \), see 2.2 so \( |N_1^+| = |N_2^+| \) is the closure of \( P_{N_1^+} \cup P_{N_2^+} \) by \( \{ F^N_{N_2^+} : F \in \tau (k) \} \{ c_t : t \in M_2 \} \). Let \( i = i_1 \), see ?

We can find \( i_1 \) such that \( i \leq_{\mathfrak{I}} i_2 \), see Definition 2.2 such that for every \( \eta \in \mathcal{S}_{\lambda} \) the sequence \( \langle h_{\eta, \alpha} (a_\alpha) : \alpha \in \eta(2^{n+1}) \rangle \) is \( n \)-indiscernible in the model \( N_2^+ \).  \( \square \)

REFERENCES


[Sh:56] Saharon Shelah, Categoricity of an abstract elementary class in two successive cardinals, revisited.


[Sh:54] Saharon Shelah, Abstract elementary classes near \( \aleph_1 \), chapter L, 0705.4137, 0705.4137.


[Sh:F1098] Saharon Shelah, Number of models in \( \aleph_1 \) for an infinitary sentence.

[Sh:F1228] Saharon Shelah, Model theory for \( \theta \)-complete ultra-powers.
[Sh:F1273] Categoricity spectrum for the atomic model of a countable $T$: thoughts.